Appendix B – Documentation of Fragmentation Impacts Caused by Roads and Transmission Lines

Examples of scientific papers documenting fragmentation caused by roads and transmission lines include the following, with select excerpts, followed by full papers.

van Dijk, R.E., Morel, T., Zwerver, K., *et al.* (2025). Road traffic has a consistent negative impact on breeding density of a wide range of bird species in different habitats. *Landsc Ecol* 40, 118. https://doi.org/10.1007/s10980-025-02100-5

> "Road traffic had a consistent negative effect on territory densities up to approximately 650 m distance from the road for different species and ecological species groups. Within road-effect zones, densities of breeding birds were significantly lower (on average 25%) than at greater distances from the road. Effect distances were positively associated with traffic intensity in various ecological species groups." (pg. 1)

> "The presence of roads and their use by traffic cause fragmentation of natural habitats, increased risk of wildlife-vehicle collisions, noise and light pollution, optical disturbance, the spread of invasive species, and pollution through the deposition of toxic heavy metals and nutrients (Spellerberg 1998; Kociolek et al. 2011; Sanderfoot and Holloway 2017)." (pg. 2)

> "The type of habitat also determines which species occur in a given location and their tolerance to pollution or disturbance. Species in pristine, undisturbed areas may be more affected by increasing disturbance than species that are used to human pressures (Radford et al. 2005; Kroeger et al. 2022)." (pg. 10)

> "In summary, we found that: (1) a wide range of bird species exhibit reduced breeding densities near roads, (2) the negative impact of road traffic on breeding densities extends over a similar distance across species and habitats, and (3) this effect is intensified by higher traffic intensity." (pg. 12)

Valdez-Leal, J. de D., & Pacheco-Figueroa, C. J. (2022). Wildlife crossings and road impact on mammals. *Therya Notes*, *3*(2), 51–52. https://doi.org/10.12933/therya_notes-22-69

> "In this issue, it is recognized that landscape connectivity is essential for maintaining the flow of mammalian individuals, their genetic variability, and allowing access to resources. An irruption of the connectivity brings, as a consequence, threats at the species and population level." (pg. 1)

Anderson, M.G., Clark, M. and A. Olivero (2023). Conservation Status of Natural Habitats in the Northeast. The Nature Conservancy and Center for Resilient Conservation Science. Newburyport, MA.

> "Fragmentation occurs when a contiguous area of forest is subdivided into smaller patches, resulting in each patch having more edge and less interior. Because edge habitat contrasts strongly with interior – drier and more exposed, higher predator densities, greater susceptibility to blowdowns – the surrounding edge habitat tends to isolate the interior region and contribute to its degradation. Thus, the divide-and-conquer effect of fragmentation can lead to an overall deterioration of forest quality and a shift in associated species from interior specialists to edge generalists." (pg. 83)

Coffin, A., Ouren, D., Bettez, N., *et al.* (2021). The Ecology of Rural Roads: Effects, Management & Research. *Issues In Ecology* 23. https://www.fs.usda.gov/psw/publications/preisler/psw_2021_preisler003_coffin.pdf

> "The four main mechanisms by which roads affect wildlife populations include: (i) decreasing habitat area, fragmenting the remaining area, and reducing habitat quality in adjacent areas; (ii) increasing mortality caused by vehicle collisions; (iii) reducing landscape connectivity because roads act as barriers (e.g., some animals avoid roads and do not cross them) and sometimes interrupting seasonal migration routes; and (iv) subdividing populations into smaller and more vulnerable sub-populations." (pgs. 12-13)

> "The effect of habitat loss is almost immediate, reduced habitat quality and traffic mortality may take longer, and reduced connectivity longer still." (pg. 13)

Carey, M., Gaines, W., Giles, R., *et al.* (2006). Highways and Habitat: Managing Habitat Connectivity and Landscape Permeability for Wildlife. U.S. Department of Agriculture, Pacific Northwest Research Station. Portland, OR. https://www.fs.usda.gov/pnw/sciencef/scifi79.pdf

> "From a wildlife manager's perspective, roads act as barriers to movement and dispersal of wildlife, often isolating and fragmenting populations. They promote human access and development into wildlife habitat, and they introduce a host of pollutants, such as exhaust, pavement de-icers, and oil. Then, of course, there are the collisions—a direct source of mortality for millions of animals each year." (pgs. 1-2)

Haddad, N. M., Brudvig, L. A., Clobert, J., *et al.* (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances*, *1*(2). https://doi.org/10.1126/sciadv.1500052

> "However, we were struck by the persistence of degradation to biodiversity and ecosystem processes and by the increase in many of the effects over time (Fig. 4). For example, extreme rainfall events at Wog Wog appeared to delay the decline in plant species richness for 5 years after fragmentation. In the Kansas Experiment, a lag of 12 years occurred before fragmentation effects on plant" (pg. 5)

> "In summary, across experiments spanning numerous studies and ecosystems, fragmentation consistently degraded ecosystems, reducing species persistence, species richness, nutrient retention, trophic dynamics, and, in more isolated fragments, movement." (pg. 5)

Charry, B. (2007). Conserving Wildlife On and Around Maine's Roads. Maine Audubon. Falmouth, ME. https://mobile.maine.gov/ifw/docs/MARoadsWildlife-FINAL.pdf

> "Quite simply, the impact on some wildlife is disastrous. Over time, species sensitive to habitat disruption decrease in number. Fragmented habitat limits natural dispersal of young animals, which leads to a loss of genetic diversity in some animal populations. Numbers of species and individuals decrease overall and, at the extreme, species become locally and regionally extinct." (pg. 2)

> "When a road is built through large, formerly intact habitat blocks—whether forest, grassland, or wetland—it fragments them into smaller areas and isolates the animals within them." (pg. 3)

> “Contamination of soil, plants, and animals extends up to 66 feet from a road, and elevated levels of heavy metals often extend 650 feet or more from the road, occurring at greater concentrations along roads with high traffic volume.13” (pg. 4)
>
> “Invasive plants and animals that are not native to a region can seriously harm wildlife habitats… Roadside erosion-control plantings, drainage ditches, maintenance and construction fill, automobiles and boats traveling from areas infested by invasive species, and animals traveling along roadways all provide a means for invasive species to disperse.” (pg. 5)

Yin, J., Wei, Q., Shao, D., *et al.* (2025). The impacts of power transmission and transformation projects on ecological corridors and landscape connectivity: a case study of Shandong province, China. *Sci Rep* 15, 6709. https://doi.org/10.1038/s41598-025-91474-2

> “The installation of PTTPs’ infrastructure, such as transmission line pillars and towers, can negatively impact the patency, length, and connection strength of ecological corridors. The results demonstrate that the presence of PTTPs has fragmented ecological landscapes, particularly in regions with high relief degrees and steep slopes, where species migration is most constrained. Moreover, constructing the PTTPs will inevitably disrupt the habitats of some species, limit the activity range of some wildlife, and create linear obstacles to their movement patterns.” (pg. 13)

STATE OF MAINE
DEPARTMENT OF ENVIRONMENTAL PROTECTION

and

STATE OF MAINE
LAND USE PLANNING COMMISSION

IN THE MATTER OF

CENTRAL MAINE POWER COMPANY
Application for Site Location of Development Act permit and Natural Resources Protection Act permit for the New England Clean Energy Connect ("NECEC")

L-27625-26- A-N
L-27625-TB-B-N
L-27625-2C-C-N
L-27625-VP-D-N
L-27625-IW-E-N

SITE LAW CERTIFICATION SLC-9

PRE-FILED TESTIMONY OF
DR. DAVID PUBLICOVER
APPALACHIAN MOUNTAIN CLUB

ON BEHALF OF INTERVENOR GROUP 4
(APPALACHIAN MOUNTAIN CLUB,
NATURAL RESOURCES COUNCIL OF
MAINE AND TROUT UNLIMITED)

February 22, 2019

Q. State your name and current position.

A. My name is David Publicover. I am currently employed as a Senior Staff Scientist and Acting Director of Research with the Appalachian Mountain Club (AMC), a non-profit conservation and recreation organization with headquarters in Boston, MA. My business address is P.O. Box 298, Gorham, NH 03581.

Q. What are your background and qualifications?

A. I have a B.S. in Forestry from the University of New Hampshire (1978), an M.S. in Botany from the University of Vermont (1986), and a D.F. in Forest Ecology from the Yale University School of Forestry and Environmental Studies (1993).

I have been employed as a staff scientist by the AMC since 1992. My primary responsibility is to provide scientific information and analyses to AMC in support of our mission in the areas of terrestrial ecology, landscape analysis, land use and conservation planning, sustainable forestry, biological conservation and energy facility siting.

For most of my tenure at AMC I have been involved with issues related to energy facility siting. I have served as an expert witness for AMC during interventions in four commercial wind power development applications in Maine and New Hampshire as well as the Northern Pass transmission line project in New Hampshire. I served as an alternate member of the Governor's Task Force on Wind power Development in Maine (2007-08) and was actively involved in the revision of the New Hampshire Site Evaluation Committee's energy facility permitting rules (2013-15). I have conducted multiple landscape-level GIS-based analyses on conflicts between wind power siting and ecological and scenic values.

I have also been involved in debates and discussions on sustainable forestry, land management and biological conservation dating back to the Northern Forest Lands Council and the Maine Forest Biodiversity Project in the 1990s. I have served on numerous public policy committees and working groups and am currently a member of the Maine Ecological Reserves Scientific Advisory Committee and the New Hampshire Forest Advisory Board. I was a contributing author to *Good Forestry in the Granite State* and served on the steering committee overseeing the development of *Biodiversity in the Forests of Maine: Guidelines for Land Management.* I oversee forest and land management planning, Forest Stewardship Council certification and forest carbon offset project development for AMC's 75,000 acres of forest land in Piscataquis County.

My CV is attached as Appendix A.

Q. Have you previously testified before DEP or LUPC?

A. I have not testified before DEP. I have testified before the (then) Land Use Regulation Commission on three wind power project permit applications.

Q. What is the purpose of your testimony?

A. For the DEP Site Law and NRPA applications, my testimony addresses the value of the Western Maine Mountains region, the fragmenting impacts of the new corridor (Segment 1) on wildlife habitat in this region, the failure of the Applicant to adequately assess these impacts, the failure of the Applicant to adequately assess alternatives to the proposed project, and the failure of the Applicant to adequately mitigate the impacts of the proposed project on wildlife habitat.

For the LUPC certification, my testimony addresses the special exception criteria related to the crossing of the Appalachian Trail P-RR zone.

Q. Please summarize your testimony.

A. DEP Site Law and NRPA applications: The Western Maine Mountains is the heart of a globally significant forest region that is notable for its relatively natural forest composition, lack of permanent development, and high level of ecological connectivity. The proposed new corridor would be one of the largest permanent fragmenting features bisecting this region and would have an adverse effect on wildlife habitat, wildlife life cycles and travel corridors. The Applicant's assessment of these impacts is cursory, overly general, lacking in specific analyses, and inappropriately conflates the impacts of the corridor with those of timber management. The Applicant has failed to meet the burden of proof requirement of 38 MRSA §486-A.2 to demonstrate that the project will not cause an unreasonable adverse impact on the natural environment. The Applicant has also failed the burden of proof to demonstrate that there is not a practicable alternative to the proposed project that is less damaging to the natural environment. Finally, the Applicant has failed to provide adequate mitigation for the project's impacts. For these reasons the DEP should deny the permit.

LUPC certification: The proposed project would significantly degrade the experience of Appalachian Trail users at the crossing of the existing transmission line corridor by widening the corridor by 50% and installing a second much larger transmission line. As proposed the project fails the second criteria for a special exception in that this increased impact cannot be buffered from existing uses. The opportunity exists to improve rather than degrade the users' experience by relocating the trail in this area. LUPC should condition the granting of the special exemption on a resolution of this

issue between the Applicant and AT trail managers. Absent such a resolution LUPC should deny the special exception.

TESTIMONY RELATED TO DEP SITE LOCATION OF DEVELOPMENT AND NATURAL RESOURCES PROTECTION ACT APPLICATIONS

Q. Please describe the values of the Western Maine Mountains region through which the new corridor would pass.

A. While the undeveloped forests of the north Maine woods (and the Western Maine Mountains region in particular) may be taken for granted by those who live, work and recreate here, they have been recognized as a regionally, nationally and even globally significant forest region by many analyses.

The values of the region have been well summarized by McMahon (2016)[1], who states:

> The five million acre Western Maine Mountains region is a landscape of superlatives. It includes all of Maine's high peaks and contains a rich diversity of ecosystems, from alpine tundra and boreal forests to ribbed fens and floodplain hardwood forests. It is home to more than 139 rare plants and animals, including 21 globally rare species and many others that are found only in the northern Appalachians. It includes more than half of the United States' largest globally important bird area, which provides crucial habitat for 34 northern woodland songbird species. It provides core habitat for marten, lynx, loon, moose and a host of other iconic Maine animals. Its cold headwater streams and lakes comprise the last stronghold for wild brook trout in the eastern United States. Its unfragmented forests and complex topography make it a highly resilient landscape in the face of climate change. It lies at the heart of the Northern Appalachian/Acadian Forest, which is the largest and most intact area of temperate forest in North America, and perhaps the world. Most importantly, the Western Maine Mountains region is the critical ecological link

[1] References are included as Appendix B.

between the forests of the Adirondacks, Vermont and New Hampshire and northern Maine, New Brunswick and the Gaspé.

The value of the Western Maine Mountains lies in both its ecological diversity (encompassing an array of mountains, lakes and ponds, rivers and streams, wetlands, and hardwood, mixed and softwood forests) and its undeveloped character. Across much of the region the primary human impact has been from timber harvesting and logging roads, and only two major fragmenting features (Routes 201 and 26) traverse the breadth of the region. It is one of the few areas in the eastern United States that is sufficiently intact and natural to maintain viable populations of almost all native species.

Globally the Western Maine Mountains lies within the Temperate Deciduous and Mixed Forest ecoregion (Olson et al. 2001). This biome encompasses some of the most heavily settled regions in the world – the eastern United States, much of Europe, and northeastern Asia (China and Japan). Within this biome the region stretching from northern New Hampshire across western and northern Maine into Maritime Canada is the largest area of relatively intact forest blocks due to the lack of permanent settlement, development and land conversion (Haselton et al. 2014; Exhibit 1).

Other sources that recognize the value of the region as a large ecologically intact forest region include:

- The Northern Maine Forest Block is the largest Globally Important Bird Area in the continental United States as identified by the National Audubon Society (NAS 2019; Exhibit 2).
- The region was identified as one of the largest areas in the eastern United States of above-average climate change "resilience" by The Nature Conservancy, due in part to the high level of "local connectedness" (i.e., the

permeability of the landscape to species movement based on fragmentation and barriers to movement). (Anderson et al. 2016; Exhibit 3).

- The region was identified as a priority ecological linkage by the Staying Connected Initiative, a regional partnership working to "conserve, restore, and enhance landscape connectivity across the Northern Appalachian/Acadian region" (SCI 2019; Exhibit 4). (Maine Department of Inland Fisheries and Wildlife and Maine Department Transportation are partners in this initiative.)

The region's values are also reflected in the Land Use Planning Commission's 2010 Comprehensive Land Use Plan (LUPC 2010) which includes the following:

- "*One of the four principle values of the Unorganized Territories is "Natural Character, which includes the uniqueness of a vast forested area that is largely undeveloped and remote from population centers. Remoteness and the relative absence of development in large parts of the jurisdiction are perhaps the most distinctive of the jurisdiction's principal values, due mainly to their increasing rarity in the Northeastern United States.*" (CLUP p. 2)
- "*Natural resources are generally enhanced when they are part of a large, relatively undeveloped area, especially one that encompasses entire watersheds or ecosystems.*" (CLUP p. 2)
- "*The forests of the jurisdiction are part of the largest contiguous block of undeveloped forestland east of the Mississippi.*" (CLUP p. 197)
- "*Scientists are increasingly aware of the value of managing forests in large blocks as part of habitat conservation efforts... However, even large habitat blocks have less value if they lack connections or corridors linking them to other*

habitat patches that allow genetic flow from one patch to another." (CLUP p. 233)

In addition, a conservation priorities map developed by MDIFW as part of the Wildlife Action Plan (MDIFW 2010) notes that "*Northern Maine is unique as the largest area of undeveloped natural land in the eastern US. It is critically important for its economically valuable forest base and as a draw for unique outdoor recreational experiences, but especially for the habitat it provides for the species characteristic of and dependent on the Eastern Forest and especially those species that need large areas to maintain viable populations.*"

Intact forests such as these are critical to the maintenance of global biodiversity, as noted by Watson et al. (2018), who stated, "*As the terrestrial human footprint continues to expand, the amount of native forest that is free from significant damaging human activities is in precipitous decline. There is emerging evidence that the remaining intact forest supports an exceptional confluence of globally significant environmental values relative to degraded forests... Retaining the integrity of intact forest ecosystems should be a central component of proactive global and national environmental strategies...*".

To summarize, the Western Maine Mountains region is the heart of a globally significant forest region that is notable for its lack of permanent development and fragmentation and high level of ecological connectivity. These are the values that would be most significantly affected by the clearing of the new NECEC corridor.

Q. Has the Applicant adequately considered the value of this region in their application?

A. They have not. Rather the Applicant consistently minimizes its value, and nowhere is there any discussion of the regional, national or global significance of the region. Instead, we find limited statements such as "*this area of the state is already intensively managed (i.e., periodically clearcut) forested land and the creation of a transmission corridor is not likely to disrupt or significantly alter existing land uses.*" (Site Law Application Chapter 7, p. 7-24; multiple similar statements may be found in Application Section 7.4.1). CMP's project website[2] states "*The new corridor section crosses through a large area of commercial woodlands laced with roadways and active areas of timber harvesting and forest management.*"

By characterizing the region as merely managed forest land, the Applicant fails to recognize that these expansive commercial forest lands are an important part of what has helped to maintain the value of the region. As noted by the Keeping Maine's Forests coalition (KMF 2010):

> Maine's forests, which include the largest unbroken tract of undeveloped forest east of the Mississippi River, sustain tens of thousands of jobs in the forest products and forest-based tourism industries. That this national resource is intact and productive today is a testament to good management by landowners and the ability of the forest-based economy to adapt, strengthen, and diversify markets for forest products and tourism

McMahon (2018) similarly notes:

> Fragmentation has already significantly degraded ecosystems in much of the eastern United States and in temperate forests throughout the world. By contrast, in large part because historical forest

[2] https://www.necleanenergyconnect.org/faqs.

management maintained vast connected forest blocks in the region, the Western Maine Mountains' biodiversity, resilience and connectivity are unparalleled in the eastern United States.

In addition, the Applicant mischaracterizes the region as "intensively managed". To a large degree these forests are managed using natural regeneration and maintain a relatively natural species composition (though the age-class structure has been significantly altered towards a younger overall condition). Only a small proportion is intensively managed as foresters understand the term, meaning the use of techniques such as planting and herbicide application to maximize timber production. This distinguishes the region from forests that are truly intensively managed such as the pine forests of the southeastern United States.

In presentations on their route selection process to AMC and others, CMP representatives described how the route was sited through working forests in a gap between higher value areas[3]. In reality no such gap exists, as can easily be seen by viewing the landscape in Google Earth – the working forests are an integral part (in fact the major component) of this vast undeveloped landscape.

It is true that the Western Maine Mountains region is not pristine wilderness. However, on a scale of human impact from natural wilderness to dense urban development, the forests of the region lie very close to the natural end of the scale. The fact that the new corridor would be carved through managed timberland rather than pristine wilderness in no way diminishes the impact of the corridor on the ecological value of the region.

[3] For example, see the recording of CMP's presentation to a forum in Lewiston, ME hosted by the Sierra Club on 8/22/18. (https://www.youtube.com/watch?v=EelQI-QCWu0 beginning at 26:30)

Q. Please describe the fragmenting impacts of the new corridor.

A. The new corridor would be one of the largest permanent fragmenting features in the Western Maine Mountains region. It would be only the third feature (other than logging roads) that completely bisects the region.

The effects of fragmentation on forests have been summarized in numerous studies, both locally (McMahan 2018) and globally (e.g., Saunders et al. 1991, Harper et al. 2005, Haddad et al. 2015). The continued loss and degradation of intact forests is one of the major threats to biodiversity and other ecosystem services worldwide; as noted by Watson et al. (2018), "*the relative value of intact forests is likely to become magnified as already-degraded forests experience further intensified pressures (including anthropogenic climate change).*"

The 53 miles of new corridor will have three types of impacts:

Direct loss of habitat. The 53.5-mile by 150-foot new corridor encompasses nearly 1,000 acres, the great majority of which would be permanently lost forest habitat.

Edge effects. The creation of extensive permanent "hard" edge along both sides of the new corridor would have significant and long-lasting adverse effects on the adjacent forest habitat. Edges alter the adjacent forest in numerous ways including increased penetration of light and wind, increased temperatures, lower humidity and soil moisture, increased blowdown, and increased growth of understory and early successional vegetation (Matlack and Litvaitis 1999, Harper et al. 2005, McMahon 2018). These effects cause significant changes in the forest within the edge zone as noted by Matlack and Litvaitis (1999, p. 227):

> One artifact of the human modification of forests has been the tremendous increase in forest edges. Historically, land managers considered the lush plant growth and diversity of animals at edges as

> beneficial. However, recent investigations have described radical changes in community structure at edges, suggesting serious problems from a biodiversity perspective. Edge habitats are advantageous to a variety of exotic plants, predators, brood parasites, and herbivores that are capable of altering the composition of local forest communities. Radical changes in the forest microclimate at edges lead to dramatic changes in plant community structure with may persist several decades, at least.

A major consequence of edge effect is the consequent decline in interior forest habitat, which is forest sufficiently removed from edge to be free of its effects. While edges are beneficial to some species, many others avoid them and require interior habitat. Pfeifer et al. (2017), in a meta-analysis of fragmentation studies from across the globe, found that while relatively equal numbers of species were attracted to or avoided edges, those that avoided edges (and were dependent on interior forest) were more likely to be habitat specialists of high conservation concern. In contrast, species attracted to edges are more likely to be common generalist species.

Mature interior forest in northern Maine comprises less than 3% of the landscape (MDIFW 2015) and some species associated with it are of high conservation concern. These include migratory songbirds such as scarlet tanager, wood thrush, veery, and various warblers as well as mammals such as American marten (Rosenberg 1999, 2003; MDIFW 2015, MAS 2017).

Different types of edge effects extend for different distances into the adjacent forest (Harper 2005, McMahon 2018). One hundred fifty to 300 feet (50-100 meters) is commonly used to define the edge zone (Rosenberg 1999), though some effects can extend farther than this. Pfeifer et al. (2017) found that the abundance of interior forest-dependent species was reduced up to 400 meters from edges.

The linear configuration of the corridor maximizes the amount of edge zone for the cleared area as compared to a more compact shape. The area within 300 feet of the new corridor encompasses nearly 4,000 acres – about four times the area that will be directly cleared. Not all of this is forest, and not all of the forest is interior forest due to the presence of roads and the shifting patterns of timber harvesting. However, in the absence of the corridor most of the forest is potential interior forest, and would be interior forest at some part of the timber management cycle. With the corridor all of this forest will be permanently subject to edge effects, reducing its ability to support interior forest species.

Reduction in connectivity. The high level of ecological connectivity is one of the most significant characteristics of the Western Maine Mountains regions, and the new corridor would be one of the most significant features impeding the connectivity, particularly because it bisects the entire region.

This impact is recognized in LUPC's 2010 Comprehensive Land Use Plan (p. 241), which states "Scientists have identified fragmentation of habitat as a serious concern. Roads, utility corridors, certain types of recreation trails, structures and clearings create breaks in the landscape. These breaks can act as barriers to animals and isolate populations of both plants and animals." Maintaining connectivity was one of three "super themes" guiding wildlife conservation actions identified in the 2015 Wildlife Action Plan (MDIFW 2015).

Not all species will be equally affected. Generalist species that use a range of habitats will likely cross the corridor with little difficulty. Some small-bodied species may find the shrubby vegetation less of a barrier than a 20' bare gravel road. The species

that will be most affected are those that avoid large openings or extensive shrub or regenerating forest habitat.

For example, American marten in the Northeast avoid openings and regenerating forest, but occupy areas with forest cover at least 30' high with canopy closure of at least 30% and diverse forest structure including snags and coarse woody debris (Payer and Harrison 2000, 2003, 2004; Lambert et al. 2017). DeMaynadier and Hunter (1995, 1998) documented significant declines in amphibian populations in recent clearcuts, with red-backed, spotted and blue-spotted salamanders and wood frogs particularly sensitive. These effects can be ameliorated by the retention of microhabitat "refugia" such as patches of retained trees and coarse woody debris. However, the corridor will be maintained in a permanent early-successional condition without retained overstory cover or woody debris inputs, and thus is likely to present a significant barrier to these species.

Q. Has the Applicant adequately assessed these impacts in their application?

A. No they have not. These impacts are discussed in Site Law Application Section 7.4.1. However, this section is marred by meaningless general statements and the absence of any significant analysis of fragmentation effects. For example:

- "*Habitat conversion along transmission line corridors results in a loss of habitat types which, in turn, may adversely impact species that are reliant on the original habitat types. Conversely, such alteration provides benefits to several species.*" Also, "*Impacts of habitat conversion along the proposed transmission line corridor are expected to be minimal, beneficial to some species while detrimental to other species.*" (Both on Site Law Application p. 7-24.) The Applicant includes a discussion of the habitat benefits of transmission line corridors (which

are irrelevant to permitting) but no discussion of which species may be adversely impacted (which is). In fact, it is mature forest habitat that is in short supply in northern Maine, not the early successional habitat that would be created by the new corridor (MDIFW 2015).

- "*Some bird species within the NECEC Project area that may be sensitive to forest fragmentation are the long distance, neotropical migrants that rely on forest interior habitats, but plentiful suitable habitat is available near the NECEC Project areas for these interior forest species. Most of the potential breeding birds that are likely to be found in the vicinity of the transmission line corridor are not dependent on mature forest stands… Most of the terrestrial mammal species that are likely to be found near the proposed transmission line corridors are likewise not dependent on mature forest*" (Site Law Application p. 7-25.) The fact that "most" species will not be affected is irrelevant. There is no assessment in the application of which species may be adversely affected, the extent of interior forest habitat in the vicinity of the project, or the effect of the project on this habitat. The Applicant wants to have it both ways – the surrounding managed landscape is already heavily fragmented by timber harvesting, but yet mature interior forest habitat is plentiful. In fact, as noted previously less than 3% of the forest in northern Maine is mature interior forest.

The Applicant also consistently and inappropriately conflates the impacts of the new corridor with the impacts of timber harvesting in the surrounding landscape. For example: "*Approximately 27 percent of the Project will require new clearing, however this area of the state is already intensively managed (i.e., periodically clearcut) forested*

land..." and "*In general, given the existing landscape characteristics of the overall NECEC Project area, construction and maintenance of the transmission line corridors will result in habitat conversion that is already common to the area, i.e. forested to scrub-shrub.*" (Both on Site Law Application p. 7-24.) However, the new corridor is qualitatively different than timber harvesting in many ways:

Permanence. The new corridor would be an enduring feature in the landscape. In contrast, timber harvesting creates a shifting mosaic of temporary impacts which are ameliorated over time through natural succession.

Spatial configuration. The new corridor would be a linear feature extending across the entire Western Maine Mountains region; a configuration that maximizes edge effect and impediments to species movement. In contrast, timber harvest units are smaller and more compact units with lower edge-to-area ratio, and which exist in a mosaic of forest conditions that allow freer movement of species throughout the landscape.

Habitat condition. The new corridor will be permanently maintained in an herbaceous or shrubby condition, without residual overstory trees or other forest structures (snags, woody debris, etc.) that provide microhabitats or localized refugia for many species. Contrary to the Applicant's contention, most timber harvesting in the state is done by various forms of partial harvesting that retains some level of residual overstory and biological legacies. Between 2013 and 2017 clearcutting accounted for less than 7% of harvested acres in the state (MFS 2013-2017).

The Applicant's conclusions regarding the fragmenting impacts of the new corridor consist of little more than general statements such as:

- "*It is anticipated that local wildlife populations will adapt and respond to any additional alterations much as they already do to uses within the vicinity of the transmission line corridor.*" (Site Law Application p. 7-24)
- "*...the creation of a transmission corridor is not likely to disrupt or significantly alter existing land uses.*" (Site Law Application p. 7-24)
- [The new corridor] "*is located in an intensively managed timber production area and therefore not likely to significantly alter existing fragmentation.*" (Site Law Application p. 7-25)
- [The new corridor is] "*located in an intensively managed area for timber production; this transmission line segment is therefore not likely to significantly alter or increase the existing edge effect.*" (Site Law Application p. 7-26)

These statements are unsubstantiated by any analysis or evidence in the application, and are contradicted by extensive evidence on the consequences of forest fragmentation. They are also contradicted by numerous photographs of the Segment 1 landscape included in Application Chapter 6 Appendix D (Photosimulations). These photos do not show a landscape dominated by clearcuts, but rather one in which recent harvest units of various shapes, sizes and intensities exist within a matrix of relatively continuous forest. Even during leaf off snowcovered conditions, when harvesting would be most noticeable, harvest units exist as patches within a dominantly forested matrix. In addition, most harvest units retain some level of residual forest overstory. Photosimulation 44 clearly illustrates the difference in spatial configuration and habitat condition between the permanent corridor and the transient harvest units. The new corridor is not just another clearcut.

Q. Are there other impacts of the new corridor that you would like to address?

A. Yes. The new corridor would clear and fragment two occurrences of the rare Jack Pine Forest[4] natural community where it passes south of No. 5 Bog. Rare natural communities are encompassed in the definition of "unusual natural areas" under DEP rules (Chapter 375.12(B)).

Jack Pine Forest is ranked as S1 ("Critically imperiled in Maine because of extreme rarity") by the Maine Natural Areas Program. S1 communities represent the rarest of the rare in the state. The occurrences that would be impacted by the new corridor represent only the second and third occurrences in the state documented by the Maine Natural Areas Program[5]. The impact of the new corridor on this extremely rare natural community is thus of very high conservation concern.

The full extent and condition of these occurrences has not been determined, precluding a full evaluation of the impact of the new corridor. One of them is described as "*fairly extensive, extending outside of the survey area to the north and south.*"[6] However, the corridor would fragment both of these occurrences, separating portions on either side of the corridor. In addition, portions of these occurrences adjacent to the corridor would be subject to edge effects that would alter the structure and composition of this community within the edge zone.

It appears that a minor relocation of the proposed corridor would eliminate the impact to these rare natural community occurrences. However, they were only

[4] This community is distinct from the Jack Pine Woodland community, which is ranked S3. Most documented occurrences of Jack Pine Woodland are located in Hancock and Washington counties.
[5] Information on documented occurrences of Jack Pine Forest was provided by MNAP in email from Lisa St. Hillaire to David Publicover dated 2/19/19. The Applicant's Rare Plant Survey Narrative Report (September 2018) lists three occurrences, but two of these are considered a single occurrence by MNAP.
[6] Application Rare Plant Survey Narrative Report, Appendix F.

documented following a request for rare plant and natural community surveys by MNAP[7]. They were not known when the route was being identified, but only after the corridor had been delineated and purchased, precluding the opportunity to route the corridor around them. This is indicative of extremely poor planning on the part of the Applicant, as well as their total lack of understanding of or consideration for the ecological values of the region through which the new corridor would pass.

In addition, the fact that these occurrences extend beyond the corridor presents an opportunity for the Applicant to work with the adjacent landowner to conserve and manage these occurrences in a way that maintains their presence and ecological values as mitigation for these impacts. However, this was not done.

Q. Has the Applicant adequately analyzed alternatives to the location of the new corridor?

A. No they have not. Such an analysis is required under the Site Location of Development law [38 MRSA §487-A(4); specific to transmission lines] and DEP rules [Chapter 310.5(A)] [8] as well as LUPC P-WL special exception determination.

The alternatives analysis is contained in NRPA application Section 2. The Applicant describes the purpose and need of the project as delivering Quebec hydropower to the New England grid "at the lowest cost to ratepayers". While cost is a consideration in determining whether an alternative is practicable, defining the purpose and need in this way is inappropriate and cannot be a consideration for DEP. This definition of purpose

[7] MNAP memo to DEP of 12/12/17.

[8] While this requirement is specific to wetland impacts, these impacts are dispersed throughout the length of the new corridor, and such an analysis would also serve to address alternatives to other impacts described in this testimony. In addition, the requirement in 38 MRSA §487-A(4) is speaks to "impact on the environment" without limitation and thus encompasses the full range of impacts.

and need makes any but the lowest-cost alternative not practicable by definition and would render the alternatives analysis meaningless.

The Applicant assesses two alternative locations for the new corridor. Neither can be considered a reasonable alternative. Alternative 1 (1980s Quebec Corridor) was denied a permit by the PUC at that time. Subsequent developments, primarily land conservation that has taken place since that time, would make the ability to reacquire rights to this corridor uncertain and in one case "highly unlikely". Alternative 2 (Bigelow Corridor) also presents many difficulties; by CMP's own admission there are serious impediments and engineering challenges to securing this route.

However, there is another alternative that should have been analyzed - burial along existing corridors, most realistically along the Spencer Road (the primary gravel road accessing the Moose River valley; see Exhibit 5) but also potentially Route 201. The new corridor parallels and lies within two miles of the Spencer Road for a distance of over 20 miles, and for the most part lies within the ownership of the same landowner (Weyerhauser) from whom CMP acquired the proposed corridor.

Burial of HVDC lines is both technologically and financially feasible, as demonstrated by its use in two projects that were competitors to NECEC in the Massachusetts RFP process. Eversource's Northern Pass project in New Hampshire proposed burial of 60 miles of line along public roadways[9]. TDI's New England Clean Power Link project in Vermont would bury 56 miles of line along public roadways and railroads[10]. Burial along paved public roadways with existing development (as in these projects) would be more difficult than burial along undeveloped gravel logging roads,

[9] http://www.northernpass.us/route-info.htm.
[10] http://www.necplink.com/about.php.

thus there is no basis to conclude that burial of the NECEC line along logging roads would be technologically or logistically unfeasible.

This alternative would almost certainly have less impact on the environment than the proposed new corridor. It would eliminate or greatly reduce the fragmentation impacts, resulting in much less clearing (just a narrow expansion of the existing road corridor), no new edge, no additional loss of existing or potential interior forest habitat, and a minimal increase in impediments to species' ability to cross the corridor. There would be wetland and stream impacts, but these resources are already impacted by the road, and burying the line next to the road would result in limited and marginal additional impacts, as opposed to the greater impacts to relatively intact streams and wetlands located within the new corridor..

We recognize that cost is a consideration in analyzing alternatives, and burial would be more expensive. That fact alone does not render an alternative as not practicable. The standard of 38 MRSA §487-A(4) is that the alternative would not "unreasonably" increase the cost. Without any financial information it is impossible to make a determination as to whether the increased cost is reasonable. However, this cost was not an impediment to the Northern Pass or Clean Power Link projects. Given that Northern Pass was the first choice in the Massachusetts RFP process, it is evident that the increased cost of burial was not an impediment to this selection. Thus it appears clear that burial is a financial feasible alternative.

To summarize, it appears that there is an alternative that is technologically, logistically and financial feasible, and which would be significantly less damaging to the

environment. The failure to include an assessment of this alternative, and to demonstrate why it should not be considered practicable, is a fatal flaw in the application.

Q. In your expert opinion, do the fragmenting impacts of the new corridor constitute an adverse effect on natural resources under the Site Location of Development law sufficient to support a denial of the permit?

A. Yes they do. My reasons for this conclusion include:

Adverse impacts of fragmentation of wildlife habitat. The new corridor would be one of the largest permanent fragmenting features bisecting the largest expanse of relatively undeveloped and intact natural forest in the eastern United States and one of the largest such areas in the Temperate Deciduous and Mixed Forest biome in the world. The corridor would eliminate thousands of acres of existing and potential interior forest habitat through clearing and edge effects, adversely impacting wildlife lifecycles[11] for species dependent on this habitat. It would reduce the permeability of the landscape and impede the ability of some wildlife species to move through the region[12]. The Applicant's discussion of these impacts is extremely cursory, general and lacking in specific analyses on the adverse fragmenting impacts of the new corridor. The Applicant mischaracterizes the nature of existing timber harvesting in the region and inappropriately equates the impacts of the corridor to those of timber harvesting. The Applicant's conclusions are unsupported by any evidence in the application, are contradicted by extensive scientific evidence on the consequences of forest fragmentation, and amount to little more than "There's lots of forest, it's already heavily impacted, the new corridor is just another clearcut so it's no problem." The Applicant's

[11] As recognized in DEP rules Chapter 375 Section 15.B(2).
[12] As recognized in DEP rules Chapter 375 Section 15.B(1).

analysis does not come close to meeting the burden of proof for a demonstration of no adverse impact on the natural environment as required under 38 MRSA §486-A.2[13].

Adverse impact on unusual natural areas[14]. The new corridor would destroy portions of and fragment two occurrences of Jack Pine Forest, ranked S1 ("critically imperiled") by the Maine Natural Areas Program and one of the state's rarest natural vegetation communities. It appears that this impact could have been completely avoided by a minor relocation of the corridor, but this was not done since the ROW was fixed prior to any survey for rare plants and natural communities. This is indicative of extremely poor planning on the part of the Applicant, as well as their total lack of understanding of or consideration for the ecological values of the region through which the new corridor would pass.

Lack of adequate alternatives analysis. The Applicant's analysis of alternative routes for the new corridor considers two alternatives that cannot be considered realistic. By the Applicant's own admission both would involve significant difficulties in route acquisition and permitting. However, they failed to consider an alternative (burial along existing road corridors) that has been utilized by at least two other major transmission line projects in New England, demonstrating that this approach is both technologically and financially feasible under more difficult conditions than would occur for this project. By not analyzing an obvious and potentially practicable alternative that would have a significantly lower impact on the environment, the Applicant has failed the burden of

[13] "At the hearings held under this section, the burden is upon the person proposing the development to demonstrate affirmatively to the department that each of the criteria for approval listed in this article has been met, and that the public's health, safety and general welfare will be adequately protected."

[1414] As recognized in DEP rules Chapter 375 Section 12.

proof standard as it applies to 38 MRSA §487-A(4) and DEP rules Chapters 310.5(A) and 335.3(A).

Lack of adequate mitigation. Mitigation consists of three components: avoidance, minimization and compensation. The Applicant falls short in all three areas.

- *Avoidance.* As noted above, the Applicant has failed to demonstrate that there is not an alternative practical route that would avoid the necessity of clearing the new corridor. At a more local scale, the Applicant has failed to avoid the impact to the Jack Pine Forest occurrences by designing a route around them.
- *Minimization.* DEP rules (Chapters 375.9 and 375.15) envision buffer strips as a way to provide wildlife travel corridors between areas of habitat. However, the riparian buffers proposed by the Applicant do not sufficiently minimize the impediment to species movement created by the new corridor. As described in Application Chapter 10 Exhibit 10-2 (Post-Construction Vegetation Management Plan) vegetation within the wire zone of riparian buffers will be maintained at a height of 10 feet. This is insufficient to provide habitat for American marten and other species that require taller forest cover of minimum density. In addition, in multiple locations mapped streams are a mile or more apart. These measures do not adequately minimize the impact of the new corridor on landscape connectivity.
- *Compensation.* The Applicant's final Compensation Plan focuses on compensation for resources considered under the Natural Resources Protection Act and for which compensation is specifically required. However, the Site Law considers impacts at a broader level. 38 MRSA §484(3) addresses impacts to

"other natural resources" without limitation. In addition, DEP rules Chapter 375.15.A addresses "the need to protect wildlife and fisheries by maintaining suitable and sufficient habitat", indicating consideration of the full range of wildlife. Chapter 375.15.B(1) and (2) speak generally of "travel lanes" and "fish and wildlife lifecycles" without reference to specific species or habitats (which are considered in 375.15.B(3)). Finally, 375.15.C addresses the need for the Applicant to provide that they have made "adequate provision for the protection of wildlife and fisheries" (again without limitation), and 375.15.C(2) includes habitat preservation as a component of mitigation for adverse impacts to wildlife. In total this section makes clear that compensatory mitigation is not limited just to NRPA-protected resources but may be applied to all wildlife habitat impacts.

The new NECEC corridor would be one of the largest permanent fragmenting features in a globally significant forest region that is distinguished by its high level of ecological connectivity. It would eliminate thousands of acres of existing and potential interior forest habitat and reduce the permeability of the landscape to species movement. The landscape includes extensive streams (particularly cold water fisheries) and wetlands that exist not as isolated features but as integral and connected parts of the broader ecological system.

The new corridor is not a compact feature such as a sawmill or shopping mall impacting degraded wetlands in an already developed area. It is a sprawling feature that will impact multiple natural resource values across a broad area of high ecological value. The 13 parcels proposed as compensatory land conservation are small (averaging about 215 acres in size), scattered and have

little nexus to the landscape-level fragmentation impacts of the project. The Applicant has provided compensation for the impact to individual pieces but not the cumulative impact to the whole interconnected ecosystem. Compensation for this cumulative impact should be held to a higher standard than provided by the Applicant.

Though we contend that the project should not be permitted as proposed, if it is permitted then very significant habitat protection should be required as compensation given the ecological values of this region and the magnitude of the impact of the new corridor on wildlife habitat. We support the position of The Nature Conservancy and Maine Audubon Society[15] that land conservation in the range of 75,000 to 100,000 acres is the appropriate scale to compensate for the project's very significant fragmenting impacts.

For these reasons, we believe that the proposed new corridor constitutes an unreasonable adverse impact on the environment and that DEP should deny the permit.

Q. Does this conclude your testimony relative to the issues before DEP?

A. Yes.

[15] See https://bangordailynews.com/2018/10/16/opinion/contributors/hydro-line-project-doesnt-go-far-enough-to-mitigate-conservation-concerns/.

TESTIMONY RELATED TO LAND USE PLANNING COMMISSION CERTIFICATION

Q. Please describe the situation regarding the crossing of the Appalachian Trail by the existing transmission line corridor (Segment 2).

A. Currently the Appalachian Trail (AT) crosses the existing 150-foot-wide transmission line corridor three times within a stretch of two-thirds of a mile. Hikers are exposed to an unnatural linear opening and multiple 45-foot-high transmission line structures that compromise the backcountry experience. We recognize that the transmission line corridor predates the establishment of the AT as a National Scenic Trail.

Q. What would be the impact of adding the new line to this corridor on the experience of hikers?

A. As proposed the addition of the new line would make the existing situation worse. The widening of the corridor and the addition of a second transmission line with taller towers would increase the exposure of hikers to the open corridor and intensify the experience of being in a developed rather than backcountry environment. The Applicant's Visual Impact Assessment (Application Chapter 6 pp. 6-43 to 6-44) rates the impact as "minimal to moderate". The Applicant also states (Application Chapter 25, Section 25.3.1.3) that there would be a "negligible" change in visual impact. However, these conclusions are contradicted by the revised Chapter 6 Appendix F (Scenic Resources Chart, 1/30/19) that rates the impact as "Moderate/Strong".

The Applicant also states (Application Chapter 6 p. 6-50), "*The Project should not negatively affect the hikers' experience or their continued use and enjoyment the Appalachian Trail.*" The statement that the project will not negatively affect hikers'

experience is made without any supporting evidence, and is contradicted by the revised impact rating of Moderate/Strong and the Applicant's recognition of the need to mitigate this impact through vegetative screening. There is a noticeable difference between a single line with wooden towers shorter than the surrounding forest and a corridor that is 50% wider with two lines, one with steel towers considerably taller than the surrounding forest, which are experienced by hikers passing directly under the line. The change is quite noticeable in the photosimulation from this area (Application Chapter 6, Appendix E, Photosimulation B, pp. 27-28). The photosimulation of the proposed vegetative screening (Appendix D: Photosimulations – Leaf Off/Snow Cover, Photosimulation 50A) does not inspire confidence that the proposed mitigation will be adequate. Vegetative screening alone cannot mitigate the exposure of hikers to the wider corridor and an additional larger transmission line.

Q. Does the proposed project satisfy the first requirement for a special exception in the AT P-RR district that "*there is no alternative site which is both suitable to the proposed use and reasonably available to the applicant*"?

A. Yes. We accept that co-locating the new line in the existing right-of-way is the preferred solution, and that an alternate location in a new corridor would have a greater impact on the AT by creating a new crossing where none currently exists.

Q. Does the proposed project satisfy the second requirement for a special exception in the AT P-RR district that "*the use can be buffered from those other uses and resources within the subdistrict with which it is incompatible*"?

A. As proposed it does not. While the existing situation is not ideal, the addition of a second larger line in a wider corridor constitutes an additional incompatible use of

moderate to strong impact that cannot be buffered from the AT. The available evidence does not support the contention that the proposed vegetation planting will be sufficient to buffer the trail from this increased impact

However, this requirement could be satisfied by a realignment of the AT that moves it away from the transmission line corridor in this area and leaves only a single crossing that minimizes exposure of hikers to the transmission line. If this were done there would be an improvement in the experience of AT hikers in this area rather than a diminishment as would occur with the project as proposed, and the increased buffering of the trail would satisfy the second requirement. This was noted as an appropriate mitigation strategy by the Applicant (Application Chapter 6 Section 6.2.2.7). We are aware that Appalachian Trail managers have had discussions with Applicant on ways to address the NECEC project impacts on trail users but we have not seen any resolution or conclusions from these discussions.

Q. Are there any conditions that the Commission should impose under Part (c) of the special exception criteria?

A. Yes. The Commission should condition the granting of the special exception on the Applicant reaching an agreement with AT managers on the relocation of the trail and providing funding for the relocation. As noted by the Applicant this would be an appropriate mitigation strategy for the increased impact on the AT experience in this area. In the absence of such an agreement the Applicant should provide funding for off-site mitigation that would be used to protect other AT viewsheds.

Q. Does that conclude your testimony relative to the LUPC certification?

A. Yes.

APPENDIX A: CURRICULUM VITAE

DAVID A. PUBLICOVER
Appalachian Mountain Club
PO Box 298
Gorham, NH 03581
(603) 466-8140, email: dpublicover@outdoors.org

Education:

Massachusetts Institute of Technology, Cambridge, MA.		1972-74
University of New Hampshire, Durham, NH	B.S. (Forestry)	1978
University of Vermont, Burlington, VT	M.S. (Botany)	1986
Yale School of Forestry & Env. Studies, New Haven, CT	D.F. (Forest Ecology)	1993

DF Thesis: *Nutrient Cycling and Conservation Mechanisms in an Oligotrophic Pine-Oak Forest in the New Jersey Pine Barrens.*

Employment History:

2001- present: Senior Staff Scientist/Assistant Director of Research, Appalachian Mountain Club, Gorham, NH.
1992-2000: Senior Staff Scientist, Appalachian Mountain Club, Gorham, NH.
1987-92: Research Assistant, Yale School of Forestry and Environmental Studies, New Haven, CT.
1979-84: Forester, USDOI, Bureau of Indian Affairs, Yakima Agency, Toppenish, WA.
1976-78: Park Technician, USDOI, National Park Service, Glacier National Park, West Glacier, MT (summers).

Publications:

- Publicover, D., K. Kimball, C. Poppenwimer and D. Weihrauch. 2018. *Ecological Atlas of the Upper Androscoggin River Watershed 2nd Edition* (Appalachian Mountain Club, Gorham, NH).
- Publicover, D.A., C.J. Poppenwimer and K. D. Kimball. *Northeastern High Elevation Areas: An Assessment of Ecological Value and Conservation Priorities. (AMC Technical Report in prep).*
- Publicover, D.A. and K. D. Kimball. *High-Elevation Spruce-Fir Forest in the Northern Forest: An Assessment of Ecological Value and Conservation Priorities* (submitted to proceedings of 2012 ECANUSA Forest Science Conference).
- Publicover, D.A., K.D. Kimball and C.J. Poppenwimer. 2011. *Ridgeline Windpower Development in Maine: An Analysis of Potential Natural Resource Conflicts* (AMC Technical Report 2011-1).
- Publicover, D.A. and C.J. Poppenwimer. 2006. *Roadless Areas in the Northern Forest of New England: An Updated Inventory* (AMC Technical Report 2006-1).
- Publicover, D. 2004. *A Methodology for Assessing Conflicts Between Windpower Development and Other Land Uses* (AMC Technical Report 2004-2).
- Publicover, D. and D. Weihrauch. 2003. *Ecological Atlas of the Upper Androscoggin River Watershed* (Appalachian Mountain Club, Gorham, NH).
- Publicover, D.A. and C.J. Poppenwimer. 2002. *Delineation of Roadless Areas in the Northern Forest of New England Using Satellite Imagery* (AMC Technical Report 2002-1).
- Vogt, K.A., D.A. Publicover, J. Bloomfield, J.M. Perez, D.J. Vogt, and W.L. Silver. 1992. *Belowground responses as indicators of environmental change*. Env. Exp. Bot. 33:189-205.

- Publicover, D.A. and K.A. Vogt. 1992. *Belowground ecology of forests.* Pp 427-429 in: McGraw-Hill Yearbook of Science and Technology. McGraw-Hill, Inc., New York.
- Publicover, D.A. and K.A. Vogt. 1991. *Canopy stereogeometry of non-gaps in tropical forests: a comment.* Ecology 72:1507-1510.

Public Policy

Service on numerous public policy technical committees and working groups addressing issues of biological conservation, sustainable forest management and renewable energy development, including:

- Appointed alternate member of Governor's Task Force on Windpower Development in Maine (2007-08), a year-long effort which compiled information on and developed recommendations for the appropriate development of this technology in the state. My GIS-based research (Publicover *et al.* 2011) was instrumental in the development of a recommendation for the designation of an "expedited wind power permitting area" that guided development to more suitable areas of the state. The Task Force's recommendations were subsequently enacted into law by the Maine legislature.
- Member of Maine Ecological Reserves Scientific Advisory Committee (1996-present), which developed information and recommendations for a legislatively-established system of ecological reserves on state land. On-going work with the committee includes evaluating research proposals within the reserves and advising the Maine Natural Areas Program on long-term monitoring protocols.
- Member of New Hampshire Forest Sustainability Standards Work Team (1995-97), which provided guidance to the State Forester on methods for evaluating and promoting sustainable forest management within the state. In this role I served as a primary author of multiple sections of the first edition of *Good Forestry in the Granite State: Recommended Voluntary Forest Management Practices for New Hampshire* (1997). Subsequently I served on the Good Forestry in the Granite State Steering Committee and served as a reviewer of the second edition of this document (2010).
- Member of the New Hampshire Forest Advisory Board (2000-present), which provides guidance to the State Forester on the management of state forest lands and issues of public policy affecting the forests of the state.
- Active participant in the Maine Forest Biodiversity Project (1994-98), a multi-year collaboration between the scientific community, state agencies, private forest landowners and environmental NGOs that provided a forum for information sharing and mutual education on issues related to forest land management and the conservation of the state's biodiversity. I served as a member of the Working Forest Committee which oversaw the development and publication of the Cooperative Extension publication *Biodiversity in the Forests of Maine: Guidelines for Land Management.*
- Member of the Forest Stewardship Council Northeast Regional Working Group that developed the first regional standards for FSC certification in the Northeast.
- Member of the Forest Guild Northeast Biomass Retention and Harvesting Guidelines Working Group that developed *Forest Biomass Retention and Harvesting Guidelines for the Northeast.*
- Participant in other forest policy working groups and technical committees including New Hampshire Forest Law Recodification Roundtable, New Hampshire Ecological Reserves Scientific Advisory Committee, Nash Stream Forest Citizens' Advisory Committee, and Maine Bureau of Parks and Lands Integrated Resource Policy working group.

APPENDIX B: REFERENCES

Anderson, M.G., A. Barnett, M. Clark, C. Ferree, A. Olivero Sheldon and J. Prince. 2016. Resilient Sites for Terrestrial Conservation in Eastern North America. The Nature Conservancy, Eastern Conservation Science, Boston, MA.

deMaynadier, P.G. and M.L. Hunter, Jr. 1995. The relationship between forest management and amphibian ecology: a review of the North American literature. Environmental Reviews 3:230-261.

deMaynadier, P.G. and M.L. Hunter, Jr. 1998. Effects of silvicultural edges on the distribution and abundance of amphibians in Maine. Conservation Biology 12:340-352.

Haddad, N.M. et al. 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. Science Advances 1.2 http://dx.doi.org/10.1126/sciadv.1500052.

Harper, K.A. 2005. Edge influence on forest structure and composition in fragmented landscapes. Conservation Biology 19:768-782.

Haselton, B., D. Bryant, M. Brown and C. Cheeseman. 2014. Assessing Relatively Intact Large Forest Blocks in the Temperate Broadleaf & Mixed Forests Major Habitat Type. Tierra Environmental and The Nature Conservancy.

Keeping Maine's Forests. 2010. Keeping Maine's Forest-Based Economy: A National Demonstration Project.

Lambert, J.D., Z.J. Curran and L.R. Reitsma. 2017. Guidelines for managing American marten habitat in New York and Northern New England. High Branch Conservation Services, Hartland, VT.

LUPC. 2010. Comprehensive Land Use Plan. Maine Department of Agriculture, Conservation and Forestry, Land Use Planning Commission, Augusta, ME.

MAS. 2017. Forestry for Maine Birds. Maine Audubon Society, Falmouth, ME.

Matlack, G.R. and J.A. Litvaitis. 1999. Chapter 6: Forest edges. Pp 210- 227 in: Maintaining Biodiversity in Forested Ecosystems (M.L. Hunter Jr., ed.). Cambridge University Press, Cambridge, UK.

MDIFW. 2010. Maine Conservation Priorities (map). https://www.beginningwithhabitat.org/pdf/NorthMaine_Draft10_Large_10_08_2010.pdf.

MDIFW. 2015. Wildlife Action Plan. Maine Department of Inland Fisheries and Wildlife, Augusta, ME.

McMahon, J. 2016. Diversity, Continuity and Resilience – The Ecological Values of the Western Maine Mountains. Occasional Paper No.1, Maine Mountain Collaborative, Phillips, ME.

McMahon, J. 2018. The Environmental Consequences of Forest Fragmentation in the Western Maine Mountains. Occasional Paper No.2, Maine Mountain Collaborative, Phillips, ME.

MFS. 2013-2017. Annual Silvicultural Activities Report. Maine Department of Agriculture, Conservation and Forestry, Maine Forest Service, Augusta, ME.

National Audubon Society. 2019. Important Bird Areas. https://www.audubon.org/important-bird-areas.

Olson, D.M. et al. 2001. Terrestrial ecoregions of the world: a new map of life on Earth. Bioscience 51(11):933-938.

Payer, D. and D.J. Harrison. 2000. Structural differences between forests regenerating following spruce budworm defoliation and clear-cut harvesting: Implications for marten. Canadian Journal of Forest Research 30:1965-1972.

Payer, D. and D.J. Harrison. 2003. Influence of forest structure on habitat use by American marten in an industrial forest. Forest Ecology and Management 179:145-156.

Payer, D. and D.J. Harrison. 2004. Relationships between Forest Structure and Habitat Use by American Martens in Maine, USA. Pp. 173-186 in: Harrison, D.J., A.K. Fuller and G. Proulx (eds), Martens and Fishers (*Martes*) in Human-Altered Environments. Springer, Boston, MA.

Pfeifer, M. et al. 2017. Creation of forest edges has a global impact on forest vertebrates. Nature 551: 187-191.

Rosenberg, K.V. et al. 1999. A land manager's guide to improving habitat for scarlet tanagers and other forest-interior birds. The Cornell Lab of Ornithology, Ithaca, NY.

Rosenberg, K.V. et al. 2003. A land manager's guide to improving habitat for forest thrushes. The Cornell Lab of Ornithology, Ithaca, NY.

Saunders, D.A., R.J. Hobbs and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology 5:18-32.

Staying Connected Initiative. 2019. http://stayingconnectedinitiative.org/.

Watson, J.E.M. et al. 2018. The exceptional value of intact forest ecosystems. Nature Ecology & Evolution 2.4 (2018): 599–610.

Dated: 2/22/19

by: _____
David Publicover

Date: 2/22/19

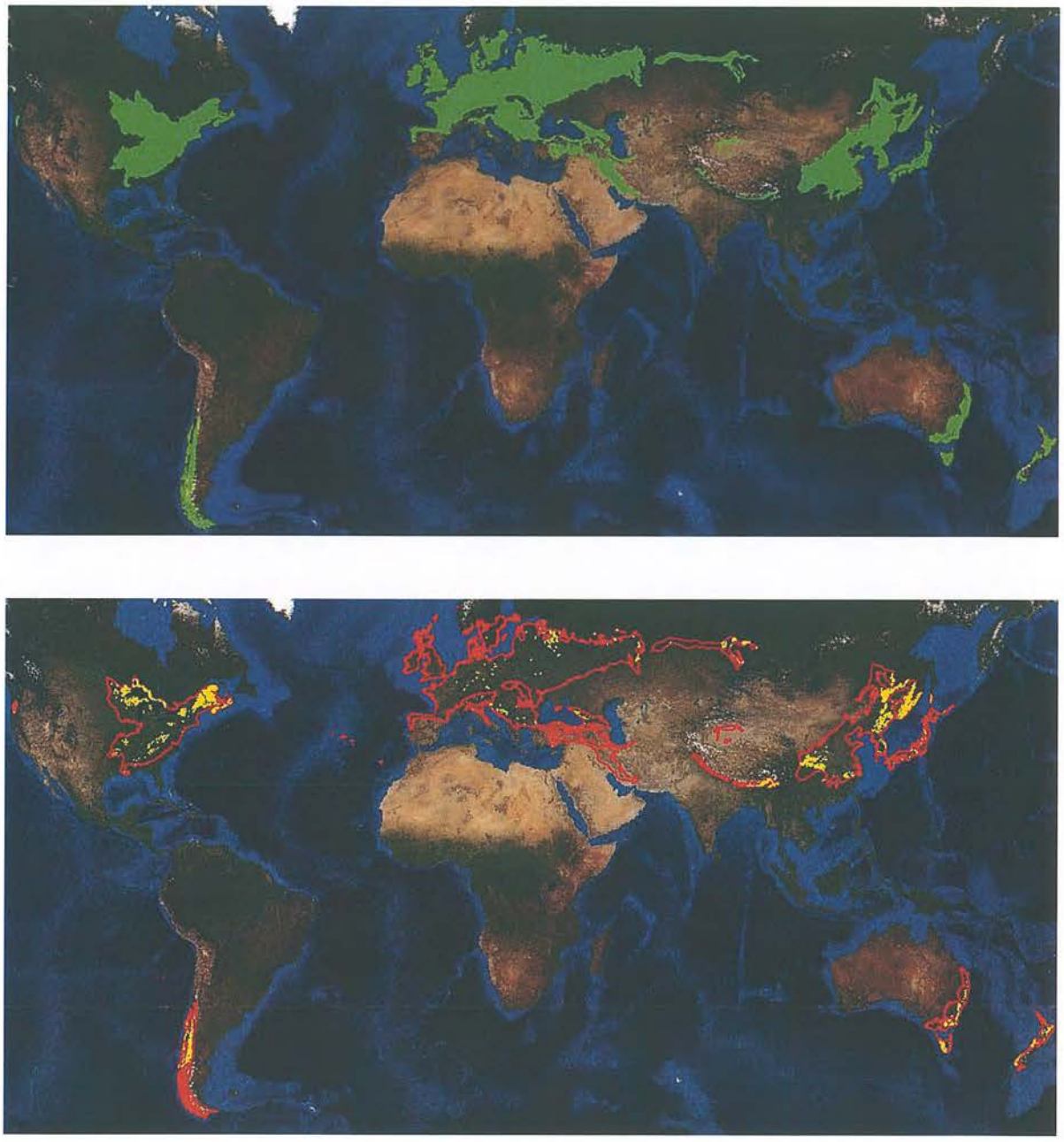
The above-named David Publicover did personally appear before me and made oath as to the truth of the foregoing pre-filed testimony.

_____
Notary Public
My Commission Expires

DENISE M. HORNE
Notary Public - New Hampshire
My Commission Expires April 19, 2022

Group 4
Exhibit 14-DP

EXHIBIT 1

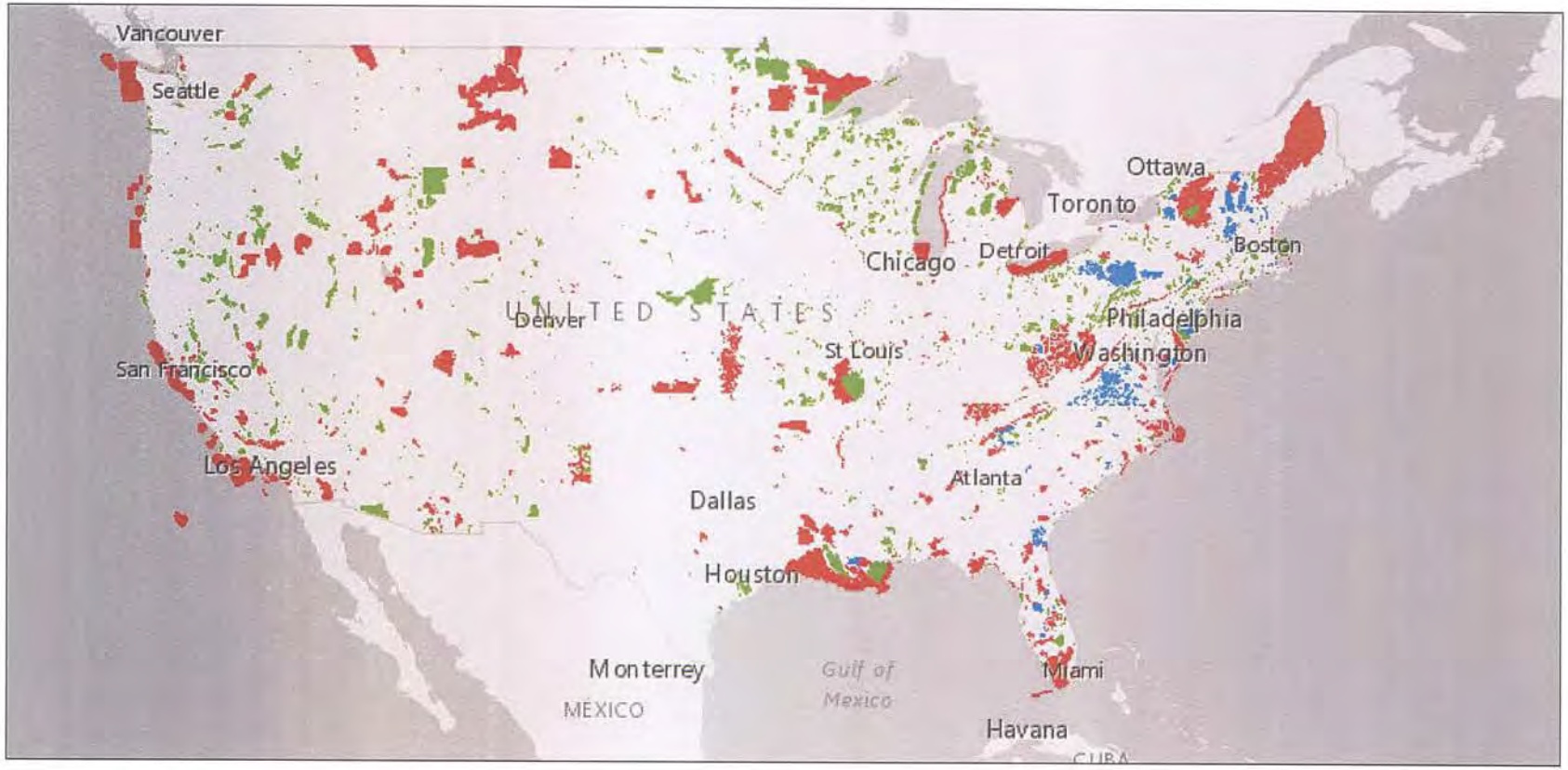


(Top) The Temperate Broadleaf and Mixed Forest ecoregion.

(Bottom) Relatively intact large forest blocks within the Temperate Broadleaf and Mixed Forest Ecoregion.

Source: Haselton et al. 2014.

EXHIBIT 2



Important Bird Areas (red – global priority, blue – continental priority, green – state priority).

Source: National Audubon Society (2019).

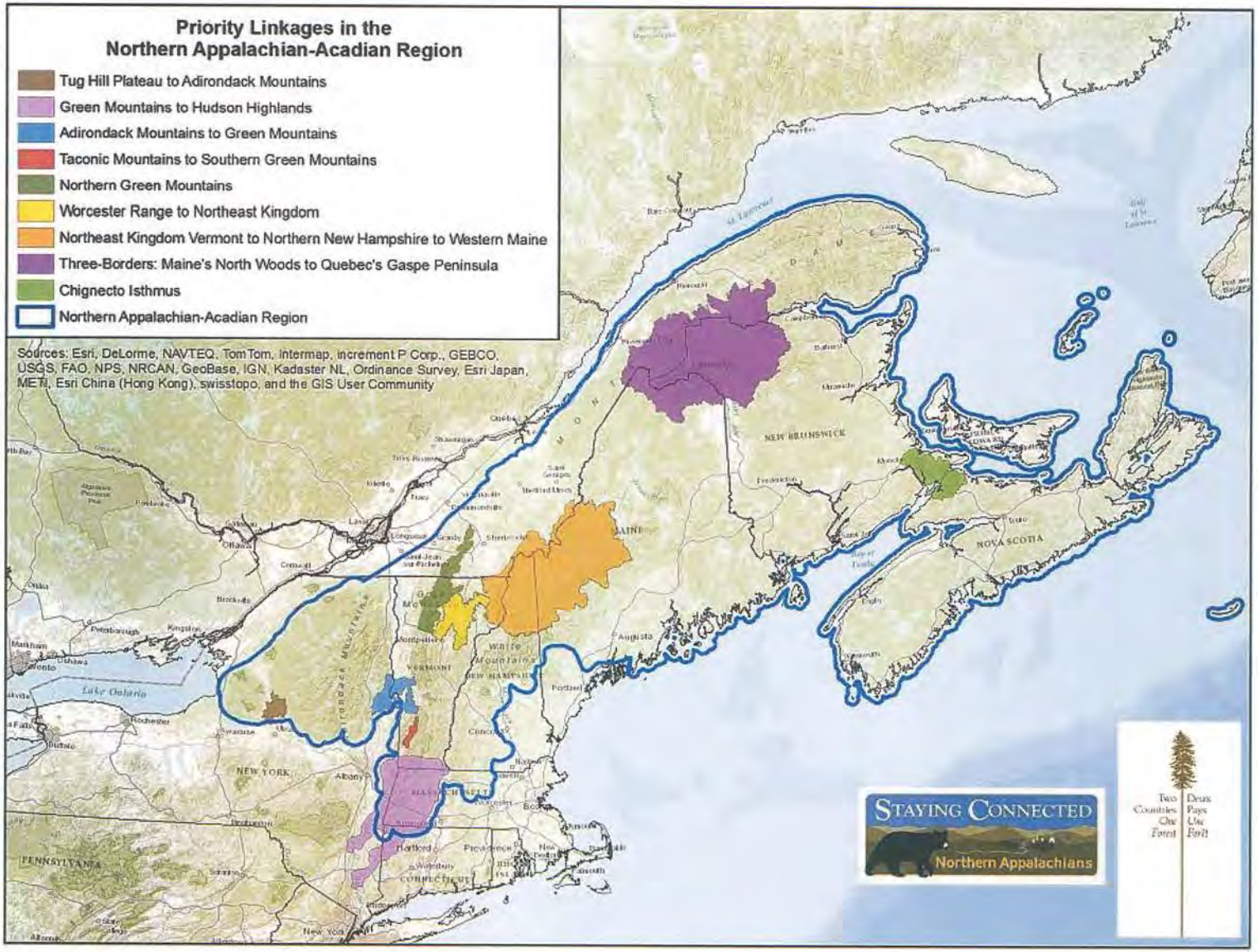
Group 4
Exhibit 15-DP

EXHIBIT 3



Source: Anderson et al. (2016), Map 3.31.

EXHIBIT 4



Source: SCI (2019); http://stayingconnectedinitiative.org/our-region/geography/.

Group 4
Exhibit 17-DP

EXHIBIT 5



The new corridor (yellow) parallels the Spencer Road (white) for over 20 miles.

Group Exhibit 18-DP

Landsc Ecol (2025) 40:118
https://doi.org/10.1007/s10980-025-02100-5

RESEARCH ARTICLE

Road traffic has a consistent negative impact on breeding density of a wide range of bird species in different habitats

René E. van Dijk · Toine Morel · Karen Zwerver · Paul van Els · Ruud P. B. Foppen

Received: 29 November 2024 / Accepted: 11 April 2025 / Published online: 11 June 2025
© The Author(s) 2025

Abstract

Context Road traffic has a major impact on the environment and numerous studies have shown how various species respond to road traffic. However, a clear picture based on large-scale studies of how complete species communities in different environments are affected by road traffic is lacking.

Objectives We assessed the distance within which road traffic negatively impacts breeding bird densities and the extent to which effect distances differ between species and habitats. We also tested how traffic intensity is associated with effect distances.

Methods We used a large dataset from protocolled breeding bird surveys of > 140,000 territories of complete breeding bird communities within 1500 m from motorways across the Netherlands. We examined effect distances of road traffic on breeding density of individual species, for various ecological species groups and for all species together. Finally, we tested how road traffic intensity influences effect distances.

Results Road traffic had a consistent negative effect on territory densities up to approximately 650 m distance from the road for different species and ecological species groups. Within road-effect zones, densities of breeding birds were significantly lower (on average 25%) than at greater distances from the road. Effect distances were positively associated with traffic intensity in various ecological species groups.

Conclusions These findings that road traffic negatively affects breeding densities in a consistent manner across species and that this effect is exacerbated by traffic intensity will allow policymakers to predict and assess the quantitative impact of road traffic with a given traffic intensity on breeding bird populations.

Keywords Road exposure · Birds · Disturbance · Effect distance · Dose–effect relationship · Road ecology

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10980-025-02100-5.

R. E. van Dijk (✉)
Sweco Netherlands, De Holle Bilt 22, 3732 HM De Bilt, The Netherlands
e-mail: vandijkre@yahoo.co.uk

R. E. van Dijk
Geonius, Voorveste 7, 3992 DC Houten, The Netherlands

T. Morel · K. Zwerver
Rijkswaterstaat Water, Transport and Environment, Postbus 2232, 3500 GE Utrecht, The Netherlands

P. van Els · R. P. B. Foppen
Sovon Dutch Centre for Field Ornithology, Toernooiveld 1, 6525 ED Nijmegen, The Netherlands

R. P. B. Foppen
Radboud University, Heyendaalseweg 135, 6525 AJ Nijmegen, The Netherlands

Introduction

Roads and road traffic are a major source of disturbance of the natural world (Forman and Alexander 1998; Forman 2003; Fahrig and Rytwinski 2009; van der Ree et al. 2015). Various factors associated with road traffic influence the abundance and composition of animal and plant communities. The presence of roads and their use by traffic cause fragmentation of natural habitats, increased risk of wildlife-vehicle collisions, noise and light pollution, optical disturbance, the spread of invasive species, and pollution through the deposition of toxic heavy metals and nutrients (Spellerberg 1998; Kociolek et al. 2011; Sanderfoot and Holloway 2017). These effects may lead to, among others, genetic impoverishment, physiological stress, reduced availability of food and suitable habitat, interference with communication, reduced survival and reproduction and ultimately reduced abundance and diversity of animals and altered species compositions near busy roads compared with locations further away from roads (van der Zande et al. 1980; Keller and Largiadèr, 2003; Palomino and Carrascal 2007; Eigenbrod et al. 2009; Slabbekoorn 2013; Sijtsma et al. 2020; Cooke et al. 2020a; Kroeger et al. 2022).

The topic of how roads and associated traffic impact ecology and the road-effect zone ('road ecology'; Forman 2003) is therefore of increasing conservation concern and has drawn the attention of researchers and policymakers for decades (Barber et al. 2010; Benítez-López et al. 2010; Gaston et al. 2017; Cooke et al. 2020a). Most studies have focused on the impact of traffic, such as effects of disturbance caused by noise, visual effects or vibrations, road victims or the effects of exhaust gases generated by cars. In general, there is substantial evidence that road traffic impacts bird populations, often represented as lower densities of breeding populations along roads. A clear picture of how such impacts caused by the different factors associated with traffic may differ between species and environments is still lacking. This is because of the complexity of the integrated effect of the various factors involved, which may all affect birds in different but often overlapping ways. Dose values of noise and visual effects, for example, decrease exponentially with distance from the road, so that dose values are well above background levels within the first few hundred metres from the road. The negative impact of road collisions is also expected to only affect bird populations in zones near the road (Reijnen and Foppen 2006). While some authors consider collision risk the key factor driving changes (Summers et al. 2011) and others suggest that it is disturbance caused by noise (Parris and Schneider 2008; Ware et al. 2015), because of such stacking of effects close to the road, it is difficult to establish which factor should be considered the most important.

Several previous authors have considered the impact of traffic on different species and species compositions and in various habitats (Reijnen et al. 1997; Garniel et al. 2007; Fahrig and Rytwinski 2009; Benítez-López et al. 2010). These studies revealed obvious differences between species in terms of the effects caused by road traffic, likely because species are not equally sensitive to disturbance caused by the different factors associated with road traffic (Fahrig and Rytwinski 2009; Ortega 2012). For example, bird species for which vocal communication is important and that communicate at frequencies that overlap with the frequency of traffic noise are more likely to be affected by road traffic noise than are species for which vocal communication is less important (Rheindt 2003; Goodwin and Shriver 2011; Halfwerk et al. 2011a, 2011b; Ortega 2012). Sound permeability and visual effects also differ between environments. The presence of trees, for example, can block visual effects, while a soft forest floor may absorb sound of certain frequencies. In contrast, visual effects are more likely to propagate over greater distances in open areas, and sound may be reflected and amplified from smooth or hard soil surfaces. The impact of road traffic also depends on the existing level of background effects, such as background noise, and the extent to which animals are habituated or able to adapt to it (Blumstein 2013; Vincze et al. 2016; Ramellini et al. 2024). Consequently, the impact of traffic depends on the environment and may, for example, differ between urban and rural landscapes or depend on the quality of the habitat and/or availability of alternative habitats (Reijnen and Foppen 1995). This makes an accurate assessment of the effects caused by traffic complex.

Largescale studies assessing effects of traffic on species communities in different environments are therefore required. In addition to how the presence of roads may influence the distribution of birds (Cooke

et al. 2020c), insight into how species from different environments may be affected by traffic and how traffic volumes may influence effects caused by road traffic provides crucial information for assessing and mitigating the impact of road traffic on birds. In this study, we used an extensive dataset containing information on the locations of more than 140,000 breeding bird territories near motorways from protocolled bird monitoring surveys throughout the Netherlands collected between 1984 and 2021. We used this dataset to analyse the pattern of breeding densities in relation to the distance of a road and assess over which distances effects on breeding birds occur for different species and species groups in different habitats.

First, we expected the impact of traffic to lead to decreased densities of breeding birds near roads. The density of breeding birds should therefore increase with increasing distance from the road. We expected this effect to be stronger closer to roads than at a greater distance from the road. Second, we expected the effect curves with distance from the road to be similar for different species of birds, but the extent of the effect to differ between species and species groups in different habitats. We tested this prediction by investigating effect distances and effect sizes for different species and ecological species groups. Finally, we also expected the extent of the effect to be positively associated with traffic intensity. We investigated this dose–effect relationship by examining whether effect distances are predicted by road traffic intensity. The results from this study may be used to assess the effects of motorway traffic on a wide array of breeding birds. The results will help predict how effects are associated with traffic intensity and how adjustments to existing roads leading to altered traffic intensity may affect the impact on breeding birds.

Methods

Data collection – breeding bird surveys

Information on the location of territories used in the analyses was collected between 1984 and 2021 using protocolled bird surveys within survey plots of the national breeding bird monitoring project BMP (www.sovon.nl/bmp). With this long-term monitoring project annual changes in numbers are obtained for nearly all species of breeding birds in the Netherlands, excluding colonial nesting birds (Vergeer et al. 2016). From this extensive long-term nationwide survey, data were selected on the basis of various characteristics. We selected survey plots adjacent to major roads (motorways). We restricted the analyses to territories within a distance of 1500 m from the motorway network in the Netherlands. Earlier studies have indicated that effect distances are unlikely to exceed 1000 m from the road (Reijnen et al. 1997; Palomino and Carrascal 2007; Benítez-López et al. 2010; Cooke et al. 2020a, b, c). A cut-off distance of 1500 m is thus likely to be conservative while also allowing the calculation of breeding densities in a control situation without the effect of road traffic. The motorway network used in this study concerned the motorways managed by Rijkswaterstaat, the executive agency of the Dutch Ministry of Infrastructure and Water Management. The first 25 m from the roadside were excluded from the analyses, because this area usually comprises a road verge, ditch or a parallel minor road not representative of the survey plots within the landscape bordering the motorway. Only survey plots between 20 and 75 ha in size were included in our analyses. Larger plots often comprise more heterogeneous habitats, while only survey plots composed of a relatively homogeneous landscape were included in our analyses. The composition of survey plots was assessed using aerial photographs in ArcGIS (Esri ArcGIS Pro v. 3.1.0, 2023). Survey plots comprising a mosaic of different habitats, such as a combination of forests, grasslands, open water and/or marshes, were excluded. This was done because of the difficulty in assessing the effect of traffic on territory density over distance from the road when species communities are associated with different types of habitats forming a mosaic within the landscape. Additionally, the propagation of noise and optical effects differ across habitats. This means that effects in mosaic landscapes are not directly comparable to those in more homogeneous landscapes. A total of 18 survey plots were excluded for this reason. The survey plots were also visually assessed for the presence of other potential sources of disturbance, such as built-up areas or other, minor, roads using aerial photographs. Survey plots with such additional sources of human-induced disturbance, caused by noise, light or presence of human activities, including survey plots within an urban environment, were excluded. Survey plots included in the analyses therefore contained

relatively few sources of disturbance other than road traffic. This means that for each plot, the presence of a motorway was considered to be the most prominent disturbing feature that may negatively affect the density of breeding birds. Survey plots within 1500 m of another motorway and/or within 1000 m of a provincial road were also excluded to avoid cumulative effects caused by road traffic from multiple roads. This selection resulted in a total of 414 survey plots distributed across the Netherlands, containing 146,110 territories of 136 bird species (Fig. 1; Online Resource 1) to be included in our analyses. Of the 414 survey plots included in the analyses, 137 were at least partly located within the first 100 m from the



Fig. 1 Locations of the survey plots (in red) and the Dutch motorway network (black lines) (Esri ArcGIS Pro, 2023)

roadside, 91 within the first 500 m and 186 between 500 and 1500 m from the road.

Data collection – traffic intensity

Data on the intensity of road traffic on Dutch motorways in each year were collected between 2012 and 2021 by Rijkswaterstaat and registered in the open access database INWEVA ('INtensiteit WEgVAkken', Rijkswaterstaat). Before 2012, no comparable data on traffic intensity were available. All analyses concerning traffic intensity were therefore based only on data collected between 2012 and 2021. Data on breeding densities from before 2012 were excluded from these analyses.

Road traffic intensities for the INWEVA database are measured at approximately 4000 road sections and estimated for the remaining road sections. The intensities comprise the total number of motor vehicles (mv) per 24 h and are averaged per year for each road section. The average traffic intensity per 24 h of all types of road traffic on working days was used. The breeding density data from each survey plot were matched with the traffic intensity data from the nearest road section. This was done separately for each year in which the number of breeding territories was counted, so that the breeding density in a given year was associated with the traffic intensity on the nearest road section in that year.

Data analysis

Analyses were performed separately at the level of species, ecological species group, species for which vocal communication is or is less important, and for all species combined. Species were divided into ecological species groups based on the typical habitat of each species to obtain eight ecological groups (Online Resource 1). First, for each of these levels of analysis, we assessed the effect distance and effect size of road traffic on breeding bird density. The response variable in these analyses was the territory density per 50 m distance contour, measured perpendicularly from the edge of the motorway. To test whether territory density is predicted by distance from the road we used a segmented regression model (Muggeo 2003, 2017) with the log-transformed territory density per 50 m distance contour as the response variable, distance from the road as the predictor variable and year, species name and survey plot ID as factors. The segmented linear regression model provides a threshold, or breakpoint, that corresponds to the effect distance within which a measurable effect caused by road traffic on the density of breeding birds can be identified. The segmented regression model obtains the relation between dependent and independent variables by linear regression within intervals into which the relation is partitioned. It estimates the breakpoint by comparing, using an iterative process, the regression slopes on either side of the breakpoint and tests if the slopes differ significantly using Davies' test (Muggeo 2003, 2017). To assess if the models' assumption of normality of residuals was met, we used histograms and normal QQ plots of the models' residuals. The models' assumptions of the regression-based models were met for all results presented in this paper.

Next, we examined dose–effect relationships. For these analyses, we divided our dataset into categories depending on the traffic intensity measured near the survey plots. The data were categorised to be able to calculate effect distances for each category since the effect distance is a calculated outcome of the segmented model and not a response variable related to traffic intensity. We used categories of 25,000 mv per 24 h (Table 1). These categories were chosen aiming at a sufficiently large sample size to confidently calculate effect distances and sufficient variation in traffic intensity categories. Using smaller categories of 10,000 or 20,000 mv per 24 h resulted in the same pattern but with a more fluctuating relationship between the effect distance and traffic intensity. Using categories of 25,000 mv per 24 h resulted in eight categories ranging from 3200–25,000 mv per 24 h to 125,000–150,000 mv per 24 h. The sample size for the only six survey plots with a traffic

Table 1 The number of territories and the total number of survey plots included in the analyses of dose–effect relationships

Category of traffic intensity (mv per 24 h)	Territories	Total number of survey plots
3200–25,000	17,040	81
25,000–50,000	17,242	82
50,000–75,000	15,972	78
75,000–100,000	16,715	56
100,000–125,000	4261	21
125,000–150,000	6027	14

intensity > 150,000 mv per 24 h was too small to confidently calculate effect distances. Survey plots near roads with a traffic intensity > 150,000 mv per 24 h were therefore excluded from these analyses. The median traffic intensity measured was 46,500 mv per 24 h.

For each category we calculated the effect distance using the segmented regression models described above. Using a regression analysis, the calculated effect distances were subsequently analysed as a function of traffic intensity to obtain a (log-linear) relationship describing the association of the effect distance with traffic intensity. We were unable to perform regressions between traffic intensity and effect distance in a similar manner for each ecological species group separately because of insufficient data. To test the effect of traffic intensity on the effect distance for each ecological species group, we divided the dataset for the ecological species groups into two categories only: survey plots near roads with a traffic intensity < 75,000 mv per 24 h and those with > 75,000 mv per 24 h. A traffic intensity of 75,000 mv per 24 h was chosen as a cut-off point between low and high traffic intensity, because the largest increase in effect distance with increasing traffic intensity appears to take place up to approximately 75,000 mv per 24 h (see Fig. 4).

Statistical analyses were conducted using R, version 4.4.0 (R Core Team 2024), using the 'segmented' (Muggeo 2003, 2017) package.

Results

We tested whether territory density is predicted by distance from the motorway for territories of individual species, per 'species group' (ecological species group and species for which vocal communication is important and species for which vocal communication is less important) and for all bird species combined.

Individual species

First, we calculated the effect distance and effect sizes for 136 individual species (Online Resource 2). Although there appears to be some variation between species in terms of effect distance, the effect distances between species within ecological species groups are largely consistent. The mean effect distance for those species for which breeding density significantly increased with distance from the road up to a threshold was 656 ± 197 m (mean ± SD; the effect distance). This was true for 65 out of 136 species (mean n per species = 1149). For 8 ecologically and taxonomically different species we found a negative relationship with distance from the road (mean n per species = 820) and for 63 species no significant effect distance could be identified, often due to limited sample sizes per species (mean n per species = 221). For the typical meadow birds Northern Lapwing, Black-tailed Godwit, Common Redshank and Meadow Pipit the calculated effect distances appeared to be a model artifact caused by a decline in territory density after the effect distance. When the distance from the road is maximised at 1000 m in the analyses for these species, effect distances of 568 ± 294 m, 500 ± 82 m, 900 ± 23m, and 601 ± 55 m, respectively, are found for these species of meadow birds ($P < 0.001$). Therefore, despite some interspecific variation, the pattern of increasing density with distance from the road up to the effect distance is similar, and statistically significant, for many different species (Online Resource 2).

We also calculated the territory density within and outside the effect distance for all species for which density significantly increased with distance (Online Resource 2). The mean territory density within the effect distance was 0.48 ± 0.13 SD territories per ha and, on average, 25% lower than that outside the effect distance (0.64 ± 0.16).

Ecological species groups

Similar to the results for individual species, for ecological species groups we found that for all groups territory density of breeding birds increased up to a certain threshold, after which density no longer changed significantly with the distance from the motorway. For ecological species groups, the effect distances of effects of road traffic on breeding bird density vary between 540 m for shrubland species and 650 m for forest birds (Table 2a; Fig. 2). Effect distances therefore appear to be consistent across the different species groups. The ecological species groups 'coast', 'pioneer vegetation' and 'streams' are excluded here because of the small sample sizes (n = 709, n = 204 and n = 126, respectively), the number of species in each group (3, 3 and 2, respectively) and the uneven

Table 2 Effect distances and effect sizes (expressed as an increase in density per 100 m stretch from the road) for (a) ecological species groups and (b) species for which vocal communication is important and species for which vocal communication is less important

(a)				
Ecological species group	Effect distance ± SE (m)	Effect size (per 100 m)	P	n
Forest	650 ± 15	0.045 ± 0.003	< 0.001	43,661
Marsh	547 ± 17	0.084 ± 0.005	< 0.001	26,095
Agricultural	600 ± 31	0.049 ± 0.005	< 0.001	15,091
Shrubland	540 ± 31	0.041 ± 0.009	< 0.001	6858
Heathland	600 ± 43	0.112 ± 0.015	< 0.001	2662
(b)				
Vocal communication	Effect distance ± SE (m)	Effect size (per 100 m)	P	n
Important	577 ± 13	0.056 ± 0.003	< 0.001	67,403
Less important	552 ± 13	0.073 ± 0.004	< 0.001	28,097

n is the number of calculated territory densities per distance contour

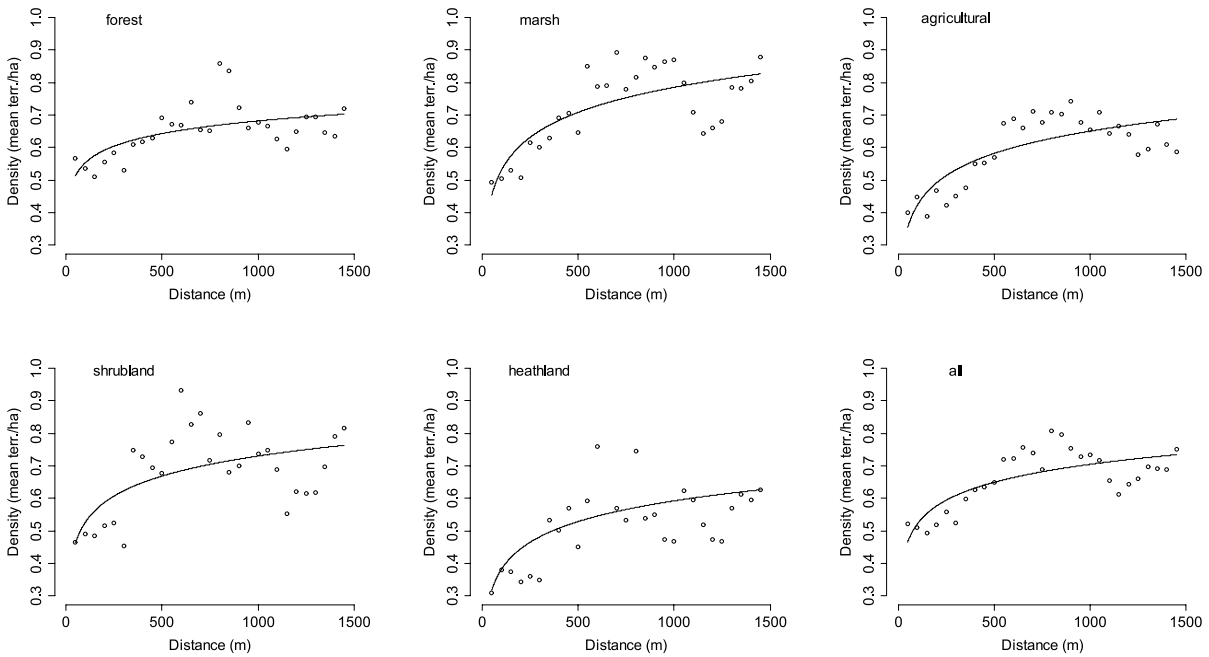


Fig. 2 Association between mean territory density per ha for each 50 m distance contour and the distance from the motorway for territories of breeding birds in each of the five ecological species groups from Table 2a and for all species together. The continuous lines represent the fitted line for the linear regression of territory density over distance from the road; the dashed line the standard error

number of species within each group. Effect distances for these three groups could therefore not be identified confidently. We also found no clear difference in effect distance between species for which vocal communication is important and those for which vocal communication is less important (Table 2b).

All species combined

For all species together, the mean effect distance was 570 m (±9 SE, P < 0.001, n = 95,500; Fig. 3). The effect size, expressed as an increase in density per 100 m distance from the road, is 0.061 ± 0.002 territories per ha, which translates to a mean increase in territory density of approximately 11% per 100 m. The mean territory density per ha within 570 m was 0.58 ± 0.62 (SD) territories per ha. Outside the effect distance the mean territory density was 26% higher, namely 0.73 ± 0.85 (SD) territories per ha.

In sum, for individual species, ecological species groups and for all species combined, we found that territory density is positively associated with distance from the motorway following a log-linear relationship and increased to a certain threshold (the effect distance), after which the density no longer changed significantly with increasing distance from the motorway.

Dose–response relationship

We found a positive association between traffic intensity and effect distance on breeding birds. This finding indicates that, when all species are considered, the impact of road traffic on breeding birds increases when the traffic intensity increases (log-linear regression; intercept ± SE = − 2657.68 ± 1080.38, model effect estimate ± SE = 298.61, P = 0.036, r^2 = 0.707, n = 6; Table 3, Fig. 4).

When we divided the dataset into two categories of high (i.e., > 75,000 mv per 24 h) and low (< 75,000 mv per 24 h) traffic intensity, we also found that the effect distance was generally greater near roads with high traffic intensity, except for shrubland birds (Fig. 5). For all birds combined, for example, the effect distance near roads with a low traffic intensity (n = 23,605) was 414 m smaller than near roads with a high traffic intensity (n = 28,901). The ecological species groups 'coast', 'pioneer vegetation' and 'streams' are excluded here because of the small sample sizes

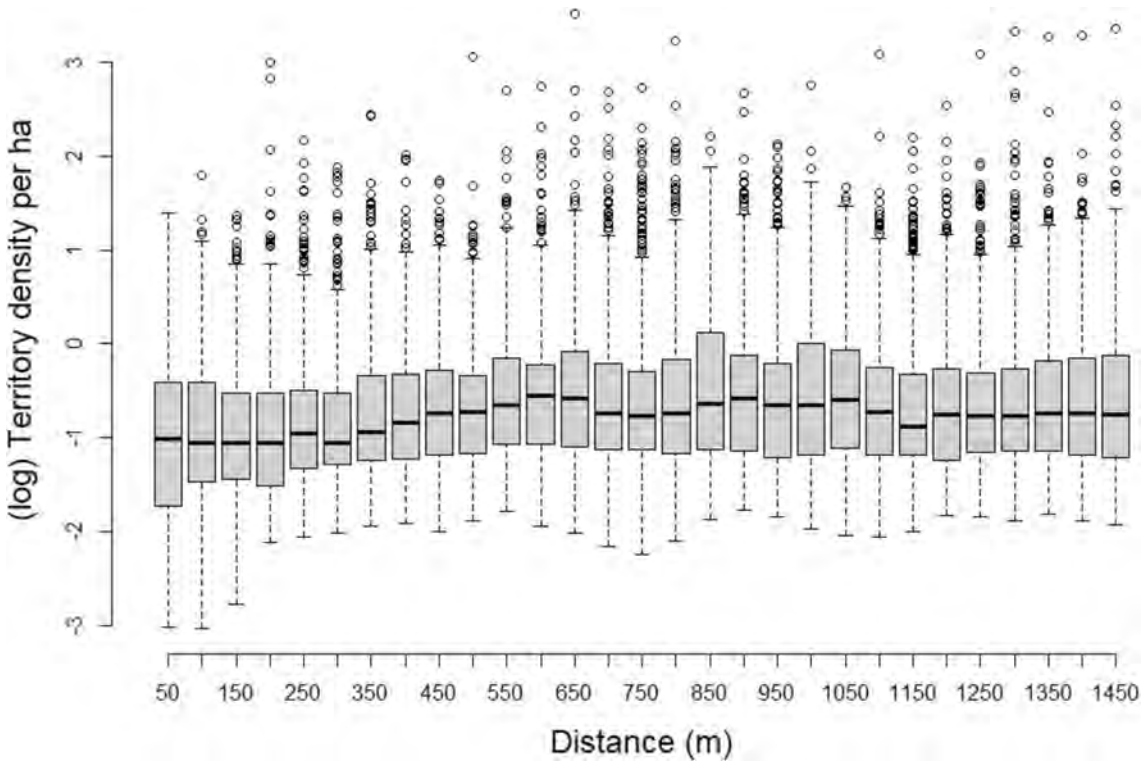


Fig. 3 Association between (log) territory density per ha for each 50 m distance contour and the distance from the motorway for territories of all species (n = 95,500). Boxplots represent the interquartile range (box), the median (black line inside the box), other values within the 1.5 × interquartile range (dashed line) and outliers (open circles)

Table 3 Effect distance per category of traffic intensity for all species

Traffic intensity (mv/24 h)	Effect distance ± SE	n
3200–25,000	422 ± 32	11,536
25,000–50,000	492 ± 16	12,069
50,000–75,000	550 ± 34	10,447
75,000–100,000	999 ± 17	10,237
100,000–125,000	850 ± 21	2865
125,000–150,000	849 ± 114	3936

n = number of calculated densities per 50 m distance contour

and number of species in each group. Therefore, no significant effect distance could be identified for these groups near roads with a low and/or high traffic intensity.

Discussion

The extent to which birds are affected by road traffic, what causes disturbance and how it may affect populations of different species remain important questions within the field of road ecology. It has important consequences for environmental impact studies related to the construction and redevelopment

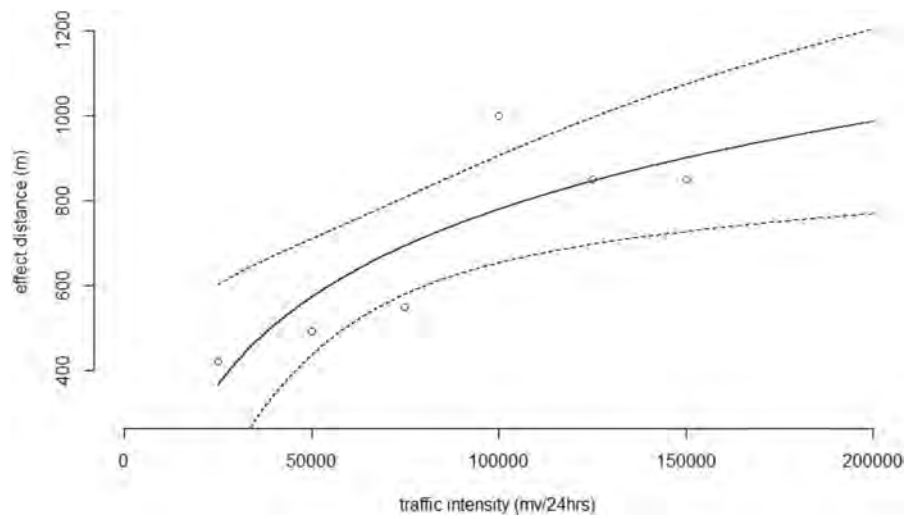


Fig. 4 Linear regression of the effect distance in response to traffic intensity on motorways in the Netherlands. The effect distance indicates the distance from the roadside to which the territory density is (negatively) associated with road traffic. The continuous line represents the fitted line for the linear regression of effect distance over traffic intensity; the dashed line the standard error

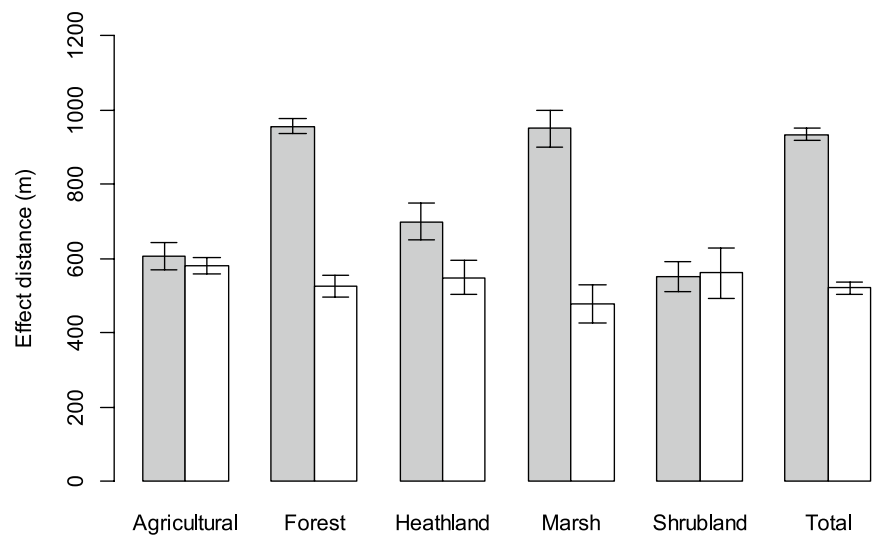


Fig. 5 Effect distances ± SE per ecological species group and for all species combines ('Total') near roads with high (> 75,000 mv per 24 h; grey bars) and low (< 75,000 mv per 24 h; white bars) traffic intensities

of roads. On the basis of a large dataset of breeding bird surveys near motorways in the Netherlands, we show that the density of breeding birds is lower near motorways and that the density increases with distance from motorways. We show that this effect is generally measurable up to a distance of approximately 550–650 m from the roadside (the effect distance), but may extend further depending on, for example, traffic volumes. The consistency of these distances across various species groups and the fact that a large proportion of the breeding bird community in the Netherlands shows negative impacts on the species level illustrates the extent of the effect on breeding birds caused by motorway traffic. Within the effect distance, the territory density is on average across species 25% lower than at a greater distance from the road. Importantly, we found that despite some variation between species, the negative effects of motorways and motorway traffic on breeding densities are broadly consistent across many ecologically and taxonomically different species. Finally, we found that the effect distance is positively related to traffic intensity. Near roads with greater traffic intensities, the area over which breeding densities are negatively affected by road traffic is larger than near roads with less traffic. This dose–effect relationship was again found for several, ecologically diverse species groups. The overall effect on population size is thus determined by a lowered density of breeding territories over larger threshold values near roads with relatively high traffic intensities.

In line with previous studies, we found that breeding densities are significantly lower near roads, especially within the first 500 m and up to approximately 1 km and that the extent of the effect is influenced by traffic intensity (Forman et al. 2002; Reijnen and Foppen 2006; Benítez-López et al. 2010; Polak et al. 2013). The differences between species may be explained by a wide range of factors, including the likelihood of birds being near or crossing a road (*cf.* collision risk), their dependence on vocal communication (*cf.* risk of acoustic masking or distraction) or their sensitivity to pollutants, which may cause a decline in habitat quality (Nijssen et al. 2017; Stevens et al. 2018; Senzaki et al. 2020). Also the habitat in which species occur may influence the negative impact of road traffic, because the habitat composition partly determines the propagation of, for example, sound and light. The type of habitat also determines which species occur in a given location and their tolerance to pollution or disturbance. Species in pristine, undisturbed areas may be more affected by increasing disturbance than species that are used to human pressures (Radford et al. 2005; Kroeger et al. 2022). In addition to the habitat within which species occur, the extent to which a species may habituate to disturbances caused by road traffic could therefore influence the effects of traffic on breeding densities. Differences between species thus depend on the extent to which a species may be impacted by, for example, its vulnerability to disturbance by sound and light and/or vulnerability to the impact of collision. Species for which vocal communication is important may be disturbed by traffic noise, especially those, including non-passerines, that communicate at frequencies that overlap with traffic noise (Reijnen and Foppen 2006; Slabbekoorn and Ripmeester 2008; Goodwin and Shriver 2011; Ortega 2012; Francis and Barber 2013). Although some birds may exhibit behavioural plasticity and adapt their songs to ambient noise, anthropogenic noise often has a particular negative effect on species that rely on vocal communication for mate attraction and territorial conflicts (Halfwerk et al. 2011a, b; Slabbekoorn 2013). If disturbance caused by traffic noise is a key factor influencing breeding densities near roads, one would therefore expect species relying on vocal communication to exhibit a clearer response than species for which vocal communication is less important.

Based on the above, one would expect species to differ in their response to road traffic. Indeed, we found that while the majority of species exhibited a negative impact of road traffic on breeding densities, eight species showed a positive association, and for 63 species, we found no significant relationship with road traffic. This aligns with previous studies that have reported a predominantly negative association between bird breeding densities and the presence of roads, while some species appear to show a positive association with roads (e.g. Cooke et al. 2020c; Ascensão et al. 2022). Although some consistency between studies exists regarding which species or species traits are positively or negatively associated with roads, no clear pattern has emerged (Cooke et al. 2020c). For example, Ascensão et al. (2022) found that urban-dwelling species and those with high fecundity were positively associated with road encroachment, whereas ground-nesting species were

negatively related with the presence of roads. However, our findings did not reveal a similar pattern. The eight species in our study exhibiting a positive relation with road traffic, as well as those that exhibited a negative or no association with road traffic, were diverse. The difference in results of our study compared to those by Cooke et al. (2020c) and Ascensão et al. (2022) probably reflects the difference in study design. Our study primarily focuses on the effects of traffic on heavily used motorways, whereas studies like Cooke et al. (2020c) and Ascensão et al. (2022) examine the broader impact of road encroachment, including the presence and density of roads themselves. Moreover, we found that the negative effect of road traffic on breeding bird density was broadly consistent across species and habitats. Similarly, we observed a comparable effect distance and effect size for both species that rely on vocal communication and those for which vocal communication is less critical. Although this may partly be explained by the fact that we did not conduct these analyses for species in different habitats or control for the frequency at which species communicate and may experience interference from traffic noise, this result suggests that multiple factors are likely to interact to generate an effect of traffic on breeding densities, also for species for which vocal communication is important.

A frequently heard criticism on roadside studies refers to biased detectability of birds near roads by observers. This could have influenced the calculated effects of road traffic on breeding densities. Different behaviour of birds near roads might cause reduced detectability. Birds, for example, may sing earlier to avoid interference with traffic noise or birds closer to roads may be warier due to collision risk or a reduced ability to detect predators. They may also become easier to detect when they forage near the roadside or use roadside structures for perches. Interference of traffic noise with bird song may make it more difficult to distinguish bird song, whereas birds near roads may also sing at higher frequencies in response to traffic noise, which might, positively or negatively, influence their detectability (Cooke et al. 2020b; Koper et al. 2016). Changes in (vocal) behaviour in response to traffic noise are likely to be costly and might thus also lead to lower densities near roads (Rheindt 2003). For example, if birds sing earlier near roads to avoid peak traffic or sing at a higher frequency to avoid acoustic interference, this may lead to reduced detectability, but also to lower densities. In that case, the effect size might be influenced, but the overall pattern of an effect of road traffic would not be influenced. The effects of biased detectability might, however, result in an under- or overestimation of territory densities nearer to roads (Cooke et al. 2020b). Although attempts have been made to estimate the effects of biased detectability, most notably by Cooke et al. (2020b), the effects of biased detectability near major roads remain uncertain and are therefore difficult to control for. Cooke et al. (2020b) reported that, of the 51 species investigated, the detectability of 36 species was significantly associated with road exposure, with both positive and negative associations for different species. Among the 51 species, only six, however, showed a significant association with major roads, only half of which were negative. The latter is likely due to the limited number of observations near major roads. Because of potential under- or overestimation of the densities near roads, the real effect size, *i.e.*, the slope of the relationship between distance from the road and territory density, might be smaller or greater than those reported here. We argue, however, that it is unlikely that biased detectability has influenced our (main) results on effect distances. At the threshold of several hundreds of meters away from the road, biased detectability is unlikely. Therefore, the threshold (the 'effect distance') will not significantly be influenced by it. Additionally, other studies also provide clues as to why such biased detectability is unlikely to have a large impact on observed densities. Survey results of bird communities in a study by Rheindt (2003) were not significantly different between working days and weekend surveys, when traffic noise is relatively low, and were not affected when potentially noise-biased data were disregarded. Moreover, differences in densities between species and species groups are likely to be much greater than apparent variability in abundance caused by a potential detectability bias (Tella et al. 2021), whereas traffic noise is also likely to be less influential on the detectability of species than the type of habitat (Lituma and Buehler 2016). Overall, we acknowledge that biased detectability might have influenced our results, but we expect this effect to

be limited and not to have significantly influenced the effect distances presented here.

Dose–response

Previous studies on the effects of traffic intensity on bird populations near roads provide ambiguous results, with some highlighting an increased negative effect with increasing traffic intensity (Reijnen and Foppen 1994; Forman et al. 2002; Rheindt 2003), while others find no effect (Peris and Pescador 2004; Benítez-López et al. 2010). In contrast to the meta-analysis by Benítez-Lopez et al. (2010), for example, who found effects of up to a distance of 1 km, but no effect of traffic intensity, we found a significant effect of traffic intensity on effect distances on the basis of territory density of breeding birds. Using an analysis of all species together, we found that the effect distance increased log-linearly with increasing traffic intensity. We also found that for several distinct species groups, the effect distance was greater near roads with high traffic intensity than near roads with lower traffic intensity. This difference appeared to be greatest in forests and marshes, which might be explained by these habitat types being characterised by relatively low human impact compared to more open landscapes (Kroeger et al. 2022). An increased level of disturbance might then cause a relatively large negative impact. Kroeger et al. (2022) similarly showed that effects of roads on bird richness were more negative in landscapes with higher tree cover.

Besides a negative impact at the species level, road traffic may also cause other effects than an impact on breeding densities. The composition of the population, for example, may also be impacted. Younger, inexperienced birds, for instance, tend to occupy lower-quality territories closer to roads than older, more experienced birds do (Foppen and Reijnen 1994). This effect of disturbance by road traffic on demographic composition may not necessarily translate into a noticeable effect on breeding density. Additionally, whether territory density comprises the best estimate of the effects of road traffic on breeding birds is debatable. For example, effects could also be expressed as a behavioural response or could primarily result in reduced breeding success. However, several studies have shown a relationship between traffic and territory densities of breeding birds (for example, Reijnen et al. 1996; Garniel et al. 2007; Summers et al. 2011; Cooke et al. 2020c, 2020a). The effects of road traffic on vital life history parameters, such as negative effects on breeding success, are likely also reflected in effects on breeding density.

A limitation of our study is that not all species could be analysed because of the lack of sufficient data. Among these are rare species, of high relevance to nature conservation, that are clearly underrepresented. However, given the high proportion of analysed species for which we found an effect, we believe that these results also hold for the rare and scarce species outside the scope of this study.

With an increase in effect distance, the density of breeding territories within the effect distance will also be reduced. On average, for all species together, the breeding density was 25% lower within the effect distance as compared to undisturbed areas, and increased by 11% per 100 m distance from the roadside. These effects decrease in magnitude with distance from the road. When is an increase in traffic intensity relevant? Clearly the results show a log-linear relationship which tells us that an increase in traffic intensity of, for instance, 5000 motor vehicles per 24 h has more impact for a road that previously had a relatively low traffic intensity than a very busy road. However, even a relatively small increase in effect distance could be very meaningful if it concerns long stretches of road. For example, an increase of 5000 motor vehicles per 24 h on a road which currently has a traffic intensity of 50,000 motor vehicles per 24 h, results in an expected increase in the effect distance of approximately 'only' 29 m. Over a stretch of 10 km road this would lead to an increase of 'affected habitats' with lowered densities of 58 ha.

In summary, we found that: (1) a wide range of bird species exhibit reduced breeding densities near roads, (2) the negative impact of road traffic on breeding densities extends over a similar distance across species and habitats, and (3) this effect is intensified by higher traffic intensity. These results highlight the significant, large-scale negative impact of road traffic on bird populations. The results will help policymakers predict the distance over which different species may be affected by road traffic and assess the impact of increased traffic intensity—for example, due to modifications to existing roads or projects that lead to higher traffic flows. The additional area that is negatively impacted by an increased traffic intensity can be quantified using the results presented here.

Additionally, the results may guide the implementation of mitigation measures to reduce the impact of road traffic, such as quieter road surfaces, reduced speed limits, noise barriers or sunken road construction in the landscape. However, the effectiveness of such mitigation measures requires further research. Future studies should also focus on disentangling the effects of the various factors associated with road traffic that negatively impact birds. This may improve our understanding of how the consistent patterns of negative effects emerge across species and help identify the most effective mitigation strategies.

Acknowledgements The research leading to the results presented here was conducted in the period from 2018 to 2024 to revise and update the methodology to assess the disturbance of breeding birds caused by road traffic as commissioned by Rijkswaterstaat Water, Transport and Environment. The research was funded by Rijkswaterstaat. We are grateful to Sovon Dutch Centre for Field Ornithology and especially Henk Sierdsema for providing the BMP data. We thank the members of the advisory board of Rijkswaterstaat for their helpful comments and feedback on the research findings and Willem Fenten (Sweco) for the GIS analyses.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analyses were performed by REvD. The first draft of the manuscript was written by REvD and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding The research was funded by Rijkswaterstaat.

Data availability The datasets analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

Open Access This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

References

Ascensão F, D'Amico M, Revilla E, Pereira HM (2022) Road encroachment mediates species occupancy,trait filtering and dissimilarity of passerine communities. Biol Conserv 270:109590

Barber JR, Crooks KR, Fristrup KM (2010) The costs of chronic noise exposure for terrestrial organisms. Trends Ecol Evol 25:180–189

Benítez-López A, Alkemade R, Verweij PA (2010) The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. Biol Conserv 143:1307–1316

Blumstein DT (2013) Attention, habituation, and antipredator behaviour: implications for urban birds. In: Gil D, Brumm H (eds) Avian urban ecology. Oxford University Press, Oxford

Cooke SC, Balmford A, Donald PF, Newson SE, Johnston A (2020a) Roads as a contributor to landscape-scale variation in bird communities. Nat Commun 11:3125

Cooke SC, Balmford A, Johnston A, Massimino D, Newson SE, Donald PF (2020b) Road exposure and the detectability of birds in field surveys. Ibis 162:885–901

Cooke SC, Balmford A, Johnston A, Newson SE, Donald PF (2020c) Variation in abundances of common bird species associated with roads. J Appl Ecol 57:1271–1282

Eigenbrod F, Hecnar SJ, Fahrig L (2009) Quantifying the road-effect zone. Ecol Soc 14:18

Esri (2023) ArcGIS Pro. Version 3.1.0, 2023. Environmental Systems Research Institute, Redlands, CA. https://www.esri.com

Fahrig L, Rytwinski T (2009) Effects of roads on animal abundance. Ecol Soc 14:20

Foppen R, Reijnen R (1994) The effects of car traffic on breeding bird populations in woodland. II. Breeding dispersal of male willow warblers (*Phylloscopus trochilus*) in relation to the proximity of a highway. J Appl Ecol 31:95–101

Forman RTT (2003) Road ecology: science and solutions. Island Press, Washington, DC

Forman RTT, Alexander LE (1998) Roads and their major ecological effects. Annu Rev Ecol Syst 29:207–231

Forman RTT, Reineking B, Hersperger AM (2002) Road traffic and nearby grassland bird patterns in a suburbanizing landscape. Environ Manag 29:782–800

Francis CD, Barber JR (2013) A framework for understanding noise impacts on wildlife: an urgent conservation priority. Front Ecol Environ 11:305–313

Garniel A, Daunicht WD, Mierwald U, Ojowski U, (2007) Vögel und Verkehrslärm. Quantifizierung und Bewältigung entscheidungserheblicher Auswirkungen von Verkehrslärm auf die Avifauna. Bonn, Kiel.

Gaston KJ, Davies TW, Nedelec SL, Holt LA (2017) Impacts of artificial light at night on biological timings. Ann Rev Ecol Evol Syst. https://doi.org/10.1146/annurev-ecolsys-110316-022745

Goodwin SE, Shriver WG (2011) Effects of traffic noise on occupancy patterns of forest birds. Conserv Biol 25:406–411

Halfwerk W, Bot S, Buikx J, van der Velde M, Komdeur J, ten Cate C, Slabbekoorn H (2011a) Low-frequency songs lose their potency in noisy urban conditions. Proc Natl Acad Sci USA 108:14549

Halfwerk W, Holleman LJM, Lessells CM, Slabbekoorn H (2011b) Negative impact of traffic noise on avian reproductive success. J Appl Ecol 48:210–219

Keller I, Largiadèr CR (2003) Recent habitat fragmentation caused by major roads leads to reduction of gene flow and loss of genetic variability in ground beetles. Proc R Soc Lond B Biol Sci 270:417–423

Kociolek AV, Clevenger AP, Clair CC, Proppe DS (2011) Effects of road networks on bird populations. Conserv Biol 25:241–249

Koper N, Leston L, Baker TM, Curry C, Rosa P (2016) Effects of ambient noise on detectability and localization of avian songs and tones by observers in grasslands. Ecol Evol 6:245–255

Kroeger SB, Hanslin HM, Lennartsson T, D'Amico M, Kollmann J, Fischer C, Albertsen E, Speed JDM (2022) Impacts of roads on bird species richness: a meta-analysis considering road types, habitats and feeding guilds. Sci Total Environ 812:151478

Lituma CM, Buehler DA (2016) Minimal bias in surveys of grassland birds from roadsides. Condor 118:715–727

Muggeo VMR (2003) Estimating regression models with unknown break-points. Stat Med 22:3055–3071

Muggeo VMR (2017) Interval estimation for the breakpoint in segmented regression: a smoothed score-based approach. Aust N Z J Stat 59:311–322

Nijssen ME, WallisDeVries MF, Siepel H (2017) Pathways for the effects of increased nitrogen deposition on fauna. Nitrogen Depos Impacts Biodivers Terr Ecosyst Mech Perspect 212:423–431

Ortega CP (2012) Effects of noise pollution on birds: a brief review of our knowledge. Ornithol Monogr 74:6–22

Palomino D, Carrascal LM (2007) Threshold distances to nearby cities and roads influence the bird community of a mosaic landscape. Biol Conserv 140:100–109

Parris KM, Schneider A (2008) Impacts of traffic noise and traffic volume on birds of roadside habitats. Ecol Soc 14:29

Peris SJ, Pescador M (2004) Effects of traffic noise on passerine populations in Mediterranean wooded pastures. Appl Acoust 65:357–366

Polak M, Wiącek J, Kucharczyk M, Orzechowski R (2013) The effect of road traffic on a breeding community of woodland birds. Eur J for Res 132:931–941

R Core Team (2024) R: a language and environment for statistical computing. R Core Team

Radford JQ, Bennett AF, Cheers GJ (2005) Landscape-level thresholds of habitat cover for woodland-dependent birds. Biol Conserv 124:317–337

Ramellini S, Lapadula S, Bonomelli L, Sciandra D, Falaschi M (2024) Effects of human disturbance on detectability of non-breeding birds in urban green areas. Glob Ecol Conserv 51:e02873

Reijnen R, Foppen R (1994) The effects of car traffic on breeding bird populations in woodland. I. Evidence of reduced habitat quality for Willow Warblers (*Phylloscopus trochilus*) breeding close to a highway. J Appl Ecol 31:85–94

Reijnen R, Foppen R (1995) The effects of car traffic on breeding bird populations in woodland. IV. Influence of population size on the reduction of density close to a highway. J Appl Ecol 32:481–491

Reijnen R, Foppen R (2006) Chapter 12: Impact of road traffic on breeding bird populations. In: Davenport J, Davenport JL (eds) The ecology of transportation: managing mobility for the environment. Springer, The Netherlands

Reijnen R, Foppen R, Meeuwsen H (1996) The effects of traffic on the density of breeding birds in Dutch agricultural grasslands. Biol Conserv 75:255–260

Reijnen R, Foppen R, Veenbaas G (1997) Disturbance by traffic of breeding birds: evaluation of the effect and considerations in planning and managing road corridors. Biodivers Conserv 6:567–581

Rheindt FE (2003) The impact of roads on birds: does song frequency play a role in determining susceptibility to noise pollution? J Für Ornithol 144:295–306

Sanderfoot OV, Holloway T (2017) Air pollution impacts on avian species via inhalation exposure and associated outcomes. Environ Res Lett 12:083002

Senzaki M, Barber JR, Phillips JN, Carter NH, Cooper CB, Ditmer MA, Fristrup KM, McClure CJW, Mennitt DJ, Tyrrell LP, Vukomanovic J, Wilson AA, Francis CD (2020) Sensory pollutants alter bird phenology and fitness across a continent. Nature 587:605–609

Sijtsma FJ, van der Veen E, van Hinsberg A, Pouwels R, Bekker R, van Dijk RE, Grutters M, Klaassen R, Krijn M, Mouissie M, Wymenga E (2020) Ecological impact and cost-effectiveness of wildlife crossings in a highly fragmented landscape: a multi-method approach. Landsc Ecol 35:1701–1720

Slabbekoorn H (2013) Songs of the city: noise-dependent spectral plasticity in the acoustic phenotype of urban birds. Spec Issue Behav Plast Evol 85:1089–1099

Slabbekoorn H, Ripmeester EAP (2008) Birdsong and anthropogenic noise: implications and applications for conservation. Mol Ecol 17:72–83

Spellerberg I (1998) Ecological effects of roads and traffic: a literature review. Glob Ecol Biogeogr Lett 7:317–333

Stevens CJ, David TI, Storkey J (2018) Atmospheric nitrogen deposition in terrestrial ecosystems: its impact on plant communities and consequences across trophic levels. Funct Ecol 32:1757–1769

Summers PD, Cunnington GM, Fahrig L (2011) Are the negative effects of roads on breeding birds caused by traffic noise? J Appl Ecol 48:1527–1534

Tella JL, Romero-Vidal P, Dénes FV, Hiraldo F, Toledo B, Rossetto F, Blanco G, Hernández-Brito D, Pacífico E, Díaz-Luque JA, Rojas A, Bermúdez-Cavero A, Luna Á, Barbosa JM, Carrete M (2021) Roadside car surveys: methodological constraints and solutions for estimating parrot abundances across the world. Diversity. https://doi.org/10.3390/d13070300

van der Ree R, Smith DJ, Grilo C (2015) Handbook of road ecology. Wiley, Hoboken

van der Zande AN, ter Keurs WJ, van der Weijden WJ (1980) The impact of roads on the densities of four bird species in an open field habitat—evidence of a long-distance effect. Biol Conserv 18:299–321

Vergeer J-W, van Dijk A, Boele A, van Bruggen J, Hustings F (2016) Handleiding Sovon broedvogelonderzoek: broedvogel Monitoring Project en Kolonievogels. Sovon Vogelonderzoek Nederland, Nijmegen

Vincze E, Papp S, Preiszner B, Seress G, Bókony V, Liker A (2016) Habituation to human disturbance is faster in urban than rural house sparrows. Behav Ecol 27:1304–1313

Ware HE, McClure CJW, Carlisle JD, Barber JR (2015) A phantom road experiment reveals traffic noise is an invisible source of habitat degradation. Proc Natl Acad Sci USA 112:12105–12109

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

THERYA NOTES 2022, Vol. 3 : 51-52 DOI: 10.12933/therya_notes-22-69 ISSN 2954-3614

Editorial

Wildlife crossings and road impact on mammals

Highways are essential for countries' economic growth; therefore, the provision of road infrastructure services is undergoing rapid and permanent expansion. In current strategies, these communication routes are considered a fundamental element in economic reactivation, fostering many ambitious road modernization and expansion projects worldwide (CEPAL 2021). Despite their usefulness, roads are also a threat with significant environmental consequences. In recent decades, they have been considered one of the main threats to wildlife globally (van der Ree *et al.* 2015), mainly due to their impact by favoring habitat fragmentation and causing the mortality of multiple species of fauna due to collisions with vehicles.

In this issue, it is recognized that landscape connectivity is essential for maintaining the flow of mammalian individuals, their genetic variability, and allowing access to resources. An irruption of the connectivity brings, as a consequence, threats at the species and population level. However, despite the topic's relevance, there is little legislation on the maintenance of ecological connectivity. As indicated by Fernández-Buces *et al.* (2022), no laws, regulations, or agreements require means to maintain the connectivity of the landscape on the roads in a planned manner. As an example, there is an absence of specific laws to design wildlife crossings as a strategy to maintain said connectivity. It is necessary to understand that when building this type of communication routes, it is necessary to avoid or mitigate to a minimum the impacts that may be generated due to the construction activities and their subsequent operation.

Monitoring is another critical element that is part of a correct prevention and mitigation of the effects of roads. In this issue, we find studies that show the record of priority species that have suffered accidents against vehicular traffic and that show the need to take actions aimed at maintaining species as charismatic and relevant to natural ecosystems as the jaguar (*Panthera onca*; Rubio-Rocha *et al.* 2022b). We also found other infrequent species in the samplings due to the effect of the monitoring techniques used, but which are also affected by the existence of this infrastructure, as occurs with the spectral vampire (*Vampyrum spectrum*; Pacheco-Figueroa *et al.* 2022). In addition, reports are presented in which mammals present a differentiated use according to the different times of the year (Ruíz-Ramírez *et al.* 2022) or type of road (Ruíz-Ramírez *et al.* 2022; Rubio-Rocha *et al.* 2022a). All this is essential information for the design of mitigation measures (Cervantes-Huerta and Durán-Antonio 2022). Despite all the relevant information concentrated in this issue, there are still many information gaps on the effects of the roads, leaving great unknowns about what is happening on them due to the effects of run over.

On the other hand, monitoring wildlife crossings is another key element that can provide information on their effectiveness and the adaptation measures they require. This is evidenced in the study by González-Gallina *et al.* (2022), where the differentiated use of these structures is reported, according to the preferences of each species of mammal, as well as by the season of the year, or the time of existence of a fauna pass since it was built.

Also, some species clearly avoid highways, and easily adapt to the culverts used on these roads, even though they are not properly designed to be used as wildlife crossings; such is the case of the sereque or guatusa (*Dasyprocta punctata*) on the Inter-American Highway in Costa Rica (Monge-Velázquez and Sáenz 2022).

In the same way, we have evidence at the population level, which shows a reduction in a wildlife population when highway expansions were carried out, as occurred in Catazajá, Chiapas (Pozo-Montuy and Bonilla-Sánchez 2022), as well as a consequent and rapid adaptation to use of aerial wildlife crossings by howler monkeys (*Alouatta pigra*).

It is clear that roads remain a major threat to mammals. Current studies increasingly include the analysis of impacts on wildlife and analyze the effectiveness of the measures implemented in road projects. However, measures adapted to each region are not yet implemented, but they continue to use those that have been effective in temperate zones of the world.

The justification for the use of strategies in such areas is based on a cost-benefit analysis and are explicitly created for megafauna that is not distributed in tropical areas. Therefore, medium or small-sized fauna do not justify the construction of wildlife crossings for certain sectors of the population and decision-makers. In reality, it is not the economic cost of the accidents that should justify the construction of these structures to protect wildlife, but rather the environmental cost caused by the consequent loss of biodiversity. The measures must be created in a particular way for each region, espe-

© 2022 Asociación Mexicana de Mastozoología, www.mastozoologiamexicana.org

cially in tropical zones, and analyze their cost-benefit for the recovered environmental services, considering a design adapted to the particular region. Faced with the current growth and modernization of communication routes globally, mammals will only have an opportunity if appropriate designs are implemented for each region and the species that inhabit it and that ensure the maintenance of landscape connectivity. Monitoring before, during, and after the construction of the infrastructure should be considered in the planning, in order to implement short, medium, and long-term measures that help maintain the diversity of mammals and their habitats adequately. Also, an effort to create an integrated legal framework that considers landscape connectivity as an essential element should be included. Road studies on the effects of communication routes on mastofauna are highly relevant. Collaboration between authorities, consultants, builders, researchers, and academia can lead to better informed and more efficient decision-making for the conservation of biodiversity and the ecosystems in which it is distributed.

Acknowledgements

We thank C. Lorenzo and A. Carrillo for guiding this issue. To J. Sáenz, for his contribution and training in this field.

Juan de Dios Valdez-Leal[1], and Coral Jazvel Pacheco-Figueroa[1]

[1]División Académica de Ciencias Biológicas, Universidad Juárez Autónoma de Tabasco. Carretera Villahermosa-Cárdenas Km. 0.5 s/n, C. P. 86040. Villahermosa, Tabasco, México. E-mail: jdvaldezleal@yahoo.com.mx (JDV-L); coral.pacheco@ujat.mx (CJP-F).

Literature cited

Cervantes-Huerta, R., and J. Durán-Antonio. 2022. Seasonal variation of mammal roadkill hotspots in the Sierra Madre Occidental, México. Therya Notes 3:70-74.

Comisión Económica para América Latina y el Caribe (CEPAL). 2021. Balance Preliminar de las Economías de América Latina y el Caribe. (LC/PUB.2022/1-P). Santiago, Chile.

Fernández-Buces, N., *et al*. 2022. Ecological connectivity and wildlife passages on roads: a reflection for México. Therya Notes 3:87-91.

González-Gallina, A., *et al*. 2022. Mammal use of some crossing structures in a Federal Highway in Jalisco, México. Therya Notes 3:59-65.

Monge-Velázquez, M., and J. C. Saénz. 2022. Drainage culverts as a measure to avoid mammal roadkills in Costa Rica: the case of *Dasyprocta punctata*. Therya Notes 3:66-69.

Pacheco-Figueroa, C. J., *et al*. 2022. Documentation of a road-killed spectral bat (*Vampyrum spectrum*) and first report of the species in Tabasco, México. Therya Notes 3:98-103.

Pozo-Montuy, G., and Y. M. Bonilla-Sánchez. 2022. Population decline of an endangered primate resulting from the impact of a road in the Catazajá wetlands, Chiapas, México. Therya Notes 3:75-81.

Rubio-Rocha, Y., *et al*. 2022a. First records of road-killed mammals in the state of Sinaloa, México. Therya Notes 3:53-58.

Rubio-Rocha, Y., *et al*. 2022b. Impact of the roadkill of a jaguar cub (*Panthera onca*) on social networks and the inhabitants of Sinaloa, México. Therya Notes 3:92-97.

Ruiz-Ramírez, L., *et al*. 2022. Comparison of road-killed mammals on roads of different types of jurisdictions and traffic volume in Veracruz, México. Therya Notes 3:82-86.

van der Ree, R., *et al*. 2015. The ecological effects of linear infrastructure and traffic: challenges and opportunities of rapid global growth. Pp. 1-9 *in* Handbook of Road Ecology (Redd, R., D. J. Smith, and C. Grilo, eds.). John Wiley and Sons Ltd. West Sessex, United Kingdom.

CENTER FOR RESILIENT CONSERVATION SCIENCE

Northeast Association of Fish & Wildlife Agencies

The Nature Conservancy

Conservation Status of Natural Habitats

in the Northeast

2023



Mark G. Anderson, Melissa Clark, Arlene Olivero

Please cite as:

Anderson, M.G., Clark, M. and A. Olivero. 2023. Conservation Status of Natural Habitats in the Northeast. The Nature Conservancy, Center for Resilient Conservation Science. Newburyport, MA.

For more information on CRCS and to access the report and data, visit: http://crcs.tnc.org

Funding for this project was provided by a grant from the Northeast Association of Fish and Wildlife Agencies.

About the Cover:

Photo Credit: © Cameron Davidson; Aerrial image of Clinch River near Artrip, Virginia with the rolling mountains of Central Appalachia in the background. The Cumberland Forest Project protects 253,000 acres of Appalachian forest in Tennessee, Kentucky, and Virginia and is one of TNC's largest-ever conservation efforts in the eastern United States.

3/2/2023

Acknowledgements

We would like to thank the Conservation Status 2.0 Steering Committee team who guided this project, including Jon Kart of Vermont Fish and Wildlife Department, Cathy Haffner of the Pennsylvania Game Commission, Lisa Williams of Pennsylvania Game Commission, Gwen Brewer of Maryland Department of Natural Resources, John Herbert of Rhode Island Department of Environmental Management, Samantha Robinson of Delaware Department of Natural Resources and Environmental Control., Sandra Houghton of New Hampshire Fish and Game Department, Steve Walker of Maine Department of Inland Fisheries and Wildlife, Justin Schlawin of Maine Natural Areas Program, Dee Blanton of U.S. Fish and Wildlife Service, Elizabeth Crisfield of Strategic Stewardship Initiative, and Karen Terwilliger and Tracy Rice of Terwilliger Consulting Inc.

We also want to acknowledge the essential work of the Nature Conservancy Northeast Secured Lands team and their agency counterparts who compiled the state conservation lands datasets, including Dan Coker of The Nature Conservancy of Maine, Michelle Canick of The Nature Conservancy of Maryland, Anna Ormiston of The Nature Conservancy of New Hampshire, Jessica Dietrich of The Nature Conservancy of Massachusetts, Mike Shanahan of The Nature Conservancy of New Jersey , David Richardson of The Nature Conservancy of New York, Tamara Gagnolet and Jacob Leizear of The Nature Conservancy of Pennsylvania, Kevin Ruddock of The Nature Conservancy of Rhode Island, Ann Ingerson of The Nature Conservancy of Vermont, Chris Bruce of The Nature Conservancy of Virginia and Conservation and Geospatial Systems, and Rachel Ralls of The Nature Conservancy Conservation Lands Program. Justin Schlawin, Maine Department of Agriculture, Conservation, and Forestry, Irina Beal, WeConservePA, David Boyd, Virginia Department of Conservation and Recreation, Virginia Natural Heritage Program, Benjamin Smith, Massachusetts Executive Office of Energy and Environmental Affairs, Emily Cheadle, New York Natural Heritage Program, Kurt Donaldson, West Virginia University, WV GIS Technical Center, Lisa Lowe, Maryland Department of Information Technology, Sharon Cost, New Jersey Dept. of Environmental Protection (DEP), Green Acres Program, Paul Jordan, Rhode Island Department of Environmental Management, Chris Phaneuf, New Hampshire Geographically Referenced Analysis and Information Transfer System (GRANIT), Vermont Center for Geographic Information, Agency of Commerce and Community Development, Graham Stevens, Connecticut Department of Energy and Environmental Protection, Michael Krumrine, Delaware Division of Parks and Recreation. We also wish to thank Brian Hall and David R. Foster of Harvard Forest Wildlands Project who shared their dataset with us to assist with coding GAP 1 lands.

We extend a large thank you to Matthew Neilson of U.S. Geological Survey Nonindigenous Aquatic Species (NAS) Program for extracting and summarizing data for the northeast states. From The Nature Conservancy's Center for Resilient Conservation Science we thank Analie Barnett who provided analysis assistance and expertise in the nutrient data compilation and the freshwater integrated protection metric; Erik Martin who assisted with compiling and updating dams in the northeast and Mary Khoury for compiling the freshwater state and federal protection designations and writing portions of the freshwater protection sections.

Conservation Status of **Natural Habitats in the Northeast**

Executive Summary

Northeast Association of Fish & Wildlife Agencies

The Nature Conservancy

The Northeast states share a long history of conservation and collaboration. The region's extensive forests, wetlands, rivers, and coastline cross state boundaries, and a tradition of working together to understand and conserve them has evolved. In 2008, the Northeast Association of Fish and Wildlife Agencies (NEAFWA) and its partners developed a multi-state monitoring framework to take stock of the condition and conservation of the species and habitats that characterize the region. In 2011, The Nature Conservancy (TNC), working with NEAFWA, produced the first regional application of the framework in the report: "*Conservation Status of Fish, Wildlife, and Natural Habitats in the Northeast*".

Synthesizing over 50 region-wide datasets, analyzing the underlying patterns, and assessing the indicators suggested by the monitoring framework, the 2011 status report presented a comprehensive and multidimensional picture of the state of the natural world across the 14-state NEAFWA Region: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia, and Washington D.C.

This document is an update to the 2011 report. In it we focus on conservation progress and trends in the last decade (2012-2022). Original indicators were revisited where the source data had the resolution and detail to allow us to detect change. Additionally, we added new metrics or revised old ones, where improved data allowed us to backcast one or two decades to detect trends.

DATA HIGHLIGHTS

- A completely revised **conservation land dataset**, developed collaboratively with state offices, and with "date conserved" added for most records since 2011
- Remotely sensed **time-sequence data** on land cover change, forest turnover, and anthropogenic fragmentation
- New and computationally intensive **tools** for measuring local connectedness, regional connectivity, and stream integrated protection
- A revised **dam dataset** and detailed information on stream nutrient enrichment
- A **template** for exploring marsh migration and the conservation of migration space
- **Models** of climate resilience, connectivity, recognized biodiversity areas, and carbon stocks

This work was guided by a steering committee led by Jon Kart of Vermont Fish and Wildlife Department and representing eight states and the regional office. We gratefully acknowledge their help, guidance, and suggestions.

CRCS CENTER FOR RESILIENT CONSERVATION SCIENCE

Mark Anderson, Melissa Clark, Arlene Olivero. February, 2023

KEY FINDINGS

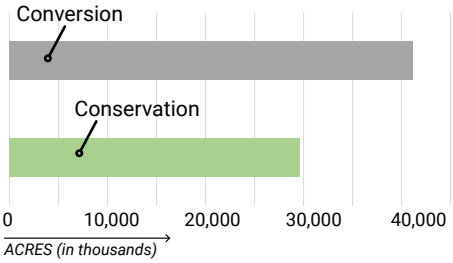
The following key findings are organized but the thematic chapters of the report. See the full chapter for detail on the methods and results.

CONSERVATION LANDS

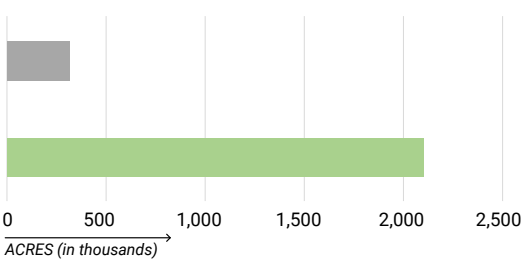
Historically, 26% of the region's natural land has been converted to development or agriculture, while 19% has been conserved for nature or multiple uses. This equals 1.4 acres converted for every acre conserved . **Over the last decade, this trend has reversed** with 6.7 acres *conserved* for every one acre converted since 2012.

The region now boasts 29 million acres of conservation land, with 2.1 million acres conserved in the last decade. Private conservation organizations accounted for half of the new conservation land, with 62% being easements and 38% fee acquisitions. Most of the new conservation lands (76%) were secured for multiple uses like recreation and forest management, while 24% were conserved primarily for nature.

ALL YEARS | 1800-2022



LAST 10 YEARS | 2012-2022

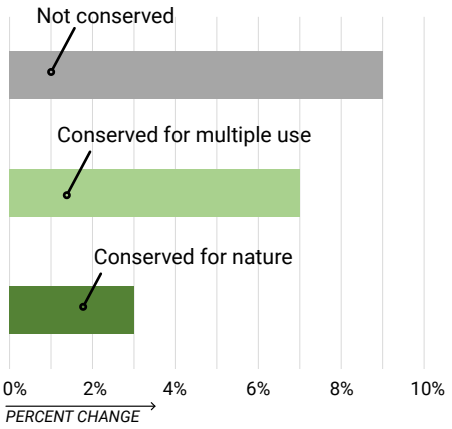


FORESTS

The region was once 91% forested but is now 61% forested with most of that permanently converted. Of the remaining forest, 24% is secured against further conversion, a ratio of 1.6 acres converted for every acre conserved.

Over the last 20 years, 8 million acres of forest have changed markedly: 57% have returned to forest after active turnover from logging or natural disturbances, 28% remains in other natural land cover, and 1% was converted to development or agriculture, a conversion rate of 35,000 acres per year. **Land conserved primarily for nature has seen much less forest change** (3%) than land conserved for multiple uses (7%) or unconserved land (9%).

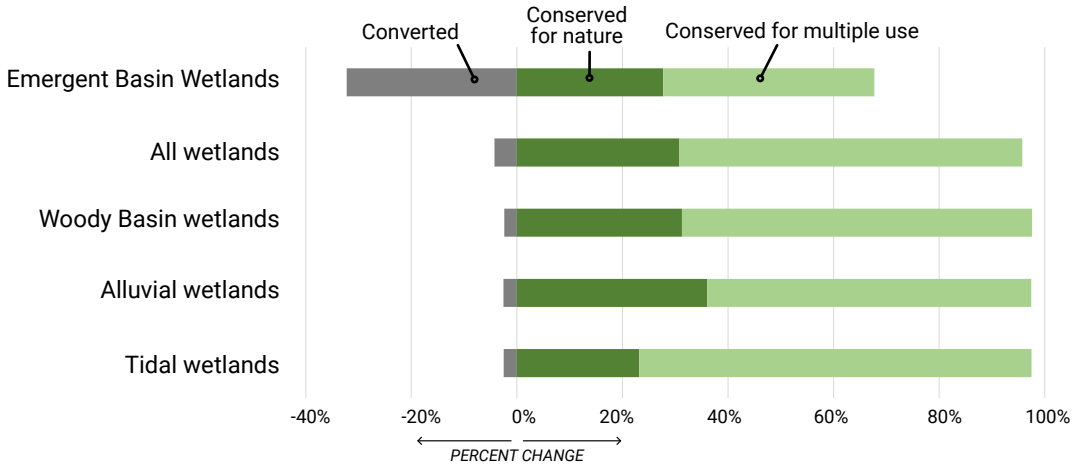
AMOUNT OF FOREST TURNOVER AND CHANGE | 2001-2022



WETLANDS

Twenty-one million acres of the region were once covered by swamp, peatlands, floodplain, and marsh supporting over 1,000 types of wetland dependent species. Now, 27% of that has been converted or drained, but 20% of the remaining wetlands are under conservation. In the last two decades regulations have further prevented wetland conversion. As a result, **wetland conservation in the last two decades surpassed conversion almost 25 to 1, reversing the historic trend**. Emergent marshes remain the wetland type most at risk.

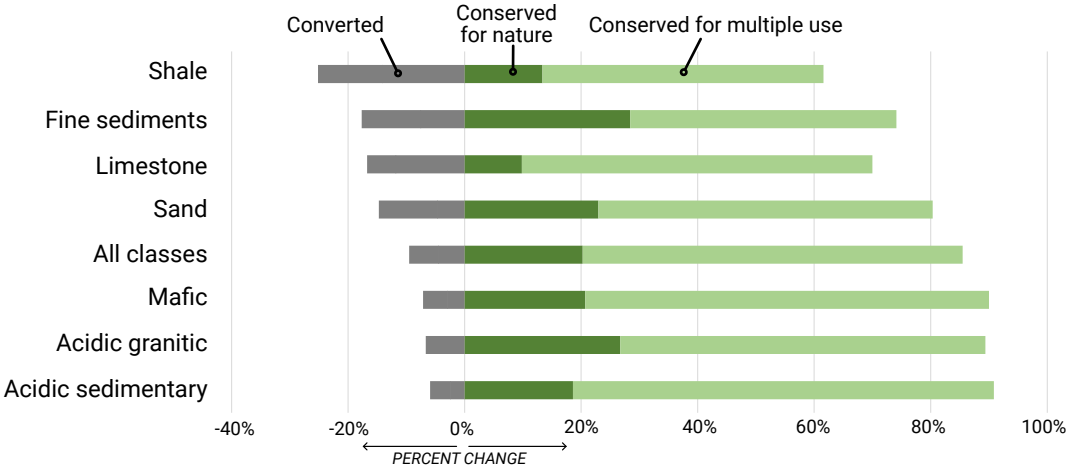
WETLAND CONSERVATION AND CONVERSION | 2001-2022



UNIQUE HABITATS

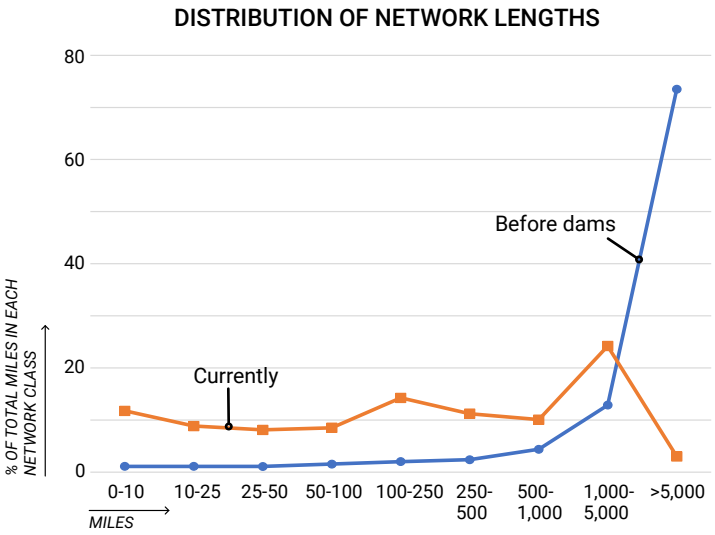
Conservation and conversion have not been distributed equally. In high elevation and granite bedrock areas conservation has exceeded conversion, but in low elevation regions with fertile soils derived from limestone or sand, conversion exceeds conservation eight to one. In the last decade this pattern has reversed with **conservation surpassing conversion across every soil type and elevation zone**. New conservation lands are a mix of multiple-use and nature focused reserves. Shale environments have had the most conversion.

CONSERVATION AND CONVERSION BY GEOLOGY CLASS | 2012-2022



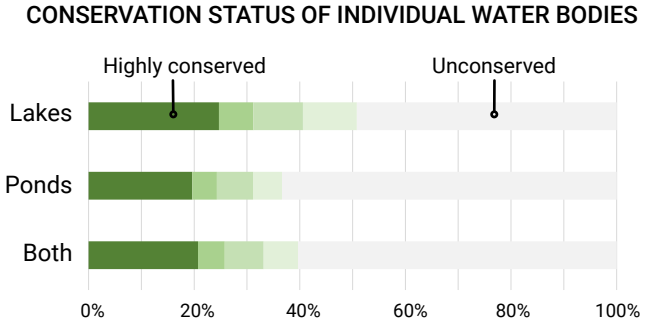
STREAMS AND RIVERS

The region's 200,000 miles of streams and rivers support thousands of species. In total, 23% of all stream miles are locally conserved, however, **only 6% have the upstream watershed conservation needed to achieve integrated protection**. Further, 14,000 dam's fragment the stream networks into segments averaging 7 dams per 100 miles. As a result, 86% of river miles are in networks less than a quarter of their pre-dam size, 21% are less than 25 miles long, and 48% are significantly altered in their hydrology. In the last decade, 346 dams were removed, opening at least 3,500 miles. This increases to over 5,000 miles of reconnected river and stream networks if we account for retrofitted or partially passable dams.



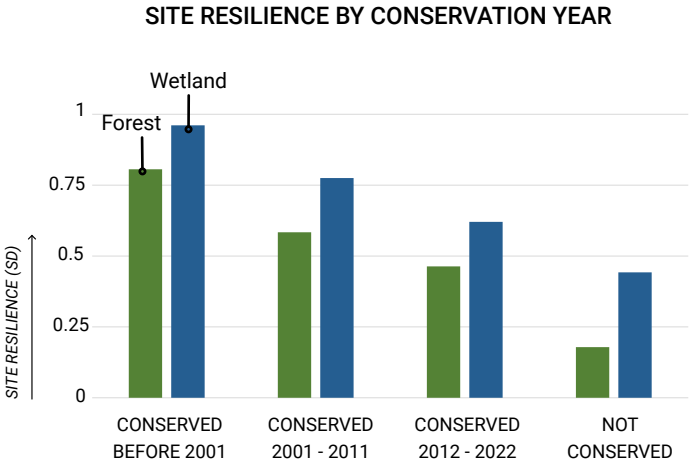
LAKES AND PONDS

Of the regions 35,000 lakes and ponds, **21% have most of their shoreline conserved**. Over the last decade, another 446 waterbodies have joined this group and another 800 have shown increased conservation of their shorelines.



CLIMATE RESILIENCE

Site resilience is a measure of a site's microclimatic buffering which help plants and wildlife persist under a changing climate. Quantitative scores for forest and wetlands on **conservation lands** suggest that they **are more resilient than their unconserved counterparts**, and that the resilience of older conservation lands is higher than the new conservation land. This likely reflects increasing levels of fragmentation across the whole region.



AMERICA THE BEAUTIFUL AND 30 BY 30

The global Convention on Biodiversity have targeted 30% of Earth to be formally protected by 2030. In the U.S., the Biden Administration's America the Beautiful initiative calls for us to work collaboratively to conserve and restore the lands, waters, and wildlife that support and sustain the nation, and to conserve 30 percent of US lands and waters by 2030.

The Nature Conservancy (TNC) has mapped a spatial blueprint for conservation that covers 34% and integrates the key principles of representation, resilience, connectivity, biodiversity, and carbon. TNC's Resilient and Connected Network (RCN) **provides an ecologically meaningful blueprint for how to distribute the conservation lands**. Collectively the **region is 19% conserved by *area*** if multi-use (GAP 3) conservation lands are included. The **RCN is 38% conserved, and averages 42% conserved by state**. Current conservation lands contain 25% of the region's forest carbon securing the stock from conversion and allowing further sequestration.

State	% Area GAP 1	% Area GAP 2	% Area GAP 3	% Area Conserved	% RCN Conserved	% Forest Carbon Conserved	Total Acres
CT	1%	4%	12%	17%	39%	20%	3,183,447
DC	0%	0%	20%	20%	100%	42%	39,988
DE	1%	4%	13%	18%	49%	30%	1,266,542
MA	3%	5%	16%	24%	46%	32%	5,200,573
MD	0%	2%	16%	18%	41%	30%	6,351,377
ME	2%	3%	16%	21%	28%	22%	20,824,982
NH	5%	8%	20%	33%	49%	36%	5,931,243
NJ	0%	13%	11%	24%	59%	37%	4,843,101
NY	9%	1%	9%	20%	46%	27%	31,055,902
PA	1%	1%	16%	18%	49%	26%	28,986,981
RI	1%	14%	5%	20%	38%	26%	697,220
VA	2%	3%	12%	17%	43%	26%	25,616,295
VT	3%	2%	16%	22%	36%	26%	6,153,095
WV	1%	2%	9%	11%	21%	13%	15,506,478
Region	3%	3%	13%	19%	38%	25%	**155,657,223**

To read and download the report, click **HERE**.

Please cite as: *Anderson, M.G., Clark, M. and A. Olivero. 2023. Conservation Status of Natural Habitats in the Northeast. The Nature Conservancy, Center for Resilient Conservation Science. Newburyport, MA.*

For more information on CRCS and to access the report and data, visit: http://crcs.tnc.org

Table of Contents

1 Chapter 1: Introduction 1-1

Methods and Approach 1-2

Organization of the Report 1-3

2 Chapter 2:Conservation Lands 2-1

Definition of Conservation Land 2-2

The Nature Conservancy's Conserved Land Dataset 2-2

Conservation Lands and GAP Status 2-3

Distribution of Conservation Lands in the Northeast and Mid-Atlantic 2-6

Basic Patterns of Land Securement 2-6

Habitat Loss versus Conservation 2-8

Ownership and Designation 2-12

Ownership 2-12

Designation 2-13

Recent Conservation Trends 2-14

Habitat Loss versus Land Conservation (2012-2022) 2-19

Chapter 2 References 2-22

Appendix 2.1. Highlights of Conservation Projects occurring between 2012-2022 in the Northeast. 2-23

Non-Governmental Organization Fee 2-23

Non-Governmental Easements 2-23

Conservation projects over 5,000 acres 2-23

Appendix 2.2: Shortened wording for definitions of GAP status 2-34

Appendix 2.3.The Nature Conservancy's 2022 Secured Lands Data Sources 2-37

3 Chapter 3: Forests 3-1

Forest Types 3-2

Northern Hardwood and Conifer Forest 3-2

Central Oak-Pine Forest: 3-2

Boreal Upland Forest: 3-2

Ruderal and Plantation Forest: 3-2

Distribution, Loss, and Protection Status 3-4

Historic Loss: 3-4
Conservation: 3-4
Recent Trends in Forest Turnover and Loss. 3-7
Conservation and Forest Change 3-12
Forest Condition: Block size and Connectedness 3-15
Trends in Local Connectedness (2010-2019) 3-24
Appendix 3.1. Sections from the 2011 report that were not revised in 2022 3-27
Forest Disturbance: 3-27
Age and Size Structure: 3-29
Trends in Forest Bird Abundance 3-33
Synthesis of Species Data with Forest Condition 3-37
4 Chapter 4:Wetlands 4-1
Wetland Types and their Fauna 4-2
Basin Wetland 4-2
Alluvial Wetlands 4-3
Tidal Wetlands 4-3
Distribution, Loss, and Protection Status 4-6
Wetland Conversion and Loss: 4-6
Wetland Conservation: 4-6
Recent Trends in Wetland Loss and Conservation (2001-2022): 4-9
Recent Wetland Conservation (2012-2022) 4-13
Wetland Condition 4-14
Local Connectedness: 4-14
Chapter 4: References 4-19
Appendix 4.1 (these sections are from the 2011 report) 4-21
Impacts in the Buffer Zone: 4-21
Road Density: 4-23
5 Chapter 5: Unique Habitats 5-1
Geophysical Settings and Natural Habitats 5-2
Characterization of the Geophysical Settings and Habitats 5-2
Sand and other Coarse-grained Surficial Sediments (295 preferential species) 5-5
Calcareous Bedrock (255) 5-6

Acidic Sedimentary Bedrock (159): 5-6
Moderately Calcareous Bedrock (135): 5-7
Granitic Bedrock (112): 5-8
Mafic or Intermediate Bedrock (57): 5-8
Acidic Shale Bedrock (38): 5-9
Ultramafic Bedrock (18): 5-10
Fine-grained Mud and Silt Deep Surficial Sediment (10): 5-10
Elevation and Landform-based Communities 5-11
Distribution, Loss, and Protection by Geophysical Setting 5-14
Recent Trends in Habitat Conversion and Conservation (2011-2022) 5-18
Fragmentation and Connectivity of Geophysical Settings 5-22
Block Analysis 5-22
Synthesis of Species Data with Habitat Condition 5-26
Individual Habitats 5-28
Habitat Types and Lexicon 5-31
Conservation Status 5-32
Non-Forested Habitat: Distribution and Protection 5-37
Chapter 5: References 5-40
Appendix 5.1: Crosswalk Tables linking Northeast Lexicon, Individual Habitats and Geophysical Settings 5-41
Forested Upland Habitats 5-41
Non-Forested Upland Habitats 5-42
Wetland Habitats 5-43
Appendix 5.2: Geophysical Settings and Preferential Species 5-44
Appendix 5.3 Other Species names used in the text 5-55
6 Chapter 6: Streams and Rivers 6-1
Distribution and Abundance 6-4
Conservation Status of Streams and Rivers 6-7
Habitat Conservation in the Riparian Zone 6-7
Land Cover Change in the Riparian Zone 6-8
Conservation in the Riparian Zone 6-8
Recent Trends in Riparian Shoreline Conservation 6-9
Integrated Protection Index 6-13

Water Quality Protection 6-19
Connectivity Protection 6-21
Flow Protection 6-23
CONDITION: Fragmentation: Dam Distribution, Size, and Purpose 6-24
Northeast Dam Dataset: 6-25
Passability: 6-28
Dam Removals: 6-28
Miles Reopened 6-31
Connected River Networks 6-33
Diadromous Fish: 6-33
Resident Freshwater Fish: 6-33
Freshwater Mussels: 6-33
Plants and Floodplain Ecosystems: 6-33
Climate Change: 6-33
Methods: 6-34
Hydrologic Alteration 6-39
Impervious Surfaces 6-45
Recent Trends in Impervious Surfaces. 6-48
BIOTIC CONDITION: Benthic Macroinvertebrate Index 6-55
Brook Trout 6-58
Non-Indigenous Aquatic Species: 6-63
Chapter 6: References 6-66
7 Chapter 7: Lakes and Ponds 7-1
Waterbody Types and Associated Species 7-2
Distribution and Abundance 7-3
Habitat Conservation of the Shoreline Riparian Zone 7-5
Land Cover of the Riparian Zone 7-5
Conservation of the Riparian Zone 7-5
Conservation Status of Individual Lakes and Ponds 7-9
Recent Trends in Riparian Shoreline Conservation 7-11
Lake Condition: Shoreline Disturbance 7-16
Lake Condition: Impervious Surfaces 7-22

Recent Trends in Impervious Surfaces 7-25
Lake Condition: National Lake Assessment 7-27
Chapter 7: References 7-31
Appendix 7.1. All 2017 National Lake Assessment Metrics by Region and Condition Class 7-33
Appendix 7.2. Additional Metrics, 2011. 7-42
8 Chapter 8: Climate Resilience 8-1
Introduction 8-2
Climate Resilience and Conservation 8-3
Assessing Site Resilience 8-4
Landscape Diversity: 8-4
Local Connectedness: 8-4
Tidal Wetland and Migration Space 8-9
Connectivity and Climate Flow 8-12
Assessing Connectivity and Climate Flow 8-12
Biodiversity Value 8-15
Resilient and Connected Network 8-18
America the Beautiful and 30 by 30 8-18
Carbon 8-21
Conserving America the Beautiful (30 by 30): 8-24
Chapter 8: References 8-26
Appendix 8.1 8-30

List of Tables

Box 2.1. Definitions of GAP categories and their crosswalk to TNC's Conservation Management Status (CMS).....2-4
Table 2.1. Description of fields in The Nature Conservancy's Conservation Land dataset. 2-5
Table 2.2. Acres and percentages of conservation lands by GAP status. 2-6
Table 2.3. The amount of land converted and conserved by state, region, and GAP status. 2-10
Table 2.4. Conservation ownership. 2-12
Table 2.5. Conservation easements. 2-12
Table 2.6. Conservation lands by ownership/interest holder. 2-14
Table 2.7: Completeness of the "Year Conserved" field by number of tracts. 2-15
Table 2.8: Acres of Conservation Land by decade conserved. 2-16
Table 2.9: Conservation fee and easements by decade, ownership type, and GAP status. 2-18
Table 3.1. Acres of forest by secured land status, forest type and sub-region. 3-7
Table 3.2: Acres of Forest Turnover and Loss from 2001-2021 by Region and Subregion. 3-11
Figure 3.6: Forest Change by Protection Level and Date Conserved. 3-13
Table 4.1: Distribution of Wetland Types 4-4
Table 4.2. Amounts of conversion, transition, and conservation securement in historic wetland area...4-7
Table 4.3: Acres of Wetland Turnover and Loss from 2001-2021 by Wetland Type. 4-10
Table 4.4. Conversion of Natural Land Use (2001-2021). 4-10
Table 4.5. Conservation of Current Wetland Extent. 4-13
Table 4.6. Top Ten Entities for Recent Wetland Conservation 4-13
Table 4.1.1. %of wetland acreage in each impact class across wetland types and subregions. 4-23
Table 5.1. Example illustrating calculation of the %AE and IV for Timber Rattlesnake 5-4
Table 5.2 Count and Density of Preferential Species by Geophysical Setting. 5-5
Table 5.3 Examples of typical communities and species. 5-5
Table 5.4 Examples of typical communities and species 5-6
Table 5.5 Examples of typical communities and species. 5-7
Table 5.6 Examples of typical communities and species. 5-7
Table. 5.7 Examples of typical communities and species. 5-8
Table 5.8. Typical communities and species of Mafic bedrock. 5-9
Table 5.9 Typical communities and species of shale bedrock. 5-9
Table 5.10. Typical Communities and Species of Ultramafic Bedrock 5-10
Table 5.11. Typical Communities and Species of Fine Silt and Clay. 5-10
Table 5.12. The Number and Type of Preferential Species by elevation zone 5-11
Table 5.13. Typical Communities and Species of Alpine and High Elevations 5-11
Table 5.14. Typical Communities and Species of the Coastal Zone 5-12
Table 5.15. Typical Communities and Species of Cliffs and Steep Slopes 5-13
Table 5.16. The percent of habitat conversion compared to percent of land conservation. 5-15
Table 5.17. Recent trends in habitat conversion compared to percent of land conservation. 5-19

Table 5.18. Conservation Status of Terrestrial Forests by Lexicon, Macrogroup and State 5-33
Table 5.19. Conservation Status of Terrestrial Non-Forest Habitats by Lexicon, Macrogroup and State ...5-34
Table 5.20. Conservation Status of Basin Wetlands by Lexicon, Macrogroup and State 5-35
Table 5.21. Conservation Status of Floodplain and Tidal Wetlands by Lexicon, Macrogroup and State 5-36
Table 5.1.1. Crosswalk between the Northeast Lexicon Project and the NETHM forest types.....5-41
Table 5.1.2. Crosswalk between the Northeast Lexicon Project and the NETHM non-forested habitats...5-42
Table 5.1.3. Crosswalk between the Northeast Lexicon Project and the NETHM wetland habitats.....5-43
Table 5.2.1. Preferential Species for Sand and other Coarse-Grained Sediments 5-44
Table 5.2.2. Preferential Species for Calcareous Bedrock areas.....5-45
Table 5.2.3. Preferential Species for Acidic Sedimentary Bedrock areas. 5-46
Table 5.2.4. Preferential Species for Moderately Calcareous Bedrock areas. 5-47
Table 5.2.5. Preferential Species for Acidic Granitic Bedrock areas. 5-48
Table 5.2.6. Preferential Species for Mafic or Intermediate Bedrock areas. 5-49
Table 5.2.7. Preferential Species for Acidic Shale Bedrock areas 5-50
Table 5.2.8. Preferential Species for Ultramafic Bedrock areas 5-51
Table 5.2.9. Preferential Species for Fine-grained Mud and Silt Deep Surficial Sediment.....5-51
Table 5.2.10. Preferential Species for the Very High Elevation zone (>3600'). 5-52
Table 5.2.11. Preferential Species for the High Elevation zone (2500'-3600'). 5-52
Table 5.2.12. Preferential Species for the Coastal zone (0'-20').....5-53
Table 5.2.13. Preferential Species for the Cliffs and Steep Slopes. 5-54
Table 6.1. Stream and River Size Classes 6-2
Table 6.2. Miles of Stream and River Types by State and Region.....6-4
Table 6.3. Acres of Riparian Land by Cover Type and Conservation Status.....6-8
Table 6.4. Conservation Risk Index (CR) and% of Riparian Land Cover and Conservation Land 6-9
Table 6.5. Recent Trends 2012-2022. Conservation and Conservation in the Riparian Zone 6-11
Table 6.6. Streams and Rivers by Integrated Protection Index Class. 6-14
Table 6.7. Tier 3 (high) and other state designations (medium) protections for water quality. 6-19
Table 6.8. Northeast Wild and Scenic Rivers 6-21
Table 6.9. Levels of flow protection for northeast states. 6-23
Table 6.10. Number, primary purpose, and density dams. 6-26
Table 6.11. Partially Passable Dams: Number, primary purpose, and density. 6-28
Table 6.12. Dam Removal and Miles of Reopened Stream Network by State and Year 6-31
Table 6.13. Top 10 Dam Removals in the last Decade by Miles Opened Upstream.....6-32
Table 6.14. Distribution of (A) Current Network Lengths and (B) Original Network Lengths 6-35
Table 6.15. Current Network Length as a Percentage of its Original Pre-Dam Length.....6-38
Table 6.16. Percent of miles in each hydrologic alteration index class by stream and river type.....6-41
Table 6.17. List of Most Hydrologically Intact Medium-Big Rivers by HUC6 Watershed 6-43
Table 6.18. Percent of Total Mile in each Impervious Surface Class 6-47
Table 6.19. Nitrogen and Phosphorus Exceedance by Percent Steam Miles: 6-53
Table 6.20. Distribution of each Benthic Invertebrate Multimetric Index (BMMI) Probability Class. 6-55

Table 6.21. Legend to Map 6.20 and Description of Eastern Brook Trout Conservation Strategy.....6-60
Table 6.22. Acres of Eastern Brook Trout Conservation Strategies by Land Cover Type and Conservation Status 6-61
Table 6.23. Eastern Brook Trou Conservation Strategies by Conservation Risk Index (CR) and% of Land Cover and Conservation Land 6-61
Table 6.24. Eastern Brook Trou Conservation Strategies by Last Decade: Conservation Land and Conservation Risk Index, 2012-2022.....6-62
Table 7.1. Types of Ponds and Lakes used in this report 7-3
Table 7.2. Number and acreage of lakes and ponds in the region (also see Map 7.1).....7-3
Table 7.3. Acres of Lake and Pond Riparian Land by Cover Type and Conservation Status 7-5
Table 7.4. Conservation Risk Index (CRI) and Nature Risk Index (NRI) for the Lake and Pond Riparian Land 7-8
Table 7.5. Last Decade (2012-2022): Lake and Pond Riparian Conservation Land and Conservation Risk Index Negative number indicate habitat lost. CRI = the ratio of acres converted to development or agriculture to acres conserved (GAP1-3) 7-8
Table 7.6. Lakes and Ponds by Individual Waterbody Conservation Status 7-11
Table 7.7. Highly Secured Lakes and Pond by Type and Subregion.....7-14
Table 7.8. The percentage and number lakes and ponds that fall within each shoreline disturbance class. 7-18
Table 7.9. Lakes and ponds that have had a large change in their shoreline disturbance index 2001-2019 7-20
Table 7.10. Number and % of Lakes and Ponds by Upstream Impervious Class 2019 7-24
Table 7.11. Number and Percent of Lakes and Ponds by Impervious Surface Impact Class Change 2011-2019 7-27
Table 7.12: Summary of Select 2017 National Lake Assessment Biological, Chemical, and Physical Condition Metrics. 7-30
Table 7.2.1. The percentage of lakes with upstream or downstream dams, arranged by type and sub-region. 7-45
Figure 7.2.3. The percentage of lakes and ponds in the region with a dam directly upstream or downstream. 7-47
Table 7.2.2. The percentage of lakes with upstream or downstream dams, arranged by type and sub-region 7-47
Table 8.1. Percent Conserved by Area, GAP status, RCN and Carbon. 8-24

List of Maps and Figures

Map 2.1. Conservation Lands by GAP status. 2-7
Figure 2.1. Conservation land by state, sub-region, and GAP status. 2-8
Map 2.2. National Land Cover Dataset (NLCD) 2019. 2-9
Figure 2.2. Distribution of habitat conversion and land conservation by state, sub-region, and region. 2-11
Figure 2.3. The distribution of conservation easements. 2-13
Map 2.3. Conservation land by ownership type and designation. 2-13
Figure 2.4. Amount of conservation land by decade, GAP status, and region. 2-16
Figure 2.5: Date conserved by fee organization or easement holder. 2-17
Figure 2.6. Percent habitat conversion versus land conservation by state. 2-19
Figure 2.7. Acres of Habitat Conversion and Conservation by State. 2-20
Map 2.4. Conservation progress and land use change between 2001 and 2019. 2-21
Map 3.1. Major Forest Types of the Northeast Region. 3-3
Map 3.2. Conservation Land and Major Forest Types. 3-5
Figure 3.1. Forest Conversion compared with Conservation. 3-6
Figure 3.2. Percent of forest acres conserved by forest type. 3-6
Map 3.3. Extent of Forest Change (Loss and Turnover) in the last 20 years. 3-8
Figure 3.3: Forest in transition in the Northeast and Mid-Atlantic. 3-9
Map 3.4. Forest Change in the last 20 years by Forest Type 3-10
Figure 3.4: Forest Transition by Forest Type 3-11
Figure 3.5: Forest Change by GAP Status. 3-12
Figure 3.6: Forest Change by Protection Level and Date Conserved 3-13
Map 3.5: Northeast Road Network and Distance to Major Roads 3-16
Map 3.6. Forest Block Size in Acres. 3-17
Figure 3.8. Percent of forest acres within major road bounded blocks. 3-18
Figure 3.9. Aerial photo image of areas with different local connectedness scores. 3-19
Map 3.7. Local Connectedness Wall to Wall. 3-20
Map 3.8. Local Connectedness of Forests 3-22
Figure 3.8. Local Connectedness and Securement 3-23
Figure 3.9: Local Connectedness Trends. 3-24
Map 3.9. Change in Local Connectedness (2010 to 2019). 3-25
Map 4.1. Distribution of Wetlands by Type 4-5
Figure 4.1. Distribution of Historic Wetland Acres by Current Land Use and Conservation Status 4-7
Figure 4.2: Conservation of Current Wetland Extent. 4-8
Figure 4.3: Wetlands in transition in the Northeast and Mid-Atlantic. 4-11
Figure 4.4. Conservation Risk Index by Wetland Type (2001-2012). 4-12
Map 4.2. Local Connectedness Wall to Wall. 4-15
Figure 4.5. Aerial photo image of areas with different local connectedness scores. 4-16

Figure 4.6. Average connectedness scores for the four wetland types.....4-17
Figure 4.7. Average connectedness scores for the four wetland types.....4-18
Map 4.1.1. Wetland occurences by impact classes 4-22
Figure 4.1.1. Disturbance in the 100 m buffer zone. 4-23
Figure 4.1.2. Acres of wetlands in each road impact category across wetland types. 4-24
Map 4.1.2. Wetland occurrences by road impact category. 4-25
Figure 4.1.3. Estimated net change in wetland acreage from 1992 to 2001.....4-26
Map 5.1. Geology of the Northeast. 5-3
Figure 5.2. Preferences of Two Plant Species for Landform Types.....5-13
Figure 5.3. Geology Classes: Amount of conversion compared with the amount of securement 5-16
Figure 5.4. Elevation Zones: The amount of conversion compared with the amount of securement. ...5-16
Figure 5.5. Landform Types: The amount of habitat conversion compared with the amount of habitat securement or protection.....5-17
Figure 5.6. The conservation risk index of geological settings, elevation zones and landform types in relation to the percent of the region covered by that feature. 5-18
Figure 5.7. Geology Classes: Conversion versus Conservation 2012-2022. 5-20
Figure 5.8. Elevation Zones: Conversion versus Conservation 2012-2022 5-20
Figure 5.9. Slope Class: Conversion versus Conservation 2012-2022.....5-21
Figure 5.10: Percent of land acres within block size classes.....5-23
Figure 5.11: Aerial Photo Image of areas with different connectedness scores. 5-24
Figure 5.12. Average connectedness scores for the nine geology types. 5-25
Figure 5.13. Average connectedness scores for the elevation zone. 5-26
Figure 5.14. Relationship between the average local connectedness score (left axis) and the density of preferential species (right axis).....5-27
Figure 5.15. Legend for the Northeast Terrestrial Habitat Map.....5-30
Figure 5.16. Conservation Status of Upland and Wetland Habitats by Northeast Lexicon Names 5-32
Figure 5.17. Conservation Status of Non-Forested Habitats by Acres.....5-38
Figure 5.18. Conservation of Non-Forested Habitat by Percent Conserved and Individual Habitat Type ..5-39
Figure 6. 1. River Continuum Concept 6-3
Map 6.1. Freshwater ecoregions and major rivers of the northeast United States. 6-5
Map 6.2. Streams and River Types.....6-6
Figure 6. 2. Riparian Zone Conceptual Model.....6-7
Figure 6. 3. The distribution of riparian land cover and conservation by stream type. 6-10
Figure 6. 4. Conservation Risk Index (CRI): Overall and Last Decade. The.....6-11
Map 6.3. Riparian Land Cover and Conservation. 6-12
Figure 6.5. Calculation of ‘achieved target protection 6-13
Figure 6.6. Streams and Rivers by Integrated Protection Class. 6-15
Map 6.4. Locally Conserved Streams and Rivers 6-16
Map 6.5. Locally Conserved Streams and Rivers by their Integrated Protection Index. 6-17
Map 6.6. Rivers Achieving Full Integrated Protection. 6-18
Map 6.7. Tier 3 (high) and other State Designations (medium) Protections for Water Quality. 6-20

Map 6.8. Federal Designations: Wild and Scenic Rivers and the National River Inventory.....6-22
Figure 6. 7. Northeast Dams by Primary Purpose and Height 6-26
Map 6.9. Dams by Primary Purpose.....6-27
Figure 6.8. Number of Dam Removals by State 2012-2021.....6-28
Map 6.10. Dams by Height and Passability.....6-29
Map 6.11. Dams Removals 2012-2021 6-30
Figure 6. 9: Functionally Connected Network (FCN) Length.....6-34
Map 6.12. Current Functional Connected Network (FCN) Length 2022.....6-36
Map 6.13. Comparing Current Network Length to Network Length Before Dams 6-37
Figure 6. 10. Distribution of Current and Historic Network Lengths 6-38
Figure 6. 11. Ecological functions and hydrograph before (blue) and after (purple) damming.....6-39
Figure 6. 12. Percent of Miles in each Hydrologic Alteration Index class by Type and Subregion 6-41
Map 6.14. Index of Hydrologic Alteration Impacts (HAI. McManamay et al. 2022.....6-42
Map 6.15. Hydrologic Alteration Index Impacts for Medium-Big Rivers 6-44
Map 6.16. Streams and rivers by upstream impervious surfaces impact class (NLCD 2019).....6-46
Figure 6. 13. Percent of Stream Miles by Upstream Impervious Surface Class.....6-47
Figure 6. 14. Change in the percentage of miles in each impervious surface impact class 2001-2019. .6-48
Map 6.17. Stream reaches with change to a more impacted upstream impervious surfaces class between 2011 and 2019 6-49
Map 6.18. Stream and River Reaches by Total Nitrogen and Phosphorus.....6-51
Map 6.19. Stream and River Reaches by deviation from EPA Criteria. 6-54
Map 6.20. Probability of Good BMMI Biotic Condition. 6-56
Figure 6. 14. Percent of miles by Predicted Probability of Good BMMI.....6-57
Figure 6.15: Eastern Brook Trout Conservation Strategies.....6-58
Map 6.21. Eastern Brook Trout Conservation Strategy Result 6-59
Figure 6.16. Conversion and Conservation within Eastern Brook Trout Conservation Strategy Areas...6-62
Figure 6.17. Number of non-indigenous aquatic species alerts by state in alphabetical order. 6-63
Figure 6.18: Major pathways of non-indigenous aquatic species introductions.....6-64
Map 6.22. Total number of non-indigenous aquatic species observed per HUC8 drainage 6-65
Map 7.1. Lakes and Ponds by Size Class. 7-4
Figure 7.1. The distribution of riparian land cover and conservation by lake and pond type.....7-7
Figure 7.2. Lake and Pond Individual Waterbody Conservation Status:.....7-9
Map 7.2. Lake and Ponds by their Individual Waterbody Conservation Status. 7-10
Map 7.3. Highly Conserved Lakes and Ponds 7-12
Figure 7.3. Highly Secured Lakes and Pond by Type and Subregion.....7-13
Map 7.4. Change in Conserved Lakes and Ponds in the last decade. 7-15
Map 7.5. Lakes and Ponds by Disturbance Class. 7-17
Figure 7.4. The percentage lakes and ponds that fall within each shoreline disturbance class.....7-18
Map 7.6. Lakes and Ponds by Shoreline Disturbance Index Change. 7-21
Map 7.7. Lakes and Ponds by Impervious Surface Impact Class (NLCD 2019) 7-23
Figure 7.5. Percentage of Lakes and Ponds by Upstream Impervious Class 2019.....7-24
Figure 7.6. Percent of Lakes and Ponds by Impervious Surface Impact Class 2001-2019.....7-25

Map 7.8. Lakes and Ponds by Change in Impervious Surface Impact Class (NLCD 2019) 7-26
Figure 7.7: NLA 2017 Biological Indicators. 7-28
Figure 7.8: NLA 2017 Chemical Indicators 7-29
Figure 7.9: NLA 2017 Physical Indicators. 7-29
Map 7.2.1. Ponds and lakes by minimum distance (in miles) to a road. 7-43
Figure 7.2.2. The percentage of lakes and ponds in the region with a dam directly upstream or downstream. 7-44
Map 8.1. Site Resilience. 8-5
Figure 8.1. Site Resilience by Forest Type and GAP status. 8-6
Figure 8.2: Site Resilience by Wetland Type and GAP status. 8-7
Figure 8.3: Resilience Score and Conservation Year. 8-8
Figure 8.4. Distribution of the 3,925 coastal units and zoom-in of a single unit. 8-9
Map 8.2. Resilient Coastal Sites. 8-10
Figure 8.5: Resilient Coastal Sites and Conservation. 8-11
Map 8.3. Connectivity and Climate Flow. 8-13
Figure 8.6: Regional Flow by Forest/Wetland Type and GAP Status. 8-14
Map 8.4. Recognized Biodiversity Value. 8-16
Figure 8.7. Conservation of Biodiversity Areas by GAP status and Decade. 8-17
Map 8.5. Resilient and Connected Network 8-19
Figure 8.8: Conserving the Resilient and Connected Network. 8-20
Map 8.6. Estimated Forest Carbon Stocks for 2010. 8-22
Figure 8.9. Forest Carbon Stocks by State and RCN. 8-23
Figure 8.10. Reaching 30 by 30: Conserving the Biodiversity and Carbon Footprint 8-25

CHAPTER

Introduction 1

Understanding and Using the Report Feb 2023

M.G. Anderson, A. Olivero and M Clark

The Northeast and Mid-Atlantic states share a long history of conservation and collaboration. The region's forests, wetlands, rivers, and coastline are extensive, but because they cross state boundaries, a tradition of working together to understand and conserve them has evolved. In 2008, the Northeast Association of Fish and Wildlife Agencies (NEAFWA) and its partners developed a multi-state monitoring framework to take stock of the condition and conservation of the species and habitats that characterize the region. The report was intended to inform decision makers and managers on how individual states were faring, as well as how the region was performing

- Monitoring the Conservation of Fish and Wildlife in the Northeast: A Report on the Monitoring and Performance Reporting Framework for the Northeast Association of Fish and Wildlife Agencies. (Tomajer et al. 2008)

In 2011, The Nature Conservancy, working with NEAFWA, produced the first regional application of the framework:

- Conservation Status of Fish, Wildlife, and Natural Habitats in the Northeast Landscape: Implementation of the Northeast Monitoring Framework. (Anderson and Olivero 2011)

Compiling region-wide data, analyzing the underlying patterns, and assessing the indicators suggested by the monitoring framework, this report presented a comprehensive and multidimensional picture of the state of the natural world in the Northeast. It was through the creation of that report we first became aware of several conservation challenges such as the fragmentation of our rivers, bird declines in forests, and the pervasive footprint of land conversion. At the same time, we became aware of the growth and reach of our collective land and water conservation network.

This report is an update to the 2011 Conservation Status report focused on progress and change in the last decade from 2012-2022. Not every indicator was revisited, only those where the source data had the resolution and detail to allow us to detect change, and that was the majority. Additionally, we added new metrics, or revised old ones, where we had better data that allowed us to backcast ten or twenty years to detect trends. Data highlights include:

- A completely revised conservation land dataset, developed collaboratively with state offices, and with "date conserved" added for most records since 2011
- Remotely sensed time-sequence data on land cover change, forest turnover, and anthropogenic fragmentation
- Computationally intensive tools for measuring local connectedness, regional connectivity, and stream integrated protection
- A revised dam dataset and detailed information on stream nutrient enrichment
- A template for exploring marsh migration and measuring the conservation of migration space
- Models of climate resilience, connectivity, recognized biodiversity areas, and carbon stocks

In addition to this written report, we have prepared excel spreadsheets to accompany each chapter and allow users to explore the data for their local geographies, or for the whole region.

The NEAFWA region includes Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia, Washington D.C. and West Virginia. In these states, Fish and Wildlife agency members are responsible for managing species and their habitats in a diverse range of ecosystems that include terrestrial, freshwater, coastal, and marine systems, all set amongst one of the most densely populated regions of the country.

All thirteen states and DC have developed State Wildlife Action Plans (SWAPs) that represent a collective vision for the future of conservation. SWAPs are proactive plans that assess the condition of each state's wildlife, identify the problems they face, and prescribe actions to conserve wildlife and vital habitats before they become more rare and costly to protect. As SWAPs form the underlying basis of the monitoring framework, we hope the findings from this report, and the detailed state-by-state data tables will be useful to, and incorporated in, the next round of plans.

Methods and Approach

The monitoring framework intentionally focused on using existing data and information, rather than requiring new sets of data, to keep its recommendations simple and manageable, and allow for the type of decadal revisit that this plan represents. Nevertheless, implementing the recommendations required the compilation and management of over 50 datasets, and inevitably some needed thorough revision or had to be created anew from state sources for this report (e.g. conservation lands). Whenever possible we worked directly with the people who created and managed the source data to ensure that we were using it correctly. A few of the data originators, such as Matthew Neilson of U.S. Geological Survey Nonindigenous Aquatic Species (NAS) Program who extracted and summarized data for the northeast states and Erik Martin of The Nature Conservancy who assisted with compiling and updating dams in the northeast, merit our thanks and acknowledgment. We are grateful for the help and goodwill we received, and any errors in the analysis or interpretation are solely our own.

This report was completed over a shorter time frame than the original and we were guided by smaller but essential eight-state steering committee. The committee met bimonthly and reviewed our workplan, data summaries, and preliminary results. As the project moved fast, the steering committee was also where we reported problems, discuss alternative solutions, and approved decisions concerning scope and content.

We are indebted to the our Conservation Status 2.0 Steering Committee team including Jon Kart of Vermont Fish and Wildlife Department (lead), Cathy Haffner of the Pennsylvania Game Commission, Lisa Williams of Pennsylvania Game Commission, Gwen Brewer of Maryland Department of Natural Resources, John Herbert of Rhode Island Department of Environmental Management, Samantha Robinson of Delaware Department of Natural Resources and Environmental Control., Sandra Houghton of New Hampshire Fish and Game Department, Steve Walker of Maine Department of Inland Fisheries and Wildlife, Justin Schlawin of Maine Natural Areas Program, Dee Blanton of U.S. Fish and Wildlife Service, Elizabeth Crisfield of Strategic Stewardship Initiative, and Karen Terwilliger and Tracy Rice of Terwilliger Consulting Inc.

Organization of the Report

This report covers the proposed status measures for seven conservation targets:

- Conservation Lands
- Eastern Forests
- Freshwater Wetlands
- Unique Habitats
- Streams and Rivers
- Lakes and Ponds
- Climate Resilience

We did not revise the chapter on Regionally Significant Species of Greatest Conservation Need because we and the steering committee agreed that what was compiled in 2011 still stands, and it would take more effort than we had available to collect all new data and detect change over the last decade. The same is true for the bird trends we had embedded within each habitat chapter. The 2011 results are still relevant and recent summaries are available from USGS Breeding Bird Survey https://www.pwrc.usgs.gov/bbs/

As with the 2011 report we did not assess managed grassland or shrublands, or highly migratory species because good regional scale indicators have not yet been proposed by the monitoring team, nor did we find off-the-shelf usable datasets to detect trends in these systems. This is a good area for research.

We maintained the added chapter on conservation lands to highlight the overall and recent patterns of land conservation for the region, and clarify the concepts of securement, protection, management, and designation. These concepts are essential for understanding the area-based conservation that now underlies the Biden Administration's America the Beautiful initiative and the Global 30 by 30 movement. They are also essential to understanding the state and status of habitats in the Northeast, and our more important findings relate to how well the network of conservation land is working (or not working) with respect to certain targets.

Similarly, we added a new chapter on climate resilience, to assess how well the conservation land network has been able to encompass resilient land, connectivity, marsh migration space, and carbon. These topics were not in the 2008 monitoring framework but are relevant to conservation today.

The chapters are organized around the habitat types with a summary of findings on the first page. Each chapter begins with basic statistics on the target habitat, then looks at conversion and conservation rates across time, and across the last decade. Each of the various indicators is addressed, with an emphasis on identifying trends from the last decade or two. The results include charts, tables, maps, and accompanying excel data tables for detailed state-by-state information.

Compiling this report has been eye-opening both to the huge challenges we are facing and to the collective progress we have made on sustaining the region's habitats and wildlife. We hope this information will be useful to others who care about the natural world and we welcome comments, questions, suggestions, criticism, or other feedback.

CHAPTER

Conservation Lands 2

In the Northeast and Mid-Atlantic

Feb 2023

A. Olivero, M. Clark, & M. Anderson

Covering 19% of the region, conservation lands represent a permanent commitment to nature and demonstrate what can be achieved through collective effort. They provide core protections for the region's outstanding habitats and threatened species and are increasingly understood as essential providers of ecosystem services and storehouses of the land's biological resources. Even as the region's ecology adjusts in response to a changing climate, conservation lands play a critical role in maintaining arenas for evolution and provide people with the opportunity and rewards of direct contact with nature.

Eastern Conservation Lands At-A- Glance	
Total Acres	29,669,493
Percent of the Region	19.06%
Number of Fee Owners	5,129
Average size of Ownership	4,393 Acres
Number of Easements	69,446
Average size of Easement	111 Acres
Number of Individual Tracts/Polygons	260,968

Definitions:

Conserved: Lands permanently secured against conversion to development = **GAP status 1 - 3**

Conserved for Nature: A secured area intended for biodiversity or nature conservation = **GAP status 1 or 2**

Conserved for Multiple Uses: A secured area intended for multiple uses such as forest management and recreation = **GAP status 3**

Conservation Land: Nineteen percent of the region is conserved against conversion to development with 6% of the land area protected explicitly for nature (GAP 1 & 2) and 13% for multiple use (GAP 3). Conservation lands are held by over 5,000 fee owners and 1,400 easement holders with state government (12 M ac.) being the largest fee owner, followed by the federal government (6 M ac.), county and local government (1.3 M ac.), and private non-profits (1.2 M ac.). Private non-profits hold the most easement land (3.6 M ac.) followed by state (3.1 M ac.), local (400 K ac.), and federal (200 K ac.).

Habitat Loss versus Conservation: In total, 26% of the region has been converted to development or agriculture, compared to the 19% conserved. Thus, 1.4 acres of natural habitat have been lost for every acre of land conserved.

Recent Trends (2012-2022): In the last decade, the collective efforts of over a hundred organizations and agencies have resulted in **2.1 million acres of new conservation land**. Easements accounted for 1.3 million acres and fee ownership for 780,000 acres. New conservation was achieved primarily by private NGOs (1.1 M ac), accounting for over half of the fee (406 K) and easement acreage (738 K).

For perhaps the first time, the area of **land conservation surpassed habitat loss by a ratio of 6 to 1.** For every one acre of land conserved, 0.15 acres of land were converted to agriculture or development. This pattern held true across almost every state. Three New England states had ratios over 15 to 1.

Background: Land and water permanently maintained in a natural state remains the most effective, long lasting, and essential tool for conserving species and habitats. By regulating the use of land and water within a network of places, conservation can sustain species populations and prevent habitat degradation at larger scales. Although most conservation lands are in a natural or semi-natural state, they are far from uniform. Individual places are governed by a variety of public and private fee owners and easement holders, with a wide range of management intents. As conservation has grown in sophistication, the tools for conserving land have greatly expanded in scope and versatility. Forever-wild reserves are but one end of a spectrum of conservation lands representing an array of restrictions, intents, designations, tenures, easements, interest holders, and ownership types.

The evolution of land and water protection to encompass a broad palette of uses and restrictions is one of the more interesting and practical advances in conservation. Ideally, it offers a credible pathway for creating natural infrastructure at a large scale with a diverse set of players. Moreover, it is a necessary response to the increasingly complex nature of the environmental crisis and the challenge of sustaining all the benefits and services provided by nature. However, monitoring is required to ensure that conservation land performs the functions we expect, with low quality or marginalized habitat unlikely to sustain the full spectrum of plants and wildlife.

In this section, we define the types of conservation land in a standardized way and then examine the general patterns of conservation across the region. In other chapters, conservation lands are examined in relation to natural features such as forests, wetlands, non-forested uplands, rivers, and lakes. Thus, the terms and data described in this chapter form the basis of understanding the other chapters in this report.

Definition of Conservation Land

In this report "**conservation land**" refers to land that is permanently secured against conversion to development. This definition was adopted by an international group of American and Canadian scientists to encompass a wide variety of public and private ownership and management types. It goes beyond the more restrictive IUCN definition of "protected areas" which refers to land with a government designation aimed at the conservation of nature. Our definition includes public land designated for conservation, but also includes land with no formal designation if the intent of the landowner or easement holder (public, private, or NGO) is for permanent conservation, and if there is a measurable capacity to fulfill the intent. For example, a permanent conservation easement held by an established land trust qualifies here as conservation land even though it is privately held and has no designation. Conversely, the definition excludes some formally designated areas, such as the Champlain-Adirondack Biosphere Reserve, if there is no conservation intent or means for sustaining permanent conservation.

The Nature Conservancy's Conserved Land Dataset

The Nature Conservancy (TNC) has been tracking and compiling information on conservation lands in the Northeast and Mid-Atlantic regions for over 20 years. TNC's Conserved Land Dataset is compiled bi-annually from over sixty state, federal, and private sources (CRCS 2022, Appendix 2.3). The foundation of the dataset is public land information maintained by each state, supplemented by federal land information from PAD-US (PAD-US 2022) and private conservation land information compiled by TNC's state field offices. State-based TNC staff compile the data for their state, assign a TNC/GAP status to each tract, and populate other standard attribute fields (Table 2.1). The completed state datasets are regionally compiled by TNC's Center for Resilient Conservation Science (CRCS), and quality checked

for consistency and discrepancies. Importantly, TNC's dataset is focused on permanent conservation and only includes land where the intent of the owner or easement holder is conservation in perpetuity and there is some legal capacity to fulfill that intent. Thus, places with important temporary, volunteer, or one-time conservation activities are not included in the dataset. The requirement for permanent protection is not based on an ecological justification, it is simply beyond our capacity to track and maintain information on non-permanent ownerships that are constantly in flux.

During this project we made an extra effort to compile a thorough dataset and to populate the "date conserved" field with a focus on the last ten years. The final dataset will be posted for public use and submitted to the national Protected Areas Database US (PAD-US) and the National Conservation Easement Database (NCED) to become part of these national datasets of conservation lands.

Conservation Lands and GAP Status

Three factors - intent, duration, and potential to manage effectively - form what the Nature Conservancy internally calls a tract's Conservation Management Status (CMS), which is roughly synonymous to the U.S. Forest Service's **GAP status** (Crist et al. 1998). The relationship between the two classifications is straightforward in the United States because governments and land-owning organizations already meet standards for appropriate governance, and by definition, have the potential for effective long-term management. Further, as the TNC dataset is focused on permanent conservation, the duration is always permanent. Therefore, GAP status and CMS in this dataset are determined primarily by intent and degree of management. As GAP status is widely used in the U.S., we use it as our primary reporting standard in this document. The definitions of the GAP categories and their crosswalk to CMS (Box 1) are modified from Crist et al. (1998); original definitions are provided in Appendix 2.

In this report, we use the term "*conserved land*" to refer to the total amount of land secured against conversion, including both strict nature reserves (GAP 1 & 2) and multiple-use public lands and easements (GAP 3). We use "*conserved for nature*" to refer to GAP 1 & 2 lands only. These are lands where the primary intent is the conservation of nature such as breeding habitat for wildlife or places where forests can grow old and develop mature characteristics. We use "*conserved for multiple uses*" to refer to land secured against conversion, but for which the primary intent includes recreation and resource extraction, as well as conservation of nature. These lands vary greatly in their habitat quality depending on the individual, organization, or agency which owns and manages them.

Box 2.1. Definitions of GAP categories and their crosswalk to TNC's Conservation Management Status (CMS). CMS designations are bolded and italicized. Definitions are modified by TNC for ease of assignment, original GAP definitions are in Appendix 2.

***Conserved*:** GAP Status 1, 2 and 3

Conserved for Nature: Conservation land where the primary intent is the conservation of nature.

- **GAP 1. Permanently Secured for Nature and Natural Processes**
  An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state where the area is allowed to "self-adjust" over time. Primary intention of the owner or easement holder is for biodiversity and nature protection. Land and water managed through natural processes including disturbances with little or no human intervention.
- **GAP 2. Permanently Secured for Nature with Management**
  An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state, but which receives hands-on management. Primary intention of the owner or easement holder is for biodiversity and nature protection. Land and water managed with hands-on manipulation of processes, species composition, and disturbance.

Conserved for Multiple Uses: Conservation land where the primary intent is multiple use.

- **GAP 3. Permanently Secured for Multiple Uses including extraction and recreation.**
  An area having permanent protection from conversion of natural land cover, but the primary intention of the owner or easement holder is for **multiple uses**, which may include biodiversity but also recreation and certain extractive uses. Extractive uses may include either a broad, low-intensity type (e.g., logging) or localized intense type (e.g., mining).

Conserved for Agriculture: Conservation land where the primary intent is the preservation of farmland.

- **GAP 39. Agricultural Easement**
  Land in a permanent agricultural easement or easement to maintain grass (e.g., vegetable farm with permanent easement to prevent development).

Not Conserved:

- **GAP 4. Unsecured**
  Temporary easement lands (e.g., CREP 5-year term, similar X-year term agreements with landowners) and/or municipal lands (school yards, golf courses, soccer fields, ball fields, town commons) where intention in management and use is not biodiversity protection.

Table 2.1. Description of fields in The Nature Conservancy's Conservation Land dataset.

2022 Conservation Land Field Name	Description of Fields in Conservation Land
STATE_PROV	Two-letter state/province postal abbreviation
AREA_NAME	Common name of secured area
FEE_OWNER	Name of the fee owner
FEE_ORGTYP	Organization type of the Fee Owner: FED: Federal, TRIB: Native American Lands, STAT: State, DIST :Regional Agency Special District, LOC: Local Government, NGO: Non-Governmental Organization, PVT: Private, JNT: Joint, UNK: Unknown, TERR: Territorial, DESG: Designation
INT_HOLDER	Name of entity holding additional interest in property
INT_ORGTYP	Organization type of Interest Owner: FED: Federal, TRIB: Native American Lands, STAT: State, DIST: Regional Agency Special District, LOC: Local Government, NGO: Non-Governmental Organization, PVT: Private, JNT: Joint, UNK: Unknown, TERR: Territorial, DESG: Designation
INT_TYPE	Type of Interest held by Interest Owner: Fee Ownership, Conservation Easement, Deed Restrictions, Deed Restrictions - Monitoring Required, Deed Restrictions - No Monitoring Required, Management Lease or Agreement, Timber Lease or Agreement, Grazing Lease, Grazing Permit, Life Estate, Right of Way Tract, Access Right of Way, Assist, Assist - Fee Ownership, Assist - Conservation Easement, Assist - Deed Restriction, Transfer, Transfer - Fee Ownership, Transfer - Conservation Easement, Transfer - Deed Restriction, Transfer - Life Estate, Transfer - Management Lease or Agreement, Transfer - Agreement, Other
ST_DESIG	The original designation as populated by the states. Could also be used to hold key information about other state types or coding.
DESIGNAT	Designation for management unit (state designations translated into generic categories for regional use): ACE- Area of Critical Environmental Concern; AGE - Agricultural Easement, CE - Conservation Easement, CRL-Crown Lands, EDU - Educational Lands (School, University), FL - Federal Land (including Military), HCA - Historic or Cultural Area, IRA-Inventoried Roadless Area, LCA-Local Conservation Area, MF - Municipal Forest, ML - Municipal Land, MP - Municipal Park, MPA - Marine Protected Area, NAT - Nature Reserve/ Preserve/ Sanctuary, NCA-National Conservation Area, NF - National Forest, NG-National Grassland, NM - National Monument, NP - National Park, NRA - National Recreation Area, NS - National Seashore, NWA - National Wilderness Area, NWR - National Wildlife Refuge, PCL - Private Conserved Land, RNA - Research Natural Area, SF - State Forest, SL - State Land, SP - State Park, TL - Tribal Land, WAT - Water, WMA - Wildlife Management Area, WSL - Water Supply Land, OTH - Other Land (use only if everything else does not apply), UNK - Unknown
GAP_STATUS	The final GAP code to use based on TNC review (matches GAP_TNC for reviewed parcels, matches GAP_ORIG for unreviewed parcels) and coding: 1 - Permanently Secured for Nature and Natural Processes 2 - Permanently Secured for Nature with Management, 3 - Permanently Secured for Multiple Uses and in natural cover, 39 - Permanently Secured and in agriculture or maintained grass cover, 4 - Unsecured (temporary easements lands and/or municipal lands that are already developed (schools, golf course, soccer fields, ball fields), 9 - Unknown
YEAR_CONSV	The Year (yyyy) the area was conserved via designation, decree, easement, or otherwise established.
PUB_ACCESS	Open Access, Limited Access, No Access, Unknown 'Open' requires no special requirements for public access to the property (may include regular hours of availability); 'Limited' requires a special permit from the owner for access, a registration permit on public land (e.g. self-permitting Wild and Scenic River, backcountry Wilderness registration) or has highly variable times when open to use; 'No Access' occurs where no public access is allowed (e.g. land bank property, special ecological study areas, military bases, many easements, etc.). 'Unknown' is assigned where information is not currently available.
GIS_ACRES	Acreage of property as calculated in ArcGIS: SHAPE_AREA x 0.0002471 or Calculate Geometry - Acres - US (ac)
SOURCE	Citation for the spatial data source dataset.
AUTHOR	Name of staff who prepared the data record
MOD_DATE	Date record was added to or updated; (Python 3 calculation: time.strftime('31/1/2000')

Distribution of Conservation Lands in the Northeast and Mid-Atlantic

Conservation efforts over the last century have resulted in over 29 million acres of conservation land distributed across the region, with over two million acres established in the last ten years. Who owns these lands? Do they add up to a larger conservation picture that represents the region's wildlife and plant diversity? Have we missed critical ecosystems or freshwater systems? In this report, we try to fit together the pieces of the conservation puzzle, take stock of our collective accomplishments, and identify where we need to put more effort. We begin by examining the overall patterns of conservation by acres, GAP status, and ownership type. In separate chapters we re-examine the secured lands with respect to the species, habitats, and natural features they were intended to conserve.

The conservation status of a parcel of land is not the same as the conservation status of a habitat or species. Conserving a habitat type, for example Northern Hardwood Forest, requires a network of conservation sites, preferably multiple viable examples of the forest, each large enough to sustain breeding populations of forest dependent species, and arranged in a configuration that sustains resilience and connectivity. Further, sustaining a species population or habitat type may also require restoration, improved management, or conservation outside the region to complement the area-based conservation documented here. We can begin to approximate the conservation status of a habitat by reviewing the set of conservation lands that contain the habitat and evaluating the distribution of their locations, sizes, and GAP status. Only in the last decade have we begun to unravel the complicated question of whether the collective set of tracts, together with other conservation strategies, accomplish the desired conservation outcomes.

Basic Patterns of Land Securement

Analysis of the 2022 Conservation Land Dataset (CRCS 2022, compiled and current through August 2022), revealed that the current network of conservation lands covered 29 million acres or 19% of the region (Map 2.1). Six percent was protected explicitly for nature (GAP 1 or 2) and 13% was secured for multiple uses (GAP 3). New England and New York had over four times the acreage of land conserved for nature, but the Mid-Atlantic had more multiple-use land (Table 2.2). Individual states also averaged 19% conservation land, and the total amount of state conservation land was highly correlated with the size of the state ($r = 0.97$). New Hampshire, Maine, and New York had more secured land than expected for their size (21% to 33% of the state). The amount of GAP 1 or 2 land conserved for nature, however, was far less correlated with a state's size, and New York, New Hampshire, New Jersey, and Virginia were all considerably above the average (Figure 2.1).

Table 2.2. Acres and percentages of conservation lands by GAP status.

Geographic Area	GAP 1		GAP 2		GAP 3		Acres: Unprotected	
	Acres	*Percent*	*Acres*	*Percent*	*Acres*	*Percent*	*Acres*	*Percent*
New England & New York	4,126,201	5.65%	1,962,866	2.69%	9,562,805	13.09%	57,394,590	78.57%
Mid-Atlantic	991,292	1.20%	2,240,386	2.71%	10,771,594	13.04%	68,607,490	83.05%
Region Total	5,117,493	3.29%	4,203,252	2.70%	20,334,399	13.06%	126,002,080	80.95%

Map 2.1. Conservation Lands by GAP status.

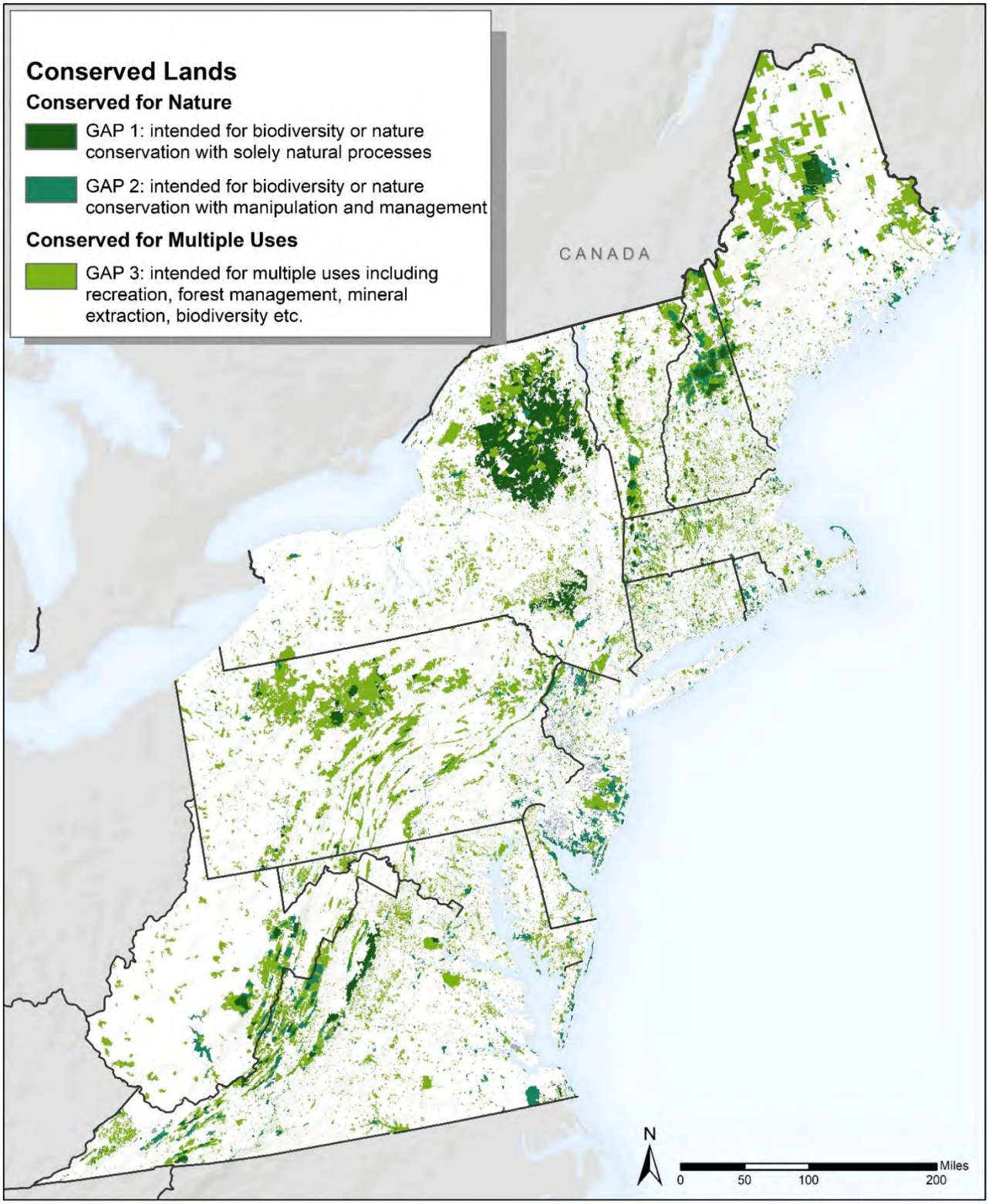
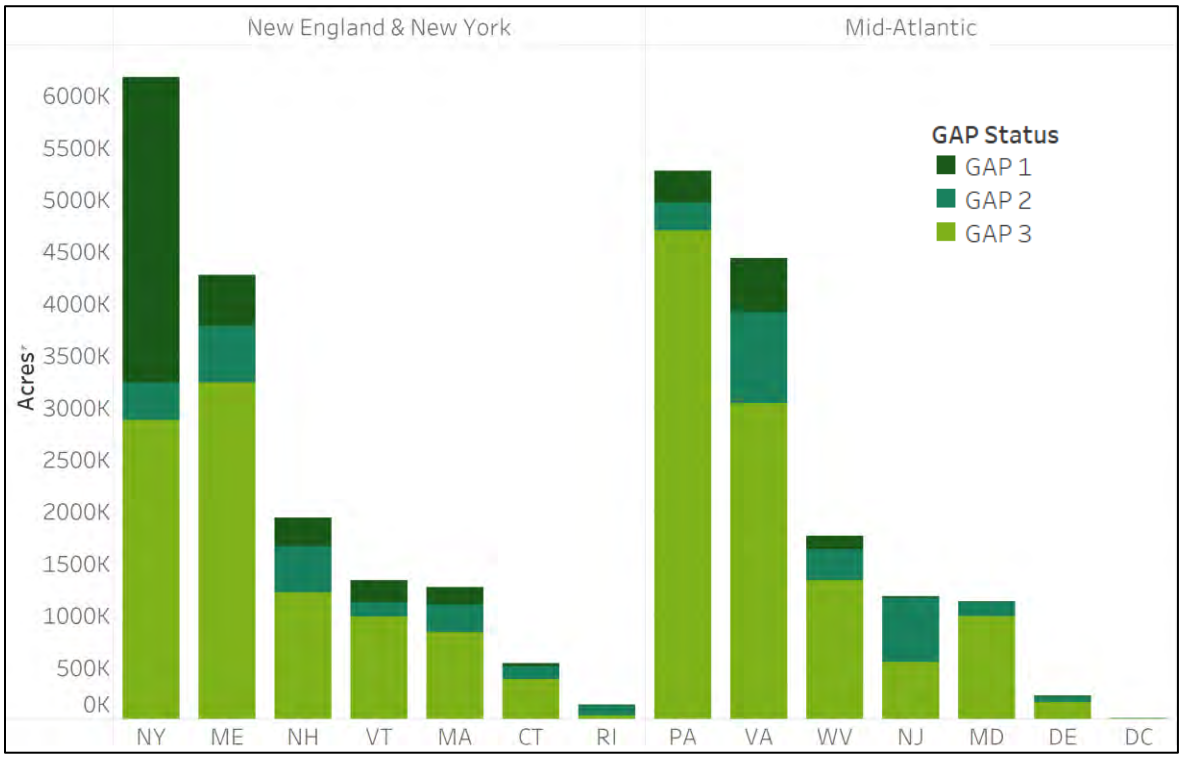


Figure 2.1. Conservation land by state, sub-region, and GAP status. The overall acreage was closely correlated with the size of the state (r=0.91).



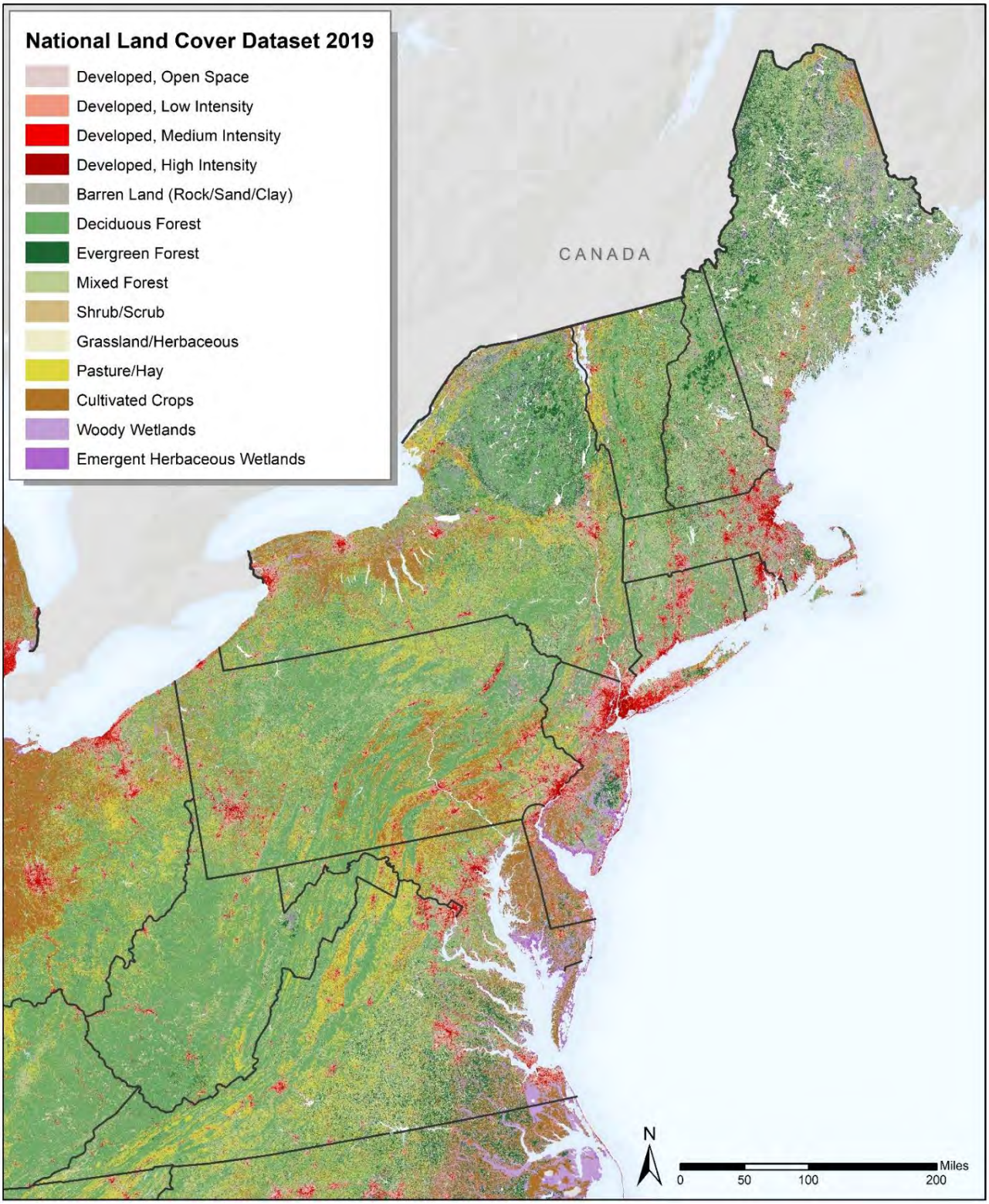
Habitat Loss versus Conservation

How much conservation do we need? One approach to answer this question is to compare the amount of land conservation with the amount of habitat loss due to conversion to development or agriculture. Hoekstra and others (2005) introduced a conservation risk index (CRI) as the ratio of conversion to conservation. We use this index, along with a stricture nature risk index (NRI) extensively in this report to understand the relative patterns of change. First, we examine the ratio at a variety of scales: from individual habitats to entire regions. For these comparisons we use the following definitions and labels.

- **CONSERVED** (CNM) This includes GAP 1-3 and encompasses both:
  - Conserved for Nature (CN) GAP 1-2 the primary intent is nature conservation
  - Conserved for Multiple Uses (CM) GAP 3, the primary intent is multiple use.
- **CONVERTED** (CV) includes conversion to development or agriculture, but not to other land cover types such as old fields that might recover to forest
- **CONSERVATION RISK INDEX** (CRI) = CV/CNM = converted / conserved
- **NATURE RISK INDEX** (NRI) = CV/CN = converted / conserved for nature

We used the 2019 National Land Cover dataset (NLCD, Dewitz and U.S. Geological Survey 2019, Map 2.2) to understand patterns of current and historic conversion. NLCD 2019 represents the most comprehensive land cover database ever produced by the USGS and was specifically developed to meet the rapidly growing demand for land cover change data. NLCD 2019 now offers consistently remapped land cover for years 2001, 2011, and 2019. We used the datasets to identify cells (30-m) that were mapped as natural in 2001 but switched to developed or row crop by 2019.

Map 2.2. National Land Cover Dataset (NLCD) 2019.



We considered land that was natural in 2001 or 2011 and currently mapped as development, at any intensity, or row crop to indicate habitat loss to conversion. Although row crops are potentially restorable, we expect food will continue to be needed and the habitat permanently degraded by fragmentation, disruption by mechanical disturbances, introduction of cultivated species, and elevated levels of nitrogen, phosphorus, and pesticides.

Using the 2019 NLCD (Map 2.2) in combination with the Conserved Lands dataset, we tabulated for every cell when it was converted from natural and to what is was converted. We also tabulate if, and when, the cell came under conservation and the GAP status, fee, or easement type and owner of the land. These two datasets allow us to compare spatial trends in habitat loss against spatial trends in land conservation.

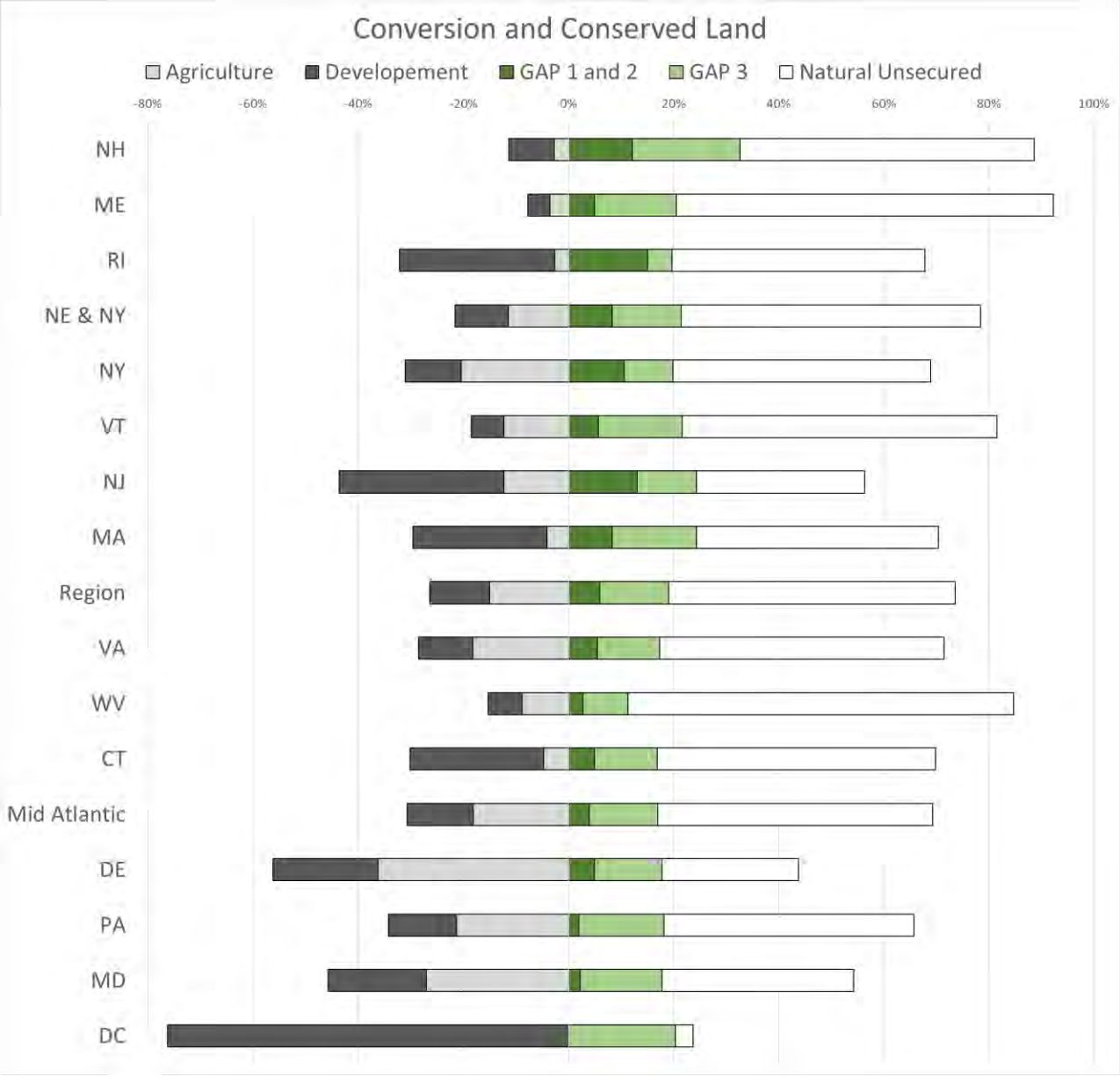
Results of our analysis show that, on average, land conservation has not offset habitat loss. For every acre of conservation land there is 1.4 acres of habitat conversion (CRI =1.4). Twenty-six percent of the land has been converted to development (11%) or agriculture (15%) compared to 19% conserved for nature (6%) or multiple uses (13%) (Figure 2.2, Table 3). Risk is slightly higher in the Mid Atlantic (CRI = 1.8) than in New England and New York where conversion equals conservation (CRI = 1.01). Maine, New Hampshire, and Vermont all have more land conserved than converted to development or agriculture.

The statistics in the previous paragraph include multiple-use lands. Focusing only on GAP1-2 land conserved for nature reveals a higher risk for the region (NRI = 4.1), with the Mid-Atlantic (NRI =7.8) having more risk than New England and New York (NRI = 2.6). New Hampshire is the only state that has more land conserved explicitly for nature than lost to conversion (NRI = 0.98).

Table 2.3. The amount of land converted and conserved by state, region, and GAP status.

		Development		Agriculture		GAP 1 & 2		GAP 3		Unsecured Natural		Total Secured		Total Converted			
		Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	NRI	CRI
New England and New York	NY	3,318,852	11%	6,319,981	20%	3,294,343	11%	2,875,551	9%	15,247,175	49%	6,169,894	20%	9,638,833	31%	2.93	1.56
	ME	880,376	4%	735,919	4%	1,032,797	5%	3,236,891	16%	14,938,998	72%	4,269,688	21%	1,616,295	8%	1.56	0.38
	NH	515,241	9%	158,550	3%	720,962	12%	1,215,293	20%	3,321,197	56%	1,936,255	33%	673,791	11%	0.93	0.35
	VT	377,695	6%	756,910	12%	348,963	6%	984,140	16%	3,685,387	60%	1,333,103	22%	1,134,605	18%	3.25	0.85
	MA	1,325,504	25%	213,882	4%	430,807	8%	836,789	16%	2,393,591	46%	1,267,596	24%	1,539,386	30%	3.57	1.21
	CT	809,279	25%	151,117	5%	156,401	5%	381,320	12%	1,685,330	53%	537,721	17%	960,396	30%	6.14	1.79
	RI	205,719	30%	18,490	3%	104,794	15%	32,819	5%	335,398	48%	137,613	20%	224,209	32%	2.14	1.63
	Total	7,432,664	10%	8,354,850	11%	6,089,067	8%	9,562,805	13%	41,607,075	57%	15,651,872	21%	15,787,514	22%	2.59	1.01
Mid Atlantic	PA	3,755,014	13%	6,162,355	21%	571,297	2%	4,696,905	16%	13,801,410	48%	5,268,202	18%	9,917,369	34%	17.36	1.88
	VA	2,630,070	10%	4,664,179	18%	1,396,981	5%	3,035,222	12%	13,889,844	54%	4,432,203	17%	7,294,249	28%	5.22	1.65
	WV	1,006,546	6%	1,370,085	9%	427,075	3%	1,333,222	9%	11,369,551	73%	1,760,297	11%	2,376,631	15%	5.56	1.35
	NJ	1,515,213	31%	596,429	12%	633,409	13%	547,855	11%	1,550,195	32%	1,181,264	24%	2,111,642	44%	3.33	1.79
	MD	1,187,892	19%	1,717,404	27%	140,329	2%	987,374	16%	2,318,378	37%	1,127,703	18%	2,905,296	46%	20.70	2.58
	DE	253,014	20%	458,649	36%	62,586	5%	162,873	13%	329,420	26%	225,459	18%	711,663	56%	11.37	3.16
	DC	30,477	76%	16	0%	1	0%	8,145	20%	1,349	3%	8,146	20%	30,493	76%	0.00	3.74
	Total	10,378,226	13%	14,969,118	18%	3,231,678	4%	10,771,594	13%	43,260,146	52%	14,003,272	17%	25,347,344	31%	7.84	1.81
Region Total		17,810,890	11%	23,323,968	15%	9,320,745	6%	20,334,399	13%	84,867,221	55%	29,655,144	19%	41,134,858	26%	4.41	1.39

Figure 2.2. Distribution of habitat conversion and land conservation by state, sub-region, and region. In this chart, each bar represents the total area of land in the geographic area. Land to the left of the center bar has been converted to development or agriculture; land to the right of the center bar remains unconverted. Unconverted land is apportioned by securement status and the percent unsecured.



Ownership and Designation

Ownership

According to our data, the 2022 conservation land network was owned by 10,088 different entities. Most fee-owned acres were held by state agencies (50%), followed by almost equal amounts of federal (25%) and private ownerships (21%). Private Non-Profits was the fastest growing sector and now accounts for over one million acres of fee owned land and over three million acres of conservation easements (Tables 4 & 5, Map 2.3), much of that acquired in the last 20 years. Land trusts, and other non-profit organizations, held the interest on most of the private easements, and reflect a growing involvement of private landowners in the long-term conservation of land (Figure 2.3).

Table 2.4. Conservation ownership. This table is organized by fee ownership types and shows both the average size of the ownership as well as the average tract or parcel size.

Organization Type	Total Acres	Number of owners	Average Acres per Owner	Max acres of Owner	Owner of Maximum	Average Tract Size	Max Tract Size
State	12,862,099	163	80,344	3,970,874	NYS Department of Environmental Conservation	206	283,137
Federal	6,349,244	27	236,890	4,424,552	USDA Forest Service	446	440,093
Local	1,427,995	3,575	400	182,871	New York City Department of Enviromental Protection	18	8,235
Private Non Profit	1,229,608	1,017	1,252	459,504	The Nature Conservancy	47	81,227
Private for Profit	335,751	336	721	4,997	Appalachian Power Company	146	4,997
District	21,748	69	312	6,356	Connecticut Metropolitan District Commission	24	1,772
Unknown	11,574					55	3,672
Tribal	155	1			Cheroenhaka Indian Tribal Heritage Foundation		
Grand total	22,238,174	5,188	53,320			135	117,591

Table 2.5. Conservation easements. This table is organized by conservation easement holder and shows both the average size of the easements as well as the average tract or parcel size.

CONSERVATION EASEMENT HOLDER					
Organization Type	Total Acres	Number of easement holders	Average Acres per Easement Holder	Max acres per Owner	Holder of Maximum
Private Non Profit	3,618,035	514	7,139	1,138,185	New England Forestry Foundation
State	3,139,308	78	43,435	1,223,602	NY Department of Environmental Conservation
Local	408,732	655	585	54,519	New York City Department of Enviromental Protection
Federal	210,917	13	16,990	72,791	USDA Natural Resource Conservation Service
Unknown	39,133				
District	845	7	22	327	Rockingham County Conservation District
Grand total	7,416,970	753	15,258		

Figure 2.3. The distribution of conservation easements. This chart shows the distribution of easements among types of interest holders. By area, most easements are held by private non-profit entities and state government. Local government has the largest number of individual tracts, followed by Private Non-Profit organizations.

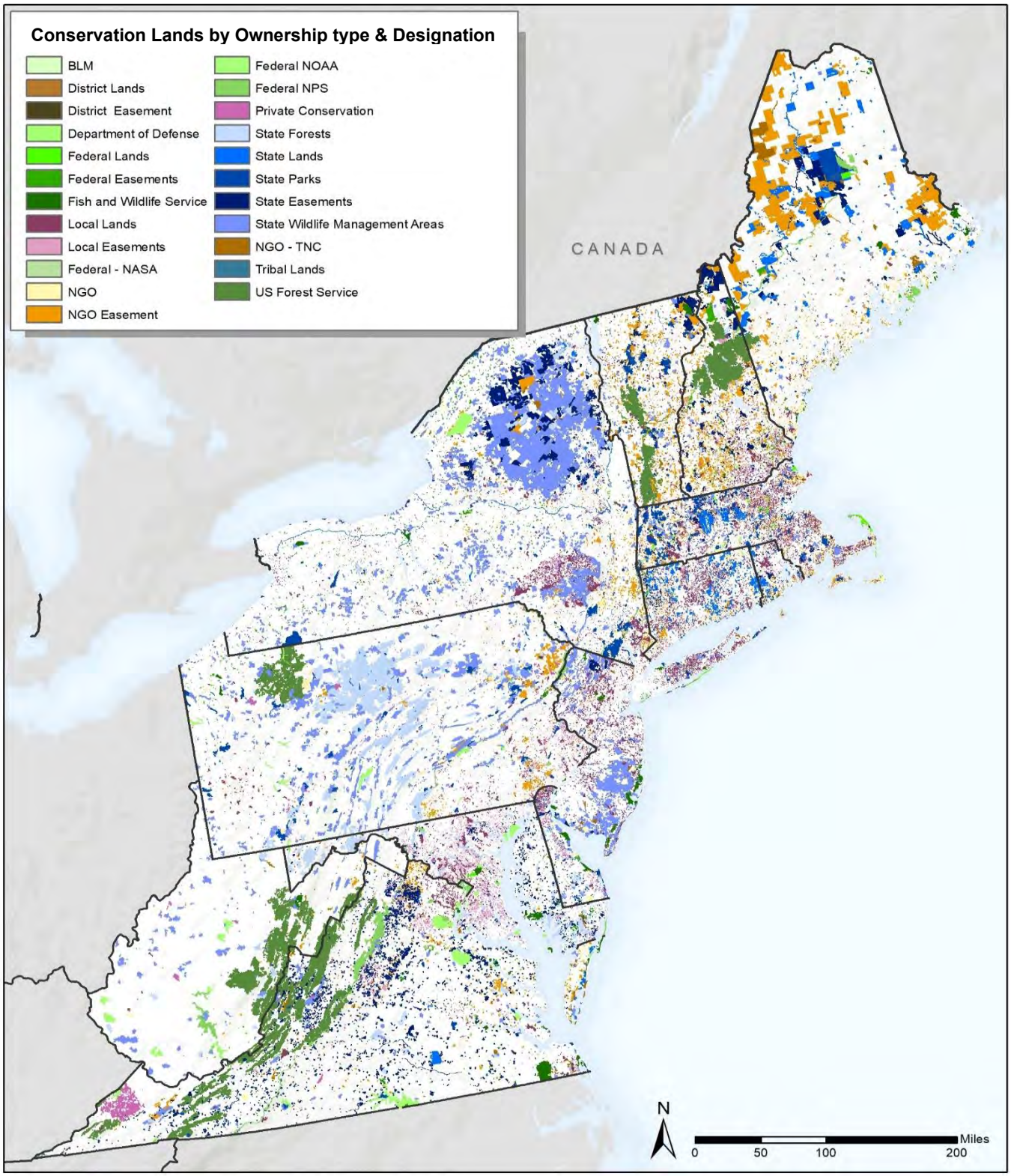


Table 2.6. Conservation lands by ownership/interest holder. State wildlife management areas comprise the conservation designation with the most land, but their intent and management varies greatly from state to state. Private Non-Profit organizations own the most land under easements, accounting for 15% of conservation land.

Fee Owner or Interest Holder	GAP 1 & 2	% G 1 - 2	GAP 3	% G3	GAP 1 - 3	% G1-3
State Wildlife Management Area	3,554,785	36.1%	3,526,989	17.3%	7,081,774	23.9%
US Forest Service	1,536,520	15.6%	2,881,848	14.2%	4,418,368	14.9%
Private Non-Profit Easement	513,765	5.2%	3,068,137	15.1%	3,581,902	12.1%
State Easement	174,304	1.8%	2,965,003	14.6%	3,139,308	10.6%
State Forest	454,068	4.6%	2,621,615	12.9%	3,075,683	10.4%
State Park	484,777	4.9%	1,009,305	5.0%	1,494,082	5.0%
Local Lands	112,560	1.1%	1,315,435	6.5%	1,427,995	4.8%
State Land	296,372	3.0%	953,211	4.7%	1,249,583	4.2%
Private Non-Profit	852,372	8.7%	377,236	1.9%	1,229,608	4.1%
National Park Service	575,520	5.8%	116,507	0.6%	692,027	2.3%
Department of Defense	7,937	0.1%	666,552	3.3%	674,489	2.3%
Fish and Wildlife Service	468,977	4.8%	7,157	0.0%	476,134	1.6%
Local Easement	20,478	0.2%	387,001	1.9%	407,479	1.4%
Private Conservation	395,317	4.0%	247,834	1.2%	335,751	1.1%
Federal Easement	94,535	1.0%	114,751	0.6%	209,285	0.7%
Federal Lands	288,249	2.9%	17,250	0.1%	81,355	0.3%
Easement Unknown Holder	17,836	0.2%	21,290	0.1%	39,126	0.1%
District Lands	404	0.0%	21,344	0.1%	21,748	0.1%
Unknown	2,556	0.0%	9,018	0.0%	11,574	0.0%
Federal - NASA	0	0.0%	6,283	0.0%	6,283	0.0%
District Easement	212	0.0%	633	0.0%	845	0.0%
BLM	519	0.0%	0	0.0%	519	0.0%
Tribal	155	0.0%	0	0.0%	155	0.0%
Federal - NOAA	310	0.0%	0	0.0%	69	0.0%
Grand Total	9,852,530		20,334,399		29,655,144	

Recent Conservation Trends

The key to tracking conservation status in the Northeast is accurate spatial data, and in the last 10 years, the TNC Conserved Land dataset has significantly improved, thanks to extensive contributions by state agency and TNC field office staff. The dataset is maintained by over 60 organizations, who are constantly making improvements to the data and creating a better database for tracking, managing, and accurately mapping conservation information.

The northeast region has seven states with the highest number of non-profit land conservation organizations in the country (PAD-US, 2021). This accounts for much conservation progress, but the large number of entities engaged in land conservation makes it particularly complex to track all the work.

Since our 2011 report (based on the 2009 dataset), the number of records grew from 136,000 to 260,000, reflecting both an increase in the number of non-profit and local conservation lands as well as detail in record keeping. Easements grew 30-fold from 2,400 to over 69,000 records, and the footprint of conservation land increased by over five million acres, raising the proportion of land in conservation from 16% to 19% of the region.

Although there was an apparent five-million-acre difference in the amount of conservation land from the 2009 to the 2022 dataset, we could only confirm that two million of those acres were due to new land acquisitions or easements. The other three million acres of land were missing from the 2009 dataset, but their "date conserved" attribute was empty and we strongly suspect they reflect error or missing data in the older dataset and not true additions (Table 2.7). Spot checking of the dataset supported this assumption. We investigated 10 large conservation parcels over 10,000 acres in this group, for example, West Canada Lake (est. 1972) in the Adirondacks, and found them to be public lands established long before 2009.

Table 2.7: Completeness of the "Year Conserved" field by number of tracts. The "No Date" columns indicate the number or percent of tracts missing date information.

State	No Date Conserved	% No Date Conserved	Before 2001	% Before 2001	Between 2001 and 2011	% Between 2001 and 2011	Between 2012 and 2022	%Between 2012 and 2022	Grand Total
MD	1,677	5.2%	5,526	17.3%	14,098	44.1%	10,664	33.4%	31,965
VT	1,321	13.6%	5,062	52.0%	1,548	15.9%	1,797	18.5%	9,728
RI	793	15.7%	2,927	57.9%	1,233	24.4%	105	2.1%	5,058
VA	2,061	18.1%	3,539	31.2%	3,650	32.1%	2,108	18.6%	11,358
PA	1,863	24.9%	2,838	37.9%	1,686	22.5%	1,105	14.7%	7,492
WV	267	30.4%	426	48.5%	147	16.7%	39	4.4%	879
CT	5,764	32.1%	9,744	54.3%	2198	12.2%	244	1.4%	17,950
MA	14,285	34.6%	16,396	39.8%	6,735	16.3%	3,828	9.3%	41,244
NH	4,790	37.7%	3,970	31.3%	3,039	23.9%	892	7.0%	12,691
ME	3,590	39.4%	3,162	34.7%	1,355	14.9%	1,015	11.1%	9,122
NJ	38,573	53.0%	18,844	25.9%	11,801	16.2%	3,527	4.8%	72,745
DC	453	55.3%	366	44.7%	0	0.0%	0	0.0%	819
NY	24,623	77.2%	3,351	10.5%	3,483	10.9%	425	1.3%	31,882
DE	7,366	91.7%	376	4.7%	233	2.9%	60	0.7%	8,035
Grand Total	107,426	0.4%	107,426	0.4%	51,206	0.2%	25,809	0.1%	29,655,144

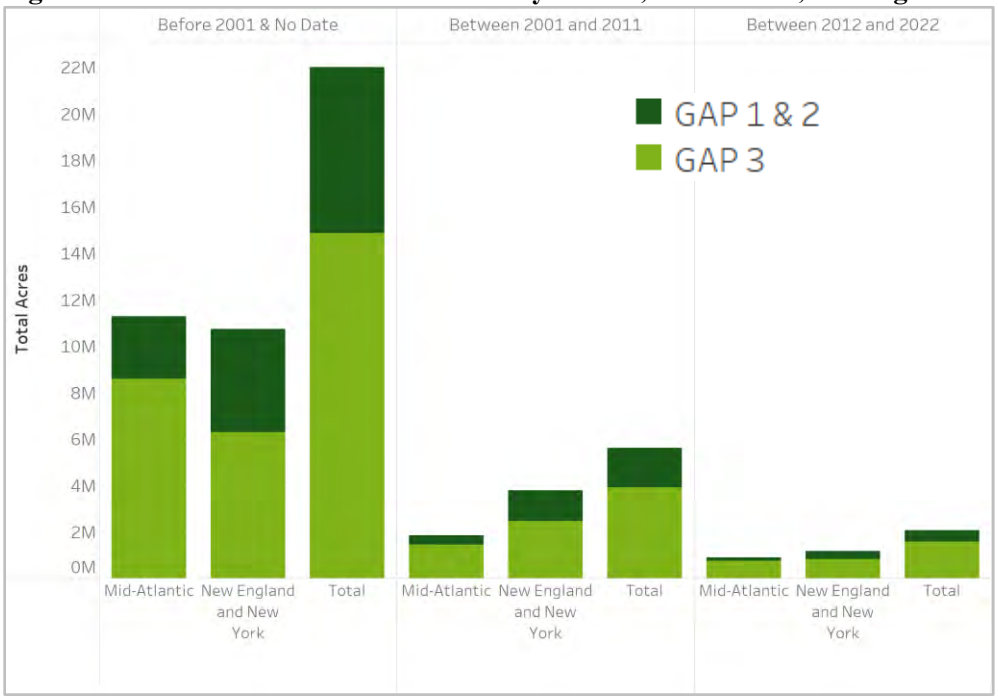
For the reasons described above, our analysis of new land conserved between 2012-2022 is based solely on the two million acres we could confirm (Table 2.8). This reflects a multi-year effort to get the "date conserved" field completed in the dataset by state data stewards. The effort was augmented by cross checking with the Conservation Almanac, PAD-US, NCED, phone calls to the steward or conservation organizations, and Google searches. Nevertheless, it is probably an underestimate of the actual acres as there is a wide variety of the completeness of the "date conserved" field across the region, with Maryland, Vermont, Maine, Rhode Island, Virginia, and Pennsylvania having the most complete records (Table 2.8).

Over the decade from 2011 to 2022, our results show that the collective efforts of over a hundred organizations and agencies **resulted in 2.1 million acres of new conservation land.** Easements accounted for 1.3 million acres and fee ownership for 780,000 acres (Table 2.8). Overall, this appeared to be slightly less conservation land than was acquired in the previous decade (Figure 2.4).

Table 2.8: Acres of Conservation Land by decade conserved. Due to missing data information as described in the text, we only counted recent acres (2012-2022) that we could confirm. Unknown dates were considered pre-2001.

State	Before 2001 (includes no Date)	% Before 2001 (includes no Date)	Between 2001 and 2011	% Between 2001 and 2011	Between 2012 and 2022	%Between 2012 and 2022	Grand Total	% of total State Area
ME	2,206,515	10.6%	1,316,898	6.3%	746,275	3.6%	4,269,688	20.5%
VA	3,024,917	11.8%	799,389	3.1%	607,896	2.4%	4,432,202	17.3%
PA	4,879,658	16.8%	214,636	0.7%	173,908	0.6%	5,268,202	18.2%
NH	1,367,566	23.1%	423,339	7.1%	145,350	2.5%	1,936,255	32.6%
MA	976,032	18.8%	185,698	3.6%	105,866	2.0%	1,267,596	24.4%
VT	1,098,007	17.8%	134,519	2.2%	100,577	1.6%	1,333,103	21.7%
NJ	980,230	20.2%	144693	3.0%	56342	1.2%	1,181,265	24.4%
NY	4,524,436	14.6%	1,591,628	5.1%	53,830	0.2%	6,169,894	19.9%
MD	470,578	7.4%	609,792	9.6%	47,333	0.7%	1,127,703	17.8%
WV	1,701,460	11.0%	47,437	0.3%	11,400	0.1%	1,760,297	11.4%
CT	433,675	13.6%	93,709	2.9%	10,337	0.3%	537,721	16.9%
RI	105,253	15.1%	26,198	3.8%	6,162	0.9%	137,613	19.7%
DE	200,882	15.9%	21,619	1.7%	2,958	0.2%	225,459	17.8%
DC	8,145	20.4%	0	0.0%	0	0.0%	8,145	20.4%
Grand Total	21,977,354	14.1%	5,609,555	3.6%	2,068,234	1.3%	29,655,144	19.1%

Figure 2.4. Amount of conservation land by decade, GAP status, and region.



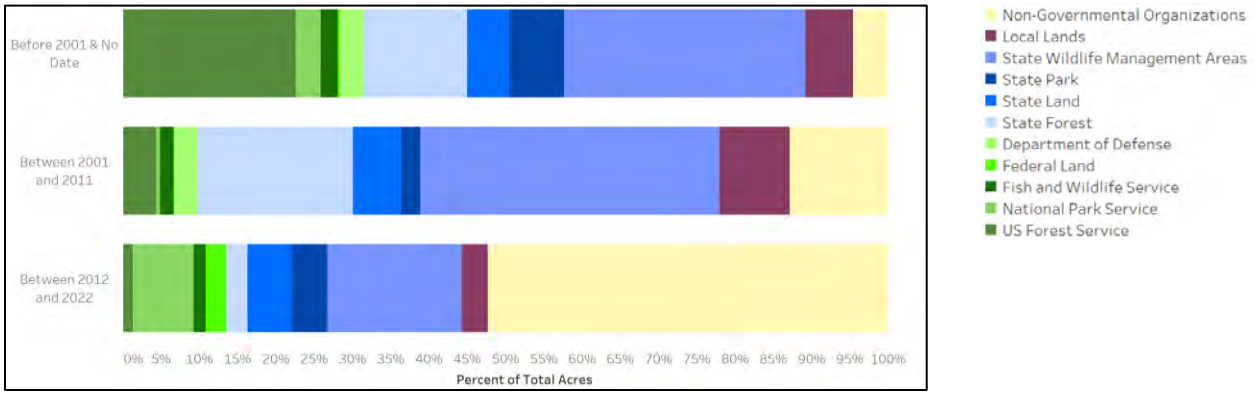
New conservation was achieved primarily by private NGOs and individuals (1.1 M ac), accounting for over half of the fee (406 K ac.) and easement acreage (738 K ac, Figure 2.5). Maine and Virginia had the largest increases in conservation land with both states adding over 600,000 acres (2% of each state). A list of the larger projects (Appendix 1) highlights major projects in many states including:

- Moosehead Forest Easement: 350,000 acres, Forest Society of Maine, ME
- Cumberland Forest (CF) Project: 154,576 acres, CF Highlands LLC (w The Nature Conservancy), VA
- Clarion Forest Junction: 25,591 acres, The Conservation Fund, PA
- Mahoosuc Gateway: 23,733 acres, NH DRED, NHDF, Conservation Fund, NH
- Elk Lake Conservation Easement: 20,440 acres, NY DEC, Adirondack Nature Conservancy, NY
- Woodbury Mountain Wilderness Preserve: 5,947 acres, Northeast Wilderness Trust, VT

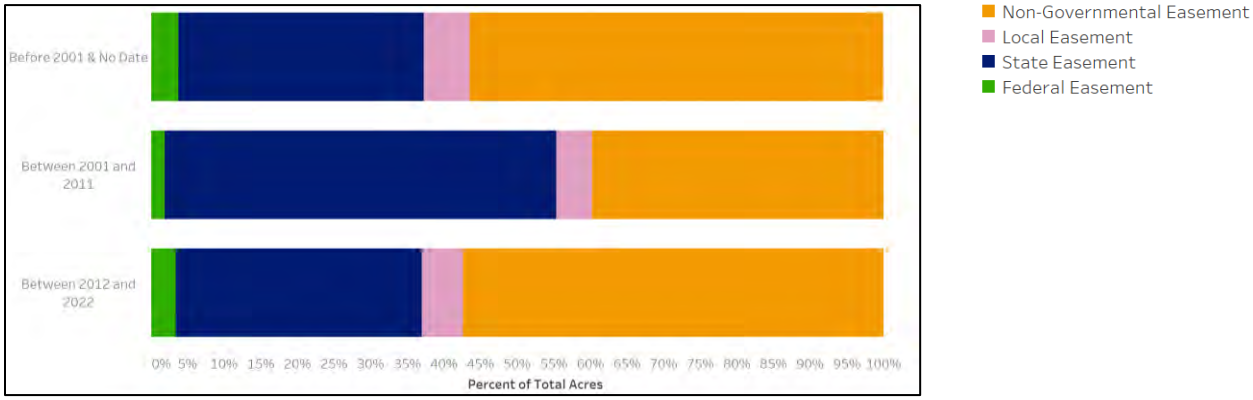
All these projects were completed with partnerships, often between state agencies and private organizations. The Cumberland Forest project formed a new organization to hold and manage the land.

Figure 2.5: Date conserved by fee organization or easement holder. The charts show the relative distribution of fee and easement land by type of organization. Colors of the organizations match Map 2.3.

FEE



EASEMENTS



There were also over 100,000 acres of new or expanded federal projects, and over 200,000 acres of state projects (Table 2.9 and Appendix 2.1), often involving private non-profit organizations as fund raisers, easement holders, or initial buyers who later transferred the properties to the state. Federal highlights include:

- Katahdin Woods and Water National Monument: 88,104 acres, US National Park Service, ME
- Umbagog National Wildlife Refuge: 7,500 acres, USFW, as part of the Androscoggin Headwaters Fee and Easements project. 28,372 acres, NH DRED, NHFG, Trust for Public Land, NH
- Cherry Valley National Wildlife Refuge: 4,213 acres, USFW, PA
- George Washington and Jefferson National Forests: 4,592 acres, USFS, Open Space Institute, Chesapeake Conservancy, VA

Harder to track, but equally important, were small expansions to many existing lands and refuges. For example, there were smaller expansions at Forsythe NWR, Cape May NWR, Great Dismal Swamp NWR, Rappahannock River Valley NWR, and Canaan Valley NWR. Funding for the NWR projects include Migratory Bird Conservation Fund Returns and Land and Water Conservation Fund Returns.

Table 2.9: Conservation fee and easements by decade, ownership type, and GAP status.

Conservation Projects	Pre 2001			2001-2011			2012-2022			Total
Fee Owner	GAP 1 & 2	GAP 3	Total Conserved	GAP 1 & 2	GAP 3	Total Conserved	GAP 1 & 2	GAP 3	Total Conserved	All Years
FEE PROTECTION - FEE OWNER										
Bureau of Land Management (BLM)	0	0	0	519	0	519	0	0	0	519
Department of Defense (DOD)	7902	593,574	601,476	36	72,978	73,014	0	0	0	674,490
Federal Lands (FED)	41,819	15,606	57,425	977	1,643	2,620	21,309	0	21,309	81,354
Fish and Wildlife Service (FWS)	414,617	7,012	421,629	42,217	138	42,355	12,143	7	12,150	476,134
National Aeronautics and Space Administration (NASA)	0	6,283	6,283	0	0	0	0	0	0	6,283
National Oceanic and Atmospheric Administration (NOAA)	69	0	69	0	0	0	0	0	0	69
National Park Service (NPS)	509,246	108,951	618,197	6,914	5,024	11,938	59,359	2,532	61,891	692,026
US Forest Service (USFS)	1,465,652	2,838,684	4,304,336	70,312	33,701	104,013	555	9,463	10,018	4,418,367
Tribal (TRIB)	0	0	0	0	0	0	155	0	155	155
State Forests (SF)	338,002	2,229,977	2,567,979	113,533	372,472	486,005	2,383	18,879	21,262	3,075,246
State Lands (SL)	268,857	781,987	1,050,844	23,002	129,824	152,826	4,945	40,259	45,204	1,248,874
State Parks (SP)	438,215	923,239	1,361,454	31,162	27,460	58,622	15,397	20,731	36,128	1,456,204
State Wildlife Management Areas (SWMA)	2,686,652	3,321,641	6,008,293	796,162	140,567	936,729	71,971	64,781	136,752	7,081,774
Local Lands (LOC)	76,806	1,104,559	1,181,365	31,517	188,587	220,104	4,238	22,288	26,526	1,427,995
District Land (DIST)	97	20,285	20,382		850	850	307	209	516	21,748
Private Protection (PVT)	46,515	48,803	95,318	23,402	23,939	47,341	18,000	20,516	38516	181,175
Non-governmental Organizations (NGO)	499,832	256,078	755,910	208,392	51,860	260,252	144,148	223,874	368,022	1,384,184
Unknown (UNK)	1,698	2,151	3,849	231	6,593	6,824	627	274	901	11,574
Total Acres Fee	6,795,981	12,258,831	19,054,812	1,348,375	1,055,637	2,404,012	355,537	423,814	779,351	22,238,174
EASEMENT PROTECTION - EASEMENT HOLDER										
Federal Easement	44,530	62,952	107,482	34,051	25,710	59,761	16,034	27,639	43,673	210,916
State Easement	80,887	911,759	992,646	67,724	1,646,095	1,713,819	25,693	407,149	432,842	3,139,307
Local Easement	8,103	171,814	179,917	7,457	149,070	156,527	4,752	67,537	72,289	408,733
District Easement	83	343	426	123	280	403	6	10	16	845
Non-governmental Organizations Easement	182,807	1,427,378	1,610,185	242,087	1,027,727	1,269,814	88,679	649,357	738,036	3,618,035
Unknown	14,752	17,135	31,887	1,623	3,596	5,219	1,461	566	2,027	39,133
Total Acres Easement	331,162	2,591,381	2,922,543	353,065	2,852,478	3,205,543	136,625	1,152,258	1,288,883	7,416,969

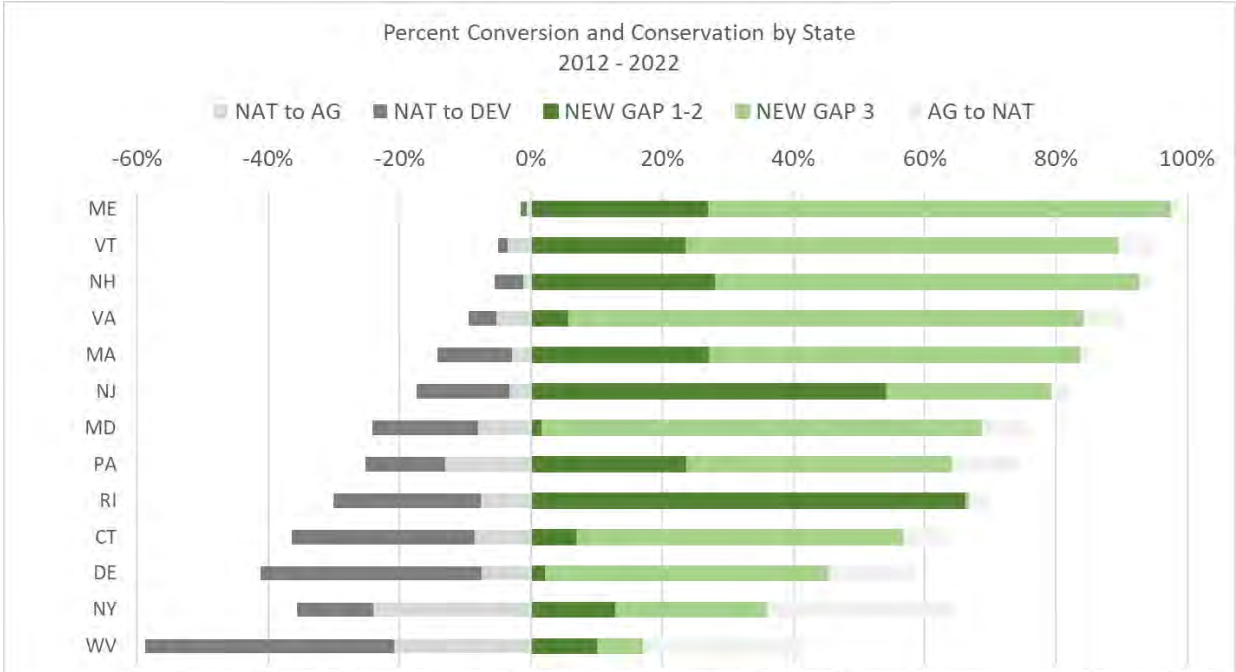
Habitat Loss versus Land Conservation (2012-2022)

To sustain the region's wildlife and plants, the big questions are whether the new conservation lands are in critical places that represent the full spectrum of biodiversity, and whether the amount of conservation land is enough to offset habitat loss. The first question is explored in detail in this report's chapters on forest, wetland, natural communities, rivers, and lakes. Here were explore the latter question of land conversion versus conservation progress.

Using the methods and terminology described previously, we calculated the conservation risk index (CRI) and nature risk index (NRI) for the last decade (2012-2022) to determine if the extent of conservation was offsetting the extent of habitat loss due to conversion.

Results show that over the last decade **land conservation surpassed habitat loss by a ratio of 6 to 1.** For every one acre of land conserved, 0.15 acres of land were converted to agriculture or development (CRI=0.15). This was true across every state except West Virginia, and for Maine, New Hampshire, and Vermont the amount of conservation was over 15 times higher than conversion (Figure 2.6).

Figure 2.6. Percent habitat conversion versus land conservation by state. The table shows the percent of historic and current acres converted, the percent secured as GAP 1-3 or protected as GAP 1-2, and the ratio of conversion to securement (CRI) or conversion to protection (NRI).

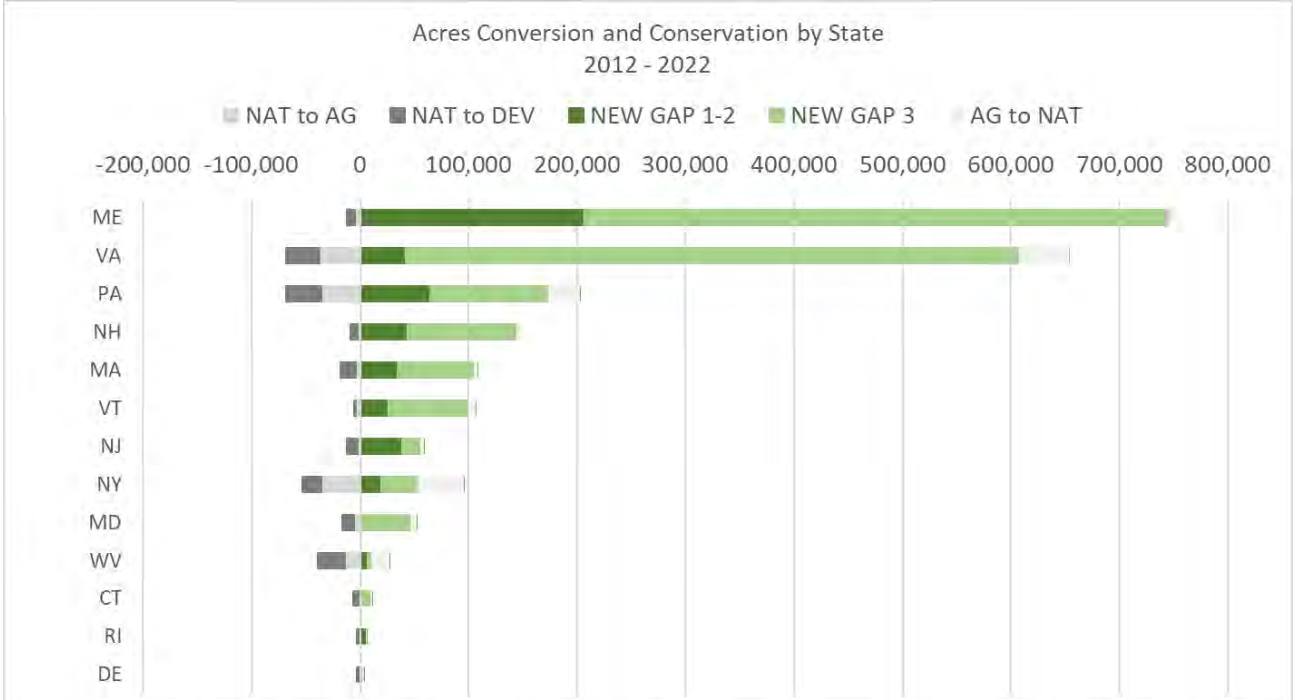


	WV	NY	DE	CT	RI	PA	MD	NJ	MA	VA	NH	VT	ME
NAT to AG	-13,725	-35,772	-487	-1,553	-696	-35,217	-5,478	-2,283	-3,563	-37,604	-1,720	-3,915	-4,250
NAT to DEV	-25,031	-17,267	-2,182	-5,071	-2,068	-32,969	-11,069	-10,078	-14,325	-30,626	-6,903	-1,618	-7,475
NEW GAP 1-2	6,723	19,392	149	1,294	6,110	64,640	1,255	38,527	34,435	42,131	44,064	26,597	206,929
NEW GAP 3	4,677	34,455	2,808	9,043	52	109,379	46,089	17,822	71,444	565,807	101,286	73,981	539,414
AG to NAT	15,882	42,117	848	1,221	282	28,550	4,824	2,292	2,524	45,314	2,602	6,078	6,385
CRI	3.40	0.99	0.90	0.64	0.45	0.39	0.35	0.22	0.17	0.11	0.06	0.06	0.02
NRI	5.76	2.74	17.86	5.12	0.45	1.05	13.19	0.32	0.52	1.62	0.20	0.21	0.06

The amount of GAP1-2 conservation for nature was considerably less than GAP 3 multiple-use conservation land, but six states had more conservation for nature than habitat conversion (NRI <1): Maine, New Hampshire, Vermont, New Jersey, Rhode Island, and Massachusetts. Two states, Pennsylvania and Virginia, had roughly equal amounts (Figure 2.7). This trend indicates substantial progress for conservation.

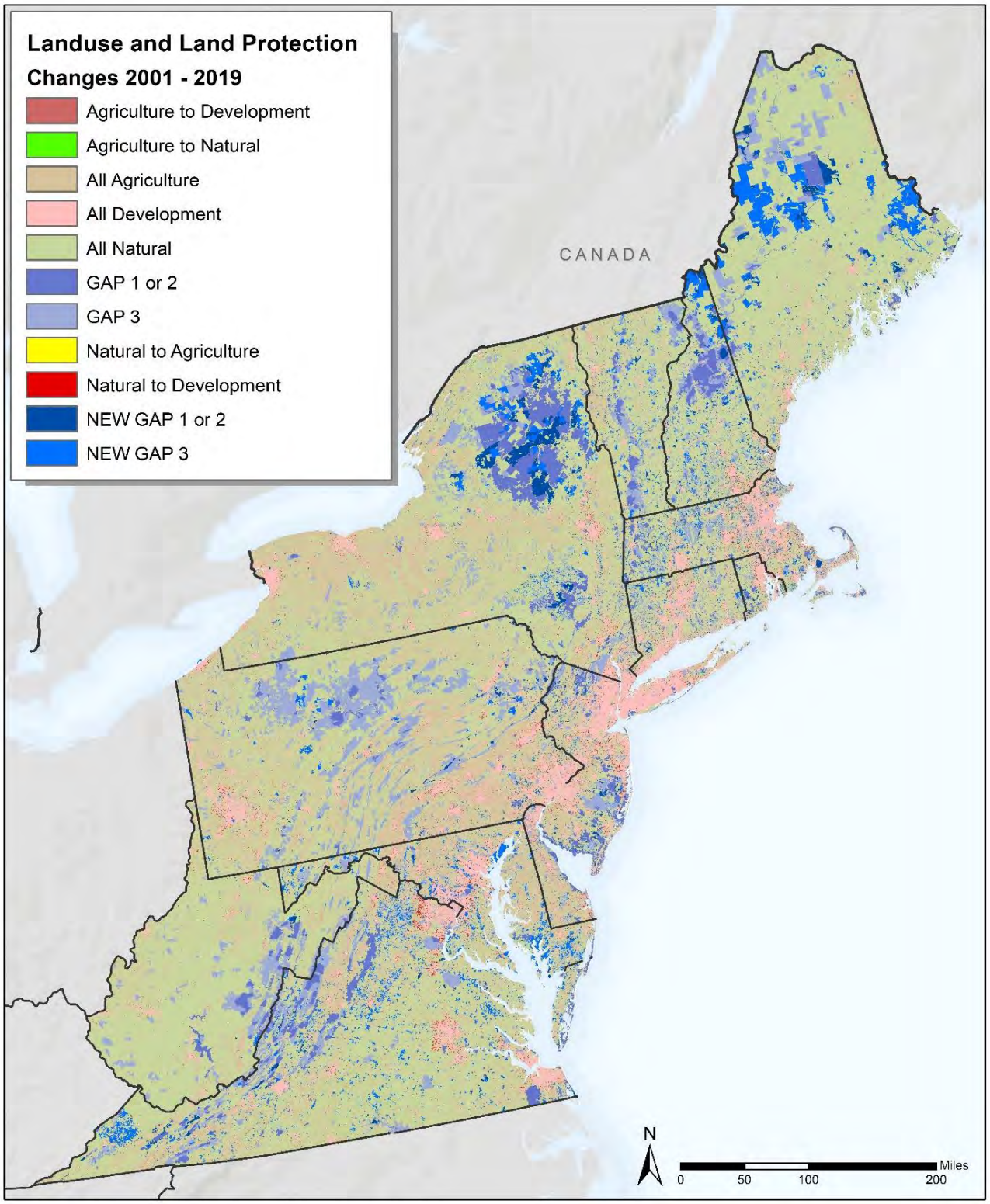
States differ dramatically in size, and the actual amount of conservation and conversion is closely related to the size of the state, with Maine, Virginia, and Pennsylvania being the three states with the largest amount of new conservation land established in the last decade (Figure 2.7). The acreage reflects the large private-public projects discussed above and listed with more detail in Appendix 2.1, and visible at the scale of the whole region (Map 2.4)

Figure 2.7. Acres of Habitat Conversion and Conservation by State. The table shows the percent of historic and current acres converted, the percent secured as GAP 1-3 or protected as GAP 1-2, and the ratio of conversion to securement (CRI) or conversion to protection (NRI).



	DE	RI	CT	WV	MD	NY	NJ	VT	MA	NH	PA	VA	ME
NAT to AG	-487	-696	-1,553	-13,725	-5,478	-35,772	-2,283	-3,915	-3,563	-1,720	-35,217	-37,604	-4,250
NAT to DEV	-2,182	-2,068	-5,071	-25,031	-11,069	-17,267	-10,078	-1,618	-14,325	-6,903	-32,969	-30,626	-7,475
NEW GAP 1-2	149	6,110	1,294	6,723	1,255	19,392	38,527	26,597	34,435	44,064	64,640	42,131	206,929
NEW GAP 3	2,808	52	9,043	4,677	46,089	34,455	17,822	73,981	71,444	101,286	109,379	565,807	539,414
AG to NAT	848	282	1,221	15,882	4,824	42,117	2,292	6,078	2,524	2,602	28,550	45,314	6,385
CRI	0.90	0.45	0.64	3.40	0.35	0.99	0.22	0.06	0.17	0.06	0.39	0.11	0.02
NRI	17.86	0.45	5.12	5.76	13.19	2.74	0.32	0.21	0.52	0.20	1.05	1.62	0.06

Map 2.4. Conservation progress and land use change between 2001 and 2019. Bright blue indicates new conservation land, while yellow and red indicate losses to conversion.



Chapter 2 References

Crist, P. J., B. Thompson, T. C. Edwards, C. J. Homer, and S. D. Bassett. 1998. Mapping and Categorizing Land Stewardship. A Handbook for Conducting Gap Analysis.

Hoekstra, J. M., Boucher, T.M., Ricketts, T.H., and C. Roberts. 2005. LETTERS: Confronting a biome crisis: Global disparities of habitat loss and protection. Ecology Letters **8**(1)**:**23-29.

Dewitz, J., and U.S. Geological Survey, 2021, National Land Cover Database (NLCD) 2019 Products (ver. 2.0, June 2021): U.S. Geological Survey data release, https://doi.org/10.5066/P9KZCM54.

The Nature Conservancy. 2022. Eastern U.S. Conservation Lands. Various scales. Compiled from multiple sources.

National Conservation Easement Database (NCED_06232022.gdb) https://www.conservationeasement.us/# The NCED is an initiative of the U.S. Endowment for Forestry and Communities.

U.S. Geological Survey (USGS) Gap Analysis Project (GAP), 2022, Protected Areas Database of the United States (PAD-US) 3.0: U.S. Geological Survey data release, https://doi.org/10.5066/P9Q9LQ4B.

Appendix 2.1. Highlights of Conservation Projects occurring between 2012-2022 in the Northeast

The Northeast has made significant progress on conservation over the last 10 years. Over two million acres of conservation land is verified new conservation. Below is a summary of large conservation projects that have been accomplished since 2011.

Non-Governmental Organization Fee

Over 1,380,000 acres of fee-based conservation have been added to the conservation lands dataset since 2011. The dataset has over 287 different non-governmental organizations owning land since 2011. The largest fee owners include The Nature Conservancy, The Conservation fund, Northeast Wilderness Trust, and New England Forestry Foundation, all owning over 10,000 acres since 2011.

Non-Governmental Easements

Over 3,600,000 acres of easements were added to the conservation lands dataset since 2011. The dataset shows over 500 different non-governmental easement holders. New England Forestry Foundation, Forest Society of Maine, The Nature Conservancy, and Vermont Land Trust all have over 100,000 acres of easements since 2011.

Conservation projects over 5,000 acres

The following projects are conservation projects in the region that are over 5,000 acres:

Moosehead Forest Easement:

Easement Holder: Forest Society of Maine
Partners: Forest Society of Maine (FSM), The Nature Conservancy, and the Appalachian Mountain Club
GIS Acres: 357,216
Year: 2019
State: Maine

The Moosehead Region Conservation Easement is the result of a Maine state-approved concept plan for Plum Creek Timber Company's lands around Moosehead Lake and a partnership effort between Forest Society of Maine (FSM), The Nature Conservancy, and the Appalachian Mountain Club. This is the largest conservation easement held by FSM and one of the largest nationally. The easement lands are near 20 existing state-owned conservation properties on and around Moosehead Lake, creating one of the largest groupings of recreational lands in the nation. This network of conserved lands provides remarkable opportunities for nearby communities to grow their natural resource-based economies, including tourism.

Cumberlands Forest Highlands:

Fee Owner: CF Highlands LLC (The Nature Conservancy)
GIS Acres: 154,576
Year: 2019
State: Virginia
At 253,000 acres, the Cumberland Forest Project, one of TNC's largest-ever conservation efforts in the eastern United States, protects sweeping forest landscapes across two parcels, one in Southwest Virginia

and one along the Kentucky and Tennessee border. Safeguarding this vast stretch of forest tackles climate change on two fronts: by storing millions of tons of carbon dioxide and by connecting a migratory corridor that scientists believe could be one of North America's most important "escape routes" as plant and animal species shift their ranges to cooler climates.

Androscoggin Headwaters-:

Androscoggin Easement Holder: NH Department of Resources & Economic Development
Umbagog National Wildlife Refuge: Fee Owner: US Fish and Wildlife Service
Greenough Ponds Wildlife Management Area: Fee Owner: NH Fish and Game Department
Partner: Trust for Public Land
GIS Acres: 28,372
Year: 2014
State: New Hampshire
The jewels of the Androscoggin Headwaters property are Greenough Pond and Little Greenough Pond, two of only three ponds in New Hampshire that sustain native, non-stocked brook trout populations. Development around these two ponds would have degraded some of the best cold-water fisheries in the eastern United States. The Trust for Public Land and partners obtained $16.7 million from federal, state and private sources to conserve this property. Approximately 7,500 acres was added to the Umbagog National Wildlife Refuge and 934 acres was conveyed to New Hampshire Department of Fish and Game for fisheries conservation. The remaining 23,000 acres of productive forestland are protected by a state-held conservation easement that allows for continued sustainable timber production.

Reed Forest:

Fee Owner: The Conservation Fund
Interest Holder: Forest Society of Maine
Partners: The Conservation Fund, Forest Society of Maine, Apple
GIS Acres: 32,462
Year: 2016
State: Maine
In November 2016, with support from Apple, The Conservation Fund donated a conservation easement at Reed to the Forest Society of Maine.

Clarion Forest Junction:

Fee Owner: The Conservation Fund
GIS Acres: 25,591
Year: 2018
State: Pennsylvania
The Conservation Fund is stepping up to quickly acquire large, threatened working forests across the country, including in Pennsylvania, where it recently acquired 32,598 acres of sustainable timberland surrounding the city of Johnsonburg. Located within the "Pennsylvania Wilds" region, the property provides a bridge between Pennsylvania Game Commission lands and the Allegheny National Forest. The Conservation Fund's purchase will maintain clean water and productive fishing streams, securing the

confluence of the East and West branches of the Clarion River and 100 miles of high-quality cold water fisheries, six miles of which hold the state's highest designation of Exceptional Value.

Mahoosuc Gateway:

Interest Holder: NH Department of Natural Resources and Economic Development
GIS Acres: 23,733
Year: 2018
State: New Hampshire
A private-public partnership was formed between the New Hampshire Division of Forests and The Conservation Fund to secure a 24,000-acre landscape of working forestland in Coos County near the Appalachian National Scenic Trail in the Mahoosuc Mountains.

Elk Lake Conservation Easement:

Easement Holder: NY Department of Environmental Conservation
GIS Acres: 20,440
Year: 2012
State: New York
In 2013, The Nature Conservancy announced that a private landowner had donated a conservation easement protecting all 12,000 acres around Elk Lake.

Fish River Chain of Lakes:

Interest Holder: Forest Society of Maine
Partners: The Conservation Fund, Forest Society of Maine, Apple
GIS Acres: 16,921
Year: 2021
State: Maine
The Fish River Conservation Easement conserves permanent working forestland on nearly 17,000 acres adjacent to Mud Lake, Cross Lake, Carry Pond, Little California Pond, and Square Lake in Aroostook County. The easement ensures unique natural habitats are conserved and wildlife habitat is maintained so that these lands can continue to be sustainably managed forests and creates a permanent right of pedestrian public access across these lands. These lakes are popular with fishermen, boaters, and other recreationists. The Fish River Conservation Easement was developed during a public process as part of the Fish River Chain of Lakes Concept Plan developed by Irving Woodlands and approved in late 2019 by the Land Use Planning Commission (LUPC).

Grafton Forest:

Fee Owner: Northeast Wilderness Trust
Easement Holder: Forest Society of Maine
GIS Acres: 15,198 easement, 5,947 Fee
Year: 2022
State: Maine
The Grafton Forest Project ensures a legacy of wildness in Western Maine. These mountains, also known as the Mountains of the Dawn in honor of the Wabanaki of Maine, or the People of the Dawnland, are

some of the first mountains to greet the rising sun as day breaks over this continent. The Western Maine Mountains are of high conservation importance, and the Wilderness Trust has turned its attention to protecting more land in this eco-region in recent years. Grafton Forest is a keystone area linking a vast public Ecological Preserve and a 15,000-acre, well-managed woodland conserved by The Forest Society of Maine. From the Preserve, a few days' hike north on the A.T. brings one to the outskirts of Northeast Wilderness Trust's Lone Mountain and Redington Wilderness Sanctuaries, which cumulatively protect 4,455 forever-wild acres near Bigelow Preserve.

West Grand Lake:

Fee Owner: Downeast Lakes Land Trust
Easement Holder: Maine Bureau of Parks and Land
GIS Acres: 14,819
Year: 2012
State: Maine
With the help of funding from the Land for Maine's Future program, the Maine Department of Agriculture, Conservation, and Forestry purchased a conservation easement on 21,870 acres of forestland. It was aided by the Downeast Lakes Land Trust, who went on to purchase the parcel in 2016 and convert it into a community forest. With charming lakes, pristine wooded areas, diverse wildlife, and bountiful recreational opportunities, the West Grand Lake Forest offers excellent examples of so much that makes Maine's nature extraordinary. It is located within a network of more than 1.4 million acres of preserved land that extends all the way into Canada. It shares a border with Farm Cove Community Forest, and the two preserves combine to form the largest community forest in the United States.

Spring River Preserve:

Fee Owner: The Nature Conservancy
GIS Acres: 13,455
Year: 2021
State: Maine
This 13,500-acre property in Downeast Maine was protected in 2021 by The Nature Conservancy. Conservation of this property will help maintain a forested connection between the Downeast coast and Maine's north woods, protecting habitat for wide-ranging wildlife and allowing species to move in response to a changing climate. The property includes 3.75 miles of shoreline on Narraguagus Lake, nearly completing conservation of the shoreline of the headwater lake for Spring River, as well as two miles of frontage on the north side of Spring River, seven miles of frontage on the West Branch of the Narraguagus River, and 46 miles of interior tributary streams. This land is important as a buffer for high-value aquatic habitat that that supports native brook trout fisheries and contributes to important Atlantic salmon habitat.

Crooked River Headwaters:

Interest Holder: Mahoosuc Land Trust
GIS Acres: 12,267
Year: 2021
State: Maine

A coalition of conservation-minded groups, federal agencies, and private landowners permanently protected 12,000 acres of forestland in Oxford County with a conservation easement. More than half of the lands filter water into Sebago Lake, the public drinking water supply for much of southern Maine. The project is considered a significant milestone to protect water quality, wildlife, and recreation.

Crocker Mountain:

Fee: Maine Bureau of Parks and Lands
Partner: Trust for Public Land
GIS Acres: 11,888
Year: 2013
State: Maine
Protected in 2013, 12,046-acre Crocker Mountain includes three of Maine's tallest mountains and some of the best opportunities for high mountain recreation including a 10-mile segment of the Appalachian Trail. Now part of the State of Maine's system of public reserve lands, the property will be open to hiking, hunting, fishing, and snowmobiling. The intact subalpine forest of Crocker's peaks also holds incredible ecological importance. Picturesque glacial cirques capture the eye, high elevation areas are home to the Northeast's most imperiled songbird, the Bicknells Thrush, and the cold-water streams host the endangered Roaring Brook Mayfly. The protection of Crocker Mountain is the latest in a notable list of conservation investments in Maine's Northern Forest by the federal Forest Legacy Program, Land for Maine's Future Program, private foundations, and individual donors. It is also a cornerstone success in a pattern of landscape conservation that links the Mahoosuc Mountains and Maine's High Peaks under the nationally recognized banner of the White Mountains to Moosehead Lake Initiative.

Boundary Mountains Preserve:

Fee Owner: The Nature Conservancy
GIS Acres: 9,527
Year: 2020
State: Maine
Boundary Mountains Preserve, at almost 10,000 acres protected by The Nature Conservancy, is an important link in a large swath of contiguous forest located adjacent to over 22,000 acres of public lands in Quebec. The preserve extends a corridor of permanently conserved lands northward to a total of over 260,000 acres, representing a key link in a major pathway of ecological connection from the White Mountains in New Hampshire through the western Maine Mountains and Quebec borderlands and beyond. The preserve includes a healthy, mature mountain forest, featuring 3,648-foot Caribou Mountain, 3,333-foot Merrill Mountain, and a dozen other peaks over 2,700 feet in elevation. It is important headwater habitat for the Kennebec River as well as headwater streams that feed into the nearby Moose River, providing great habitat for wild brook trout.

DeHart Property:

Fee Owner: Capital Region Water
Interest Holder: The Nature Conservancy
GIS Acres: 8,193
Year: 2016

State: Pennsylvania
In 2016, Capital Region Water's Board of Directors approved an agreement to conserve its 8,200-acre DeHart Property in Dauphin County by easement in partnership with The Ward Burton Wildlife Foundation, The Nature Conservancy, and Fort Indiantown Gap. The 8,200-acre DeHart Property located in northern Dauphin County is the primary source of drinking water for Capital Region Water's 60,000 plus customers. The DeHart Property includes the five-mile long and six-billion-gallon DeHart Reservoir and 7,500 acres of forestland. This pristine reservoir and forestland are the foundation to Capital Region Water's award-winning drinking water.

Sterling Run Conservation Easement:

Fee Owner: Pennsylvania Department of Conservation and Natural Resources
GIS Acres: 9,132
Year: 2018
State: Maine
Protected in 2018, the DCNR's Bureau of Forestry is applying a new approach to conserving forest land and expanding forest recreation opportunities in Pennsylvania. This new approach involves partnering with private landowners and employing a tool known as working forest conservation easements. The DCNR partnered with the Lyme Timber Company to conserve the first of these lands near Sterling Run, in Cameron County. This more than 9,000-acre tract is owned by an affiliate of The Lyme Timber Company, with DCNR holding a conservation easement for the public access and recreation rights as well as landowner requirements for conservation and sustainable forest management. Public access will be managed by the Bureau of Forestry as part of Elk State Forest.

USN Ursa Major:

Easement Holder: US Navy
Partner: Trust for Public Land
GIS Acres: 8,492
Year: 2020
State: Maine
Protecting this land ensured permanent public access in a part of Maine where many communities are looking for more places to get outside in all four seasons. This project also maintained one of the most scenic views from the Appalachian Trail, conserved an intact working forest, and protected habitat for the endangered Atlantic salmon and Bicknell's Thrush, a state species of concern. Through a unique partnership, the project also helped the Navy meet their military readiness goals by buffering the SERE School, a remote training facility.

Cold Stream Forest:

Fee Owner: Maine Bureau of Parks and Lands
Partner: Trust for Public Land
GIS Acres: 8,157
Year: 2016

State: Maine
The Trust for Public Land helped protect 8,000 acres known as Cold Stream Forest in 2016—a refuge for the wild native brook trout, threatened Canada lynx, and dwindling northern Maine deer herd that have attracted generations of hunters, naturalists, and fly fishermen. The trout pond populations on this property alone are larger than those found in Massachusetts, New Hampshire, and Vermont combined.

Gulf Hagas - White Cap:

Fee Owner: Maine Bureau of Parks and Lands
Partner: Forest Society of Maine
GIS Acres: 8,401
Year: 2016
State: Maine
This 10,000-acre property protected in 2016 by The Forest Society of Maine, the Gulf Hagas – Whitecap conserved lands maintain productive forestland to help forest products businesses; provide an important buffer to 11 miles of the Appalachian Trail corridor; preserve and enhance public access to numerous campsites, hiking trails, Gulf Hagas, and a segment of the popular Interconnected Trail System for snowmobiles; and protects Eastern brook trout habitat and supports Atlantic salmon restoration.

Leuthold Forest Preserve:

Fee Owner: The Nature Conservancy
Partner: Forest Society of Maine
GIS Acres: 6,566
Year: 2015
In 2015, there was a 6,500-acre addition to the Leuthhold Forest TNC preserve in Maine, which features a unique Fir-Heart Leaved Birch Alpine Forest and the fourth largest contiguous Spruce-Fir/Northern Hardwood Forest in Maine. The complete shorelines of seven ponds are also protected within the preserve. Among the wildlife species that thrive here are pine marten, gray jay, boreal chickadee, Blackburnian warbler, and blackpoll warbler.

Upper St John River Watershed:

Fee Owner: The Nature Conservancy
Partner: Forest Society of Maine
GIS Acres: 6,364
Year: 2014
This GAP 1 forest reserve owned by The Nature Conservancy, with an easement by the Forest Society of Maine in 2014, this property connects to the larger Upper St John River Forest in northwestern Maine.

Albany Water Board Conservation Easement:

Easement Holder: Mohawk Hudson Land Conservancy
GIS Acres: 6,343
Year: 2019
State: New York

The City of Albany's drinking water reservoirs are surrounded by about 5,000 acres of forest that work to filter surface and groundwater and improve water quality. To protect these lands, in 2019, the Albany Water Board joined The Nature Conservancy's Working Woodlands Program, a program that preserves forest land and generates revenue by marketing carbon credits to a voluntary carbon market. Through this program, the city will improve forest health, protect water resources, and create new revenue to maintain these benefits for people and nature into the future.

Redington Easement:

Easement Holder: US Department of the Navy, Maine Appalachian Trail Land Trust
GIS Acres: 6,335
Year: 2019
State: New York
Protected in 2018, this easement is co-held by the US Navy and Maine Appalachian Trail Land Trust.

East Grand Lake:

Fee Owner: Maine Bureau of Parks and Lands
Partner: The Conservation Fund, US Forest Service Forest Legacy
GIS Acres: 6,070
Year: 2016
State: Maine
In 2016, The Conservation Fund secured 7,486 acres of working forestland in the town of Orient. Located along the international border of eastern Maine and New Brunswick, Canada, the newly conserved land will continue to be sustainably harvested for timber while securing the largest white-tail deer wintering area in the region and protecting key waterfowl habitat along North Lake and Monument Brook, both of which are essential to the local recreation economy. Made possible in part with funding from the U.S. Forest Service's Forest Legacy Program, through the Land and Water Conservation Fund (LWCF), The Conservation Fund conveyed 5,992 acres and a conservation easement on 1,494 acres to the Maine Bureau of Parks and Lands in late March 2016.

Woodbury Mountain Wilderness Preserve:

Fee Owner: Northeast Wilderness Trust
GIS Acres: 5,947
Year: 2021
State: Vermont
This preserve, purchased in 2021 by the Northeast Wilderness Trust, is the largest non-governmental wilderness area in the state of Vermont. Woodbury Mountain Wilderness Preserve includes headwater streams of the Lamoille and Winooski Rivers. It protects regional wildlife connections, and includes stunning northern hardwood forests, a diversity of wetlands, and 39 miles of headwater streams.

Orbeton Stream:

Easement Holder: Maine Bureau of Parks and Lands
GIS Acres: 5,778
Year: 2012

State: Maine
The Orbeton Stream conservation easement was completed in 2014 by a coalition of partners that included The Trust for Public Land, Maine Appalachian Trail Land Trust, High Peaks Alliance, and others. The Land for Maine's Future program allocated $150,000 to the project and other funding came from the Open Space Institute, Wildlife Conservation Society, Fields Pond Foundation, Hopwood Charitable Trust, John Sage Foundation, and many private donors. The easement is held by the Maine Bureau of Parks and Lands, over land owned by Linkletter Timberlands, LLC. The land contains 5,495 acres of working forest with trail access for both motorized and non-motorized activities. The Appalachian Trail runs along the western edge of the property and the Orbeton Stream, which is the site of Atlantic Salmon breeding grounds and some spectacular waterfalls, runs through the middle of the property.

Seboeis:

Fee Owner: Maine Bureau of Parks and Lands
Partner: Trust for Public Land
GIS Acres: 5,749
Year: 2012
State: Maine
The 5,741-acre Lake View Plantation parcel was added in 2012 to the roughly 15,600-acre Seboeis Public Reserved Lands Unit, which is managed by the Maine Bureau of Parks and Lands for timber harvesting, outdoor recreation, and wildlife. The Trust for Public Land, a national land conservation organization, worked with the state to arrange the acquisition from Bigelow Timber Corp. of Madison.

Bald Eagle Mountains:

Easement Holder: The Nature Conservancy
GIS Acres: 5,296
Year: 2013
State: Pennsylvania
In 2013, Lock Haven City in Pennsylvania worked with The Nature Conservancy to protect 5,200 acres in a conservation easement. Lock Haven City Authority, as a partner in The Nature Conservancy's Working Woodlands Program, agreed to forever protect and sustainably manage its forest and freshwater resources.

George Washington and Jefferson National Forests:

Fee Owner: US Forest Service
Partners: The Open Space Institute, and the Chesapeake Conservancy
GIS Acres: 4,592 (in total 7676 acres protected over the last 10 years in George Washington and Jefferson National Forests)
Year: 2019
State: Virginia
In 2019, the US Forest Service, the Open Space Institute, and the Chesapeake Conservancy announced a Land and Water Conservation Fund success in protecting a significant property within the George Washington and Jefferson National Forests. The purchase of the 4,664.5-acre property in Botetourt County, Virginia will preserve a local historic asset, enhance recreation access, and protect the water

quality of Craig Creek, a tributary to the James River and the Chesapeake Bay. The property is one of the largest tracts to be acquired for conservation purposes in Virginia in decades.

Charlotte State Forest:

Fee Owner: VA Department of Forestry
GIS Acres: 5003
Year: 2020 and 2021
State: VA
The Charlotte State Forest is 5,005 acres (2,531 acres acquired in late 2020 as phase 1 and 2,474 acres acquired in 2021 as phase 2) in Charlotte County. It is managed for sustainable timber production, demonstration of scientific forest management, applied forest research, diverse wildlife habitat, watershed protection, biological diversity, and passive outdoor recreation.

New Federal National Monument:

Katahdin Woods and Waters National Monument:

Fee Owner: US National Park Service / US Department of the Interior
GIS Acres: 88,104
Year: 2016
State: Maine
The 413th national park, Katahdin Woods and Waters, is part of Maine's famed North Woods, offering recreation opportunities for all. Comprised of 87,500 acres in Penobscot County, Maine, the Katahdin region is a popular destination for outdoor recreation and home to a wide diversity of wildlife, and contains spectacular mountains, important historical resources, and areas of great cultural significance. The area contains opportunities for hiking, camping, mountain biking, fishing, hunting, and snowmobiling. These uses are fully protected and enhanced under the President's national monument designation signed on August 24, 2016.

National Wildlife Refuges:

Over the last 10 years, more than 13,542 acres were added to the National Wildlife Refuges. The largest addition was to Umbagog National Wildlife Refuge (4,500 Acres) as a part of the Androscoggin Headwaters Fee and Easements project. The other large acquisition was Cherry Valley National Wildlife Refuge in Pennsylvania (4,213 Acres). Other smaller acquisitions include Forsythe NWR, Cape May NWR, Great Dismal Swamp NWR, Rappahannock River Valley NWR, and Canaan Valley NWR. Funding for the NWR acquisitions and easements include Migratory Bird Conservation Fund Returns and Land and Water Conservation Fund Returns.

State Easement Programs:

Several states have coordinated easement acquisition programs that we were able to identify in the database. These coordinated easement programs protected around 330,000 acres in the region. The largest of these programs is Virginia Outdoors Foundation with 235,510 acres in easements. Established by the Virginia General Assembly in 1997 and administered by the Virginia Outdoors Foundation (VOF), the Open-Space Lands Preservation Trust Fund (PTF) provides grants for acquisitions, easements, rights of way, and other methods of protecting open space for farming, forestry, recreation, wildlife, water quality,

and more. They currently have 1.8 million in funding available for the second half of 2023. Virginia established Land Preservation Tax Credits in 2000 to encourage private landowners to limit development of rural open spaces and keep the land available for farming, forestry, recreation, and other traditional rural uses. About 83% of all the land that VOF has protected since it was established in 1966 has been protected since 2000. Maryland's Forest Conservation Act Easements have protected 21,909 Acres since 2011. Massachusetts has several state easement programs which include easements held by DCR Parks and Rec, DCR Division of Water Supply Protection WPR easements, and MA Department of Fish and Game.

State Fee Programs:

Mass Division of Fisheries and Wildlife: actively protects lands. In FY 2022 they completed 11 projects and protected 937 acres. These projects were completed using bond funds, Land Stamp funds, and cooperative partnerships with land trusts.

PA State Wildlife Management Additions (29,000 acres). Some examples of new State Game Land Acquisition include State Game Land 042, State Game Land 332, State Game land 334, and State Game land 333. Recently in 2022, nearly 1,000 acres were added on various properties. PA Game Commission acquisitions are funded primarily by hunting and furtaker license sales; State Game Lands timber, mineral, and oil/gas revenues; and a federal excise tax on sporting arms and ammunition (Pittman-Robertson Act). The Commission is almost entirely supported by hunters and trappers, or assets that have been procured with license dollars. Some of these PGC acquisitions are "matched" with other state acquisition money from the Dept of Conservation and Natural Resources C2P2 Grant program or other private funds, e.g., PGC will pay for half and TNC (or other land trusts) might raise the other 50% through private (donors, OSI, ATC) and other state grant programs.

New Jersey Green Acres Program Fee (40,500 acres) is one of the first state land acquisition programs, founded in 1961. It is funded through the Garden State Preservation Trust act and Preserve New Jersey Act. Over the past sixty years, Green Acres has passionately strived to accomplish the ambitious goals of the State's early conservation efforts. As of March 2021, Green Acres has funded the preservation of 714,558 acres of parkland through state, local, and nonprofit acquisitions, adding them to the system of protected public open space in the state and preserving the environmental and recreational resources within them.

Appendix 2.2: Shortened wording for definitions of GAP status

GAP 1: Permanent protection for biodiversity. Examples: Nature reserves, research natural areas, wilderness areas, and Forever-Wild easements.

GAP 2: Permanent protection to maintain a primarily natural state. Examples: National Wildlife Refuges, many state parks, and high use National Parks.

GAP 3: Permanent protection for multiple uses, typically retaining natural cover but often subject to extractive uses such as logging. Examples: State or Town forest or Crown lands in Canada managed for timber; land protected from development by forest easements. GAP 3x refers to permanent protection where natural cover is removed (permanent farm easements, city parks).

GAP 4: Temporarily protected lands, or lands with no securement. If there is no practical way to contact each manager of every protected area to determine management practices, these assignments based on the designation can be used as a starting point, after first determining if the area has permanent protection or is not already developed.

Status 1: National Park, National Monument, Wilderness Area, Nature Reserve/Preserve, Research Natural Area, Heritage areas

Status 2: State Parks, State Recreation Areas, National Wildlife Refuge, National Recreation Area, Area of Critical Environmental Concern, Wilderness Study Area, Forever-Wild Conservation Easement, National Seashore

Status 3: BLM Holdings, Military Reservations, National Forests, State Forest, Wildlife Management Areas, Game and Fish Preserves, State Commemorative Area, Access Area, National Grassland, ACOE Holding. Private Land with Conservation Easement

Status 4: Private Land with no easements, Tribal Land, City Park, Undesignated State Land, County Land, City Land, Fish Hatcheries

Dichotomous key for assigning GAP protection status codes

A-1:

If the management intent can be determined through agency or institutional

documentation GO TO A-2, if not, GO TO A-5

A-2:

If the land unit is subject to statutory or legally enforceable protection from conversion to

anthropogenic use of all or selected biological features by state or federal legislation,

regulation, private deed restriction, or conservation easement intended for permanent status, GO TO B-1; if not, GO TO A-3

A-3:

If ecological protection is not legally enforceable, temporary, or lacking but managed by a plan intended for permanent status, GO TO A-4; if not, GO TO A-5

A-4:

Management to benefit biological diversity is provided by a written plan in place or in process under an institutional policy requiring such management - Status 3

A-5:

Not subject to an adopted management plan or regulation that promotes biological diversity, or management intent is unknown - Status 4

B-1:

If the total system in the land unit is conserved for natural ecological function with no more than 5% of the land unit in anthropogenic use, GO TO B-4; if conservation provisions apply only to selected features or species, GO TO B-2

B-2:

If management emphasizes natural processes including allowing or mimicking natural ecological disturbance events, but also allows low anthropogenic disturbance, renewable resource use, or high levels of human visitation on more than 5% of the land unit - Status 2; if not, GO TO B-3

B-3:

Management allows intensive, anthropogenic disturbance such as resource extraction, military exercises, or developed or motorized recreation on more than 5% of the land unit, but includes ecological management for select features - Status 3

B-4:

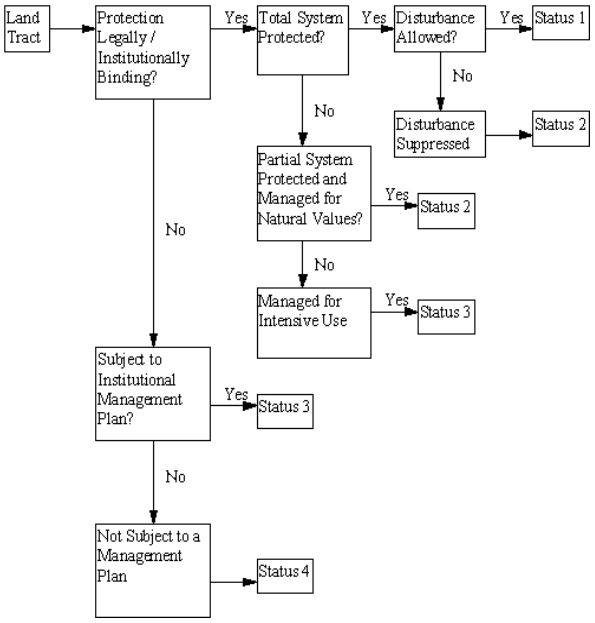
If management strives for natural processes including allowing or mimicking natural

ecological disturbance events - Status 1; if not, GO TO B-5

B-5:

Managed for natural processes, but some or all disturbance events are suppressed or modified - Status 2

Dichotomous key for assigning GAP protection status codes



Appendix 2.3.The Nature Conservancy's 2022 Secured Lands Data Sources

The 2022 Northeast Conservation Lands dataset used in this report was compiled from multiple sources. These include state, federal, and other non-profit and land trust data. The primarily datasets are listed below. TNC reviewed the source data for spatial accuracy and assigned GAP status along with other attributes in our standard conservation lands database attribute template as possible. Please contact the primary TNC State GIS analysts for additional detailed information on the input sources within their states, GAP coding rules, and other questions within states.

CONNECTICUT
Overview: This Connecticut Conservation Lands dataset was based on an update of the existing 2018 Secured Lands dataset compiled by TNC which had its roots in 1) the 2005 Protected Open Space Phase 1 dataset which mapped parcels designated as permanently protected open space by the Connecticut Department of Environmental Protection, 2) a Municipal and Private Open Space data layer from the Connecticut Office of Policy and Management DEP which mapped property owned by Connecticut municipalities and private organizations for the purpose of preserving open space including land conservation trust property, town open space, parks, school playgrounds, campgrounds, golf courses, club/association recreational property, and cemeteries, and 3) a DEP Property dataset which included state owned property such as natural area preserves, state forests, state parks, state park scenic reserves, state park trails, wildlife areas, and wildlife sanctuaries. This dataset was augmented in summer 2022 with updated TNC lands, Harvard Forest Wildlands 6/2022 parcels, Northeast Wilderness Trust properties, and a newly available protected open space dataset for eastern Connecticut from efforts of the CT Land Conservation Council/The Last Green Valley Protected Open Space Mapping Project (5/2/2022 Brian Hall, Hunter Brawley, Amy Patterson, Lois Bruinooge).
Contact Information: Anna Ormiston anna.ormiston@TNC.ORG, The Nature Conservancy of New Hampshire
Last Updated: September 2022

DELWARE
Secured lands are present in Delaware via their FirstMap online service, under their Preserved Lands Network 2.0 layer. Additionally, Drexel University was able to provide more data on secured lands throughout the Delaware River Basin. A similar process to that descried for Delaware was used to crosswalk between the fields in this dataset and the secured areas schema Sources: FirstMap Delaware, Drexel, The Nature Conservancy, PAD-US 3.0
Contact Information: Melissa Clark, melissa_clark@tnc.org, The Center for Resilient Conservation Science, The Nature Conservancy
Last Updated: December 2022

MAINE
Overview: The Maine Conservation Lands Geodatabase is maintained and updated by the Maine Chapter of The Nature Conservancy in cooperation with Justin Schlawin, Maine Department of Agriculture, Conservation, and Forestry. It includes most of the state, federal, and larger private conservation lands with legal protection in the state of Maine. TNC in Maine is working with both state agencies and land trusts to improve comprehensive updating and the overall content of this dataset. The spatial data is compiled from over 300 different data sources and are from a variety of scales, ranging from 1:100,000 scale to high-accuracy digital surveys.
Contact Information: Dan Coker dcoker@TNC.ORG, The Nature Conservancy of Maine.
Last Updated: May 2022

MARYLAND
Overview: The Maryland Conservation Lands dataset is based on a compilation of multiple sources, with most data coming from the https://imap.maryland.gov/, data downloaded Feb 2022. The iMAP data sources included DNR Owned and Conservation Easements, MD Environmental Trust Easements, Protected Federal Lands, Coastal Estuarine Land Conservation Progam, Rural Legacy Properties, Private Conservation Lands, Local Protected Lands, MALPF Easements, Transfer Purchased Development, and Forest Conservation Act Easements. Additional sources include NRCS Geospatial Data Gateway Agricultural Conservation Easement Program Wetlands Reserve Easements, military lands from the previous 2018 MD Secured Areas dataset, and updated TNC lands.
Contact Information: Michelle Canick mcanick@TNC.ORG, The Nature Conservancy of Maryland
Last Updated: June 2022

MASSACHUSETTS
Overview: The Massachusetts Conservation Lands layer is based primarily on the Protected and Recreational Open Space, MassGIS. Link to Data Version April 2022, from the Executive Office of Energy and Environmental Affairs, Office of Geographic and Environmental Information (MassGIS). This layer contains the boundaries of conservation lands and outdoor recreational facilities in Massachusetts. The associated database contains relevant information about each parcel, including ownership, level of protection, public accessibility, assessor's map and lot numbers, and related legal interests held on the land, including conservation restrictions. Additional parcels and attributes were added from TNC_Interests Version March 2022, DCR Landscape Designations Version 2012, and Harvard Forest Wildlands June 2022 datasets.
Contact Information: Jessica Dietrich jessica.dietrich@TNC.ORG, The Nature Conservancy of Massachusetts
Last Updated: October 2022

NEW HAMPSHIRE
Overview: The New Hampshire Conservation Lands dataset was based primarily on NH GRANIT data as of July 2022. The New Hampshire Geographically Referenced Analysis
and Information Transfer System (NH GRANIT) https://www.nhgeodata.unh.edu/ maintains and updates the statewide conservation lands dataset through extensive outreach to federal and state agencies, municipalities, land trusts and private land owners. TNC worked to integrate additional land trust lands compiled by TNC in cooperation with GRANIT but which had not been integrated into the latest GRANIT posted conservation lands dataset, additional properties from the Harvard Forest Wildlands project, and management zones from the US Forest Service land in the White Mountains of New Hampshire using the US Forest Service Management Areas.
Contact Information: Anna Ormiston anna.ormiston@TNC.ORG, The Nature Conservancy of New Hampshire **Last Updated:** September 2022

NEW JERSEY
Overview: The New Jersey Conservation Lands dataset was based primarily on the New Jersey Department of Environmental Protection (NJDEP), Green Acres Program state-local-and-nonprofit-open-space layer (version 20220810) which includes Green Acres encumbered and unencumbered protected open space and recreation areas. The Green Acres encumbered lands are owned in fee simple interest by either the state, county, municipality, or a nonprofit agency and have either received funding through the Green Acres State or Local Assistance Program or are listed on a Green Acres approved Recreation and Open Space Inventory (ROSI). The unencumbered open space lands do not fall under Green Acres rules and regulations and therefore have a lesser level of protection. Types of open space property in this data layer include parks, conservation areas, preserves, historic sites, recreational fields, beaches, etc. The data was derived from a variety of mapped sources which vary in scale and level of accuracy. This dataset was

augmented with additional Federal conservation land from USGS Protected Areas Database 2.1, TNC lands as of September 2022, and the Farmland Preservation File http://www.state.nj.us/agriculture/sadc/farmprogress.htm .
Contact Information: Mike Shanahan mshanahan@TNC.ORG, The Nature Conservancy of New Jersey
Last Updated: September 2022

NEW YORK
Overview: The New York Conservation Lands dataset used in this report is based primarily on the draft New York Protected Areas Database (NYPADv20) obtained for use in this project 5/2022 from New York Natural Heritage Program Department of Environmental Conservation. This data layer represents a new effort to update and combines the most current known parcels of land in New York state that have some level of protection including state, federal, local, municipal, and non-profit lands and easements. Given the draft nature of this dataset, NY NHP asked the digital data not be further re-distributed but only used in statistics and static maps developed as part of this NEAFWA Conservation Status report. Upon study and comparison of the draft NY PAD to the 2018 New York Secured Areas dataset previously compiled by TNC, the draft NYPAD was found to be missing various non-profit lands and easements and in some cases other local conservation lands and military ownership lands. These missing GAP 1-3 lands were added from the 2018 New York Secured Areas dataset and updated TNC lands were also added into the resultant New York Conservation Lands dataset used in this analysis.
Contact Information: David Richardson david.richardson@TNC.ORG, The Nature Conservancy of New York
Last Updated: September 2022

PENNSYLVANIA
Overview: The Pennsylvania Conservation Lands dataset was derived from the WeConservePA dataset which maintains and regularly updates a comprehensive, statewide series of datasets mapping conserved Federal, State, Local, LandTrust, and Easement lands. A most current version of these datasets was obtained from Irina Beale at WeConservePA as of 9/1/2022. Some additional management zones within larger state or federal forests were added based on PAD-US 3.0.
Contact Information: Tamara Gagnolet tgagnolet@TNC.ORG, Jacob Leizear jacob.leizear@TNC.ORG The Nature Conservancy of Pennsylvania
Last Updated: December 2022

RHODE ISLAND
Overview: The Rhode Island Conservation Lands dataset is based on a compilation of state, federal, local and NGO datasets. It builds upon the 2018 Secured Areas dataset compiled by TNC. The primary source dataset is the State Conservation and Park Lands layer from The State of Rhode Island Department of Environmental Management which contains approximate edges of conservation lands protected by the State of Rhode Island through Fee Title Ownership, Conservation Easement, or Deed Restriction. Additional local and NGO lands were added from the State DEM local conservation lands dataset, TNC lands, and other land trusts as available.
Contact Information: Kevin Ruddock kruddock@tnc.org, The Nature Conservancy of Rhode Island
Last Updated: September 2022

VERMONT
Overview: The Vermont Conservation Lands Database was developed using multiple sources. It included the Vermont Protected Areas Database as of 8/28/2022 from VT Center for Geographic Information which incorporates revisions from Cooperating Technical Partners (Vermont Agency of Natural Resources, Vermont Land Trust, Green Mountain National Forest, Upper Valley Land Trust, Vermont Housing and Conservation Board, Green Mountain Club, The Nature Conservancy). Substantial further

improvements were made in the summer and fall of 2022 by TNC including effort to remove duplicates, overlaps, and add new data from Northeast Wilderness Trust, Protected Areas Database US Version 2.1, State of Vermont Forest Legacy Program, Stowe Land Trust, Upper Valley Land Trust, Vermont Agency of Natural Resources, VT DEC River Corridor Easements, Vermont Land Trust and Vermont River Conservancy, Harvard Forest Wildlands, and updated TNC lands.
Contact Information: Ann Ingerson ann.ingerson@TNC.ORG, The Nature Conservancy of Vermont
Last Updated: November 2022

VIRGINIA
Overview: The Virginia Conservation Lands dataset was developed primarily from Virginia Department of Conservation and Recreation data, TNC lands, and USGS Protected Areas Database 2.1 The primary source was the Virginia Conservation Lands Database that is continually maintained and updated by the state Department of Conservation & Recreation. It includes all state and federal lands and many local and private conservation lands. A current version of which was obtained from David Boyd at DCR. This dataset includes TNC lands, however to ensure the most up-to-date and accurate TNC lands data were included in the secured areas data, TNC lands were removed from the DCR data before starting. TNC assigned GAP status using information in the source data and also attemped to eliminate the many overlapping polygons (>20 acres in size) present in the DCR data, due to multiple designations (e.g., national forest and wilderness area) or conservation easements co-held by multiple organizations.
Contact Information: Chris Bruce cbruce@TNC.ORG, (David.Boyd@dcr.virginia.gov)
Last Updated: September 2022.

WEST VIRGINIA
Overview: The West Virginia Conservation Lands dataset was based on the WV protected lands data that was submitted to PAD-US by Maneesh Sharma, of the West Virginia GIS Technical Center. It was later determined that this dataset did not include certain Federal lands, so additional Federal lands were added from the USA Federal Lands data published by Esri in the Living Atlas and from USFWS ownership data. Agricultural and some other easements were also not included so these were obtained from the WV Farmland Protection Program and incorporated. Upon the release of PAD-US 3.0, some edits were made based on these data. Finally, updated TNC Lands data were incorporated. GAP status and other fields in the dataset were populated by TNC as possible given available source information.
Contact Information: Chris Bruce cbruce@TNC.ORG, The Nature Conservancy of Virginia
Last Updated: September 2022.

Additional Data Sources

U.S. Geological Survey (USGS) Gap Analysis Project (GAP), 2022, Protected Areas Database of the United States (PAD-US) 3.0: U.S. Geological Survey data release, https://doi.org/10.5066/P9Q9LQ4B.

National Conservation Easement Database (NCED_06232022.gdb)
https://www.conservationeasement.us/# The NCED is an initiative of the U.S. Endowment for Forestry and Communities.

Harvard Forest Wildlands (Wildlands_06062022.shp). Compiled for the project Wildlands in New England. Past, Present and Future. Foster, David R. drfoster@fas.harvard.edu Hall, Brian R. <brhall@fas.harvard.edu>

Northeast Wilderness Trust Properties, September 2022

The Trust for Public Land, *Conservation Almanac*, 2022, www.conservationalmanac.org.

CHAPTER

Forests

3

Condition and Conservation Status

Feb 2023

M. Clark, M. G. Anderson, & A. Olivero

Forests define the eastern landscape, but although forests give a feel of permanence to the land they have been in continual change for centuries. In this chapter we examine the state of our forests, and take stock of their conservation, turnover, historic and recent conversion, fragmentation, and connectedness.

Historic Loss and Conservation: Ninety-one percent of the region was once covered by forest, now forest covers 61% with the rest converted to converted to agriculture (15%), development (12%) or other natural systems (3%). Of the remaining forest, conservation efforts have secured 24% against conversion including 8% explicitly for nature and 17% for multiple use. Thus, for every acre of forest conserved, 1.6 acres have been lost to conversion. Boreal Upland Forest is considerably more conserved (39%) than Northern Hardwood Forest (25%) or Central Oak Pine Forest (22%).

Recent Trends in Turnover and Loss: Eight million acres (8%) of eastern forests have changed markedly over the last twenty-years (2001-2021). Forest turnover accounts for 57% of the change reflecting active logging and natural disturbances followed by regrowth back to forest. Another 28% transformed to other natural land cover reflecting recent turnover that may return to forest or changing climate regimes. Less than 1% was converted to development (0.6%) or industrial agriculture (0.2%) an annual loss 35,500 acres per year.

Recent Trends in Conservation: Across the last two decades (2001-2021) conservation greatly surpassed conversion reversing the historic trend for all forest types: Boreal Upland (89:1), Northern Hardwood (7:1) Central Oak Pine (5:1), an average of 7.6 acres conserved for every acre converted. Land conserved explicitly for nature showed markedly less forest turnover and change (3%) than land conserved for multiple uses (7%) or unconserved land (9%). Recent easements have focused on forest with high levels of turnover and change.

Forest Connectivity: Forests in the region are highly fragmented by permanent roads, powerlines, and fields. Boreal Upland was the only forest type to score markedly above the regional mean for local connectedness (1.3 SD). This likely reflected the large amount of conservation land. Land conserved for nature (1.25 SD) and land conserved for multiple uses (0.79 SD) both had average connectedness values far above the regional mean. Losses in connectedness over the last decade were localized but pervasive across the region.

Forest Types

Ecologists recognize four major forest types in this region and 30 to 40 variations related to latitude, soil, elevation and distance to the coast. We used a simplified version of TNC's Terrestrial Habitat map (Ferree and Anderson 2013) augmented with current land use (NLCD 2019) and forest extent (GFC 2022) to map existing vegetation to quantify the abundance of each type.

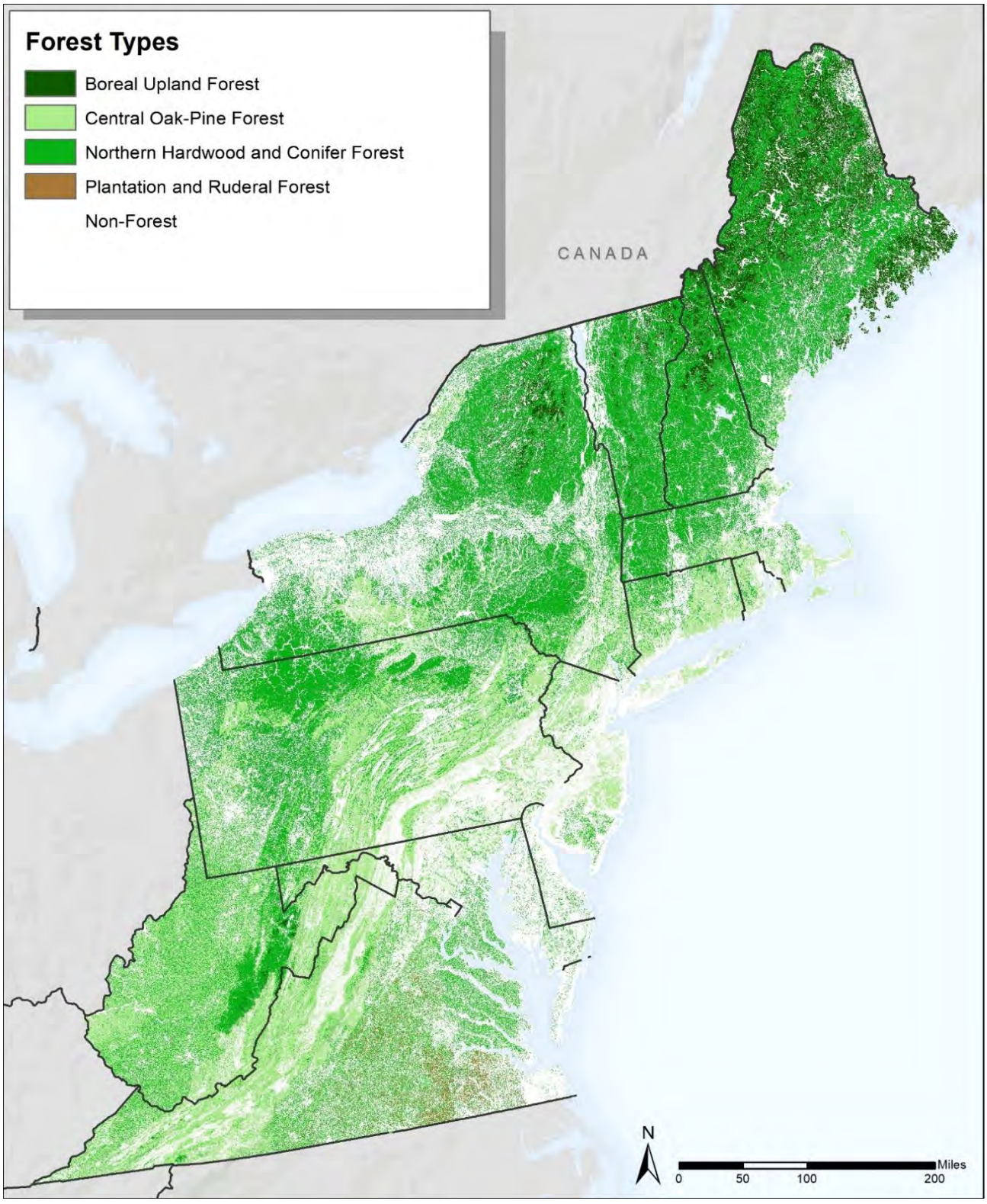
Northern Hardwood and Conifer Forest: This heterogeneous forest type typical of mesic settings covered 54% of the region (50.5 million acres) and occurred throughout at higher elevation or northern latitudes (Map 1). It is a deciduous or mixed forest dominated by sugar maple, American beech, and yellow birch (i.e. hardwoods other than oaks and hickories). Conifers, when present, include white pine, eastern hemlock, or red spruce. Other deciduous associates include red maple, white ash, paper birch, red oak, American basswood, and tulip tree. Mixed forests are often dominated by some combination of hemlock with sugar maple and tend to occur in moist ravines or north slopes. In the southern portion of the region, examples in coves or protected settings may include the characteristic trees: cucumber-tree, mountain magnolia, umbrella-tree, yellow buckeye, and mountain silverbell, and a diverse herb layer with blue cohosh, black bugbane, American ginseng, and northern maidenhair.

Central Oak-Pine Forest: This forest type was most common in the southern portion of the region, covering 35% of the region's forests (32.4 million acres, Map 1). Oaks and pines dominate these dry forests that typically have a well-developed understory and a full or discontinuous canopy. Characteristic trees include eastern white pine, pitch pine, or red pine with chestnut oak, northern red oak, and/or bear oak. Early-successional examples are often more strongly pine-dominated with oaks and hickories increasing over time. Sometimes the pines are absent and oaks, hop hornbeam, or sugar maple dominate. Chestnut oak often prevails on dry exposed ridges and plateaus, usually with an understory of heathy shrubs. On more mesic sites a mix of oaks (northern red oak, white oak, black oak, scarlet oak) and hickories (mockernut hickory, shagbark hickory, red hickory) are common associates.

Boreal Upland Forest: This forest type makes up 8% of the region's forests (7.7 million acres) and was largely restricted to the northern states or high elevation settings (Map 1). Spruce and fir are characteristic trees, with conifer cover generally exceeding deciduous. In mountain settings, yellow birch may share the canopy over an understory of mountain-ash and other montane species. Red spruce, balsam fir and jack pine tend to dominate in valley settings with hardwood associates such as yellow birch, paper birch, or American beech. Black spruce is characteristic of imperfectly drained flat soils.

Ruderal and Plantation Forest: This is a forest type dominated by early-successional trees such as red maple, paper birch, loblolly pine, Virginia pine, bigtooth aspen, or quaking aspen without a strong component of oak, hickory or other hardwoods. It is a forest is comprised of short-lived, light-requiring trees that develops quickly on land reverting from being cleared, plowed, or grazed. Plantations are identified by trees apparently in row or having other evidence of intentional planting by humans. Ruderal forest comprised 2.4 % of the region's forests (2.3 million acres, Map 1).

Map 3.1. Major Forest Types of the Northeast Region.



Distribution, Loss, and Protection Status

Forest currently covers 61% of the region's land area (93 million acres) and is composed of three major forest types: northern hardwood (54%), central oak-pine (35%), boreal upland (8%), plus a small component of ruderal forest that is always in flux (3%, Map 3.1). The northern region differs substantially in composition from the south. New England and New York forests are 72% northern hardwoods, 17% boreal forest, and 11% central oak-pine (Figure 3.1). In contrast, Mid-Atlantic forests are 57% central oak pine, 39% northern hardwoods and 4% ruderal forest, with a small amount of boreal forest occurring in the extreme mountainous areas.

Historic Loss: The region has a long history of forest clearing and conversion. To quantify forest conversion, we overlaid the most recent National Land Cover Data (2019) on the LANDFIRE map of biophysical settings (BpS, LANDFIRE 2016) which represents the vegetation system that may have been dominant on the landscape prior to Euro-American settlement. We calculated the difference between the historic distribution and the current distribution by subtracting all the current non-forest cells (30-m) that fall within historic forest distribution and quantifying the land use type of each. The results indicate that 36.5 million acres, or 27% of all historic forest, have been permanently converted to agriculture (15%) or development (12%). A larger percentage of forest in the Mid-Atlantic has been converted than in New England/New York mostly to agriculture (Figure 3.1A).

Conservation: The region also has a long history of public and private conservation. To measure the amount of conserved forest in the region, we overlaid the 2022 TNC conserved lands dataset (described in the Conservation Lands chapter) on the map of existing forest types (Map 3.2). The results show that 25% of the remain forest is now under conservation (Figure 3.1 &3.2, Table 3.2), including 7 million acres of forest conserved for nature (GAP 1-2) and 15 million acres conserved for multiple uses (GAP 3). Boreal forests had the highest proportion of conservation land with 38% (2.8 million acres) conserved including 8% explicitly for nature. Central Oak-Pine was proportionally the least conserved forest (22%, 5.3 million acres) and had the least conservation for nature (5%). Northern Hardwood forests were intermediate with 23% conserved including 8% conserved for nature and 15% for multiple uses.

Conservation Land Terminology

Conserved (GAP 1-3): The land is permanently secured against conversion to development.

Conserved for Nature (GAP 1): The land is conserved for nature and natural processes.

Conserved for Nature (GAP 2): The land is conserved for nature with management.

Conserved for Multiple Uses (GAP 3): The land is secured AND the intent of the management is for multiple uses, including forest management. This land may provide implicit conservation value such as connectivity or providing stream buffers.

CRI = Conservation Risk Index = %Conv / %GAP1-3

NRI = Nature Risk Index = % Conv / %GAP 1-2

Map 3.2. Conservation Land and Major Forest Types.

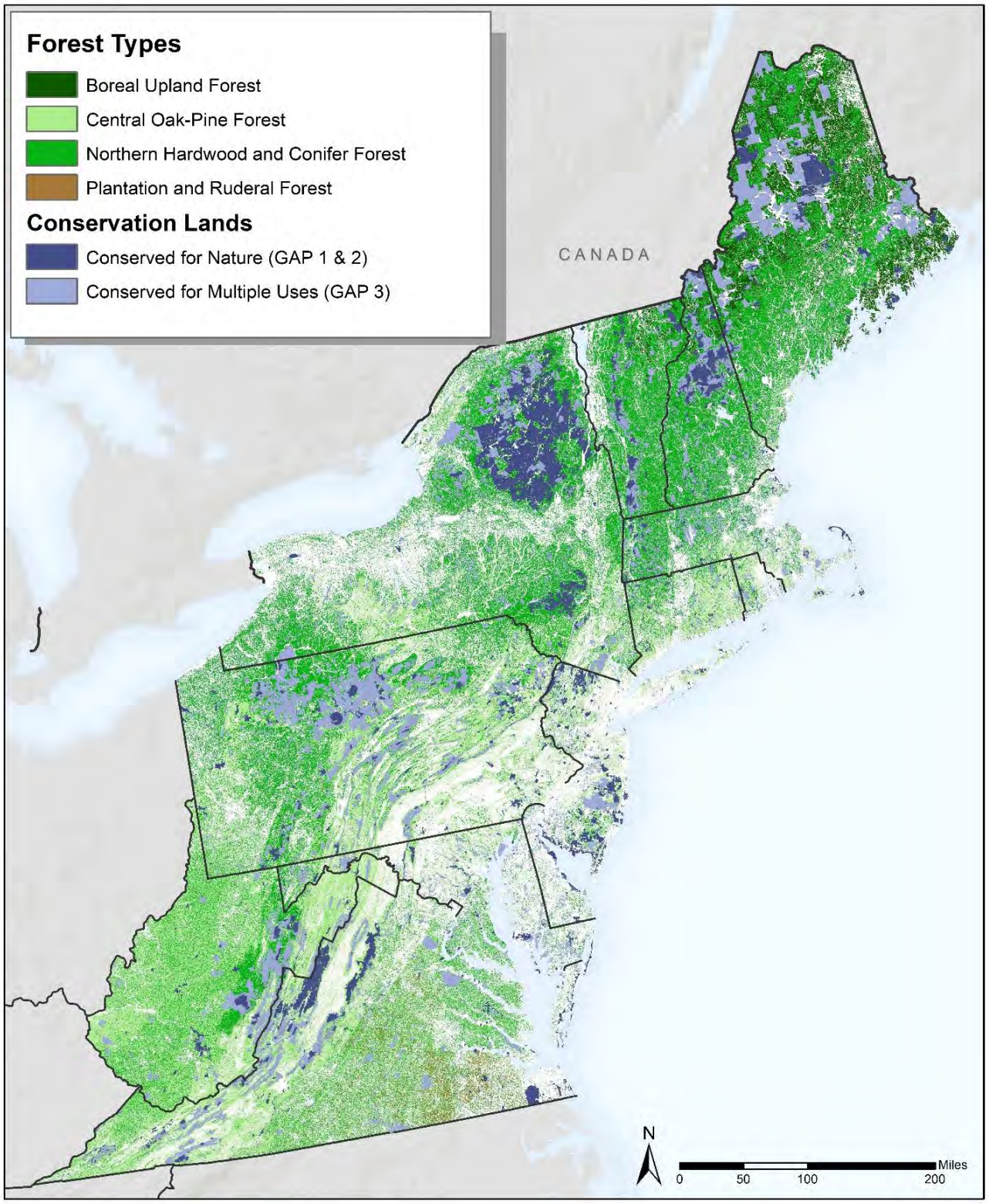


Figure 3.1. Forest Conversion compared with Conservation. Figure A is by subregion. Figure B is by forest type. Each bar represents 100% of the historic forest area. Conservation is land permanently secured against conversion to agriculture or development and either protected for nature conservation (GAP 1-2, dark blue) or intended for multiple uses (GAP 3, light blue). Red and Orange represent conversion to agriculture or development. Purple and green represent transitions to other land cover.

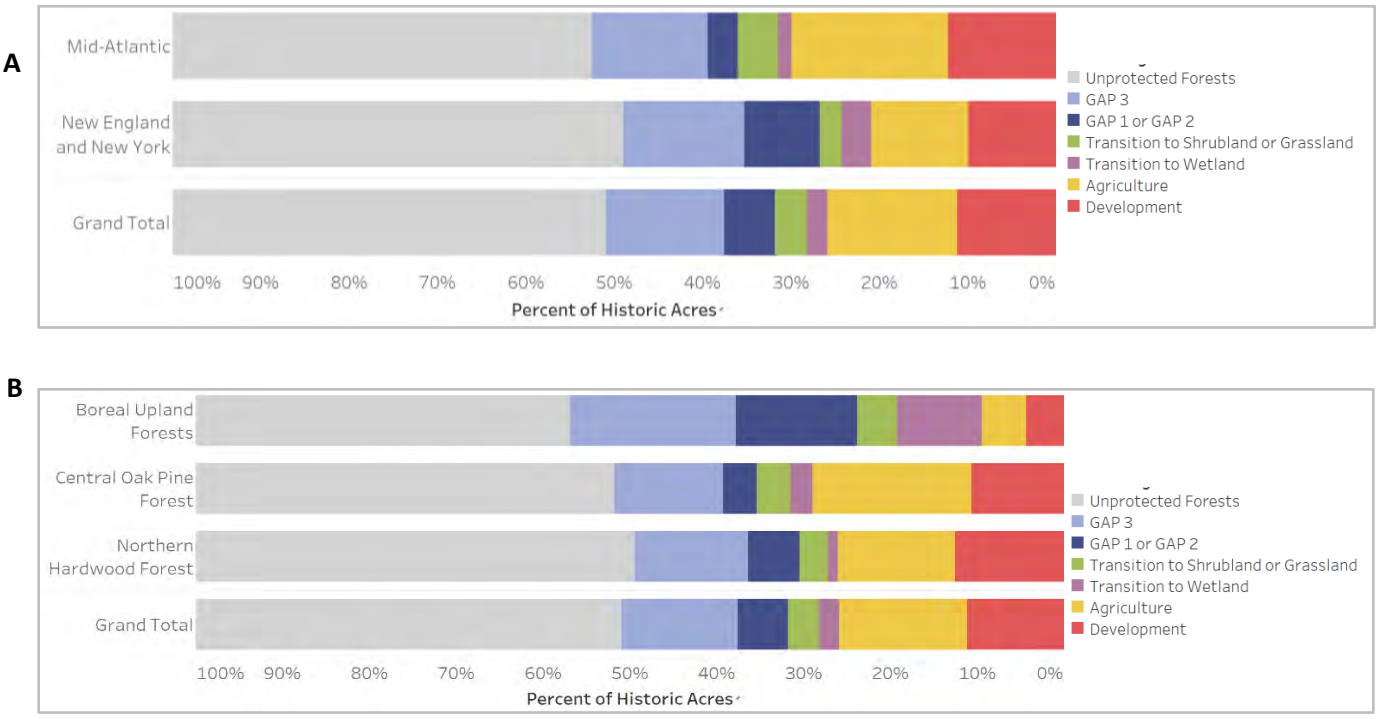


Figure 3.2. Percent of forest acres conserved by forest type. The bar represents the current distribution of each forest type. Of the three major forest types, boreal upland forests are the most conserved and central oak-pine the least, the differences mostly due to the amount of GAP1-2 land conserved for nature.

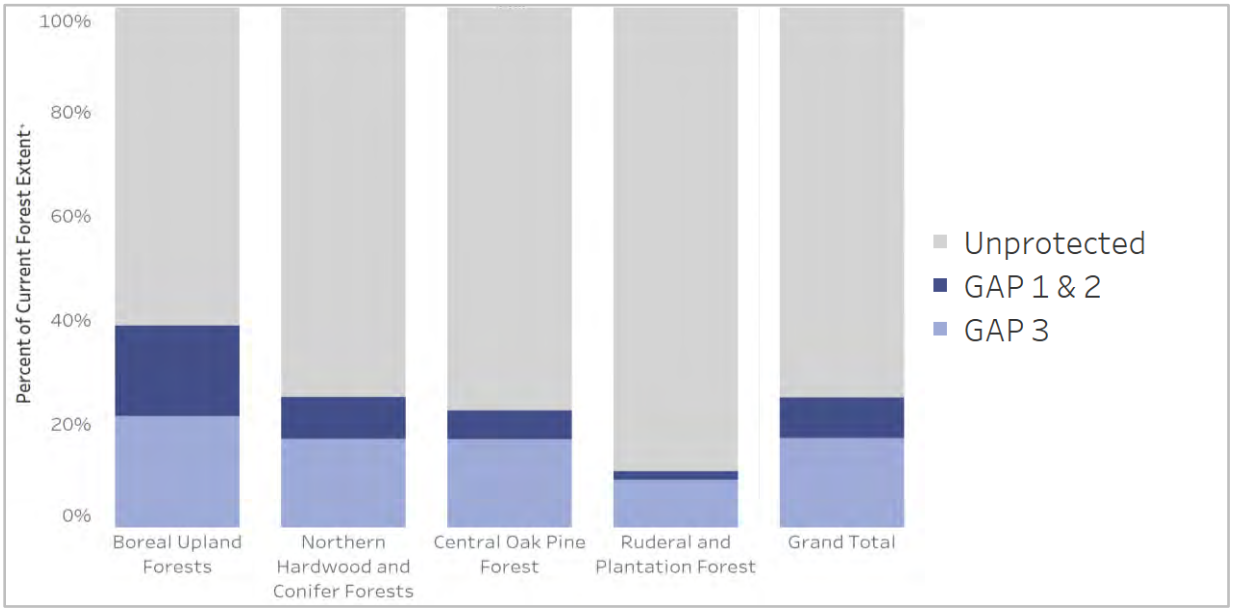


Table 3.1. Acres of forest by secured land status, forest type and sub-region. In this table, %L is the percent forest lost through conversion to development or agriculture and %C is the percent conserved (GAP1-3). CRI is the ratio of forest loss to conserved (%L/%C). NRI is the ratio of loss to conservation explicitly for nature (%L/%GAP 1-2) and is always larger than CRI.

REGION		GAP 1-2	GAP 3	UNPROTECTED	TOTAL ACRES	% L	%C	CRI	NRI
MID-ATLANTIC									
	Boreal Upland Forests	32,422	22,824	6,906	62,153	8%	89%	0.1	0.2
	Northern Hardwood and Conifer Forests	710,363	3,266,600	14,358,268	18,335,231	46%	22%	3.9	21.6
	Central Oak Pine Forest	1,477,178	4,839,806	20,930,870	27,247,853	20%	23%	1.1	4.6
MID-ATLANTIC TOTAL		2,219,962	8,129,230	35,296,045	45,645,237	33%	23%	2.1	10.0
NEW ENGLAND AND NEW YORK									
	Boreal Upland Forests	1,256,338	1,562,593	4,521,322	7,340,253	12%	38%	0.4	0.8
	Northern Hardwood and Conifer Forests	3,286,749	5,149,488	22,686,979	31,123,217	11%	27%	0.4	1.1
	Central Oak Pine Forest	286,803	578,041	3,837,707	4,702,550	63%	18%	9.3	27.9
NEW ENGLAND AND NEW YORK TOTAL		4,829,891	7,290,122	31,046,008	43,166,020	23%	28%	1.1	2.6
REGION									
	Boreal Upland Forests	1,288,760	1,585,417	4,528,228	7,402,406	12%	39%	0.3	0.8
	Northern Hardwood and Conifer Forests	3,997,112	8,416,088	37,045,247	49,458,448	28%	25%	1.5	4.8
	Central Oak Pine Forest	1,763,981	5,417,847	24,768,577	31,950,403	32%	22%	2.1	8.4
REGION TOTAL		7,049,853	15,419,352	66,342,053	88,811,258	28%	25%	1.6	5.0

Recent Trends in Forest Turnover and Loss.

In addition to analyzing historic patterns of forest loss, we also examined trends in forest turnover and loss over the last 20 years. To explore this, we used the global forest change dataset (Hansen et al. 2021) which uses real-time remotely sensed imagery to measure forest loss and gain between 2001-2021 at a 30-meter scale. We analyzed areas of forest loss detected by Hansen et al. (2021) and compared them to the land use changes and current values in the National Landcover Dataset (NLCD 2019).

Results show that 8 million acres (8%) of our forests changed over the last 20 years (Map 3.3, Figure 3.3). Forest turnover accounted for most of change (57%). We defined turnover as areas (30 m cell) of forest in 2001 that initially changed to another natural landcover and then changed back to forest by 2022 suggesting disturbance and regrowth. Change to another natural landcover accounted for another 28% most of this was to shrubland or grassland and could represent potential turnover that has not converted back to forest. Less than 1% (709, 985 acres) converted to development (0.6%) or industrial agriculture (0.2%). This suggests an annual rate of 35,500 acres lost to conversion each year. The two subregions had similar amounts of turnover.

Map 3.3. Extent of Forest Change (Loss and Turnover) in the last 20 years.

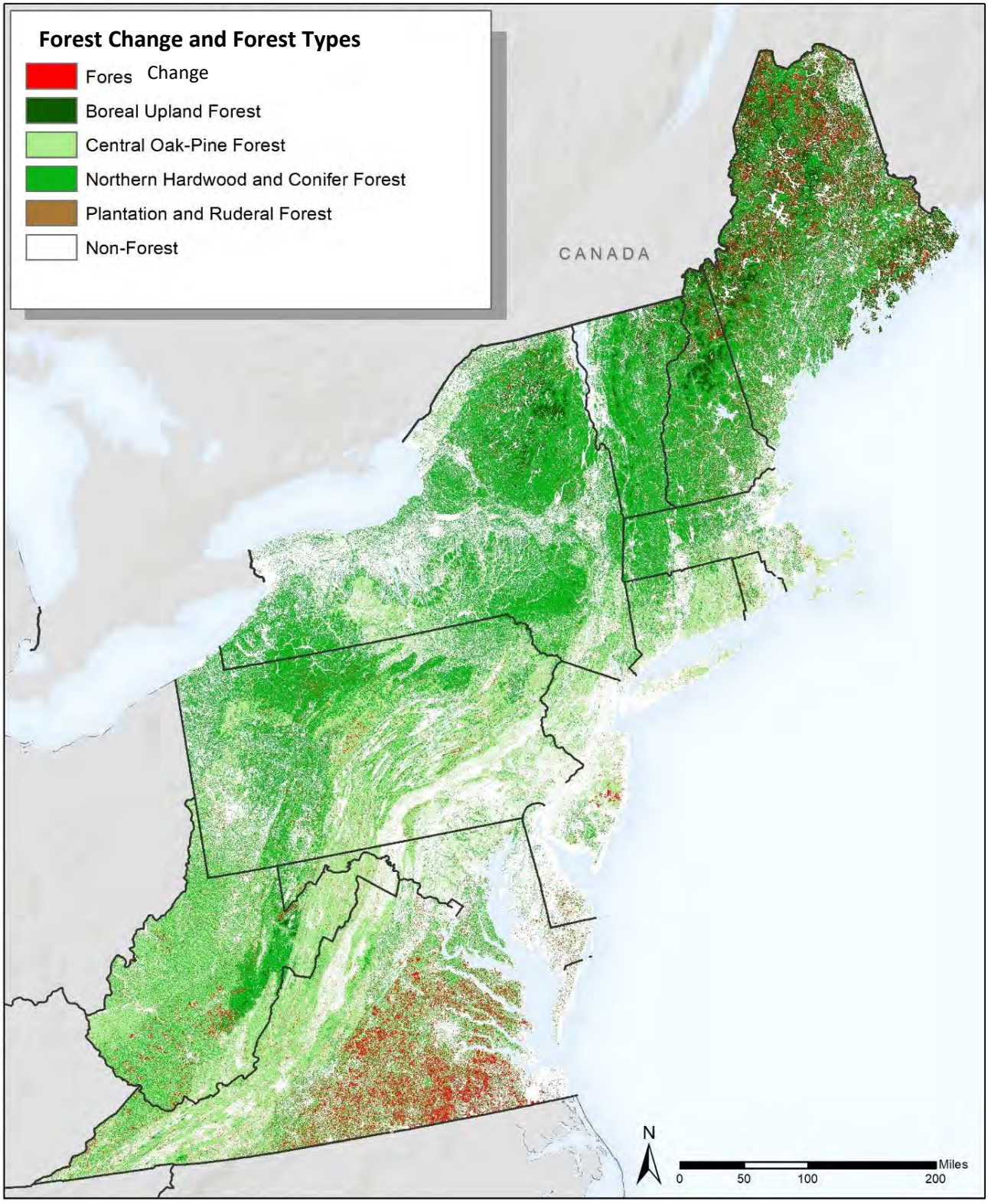
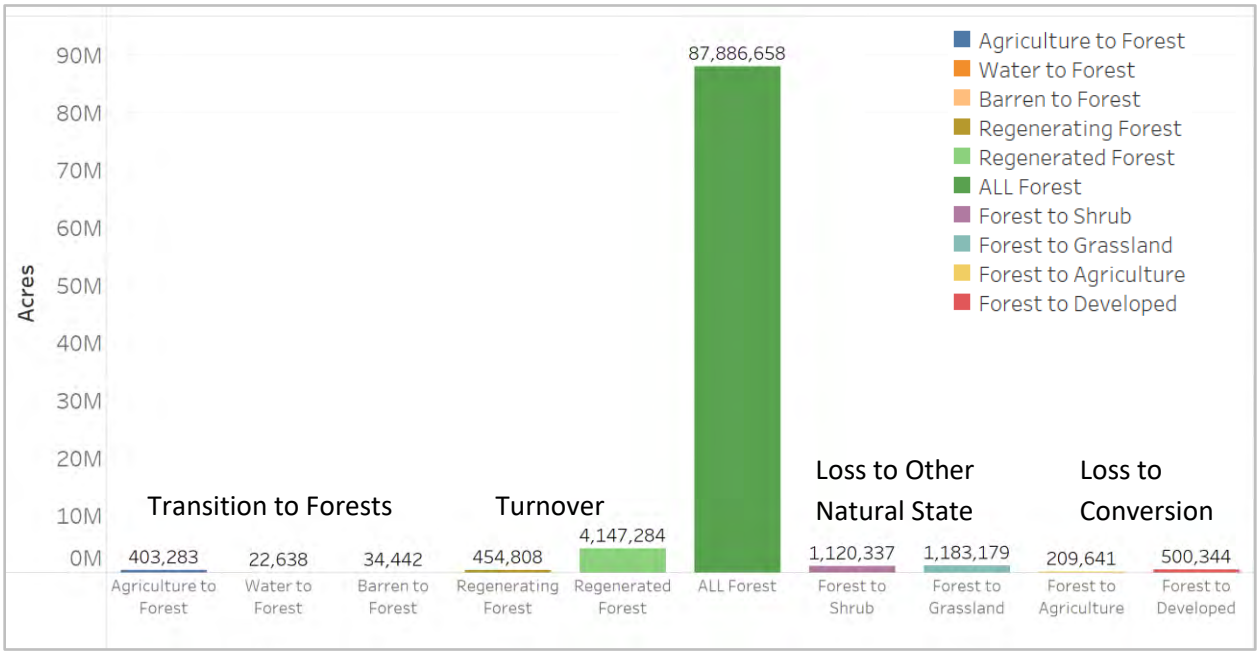


Figure 3.3: Forest in transition in the Northeast and Mid-Atlantic. 92% of forests were undisturbed across the last 20 years. Most forest change was due to turnover (5%) reflecting cutting and regrowth. Another 2% transitioned to another natural state (shrub or grassland) that may with succession eventually return to forests. Only 2.4% of forests were converted to development or agriculture.



Boreal forests had the largest percent forest change (15%), most of that due to turnover (10%) or change to other natural landcover (5%, Map 3.4, Figure 3.4). Presumably this reflects the many industrial forest operations in this part of the region. A small percentage (0.13%) of boreal forest was converted to development or agriculture. Change in northern hardwood forest was a more modest 8%, with 5% being turnover, 2% being change to other natural landcover and 1% loss to conversion (500 K acres). Central oak-pine forest had very similar transitions to northern hardwoods: 8% overall change, 4% being turnover, 3% being change to other natural landcover and 1% loss to conversion (Table 3.2).

Both historically and recently, losses to conversion in New England and New York were highest in oak-pine forest. This makes sense because this southern part of the region is where most of the new population growth and development is happening. A surprising pattern was that both historically and recently losses to conversion in the Mid-Atlantic were highest for northern hardwood forests, a forest type associated with higher elevations. This might be explained by the mapping of plantation forests which was concentrated on the coastal plain portion of the Mid-Atlantic, an area that historically would have been oak-pine forest (Map 3.4). As expected, plantation forests have the most forest change. 32% of plantation forests have changed state over the last 20 years, and most of that was either turnover or change to other natural land cover.

Map 3.4. Forest Change in the last 20 years by Forest Type.

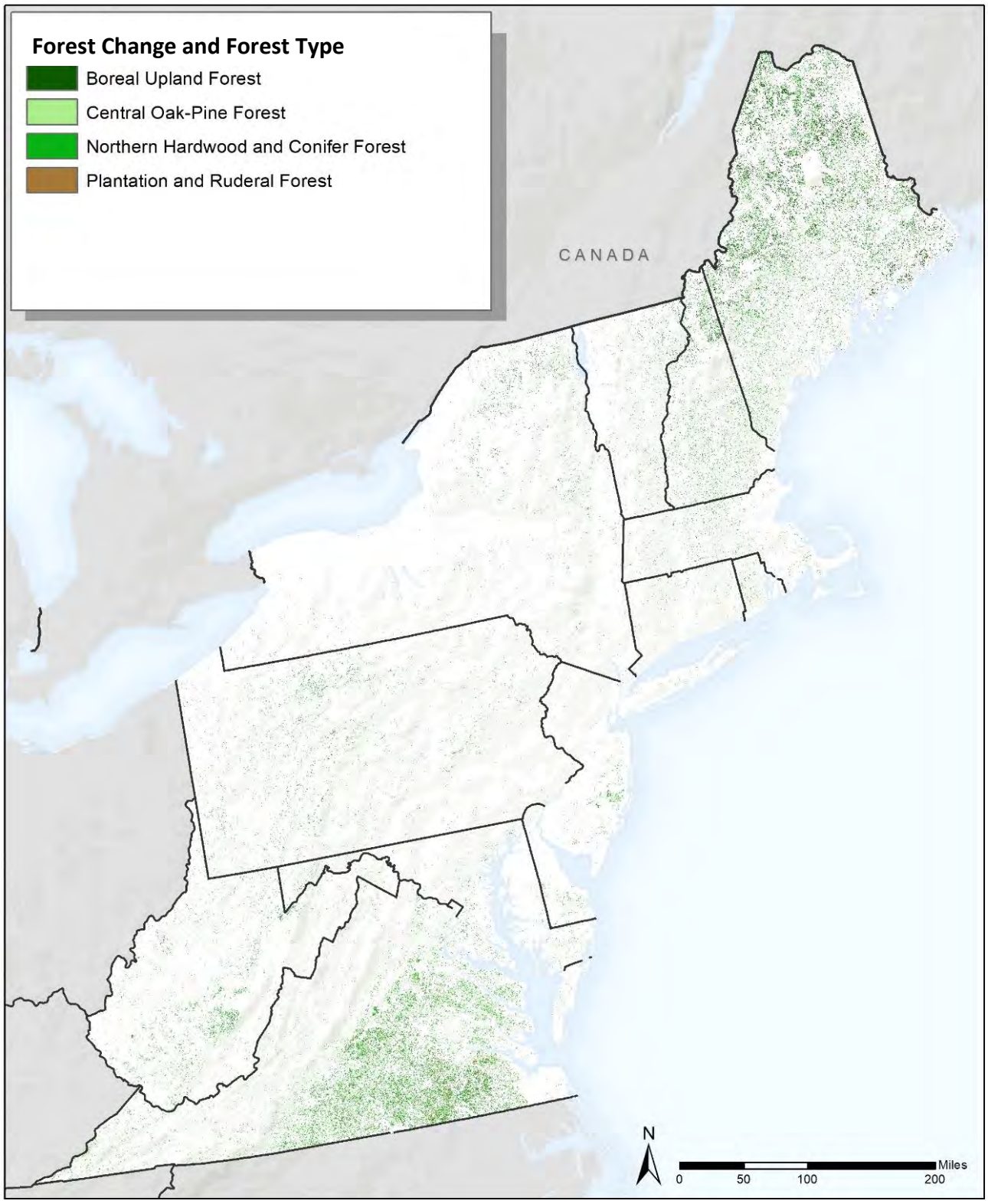


Figure 3.4: Forest Transition by Forest Type. By percentage, boreal forests had the largest amount of forest change. Across all types, forest turnover (light green) was the largest change that was observed.

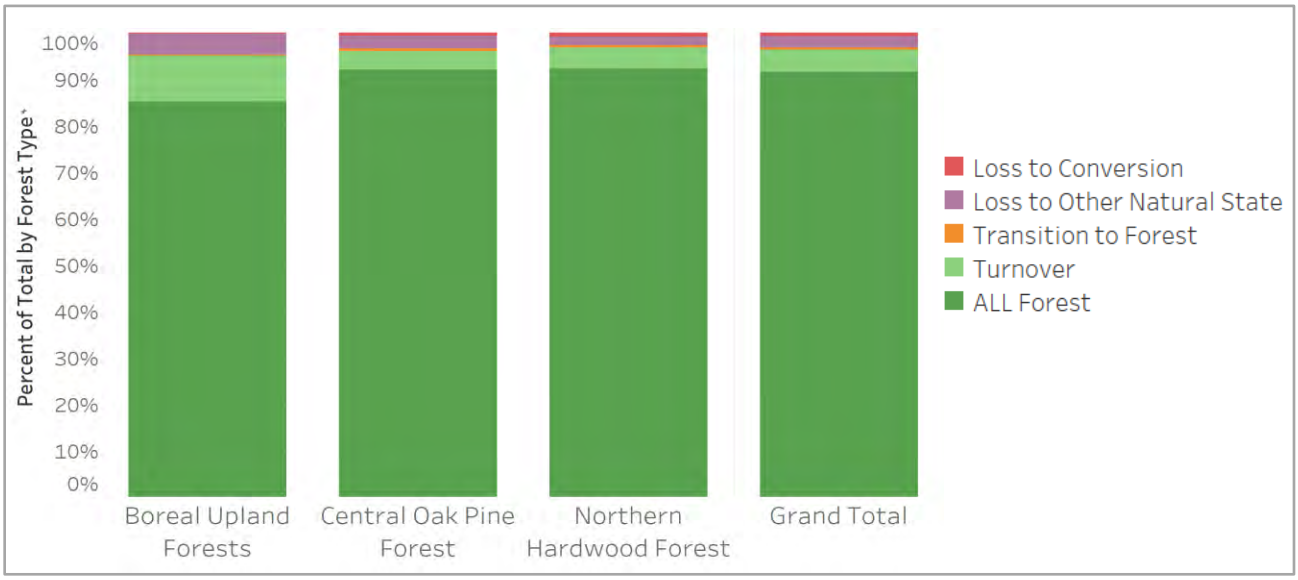


Table 3.2: Acres of Forest Turnover and Loss from 2001-2021 by Region and Subregion. Note - These totals will not match exactly with the current totals because some of the logged forest has regrown.

	Forest w No Change		Turnover		Transition to Forest		Loss to Conversion		Loss to Other Natural		TOTAL ACRES
	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	
Mid-Atlantic											
Boreal Upland Forests	63,393	79%	3,486	4%	39	0.0%	592	0.7%	13,096	16%	80,605
Central Oak Pine Forest	26,773,945	99%	1,189,536	4%	167,357	0.6%	123,369	0.4%	445,093	2%	28,699,300
Northern Hardwood Forest	18,543,200	88%	1,201,941	6%	123,165	0.6%	325,133	1.5%	861,718	4%	21,055,157
New England and New York											
Boreal Upland Forests	6,840,318	85%	802,020	10%	17,714	0.2%	9,702	0.1%	357,067	4%	8,026,821
Central Oak Pine Forest	4,865,287	86%	179,479	3%	27,570	0.5%	99,422	1.8%	505,997	9%	5,677,755
Northern Hardwood Forest	30,800,514	95%	1,225,630	4%	124,517	0.4%	151,769	0.5%	120,546	0.4%	32,422,975
Region Total											
Boreal Upland Forests	6,903,711	85%	805,506	10%	17,753	0.2%	10,294	0.1%	370,163	5%	8,107,426
Central Oak Pine Forest	31,639,232	92%	1,369,015	4%	194,927	0.6%	222,791	0.6%	951,090	3%	34,377,055
Northern Hardwood Forest	49,343,714	92%	2,427,571	5%	247,682	0.5%	476,902	0.9%	982,264	2%	53,478,132
TOTAL ACRES	87,886,658		4,602,092		460,362		709,985		2,303,516		95,962,613
Plantation Forests	1,005,113	62%	296400	18%	2,426	0.2%	4,852	0.4%	305,597	19%	1,615,355

Conservation and Forest Change

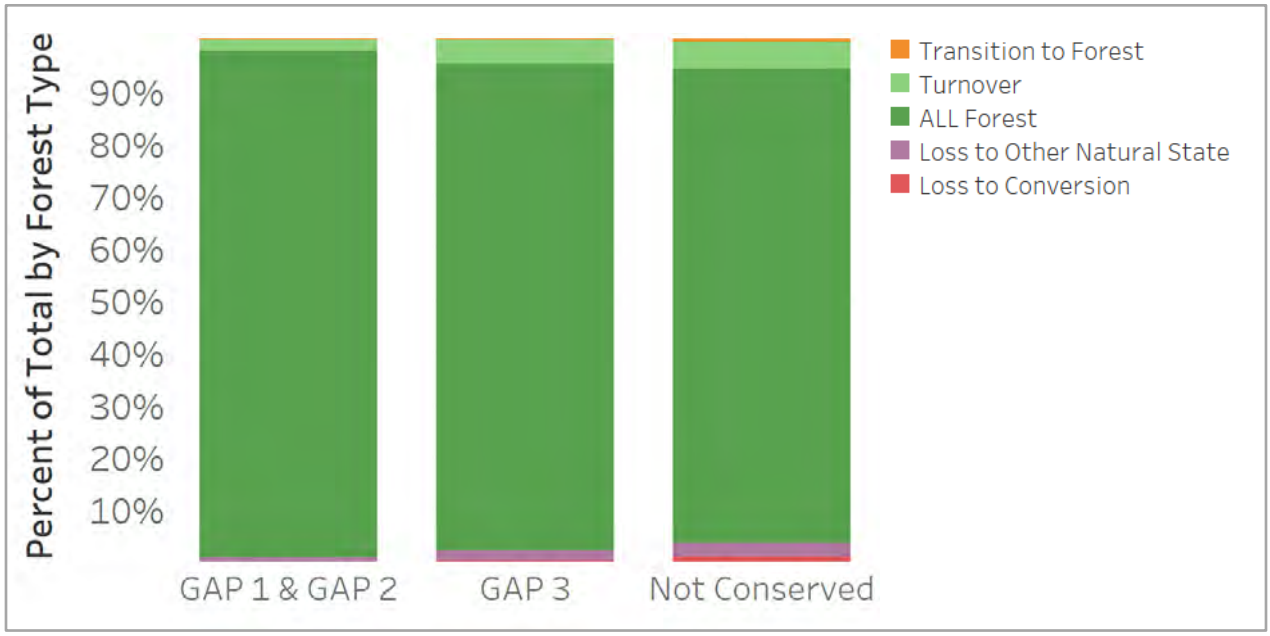
The 20-year period we analyzed for forest change was also very active for conservation with over five million acres of forest conservation land being acquired as fee or put under a conservation easement. Of the 2.1 M acres conserved over the last decade (2012-2022) about 75% was forested land. A conservation risk assessment (CRI = acres converted/acres conserved) across both decades indicates that **conservation greatly surpassed conversion for all forest types** (Table 3.3): Boreal Upland (CRI= 0.01), Northern Hardwood (CRI=0.14), Central Oak Pine (0.20). This equates to a CRI of 0.13 for the region or 7.6 acres conserved for every one acre converted.

Table 3.3. Conservation by Forest Type over the last Two Decades (2001-2022)

	2001-2011			2012-2022			2001-2022	2001-2022	CRI
Forest Type	GAP 1-2	GAP 3	Total	GAP 1-2	GAP 3	Total	Grand Total	Conversion	
Boreal Upland Forest	175,942	437,356	613,298	70,594	237,112	307,705	**921,004**	**10,294**	**0.01**
Northern Hardwood	788,812	1,698,249	2,487,061	195,559	619,051	814,610	**3,301,670**	**476,902**	**0.14**
Central Oak-Pine Forest	229,020	552,812	781,832	78,458	280,938	359,396	**1,141,228**	**222,791**	**0.20**
Ruderal Forest	4,819	15,581	20,399	4,211	25,113	29,323	**49,723**	**4,852**	**0.10**
Grand Total	**1,198,592**	**2,703,998**	**3,902,590**	**348,821**	**1,162,214**	**1,511,035**	**5,413,625**	**714,839**	**0.13**

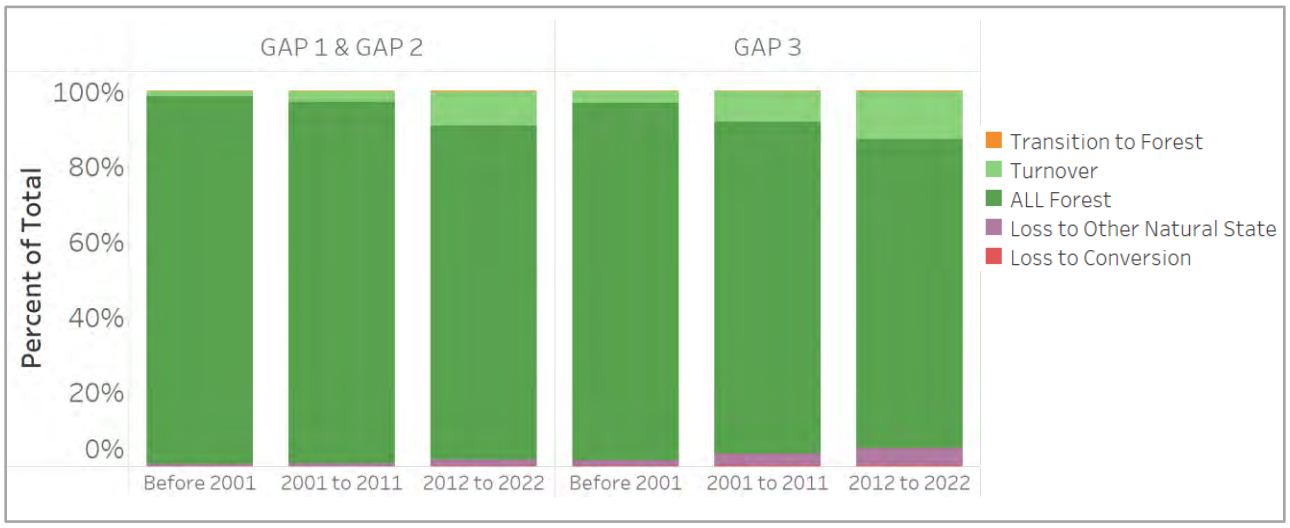
Does conserving forest have any effect on turnover and conversion rates? Do those effects differ between GAP Status? Overlaying the 2022 conservation lands on the forest change datasets allowed us to examine these questions and quantify the differences. We found that forest change differed markedly between unconserved forest (9%), forest conserved for multiple-uses (7%) and forests conserved for nature (3%). Unconserved forest had higher turnover rates, higher loss to conversion and higher change to other natural land covers (Figure 3.5). Forests conserved for nature (GAP 1-2) had no loss to conversion and much lower turnover rates, likely reflecting only natural disturbances. Surprisingly, GAP 3 multiple-use forests had turnover rates almost equivalent to unconserved forest although considerably less conversion to development or agriculture (Figure 3.5).

Figure 3.5: Forest Change by GAP Status.



The establishment date of the conservation lands explains some of the variation in turnover and conversion. Regardless of GAP status, the more recently the land was conserved the higher the turnover (Figure 3.6). Presumably this is because the turnover we are detecting over a 20-year period was largely happening before the land was conserved. For instance, land conserved in 2018, would have a change profile equal to 17 years unconserved and 4 years conserved relative to our time horizon. When time is factored out, GAP 3 land conserved for multiple uses has turnover rates intermediate between GAP 1-2 and unconserved (Figure 3.6, leftmost columns of each GAP class). Conversely, recently conserved GAP 1-2 land has a change profile that looks very similar to unconserved land, reflecting both the recent purchase time and the condition of the land when it was acquired.

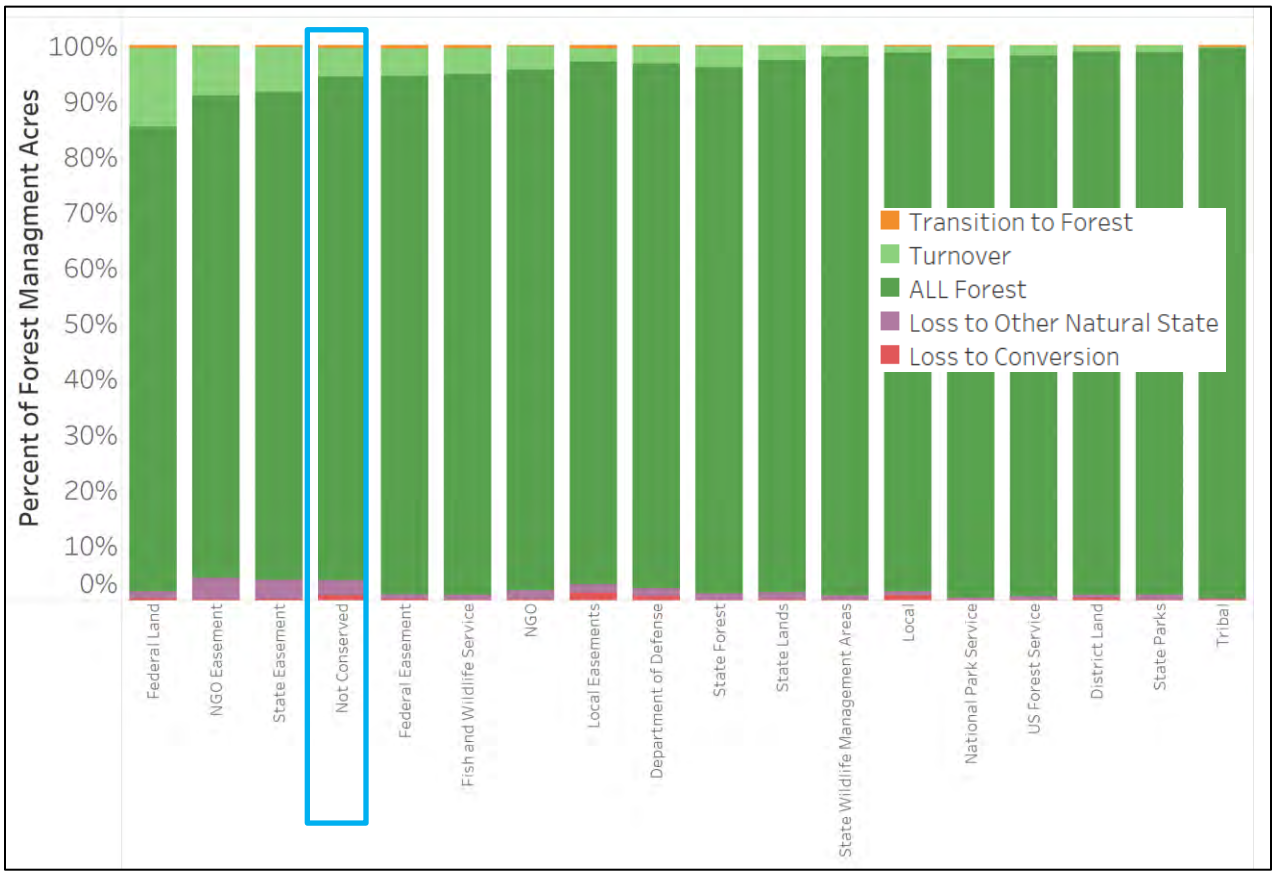
Figure 3.6: Forest Change by Protection Level and Date Conserved**.**



Trends in forest change also varies across ownership and management type. Surprisingly, we found that the percent of forest change was higher over the last two decades on NGO easements and State easements, than on unconserved land (Figure 3.7, left of the blue outline). This pattern may be explained by their recent increase in easement numbers and size. Over 25% have happened in the last 5 years and over 80% in the last 10 years. This is compounded by the fact that forest land is sometimes sold to conservation entities at a discount after it has been recently harvested. This would create the conditions where recent conservation easements show more internal change and turnover than unconserved forest.

Forest change was highest on miscellaneous federal lands not owned by the National Park Service, Fish and Wildlife Service or the Forest Service, all of which has lower amounts of change than unconserved lands (Figure 3.7). The latter two agencies showed less change than NGO lands perhaps reflecting longer ownerships. Notably, the least amount of forest change was seen on tribal land followed by State Parks.

Figure 3.7: Forest Change by Ownership Type. In this figure the dark green represents forest that remained forest over the last 20 years. The Orange represents is other land use classes that transitioned **to** forest. The lighter green is forest turnover (forest that was converted to non-forest but have either returned or are returning to forest). The purple is forest land that have converted to another natural land use class. The red is forest that has been converted to development of industrial agriculture.



Forest Condition: Block size and Connectedness

Forests in the Northeast have a long history of human use, from widespread local-scale burning by Native Americans, to extensive clearing for agriculture and pasture by settlers in the 1800s, to the current logging of hardwoods and conifers for materials. Moreover, as eastern forests recovered from turn-of-the-century clearing, other changes transformed the land. These include an increase of the human population from a few hundred thousand to 75 million, and the development of a road network that now includes over 732,000 miles of permanent roads (enough to circle the equator 29 times; Map 3.5). One effect of these changes has been dramatic shifts in the type and abundance of wildlife; most dramatically, a decrease in forest interior species, a spike in the abundance of open habitat species, and a recent increase in forest generalists and game species. While it is difficult to comprehend the scope of these changes, the aim of this section is to objectively assess the degree of forest fragmentation and its inverse "local connectedness" and determine the rate of change over the last decade.

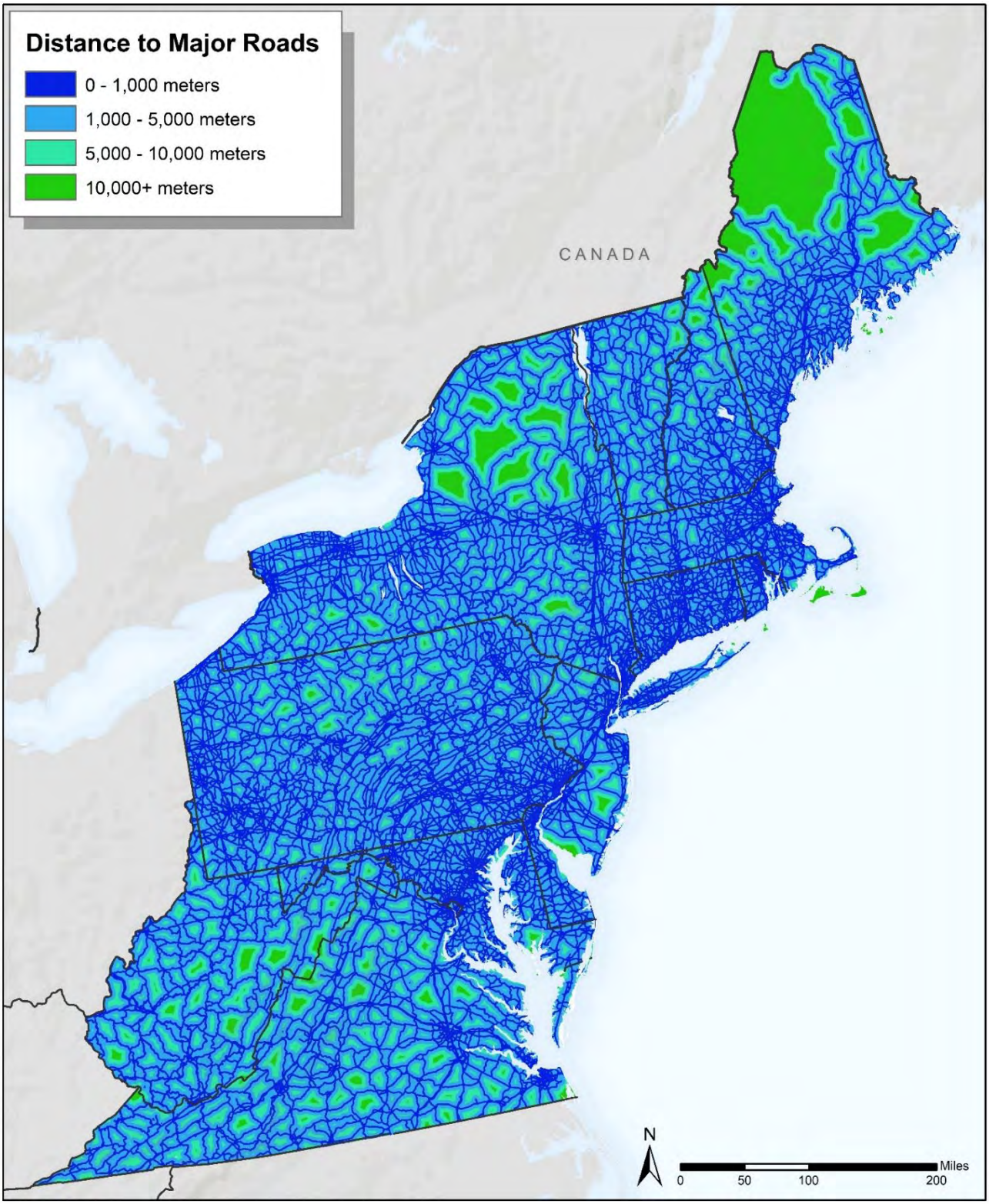
Fragmentation occurs when a contiguous area of forest is subdivided into smaller patches, resulting in each patch having more edge and less interior. Because edge habitat contrasts strongly with interior - drier and more exposed, higher predator densities, greater susceptibility to blowdowns - the surrounding edge habitat tends to isolate the interior region and contribute to its degradation. Thus, the divide-and-conquer effect of fragmentation can lead to an overall deterioration of forest quality and a shift in associated species from interior specialists to edge generalists.

A simple way to measure fragmentation is through the distribution of forest block sizes created by the road network. Roads affect forest systems primarily by providing access into forest interior regions, thus decreasing the amount of sheltered secluded habitat preferred by many species for breeding. Additionally, heavily used paved roads create noisy edge habitat that many species avoid, and the roads themselves may form movement barriers to small mammals, reptiles, and amphibians.

To evaluate the extent and potential impact of roads on Northeast forests, we examined the patterns created when major roads connect to encircle contiguous blocks of forest (Map 3.4). To this end, we defined a forest block as a distinct area of forest surrounded by major roads (Tiger roads 2022. Major Road classes MTFCC = S1100, S1200), and we mapped the major-road bounded blocks comprehensively across the region (Map 3.6). The area of each block was calculated, assigned to a block size class, and the amount of each forest type within each block was summarized to determine the size class distribution of different forest types (Figure 3.8). Our assumption was that the highest quality interior habitat would be found in the central core of each block, essentially the region greater than 100 meters from any major road, field or developed area, and that the effects of the fragmenting feature would decrease with the size of the blocks (Map 3.6).

Across the entire region, block size distribution patterns showed a relatively even distribution of forest block sizes (Figure 3.7 last column). Forest types differed markedly in their degree of fragmentation with boreal upland forest being the least fragmented forest type having 74 percent of its area in blocks over 250,000 acres. Central oak-pine forest, in contrast, had less than 1 percent of its distribution in blocks over 250,000 acres, and almost 19 percent of its distribution in blocks less than 5,000 acres (Figure 3.8).

Map 3.5: Northeast Road Network and Distance to Major Roads.



Map 3.6. Forest Block Size in Acres. Each area indicated a forested patch bounded on all sides by major roads.

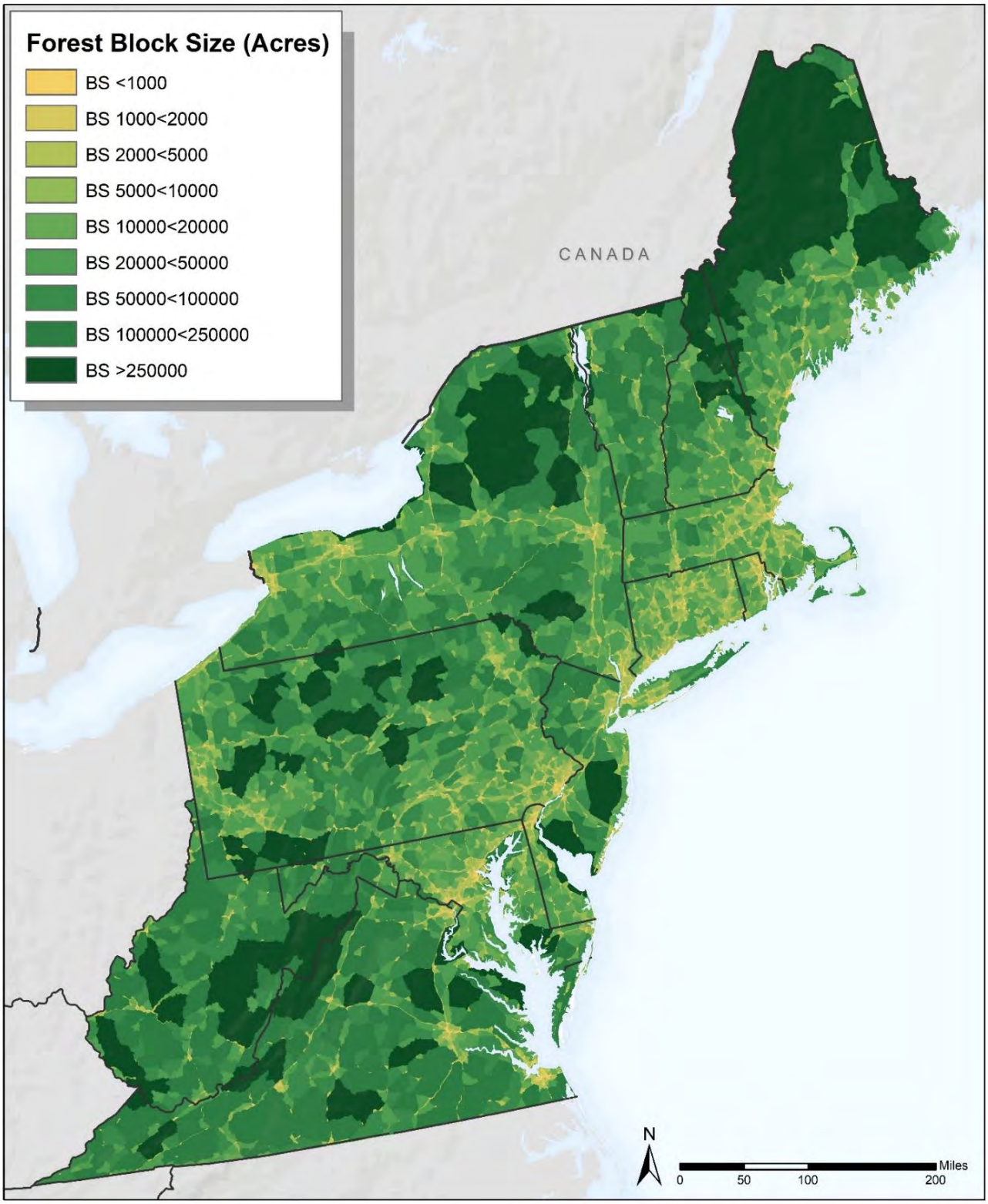
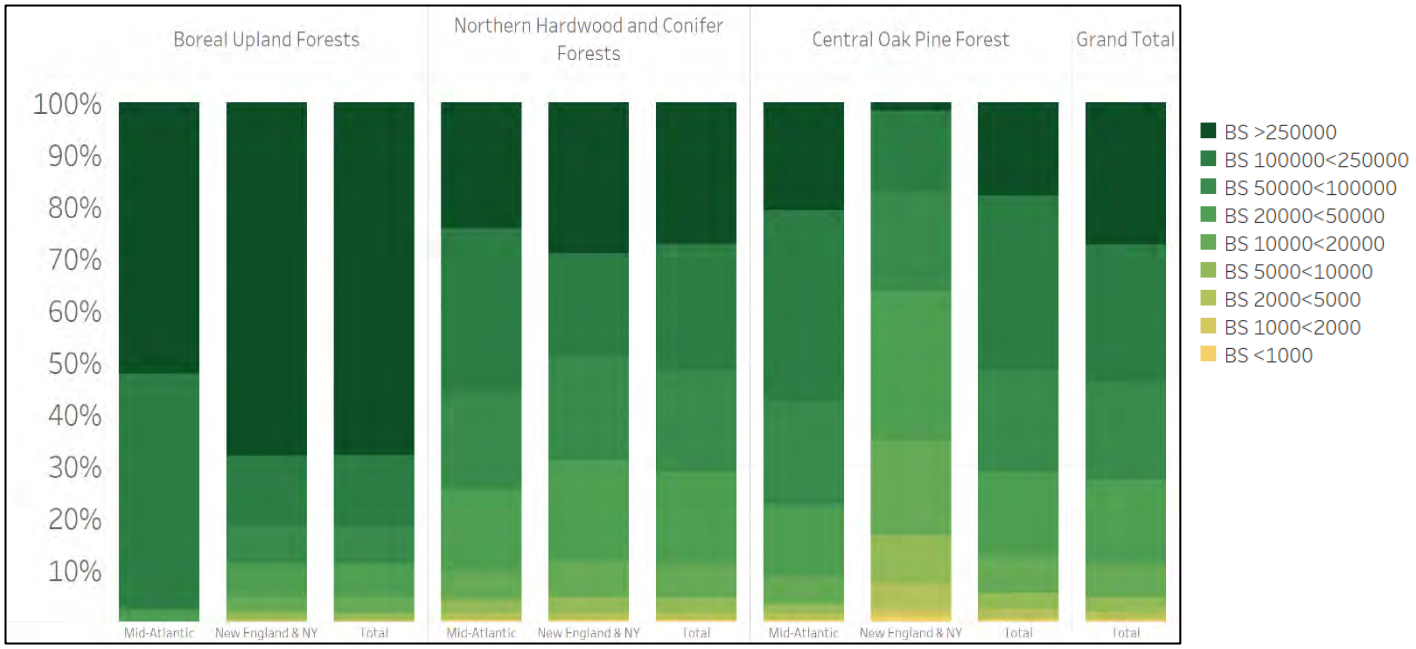


Figure 3.8. Percent of forest acres within major road bounded blocks. Size classes are in acres.



The two sub-regions differed in their degree of fragmentation. The New England and New York region had 20 percent more large blocks than the Mid-Atlantic, although both shared roughly the same amount of smaller blocks (Figure 3.8). Blocks of central oak-pine forest were larger in the Mid-Atlantic, where this forest type dominates, than in New England and New York, where it is restricted to low elevations and coastal areas which are highly developed (Figure 3.8).

Local Connectedness:

One solution to the pervasive problem of fragmentation is to preserve connectivity, which helps maintain the quality of the whole ecosystem. The metric we used to measure connectivity - local connectedness - is related to, but more sensitive than, the forest block analysis in the previous section. We measured local connectedness metric using a resistant kernel algorithm to account for the impacts of major and minor roads, as well as the density of all nearby roads and the degree of nearby conversion. The method follows Compton et al. (2010) and treats the landscape as having a gradient of permeability where highly contrasting land cover types have reduced permeability between them, and highly similar ones have enhanced permeability. Every point on the landscape is scored based on how connected it is in all directions within its local 3-km neighborhood. In applying the metric, we differentiated between developed lands, agricultural lands, and natural cover, but all forms of natural land cover were combined into one class for the analysis. The assessment of local connectivity was developed by Brad Compton at the University of Massachusetts (detail in Compton 2010). Our application was run with the 30 m 2019 National Land Cover dataset (Homer et al. 2004) land cover map supplemented with major and minor road information (Tiger Roads 2022).

For every 30 m grid cell in the region, a circular area with a 3 km radius around the cell was evaluated and the amount of resistance /permeability was calculated to create a wall-to-wall grid with cell values ranging from 0 to 100; these scores were then put on a standard normal scale (z-score) and multiplied by 1000 to scale the results from -3500 (-3.5 SD below the mean) to 3500 (3.5 SD above the mean). In the results "-3500" indicates complete impermeability (e.g. developed), 0 = average local connectedness for the region, and "3500" indicates complete permeability (e.g. natural cover with no barriers, Figure 3.9).

Figure 3.9. Aerial photo image of areas with different local connectedness scores.



Local Connectedness = 3500
Completely natural, no roads, agriculture, or development



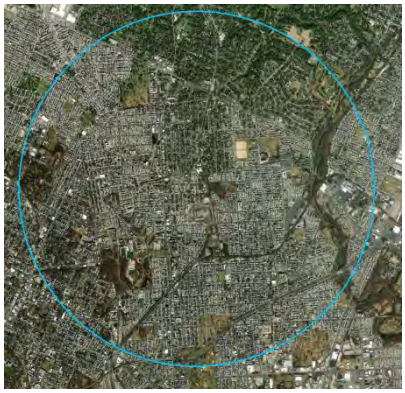
Local Connectedness = 1000
Mostly natural, some roads and minor development



Local Connectedness = 0
Mixed landscape, some natural, some agriculture/minor development/roads.

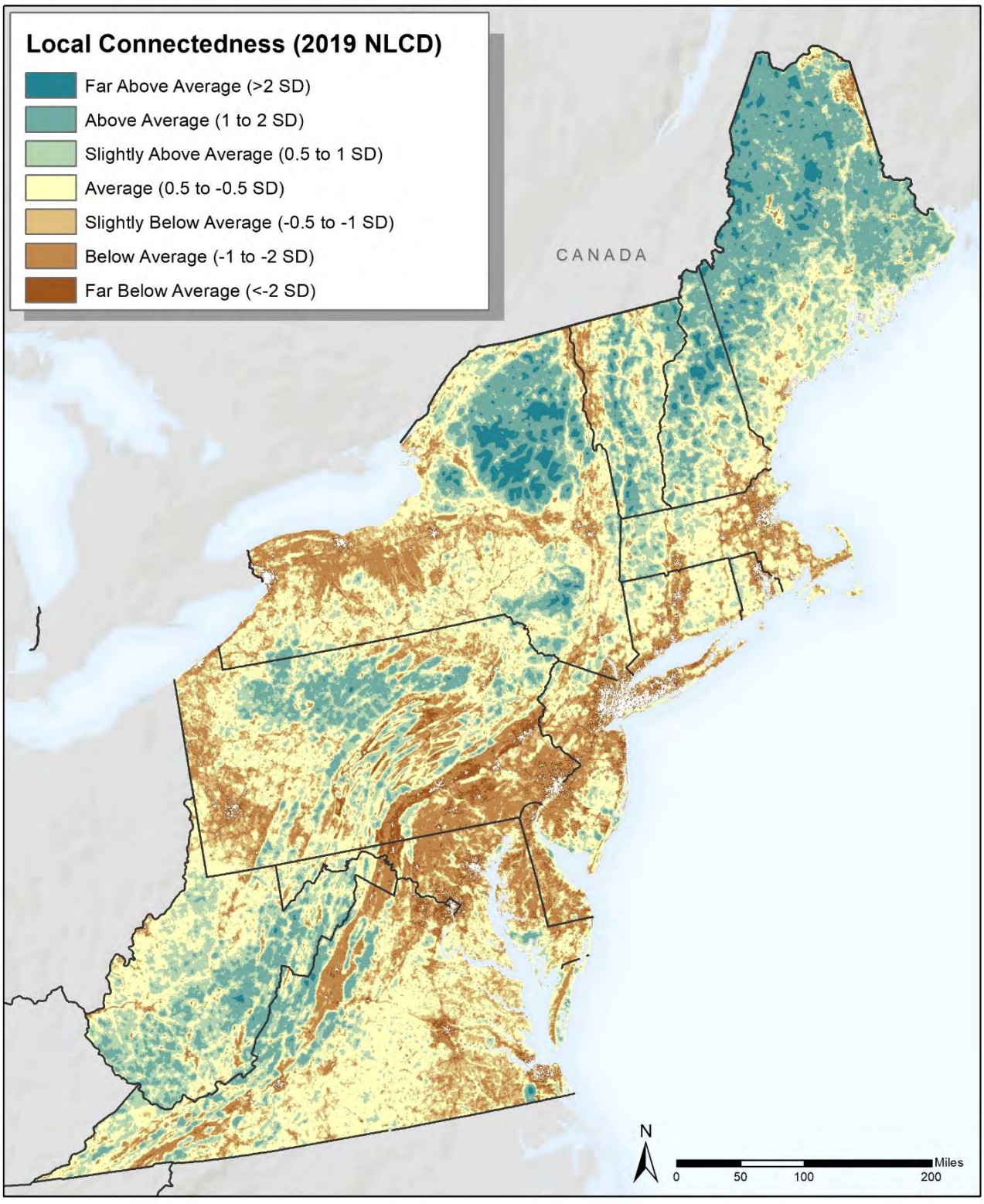


Local Connectedness = -1000
Mostly disturbed, roads, agriculture, and high density development.



Local Connectedness = -3500
High Density Development

Map 3.7. Local Connectedness Wall to Wall.

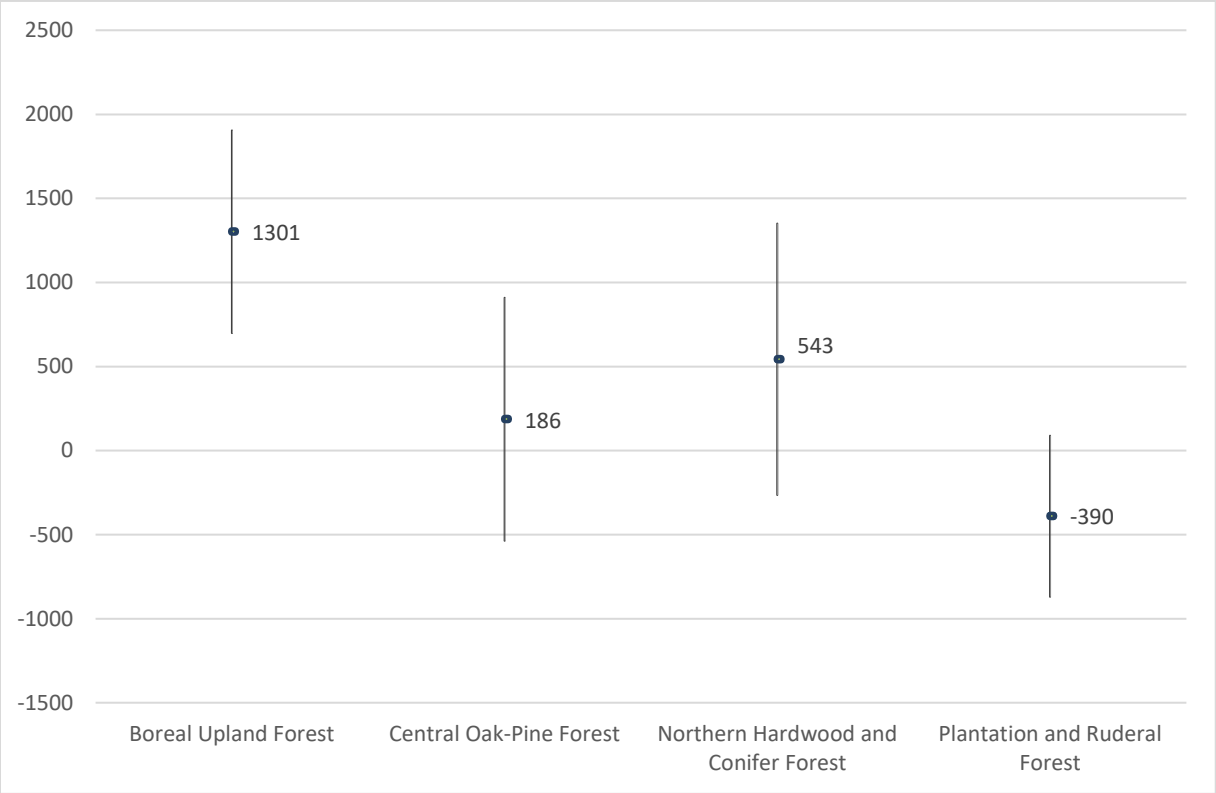


We measured the relative connectedness of all forest and the four forest types by overlaying the local connectedness grid on all cells of forest cover and tabulating the mean for all cells of each forest type.

The mean connectedness score for all forest (LC = 460, 0.46 SD) indicates that forests are more connected, on average, that the region in general (LC=0, Map 3.8). Visually, areas with this score appear to have fairly contiguous cover, broken by small patches of field, power-lines or minor roads (Figure 3.9).

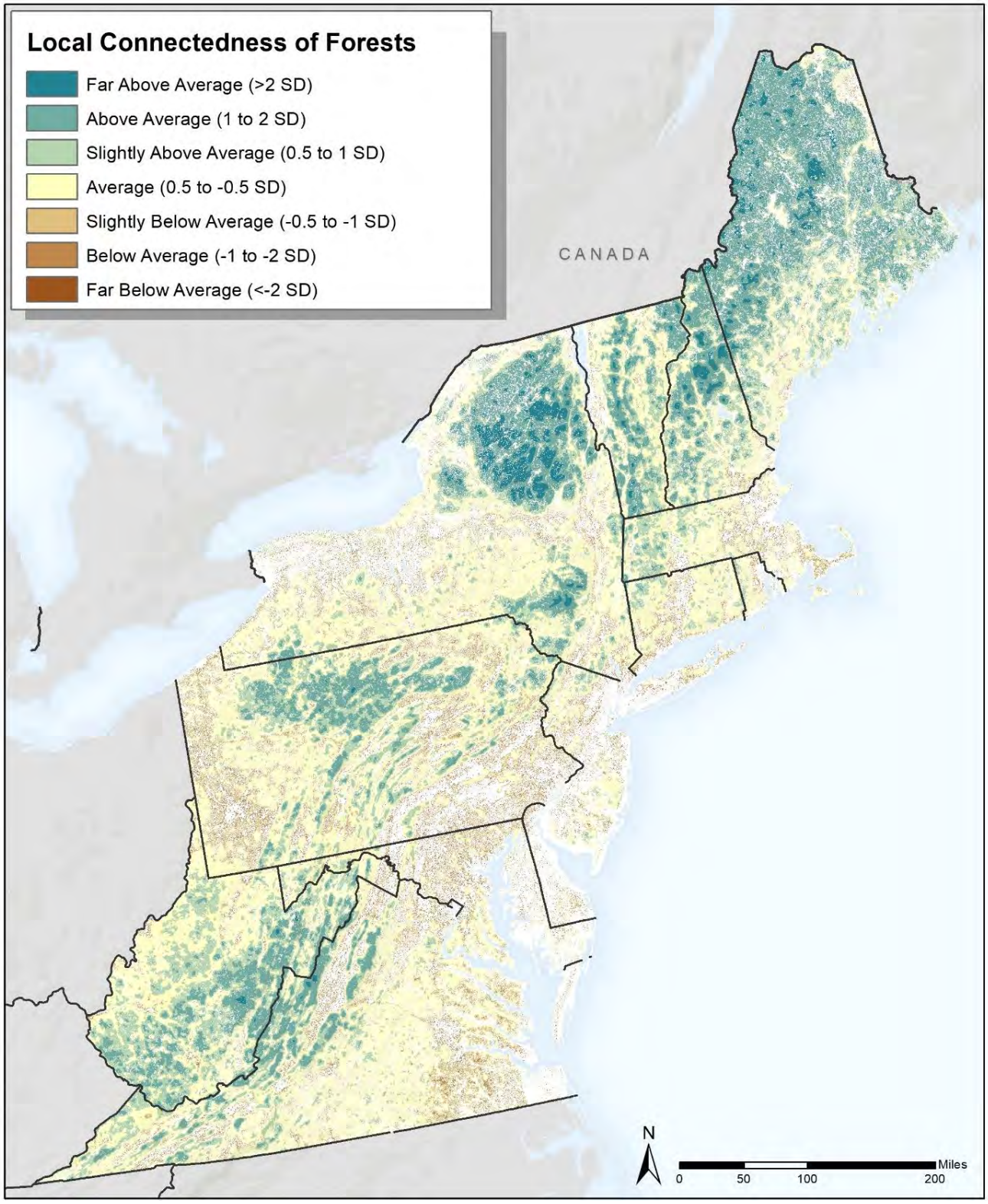
The three natural forest types differed markedly in their connectedness scores. Boreal upland forest (LC = 1321, 1.3SD) scored the highest and was the only forest to score considerably above the region average mean. Plantation and ruderal forest (LC = -397, -0.4 SD) were the only forests to score below average with the lowest score of all of the forest types. Northern Hardwood and Conifer Forest (525, 0.53 SD) and Central Oak Pine (127, 0.13 SD) both scored close to average (Figure 3.7).

Figure 3.7. Average connectedness scores for the four forest types. The numbers are in Z-scores (standard deviations) multiplied by 1000. The average score for the region is 0 and Boreal Forest (for example) score 1.3 SD above the average.



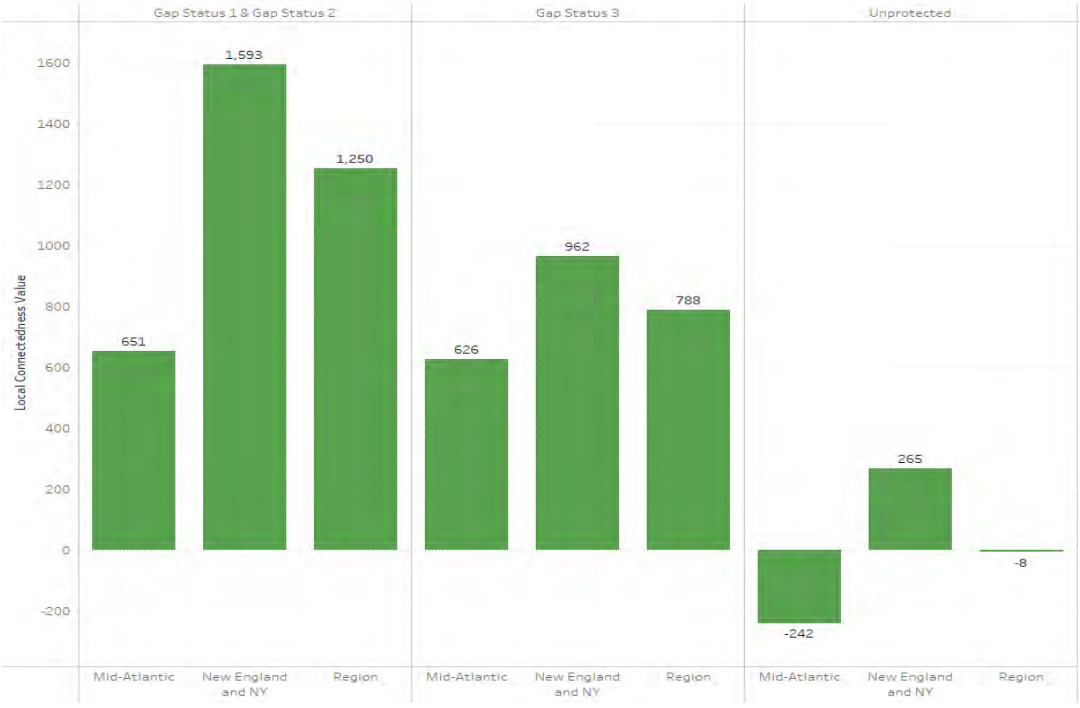
.

Map 3.8. Local Connectedness of Forests



By overlaying the 2022 conservation lands on the local connectedness grid we could examine whether conservation lands appeared to maintain local connectedness. Results of that overlay showed that forest on lands conserved for nature (GAP 1&2) had an average local connectedness score of 1250 (1.3 SD) while land conserved for multiple use lands (GAP 3) had an average of 788 (0.8 SD). Unsecured land (-8, -0.08 SD) had scores near the average. While this result was as expected, we could not say whether this pattern was due to conservation organizations selecting lands that had a high local connectedness for acquisition, or connectedness improving due to conservation. Likely it is a little of both.

Figure 3.8. Local Connectedness and Securement.

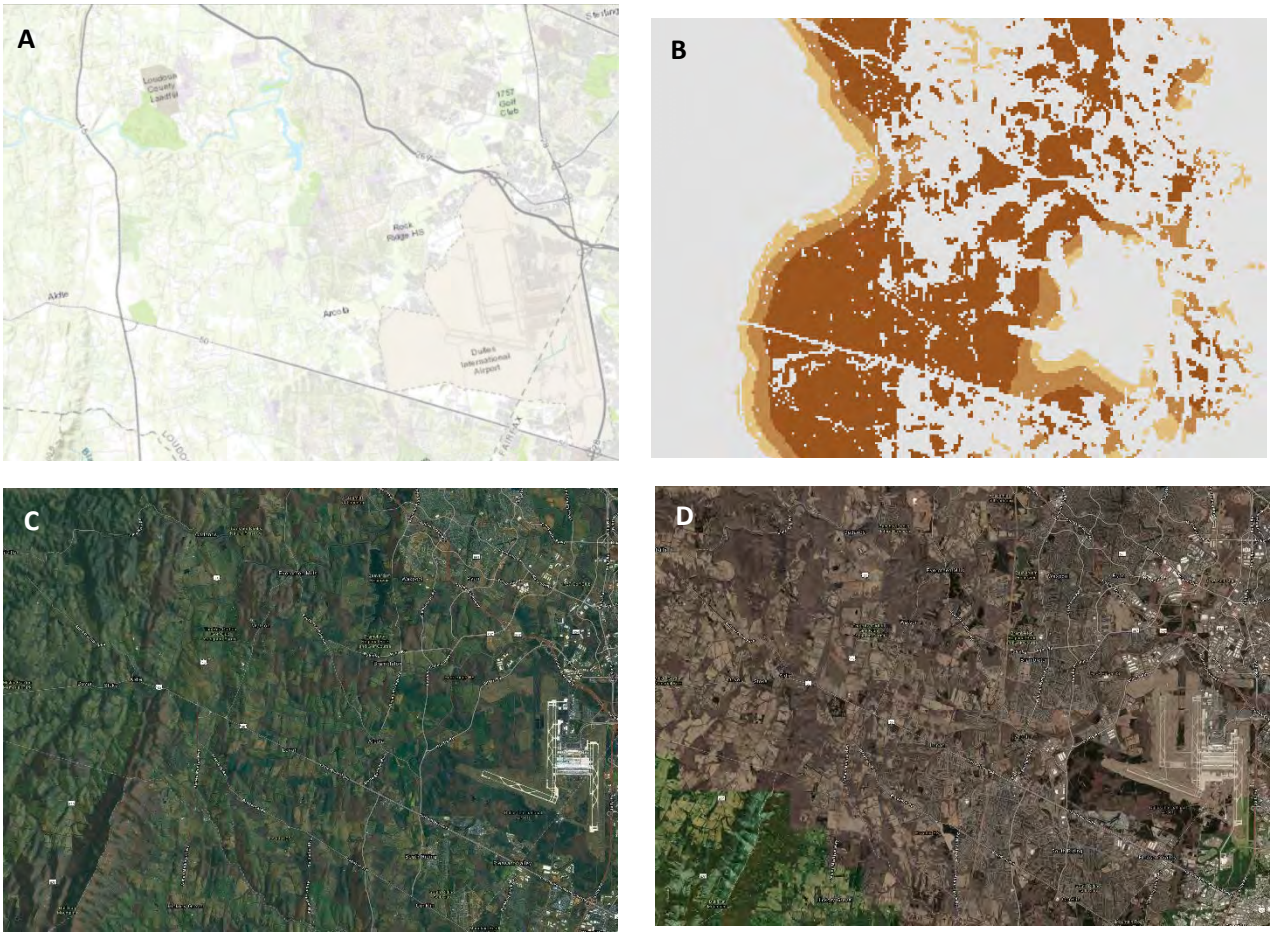


Local Connectedness also varied by state, region, and forest type. Boreal forests had high local connectedness in all states while plantation forests had low. Oak-pine forests varied from a very low in DC (LC= -1.8 SD) to relatively high in West Virginia (LC = 0.52 SD). Northern hardwood forests were generally above the mean in New England and below the mean in the Mid-Atlantic.

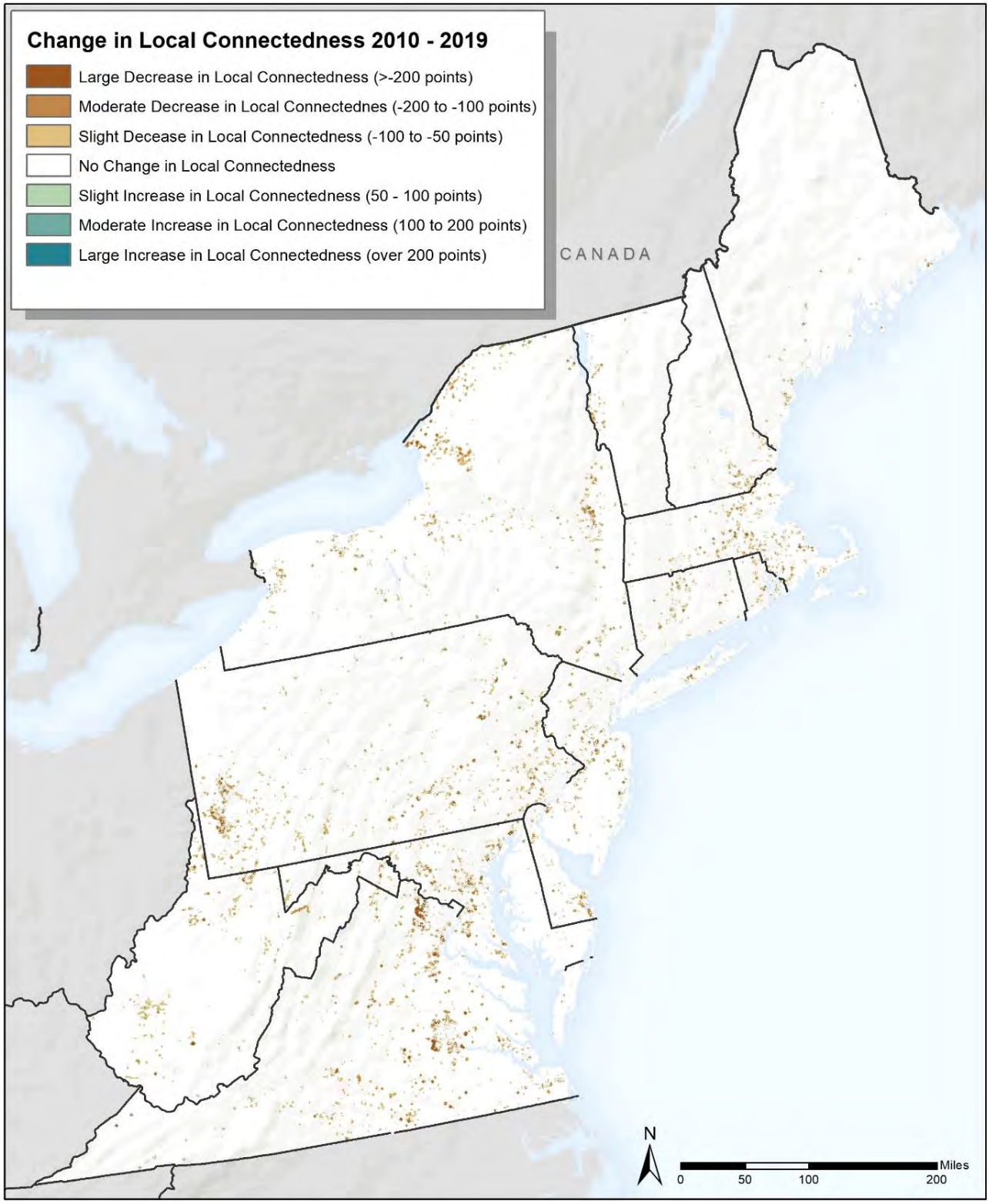
Trends in Local Connectedness (2010-2019)

We ran the local connectedness metric for two time periods: 2010 and 2019 and overlaid the data to detect any change in connectedness. The results were almost identical similar and suggest that changes in local connectedness are very localized. However, there were many places in the region where local connectedness has decreased, and decreases were much more common than increases. Many of the decreases were areas of suburban development (Figure 3.9, Map 3.9)

Figure 3.9: Local Connectedness Trends. Example area. In this area west of Dulles International Airport outside of Washington DC (A), local connectedness decreased between 2010 and 2019 (B). The darker brown areas in B indicate larger changes decreases in local connectedness. In aerial imagery from 2014 (C) the area was a mixture of agriculture, pasture, and forests. In 2020 (D), the area has been developed into medium density suburban development.



Map 3.9. Change in Local Connectedness (2010 to 2019).



Chapter 3 References

Compton, Brad. 2010. Resistant Kernal. 90m cell. University of Massachusetts. 2010.

DeGraff, R. M., and M. Yamasaki. 2001. New England Wildlife: Habitat, Natural History and Distribution. University Press of New England, Hanover, NH.

Foster, David. 2010. Changes in forest cover, population, and wildlife composition over the last three centuries. Unpublished presentation.

Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan. 2004. Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing.

LANDFIRE: LANDFIRE 1.1.0. 2009. Existing Vegetation Type layer. U.S. Department of Interior, Geological Survey. [Online]. Available: http://landfire.cr.usgs.gov/viewer/ [2010, October 28].

McCarthy, J. W. and G. Weetman. 2006. Age and size structure of gap-dynamic, old-growth boreal forest stands in newfoundland. Silva Fennica **40**(2)**:**209-230.

Poole, A. and F. Gill, (eds) 1992-ongoing. The Birds of North America Online. Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/

Tele Atlas North America, Inc., 2009. U.S. and Canada Streets Cartographic. 1:100,000 Tele Atlas StreetMap Premium v. 7.2 ESRI® Data & Maps: StreetMap. 2009 Data Update: North America. Redlands, California, USA.

Tele Atlas North America, Inc. 2009. U.S. and Canada Railroads. 1:100,000. ESRI® Data & Maps: StreetMap. 2009 Data Update: North America. Redlands, California, USA. U.S. and Canada Railroads represent the railroads of the United States and Canada.

The Nature Conservancy. 2009. Eastern U.S. Secured Lands. Various scales. Compiled from multiple sources.

LANDFIRE, Biophysical Setting Layer (LC16_BpS_200). LANDFIRE 2016 REMAP LF 2.0.0 (US Department of the Interior, Geological Survey, and US Department of Agriculture, Washington, DC, 2016). https://www.landfire.gov/viewer/. Accessed 11 May 2022.

Appendix 3.1. Sections from the 2011 report that were not revised in 2022

After review of the data sources and discussion with our 2022 steering committee, it was agreed that we would not revise these three sections as the results were unlikely to have changed in ways detectable by our methods. We include them here for completeness sake.

Forest Disturbance:

Forest Disturbance: Eastern forests are subject to an array of natural disturbances and over time these structure the ecosystem. Disturbances have several benefits, as patches of tree damage free up resources such as light and water, and contribute nutrients and woody debris to the soil. Periodic insect outbreaks may be accompanied by irruptions of specialist bird species, and fires may stimulate the regenerations of particular species. This constant adjusting to the perpetual cycles of disturbances creates a shifting mosaic of ages and composition in an old forest.

Natural Disturbance Types in FIA

Ice: snapping of branches or crown by ice load

Wind: blowdowns and breakage from downburst and hurricanes

Fire: mortality or scarring from crown and understory fires

Flood: mortality or stress from flooding

Drought: mortality due to insufficient water availability

Animal: damage by deer, porcupine, beaver

Insect: leaf and bark damage by insects

Vegetation: competition or suppression by vines etc.

To understand the extent of various forest disturbances we again used the FIA data, in which primary disturbances were noted by field crews when the data is collected. From this information it was possible to create a disturbance profile for each forest types (Figure 3.1A.1). Importantly, 96 % of the forest stands showed no effects from natural disturbance; the pie-charts and damage percentages shown in Figure 3.1A.1reflect only the 4 % of the samples that had evidence of disturbance. Harvesting is treated as a special case of disturbance by FIA and is tracked separately; we also examined it separately.

Among all forests, ice was the predominant natural disturbance accounting for 24 % of all observed tree damage (Figure 3.1A.1). The next three most common disturbances were all biotic: animals, vegetation, and insects. Upland boreal forests had simpler disturbance regimes, ice and wind were the prevalent disturbances and five types accounted for all the observed damage. Northern hardwood forests had more complex disturbance profiles with evidence of nine disturbance types, and dominated by ice and animal damage. Oak-pine forests were similar to northern hardwoods but differed in having a larger component of fire and vegetation impacts, and less ice damage.

We examined forest harvesting patterns separately from disturbance using the treatment information recorded for each stand that indicated whether the stand was recently cut, or if it showed signs of harvest preparation. Over all forests types, 10 % showed some evidence of harvest (Figure 3.1A.2). More than twice as much harvesting was found in the upland boreal forest stands than in the oak pine forests, the former having evidence of cutting in 14 % of the stands, and the latter in 6 %.

Figure 3.1A.1. Disturbances and forest types: The relative amounts of disturbances affecting forest.

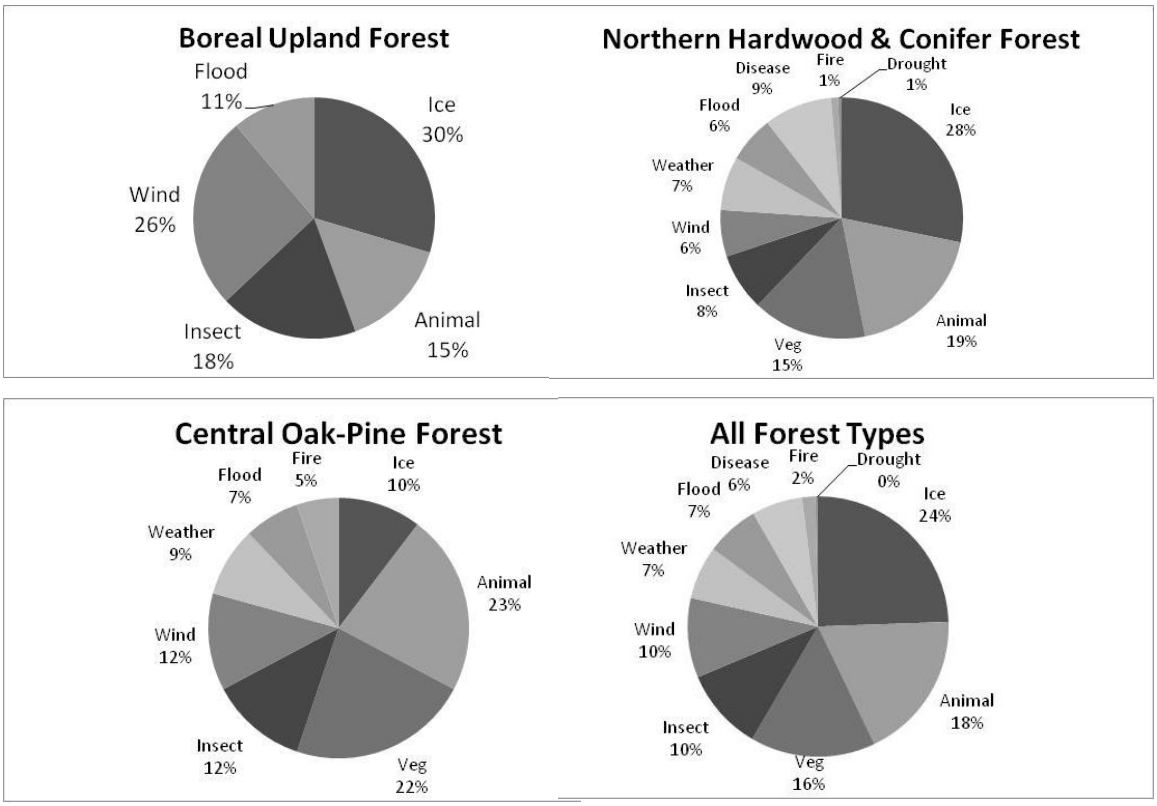
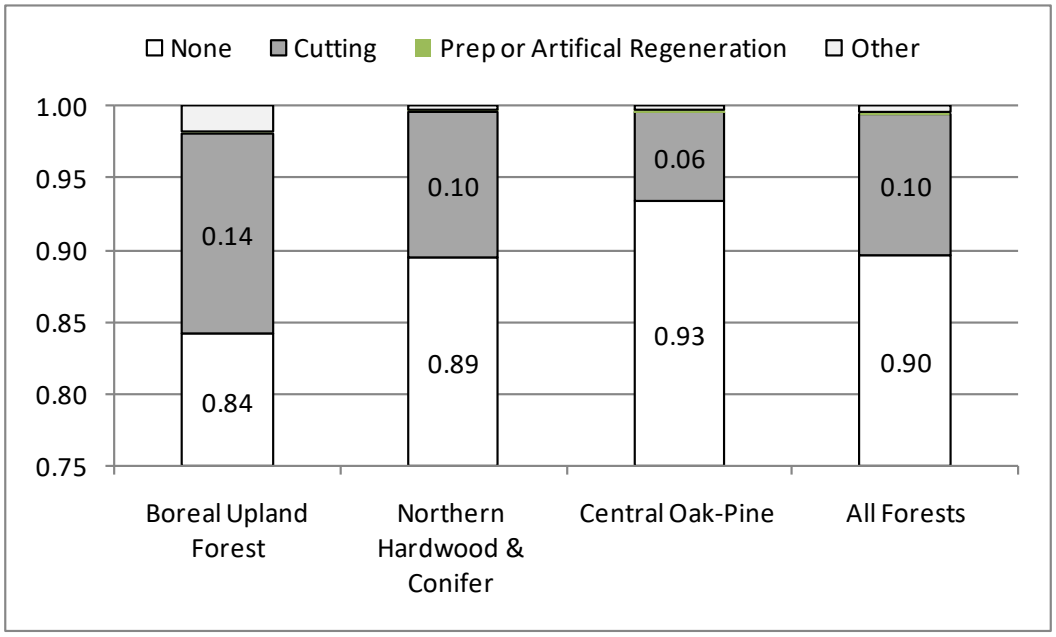


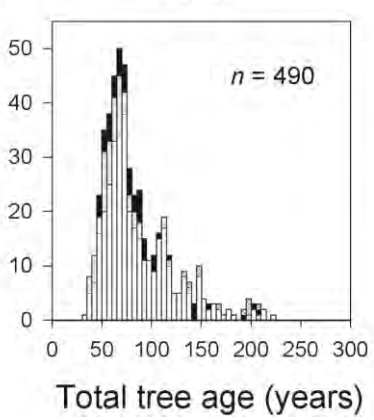
Figure 3.1A.2. Percent harvest by forest type.



Forest Stand Age, Size and Height.

Age and Size Structure: The age and size structure of a forest provides a picture of ecosystem development. Over centuries, an unmanaged forest will develop a complex structural heterogeneity characteristic of the classic self-regenerating uneven-aged old growth stand (Figure 3.1A.3). In contrast, a young or heavily managed forest is more likely to have an even age structure with most trees being close in age, and the spread of ages approximating a normal distribution with spikes of recruitment to the left of the mean.

Figure 3.1A.3. Characteristic old growth plots of a boreal forest stand. The chart shows the uneven age size classes as spikes in older age classes (adopted from McCarthy and Weetman 2006).



Note the low amount of regeneration and the high frequencies of trees over 100 years of age.

In 2011, we used USDA Forest Service's Forest Inventory and Analysis (FIA) data to assess the age and size structure of forests in the region and we did not redo this analysis in 2021 as we did not expect that it would detect changes. Instead, we analyzed and newly available dataset on forest height.

Here is a brief review of the 2011 methods and results. FIA is an annual and continuous forest census, designed to collect the information needed to evaluate whether current forest management practices are sustainable in the long run. The survey collects data on tree species composition, size, and health of trees; tree growth, mortality, and removals by harvest. More information on the program is available here: http://fia.fs.fed.us/

We obtained all 6,952 FIA samples points available for this region from USFS, with each point containing information on its tree composition, age, and size structure. To connect the FIA data with the maps of forest types, we overlaid the points on the forest type data layer and assigned each point to one of the four major forest types. Note that the FIA point locations we received were slightly generalized to protect the actual location of the plot, so there may be some error associated with these assignments; presumably the error was distributed evenly across the forest types so as not to skew the results.

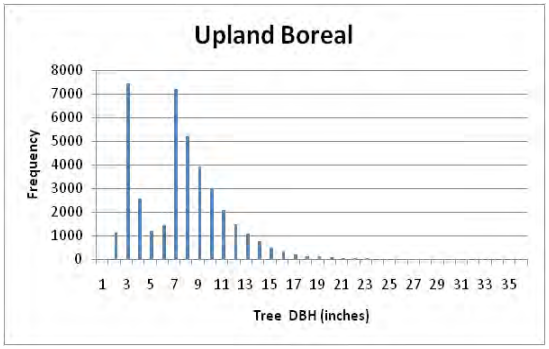
We assessed forest age and size structure at two scales: across-stands and within stands. To examine the across-stand structure we tabulated the average stand age for each forest type using the FIA field "stand age," and examined the stand age distributions across all stands in the region using histograms to show the frequency of age classes (Figure 3.1A.4). Across all stands, we expected a wide range of stand ages

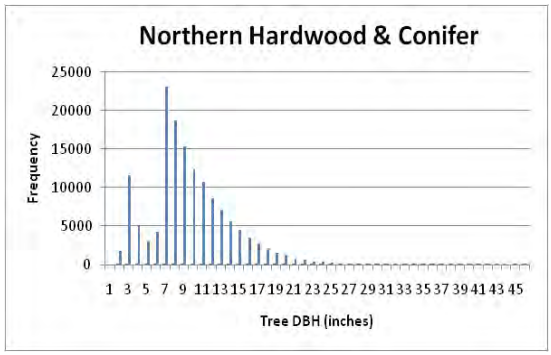
indicating forests with different cutting histories and intensities, but the results showed that our forests are overwhelmingly similar in age with the average age being 60 years and most stands (68 %) averaging between 50 and 90 years old (Figure 3.1A.5). There was little difference in average stand age between forest types, although the upland boreal forest had a substantially larger component of young, 20-30 year old, stands, perhaps reflecting more active logging (Figure 3.1A.4 and 3.1A.5).

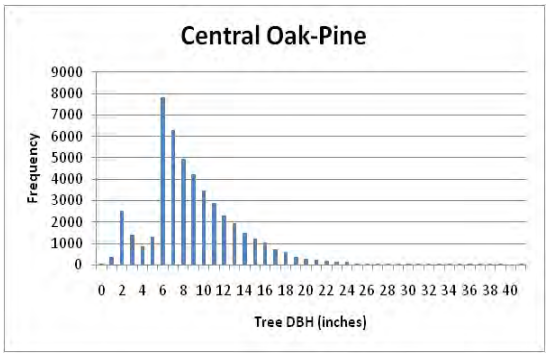
The size structure of forests is easier to measure in the field than the age structure, as the latter requires coring individual trees. Thus, the FIA data had more comprehensive information on size structure, and, because size is recorded along with each individual tree species, we could summarize the internal size structure for each sample. The results of summarizing the size structure across all plots indicated that the forest stands were almost entirely composed of small trees: 6" to 7" in diameter (Figure 3.1A.4). In the upland boreal forest the most frequent size class was even smaller, 3" in diameter, consistent with intensive logging. For the other two forest types, the most frequent size class was 6" to 7" in diameter, with the profiles of both types showing small spikes in the 2" to 3" diameter class. Although size is not necessarily related to age, the size structure patterns corresponded strongly with the patterns of age structure.

In addition to individual tree size measurements, FIA crews make their own plot-based field assessment of size class distributions using four simple categories, recorded in the data as the "field-stand size class code." We summarized this information by forest type and found that it strongly reinforced the patterns described above (Figure 3.1A.5). The upland boreal forest was composed of 30 % seedlings and saplings under 5" in diameter, while the northern hardwood and central oak-pine had had only 10 % of their trees this small size class; both of the latter types having the majority of their trees in size class 3 (9-20" in diameter). No significant component of any forest types was in the larger size classes 4 or 5, indicating that in none of the almost 7,000 samples was the plurality of the canopy cover made up of trees over 20" in diameter. The results suggest that the forests in this region are not simply growing back after 19th century clearing but are actively being maintained in a young state with small diameter trees.

Figure 3.1A.4. Stand level size structure of forests in the Northeast and Mid-Atlantic. The figures are based on all FIA samples that contained diameter at breast height (DBH) information for all trees. For each forest type, this amounts to the following: Upland Boreal (40,266 trees), Northern Hardwood and Conifer (145,832 trees), Central Oak-Pine (47,309 trees), Plantation and Ruderal (not shown 5664 trees).







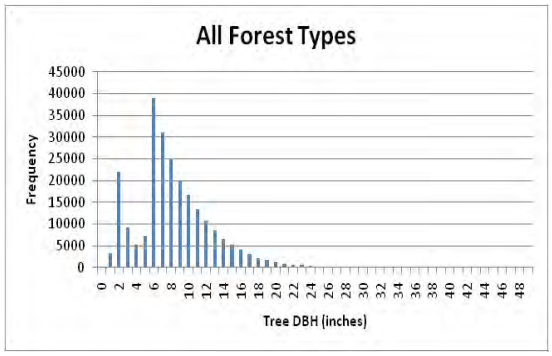
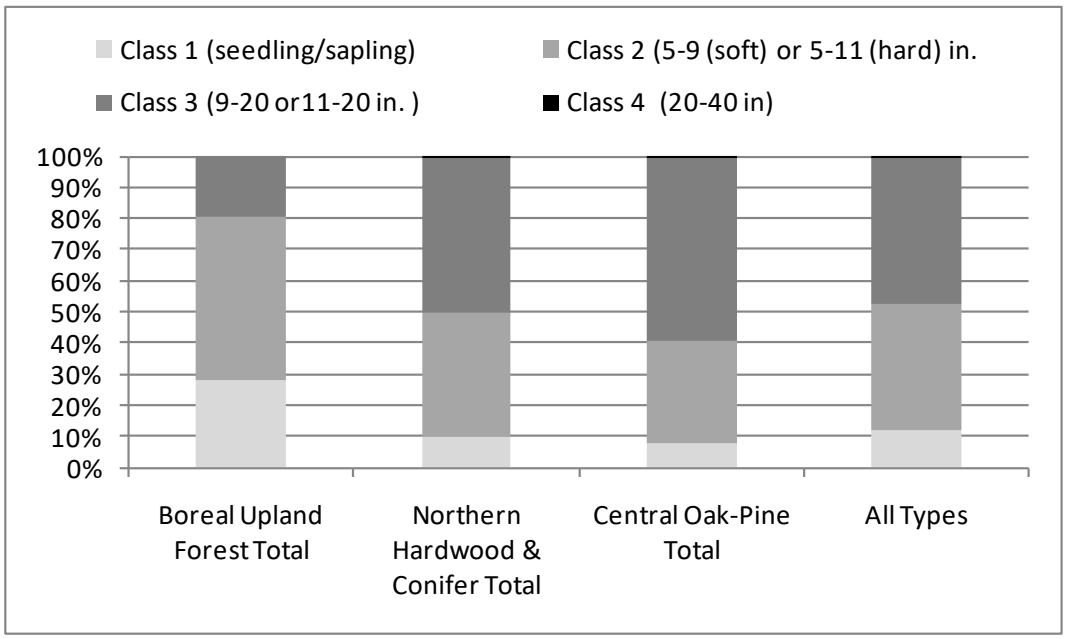


Figure 3.1A.5. Size structure classes for the forest types based on the field stand-size code. This is a field assigned classification where Class 1 = Seedlings, saplings, two-thirds of stand less than 5 inches, Class 2 = one-third of crown cover is in trees greater than 5 inches and the plurality of cover is softwoods 5-9 inches or softwoods 5-11 inches in diameter, Class 3 = plurality of cover is softwoods 9-20 inches or softwoods 11-20 inches in diameter, and Class 4 = plurality of crown cover is 20-40 inches in diameter.



Trends in Forest Bird Abundance

Changes in the abundance of forest breeding birds may give some indication of forest quality and condition. However, because abundance shifts in any individual species may be unrelated to local forest characteristics, bird data is most telling when they show consistent trends across many species and many states. We identified a set of breeding species associated with each of the four forest types based on a published list of preferred breeding habitat for northeast wildlife (DeGraaf and Yamasaki, 2001), and then used breeding bird survey data to examine their regional abundance patterns over the last four decades. The breeding bird survey (BBS) is a long-term, large-scale, avian monitoring program initiated in 1966 to track the status and trends of North American bird populations, and coordinated in the US by the USGS Patuxent Wildlife Research Center. More information on the program may be found here: http://www.pwrc.usgs.gov/bbs/.

The breeding bird survey annually collects bird population data along roadside routes allowing users to inspect trends occurring within states, regions, and continentally. We summarized statistically significant declines and increases for each species in each state, using only species for which there was adequate data (category blue or yellow). Next, we looked at the data across all states to examine how consistent the trend was across the region. In the tables below, for each species we show whether there was a consistent trend across states, whether it was an increase, decrease or mixed signal, how many states it was detected in, and whether the trend was apparent at both the 40 year time interval and a more recent 20 year time interval.

Upland Boreal Forest: DeGraaf and Yamasaki (2001) list 32 species as breeding in spruce or fir forests and the breeding bird survey had sufficient data on 19 of them to examine temporal trends. Results indicated more consistent increases than declines, with four species: **magnolia warbler, red-breasted nuthatch, northern parula,** and **yellow-rumped warbler**, increasing in three or four states over both (Table 3.1A.1). Mild declines were apparent in **purple finch** in four states. **Olive-sided flycatchers** have sharply declined in two states over forty years. In the last twenty years, **yellow warblers** have declined in five states and **Nashville warblers** in two, suggesting some concern about these species.

Table 3.1A.1. Forty year trends in the abundance of bird species associated with Boreal Upland Forests. DNS = Declining or not Significant, INS = Increasing or not significant, NS = Not significant. Data quality codes: B= blue adequate data, Y = yellow, usable but with significant gaps, R = red data not usable. The total possible states for this group was six.

BOREAL UPLAND FOREST	40 Year Trend (1966-2007)					20 Year Trend (1980-2007)				
SPECIES	Status	Declines (# of states)	Increases (# of states)	Data Quality	Regional Trend	Status	Declines (# of states)	Increases (# of states)	Data Quality	Regional Trend
Purple Finch	DNS	4	0	B	-0.6	DNS	2	0	B	0.5
Blackburnian Warbler	DNS	2	0	B	0.6	DI	1	1	B	1.1
Olive-sided Flycatcher	DNS	2	0	Y	-5.1	DNS	2	0	Y	-6.7
Bay-breasted Warbler	DNS	1	0	Y	-1	NS	0	0	Y	-1.3
Dark-eyed Junco	DNS	1	0	B	0	NS	0	0	B	0
Ruby-crowned Kinglet	DNS	1	0	B	-4.4	DNS	1	0	B	-2.7
Magnolia Warbler	INS	0	4	B	3.1	INS	0	3	B	2.1
Red-breasted Nuthatch	INS	0	4	B	1.6	INS	0	2	B	0.9
Northern Parula	INS	0	3	B	1.7	INS	0	3	B	1.8
Yellow-rumped Warbler	INS	0	3	Y	2.1	INS	0	2	Y	1.2
Swainson's Thrush	INS	0	1	B	0.5	INS	0	1	B	1
Yellow Warbler	DI	2	1	Y	-0.3	DNS	5	0	Y	-1.1
Hermit Thrush	DI	1	3	Y	2.5	INS	0	3	Y	2.8
Evening Grosbeak	DI	1	2	B	-8.1	DNS	1	0	B	-9.9
Nashville Warbler	DI	1	1	Y	-0.9	DNS	2	0	Y	-2.2
Boreal Chickadee	NS	0	0	Y	1.2	NS	0	0	Y	1.4
Cape May Warbler	NS	0	0	Y	-3.4	DNS	1	0	Y	-5
Golden-crowned Kinglet	NS	0	0	Y	1	DNS	1	0	Y	-0.3
Pine Siskin	NS	0	0	Y	-2.6	NS	0	0	Y	-2
Black-backed Woodpecker	NS	0	0	R	1.3	NS	0	0	R	-2.1
Sharp-shinned Hawk	INS	0	4	R	5.3	INS	0	2	R	3.2
Blackpoll Warbler	NS	0	0	R	-3.8	NS	0	0	R	-2.5
Gray Jay	NS	0	0	R	2.1	NS	0	0	R	-0.9
Merlin	NS	0	0	R	-5.2	NS	0	0	R	-5.6
Red Crossbill	NS	0	0	R	7.1	NS	0	0	R	-0.1
Rusty Blackbird	NS	0	0	R	10.6	NS	0	0	R	10.3
White-winged Crossbill	NS	0	0	R	0.5	NS	0	0	R	-1.2

Northern Hardwood and Conifer Forest: DeGraaf and Yamasaki (2001) list 37 species as breeding in Northern Hardwood forest; the breeding bird survey had adequate data on 27 of them (Table 3.1A.2). Of those 27, six species showed significant declines in four or more states and over multiple decades: **wood thrush, least flycatcher, common yellowthroat, black-and-white warbler, rose-breasted grosbeak**, and **scarlet tanager**. **Wood thrush** declines were the most widespread, occurring in ten states, and worsening in recent years. In contrast, five species showed increases across three or more states: **white-breasted nuthatch, ruby-throated hummingbird, black-capped chickadee, northern parula,** and **ovenbird**. Five of the six declining species are described in the literature (Poole and Gill, 1999-ongoing) as sensitive to forest fragmentation, as are ovenbirds which are increasing in three states. In contrast, the increasing chickadee, nuthatch and hummingbird are common feeder birds that appear to do well in fragmented systems. Among the mixed trend species, **pileated woodpeckers** are apparently rebounding from low population levels associated with forest clearing, but **veery** have declined in six states.

Table 3.1A.2. Forty year trends in the abundance of bird species associated with Northern Hardwood and Conifer Forest. DNS = Declining or not Significant, INS = Increasing or not significant, NS = Not significant. Data quality codes: B= blue adequate data, Y = yellow, usable but with significant gaps, R = red data not usable.

NORTHERN HARDWOOD & CONIFER	40 Year Trend (1966-2007)					20 Year Trend (1980-2007)				
SPECIES	Status	Declines (# of states)	Increases (# of states)	Data Quality	Regional Trend	Status	Declines (# of states)	Increases (# of states)	Data Quality	Regional Trend
Wood Thrush	DNS	10	0	Y	-2.2	DNS	11	0	Y	-2.3
Least Flycatcher	DNS	8	0	B	-2	DNS	8	0	B	-2.4
Common Yellowthroat	DNS	7	0	Y	-0.4	DNS	10	0	Y	-0.7
Black-and-white Warbler	DNS	6	0	B	-2.5	DNS	6	0	B	-3
Rose-breasted Grosbeak	DNS	4	0	Y	-0.8	DNS	6	0	Y	-2.2
Scarlet Tanager	DNS	4	0	Y	-0.4	DNS	4	0	Y	-0.6
Ruffed Grouse	DNS	2	0	Y	-3	DNS	1	0	Y	-7.4
Broad-winged Hawk	DNS	1	0	Y	1.2	DNS	1	0	Y	1.6
Tennessee Warbler	DNS	1	0	Y	-8.4	DNS	1	0	Y	-12.7
White-breasted Nuthatch	INS	0	5	Y	2.4	INS	0	6	Y	2.4
Ruby-thr. Hummingbird	INS	0	4	Y	2.5	DI	1	3	Y	1.5
Black-capped Chickadee	INS	0	3	B	1	DI	1	1	B	0.2
Ovenbird	INS	0	3	B	1.4	DI	2	3	B	1.1
Northern Parula	INS	0	3	B	1.7	INS	0	3	B	1.8
Philadelphia Vireo	INS	0	1	Y	12.6	INS	0	1	Y	11.1
Swainson's Thrush	INS	0	1	B	0.5	INS	0	1	B	1
Mourning Warbler	INS	0	1	Y	1	NS	0	0	Y	0.5
Prothonotary Warbler	INS	0	1	Y	1.5	NS	0	0	Y	1.6
Chestnut-sided Warbler	DI	5	1	B	-0.5	DI	4	2	B	-0.2
American Redstart	DI	4	1	B	-1.2	DI	4	2	B	-1.2
Veery	DI	4	1	Y	-1.3	DI	6	1	Y	-1.9
Red-eyed Vireo	DI	2	5	Y	1.3	DI	2	5	Y	1.2
Pileated Woodpecker	DI	1	10	B	3.1	DI	1	6	B	2.4
Hermit Thrush	DI	1	3	Y	2.5	INS	0	3	Y	2.8
Hairy Woodpecker	DI	1	2	Y	1.7	INS	0	2	Y	2.8
Downy Woodpecker	DI	1	1	Y	-0.4	DI	1	1	Y	-0.4
Nashville Warbler	DI	1	1	Y	-0.9	DNS	2	0	Y	-2.2

Central Oak-Pine Forest: DeGraaf and Yamasaki (2001) list 45 species as breeding in Oak-Pine forest; the breeding bird survey has adequate data on 40 of them (Table 3.1A.3). Of those 40, 11 showed significant declines in three or more states and over multiple decades: **eastern towhee, northern flicker, wood thrush, brown thrasher, least flycatcher, common yellowthroat, black-and-white warbler, rose-breasted grosbeak, scarlet tanager, blue-winged warbler**, and **prairie warbler** (six species overlap with northern hardwood forest). Declines of **eastern towhee** and **northern flicker** were the most widespread, occurring in 11 or more states, and continuing in recent years. In contrast, ten species showed increases in three or more states: **tufted titmouse, wild turkey, eastern bluebird, red-bellied woodpecker, pine warbler, red-tailed hawk, white-breasted nuthatch, red-breasted nuthatch, ruby-throated hummingbird**, and **ovenbird**. As for northern hardwood forests, the increasing birds are mostly common birds of rural landscapes, familiar with fragmentation, but other than ovenbird, the five declining species are known to be sensitive to forest fragmentation (Poole and Gill 1999-ongoing). Among the mixed trend species, **mourning dove** and **pileated woodpecker** are increasing in most states, while **blue jay s**howed decreases in six states.

Table 3.1A.3. Forty year trends in the abundance of bird species associated with Central Oak-Pine Forest. DNS = Declining or not Significant, INS = Increasing or not significant, NS = Not significant. Data quality codes: B= blue adequate data, Y = yellow, usable but with significant gaps, R = red data not usable.

CENTRAL OAK_PINE	40 Year Trend (1966-2007)					20 Year Trend (1980-2007)				
SPECIES	Status	Declines (# of states)	Increases (# of states)	Data Quality	Regional Trend	Status	Declines (# of states)	Increases (# of states)	Data Quality	Regional Trend
Eastern Towhee	DNS	12	0	Y	-2.6	DNS	7	0	Y	-0.7
Northern Flicker	DNS	11	0	Y	-2.9	DNS	8	0	Y	-1.1
Wood Thrush	DNS	10	0	Y	-2.2	DNS	11	0	Y	-2.3
Brown Thrasher	DNS	8	0	B	-2.4	DNS	3	0	B	-0.6
Least Flycatcher	DNS	8	0	B	-2	DNS	8	0	B	-2.4
Common Yellowthroat	DNS	7	0	Y	-0.4	DNS	10	0	Y	-0.7
Black-and-white Warbler	DNS	6	0	B	-2.5	DNS	6	0	B	-3
Rose-breasted Grosbeak	DNS	4	0	Y	-0.8	DNS	6	0	Y	-2.2
Scarlet Tanager	DNS	4	0	Y	-0.4	DNS	4	0	Y	-0.6
Blue-winged Warbler	DNS	3	0	Y	-1.2	DNS	3	0	Y	-2.9
Prairie Warbler	DNS	3	0	B	-2.1	DNS	4	0	B	-1.8
Blackburnian Warbler	DNS	2	0	B	0.6	DI	1	1	B	1.1
Canada Warbler	DNS	2	0	Y	-2.7	DNS	3	0	Y	-2.5
Whip-poor-will	DNS	2	0	Y	-2.9	DNS	2	0	Y	-3.8
Broad-winged Hawk	DNS	1	0	Y	1.2	DNS	1	0	Y	1.6
Yellow-throated Vireo	DNS	1	0	Y	0	DNS	2	0	Y	0
Tufted Titmouse	INS	0	9	Y	1.9	INS	0	8	Y	1.9
Wild Turkey	INS	0	8	Y	8.9	INS	0	7	Y	10.1
Eastern Bluebird	INS	0	7	Y	1.8	INS	0	6	Y	1.6
Red-bellied Woodpecker	INS	0	7	Y	2.4	INS	0	8	Y	3
Pine Warbler	INS	0	6	Y	1.7	INS	0	5	Y	0.3
Red-tailed Hawk	INS	0	6	Y	2.6	INS	0	1	Y	1.7
White-breasted Nuthatch	INS	0	5	Y	2.4	INS	0	6	Y	2.4
Red-breasted Nuthatch	INS	0	4	B	1.6	INS	0	2	B	0.9
Ruby-thr. Hummingbird	INS	0	4	Y	2.5	DI	1	3	Y	1.5
Ovenbird	INS	0	3	B	1.4	DI	2	3	B	1.1
Prothonotary Warbler	INS	0	1	Y	1.5	NS	0	0	Y	1.6
Worm-eating Warbler	INS	0	1	Y	-0.8	DI	1	1	Y	-1.2
Blue Jay	DI	6	2	B	-0.6	DI	6	1	B	-0.5
Gray Catbird	DI	4	2	Y	0.1	DI	3	2	Y	0.2
Black-billed Cuckoo	DI	4	1	Y	-2.6	DI	2	1	Y	-3.4
Chipping Sparrow	DI	3	4	Y	-0.8	DI	3	3	Y	-0.8
Yellow-billed Cuckoo	DI	3	1	Y	-0.6	DNS	3	0	Y	-1
Blue-gray Gnatcatcher	DI	2	1	B	-0.3	DNS	2	0	B	-0.7
Cerulean Warbler	DI	2	1	Y	-3.4	INS	0	1	Y	-1.7
Red-headed Woodpecker	DI	2	1	Y	-1.6	DNS	1	0	Y	1.8
Pileated Woodpecker	DI	1	10	B	3.1	DI	1	6	B	2.4
Mourning Dove	DI	1	8	Y	1.3	DI	2	7	Y	0.7
Hermit Thrush	DI	1	3	Y	2.5	INS	0	3	Y	2.8
Downy Woodpecker	DI	1	1	Y	-0.4	DI	1	1	Y	-0.4
Sharp-shinned Hawk	INS	0	4	R	5.3	INS	0	2	R	3.2
Barred Owl	INS	0	2	R	6	INS	0	2	R	6.3
Cooper's Hawk	INS	0	2	R	10	DI	1	3	R	7.2
Gray Jay	NS	0	0	R	2.1	NS	0	0	R	-0.9

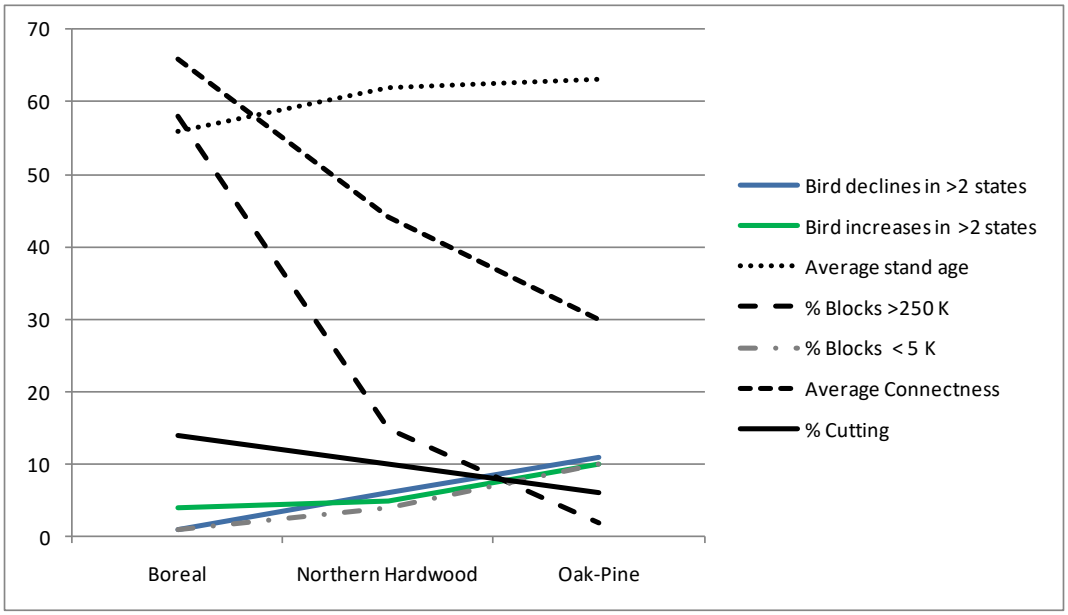
Synthesis of Species Data with Forest Condition

We tested whether significant trends in breeding birds – both increases and decreases – correlated in any way with the metrics of forest condition. To do this, we first tabulated the number of species in each forest type showing a significant trend in three or more states, and the proportion of all possible states that showed trends. Next, we tested whether these summary numbers correlated with the average connectedness, mean age, % cutting, and the % of the forest in very large or very small blocks. The results suggest that breeding bird changes were most extensive in the oak-pine forest, and changes across the three forest types correlated with increasing forest fragmentation (Figure 3.1A.6). Degree of harvest was less correlated with changes in bird abundances suggesting that logging has had a less dramatic effect of bird populations than fragmentation. This question, however, needs further research as we did not correct for the different amounts of usable data in the forest types or the degree of overlap between types.

Table 3.1A.4. Summaries of bird declines and increases. This chart shows stand age, forest fragmentation and local connectedness, by forest types. All of these averages are strongly correlated with forest type but the correlations are highest between the number of declines and the average connectedness and between the total changes in bird composition (summary of declines and increases) and the number of block less than 5,000 acres.

	Species Change in >= 3 States			Species Change in >= 30 % of All Possible States			Average stand age	% Blocks >250 K	% Blocks < 5 K	Average Connectness
Forest Types	Declines	Increases	Total Change	Declines	Increases	Total Change				
Boreal Upland	1	4	5	3	4	7	56	58	1	66
Northern Hardwood	6	5	11	6	5	11	62	15	4	44
Oak-Pine	11	10	21	9	9	18	63	2	10	30

Figure 3.1A.6. Relationships between bird declines and increases, forest fragmentation, connectivity, mean age, and degree of cutting.



Species names

American basswood (Tilia americana)
American beech (Fagus grandifolia)
American ginseng (Panax quinquefolius)
American mountain-ash (Sorbus americana)
balsam fir (Abies balsamea)
bear oak (Quercus. ilicifolia)
birch (Betula spp.)
black bugbane (Actaea racemosa)
black bugbane (Cimicifuga racemosa)
black cherry (Prunus serotina)
black oak (Quercus velutina)
Black spruce (Picea mariana)
black walnut (Juglans nigra)
blue cohosh (Caulophyllum thalictroides)
Catawba rosebay (Rhododendron catawbiense)
chalk maple (Acer leucoderme)
chestnut oak (Quercus prinus)
Clayton's sweetroot (Osmorhiza claytonia)
cucumber-tree (Magnolia acuminata)
eastern red-cedar (Juniperus virginiana)
eastern white pine (Pinus strobes)
heartleaf (Hexastylis spp.)
highland doghobble (Leucothoe fontanesiana)
jack in the pulpit (Arisaema triphyllum)
jack pine (Pinus banksiana)
mockernut hickory (Carya alba)
mountain magnolia (Magnolia fraseri)
mountain silverbell (Halesia tetraptera)
mountain woodfern (Dryopteris campyloptera)
mountain woodsorrel (Oxalis montana)
northern maidenhair (Adiantum pedatum)\
northern mountain-ash (Sorbus decora)
northern red oak (Quercus rubra)
paper birch (Betula papyrifera)
pitch pine (Pinus rigida)
red hickory (Carya ovalis)
red maple (Acer rubrum)
red pine (Pinus resinosa)
red spruce (Picea rubens)
running strawberry bush (Euonymus obovatus)
scarlet oak (Quercus coccinea)
shagbark hickory (Carya ovata)
smooth Solomon's seal (Polygonatum biflorum)
sourwood (Oxydendrum arboreum)
southern sugar maple (Acer barbatum)
Spruce (Picea spp.)
stickywilly (Galium aparine)
strawberry bush (Euonymus americana)
sugar maple (Acer saccharum)
sweet birch (Betula lenta)
Table Mountain pine (P. pungens)
tuliptree (Liriodendron tulipifera)
umbrella-tree (Magnolia tripetala)
Virginia pine (Pinus virginiana)
white ash (Fraxinus Americana)
white oak (Quercus alba)
white trillium (Trillium grandiflorum)
wild hydrangea (Hydrangea arborescens)
yellow birch (Betula alleghaniensis)
yellow buckeye (Aesculus flava)

CHAPTER

Wetlands

4

Condition and Conservation Status

Feb 2023

M. Clark, M.G. Anderson, & A. Olivero Sheldon

From marshes, to swamps, to bogs, to fens, to floodplains, wetlands are among the most productive and diverse ecosystems on earth, and a truly distinctive feature of the eastern landscape. In this region, there are over 11.6 million acres of wetlands, representing 8 %of the land area. In this chapter, we examine their loss and degradation, as well as their conservation, and consider the implications of these factors to wildlife.

Distribution, Loss, and Protection: An estimated 21 million acres of the region was once covered by swamps, peatlands, floodplains, and marshes supporting 1,500 obligate or facultative plants and at least 475 rare species. Today, 27% of that historic wetland area has been permanently converted to development (13%) or industrial agriculture (13%). At the same time wetland appreciation and conservation had grown and 20% of the remaining wetland are now conserved primarily for nature (8%) or for multiple uses (12%), a ratio of 1.3 acres of habitat lost for every one acre conserved.

Recent Conservation Trends 2001-2012. In the last two decades, conservation of wetlands has increased, and regulations have been enacted to prevent wetland conversion. As a result, wetland conservation surpassed habitat conversion and loss almost 250 to 1, reversing the historic trend. This pattern held across all wetland types. Emergent marshes lost 21,000 acres to development but conserved 602,000. Alluvial floodplain and riparian wetlands lost 5000 acres but conserved 2.1 million acres. Wetland extent have been remarkably stable through this time with 99% unchanged.

Local Connectedness: Wetlands are not as intact and connected as they used to be. Our previous study found that 66% all the region's wetlands were close to paved roads and had development or agriculture directly in their buffer zones. Our reassessment with a more comprehensive analysis found that regardless of wetland type, all had measures of connectedness and fragmentation equal to the average of the region. This equates to a mixed landscape, with some natural elements, some agriculture, some minor development, and roads. Conserved wetlands had a very different connectedness profile with wetlands conserved for nature having a score far above the average (1.8 SD), and wetlands conserved on multiple use land also being above average (0.5 SD).

Wetland Types and their Fauna

Wetland are vegetated habitats dominated by rooted plants that thrive in saturated soils. The Northeast Terrestrial Habitat Map (NETHM, Ferree and Anderson 2013) recognizes 35 wetland types covering 11 million acres. They range in size from tiny limestone fens that form where alkaline water is discharged on a hillslope to extensive blanket bogs and peatlands that cover thousands of acres. Depending on their hydrology, wetlands maybe dominated by trees (swamps and forested peatlands), shrubs (bogs and shrub swamps) or emergent herbaceous vegetation (marshes, wet meadows, fens), and this difference in structure greatly influences their composition and wildlife communities. Wetlands, however, are extremely dynamic ecosystems that constantly change. During wet years, emergent marshes may expand in size while during dry years they contract as trees and shrubs reclaim ground.

For this report we group wetlands into three basic types based on their hydrology (Table 4.1, Map 4.1) and we crosswalk our names to the NE Lexicon Project:

- Basin Wetland: swamps, marshes and peatland that form in depressions where surface water collects (*Lexicon = non-tidal wetland*):
- Alluvial Wetland: forests and marshes that form in areas subject to regular flooding by stream overflow and ground water discharge (*Lexicon = land-water interface)*
- Tidal Wetland: Marshes and forests that form in places of regular tidal inundation (*Lexicon = tidal wetlands and flats)*

Basin Wetland (*Lexicon: Non-Tidal Wetland*): Basin wetlands form the vast majority (72%) of wetlands in the Northeast including the familiar bogs, swamps, marshes, peatlands, shrub swamps, wet meadow, and fens - virtually any wetland not associated with a flowing river or tidal flooding. They are commonly subdivided into two structurally distinct types based on the dominance of woody or herbaceous vegetation:

> *Woody Wetlands*: Wetlands dominated by trees and shrubs that tolerate occasional inundation or semipermanent saturation. They often surround and intermix with permanently saturated marshes. It is no surprise that in our predominantly forested region, woody wetlands dominate, making up **67% of wetlands** by total area. Throughout the region woody wetlands support birds like barred owl, alder flycatcher, Wilson's snipe, northern harrier, northern waterthrush, swamp sparrow, willow flycatcher, yellow-bellied flycatcher blue-headed vireo, great-crested flycatcher, green heron, green-winged teal, veery, and wood duck. Black bear, northern flying squirrel, snowshoe hare, northern leopard frog, and spotted turtle may be abundant
>
> *Emergent Herbaceous Wetlands:* Wetlands dominated by herbaceous perennials like cattail, bullrush, tussock sedge, and rush. Tolerating permanently saturated, wetter soils than the woody wetlands, they are found throughout the region in depressions where water and organic matter accumulates. These wetlands comprise **5% of the total wetlands** by area and collectively cover over half a million acres. They sustain an abundant and diverse invertebrate fauna and support an array of wildlife including least bittern, Virginia rail, sedge wren, king rail, marsh wren, yellow rail, red-winged blackbird, great blue heron, least bittern, marsh wren, pied-billed grebe, sora, swamp sparrow, muskrat, racoon, bog lemming, water shrew, lesser siren, and boreal chorus frog,

To map basin wetlands. we used the latest 2019 National Land Cover Dataset (Dewitz, J., and U.S. Geological Survey, 2021) to identify the extent of current wetlands. These were separated into tidal and non-tidal wetlands based on distance to coast, landscape setting, and overlay analysis (see below). The non-tidal wetlands were further separated into land-water interface (Alluvial systems) based on position in a river floodplain (See below). The remaining wetlands were considered Basin Wetlands. Basin wetlands were classified into their two physiognomies using the NLCD dataset: woody wetlands (woody vegetation) or emergent herbaceous wetlands (emergent herbaceous).

Alluvial Wetlands (*Lexicon: Land-Water Interface*): Alluvial wetland exist in the land water interface associated with the riparian and floodplain region around flowing streams and rivers. The wetlands tolerate periodic inundation and during floods provide critical nursery, breeding and feeding areas for fish and a wide variety of wildlife. Alluvial wetlands are common throughout the region, composing **19% of total wetlands** by area. Floodplain associated species include bald eagle, cerulean warbler, red-shouldered hawk, veery, warbling vireo, wood duck, kingfisher, yellow warbler, big brown bat, eastern pipistrelle, little brown myotis, northern long-eared bat, long-tailed weasel, mink, river otter, moose, and northern short-tailed shrew.

To map alluvial wetlands, we used current wetlands from the 2019 NLCD overlaid with the 100-year floodplain area (Bates et al, 2021, First Street Foundation, 2020) or wetlands that were identified as floodplain in the NETHM (Ferree and Anderson, 2013) including: Laurentian-Acadian Large River Floodplain, North-Central Appalachian Large River Floodplain, North-Central Interior Large River Floodplain, North-Central Interior Large River Floodplain.

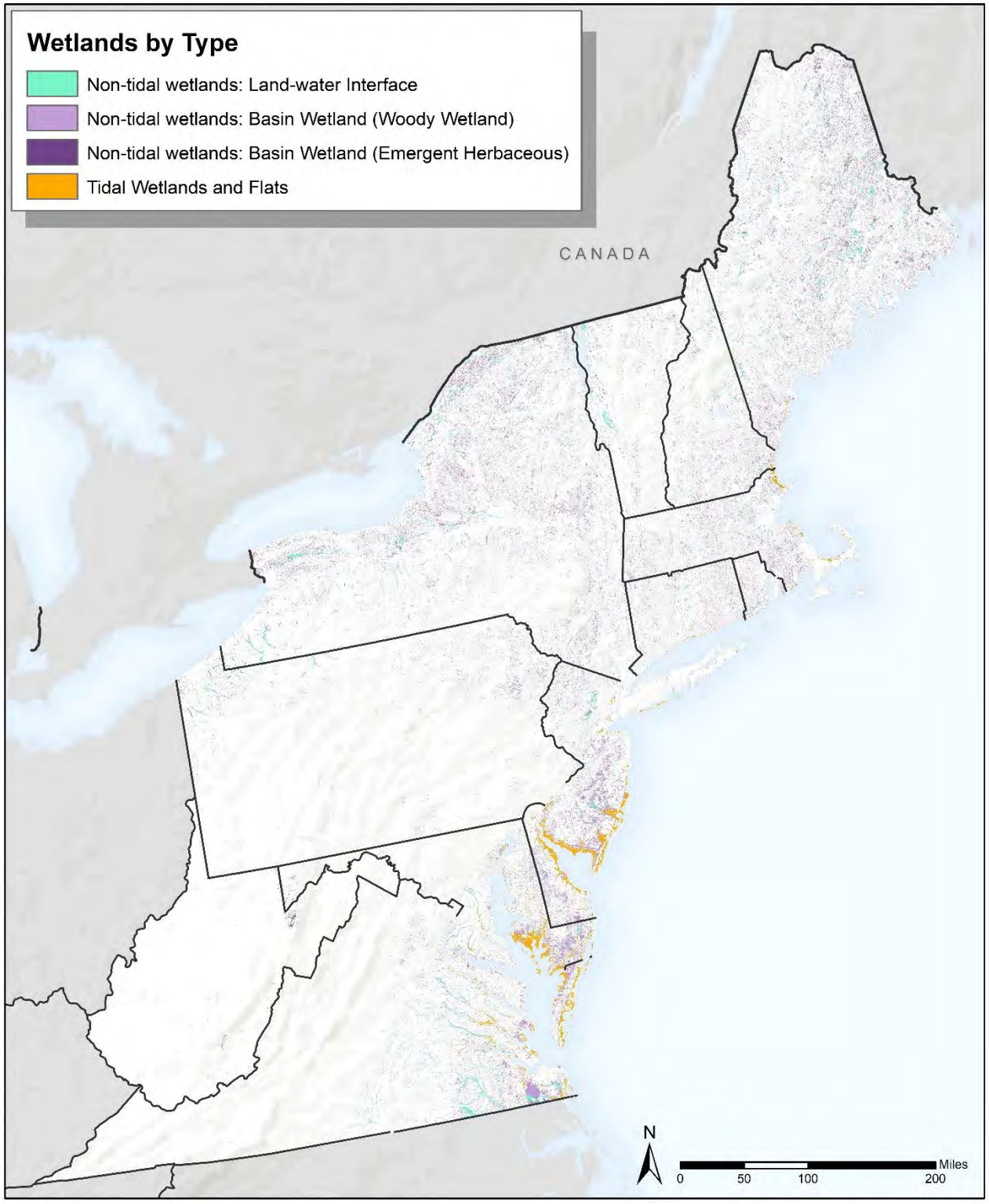
Tidal Wetlands (*Lexicon = Tidal Wetlands and Flats*): Tidal wetlands form in the intertidal region inundated regularly by salt water and occasionally exposed to freshwater. Only a few plant species, such as cordgrass, saltgrass, and glasswort (all of them herbaceous perennials), can tolerate such conditions and these species dominate these unique wetlands. Tidal wetlands provide habitat for a remarkable set of specially adapted species and are important feeding areas for many birds. When inundated they become nursery areas for several marine species. Fringing the coast from Virginia to Maine, tidal wetlands and flats account for **9% of the region's total wetlands.** In the Mid-Atlantic coastal states, they account for between a fifth to a third of total wetlands by area. Species associated with tidal wetlands include saltmarsh sparrow, American oystercatcher, arctic tern, black skimmer, black-crowned night-heron, clapper rail, common tern, Forster's tern, glossy ibis, great egret, gull-billed tern, little blue heron, osprey, royal tern, willet, yellow-crowned night-heron, and North American least shrew

To map tidal wetlands, areas identified as wetlands in the NLCD 2019 were classified as tidal if they occurred as part of a tidal Complexes in TNC resilient coastal sites study (Anderson and Barnett 2017) or were mapped as tidal habitats in the NETHM. The tidal habitats in the NETHM included: Coastal Plain Tidal Swamp, Tidal Salt Marsh, Estuarine Marsh, Atlantic Coastal Plain Embayed Region Tidal Freshwater/Brackish Marsh.

Table 4.1: Distribution of Wetland Types

Sub Region	State	Emergent Basin Wetland (Non-tidal Wetland)	Woody Basin Wetland (Non-tidal Wetland)	Alluvial Wetland (Land-water Interface)	Tidal Wetlands & Flats	Total Acres
Mid-Atlantic	VA	42,794	796,599	365,665	266,104	1,471,163
	NJ	20,269	662,386	118,810	249,603	1,051,069
	MD	20,758	500,753	69,571	281,479	872,562
	PA	49,564	333,218	157,739	1,732	542,252
	DE	5,826	199,528	16,765	87,731	309,850
	WV	16,342	17,179	13,965	0	47,486
	DC	7	115	265	99	487
	Mid-Atlantic Total	**155,561**	**2,509,779**	**742,780**	**886,748**	**4,294,868**
New England & New York	ME	179,153	2,006,989	583,907	33,229	2,803,277
	NY	168,224	1,982,525	553,257	39,251	2,743,257
	MA	32,600	474,365	93,224	58,818	659,007
	NH	26,058	303,978	86,862	6,904	423,802
	VT	27,155	208,150	88,102		323,407
	CT	10,278	229,363	39,538	14,836	294,016
	RI	3,009	68,406	11,707	6,437	89,559
	New England & New York Total	**446,477**	**5,273,777**	**1,456,597**	**159,475**	**7,336,326**
Total Acres		**602,038**	**7,783,556**	**2,199,376**	**1,046,223**	**11,631,194**

Map 4.1. Distribution of Wetlands by Type.



Distribution, Loss, and Protection Status

Wetland Conversion and Loss:

Wetlands comprise only 7 %of the total land area in this region, but this small percentage of land supports a large piece of the total biodiversity of the region, including over 1,500 plants considered obligate or facultative wetland species (Reed and Porter 1988), and at least 475 rare species (see chapter on open habitats). The immense value of wetlands was unrecognized for most of the last two centuries during which time they were systematically drained to create land suitable for agriculture and development.

How many wetlands were lost to conversion? Using historical literature, Dahl (1990) estimated that across all 14 states, about 7.2 million acres were lost between 1780 and 1980. Here we revised these estimates using spatially-specific flow accumulation models combined with topographic position to identify areas where wetlands naturally occur. Our model encompassed all the known wetlands mapped by NLCD 2019, but also identified wet basins where wetlands would be expected to occur but that are now filled with development or agriculture. Assuming all potentially suitable wetland habitat now occupied by development or agriculture can be considered converted wetlands, the analysis suggests 6.9 million acres have been converted: 28% of all historic wetland area. Our estimate was slightly smaller than Dahl's but agrees in terms of pattern and magnitude of loss.

Using a spatial model allowed us to quantify all the transitions apparent in the data. We found that just over 13% of the potential historic wetlands were converted to agriculture and just over 13% were converted to development (Table 4.2, Figure 4.1)**.** An additional 24% appear to have transitioned to forest, shrubland, or grasslands, although much of this area could result from misclassification in the 2019 NLCD**.** Basin wetland had the largest proportion converted (29%), followed by alluvial wetland (20%), and tidal wetland (14%) (Table 4.2, Figure 4.1b).

Transitions to upland habitats suggesting drier conditions, mostly affected basin wetland (18%) and alluvial wetland (18%) and most of that transitioned to forest. Less than 3% of tidal wetlands transitioned to forest which makes sense as these are tidally inundated. However, 8% of tidal wetlands transitioned to grassland and shrubland which could indicate drier conditions, but more likely indicates classification error as the distinction between emergent marsh or grassland can be hard to detect using remote information. We had the most confidence in the conversion to development or industrial agriculture as these state changes can be detected with remote sensing and spot checking the data confirmed them to be real in all the places we examined. This chapter does not address loss of tidal wetlands to open ocean or mudflats, but tidal wetlands are currently being lost to sea level rise.

Wetland Conservation:

Conservation of wetlands effectively began in the 1970's when their value was widely recognized, and federal and state laws were enacted to curb their loss (Mitsch and Gosselink 1986). Conservationists also increased their efforts to conserve, protect and restore existing wetlands. To quantify the amount of wetland area currently conserved, we overlaid the TNC 2022 conservation lands dataset on the wetland extent and tabulated the degree of securement these habitats have from conversion or degradation.

Table 4.2. Amounts of conversion, transition, and conservation securement in historic wetland area. The units are in acres, organized by wetland type. CRI = area converted/area conserved (GAP1-3). NRI = area converted/ area conserved for nature (GAP 1-2).

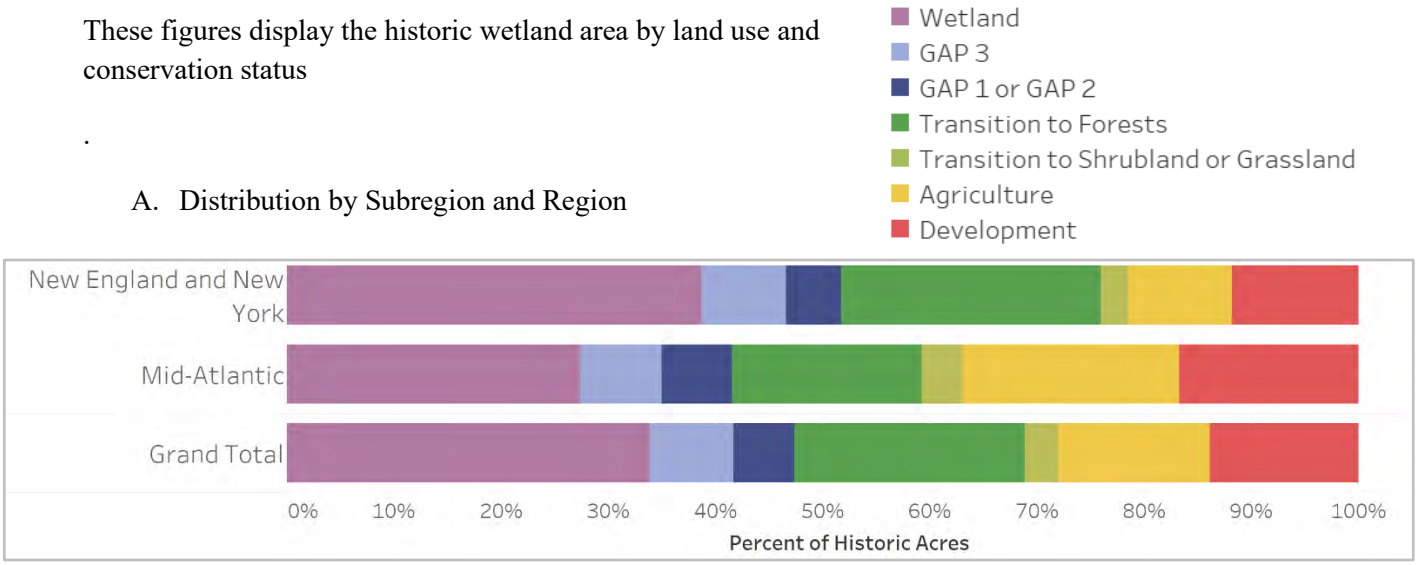
Historic Wetland Type	Current Landuse	Wetland not conserved	Wetland GAP 3	Wetland GAP 1-2	Total Current Wetlands	Transition to Forests	Transition to Shrubland/ Grassland	Agriculture	Development	Total Historic Wetlands	Total Converted to Developed Classes	Total Conserved	CRI	NRI
Basin Wetland	**Acres**	**5,463,609**	**2,035,190**	**1,091,883**	**8,590,680**	**2,993,052**	**434,956**	**2,497,268**	**2,498,978**	**17,014,934**	**4,996,245**	**3,127,072**	**1.60**	**4.58**
		32%	12%	6%		18%	3%	15%	15%		29%	18%		
(Emergent Herbaceous)	Acres	402,850	172,311	81,375	656,536	0	197,545	1,013,867	864,672	2,732,620	1,878,538	253,686	7.40	23.09
		15%	6%	3%		0%	7%	37%	32%		69%	9%		
(Woody)	Acres	5,060,759	1,862,878	1,010,508	7,934,144	2,993,052	237,411	1,483,401	1,634,306	14,282,314	3,117,707	2,873,386	1.09	3.09
	%	35%	13%	7%		21%	2%	10%	11%		22%	20%		
Tidal Wetland	**Acres**	**446,163**	**213,455**	**312,888**	**972,505**	**18,850**	**96,935**	**42,946**	**99,119**	**1,230,356**	**142,065**	**526,344**	**0.27**	**0.45**
	%	36%	17%	25%		2%	8%	3%	8%		12%	43%		
Alluvial Wetland	**Acres**	**1,351,694**	**455,898**	**260,185**	**2,067,777**	**458,676**	**69,459**	**332,031**	**242,182**	**3,170,125**	**574,212**	**716,083**	**0.80**	**2.21**
	%	43%	14%	8%		14%	2%	10%	8%		18%	23%		
All Wetlands	**Acres**	**7,261,465**	**2,704,543**	**1,664,956**	**11,630,963**	**3,470,578**	**601,350**	**2,872,244**	**2,840,279**	**21,415,415**	**5,712,523**	**4,369,498**	**1.31**	**3.43**
	%	34%	13%	8%		16%	3%	13%	13%		27%	20%		

Figure 4.1. Distribution of Historic Wetland Acres by Current Land Use and Conservation Status.

These figures display the historic wetland area by land use and conservation status

.

A. Distribution by Subregion and Region



B. Distribution by Wetland Type

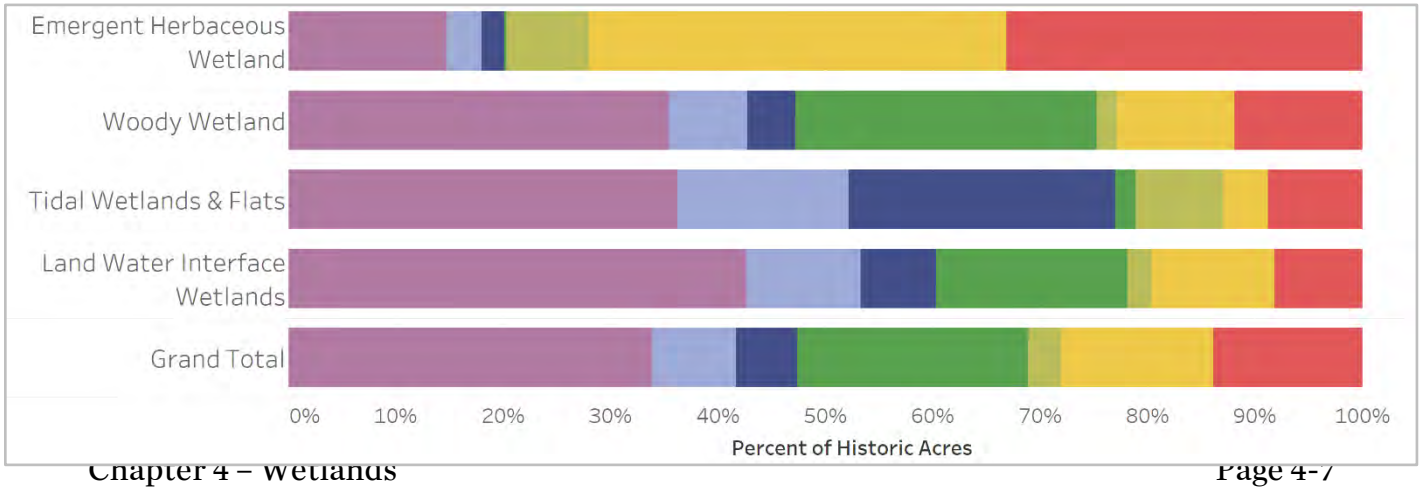
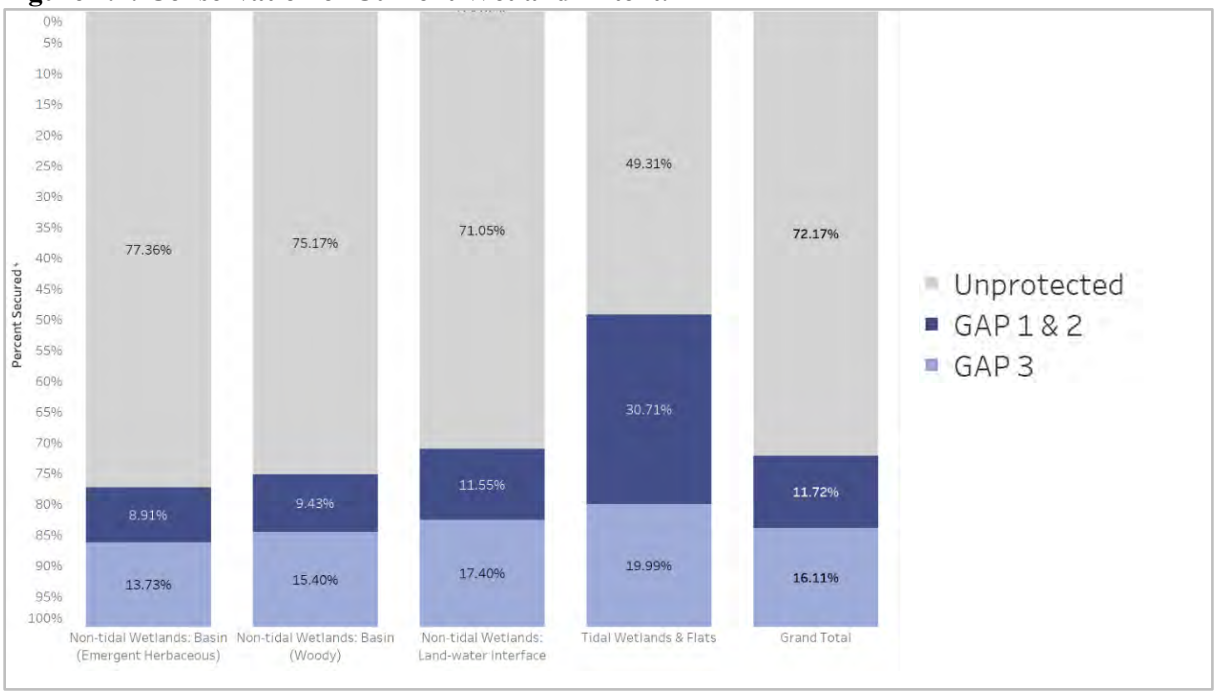


Figure 4.2: Conservation of Current Wetland Extent.



The results of the overlay indicate that 28% of current wetlands now fall on land that is either permanently conserved for nature (GAP 1-2: 12%) or conserved for multiple uses (GAP 3: 16%), leaving 72% is on unsecured land (Figure 4.2). Tidal wetland have the highest level of securement (51%), followed by alluvial wetland (29%), woody basin wetland (25%) and emergent basin wetlands (13%).

We calculated a Conservation Risk Index (CRI, Hoekstra et al. 2005) to compare the amount of wetland converted to development or agriculture to the amount of conserved wetland in both the historic and recent footprint. This can help determine whether conservation is outpacing or losing to the conversion of wetlands. CRI is calculated as:

CRI = acres of wetland converted to development or agriculture / acres permanently conserved (GAP1-3)

The calculation yields a ratio that when less than one indicates more conservation than habitat loss and when greater than one indicates more conversion than conservation. A similar ratio, the Nature Risk Index (NRI), compares the amount of loss only to land conserved explicitly for nature (GAP 1-2) excluding the GAP 3 lands which are for multiple use.

The results of applying the CRI to the *historic* wetland footprint suggests that conversion of wetland has surpassed conservation 2 to 1. That is, 2.1 acres of wetland habitat has been converted to development or agriculture for every one acre that has been conserved (Figure 4.1, Table 4.2). The Mid-Atlantic states has lost 37% of its historic wetland footprint and shows a higher ratio of loss to conservation (CRI=2.6) than New England and New York which have lost 22% of their historic wetland footprint and have a lower ratio of conversion to conservation (CRI=1.6).

All wetland types except basin wetlands had CRI ratios less than one indicating more conservation than loss in their historic footprint (Table 4.2). Basin wetlands had the highest risk (CRI = 1.6) having lost

29% of their historic footprint but conserved 18% equivalent to 4.9 million acres lost and 3.1 million acres conserved. Conservation of basin wetland largely occurs on GAP 3 multiple-use land and the NRI (4.58) is relatively high: 5 acres converted for every one acre conserved explicitly for nature.

Alluvial wetlands had a CRI of 0.8 indicating less conversion (18%) than conservation (23%) of these critical riparian and floodplain zones. That they flood regularly may be part of the reason for their low ratio but as they store water during extreme precipitation and runoff events it is beneficial for people as well as wildlife to have ample amounts under conservation. Again the NRI is greater than one (3.46) suggesting the conservation is mostly multiple use land.

Tidal wetlands had a very low CRI of 0.3 as only 12% have been converted to development or agriculture and 43% are conserved. This makes sense given these areas are likely some of the wettest and hardest to develop given coastal inundation and frequent flooding from river systems is incompatible with most development and many types of agriculture. Not only are these wetlands extremely productive and full of distinct biodiversity but they also buffer the coastline from extreme storms. The question now under sea level rise is whether we have conserved the migration space needed to help them migrate and reform in response to the changing tidal patterns.

Recent Trends in Wetland Loss and Conservation (2001-2022):

In addition to analyzing historic patterns of wetland loss, we also examined trends in wetland turnover loss and conservation over the last 20 and 10 years. To explore this, we overlayed the 2001, 2011 and 2019 National Land Cover dataset (NLCD 2019, Dewitz and U.S. Geological Survey 2021) on the wetland dataset. The NLCD products have been corrected for evolving mapping methods and allow direct comparisons between time periods. We did the same with the 2022 TNC conservation lands selecting only conservation that occurred in one of three time sets pre-2001, 2002-2011, and 2012-2022.

Results show that less than 1% (45,000 acres) of wetland was converted to development or agriculture over the last 20 years (Table 4.3). Most of this was emergent basin wetland (21,000 acres, 3% of extent) followed by woody basin wetlands (16,000 acres, 0.2% of extent). Transition to forest or other natural cover converting to wetland were all very small (<1%). In all, wetlands have remained surprisingly stable in extent over the last two decades, with 99.7% staying the same (Table 4.3, Figure 4.3).

The stability of wetlands is especially striking compared to forests that in response to logging and disturbance have almost 8% turnover as forest change to open shrubland and then regrow as forest. However the rate of permanent conversion to development or agriculture is on par, with both wetlands (0.4%) and forest (0.8%) both having less than one percent (Table 4.4).

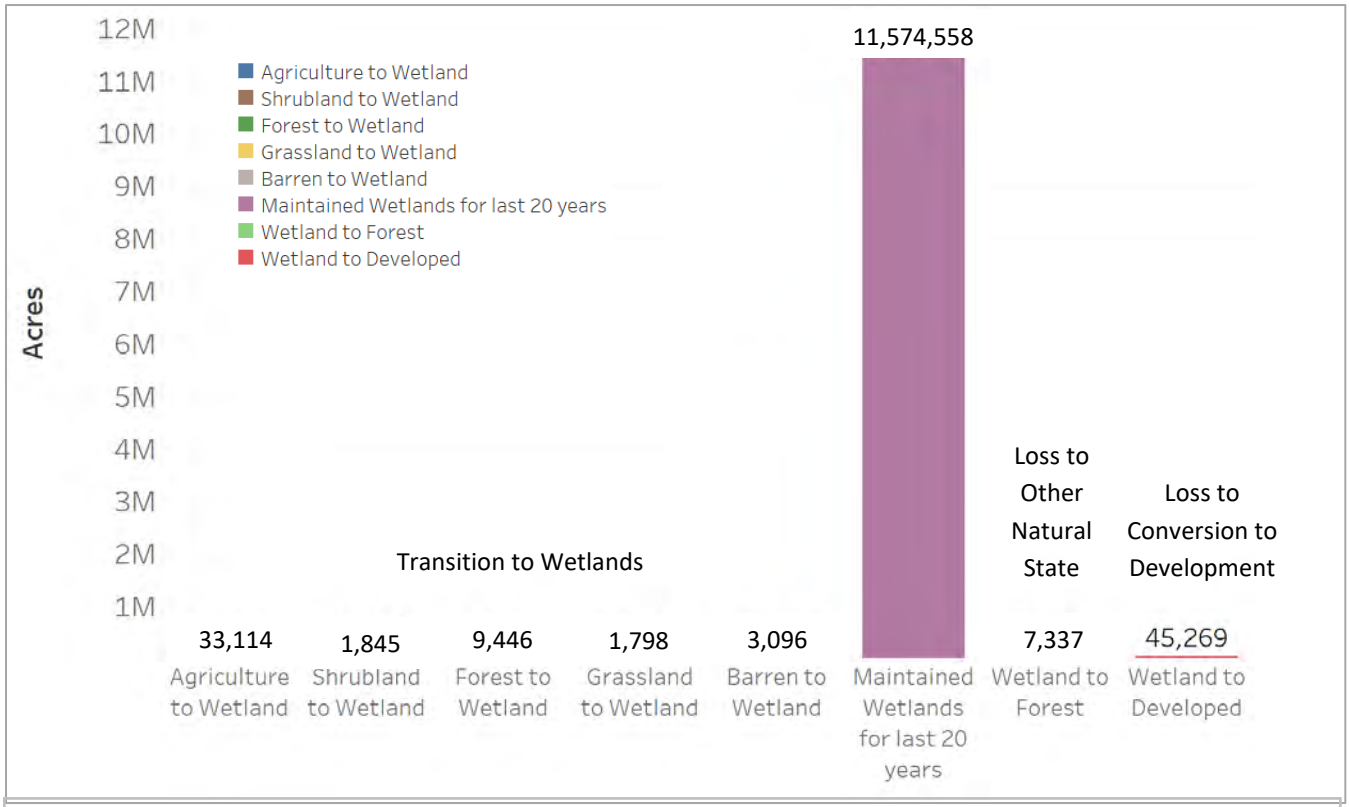
Table 4.3: Acres of Wetland Turnover and Loss from 2001-2021 by Wetland Type.

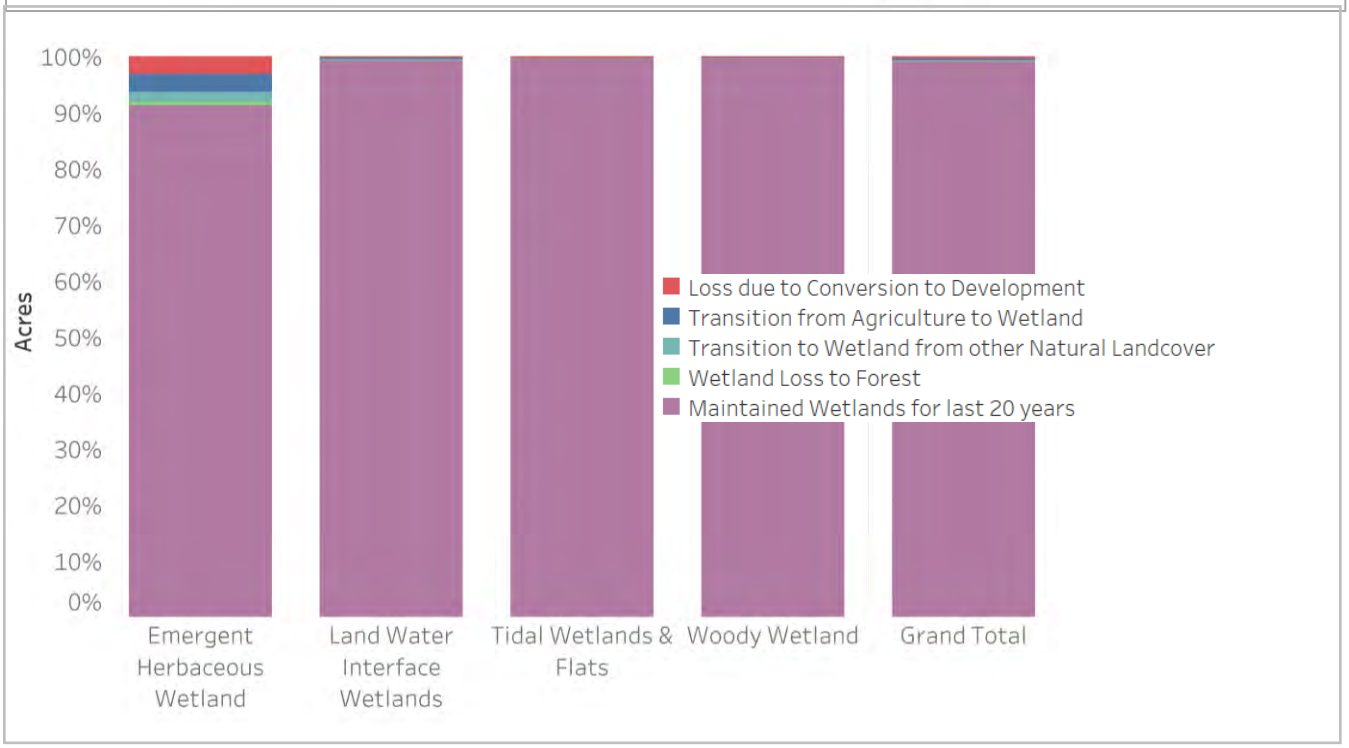
	Maintained Wetland for last 20 Years		Transition from Agriculture to wetlands		Transition to Wetland from other Natural Cover		Wetland Loss to Forest		Wetland Loss to Conversion to Development	
	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Emergent Basin Wetlands	571,665	96.75%	17,711	3.00%	1,480	0.25%	3,531	0.60%	20,787	3.52%
Alluvial Wetlands	2,187,917	99.62%	7,881	0.36%	481	0.02%	1,267	0.06%	4,826	0.22%
Tidal Wetlands & Flats	1,045,012	99.90%	96	0.01%	929	0.09%	54	0.01%	3,716	0.36%
Woody Basin Wetlands	7,769,965	99.90%	7,426	0.10%	207	0.00%	2,485	0.03%	15,942	0.20%
Grand Total	**11,574,558**	**99.69%**	**33,114**	**0.29%**	**3,096**	**0.03%**	**7,337**	**0.06%**	**45,270**	**0.39%**

Table 4.4. Conversion of Natural Land Use (2001-2021). This table provides conversion of natural land uses to and from agriculture and development in the last 20 years by total acres in the region. The large fluctuations in the grasslands and shrublands are likely classification error.

	Conversion from Agriculture or Developed back to Natural		Maintained Natural State in last 20 years	Conversion from Natural to Agriculture or Developed	
	Acres	Percent	Acres	Acres	Percent
Wetlands	33,163	0.29%	11,643,300	-45,269	-0.39%
Forests	403,283	0.44%	92,033,942	-709,985	-0.77%
Grasslands and Shrublands	54,864	1.31%	4,198,954	- 53,431	-1.27%
Total Natural	**491,310**	**0.46%**	**107,876,196**	**-808,685**	**-0.75%**

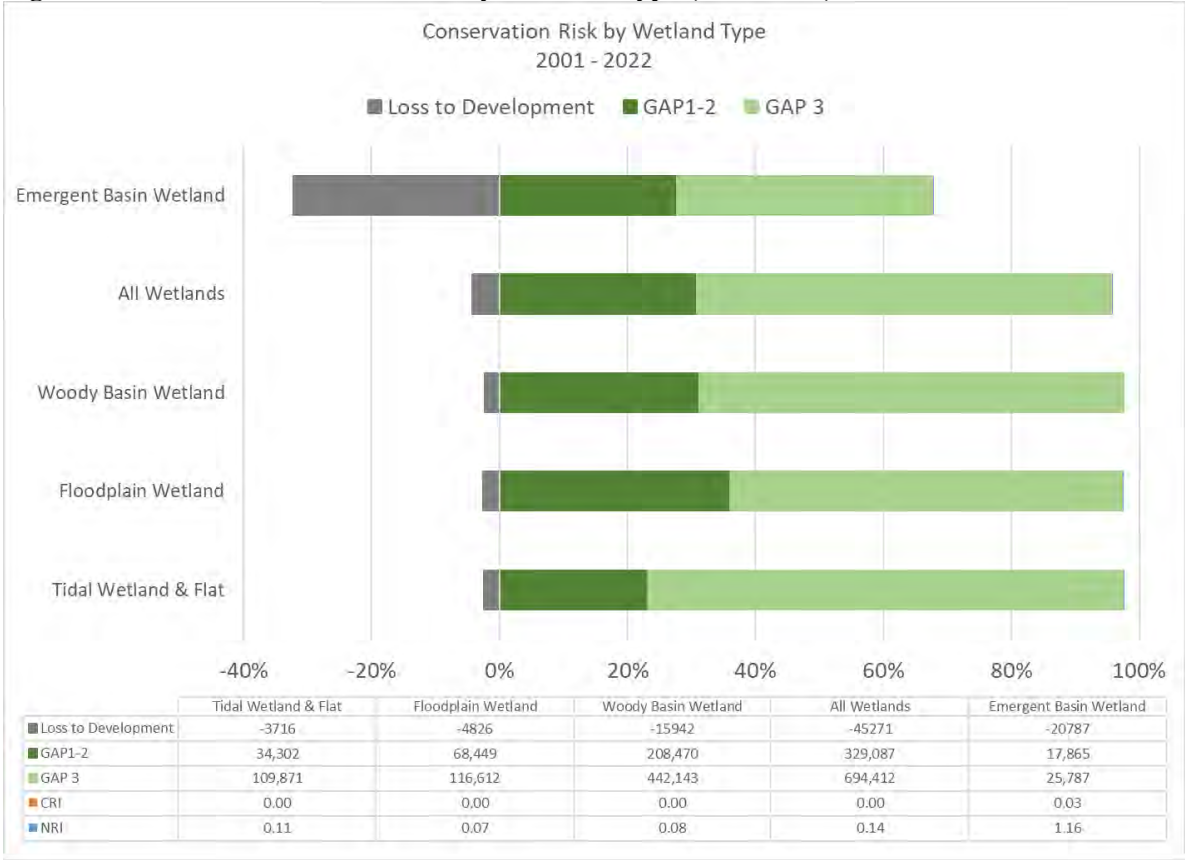
Figure 4.3: Wetlands in transition in the Northeast and Mid-Atlantic. 99% of wetlands were unchanged in extent across the last 20 years. Most change was due to loss from conversion to development (0.4%).





The Conservation Risk Index (CRI, Figure 4.4) for the last two decades shows that conservation has surpassed conversion almost 250 to 1. This reflects the large decline in wetland conversion due to regulatory action combined with over a million acres of wetland on new conservation land (Figure 4.4). The CRI is less than one for all wetland types, and the Nature Risk Index, which looks explicitly at land conserved for nature is less than one for all types except emergent basin marsh (NRI=1.16) which indicates 1.2 acres converted for every on conserved for nature.

Figure 4.4. Conservation Risk Index by Wetland Type (2001-2012).



	Tidal Wetland & Flat	Floodplain Wetland	Woody Basin Wetland	All Wetlands	Emergent Basin Wetland
Loss to Development	-3716	-4826	-15942	-45271	-20787
GAP1-2	34,302	68,449	208,470	329,087	17,865
GAP 3	109,871	116,612	442,143	694,412	25,787
CRI	0.00	0.00	0.00	0.00	0.03
NRI	0.11	0.07	0.08	0.14	1.16

Recent Wetland Conservation (2012-2022)

To quantify the amount of wetland area conserved in the last decade, we overlaid the TNC 2022 conservation lands dataset on the wetland extent and restricted the data only to conservation since 2012 using the "date conserved" field.

Results show that over the last decade 231,654 acres of wetlands were conserved through land acquisition and easement including 80,000 acres (35%) conserved explicitly for nature (GAP1-2) and 152,000 acres (65%) for multiple use (GAP 3, Table 4.5). Conservation was spread across all wetland types with 64% for woody basin wetland, 23% for floodplain wetland, 8% for tidal wetland and 4% for emergent basing wetland. State Wildlife Management Areas added the most wetland to the conservation network followed by NGO and State easements (Table 4.6).

Table 4.5. Conservation of Current Wetland Extent. This table provides the total acres and percent of the current wetland extent in GAP 1-2 and GAP 3 conservation land. It also summarizes the acres and percent of all conservation gained in the last decade.

							Conservation Gains 2012-2022		
Wetland Type		**GAP 1 & 2**	**GAP 3**	**Total GAP 1-3**	**Unprotected**	**Total**	**New GAP 1 & 2**	**New GAP 3**	**New GAP 1-3**
Non-tidal Wetlands: Basin (Emergent Herbaceous)	Percent	8.91%	13.73%	22.64%	77.36%	100.00%	0.51%	1.18%	1.68%
	Acres	53,619	82,681	136,300	465,718	602,017	3,057	7,083	10,140
Non-tidal Wetlands: Basin (Woody)	Percent	9.43%	15.40%	24.83%	75.17%	100.00%	0.61%	1.30%	1.92%
	Acres	734,191	1,198,818	1,933,009	5,850,533	7,783,542	47,845	101,413	149,258
Non-tidal Wetlands: Land-water Interface	Percent	11.55%	17.40%	28.95%	71.05%	100.00%	0.95%	1.49%	2.44%
	Acres	254,134	382,605	636,739	1,562,637	2,199,376	20,826	32,789	53,615
Tidal Wetlands & Flats	Percent	30.71%	19.98%	50.69%	49.31%	100.00%	0.79%	0.99%	1.78%
	Acres	321,217	209,020	530,237	515,790	1,046,028	8,280	10,362	18,642
Total of All Wetlands	Percent	11.72%	16.10%	27.82%	72.18%	100.00%	0.69%	1.30%	1.99%
	Acres	1,363,161	1,873,125	3,236,286	8,394,677	11,630,963	80,008	151,646	231,654

Table 4.6. Top Ten Entities for Recent Wetland Conservation

Protection Holder	Emergent Basin Wetland	Woody Basin Wetland	Floodplain Wetland	Tidal Wetlands	Total Acres
State Wildlife Management Area	34,922	570,493	180,201	135,449	921,065
NGO Easement	23,700	285,041	79,476	18,809	407,025
State Easement	13,078	220,554	56,084	39,097	328,813
Fish and Wildlife Service	11,678	117,506	59,161	100,555	288,899
NGO Fee	10,764	148,454	50,319	51,375	260,913
Local Fee	7,854	148,734	51,030	23,798	231,416
State Forest	4,098	106,518	21,501	71,467	203,584
State Land	7,307	101,220	42,469	29,847	180,842
State Park	6,466	68,643	21,982	16,804	113,894
Dept. of Defense	3,238	34,648	25,621	14,195	77,703

Wetland Condition

Local Connectedness:

One solution to the pervasive problem of fragmentation is to preserve connectivity, which helps maintain the quality of the whole ecosystem. The metric we used to measure connectivity - local connectedness - uses a resistant kernel algorithm to account for the impacts of major and minor roads, as well as the density of all nearby roads and the degree of nearby conversion. The method follows Compton et al. (2010) and treats the landscape as having a gradient of permeability where highly contrasting land cover types have reduced permeability between them, and highly similar ones have enhanced permeability. Every point on the landscape is scored based on how connected it is in all directions within its local 3-km neighborhood. In applying the metric, we differentiated between developed lands, agricultural lands, and natural cover, but all forms of natural land cover were combined into one class for the analysis. The assessment of local connectivity was developed by Brad Compton at the University of Massachusetts (detail in Compton 2007). Our application was run with the 30 m 2019 National Land Cover dataset (Dewitz, J., and U.S. Geological Survey 2021) supplemented with major and minor road information (Tiger Roads 2022).

For every 30 m grid cell in the region, a circular area with a 3 km radius around the cell was evaluated and the amount of resistance /permeability was calculated to create a wall-to-wall grid with cell values ranging from 0 to 100; these scores were then put on a standard normal scale (z-score) and multiplied by 1000 to scale the results from -3500 (-3.5 SD below the mean) to 3500 (3.5 SD above the mean). In the results "-3500" indicates complete impermeability (e.g. developed), 0 = average local connectedness for the region, and "3500" indicates complete permeability (e.g. natural cover with no barriers, Figure 4.6).

The results create a wall-to-wall map of connectedness that is both spatially comprehensive and sensitive to local scale fragmentation (Map 4.2). The approach can detect difference in local patterns from completely natural, to a few minor roads and houses, to a mixed landscape with some agriculture to fully developed (Figure 4.5) conveying a lot of information about the context of the site and intactness of its local neighborhood.

We measured the relative connectedness of all wetlands and wetland types by overlaying the local connectedness grid on all cells of wetland cover and tabulating the mean for all cells of each forest type. Additionally, we overlaid the 2022 TNC conservation lands on the wetland data to detect difference in local connectedness associated with their GAP status.

Map 4.2. Local Connectedness Wall to Wall.

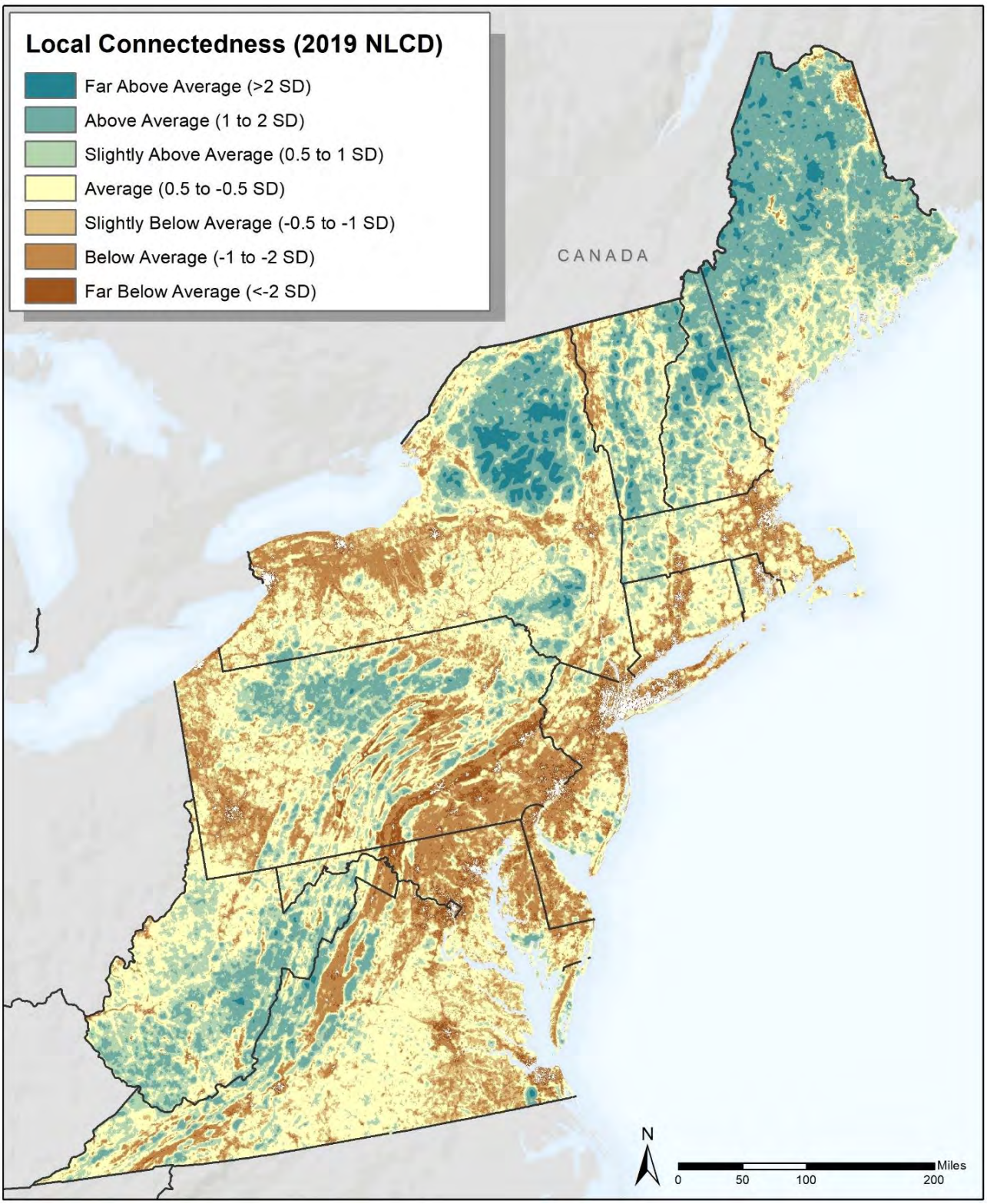


Figure 4.5. Aerial photo image of areas with different local connectedness scores.



Local Connectedness = 3500
Completely natural, no roads, agriculture, or development



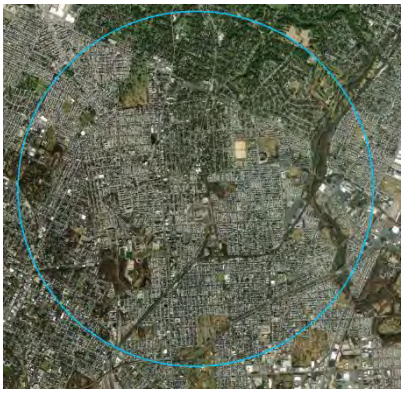
Local Connectedness = 1000
Mostly natural, some roads and minor development



Local Connectedness = 0
Mixed landscape, some natural, some agriculture/minor development/roads.



Local Connectedness = -1000
Mostly disturbed, roads, agriculture, and high density development.

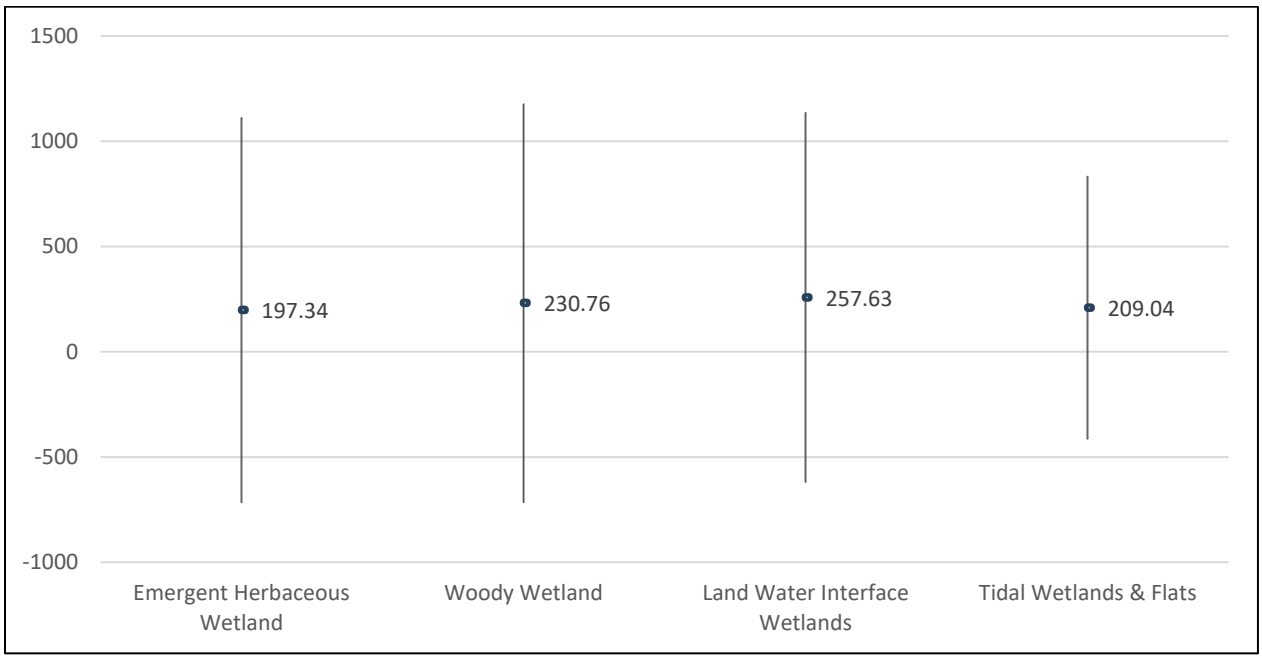


Local Connectedness = -3500
High Density Development

Results show the mean connectedness score for wetlands to be slightly above the regional mean (LC = 232, 0.23 SD) indicating that wetlands have about the same or slightly better connectedness than the region in general (Figure 4.6). Visually, areas with a score of 0 (the mean) appear to have mixed landscape, with some natural and some agriculture or minor development and roads (Figure 4.5).

The three wetland types did not differ markedly in their connectedness scores (Figure 4.7). Floodplain wetlands (Land-Water interface) had the most connectedness (LC = 258) followed by woody basin wetland (LC=231), tidal wetland (209, and emergent basin wetland (LC=197). All of these are well within the range of the mean considered as +/- a half standard deviation.

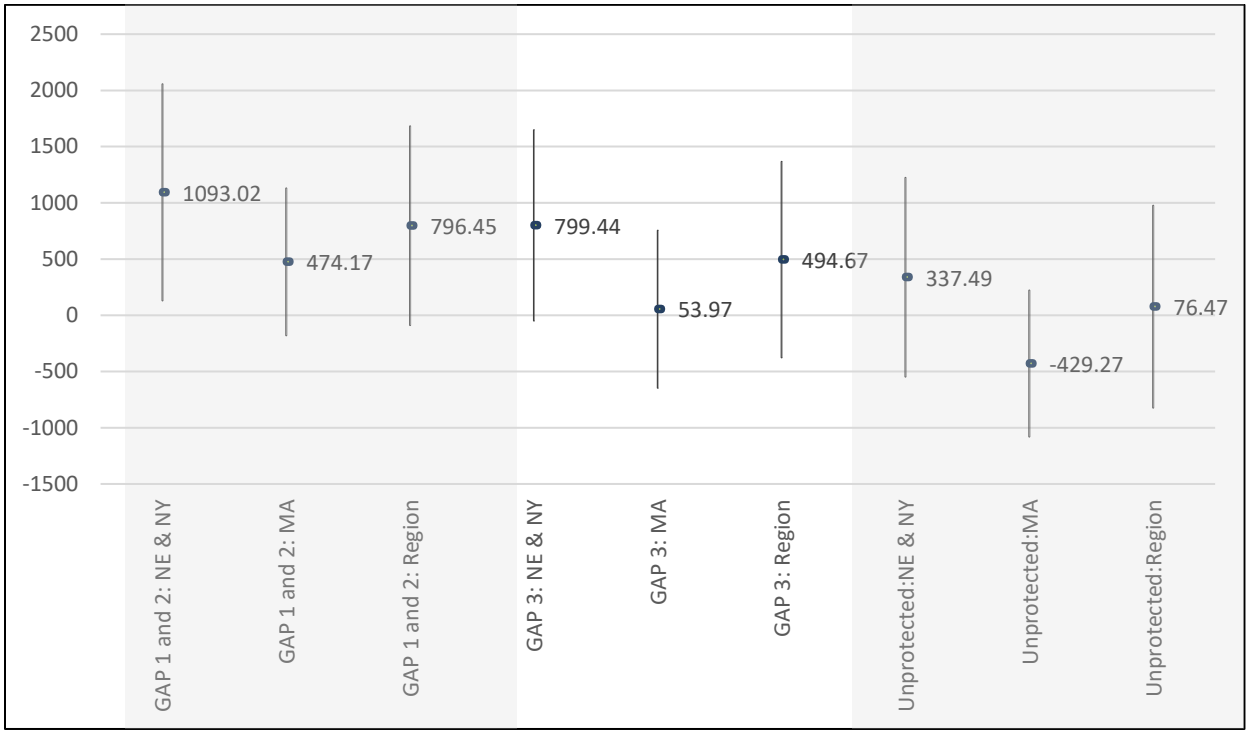
Figure 4.6. Average connectedness scores for the four wetland types. The numbers are in Z-scores (standard deviations) multiplied by 1000. The average score for the region is 0 and all wetland types are well within the range of average (+/- 500) with the highest being the interface floodplains (0.26 SD).



Conserved wetlands score distinctly better for local connectedness than unconserved wetlands, suggesting that conservation land may help maintain wetland connectivity (Figure 4.7). Wetlands on land conserved primarily for nature (LC=795) scored above the average for the region and above one standard deviation (LC = 1093 = 1.1 SD) for New England and New York. They scored well in the Mid Atlantic (LC = 474) although a little lower. Multiple use land was not quite as connected, scoring (LC = 495) for the region, (LC=799) for New England and New York, and (LC = 54) for the Mid Atlantic.

Without the conservation lands the region still scored about average but the two subregions differed as New England and New York scored a little above the mean (LC = 337) and the Mid Atlantic scored below the mean (LC = -429).

Figure 4.7. Average connectedness scores for the four wetland types. The numbers are in Z-scores (standard deviations) multiplied by 1000. The average score for the region is 0. The GAP 1 conserved for nature lands score distinctly higher for local connectedness than the multi-use conservation lands, but both type scored above the unconserved wetlands.



Chapter 4: References

Anderson, M.G. and Barnett, A. 2017. Resilient Coastal Sites for Conservation in the Northeast and Mid-Atlantic U.S.. The Nature Conservancy, Eastern Conservation Science. Boston, MA
View the interactive map, download the data, and read the report at:
https://www.nature.org/resilientcoasts

Anderson, M. G., Lombard, K., Lundgren, J., Allen, B., Antenen, S., Bechtel, D., Bowden, A., Carabetta, M., Ferree, C., Jordan, M., Khanna, S., Morse, D., Olivero, A., Sferra, N., Upmeyer, A. 2006b. The North Atlantic Coast: Ecoregional Assessment, Conservation Status Report and Resource CD. The Nature Conservancy, Eastern Conservation Science, Boston, MA.

Bates, P. D., Quinn, N., Sampson, C., Smith, A., Wing, O., Sosa, J., et al. (2021). Combined modeling of US fluvial, pluvial, and coastal flood hazard under current and future climates. Water Resources Research, 57, e2020WR028673. https://doi.org/10.1029/2020WR028673

Compton, B.W, McGarigal, K, Cushman S.A. and L.G. Gamble. 2007. A resistant-kernel model of connectivity for amphibians that breed in vernal pools. Conservation Biology 21: 78-799.
http://www.umasscaps.org/

Dahl, T. E. 1990. Wetlands losses in the United States 1780's to 1980's. Washington, D.C: U.S. Department of the Interior, Fish and Wildlife Service.

Dewitz, J., and U.S. Geological Survey, 2021, National Land Cover Database (NLCD) 2019 Products (ver. 2.0, June 2021): U.S. Geological Survey data release, https://doi.org/10.5066/P9KZCM54.

Ferree, C. 2008. Ecological Land Units. Version 11/2008. The Nature Conservancy Eastern Conservation Science Office. Boston, MA.

Ferree, C and M. G. Anderson. 2013. A Map of Terrestrial Habitats of the Northeastern United States: Methods and Approach. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA.
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/habitatmap/Pages/default.aspx

First Street Foundation. (2020). First Street Foundation Flood Model Technical Methodology Document. Zenodo. https://doi.org/10.5281/zenodo.4740762

Findlay, S. and Houlahan, J. 1997. Anthropogenic Correlates of Species Richness in Southeastern Ontario Wetlands. Conaservation Biology, Vol. 11 No. 4. Pp 1000-1009

Fry, J.A., Coan, M.J., Homer, C.G., Meyer, D.K., and Wickham, J.D., 2009, Completion of the National Land Cover Database (NLCD) 1992 -2001 Land Cover Change Retrofit product: U.S. Geological Survey Open-File Report 2008: 1379, 18 p.

Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan, 2004. Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing.

Hoekstra, J.M., Boucher, T.M., Ricketts, T.H. and Roberts, C., 2005. Confronting a biome crisis: global disparities of habitat loss and protection. *Ecology letters*, *8*(1), pp.23-29.

Mitsch, W. J., Gosselink, J. G. (1986). Wetlands. New York: Van Nostrand Reinhold Co..
Poole, A. and Gill, F. (eds), 1999-ongoing. Birds of North America. 1992-2010. Species accounts. The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, D. C.

Reed, Jr., Porter B. 1988. National List of Plant Species That Occur in Wetlands: National Summary. U.S. Fish & Wildlife Service. Biol. Rep. 88 (24). 244 pp.

The Nature Conservancy. 2009. Eastern U.S. Secured Lands. Various scales. Compiled from multiple sources.

Sauer, J. R., J. E. Hines, and J. Fallon. 2008. The North American Breeding Bird Survey, Results and Analysis 1966 - 2007. Version 5.15.2008. USGS Patuxent Wildlife Research Center, Laurel, MD http://www.pwrc.usgs.gov/BBS/

Sheldon, A. O. 2009. Active River Area. 30m. The Nature Conservancy Eastern Conservation Science. Boston, MA.

Tele Atlas North America, Inc., 2009. U.S. and Canada Streets Cartographic. 1:100,000 Tele Atlas StreetMap Premium v. 7.2 ESRI® Data & Maps: StreetMap. 2009 Data Update: North America. Redlands, California, USA.

Tele Atlas North America, Inc. 2009. U.S. and Canada Railroads. 1:100,000. ESRI® Data & Maps: StreetMap. 2009 Data Update: North America. Redlands, California, USA. U.S. and Canada Railroads represent the railroads of the United States and Canada.

U.S. Environmental Protection Agency (USEPA). 2009. National Lakes Assessment: A Collaborative Survey of the Nation's Lakes. EPA 841-R-09-001. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, D.C.

Appendix 4.1 (these sections are from the 2011 report)

With approval of the project steering committee, we chose to focus our 2022 analysis on the highest priority metrics, those we expected to see more change in, and/or that were not covered in other recent reports (e.g. birds). These metrics are from the previous 2011 Conservation Status of Fish, Wildlife and Natural Habitats in the Northeast Landscape report (Anderson and Olivero-Sheldon 2011). They may be of interest to some readers looking for additional information on wetlands..

Impacts in the Buffer Zone:

The area immediately surrounding a wetland, its buffer zone, has a strong influence on the quality and diversity of the wetland. To assess the condition of this area, we defined a 100 m zone around each individual wetland greater than 2 acres in size and calculated the amount of development, agriculture, and natural vegetation within it. We summarized this information in an index of disturbance, by calculating a weighted sum of the anthropogenic features present and weighting the effect of development more than agriculture. Scores ranged from 100 for a wetland with its buffer zone totally developed, to 0 where the buffer was completely within natural cover types:

> *Disturbance Score = 1.0 times the %high intensity development + 0.75 times the %low intensity development, + 0.50 time the %agriculture*

To interpret the index, we developed categories of impact based on the correlation of the impact scores to observed measurements of shoreline human disturbance for sites sampled by the National Lake Assessment (EPA National Lake Assessment 2009, R^2 squared = 0.56, $p < 0.0001$). We matched the three disturbance categories used in the lake assessment by calculating the mean impact score for the set of known sites in each disturbance category, using the point halfway (log scale) between the means as the cutoffs:

- Low disturbance 0 < 3.7
- Moderate disturbance >= 3.7 < 15.0
- Severe disturbance >=15.0

Across all wetlands, the results indicated a nearly equal distribution of total acres in each of the three impact categories (Map 4.1.1, Table 4.1.1, Figure 4.1.1). By type, tidal wetlands were the most disturbed, with only 15 %of them in the undisturbed class. Basin wetlands were the least disturbed with 43 %undisturbed, and alluvial wetlands were intermediate with 31 %undisturbed. The %of wetlands in the undisturbed class in New England and New York (43 percent) was over twice that of the Mid-Atlantic (18 percent) although this largely reflected the basin wetlands. Alluvial and tidal wetlands were relatively less impacted in the Mid-Atlantic (Table 4.1.1).

Map 4.1.1. Wetland occurences by impact classes.

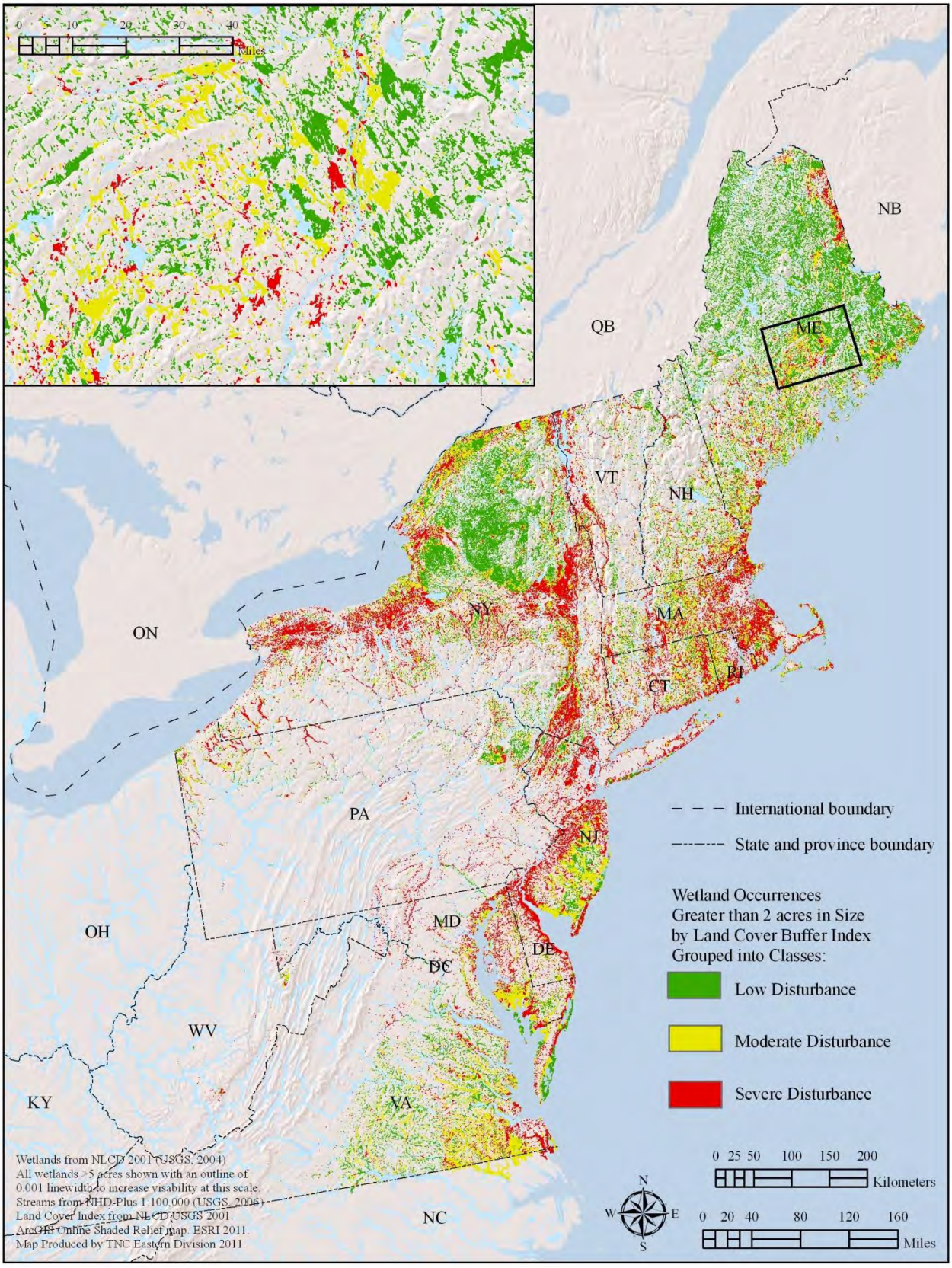
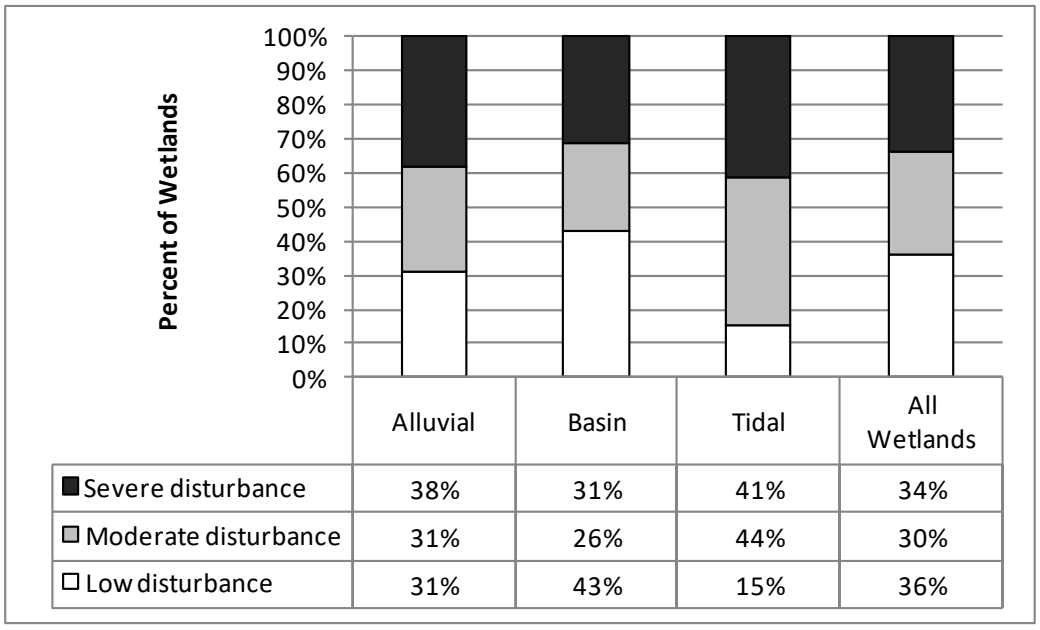


Table 4.1.1. %of wetland acreage in each impact class across wetland types and subregions.

Region	Type	Low disturbance	Moderate disturbance	Severe Disturbance
Mid-Atlantic	Alluvial	15%	55%	30%
	Basin	26%	37%	37%
	Tidal	14%	49%	37%
Mid-Atlantic Total		18%	46%	36%
New England & New York	Alluvial	37%	23%	40%
	Basin	47%	24%	29%
	Tidal	18%	24%	58%
New England & New York Total		43%	24%	33%
Region	Alluvial	31%	31%	38%
	Basin	43%	26%	31%
	Tidal	15%	44%	41%
Region Total	All Wetlands	36%	30%	34%

Figure 4.1.1. Disturbance in the 100 m buffer zone. This chart shows the percentage of 435,000 individual wetlands in each disturbance class. Only wetlands >2 acres were included.



Road Density: The species richness of birds, amphibians, reptiles, and plants within an individual wetland is negatively correlated with the density of paved roads surrounding a wetland (Forman 2003), with the sensitive impact distances varying from 500 m to 2,000 m depending on the taxa (Findlay and Houlahan, 1997). To measure this, we created a road density data layer for the whole region by calculating the density of roads (meters/hectare) within a 1,000 meter radius of each 30 m pixel of land ar in the region.

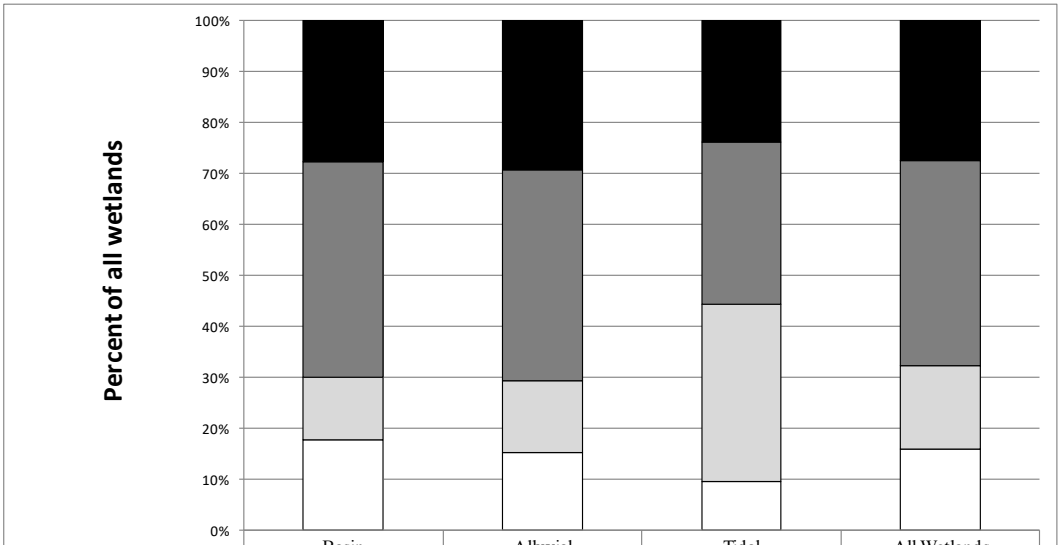
Subsequently, we calculated the mean road density value for each wetland by taking the average of all pixels within each occurrence. This method takes into account roads in the buffer zone as well as the total size of the wetland, so that large wetlands show fewer impacts from roads.

We created a road impact index for each wetland occurrence based on Findlay and Houlahan (1997) who found that plant species richness decreased 13 %with every 2 m/ha of paved roads within a buffer zone, and showed similar patterns for other taxa. The road dataset we used consisted primarily of paved roads including major highway, local thoroughfares, neighborhood connectors, and rural roads, but we do not know the number of unpaved road in the dataset (Tele Atlas North America, Inc 2009). Four-wheel drive roads and other trails were not included due to inconsistencies in their mapping across the region in the source dataset. Our index, based on roads in the 1,000 m buffer, was as follows:

- No impact: 0- 2 m/ha roads of roads (estimated 80-100% of natural species richness)
- Moderate impact: 2 to 6 m/ha of roads (estimated 50-80% of natural species richness)
- Impacted: 6 to 18 m/ha of roads (estimated 25-50 of natural species richness)
- Severe impact: >18 m/ha of roads (estimated >25% of natural species richness)

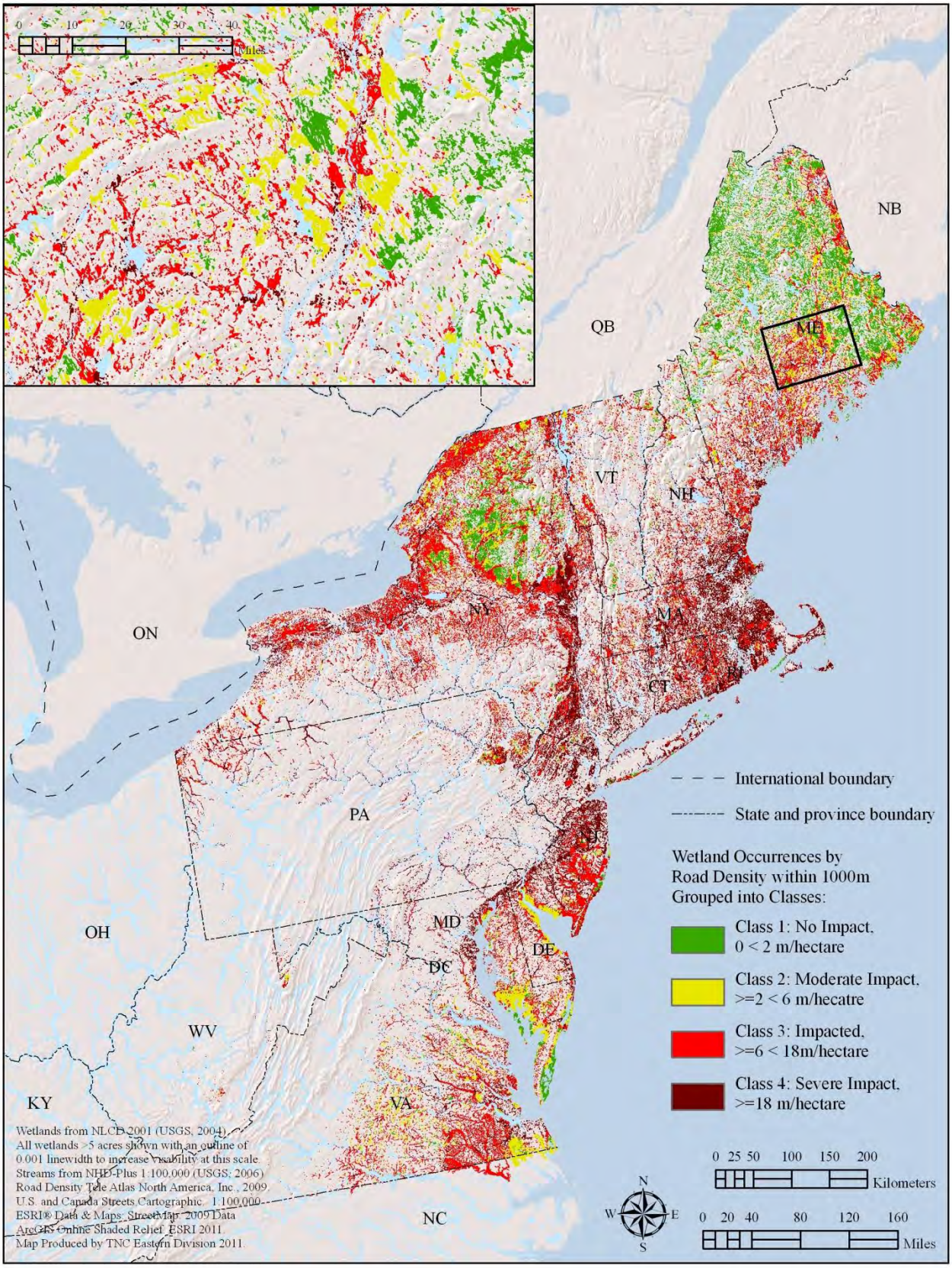
The results of applying the index to all wetlands indicated that only 16 %of all wetlands in this region were free of road impacts. Sixty-seven %were in the impacted to severe impact categories, suggesting that most wetlands in the region do not support a full complement of native species. The alluvial and basin wetlands had the largest proportion of impacted wetlands, perhaps because they were smaller than tidal wetlands (Figure 4.1.2, Map 4.1.2).

Figure 4.1.2. Acres of wetlands in each road impact category across wetland types. This metric was calculated for a 1,000 m buffer zone around each individual wetland.



	Basin	Alluvial	Tidal	All Wetlands
Class 4: Severe Impact (>=18 m/hectare)	28%	29%	24%	27%
Class 3: Impacted (>=6 < 18m/hectare)	42%	41%	32%	40%
Class 2: Moderate Impact (>=2 < 6 m/hecatre)	12%	14%	35%	16%
Class 1: No Impact (0 < 2 m/hectare)	18%	15%	10%	16%

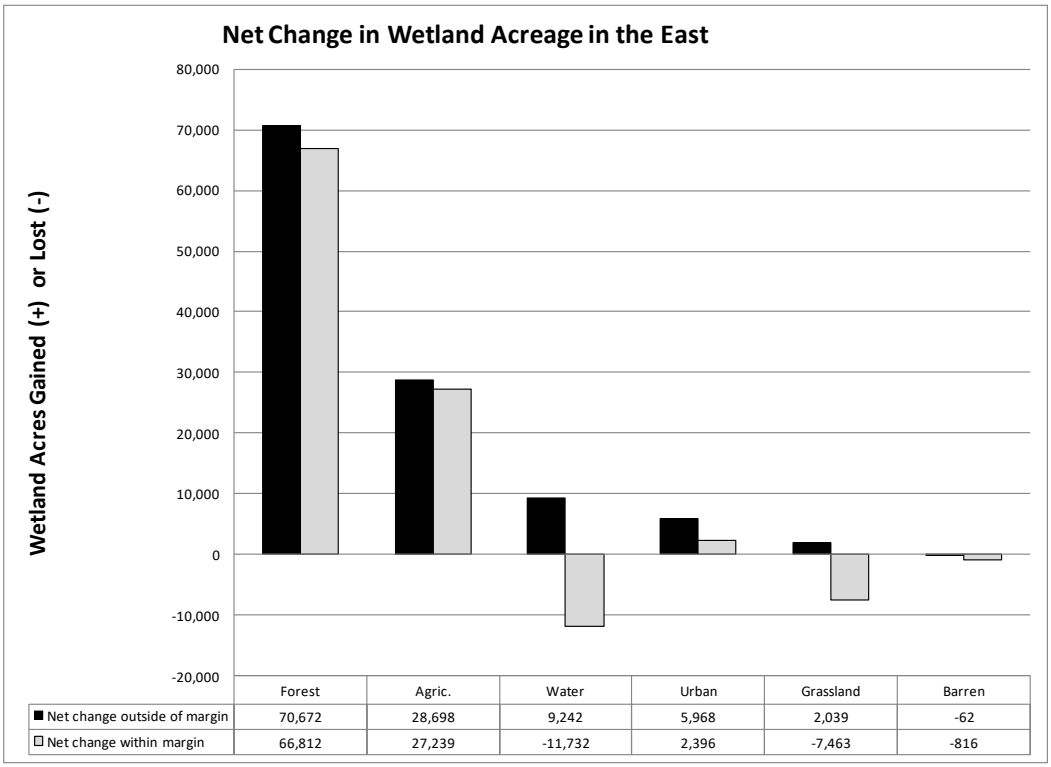
Map 4.1.2. Wetland occurrences by road impact category.



Lastly, to identify the wetlands in the best condition with respect to both roads and land use, we combined the buffer impact index and the road density index and selected those wetlands that were above the average value for both attributes. This highlighted wetlands in northern Maine, the Adirondacks, southern New Jersey, the Chesapeake Bay region, and the Virginia coast.

Changes in Wetland Acreage over Time: Over the last two decades, the region has seen both losses and gains in wetland acreage. The National Land Cover Database (NLCD) 1992–2001 Land Cover Change Retrofit Product (Fry et al. 2009) was developed to provide a more accurate and useful land cover change dataset. At a resolution of 30 meters, this dataset contains unchanged pixels that have been cross-walked to a modified Anderson Level I class code along with changed pixels labeled with a "from-to" class code. Judging from this dataset, wetlands appear to have increased by roughly 100,000 acres since 1992 (Figure 7). Close examination of the data revealed that, 91 %of this change was explained by small increases in the size of thousands of existing forested wetlands. Because 63 %of the gained acres were located within the 1 pixel edge of existing wetlands, this trend might reflect mapping error between the between the 1992 and 2001 satellite-derived maps in the exact boundaries of each wetland. However, when the acres of wetland gained beyond those in the 1 pixel edge zone were examined independently, the data still suggested a net gain of wetlands in the region of about 9,000 acres. The largest and most consistent transitions to wetlands appear to be from forests, agriculture, and open water (Figure 4.1.3), but the data on transitions were occasionally contradictory.

Figure 4.1.3. Estimated net change in wetland acreage from 1992 to 2001. The chart compares changes within and without of the 1 pixel margin. Data from The National Land Cover Database (NLCD) 1992–2001 Land Cover Change Retrofit Product (Fry et al. 2009)



	Forest	Agric.	Water	Urban	Grassland	Barren
■ Net change outside of margin	70,672	28,698	9,242	5,968	2,039	-62
□ Net change within margin	66,812	27,239	-11,732	2,396	-7,463	-816

CHAPTER

Unique Habitats

Condition and Conservation Status

M. Anderson, M. Clark, & A. Olivero

CHAPTER 5

Feb 2023

The rich biodiversity of the Northeast and Mid-Atlantic is associated with unique habitats that reflect the complex geologic history and varied landscape of the region. It is one of the few regions where one can find coastal beaches, alpine summits, limestone valleys, and silty floodplains all in relative proximity.

Geophysical Settings and Rare Species: Eleven distinct geophysical settings collectively sustain the 17,556 plants, vertebrates and macro invertebrates that inhabit the Northeast. Each setting supports a set of preferential species that are concentrated within it, although not necessarily restricted to it. Six geologic, topographic, or elevational settings had much higher densities of rare species than would be expected based on their abundance. These were coarse-grained sand, calcareous bedrock, ultramafic serpentine, cliffs and steep slopes, high elevation and the coastal zone.

Conservation and Habitat Loss: On average, for every one acre of habitat conserved, 1.8 acres of habitat has been lost through conversion to development or agriculture. The exceptions are high elevations and granitic bedrock regions where conservation exceeds habitat loss. At low elevations, habitat loss exceeds conservation 3:1, and 13:1 if you exclude multiple use land. Areas underlain by calcareous limestone, shale, coarse sand, and fine silt are at risk due to their high ratio of conversion to conservation ranging from 3:1 to 36:1.

Recent Conservation Trends: Over the last decade conservation has surpassed habitat conversion across every geologic type, elevation zone and slope class. Regions underlain by acidic shale had the highest level of conversion reflecting the rise of shale gas fracking, but although 50,000 acres were lost to conversion, 122,000 acres were put under conservation. Most of the conservation land on shale and calcareous limestone areas were multiple-use, and both these settings still lack many lands where the primary purpose is nature conservation

Fragmentation and Connectivity: Fragmentation and loss of connectivity is pervasive at lower elevation across all geology classes. The highest fragmentation and lowest connectivity were in calcareous bedrock, coarse and fine sediment settings, and elevations under 800 feet. Over the last decade connectivity decreased across every geophysical setting the largest decreases in land underlain by acid shale (2%), calcareous limestone (1%) or elevations below 800 feet (1%),

Non-Forested Upland Habitats. Patches of non-forested habitats on summits, cliffs, barrens, outcrops, dunes and grasslands are hotspots of diversity. High elevation alpine habitats are almost fully conserved as are many cliff and outcrop habitats, but low elevation limestone glades and ephemeral grasslands need more conservation focus.

This chapter first assesses the geophysical settings that underlie our forests, wetlands, and unique natural habitats. Second, we look specifically at the unique non-forested and non-wetland habitats that support much of the region's rare plants and animals. In both sections we examine the distribution, condition, securement, and trends in recent conversion.

Geophysical Settings and Natural Habitats

This section is organized by geologic, elevational, and landform settings that have distinct ecological and biological expressions. Total species diversity in the Northeast is highly correlated with the variety of geophysical settings (Anderson and Ferree 2010). Here we evaluate the condition and conservation status of the natural land in respect to the geological classes, elevation zones and landforms that support distinctive biological diversity. The geophysical settings include:

- Limestone valleys, wetlands and barrens (Calcareous settings)
- Soft sedimentary valleys and hills (Moderately calcareous settings)
- Acidic sedimentary pavements and ridges (Acidic sedimentary settings)
- Shale barrens and slopes (Shale settings)
- Granitic mountains and wetlands (Granite and Mafic settings)
- Serpentine outcrops (Ultramafic settings)
- Coarse sand barrens and dunes (Coarse-grained sediment settings)
- Silt floodplains and clayplain forests (Fine-grained sediment settings)
- Alpine meadows and krumholz (High elevation settings)
- Coastal dunes and marshes (Coastal settings)
- Steep cliff communities (Cliff landforms)

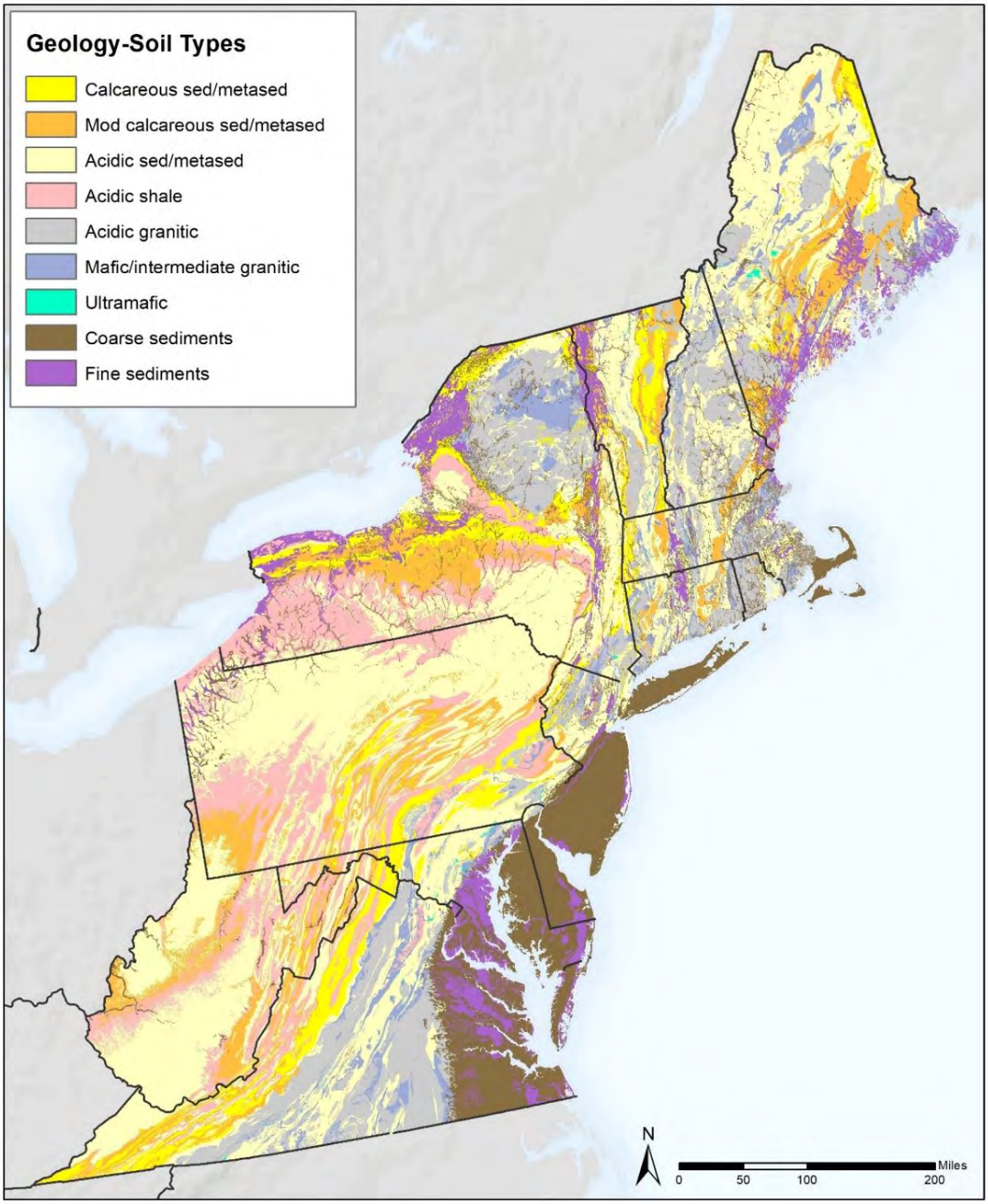
Characterization of the Geophysical Settings and Habitats

We created a spatially comprehensive regional database of bedrock geology classes at a resolution of 30 m by obtaining digital bedrock and surficial geology data layers from each of the 14 states (Figure 5.1) and compiling the individual state geological maps into a single integrated digital layer at the scale of 1:125,000. We grouped the 400+ bedrock types into nine lithogeochemical classes based on genesis, chemistry, weathering properties, and the textures of soils derived from the classes following Anderson and Ferree (2010) and relying heavily on the description and the US Geological Survey (USGS) crosswalk of state geologic maps to a national taxonomy (http://mrdata.usgs.gov/geology/state/). Our classification was irrespective of geologic age or degree of metamorphism. We used surficial data derived from the bedrock geology maps and grouped the sediments into two size classes: course sediment and fine sediment. In a few unmapped surficial areas we supplemented the data with SSURGO soils map units to fill in holes (Soil Survey Staff, 2014). Elevation zones were mapped from a DEM using zone boundaries from Anderson and Ferree (2010).

To characterize the biodiversity associated with each geophysical setting, we used information from a previously published overlay (Anderson and Weaver 2015) consisting of compiled information on the point location of natural communities and rare species tracked by the 14 State Natural Heritage programs intersected with information on the geology, elevation and landform maps that characterized each point. Keep in mind that while the relationships between species, communities and geophysical settings have

likely remained the same, the numeric information on rare species counts are only an approximation of the true values because our data sources are a few years old and varied in effort, focus, and completeness.

Map 5.1. Geology of the Northeast. This map was assembled from state-based sources crosswalked into seven bedrock and two surficial classes particularly relevant to species and habitats.



We quantified the relationships between rare species and geophysical settings by defining a "**preferential species**" as one that occurred more often than expected on a particular setting (landform, elevation zone or geology class) than on any other setting. We defined this mathematically as a species-setting relationship with an Importance Value greater than one (IV >1) where:

*Importance Value (IV) = %AE * Number of Observations)*

Percent above expected (%AE) was defined as the percent of samples occurring on a given setting minus the percent of samples expected to occur on the setting from random chance (*%Observed - % Expected)*. The number of observations was the number of element occurrences of that species in the entire region. Using this method we calculated a %AE and IV for every species-setting relationship (Table 5.1 provides a worked example for Timber Rattlesnake).

Table 5.1. Example illustrating calculation of the %AE and IV for Timber Rattlesnake (*Crotalus horridus*). Based on the element overlay on the landform map, there were seven topographic settings where dens occurred (or were in error). Of those 29% occurred on steep slopes. As steep slopes are relatively rare (1% expected) they had the highest percent above expected (%AE = 0.28). The %AE for all other topographic settings were negative except for warm sideslopes (0.08) and summits (0.01). We had 738 independent observations, so our importance value was much greater than 1 (IV=206) and our confidence in the results is high. Timber rattlesnake was identified as a preferential to steep slopes.

Timber Rattlesnake (Crotalus horridus) Observations = 738							
	Steep Slopes	Sideslope	Cove	Summit	Dry flat	Wet flat	Water
Expected %	0.01	0.36	0.14	0.16	0.18	0.08	0.06
Observed %	0.29	0.44	0.07	0.17	0.02	0.01	0
O-E	0.28	0.08	-0.07	0.01	-0.16	-0.07	-0.06
MAX %AE	0.28 = Steep Slopes						
N =737	IV = 206						

Although the region's dominant species occur across many geophysical settings, we found that each setting supported a distinct set of preferential species. These were non-overlapping within a class but a species could be preferential to several classes. For example, Cow Knob Salamander was preferential to slope crests and sideslopes on sedimentary rock at high elevation which describes the upper reaches of the Central Appalachian Mountains where it occurs. This approach and species relationship tables were developed in Anderson and Weaver (2015).

The numbered of preferential species differed strikingly across geology classes. Coarse sand (295) and calcareous bedrock (255) had the most. Although they both supported all taxonomic groups, coarse sand was particularly high for plants, birds, and reptiles, while calcareous was high for invertebrates, fish, and mussels perhaps reflecting the importance of limestone in creating alkaline waters. Ultramafic, a very rare setting consisting mostly of serpentine bedrock, had the highest density of species supporting 11 preferential plants and 7 preferential invertebrates even though there is less than 500,000 acres of serpentine in the region.

Table 5.2 Count and Density of Preferential Species by Geophysical Setting. The table shows the number of G1-G4 species preferential to each geophysical setting measured by an Importance Value greater than one (IV > 1). Density is the count of species divided by the area of the setting in the Northeast.

Geology Class	Amphibians	Reptiles	Birds	Mammals	Fish	Mussels	Invertebrates	Plants	Total	Density / 100 K Ac.
Coarse Sand	4	5	14	4	6	4	84	174	295	2.29
Calcareous	1	2	5	3	16	25	109	94	255	1.81
Acidic Sedimentary	5	2	1	5	10	10	40	86	159	0.20
Mod. Calcareous	1	3	3	2	16	23	34	53	135	0.82
Granitic	5	1	4	1	6	4	42	49	112	0.37
Mafic		2	1		2	4	9	39	57	0.54
Acidic Shale					3	4	10	21	38	0.29
Ultramafic							7	11	18	3.68
FineSediment			1	1			1	7	10	0.10
Grand Total	**16**	**15**	**29**	**16**	**59**	**74**	**336**	**534**	**1079**	**Ave =1.12**

Below we briefly characterize each geophysical setting and give examples of the preferential species. The section is arranged in order of the total preferential species

Sand and other Coarse-grained Surficial Sediments (295 preferential species)

Deep, coarse, sandy soils characteristic of outwash plains, coastal shorelines, and large riverbeds. Deep sand accounts for nine percent of the landscape and underlie some of our most iconic natural communities like coastal beaches and dunes, sandplain grasslands, and pitch pine barrens. The setting occurs in highly fragmented human-dominated landscapes, where it is difficult to maintain natural fire regimes or allow for natural shore migration. Many well-known species are associated with these environments and rarities are abundant including several federally listed species (Table 5.3. Appendix 1). Species that thrive in sand often have adaptations for burial, salt spray, or fire.

Table 5.3 Examples of typical communities and species. Longer list in appendix 5.2

Sand and Coarse Sediment		
Communities	**Rare Species**	
Example	**Taxa Group**	**Example**
Coastal Oak-Hickory Forest	Amphibians	Pine Barrens Tree Frog
Pitch Pine-Scrub Oak Barrens	Birds	Piping Plover
Coastal Plain White Cedar Swamp	Mammals	Maritime Shrew
Beach and Dune communities	Reptiles	Loggerhead
Sandplain and Maritime grassland	Insects	NE beach tiger beetle
Coastal Pitch Pine barren	Mollusks	New England Siltsnail
Sea level Fen	Ferns	Northern Appressed Clubmoss
Maritime interdunal swale	Plants	Pine Barren Gentian

Calcareous Bedrock (255)

Limestone, dolomite, and marble are sedimentary rocks composed of calcite derived from the remains of marine organisms and deposited in a shallow water environment. Calcareous settings make up six percent of the region and degrade to slightly alkaline soils (pH 6-8) that support a host of plants and animals sensitive to low pH. Soluble in slightly acidic water, calcareous settings are riddled with caves, springs and alkaline fens, the latter supporting botanical jewels like pumpkin sedge (*Carex aurea*) or Kalm's lobelia (*Lobelia kalmii*). Soils derived from limestone are productive for agriculture, although in bedrock form it is relatively infertile. Calcareous barrens, glades, and alvars, dominated by trees like chinquapin oak and red cedar, are low in biomass but rich species diversity (Table 5.4).

Table 5.4 Examples of typical communities and species. Longer list in appendix 5.2

Calcareous Bedrock		
Communities	**Rare Species**	
Example	**Taxa Group**	**Example**
Cave	Fish	Popeye Shiner
Calcareous fen & seep	Mammal	Indiana Bat
Dry Calcareous Forest	Reptile	Bog Turtle
Calcareous cliff and summit	Arthropod	Greenbrier Valley Cave Millipede
Calcareous glade and prairie	Insect	Northern Metalmark
Alvar grassland	Mollusk	Spiny Riversnail
	Vascular Plant	Ram's Head Lady's Slipper
	Fern	Hart's-tongue Fern

Acidic Sedimentary Bedrock (159):

This is a catch-all group of similar granular rock formed by consolidation and compaction of weathered mineral grains and rock fragments. The group includes sandstone, mudstone, siltstone, conglomerate, breccia, and greywacke, and their metamorphic equivalents, from slate to granofels. Most are relatively erodible, but some, like quartzite, are highly resistant and underlie ridges and slopes. This widespread class makes up a full 40 percent of the region (Map 5.1) and supports most of the common communities. Although this setting has its unique habitats and plenty of rarities (Table 5.5), because it is so widespread its density of rare species is relatively low (0.20 species per 100,000 acres).

Table 5.5 Examples of typical communities and species. Longer list in appendix 5.2.

Acidic Sedimentary Bedrock		
Communities	**Rare Species**	
Examples	**Taxa Group**	**Example**
Most Northeast forest and wetland habitats	Amphibian	Cheat Mountain Salamander
Unique communities include:	Fish	Northern Redbelly Dace
Sandstone Pavement Barrens	Mammal	Allegheny Woodrat
Acidic cliff and talus	Reptile	Timber Rattlesnake
Riverwash Bedrock Prairie	Insect	Bog Copper
Acidic Cove Forest	Mussel	Longsolid
	Vascular Plant	Alpine Milkvetch
	Lichen	Appalachian Trail Lichen
	Fern	Mountain Spleenwort

Moderately Calcareous Bedrock (135):

Moderately calcareous bedrocks are substrates composed of sand or silt particles cemented by a calcareous matrix and having a neutral pH, for example, calcareous shales or sandstones. These settings share many of the attributes of calcareous limestone settings but are less extreme and more widespread, covering 11 percent of the region (Map 5.1). Caves, rich woods, underground streams and alkaline waters are all typical, but not the hard calcareous glades and pavements formed by limestone or dolomite. Rare species, especially plants, arthropods and mollusks are common (Table 5.2) and common trees, such as black locust, hackberry, redbud, and American elm are abundant in these settings (Table 5.6).

Table 5.6 Examples of typical communities and species. Longer list in appendix 5.2

Moderately Calcareous Bedrock		
Communities	**Rare Species**	
Examples	**Taxa Group**	**Example**
Yellow oak - redbud woodland	Amphibians	Hellbender
Significant karst area	Fish	Ohio Lamprey
Underground pond and stream	Mammals	Northern Myotis
Appalachian Terrestrial Riparian Cave	Reptiles	Blanding's Turtle
Freshwater Mussel Concentration Area	Arthropod	Cave Cobweb Spider
	Insects	Karner Blue
	Mollusks	Tennessee Clubshell
	Plants	Orono Sedge
	Ferns & Bryophytes	Blunt-lobed Grape Fern

Granitic Bedrock (112):

Granitic bedrocks include all forms of igneous or metamorphic rocks with interlocking grains dominated by siliceous minerals: granite, granodiorite, rhyolite, felsite, pegmatite, granitic gneiss, and others. Similar rock with a high proportion of iron and magnesium (mafic) minerals are described under mafic or ultra mafic rock. Granites weather to acid, nutrient poor, shallow soils and are not particularly rich in rare species, but because they are very resistant to weathering and underlay many of the region's mountain ranges and rocky coasts they support some of our most distinct species and habitats (Table 5.7). Poor soil and spectacular rugged scenery make granite settings a favorite for hiking and conservation.

Table. 5.7 Examples of typical communities and species. Longer list in appendix 5.2

Acidic Granitic		
Communities	**Rare Species**	
Examples	Taxa Group	Example
Granitic flatrock	Amphibians	Peaks of Otter Salamander
Jack or Red Pine woodland	Fish	Kanawha Minnow
Montane acidic cliff and summit	Mammals	Eastern Red Bat
Boreal Talus Woodland	Reptiles	Northern Red-bellied Cooter
Boreal heath barrens	Mollusk	Eastern Pearlshell
Low-elevation Bald	Insects	Ringed Bog Hunter
Lowland spruce flat	Vascular Plants	Northeastern Bladderwort
Red oak woodland	Bryophytes & Lichens	Narrowleaf Peatmoss
Alpine heath & tundra	Ferns	Acadian Quillwork

Mafic or Intermediate Bedrock (57):

Mafic bedrocks include forms of volcanic, plutonic or metamorphic rocks with a high proportion of dark colored minerals high in magnesium and iron (the term comes from contracting "magnesium and ferric"), often the result of rapid cooling, such as in the extrusive basalts. Rock types include: anorthosite, gabbro, diabase, basalt, diorite, andesite, and others, as well as their metamorphic equivalents: greenstone, and amphibolites. Mafic rocks weather to a richer soil that granites, but like granites they are resistant to weathering and underlay many of the region's ridges, mountains, and rocky coasts. Derived soils may be of neutral pH, hence the name "basic" in some natural community names, and they may share species with moderately calcareous soils (Table 5.8). In the extreme, mafic substrates may share flora with the ultramafic serpentines. Mafic soils only account for 5 percent of the region but underlay large sections of the Adirondack Mountains (Map 5.1).

Table 5.8. Typical communities and species of Mafic bedrock. Longer list in appendix 5.2

Mafic or Intermediate Granitic		
Communities	**Rare Species**	
Examples	Taxa Group	Example
Alpine Krummholz & Meadow	Reptiles	Five-lined Skink
Circumneutral Rocky Summit/Rock Outcrop	Mollusk	Intricate Fairy Shrimp
Mountain fir forest	Insects	Spine-crowned Clubtail
Basic Oak - Hickory Forest	Vascular Plants	Longleaf Bluet
Mountain / Piedmont Basic Woodland	Ferns	Ledge Spikemoss
High-elevation Outcrop Barren		
Low-elevation Basic Outcrop Barren		

Acidic Shale Bedrock (38):

Shale is a mud-based fine-grained fissile sedimentary rock that characteristically flakes into thin layers along bedding planes, creating unstable hill slopes. Shale underlies many common forest habitats, amounting to 11 percent of the region (Map 5.1). Although less permeable than sandstone, its ability to store natural gas has made shale the focus of the recent boom in hydrologic fracturing (fracking). Ecologically shale is best known for creating the unique shale barrens and cliff communities found in the Appalachians. Plant rarities, such as shale barren rockcress and shale barren evening primrose, are adapted to hot dry slopes and continually creeping bedrock. Although a few fish, reptiles and small mammals are found almost exclusively in shale settings it is not clear whether this is a coincidence or if there an ecological reason for their distribution patterns (Table 5.9). Shales held together by a calcareous matrix are not placed here but in the moderately calcareous class.

Table 5.9 Typical communities and species of shale bedrock. Longer list in appendix 5.2

Acidic Shale		
Communities	**Rare Species**	
Examples	Taxa Group	Example
Appalachian Shale Barren	Amphibians	Northern Cricket Frog
Shale Cliff And Talus Community	Fish	Roughhead shiner
Red-cedar - hardwood rich shale woodland	Arthropod	Northern Clearwater Crayfish
	Insects	Olympia Marble
	Mollusks	James Spinymussel
	Plants	Shale barren Pussytoes
	Ferns	Appalachian Woodsia

Ultramafic Bedrock (18):

Ultramafic bedrocks include igneous and meta-igneous rocks that are very high in magnesium and iron, and very low in silica and potassium: serpentine, soapstone, pyroxenite, dunite, peridotite, talc schist. These substrates weather to soils that are rich in magnesium, but poor in calcium, and they may have elevated levels of chromium or nickel. These extreme soils are toxic to many plants and a unique flora of tolerant species has evolved. Serpentine barrens tend to be open woodlands with stunted trees and a herb flora rich with endemics. Ultramafic settings cover less than 1 percent of the region (Map 5.1) and have the highest density of rare species of any geology (3.7 per 100,000 acres).

Table 5.10. Typical Communities and Species of Ultramafic Bedrock. Longer list in appendix 5.2

Ultramafic		
Communities	**Rare Species**	
Examples	Taxa Group	Example
Serpentine Barren	Insect	Falcate Orangetip
Serpentine Outcrop	Plant	Serpentine aster
Mafic Fen	Fern	Green Mountain maidenhair-fern

Fine-grained Mud and Silt Deep Surficial Sediment (10):

This is a deep sediment setting formed of fine-grained mud and silt. It can be found in clay-plains formed in old lake beds, silt floodplains created by river deposits, and organic mud underlying the tidal marshes. This environment favors species that tolerate poorly drained soils, and most of the characteristic communities are marshes, floodplains or swamps. Forests that form on river floodplains or on ancient clay-plains often have a diversity of trees species uncommon in the surrounding landscape. This setting covers 6 percent of the region and supports a few rare species (Table 5.11).

Table 5.11. Typical Communities and Species of Fine Silt and Clay. Longer list in Appendix 5.2.

Fine Silt and Clay		
Communities	**Rare Species**	
Examples	Taxa Group	Example
Deep Bulrush Marsh	Amphibians	Lesser Siren
Freshwater Tidal Swamp & Marsh	Fish	Slenderhead Darter
Lakeside Floodplain Forest	Reptiles	Canebrake Rattlesnake
Major-river Floodplain Forest	Insects	Two-striped Forceptail
Pond Pine Woodland / Pocosin	Mollusks	Pink Papershell
Valley Clayplain Forest	Plants	Elongated Lobelia

Elevation and Landform-based Communities

Elevation strongly influences species diversity patterns especially at the extremes. Nowhere is this more apparent than in the mountainous high elevation settings where wind, ice, and snow create alpine-like conditions. Supporting 103 preferential species high elevation and alpine environments have the highest density of rare species in the region (Table 5.12). At the other extreme, regular tidal movement at sea level creates its own distinct environment favoring species adapted to some level of salt spray or complete inundation. The thin coastal zone that flanks the region supports 177 preferential rare species as well as many common species like saltmarsh cordgrass (Spartina alterniflorus) that are adapted to this zone.

Table 5.12. The Number and Type of Preferential Species by elevation zone.

Elevation Zone	Amphibians	Reptiles	Birds	Mammals	Fish	Mussel	Invertebrate	Plant	Total	Density / 100 K ac.
Coastal 0-20	1	6	14	6	8	3	35	104	177	1.60
Very Low 20-800'	2	4	4	2	12	14	102	162	302	0.28
Low 800-1700'	1	4	4	3	28	40	71	105	256	0.49
Mid 1700-2500'	3		1	4	12	14	75	44	153	1.04
High 2500-3600'	3		1	2		4	27	35	72	2.01
Very High 3600'+	5		1				6	19	31	6.64
Grand Total	**15**	**14**	**25**	**17**	**60**	**75**	**316**	**469**	**991**	**Avg. = 2.01**

Altitudes above 3600 ft. cover less than one percent of the region, but these areas support a distinctive flora and fauna that share elements with alpine regions around the world. Habitats tracked by the heritage network include alpine meadows, bogs, tundra, snowbanks, and krummholz communities formed by stunted and wind-twisted trees. In the north, spruce and fir are characteristic of these habitats, but in the Central Appalachians gnarled red oaks are one of the dominant trees. Many rare species are associated with high elevation communities, the majority of them being plants or invertebrates (Table 5.13).

Table 5.13. Typical Communities and Species of Alpine and High Elevations. Longer list in Appendix 5.2.

Alpine and High Elevation		
Communities	**Rare Species**	
Examples	**Taxa Group**	**Example**
Alpine Krummholz/Mt fir forest	Amphibians	Cheat Mountain Salamander
Alpine tundra, wind-swept ridge	Bird	Bicknell's Thrush
Alpine bog, meadow, sliding fen	Mammals	Rock Shrew
Central Appalachian soft sedge fen	Insects	Mitchell's Saytr
High elevation red oak forest	Plants	Alpine Azalea
High-elevation boulderfield woodland	Ferns	Appalachian Firmoss
High-elevation Cove Forest		

The coastal zone between sea level and 20' is one of the most distinctive and productive zones in the Northeast supporting tidal marshes. Mud flats, beaches, sand dunes, and a thin strip of distinctive maritime forest. This is a very dynamic portion of the region and sea level rise is already changing the profile of the zone. We report on the zone here as if it where static but see the climate resilience chapter for a discussion of sea level rise and marsh migration.

Table 5.14. Typical Communities and Species of the Coastal Zone. Longer list in Appendix 5.2.

Coastal Zone		
Communities	**Rare Species**	
Examples	Taxa Group	Example
Atlantic Coastal Plain Beach and Dune	Bird	Roseate Tern
Great Lakes Dune and Swale	Bird	Salt Marsh Sparrow
North Atlantic Coastal Plain Heathland and Grassland	Fish	Atlantic sturgeon
Tidal Salt Marsh	Reptiles	Loggerhead
Coastal Plain Tidal Swamp	Mollusk	Tidewater mucket
Estuarine Marsh	Insects	Rare skipper
Tidal Salt Flat	Vascular Plants	Seabeach knotweed
Coastal Plain Maritime Forest	Vascular Plants	Estuary Beggarticks
	Ferns	Curly Grass Fern

Topographic settings influence the distribution of species because local relief controls the distribution of solar radiation and moisture. The relationship between most landforms and species is less direct than for geology or extreme elevations as most species occur across several related landform types but still show a preference for a particular topographic position (Figure 5.2).

Two topographic settings that do determine species composition are wetlands and cliffs, as they create unique conditions that demand specific adaptations. Wetlands are by far the most widespread and species rich of the landform habitats covering 14% of the region and supporting over 1000 preferential species. They are discussed in their own chapter. Cliffs and steep slopes (3 percent of the region) offer a challenging setting for many species. Species partial to cliffs range from tenacious wiry herbs to falcons and ravens that use their isolated ledges for nesting (Table 5.15). Note: this dataset maps large cliffs and does not accurately reflect all small cliffs and outcrop in the region; for example, only 35 percent of peregrine falcon nests show up on the mapped cliffs, although almost all of the nests are on cliffs.

Figure 5.2. Preferences of Two Plant Species for Landform Types. The "0" line indicates no preference, positive numbers equal more than expected and negative equal less. Occurrences of Smooth cliff fern (*Woodsia glabella*) were preferential to cliffs (%AE =30) but are also found on warm south-facing steep slopes (24), slope crests (14) and coves (5). They are negative to all other topographic settings. Sandplain Gerardia (*Agalinis acuta*) was preferential to flats especially hilltop flats (21), dry flats (12) and moist flat (17) but were neutral to wet flats and negative to gentle slopes and sideslopes.

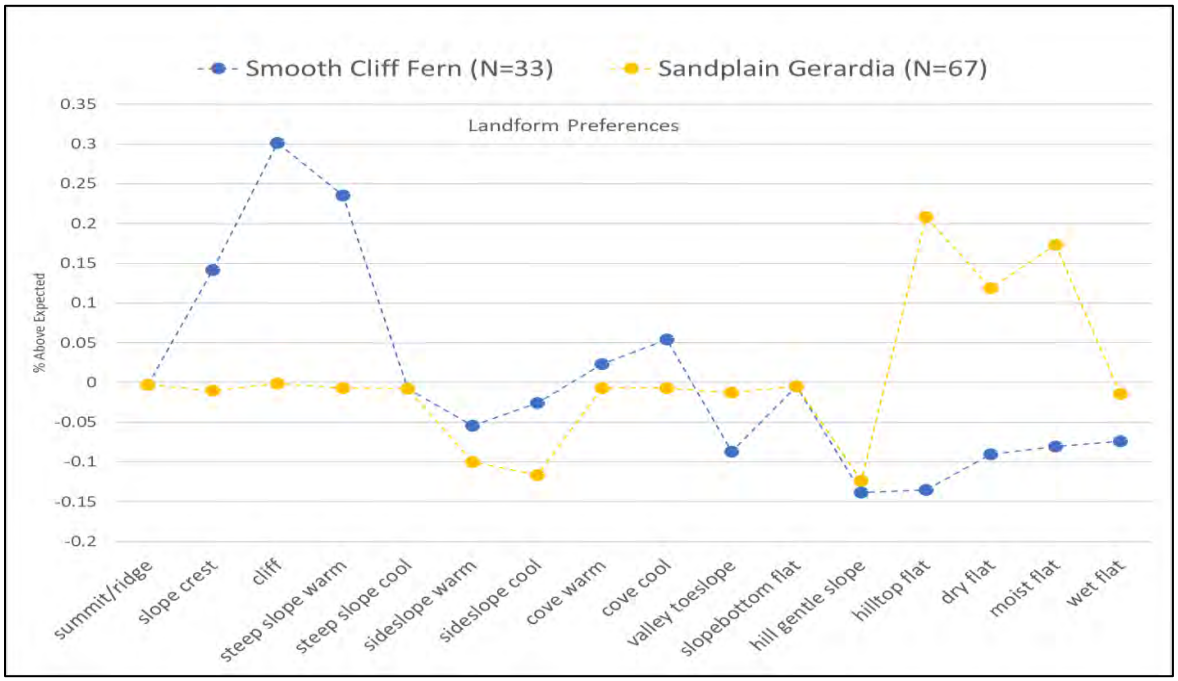


Table 5.15. Typical Communities and Species of Cliffs and Steep Slopes. Longer list in Appendix 5.2.

Cliff and Steep Slope		
Communities	**Rare Species**	
Examples	Taxa Group	Example
Acidic Cliff	Amphibians	Shenandoah Salamander
Acidic Talus Slope Woodland	Birds	Golden Eagle
Boreal Talus Woodland	Mammals	Rock Vole
Calcareous Cliff Community	Reptiles	Timper Rattlesnake
Sandstone cliff	Vascular Plants	Purple Clematis
High-elevation Boulderfield Forest / Woodland	Fern	Fragrant Cliff Fern
Northern White-Cedar Slope Forest		
Shale Cliff And Talus Community		

Distribution, Loss, and Protection by Geophysical Setting

To understand the relative level of habitat conversion in relation to land conservation within each geophysical setting, we overlaid the conservation lands data (The Nature Conservancy. 2022) and the NLCD landcover data (Dewitz and U.S. Geological Survey, 2021) on the geophysical maps and tabulated the amount of each by geology class, elevation zone, and landform. Below we summarize the results for each geophysical settings and compare the rate of conversion and conservation in the last 10 years to the average rate overall.

In this section we use the terminology presented in the conservation lands chapter:

Conserved = GAP 1-3. Land secured against conversion regardless of primary purpose
Conserved for Nature = GAP 1-2. The primary purpose is nature conservation
Conserved for Multiple Uses = GAP 3. The primary purpose is multiple use: recreation, harvest

Conservation Risk Index (CRI) = (Percent Converted)/ (Percent GAP 1,2&3)
Nature Risk Index (NRI) = (Percent Converted)/(Percent GAP 1&2)

Results of this analysis show that on average land conservation has not caught up with habitat conversion. For every one acre of habitat conserved, 1.8 acres of habitat has been converted, and for every acre conserved for nature, 4.4 acres have been converted to development or agriculture (Table 5.16).

Conservation and conversion, however, were distributed unevenly across the region's geophysical settings (Table 5.16 Figures 5.3-5.5). Granitic and mafic settings with their resistant bedrock and thin shallow-to-bedrock soils, show the reverse of the regional pattern with two acres conserved for every one converted. At the other extreme, calcareous settings show 8 acres converted for every 1 acre conserved, and 32 acres converted for every 1 acre conserved for nature (CRI 7.9, NRI 31.6). The high value of these productive soils makes calcareous settings the most converted (51%) and the least conserved (6%) of all settings. Acidic shale had the second highest risk with 4 acres lost to conversion for every 1 acre conserved, and 29 acres converted for every 1 acre conserved for nature. Coarse-grained sands were the second most converted (43%) but had higher levels of conservation (11%) equivalent to 4 acres converted for every 1 acre conserved. In all, six settings had conservation risk indices greater than 1 (range 1.4-7.9) indicating higher amounts of conversion than securement for all settings except granitic, mafic and acidic sedimentary (Table 5.16). All settings had nature risk indices greater than one (range 1.1-31.7) suggesting that we have not conserved enough quality habitat explicitly for breeding and population growth of wildlife and plants relative to the amount we have converted for our own needs and uses (Table 5.16).

Similar trends were apparent by elevation zone, with the three highest elevation zones (all over 1700') showing more habitat conserved than lost to conversion (Table 5.16, Figure 5.4). At very high elevations over 3600' conversion is virtually absent (1%) and almost 71% percent of the area is conserved, most of that for nature (NRI = 0.03). Alpine is, of course, a tiny proportion of the landscape. The zones where most of the population live (20-800') are the most converted (36%) and the least conserved (11%) with 3.3 acres converted for every 1 acre conserved. The coastal zone is also highly converted (34%) but has significantly more conservation (27%, CRI = 1.3)) reflecting a network of coastal protection like Cape May and Parker River National Wildlife Refuges and Cape Cod National Seashore. Unfortunately beaches and tidal marshes are now threatened by sea level rise (see the climate resilience chapter).

Table 5.16. The percent of habitat conversion compared to percent of land conservation. The ratios of conversion to conservation are given in various combinations where CRI is the ratio of conversion to conservation for nature or multiple uses (GAP 1-3) and NRI is the ratio of conversion to conservation explicitly for nature (GAP 1-2).

	Conversion versus Conservation: All Years (acres)									
	Habitat Loss to Conversion			Conservation			Unconserved		Risk Index	
Geology	Developed	Agriculture	%	GAP 1 & 2	GAP 3	%	Natural	%	CRI	NRI
Calcareous	3,535,018	1,549,565	51%	160,592	481,791	6%	4,332,952	43%	7.92	31.66
Acidic shale	4,230,657	1,924,656	33%	339,095	1,627,046	11%	10,263,284	56%	3.13	18.15
Fine sediments	1,858,596	1,423,144	37%	451,635	692,629	13%	4,511,784	50%	2.87	7.27
Coarse sediments	3,270,208	3,916,984	41%	1,032,333	1,728,864	16%	7,460,113	43%	2.60	6.96
Moderately Calcareous	*2,935,861*	*1,549,220*	*29%*	*349,564*	*1,564,137*	*12%*	*9,240,396*	59%	*2.34*	*12.83*
All Geology Classes	*23,301,667*	*17,766,124*	*26%*	*9,277,844*	*20,298,339*	*19%*	*84,646,567*	*55%*	*1.39*	*4.43*
Ultramafic	11,998	18,697	26%	9,175	13,056	19%	64,759	55%	1.38	3.35
Acidic sedimentary	5,301,104	4,734,588	18%	2,705,976	9,729,563	22%	33,457,820	60%	0.81	3.71
Mafic/Intermediate	530,101	775,206	18%	1,031,367	1,105,953	30%	3,763,586	52%	0.61	1.27
Acidic granitic	1,628,124	1,874,063	16%	3,198,108	3,355,302	30%	11,551,873	53%	0.53	1.10
	Habitat Loss to Conversion			Conservation			Unconserved		Risk Index	
Elevation	Developed	Agriculture	%	GAP 1 & 2	GAP 3	%	Natural	%	CRI	NRI
20-800'	11,980,216	11,628,008	36%	1,813,358	5,340,487	11%	33,933,019	52%	3.30	13.02
All Elevation Zones	*23,301,667*	*17,766,124*	*26%*	*9,277,844*	*20,298,339*	*19%*	*84,646,567*	*55%*	*1.39*	*4.43*
< 20'	523,508	978,526	34%	592,829	591,669	27%	1,760,945	40%	1.27	2.53
800-1700'	8,235,736	4,119,059	22%	2,461,045	7,639,036	18%	34,347,629	60%	1.22	5.02
1700-2500'	2,094,932	859,179	13%	2,789,245	5,200,967	36%	11,449,063	51%	0.37	1.06
2500-3600'	464,408	175,835	10%	1,349,304	1,296,728	42%	2,955,985	47%	0.24	0.47
> 3600'	2,867	5,517	1%	272,064	229,451	71%	199,926	28%	0.02	0.03
	Habitat Loss to Conversion			Conservation			Unconserved		Risk Index	
Slope Class	Developed	Agriculture	%	GAP 1 & 2	GAP 3	%	Natural	%	CRI	NRI
Upper Flats	4,650,893	3,895,314	47%	554,022	1,767,240	13%	7,261,374	40%	3.68	15.43
Lower Slopes	8,628,345	5,805,477	32%	1,853,859	5,407,177	16%	22,872,940	51%	1.99	7.79
Lower Flats	5,994,038	5,420,554	31%	2,292,300	4,374,005	18%	18,365,302	50%	1.71	4.98
All Slope classes	*23,301,667*	*17,766,124*	*26%*	*9,277,844*	*20,298,339*	*19%*	*84,646,567*	*55%*	*1.39*	*4.43*
Upper Slopes	3,998,269	2,579,339	13%	4,397,125	8,363,549	24%	33,027,928	63%	0.52	1.50
Water	30,122	65,440	3%	180,539	386,368	15%	3,119,023	82%	0.17	0.53

Figure 5.3. Geology Classes: Amount of conversion compared with the amount of securement. Each bar represents 100% of the historic area. Area to the left of the "0" axis indicates acreage converted, area to the right shows the remaining natural land by securement status (see also Figures 5.4-5.5).

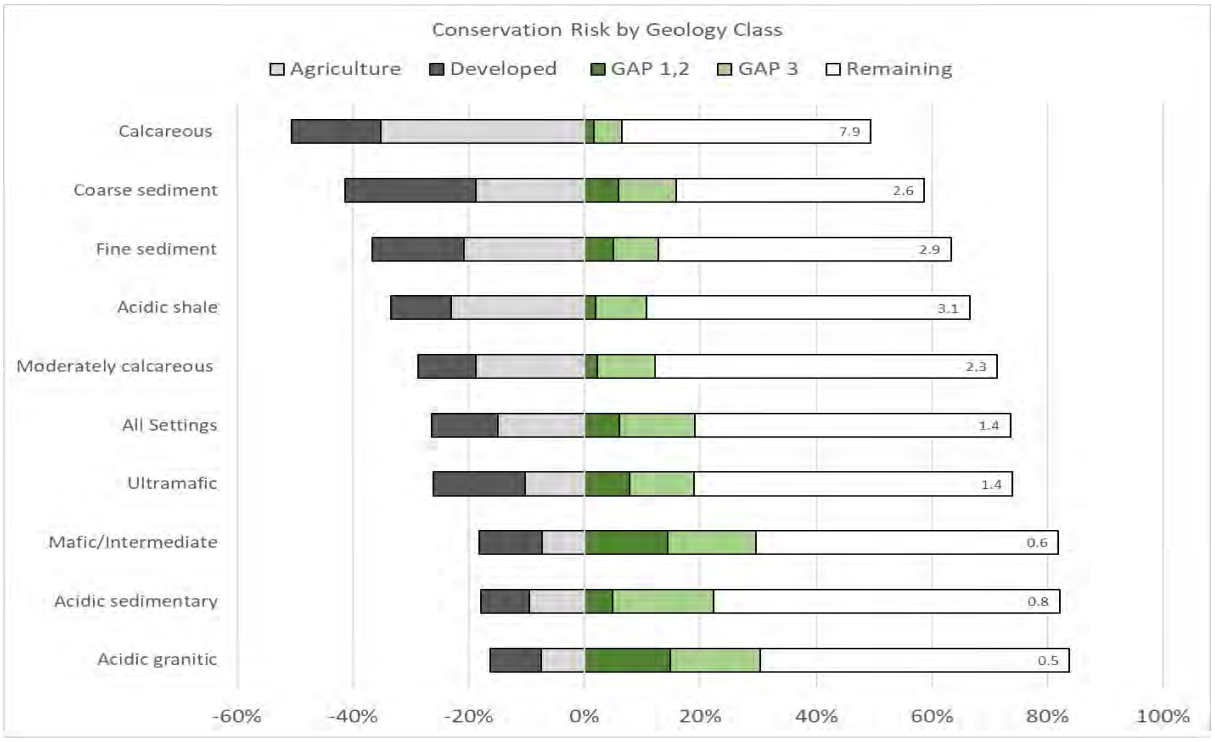
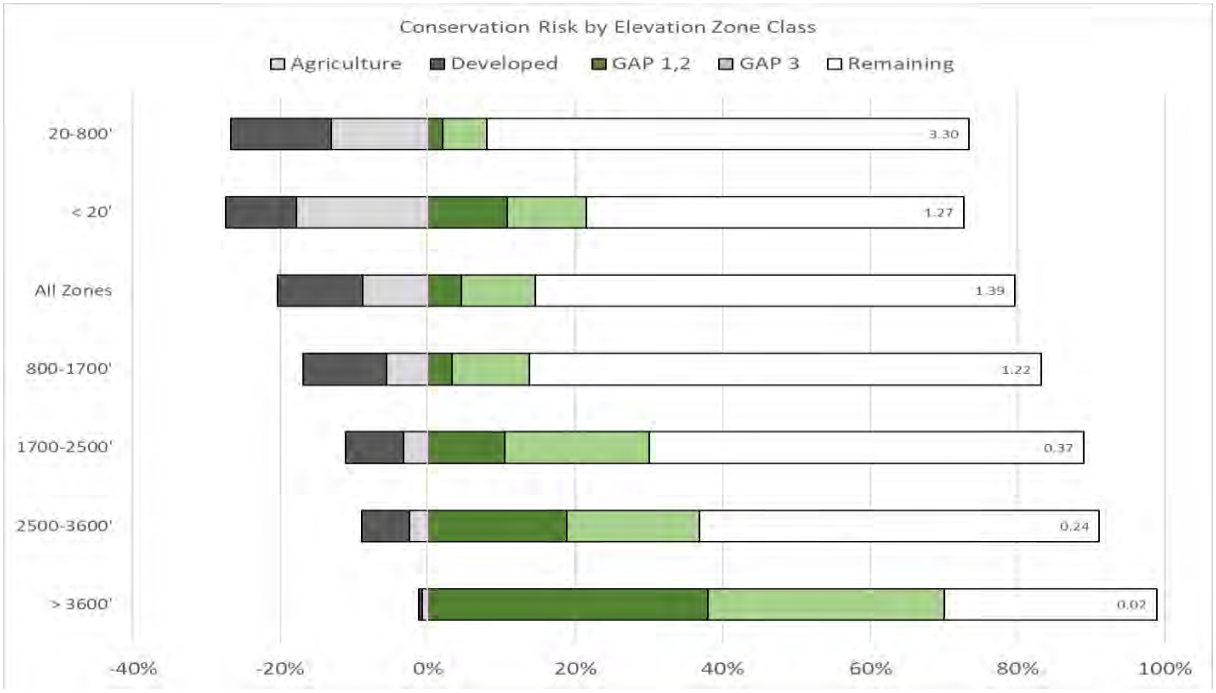
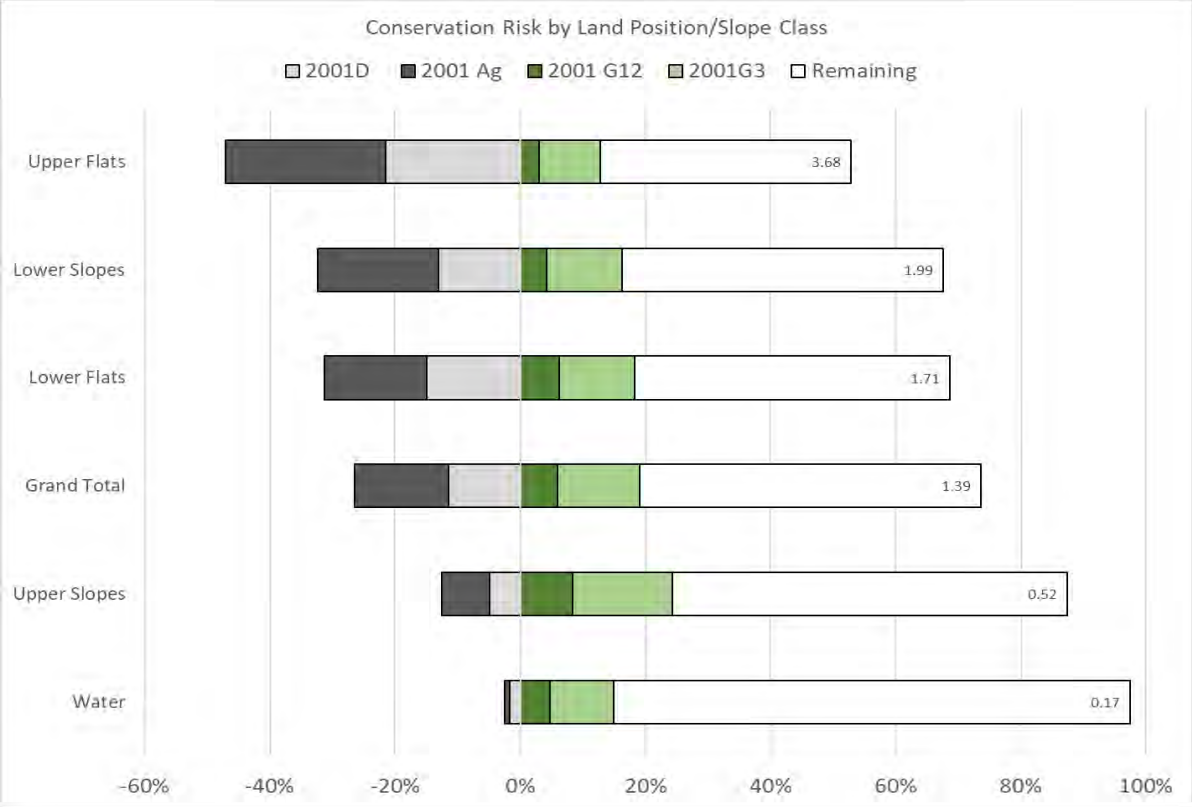


Figure 5.4. Elevation Zones: The amount of conversion compared with the amount of securement. Legend as for Figure 5.3 above. See also Figure 5.6



From a landform perspective, we have conversed slopes and converted flats (Table 5.16, Figure 5.5). Settings like upper flats (CRI 3.7), lower flats (CRI 1.7) and lower slopes (CRI 2) all have more conversion than conservation). In contrast, upper slopes (CRI 0.5) have more conservation than conversion to development or agriculture.

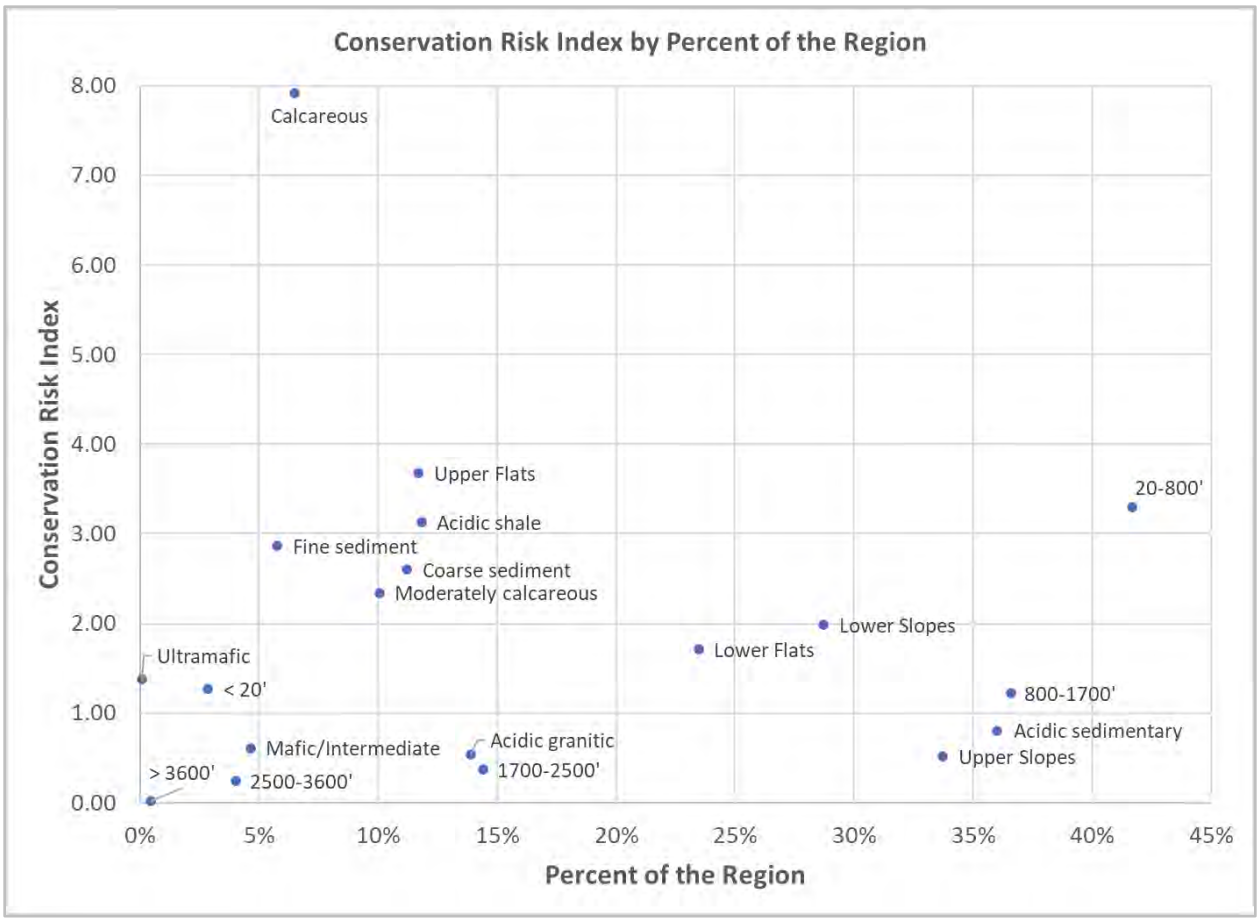
Figure 5.5. Landform Types: The amount of habitat conversion compared with the amount of habitat securement or protection. Legend as for figure 3 above. See also Figure 5.7.



We tested whether the ratio of conversion to conservation was simply a function of acreage, with small environments like alpine having more conservation, but we found that CRI was unrelated to the amount of each setting present in the region (Figure 5.6).

In summary, low elevation flat lands in calcareous, acidic shale, or coarse sand show a high conservation risk, and species associated with them are likely to face challenges. These settings had the highest amount of conversion to agriculture or development, and the least conservation. High elevation slopes in acidic granitic, mafic, or sedimentary soils were the opposite and are for the most part conserved. No setting except alpine, has enough area conserved explicitly for nature to offset the amount converted.

Figure 5.6. The conservation risk index of geological settings, elevation zones and landform types in relation to the percent of the region covered by that feature. Features below the 1.0 line have more securement than conversion, Features above the 1.0 line have more conversion than securement



Recent Trends in Habitat Conversion and Conservation (2011-2022)

For this section we focus on the 2012-2022 decade since the release of our first report (Anderson and Olivero 2011). We used the methods described above to understand the relative level of habitat conversion and land conservation securement within each geophysical setting, except that we restricted the conservation lands data (The Nature Conservancy. 2022) to conservation achieved since 2011 and used the NLCD landcover change data (Dewitz and U.S. Geological Survey, 2021) to identify changes in land cover or land use between 2011 – 2021. Below we summarize the results and compare the rate of conversion and conservation in the last 10 years to the average rate overall.

In contrast to the previous results for all years, this analysis shows that *on average for the last decade the amount of land conservation implemented has surpassed the amount of conversion to agriculture or development.* For every one acre of land conserved, 0.11 acres of habitat has been converted to development or agriculture, and for every one acre conserved for nature, 0.48 acres have been converted (Table 5.17).

Conservation and conversion were distributed relatively evenly across the region's geophysical settings with all setting showing Conservation Risk Indices less than one (CRI range 0.04-0.41, Table 5.17, Figure 5.7). This held true for the Nature Risk Index also with all setting except acidic shale and calcareous having NRI less than one (NRI range 0.06-0.79). Acid shale settings had the highest percentage of recent habitat loss to conversion (25%) and the lowest percent of new land conservation (60%) with 1.8 acres lost to conversion for every acre conserved for nature. Likely this reflects the boom in fracking that has resulted in thousands of new oil and gas wells situated in the Marcellus shale regions of Pennsylvania and Maryland before it was banned by the latter. Calcareous areas are still being converted faster than they are conserved for nature, but the rate is much slower (recent NRI 1.71 versus all years NRI 31.6)

Trends by elevation zone, were optimistic for wildlife and plants with CRI and NRI ratio less than one for evey elevation zone. Even the very low elevation zone with the most development (20-800') had more land conservation (78%) than conversion to development or agriculture (15%) an impressive trend.

Table 5.17. Recent trends in habitat conversion compared to percent of land conservation. The ratios of conversion to conservation are given in various combinations where CRI is the ratio of conversion to total conservation for nature or multiple uses (GAP 1-3) and NRI is the ratio of conversion to conservation explicitly for nature (GAP 1-2).

	Recent Trends: 2012-2022 (acres)									
	Habitat Loss to Conversion			Conservation			Habitat Gain	Total Change	Risk Index	
Geology	Developed	Agriculture	%CV	GAP 1 & 2	GAP 3	%CNMU	Ag to Natural	Acres Changed	CV/CNMU	CV/CN
Acidic shale	22,008	27,929	25%	26,390	95,302	62%	25,951	197,579	0.41	1.89
Fine sediments	13,964	10,379	18%	38,909	62,543	74%	11,070	136,865	0.24	0.63
Calcareous	5,962	14,194	17%	11,763	71,938	70%	15,714	119,571	0.24	1.71
Coarse sediments	29,501	13,875	15%	67,153	167,683	80%	14,068	292,280	0.18	0.65
Moderately Calcareous	15,173	17,019	13%	40,657	148,230	79%	18,228	239,306	0.17	0.79
All Classes	*166,415*	*146,144*	*10%*	*657,724*	*2,115,056*	*85%*	*158,732*	*3,244,071*	*0.11*	*0.48*
Mafic/Intermediate	8,554	6,057	7%	41,821	139,985	90%	5,572	201,988	0.08	0.35
Acidic granitic	17,765	19,817	7%	148,186	347,927	89%	21,360	555,055	0.08	0.25
Acidic sedimentary	53,269	36,811	6%	277,766	1,078,795	91%	46,690	1,493,331	0.07	0.32
Ultramafic	218	65	3%	5,078	2,655	96%	79	8,095	0.04	0.06
	Habitat Loss to Conversion			Conservation			Habitat Gain	Total Change	Risk Index	
Elevation	Developed	Agriculture	%CV	GAP 1 & 2	GAP 3	%CNMU	Ag to Natural	Acres Changed	CV/CNMU	CV/CN
Very Low ('20-800')	102,062	69,775	15%	252,898	630,779	78%	70,385	1,125,898	0.19	0.68
All Elevations	*166,415*	*146,144*	*10%*	*657,724*	*2,115,056*	*85%*	*158,732*	*3,244,071*	*0.11*	*0.48*
Low (800-1700')	45,416	55,049	8%	198,947	836,683	87%	58,158	1,194,253	0.10	0.50
Coastal (< 20')	5,424	1,296	8%	27,298	47,921	90%	1,545	83,484	0.09	0.25
Mid (1700-2500')	10,584	15,487	4%	108,669	457,758	92%	22,268	614,765	0.05	0.24
High (2500-3600')	2,831	4,385	4%	66,101	120,499	93%	6,179	199,995	0.04	0.11
Alpine (> 3600')	98	154	1%	3,811	21,415	98%	197	25,676	0.01	0.07
	Habitat Loss to Conversion			Conservation			Habitat Gain	Total Change	Risk Index	
Slope Class	Developed	Agriculture	%CV	GAP 1 & 2	GAP 3	%CNMU	Ag to Natural	Acres Changed	CV/CNMU	CV/CN
Upper Flats	29,328	23,094	16%	52,040	205,912	78%	19,776	330,150	0.20	1.01
Lower Slopes	54,705	55,060	12%	161,936	577,787	82%	52,435	901,923	0.15	0.68
Lower Flats	40,059	33,152	10%	167,669	462,049	85%	38,567	741,495	0.12	0.44
All Landforms	*166,415*	*146,144*	*10%*	*657,724*	*2,115,056*	*85%*	*158,732*	*3,244,071*	*0.11*	*0.48*
Upper Slopes	41,621	34,427	6%	269,206	822,573	90%	47,314	1,215,141	0.07	0.28
Water	702	411	2%	6,873	46,735	97%	640	55,361	0.02	0.16

Figure 5.7. Geology Classes: Conversion versus Conservation 2012-2022.

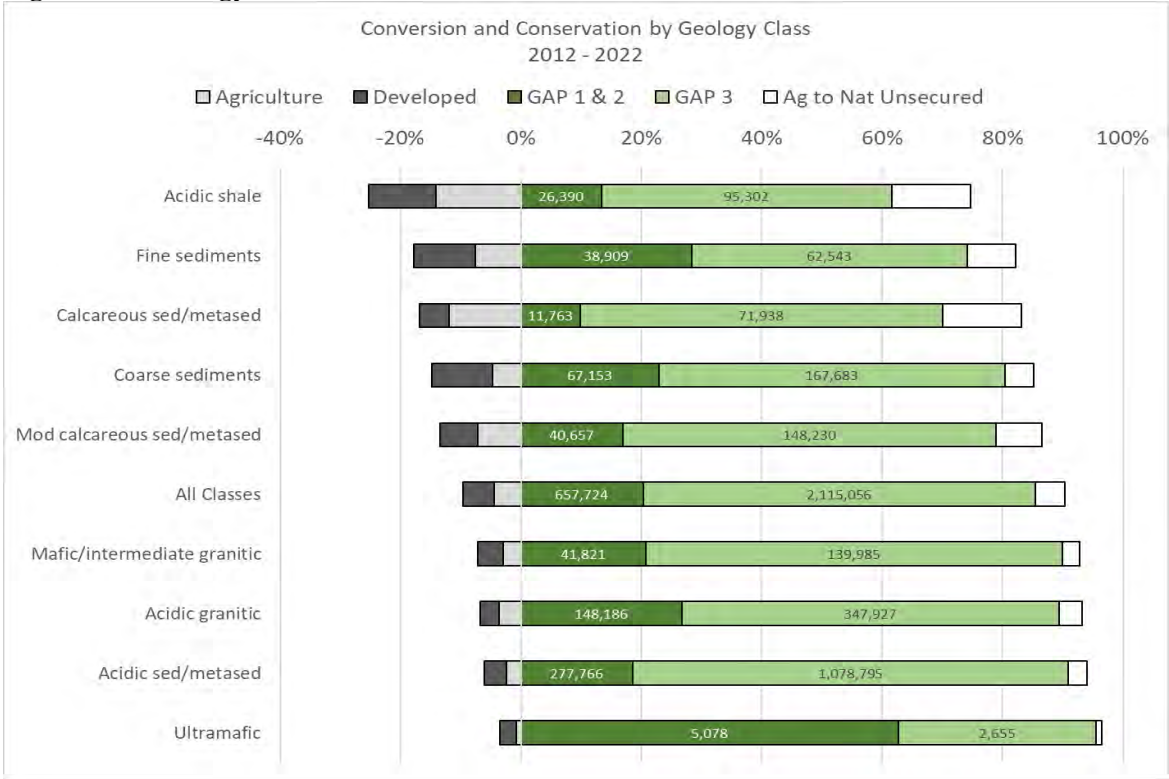


Figure 5.8. Elevation Zones: Conversion versus Conservation 2012-2022.

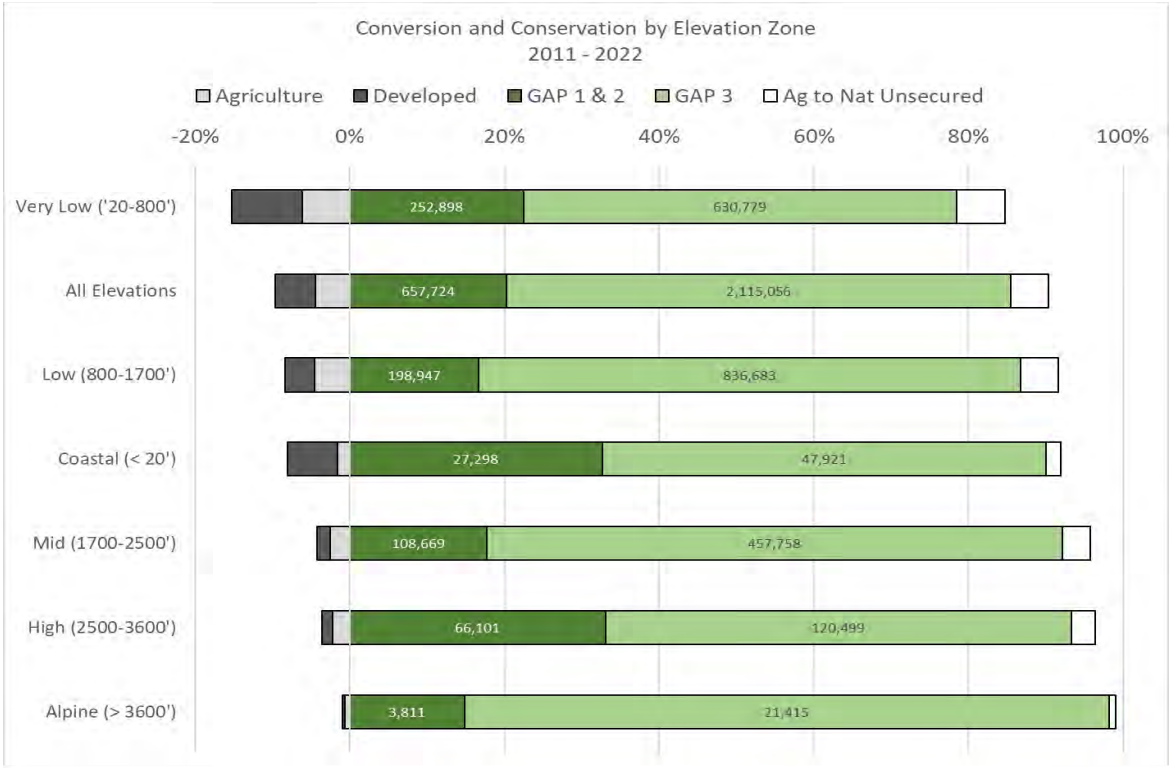
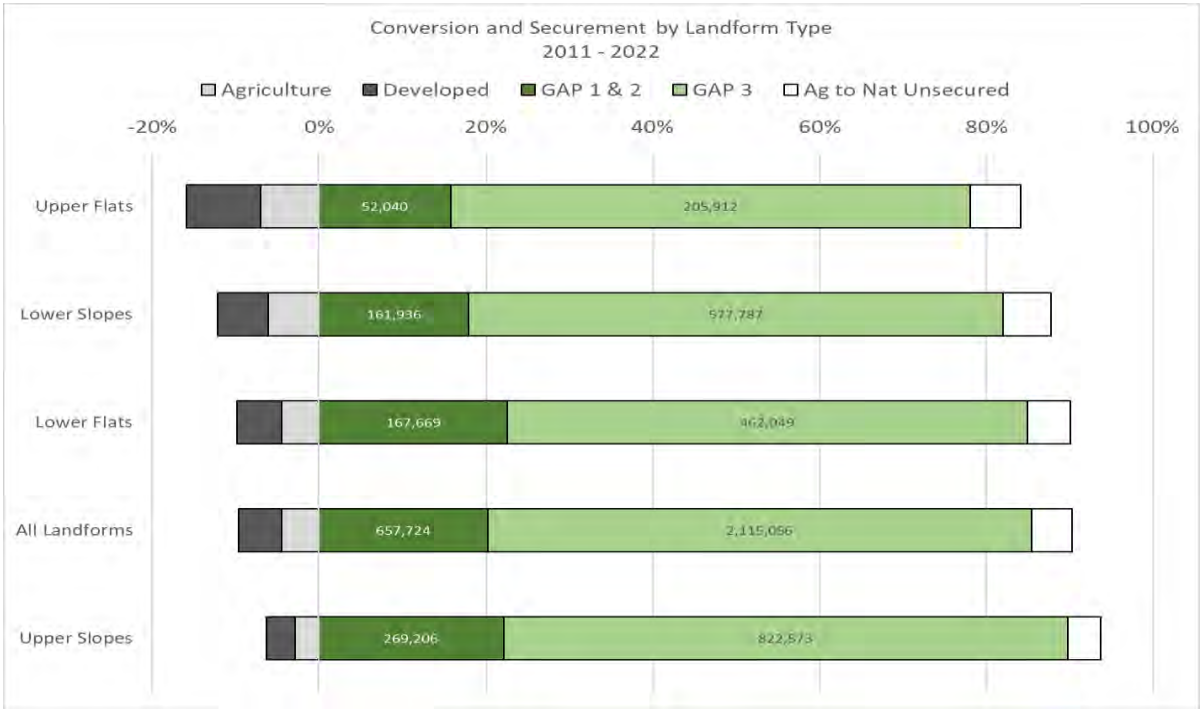


Figure 5.9. Slope Class: Conversion versus Conservation 2012-2022.



Slope patterns largely tracked the patterns seen in other setting with CRI and NRI all less than one, with the exception of the upper flats (equating generally to dry flat settings) where the conversion and conservation for nature were equal (NRI = 1.01, Figure 5.9)

In summary, the last decades has seen great progress in conservation. The combination of land conservation for nature and/or for multiple uses has surpassed habitat conversion across every geology type, elevation zone and slope class. Conservation explictly for nature shows the same trend with two exceptions: Shale has shown the most conversion and habitat conversion still surpassses land conservation about tow to one. Calcareous settings also show a roughly two-to-one ratio if habitat conversion to land conservation but this is a large drop from the 32 to 1 ration seen over the last century.

Fragmentation and Connectivity of Geophysical Settings

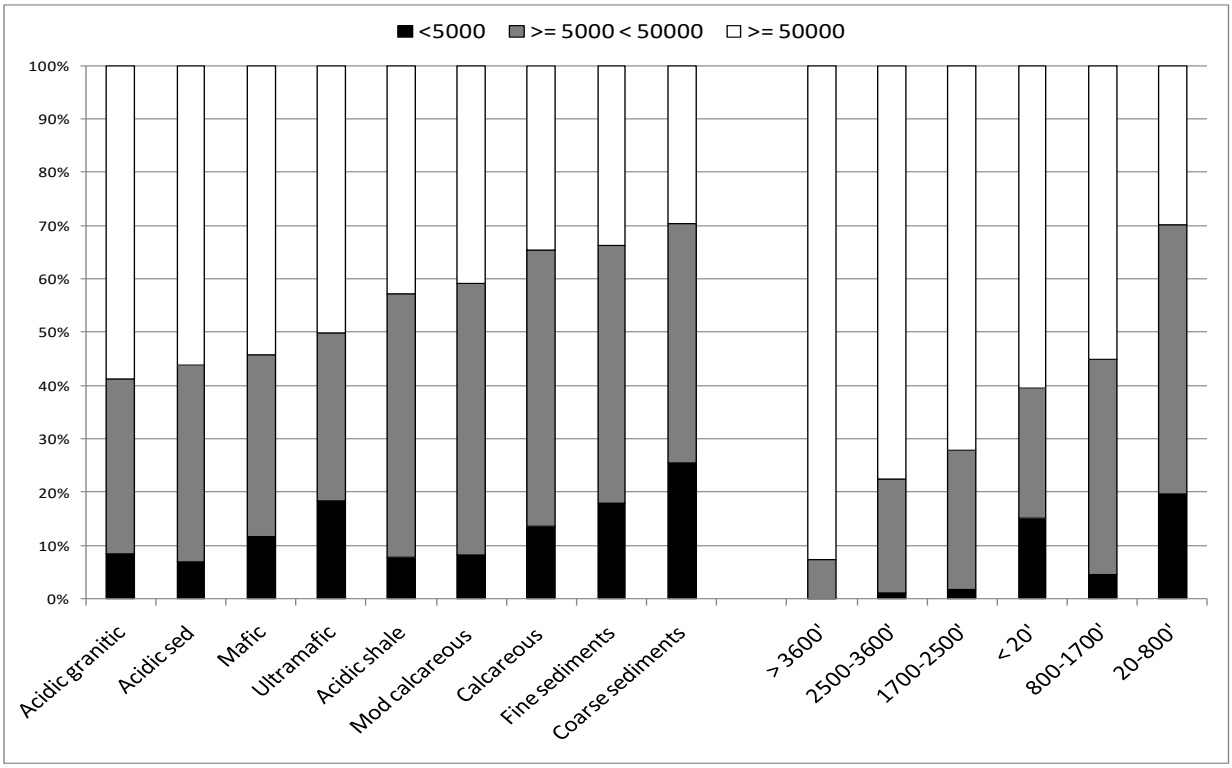
The region now supports 75 million people, 4 million more than in 2011. The infrastructure to support the human population include buildings and development, energy infrastructure, agricultural farmlands, mining and waste disposal areas, and at least 732,000 miles of permanent roads, pipelines, and transmission lines. In this section we examine the spatial distribution of these fragmenting features in relationship to the underlying geophysical settings to assess the degree of fragmentation present in each setting and how much it has changed over the last decade. We used two types of analysis to measure fragmentation. The first, a road bounded block analysis, was not repeated in 2022 as the major road network did not change enough for us to report on. We include the 2011 analysis as it provides a useful characterization of the region. The second, the local connectedness analysis, is very sensitive to changes in multiple fragmenting features including minor roads and building footprints. For this analysis, we were able to create and new resistance grid, run the analysis again and assess change over that last decade.

Fragmentation occurs when a contiguous area of natural land is subdivided into smaller patches, resulting in each patch having more edge habitat and less interior. Because edge habitat contrasts strongly with interior the surrounding edge habitat tends to isolate the interior region and contribute to its degradation. Thus, fragmentation can lead to an overall deterioration of ecological quality and a shift in associated species from interior specialists to edge generalists.

Block Analysis (from 2011) The regions 732 thousand permanent roads are the primary fragmenting features providing access into interior regions, and decreasing the amount of sheltered secluded habitat preferred by many species. Heavily-used paved roads create noisy disturbances that many species avoid, and the roads themselves may be barriers to the movement of small mammals, reptiles, amphibians and ground insects. To evaluate the extent and impact of roads, we examined the patterns created when major roads connect to encircle contiguous blocks of land. We defined a block as a distinct area of land surrounded on all sides by major roads (e.g. wide paved roads with significant traffic volume). The area of each block was calculated, the block was assigned to a size class, and the amount of each geophysical setting within each block was summarized to determine the size class distribution for blocks of each setting type (Map 5.3, Figure 5.4, Table 5.2). Our assumption was that the highest quality habitat is found in the central core of each block - the region greater than 100 meters from any major road, field or developed area – and that the effect of the fragmenting feature decreases with the size of the blocks.

Results of the overlay reveal progressively decreasing large blocks of natural land as the settings go from acidic bedrock to calcareous bedrock and then to surficial deposits. The same pattern can be seen from high elevation to low elevations (Figure 5.10). Only 30 percent of the coarse-grained sediment areas, and elevations between 20 and 800 feet were found in blocks over 50,000 acres compared to almost 60 percent for granitic settings, and 92 percent for alpine settings.

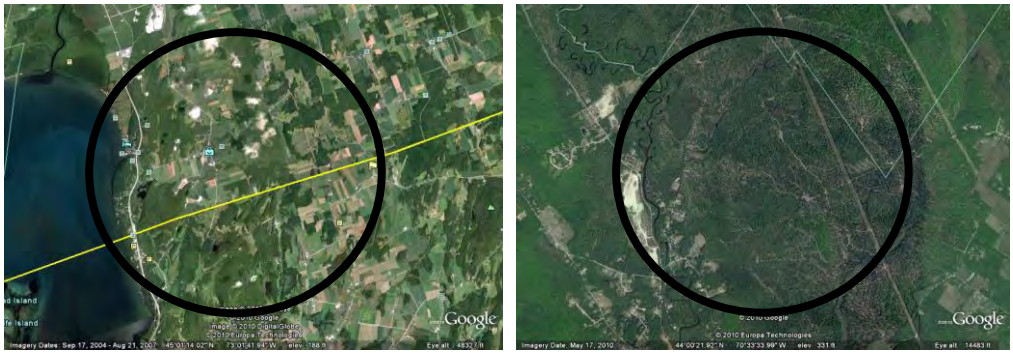
Figure 5.10: Percent of land acres within block size classes arranged by setting in order of decreasing large blocks (from 2011 report). The largest blocks (>50,000 acres) are shown in white



Connectivity. The opposite of fragmentation is connectivity, a measure of how easy it is for species and processes to freely move across the landscape. The metric we used to measure connectivity –local connectedness - was related to the forest block analysis of the previous section but goes beyond major roads to account for local roads, the relative density of all nearby roads, building footprints, land cover, oil and gas wells, solar farms and other land uses. The metric treats the landscape as having a gradient of permeability such that highly contrasting land cover types or dense areas of fragmenting features have reduced permeability between them, and highly similar or unfragmented ones have enhanced permeability. In applying the metric, we differentiated between developed lands, agricultural lands and natural cover, lumping together all types of natural cover including a variety of forest and wetland types.

This assessment of local connectivity was developed by Brad Compton at University of Massachusetts, based on a 30m NLCD (2001, 2011, 2021) land cover maps supplemented with major and minor road information from ESRI 2008 that as synthesized into a wall-to-wall resistance grid. For every 90 m grid cell in the region, a 3 km area around the cell was evaluated and the amount of resistance /permeability was calculated to create a wall-to-wall grid with cell values ranging from 0 to 100; "0" indicating complete impermeability (e.g. developed) and "100" indicating complete permeability (e.g. natural cover with no barriers, Figure 5.11). See Anderson et al 2012 for detail on the methods.

Figure 5.11: Aerial Photo Image of areas with different connectedness scores. The image on the left has a mean score of "10" for the area under the circle, close to the mean score of 14 for limestone settings. The image on the right has a mean score of "43" for the area under the circle, similar to the mean score of 42 for granitic settings. A pristine area with no roads, power-lines, development or farms would score "100."

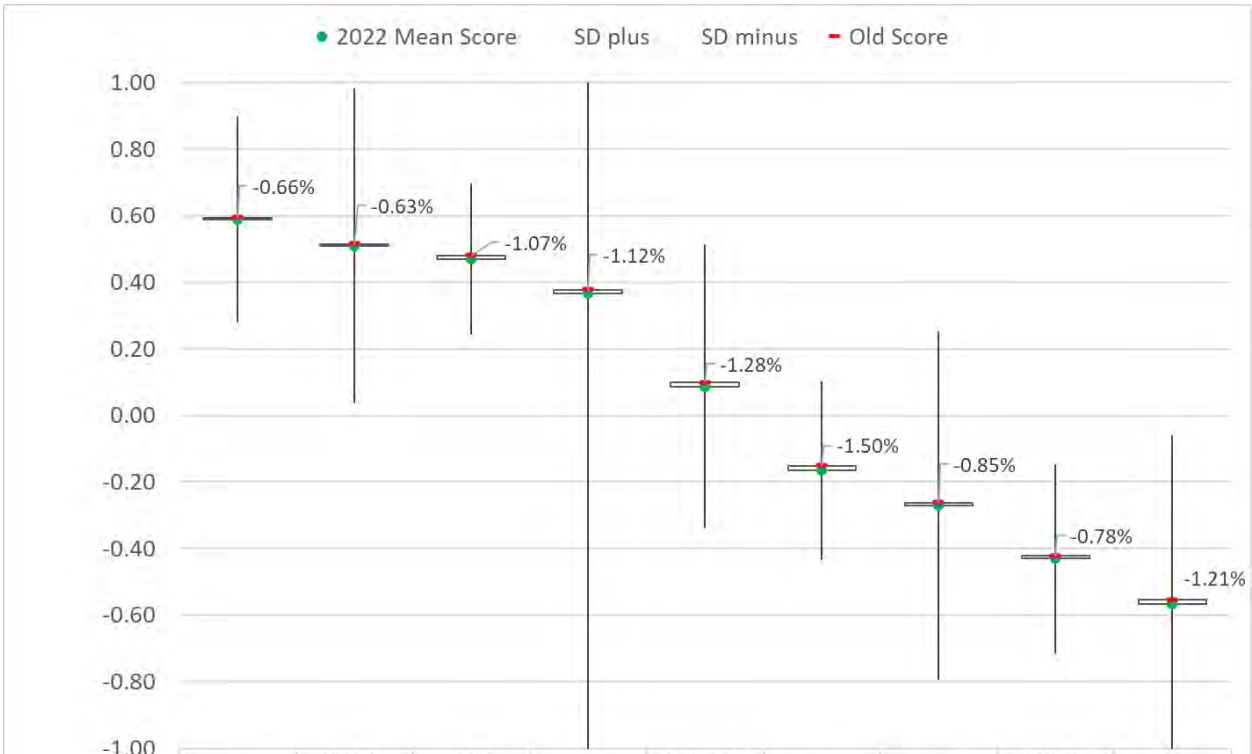


In 2022 we revised the resistance grid and reran the analysis using the following steps. We reclassified the 2011 and 2019 NLCD with the region-specific resistances. We identified all areas of change in resistance from the 2011 NLCD to the 2019 NLCD, then reran the neighborhood stats, kernel stats to calculate Local Connectedness for the areas within 3km of the changed cells. Compared the results from the 2011 and 2019 neighborhood stats. For the calculation of amount of change, we took the raw amount of change and divided by the standard deviation of the 2011 focal stats grid to put the scores into a standard normal distribution (Z-scores).

We added or subtracted the amount of change to the Local Connectedness grid, but because the methods were slightly different between the 2011 and 2019 NLCD dataset and we didn't want to incorporate this data "noise" in the results. To account for this we only changed the scores when they were a change of at least 100 points in either direction on the 0.0 to 3.5 SD scale. Finally, we added areas of High Density Developed to the Developed Category on the Local Connectedness map.

Results of the analysis revealed that the region's different geologic settings differ markedly in their degree of local connectedness. Calcareous areas have the lowest scores, averaging 14, suggesting that they have lost about 84 percent of their natural connectedness (Figure 5.12). Both surficial settings, coarse-grained and fine-grained, have scores averaging less than 20. Even the high scoring regions of granite and mafic materials, average only in the 40s, this highlights how pervasive fragmentation is across the region, although scores in the 40s can be fairly intact (Figure 5.12). Visually, areas with this score appear to have fairly contiguous cover, broken only by small patches of field, power-lines or minor roads (Figure 5.11).

Figure 5.12. Average connectedness scores for the nine geology types. Error bars show the one standard deviation above and below the mean. The new score is shown as a green dot and the old score as a red line. Labels show the change in the mean score over the last 10 years which corresponds to the width of the horizontal box.

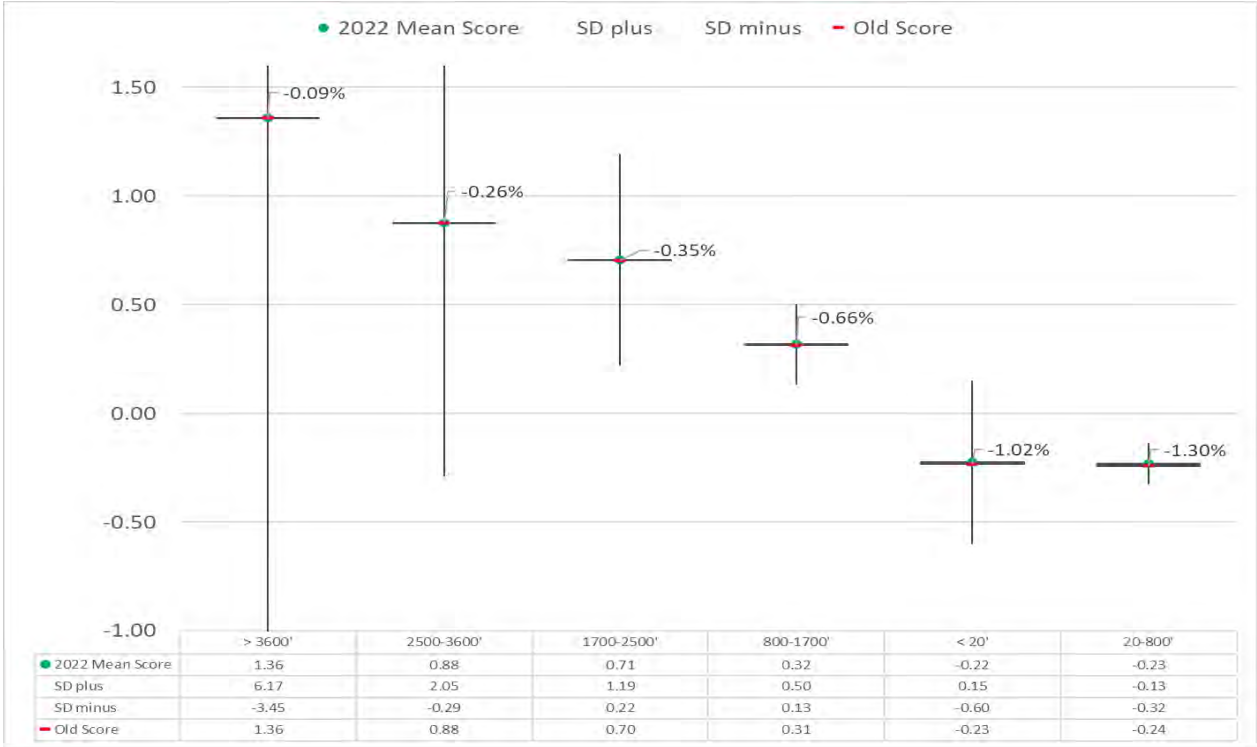


	Acidic granitic	Mafic/ Intermediate	Acidic Sedimentary	Ultramafic	Moderately Calcareous	Acidic shale	Fine sediments	Coarse sediments	Calcareous
2022 Mean Score	0.59	0.51	0.47	0.37	0.09	-0.17	-0.27	-0.43	-0.57
SD plus	0.90	0.98	0.70	4.96	0.51	0.10	0.25	-0.15	-0.06
SD minus	0.28	0.04	0.24	-4.23	-0.34	-0.43	-0.79	-0.71	-1.07
Old Score	0.60	0.52	0.48	0.38	0.10	-0.15	-0.26	-0.42	-0.55

Results of the analysis revealed that the region's different geologic settings differ markedly in their degree of local connectedness (Figure 5.12). Four settings had scores well below the average (0) for the region: calcareous (-0.5 SD), coarse sand (-0.43 SD), fine silts and clay (-0.27 SD) and acidic shale (-0.17 SD). The most connected settings were again those on granite (0.59 SD) or mafic (0.51 SD) bedrocks. The scores of all settings decreased over the last decade but the decrease was small, ranging from 0.66% in granite to a high of 1.5% in shale. Both calcareous and moderately calcareous settings showed a decrease of over 1%. These results reinforce the finding that shale and calcareous settings continue to fragment due to fracking or conversion.

Trend in elevation zone were more pronounced (Figure 5.13). Local connectedness was lower in the two lowest elevation zones which were below the mean score for the region. These two zones had the highest decrease in connectivity over the last decade: 20-80 feet (1.3%) and 0-20 feet (1.02%).

Figure 5.13. Average connectedness scores for the elevation zone. Error bars show the one standard deviation above and below the mean. The new score is shown as a green dot and the old score as a red line. Labels show the change in the mean score over the last 10 years which corresponds to the width of the horizontal box.

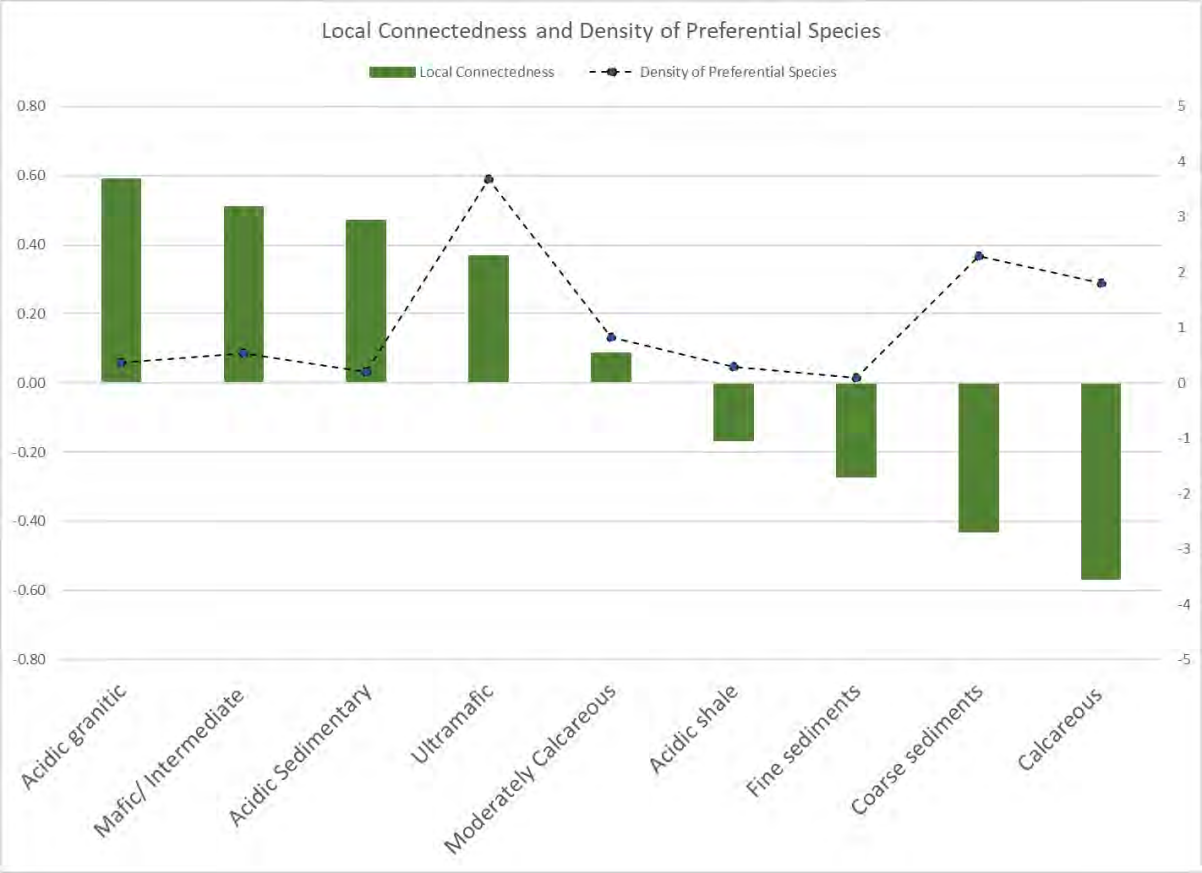


	> 3600'	2500-3600'	1700-2500'	800-1700'	< 20'	20-800'
2022 Mean Score	1.36	0.88	0.71	0.32	-0.22	-0.23
SD plus	6.17	2.05	1.19	0.50	0.15	-0.13
SD minus	-3.45	-0.29	0.22	0.13	-0.60	-0.32
Old Score	1.36	0.88	0.70	0.31	-0.23	-0.24

Synthesis of Species Data with Habitat Condition

Lastly, we examined how the density of restricted species described in the initial sections of this chapter, related to the conversion, fragmentation and connectivity scores. We found that with the exception of the extremely rare ultramafic settings, the more fragmented and least connected environments were the ones with the higher densities of restricted species (Figure 5.14). Coarse-grained sediment, calcareous bedrock and fine-grained sediment emerged as the three habitats of the highest concern, paralleling the results of the conversion to securement ratios.

Figure 5.14. Relationship between the average local connectedness score (left axis) and the density of preferential species (right axis). The two setting with the lowest connectedness score also had the second and third highest density of preferential species.



Individual Habitats

In this section we look at the conservation and conversion status of individual habitats. Forests and wetland habitats are covered in their own chapters, so here the focus is on non-forested communities like barrens, cliffs, dunes, and grasslands. We will also provide comprehensive detail on all the terrestrial habitats mapped in the Northeast Terrestrial Habitat Map (NETHM Ferree and Anderson 2013) which was completed in 2014 and not available for the 2011 report.

The terrestrial and wetland habitats defined and described in the NETHM follow the Northeast Terrestrial Wildlife Habitat Classification (Gawler et al. 2008) with modifications as necessary to enable consistent mapping in the Northeast. The NETHM is a comprehensive and standardized representation of natural habitats across fourteen states and four Canadian provinces (Map 5.3 and Figure 5.15. U.S. portion only). The habitats are equivalent in scale and concept to the NatureServe ecological system (Comer 2003), which was developed to provide a common base for characterizing vegetation habitats across states. The map was developed to promote an understanding of terrestrial and aquatic biodiversity patterns across the region, and not intended to replace state classifications, which often have more detail and nuance.

NatureServe's ecological system classification presents units that are readily identifiable by conservation and resource managers in the field (Comer 2010). Although based on dominant vegetation, they are defined as recurring groups of biological communities that are found in similar physical environments and are influenced by similar dynamic ecological processes, such as fire or flooding. Each ecological system type is named based on biogeographic region, dominant cover type, and ecological setting such as an elevation zone, moisture regime, or disturbance process (e.g., Acadian Low-Elevation Spruce-Fir-Hardwood Forest). The classification includes all upland, wetland, and estuarine habitats, but does not include aquatic freshwater or marine habitats.

Many resources are available for those interested in exploring the Northeast Terrestrial Habitat Map:

Web Viewer https://maps.tnc.org/nehabitatmap/

Habitat Guides: Descriptions, distribution, synonyms, and ecological information about each habitat http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/hg/Pages/default.aspx

Methods Document: Full description of how the map was created (Ferree and Anderson 2013). https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/Documents/HabitatMap_Methods.pdf

Data Download: GIS dataset
https://tnc.app.box.com/s/ujvjfelrfk0nqgslgli89lkgp7zxbwdy

Web Page on The Nature Conservancy's Conservation Gateway
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/habitatmap/Pages/default.aspx

Map 5.2. The Northeast Terrestrial Habitat Map This dataset (Ferree and Anderson 2014) maps the distribution of 140 types of forests, wetlands, unique communities, and tidal systems across the Northeast. To explore the map and view the legend, go to **http://nature.ly/NEhabitat**

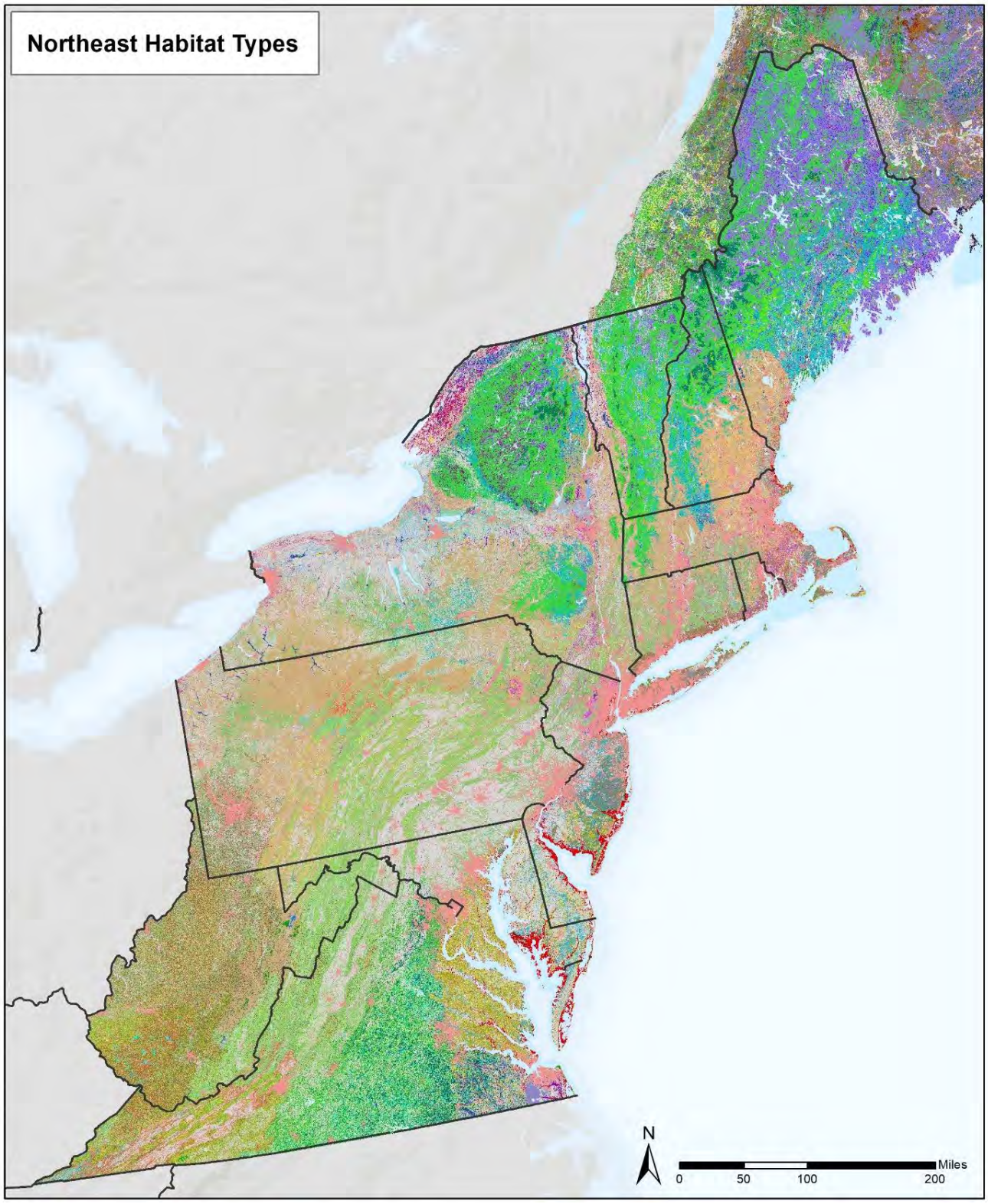


Figure 5.15. Legend for the Northeast Terrestrial Habitat Map



The mapping process was intensely data-driven, relying on comprehensive datasets of ecological variables (geology, landforms, precipitation, etc.) and more than 70,000 ecological community samples contributed by the State Natural Heritage Programs . Whenever possible, we used field-collected data combined with national datasets. Very briefly, the basic mapping steps were as follows:

- Compile foundation datasets for the entire region (landforms, geology, climate, land cover, etc.).
- Develop a list of ecological systems, and meet with appropriate state, federal, and NGO staff to understand the distribution, scale, and landscape pattern of ecological systems.
- Compile plot samples for ecological systems using State Natural Heritage data, forest inventory and analysis points, and other sources. Tag each sample with the appropriate ecological system.
- Develop models for the dominant matrix-forming forest types using regression tree analysis of tagged plot samples on the data sets of ecological information.
- Map the dominant forest types onto the landscape using landform-based units.
- Develop models for the wetland systems (swamps, marshes, bogs, etc.) and the patch-forming upland systems (barrens, glades, summits, cliffs, etc.).
- Assemble models into one region-wide map and develop legend.
-

Habitat Types and Lexicon

Natural habitats mapped within the NETHM can be grouped and sorted various ways, and default grouping schemes (Class, Formation, Macrogroup) are built into the dataset. The Northeast Lexicon project has also provided suggested classification schemes amendable to developing Wildlife Action Plans or evaluating conservation Success. We have crosswalked these to the three major groups.

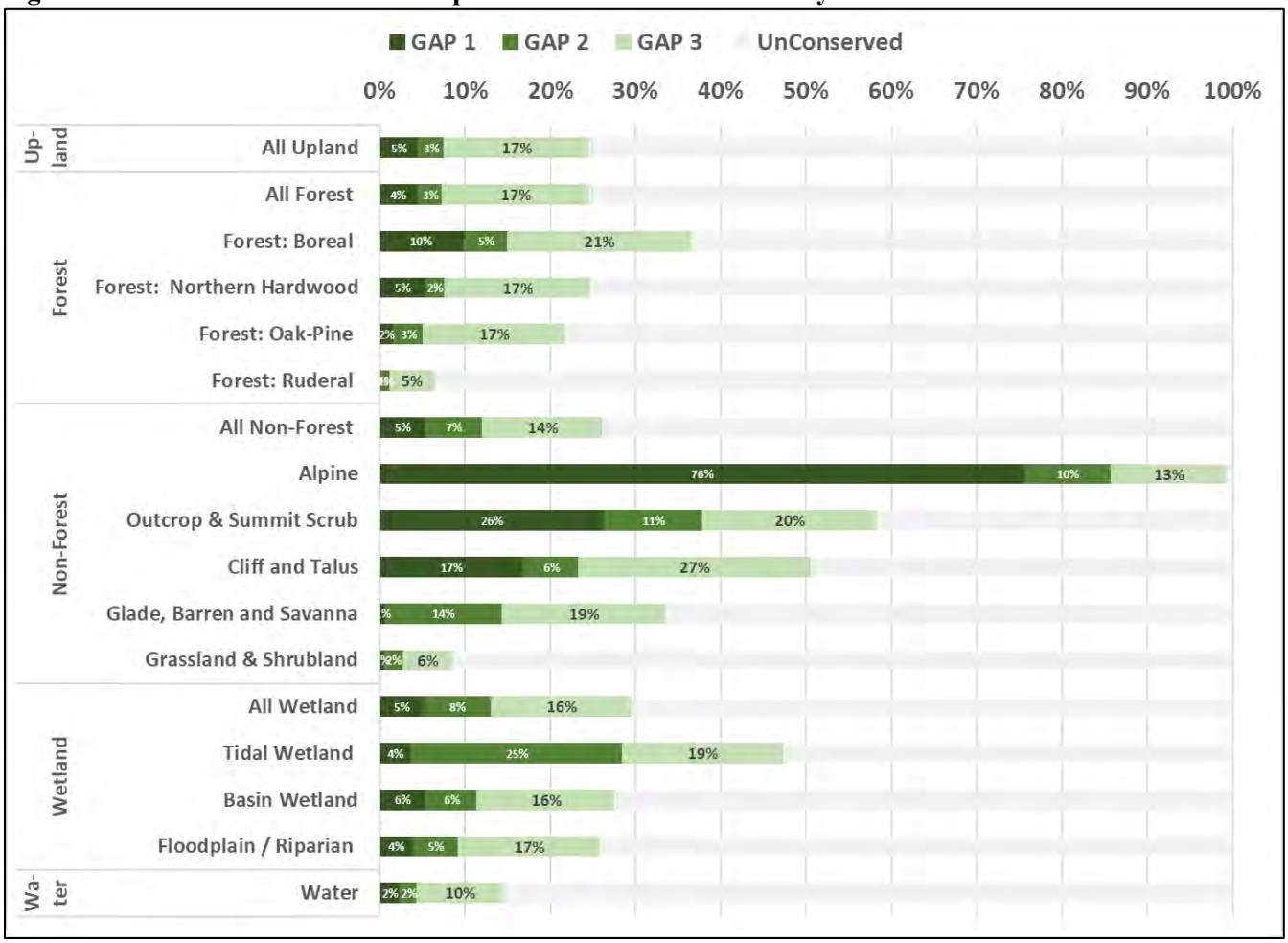
Upland Forest (Table 5.18): Dominant forest types that occupy large contiguous areas (generally >5,000 acres under natural conditions) and form the background matrix of a geographic region are mapped across their distribution. Other habitats tend to nest within the forest matrix where local conditions differ in moisture, soil depth, or disturbance regimes. An example of a matrix forest is the Acadian Low-Elevation Spruce-Fir-Hardwood Forest, which dominates at low elevations in northern Maine. Smaller scale, unusual upland forest types such as maritime forest, pine barrens, and clayplain forests are also included in the map. Lexicon: *Upland Forest, Boreal Forest, Northern Hardwood Forest, Oak-Pine Forest*.

Upland Non-Forested Habitat (Table 5.19): Patch-forming habitats occur under localized environmental conditions that are distinctly different from the surrounding landscape (e.g., Acidic Rocky Outcrop). The habitat often reflects extreme conditions in soil (bedrock or shifting sand), exposure (alpine winds, steep slopes), or disturbance regime (fire, mowing). Patch habitats tend to have high plant diversity and host some of New England's rarest species. Lexicon: *Alpine, Cliff and Talus, Glade, Barren, and Savannah, Grassland and Shrubland, Beach and Dune. (high elevation forest)*

Wetland (Table 5.20 & 5.21): **S**wamps, bogs, marshes, floodplains, and fens that form in annually flooded or permanently saturated conditions where water collects. These habitats are smaller than the matrix-forming forests and generally occupy 10 acres to 5,000 acres under natural conditions. An example is the North Atlantic Coastal Plain Basin Peat, which is a peat-accumulating forested wetland common to the coastal plain. Lexicon: *Basin Wetland, Floodplain/Riparian Wetland, Tidal Wetland*

Attention to these scales is an important part of understanding the distribution, securement, and resilience patterns of nature Attention to these scales is an important part of understanding the distribution, securement, and resilience patterns of nature.

Figure 5.16. Conservation Status of Upland and Wetland Habitats by Northeast Lexicon Names



Conservation Status

We overlaid the NETHW dataset with the Conservation Lands dataset to determine the current conservation status of each habitat as well as the patterns across habitat types (Figure 5.16). Conserving wildlife habitat is a shared responsibility but typically some states contain a disproportionate amount of the habitat and thus have greater responsibility towards its conservation (Table 5.18-5.21). For users interested in connecting the habitat types with the geophysical settings this information is often given at the individual habitat level (Tables 5.22-5.24) and we recommend reading through the descriptions in the Habitat Guides.

The 29 million acres of conserved land in the Northeast is spread relatively evenly across forests (26%) non forest (26%) and wetlands (29%). Within these groups there are some clear biases and gaps with are discussed in the forest and wetlands chapters, and later in this chapter for non-forested habitats.

Table 5.18. Conservation Status of Terrestrial Forests by Lexicon, Macrogroup and State

Northeast Habitats	RESPONSIBILITY % Habitat	% Conserved	ACRES Unconserved	GAP 1	GAP 2	GAP 3	Total Acres	% %UC	%GP1	%GP2	%GP3	Total
Upland	**100%**	**18%**	**118,117,158**	**4,530,132**	**3,306,932**	**18,485,111**	**144,439,333**	**82%**	**3%**	**2%**	**13%**	**100%**
Upland Forest	**100%**	**25%**	**70,206,416**	**4,168,205**	**2,693,749**	**15,925,865**	**92,994,235**	**75%**	**4%**	**3%**	**17%**	**100%**
Forest: Boreal	**100%**	**36%**	**5,216,473**	**812,276**	**427,242**	**1,748,295**	**8,204,287**	**64%**	**10%**	**5%**	**21%**	**100%**
Boreal Upland Forest		0%										
MA	0%	55%	561	688			1,249	45%	55%	0%	0%	100%
ME	80%	29%	4,698,564	244,682	214,297	1,417,286	6,574,829	71%	4%	3%	22%	100%
NH	7%	71%	167,529	99,071	167,247	139,851	573,699	29%	17%	29%	24%	100%
NY	8%	81%	120,560	414,993	4,425	78,561	618,539	19%	67%	1%	13%	100%
VA	0%	80%	1,263	1,418	1,915	1,809	6,404	20%	22%	30%	28%	100%
VT	5%	40%	221,380	35,915	24,695	88,981	370,971	60%	10%	7%	24%	100%
WV	1%	89%	6,575	15,509	14,664	21,803	58,551	11%	26%	25%	37%	100%
Cold-temperate Upland Forest		0%										
ME	0%	10%	40			5	45	90%	0%	0%	10%	100%
Forest: Northern Hardwood	**100%**	**25%**	**38,881,341**	**2,802,207**	**1,160,401**	**8,762,078**	**51,606,027**	**75%**	**5%**	**2%**	**17%**	**100%**
Northern Hardwood & Conifer		0%										
CT	1%	25%	470,338	8,042	37,067	112,593	628,040	75%	1%	6%	18%	100%
DC	0%	73%	639			1,764	2,404	27%	0%	0%	73%	100%
DE	0%	22%	86,561	495	2,399	21,843	111,298	78%	0%	2%	20%	100%
MA	4%	34%	1,326,450	113,069	102,884	477,326	2,019,729	66%	6%	5%	24%	100%
MD	2%	23%	656,653	1,753	23,184	174,916	856,506	77%	0%	3%	20%	100%
ME	17%	19%	7,136,729	146,754	188,920	1,323,468	8,795,872	81%	2%	2%	15%	100%
NH	8%	32%	2,694,338	136,626	221,140	911,153	3,963,257	68%	3%	6%	23%	100%
NJ	1%	31%	181,867	237	50,765	32,333	265,201	69%	0%	19%	12%	100%
NY	26%	29%	9,371,115	1,938,230	119,645	1,810,970	13,239,960	71%	15%	1%	14%	100%
PA	17%	26%	6,614,778	121,925	73,153	2,096,521	8,906,377	74%	1%	1%	24%	100%
RI	0%	38%	38,484	1,015	16,556	5,958	62,013	62%	2%	27%	10%	100%
VA	8%	16%	3,668,492	105,342	118,033	485,698	4,377,566	84%	2%	3%	11%	100%
VT	8%	25%	2,911,234	140,596	78,676	773,315	3,903,820	75%	4%	2%	20%	100%
WV	9%	17%	3,723,664	88,123	127,978	534,221	4,473,985	83%	2%	3%	12%	100%
Forest: Oak-Pine	**100%**	**22%**	**25,053,447**	**552,277**	**1,093,761**	**5,356,944**	**32,056,429**	**78%**	**2%**	**3%**	**17%**	**100%**
Central Oak-Pine		0%										
CT	4%	20%	954,235	19,843	54,200	170,065	1,198,344	80%	2%	5%	14%	100%
DC	0%	69%	697			1,538	2,235	31%	0%	0%	69%	100%
DE	0%	27%	59,819	1,159	3,078	17,505	81,562	73%	1%	4%	21%	100%
MA	2%	26%	442,676	19,524	34,138	100,037	596,374	74%	3%	6%	17%	100%
MD	4%	27%	889,370	2,439	30,574	304,275	1,226,657	73%	0%	2%	25%	100%
ME	0%	14%	100,805	557	6,365	9,623	117,349	86%	0%	5%	8%	100%
NH	0%	24%	45,399	1,488	2,324	10,303	59,514	76%	2%	4%	17%	100%
NJ	3%	31%	618,193	847	121,311	160,185	900,536	69%	0%	13%	18%	100%
NY	8%	13%	2,155,622	9,218	58,282	251,101	2,474,224	87%	0%	2%	10%	100%
PA	25%	28%	5,884,364	128,045	109,689	2,021,997	8,144,094	72%	2%	1%	25%	100%
RI	1%	23%	194,502	3,521	43,098	12,634	253,755	77%	1%	17%	5%	100%
VA	28%	27%	6,663,926	341,189	503,058	1,622,729	9,130,902	73%	4%	6%	18%	100%
VT	0%	14%	54,293	2,295	1,219	5,508	63,314	86%	4%	2%	9%	100%
WV	24%	10%	6,968,903	19,895	123,101	666,538	7,778,437	90%	0%	2%	9%	100%
Central Oak-Pine/Longleaf Pne		0%										
VA	0%	57%	251	326		2	579	43%	56%	0%	0%	100%
Southern Oak-Pine		0%										
VA	0%	29%	20,389	1,933	3,324	2,904	28,550	71%	7%	12%	10%	100%
WV	0%	0%	4				4	100%	0%	0%	0%	100%
Forest: Ruderal	**100%**	**6%**	**1,055,155**	**1,444**	**12,346**	**58,547**	**1,127,492**	**94%**	**0%**	**1%**	**5%**	**100%**
Plantation and Ruderal Forest		0%										
MD	0%	26%	753		5	261	1,018	74%	0%	0%	26%	100%
ME	0%	25%	361	24	0	98	483	75%	5%	0%	20%	100%
NH	0%	40%	43		4	24	72	60%	0%	6%	34%	100%
VA	100%	6%	1,053,821	1,420	12,336	58,107	1,125,685	94%	0%	1%	5%	100%
VT	0%	24%	176	0		56	233	76%	0%	0%	24%	100%

Table 5.19. Conservation Status of Terrestrial Non-Forest Habitats by Lexicon, Macrogroup and State

Northeast Habitats	RESPONSIBILITY % Habitat	% Conserved	ACRES Unconserved	GAP 1	GAP 2	GAP 3	Total Acres	% %UC	%GP1	%GP2	%GP3	Total
Upland Non Forest	**26%**	**100%**	**2,814,894**	**207,508**	**253,186**	**534,760**	**3,810,348**	**74%**	**5%**	**7%**	**14%**	**100%**
Alpine	**100%**	**99%**	**66**	**6,194**	**834**	**1,092**	**8,185**	**1%**	**76%**	**10%**	**13%**	**100%**
Alpine		0%										
ME	44%	99%	32	1,763	747	1,084	3,624	1%	49%	21%	30%	100%
NH	51%	99%	34	4,065	62		4,160	1%	98%	1%	0%	100%
NY	3%	100%		277		8	285	0%	97%	0%	3%	100%
VT	1%	100%	0	89	26		115	0%	77%	22%	0%	100%
Cliff and Talus	**100%**	**51%**	**333,946**	**114,251**	**43,532**	**182,964**	**674,693**	**49%**	**17%**	**6%**	**27%**	**100%**
Cliff and Talus		0%										
CT	1%	41%	2,304	153	662	784	3,903	59%	4%	17%	20%	100%
DE	0%	100%				4	4	0%	0%	0%	100%	100%
MA	2%	54%	5,373	3,033	798	2,496	11,700	46%	26%	7%	21%	100%
MD	0%	49%	429	2	81	328	841	51%	0%	10%	39%	100%
ME	7%	53%	20,648	8,189	8,551	6,547	43,935	47%	19%	19%	15%	100%
NH	6%	70%	11,929	6,321	13,154	8,491	39,895	30%	16%	33%	21%	100%
NJ	1%	68%	1,309		1,395	1,360	4,064	32%	0%	34%	33%	100%
NY	21%	53%	68,315	52,577	3,575	20,141	144,608	47%	36%	2%	14%	100%
PA	32%	65%	75,806	28,832	1,899	108,226	214,762	35%	13%	1%	50%	100%
RI	0%	0%	3				3	100%	0%	0%	0%	100%
VA	8%	44%	30,176	6,285	6,119	11,778	54,357	56%	12%	11%	22%	100%
VT	8%	40%	33,935	8,130	1,810	12,896	56,770	60%	14%	3%	23%	100%
WV	15%	16%	83,719	729	5,488	9,913	99,850	84%	1%	5%	10%	100%
Glade, Barren and Savanna	**100%**	**34%**	**667,189**	**7,329**	**138,025**	**191,036**	**1,003,579**	**66%**	**1%**	**14%**	**19%**	**100%**
Pine Barren		0%										
CT	0%	55%	65		43	38	147	45%	0%	29%	26%	100%
MA	10%	47%	54,281	1,109	27,608	20,339	103,336	53%	1%	27%	20%	100%
ME	1%	40%	5,514	708	300	2,630	9,152	60%	8%	3%	29%	100%
NH	1%	36%	3,656	434	319	1,312	5,721	64%	8%	6%	23%	100%
NJ	33%	56%	143,972	118	85,439	96,948	326,476	44%	0%	26%	30%	100%
NY	8%	28%	59,911	296	9,899	12,823	82,929	72%	0%	12%	15%	100%
RI	1%	45%	3,320	104	2,401	185	6,010	55%	2%	40%	3%	100%
VT	0%	19%	430			103	534	81%	0%	0%	19%	100%
Glade, Barren and Savanna		0%										
CT	0%	48%	48	3	1	40	92	52%	3%	1%	44%	100%
DE	0%	70%	3			7	10	30%	0%	0%	70%	100%
MA	0%	28%	145	41	15		202	72%	20%	8%	0%	100%
MD	3%	22%	25,821	76	947	6,459	33,303	78%	0%	3%	19%	100%
ME	0%	16%	153	1		29	183	84%	0%	0%	16%	100%
NH	0%	25%	12			4	15	75%	0%	0%	25%	100%
NJ	0%	28%	104		12	29	144	72%	0%	8%	20%	100%
NY	3%	13%	24,199	57	2,499	1,182	27,937	87%	0%	9%	4%	100%
PA	12%	10%	110,872	156	905	11,229	123,161	90%	0%	1%	9%	100%
VA	12%	29%	89,177	3,871	6,978	25,277	125,303	71%	3%	6%	20%	100%
VT	0%	20%	2,762	244	51	404	3,461	80%	7%	1%	12%	100%
WV	15%	8%	142,728	113	608	11,990	155,439	92%	0%	0%	8%	100%
Serpentine Woodland (Canada)												
ME	0%	31%	18			8	26	69%	0%	0%	31%	100%
Grassland & Shrubland	**100%**	**9%**	**1,705,521**	**11,114**	**41,216**	**106,931**	**1,864,783**	**91%**	**1%**	**2%**	**6%**	**100%**
Coastal Grassland & Shrubland		0%										
CT	0%	24%	3,868	97	598	527	5,090	76%	2%	12%	10%	100%
DE	0%	54%	1,891	41	212	1,930	4,074	46%	1%	5%	47%	100%
MA	3%	39%	34,256	2,181	12,540	7,308	56,285	61%	4%	22%	13%	100%
MD	0%	81%	593		2,289	300	3,182	19%	0%	72%	9%	100%
ME	0%	12%	3,907	29	370	137	4,443	88%	1%	8%	3%	100%
NH	0%	29%	656		21	245	922	71%	0%	2%	27%	100%
NJ	1%	48%	5,186	624	1,296	2,880	9,985	52%	6%	13%	29%	100%
NY	2%	35%	18,820		4,193	5,962	28,975	65%	0%	14%	21%	100%
PA	0%	65%	149			276	425	35%	0%	0%	65%	100%
RI	0%	23%	5,345	73	1,038	480	6,936	77%	1%	15%	7%	100%
VA	1%	52%	5,210	1,993	3,145	618	10,966	48%	18%	29%	6%	100%
VT	0%	18%	5		0	1	6	82%	0%	4%	14%	100%
Ruderal Shrubland & Grassland		0%										
CT	0%	6%	4,812	16	70	199	5,098	94%	0%	1%	4%	100%
MA	1%	31%	12,371	69	3,513	2,066	18,020	69%	0%	19%	11%	100%
MD	0%	22%	3,830		29	1,044	4,902	78%	0%	1%	21%	100%
ME	1%	8%	20,795	374	419	1,045	22,634	92%	2%	2%	5%	100%
NH	0%	14%	3,542	54	187	327	4,110	86%	1%	5%	8%	100%
NJ	0%	0%	52				52	100%	0%	0%	0%	100%
NY	25%	3%	448,720	127	3,016	11,651	463,514	97%	0%	1%	3%	100%
PA	9%	13%	138,991	3,415	794	16,500	159,701	87%	2%	0%	10%	100%
RI	0%	17%	2,659	10	246	274	3,189	83%	0%	8%	9%	100%
VA	48%	6%	836,248	2,011	7,118	47,474	892,850	94%	0%	1%	5%	100%
WV	9%	4%	153,615		120	5,689	159,423	96%	0%	0%	4%	100%
Outcrop & Summit Scrub	**100%**	**58%**	**108,172**	**68,620**	**29,578**	**52,737**	**259,107**	**42%**	**26%**	**11%**	**20%**	**100%**
Outcrop & Summit Scrub		0%										
CT	0%	19%	74	0	14	3	91	81%	0%	15%	3%	100%
MA	2%	55%	2,261	1,304	254	1,186	5,005	45%	26%	5%	24%	100%
ME	25%	38%	40,139	6,292	5,892	12,052	64,375	62%	10%	9%	19%	100%
NH	21%	74%	13,782	10,517	19,098	9,929	53,327	26%	20%	36%	19%	100%
NY	25%	81%	12,238	41,105	868	10,181	64,392	19%	64%	1%	16%	100%
VA	0%	43%	48	14		22	83	57%	16%	0%	27%	100%
VT	24%	47%	32,502	7,440	2,544	18,441	60,926	53%	12%	4%	30%	100%
WV	1%	73%	851	1,874	364	110	3,198	27%	59%	11%	3%	100%
Rocky Coast		0%										
CT	0%	13%	413	5	40	18	477	87%	1%	8%	4%	100%
MA	1%	18%	2,155	41	68	362	2,626	82%	2%	3%	14%	100%
ME	1%	19%	2,549	13	280	307	3,148	81%	0%	9%	10%	100%
NH	0%	28%	153		5	53	211	72%	0%	2%	25%	100%
NY	0%	34%	119			62	182	66%	0%	0%	34%	100%
RI	0%	17%	888	15	152	9	1,064	83%	1%	14%	1%	100%

Table 5.20. Conservation Status of Basin Wetlands by Lexicon, Macrogroup and State

Northeast Habitats	RESPONSIBILITY % Habitat	% Conserved	ACRES Unconserved	GAP 1	GAP 2	GAP 3	Total Acres	% %UC	%GP1	%GP2	%GP3	Total
Wetland	**100%**	**29%**	**7,936,865**	**587,267**	**891,384**	**1,836,623**	**11,252,139**	**71%**	**5%**	**8%**	**16%**	**100%**
Basin Wetland	**100%**	**28%**	**6,625,246**	**505,931**	**548,249**	**1,460,228**	**9,139,653**	**72%**	**6%**	**6%**	**16%**	**100%**
Central Hardwood Swamp		0%										
CT	0%	16%	7,755	15	296	1,219	9,284	84%	0%	3%	13%	100%
MA	0%	24%	7,337	28	599	1,668	9,632	76%	0%	6%	17%	100%
MD	0%	14%	634		1	103	737	86%	0%	0%	14%	100%
ME	0%	3%	2,706		59	25	2,790	97%	0%	2%	1%	100%
NH	0%	26%	1,459	17	73	414	1,963	74%	1%	4%	21%	100%
NJ	0%	24%	4,796		154	1,347	6,296	76%	0%	2%	21%	100%
NY	1%	11%	109,856	171	4,749	8,326	123,101	89%	0%	4%	7%	100%
PA	0%	4%	1,631	10	4	58	1,702	96%	1%	0%	3%	100%
VA	0%	11%	19,053	210	196	2,012	21,470	89%	1%	1%	9%	100%
VT	0%	15%	13,397	477	567	1,401	15,842	85%	3%	4%	9%	100%
WV	0%	4%	145	4		2	150	96%	3%	0%	1%	100%
Coastal Plain Peat Swamp		0%										
CT	0%	42%	1,438	143	198	702	2,480	58%	6%	8%	28%	100%
DE	0%	70%	1,444	31	3,218	152	4,846	30%	1%	66%	3%	100%
MA	0%	50%	5,928	1,563	2,400	1,939	11,830	50%	13%	20%	16%	100%
MD	0%	57%	52	2	13	55	121	43%	1%	11%	45%	100%
ME	0%	20%	521		27	106	654	80%	0%	4%	16%	100%
NH	0%	62%	442	214	55	447	1,158	38%	18%	5%	39%	100%
NJ	0%	63%	13,086	5	10,465	11,811	35,367	37%	0%	30%	33%	100%
NY	0%	74%	26		59	12	97	26%	0%	62%	12%	100%
RI	0%	45%	959	91	677	22	1,750	55%	5%	39%	1%	100%
Coastal Plain Peatland		0%										
MA	0%	40%	566	30	149	191	936	60%	3%	16%	20%	100%
NJ	0%	83%	686	5	722	2,627	4,040	17%	0%	18%	65%	100%
NY	0%	57%	123		53	109	285	43%	0%	19%	38%	100%
VA	0%	100%	1	1,202	1,052		2,256	0%	53%	47%	0%	100%
Coastal Plain Swamp		0%										
DC	0%	69%	25			55	81	31%	0%	0%	69%	100%
DE	2%	24%	114,486	754	8,960	27,032	151,232	76%	0%	6%	18%	100%
MD	4%	28%	231,505	336	15,210	75,919	322,970	72%	0%	5%	24%	100%
NJ	5%	40%	266,275	496	82,670	95,341	444,782	60%	0%	19%	21%	100%
NY	0%	31%	12,505		3,137	2,605	18,246	69%	0%	17%	14%	100%
PA	0%	21%	4,065	67	188	804	5,124	79%	1%	4%	16%	100%
RI	0%	26%	473	49	115	3	640	74%	8%	18%	0%	100%
VA	5%	29%	303,455	2,979	87,302	32,938	426,675	71%	1%	20%	8%	100%
Emergent Marsh		0%										
CT	0%	32%	11,151	316	1,326	3,597	16,391	68%	2%	8%	22%	100%
DC	0%	40%	37			24	61	60%	0%	0%	40%	100%
DE	0%	32%	14,874	343	936	5,618	21,771	68%	2%	4%	26%	100%
MA	1%	34%	37,757	1,620	4,836	12,797	57,011	66%	3%	8%	22%	100%
MD	1%	27%	39,239	5	1,795	12,767	53,806	73%	0%	3%	24%	100%
ME	2%	21%	178,195	6,836	11,067	29,599	225,696	79%	3%	5%	13%	100%
NH	1%	31%	33,793	1,689	1,519	11,654	48,656	69%	3%	3%	24%	100%
NJ	1%	31%	67,980	380	15,432	15,013	98,806	69%	0%	16%	15%	100%
NY	2%	28%	161,618	21,885	9,246	30,761	223,511	72%	10%	4%	14%	100%
PA	1%	19%	39,637	686	850	7,559	48,733	81%	1%	2%	16%	100%
RI	0%	30%	3,587	63	1,120	321	5,091	70%	1%	22%	6%	100%
VA	1%	15%	89,723	305	2,573	13,432	106,033	85%	0%	2%	13%	100%
VT	0%	25%	29,516	1,629	2,089	6,219	39,454	75%	4%	5%	16%	100%
WV	0%	7%	6,303	14	143	306	6,766	93%	0%	2%	5%	100%
Northern Peatland		0%										
CT	0%	42%	346	48	44	162	599	58%	8%	7%	27%	100%
MA	0%	45%	2,725	305	604	1,313	4,948	55%	6%	12%	27%	100%
ME	4%	30%	252,881	20,531	21,701	67,298	362,411	70%	6%	6%	19%	100%
NH	0%	54%	4,739	1,561	955	3,054	10,310	46%	15%	9%	30%	100%
NJ	0%	97%	5		85	74	164	3%	0%	52%	45%	100%
NY	1%	57%	51,804	32,006	2,858	32,769	119,436	43%	27%	2%	27%	100%
PA	0%	54%	13,839	2,683	775	12,872	30,169	46%	9%	3%	43%	100%
RI	0%	69%	109	1	245		355	31%	0%	69%	0%	100%
VT	0%	69%	2,895	2,282	2,150	1,980	9,307	31%	25%	23%	21%	100%
Northern Swamp		0%										
CT	2%	24%	132,618	2,471	10,003	28,931	174,024	76%	1%	6%	17%	100%
DC	0%	27%	122			44	166	73%	0%	0%	27%	100%
DE	0%	50%	193		93	100	386	50%	0%	24%	26%	100%
MA	4%	33%	270,042	11,690	28,902	90,313	400,947	67%	3%	7%	23%	100%
MD	0%	23%	18,790	241	945	4,310	24,286	77%	1%	4%	18%	100%
ME	14%	20%	1,017,712	28,691	32,691	194,911	1,274,004	80%	2%	3%	15%	100%
NH	2%	30%	117,611	5,829	8,479	35,602	167,520	70%	3%	5%	21%	100%
NJ	2%	36%	97,052	140	24,616	30,074	151,882	64%	0%	16%	20%	100%
NY	21%	27%	1,411,137	255,727	39,840	238,577	1,945,281	73%	13%	2%	12%	100%
PA	3%	28%	173,635	3,520	6,245	58,134	241,534	72%	1%	3%	24%	100%
RI	1%	31%	50,365	1,402	17,447	4,203	73,416	69%	2%	24%	6%	100%
VA	0%	17%	26,597	253	425	4,904	32,179	83%	1%	1%	15%	100%
VT	1%	32%	77,028	7,198	6,936	21,424	112,586	68%	6%	6%	19%	100%
WV	0%	52%	13,216	1,612	8,627	4,139	27,594	48%	6%	31%	15%	100%
Southern Bottomland Forest		0%										
MD	0%	27%	2,707		106	900	3,712	73%	0%	3%	24%	100%
VA	4%	12%	310,298	8,533	5,029	30,690	354,550	88%	2%	1%	9%	100%
Wet Meadow / Shrub Marsh		0%										
CT	0%	26%	17,241	210	1,681	4,238	23,370	74%	1%	7%	18%	100%
DE	0%	43%	6,659	0	1,013	3,944	11,616	57%	0%	9%	34%	100%
MA	1%	34%	50,566	1,973	6,982	17,195	76,715	66%	3%	9%	22%	100%
MD	0%	45%	16,207	2	1,121	12,044	29,375	55%	0%	4%	41%	100%
ME	3%	21%	236,179	7,476	9,985	44,057	297,698	79%	3%	3%	15%	100%
NH	1%	31%	41,093	1,610	3,187	13,874	59,764	69%	3%	5%	23%	100%
NJ	1%	41%	40,020	159	15,951	12,223	68,353	59%	0%	23%	18%	100%
NY	3%	37%	185,010	59,746	6,369	42,822	293,946	63%	20%	2%	15%	100%
PA	0%	20%	31,925	800	588	6,483	39,796	80%	2%	1%	16%	100%
RI	0%	39%	3,130	104	1,601	301	5,135	61%	2%	31%	6%	100%
VA	1%	16%	72,522	968	2,466	10,403	86,359	84%	1%	3%	12%	100%
VT	0%	21%	33,430	1,484	1,182	6,412	42,508	79%	3%	3%	15%	100%
WV	0%	13%	2,557	6	23	341	2,928	87%	0%	1%	12%	100%

Table 5.21. Conservation Status of Floodplain and Tidal Wetlands by Lexicon, Macrogroup and State

Northeast Habitats	RESPONSIBILITY % Habitat	% Conserved	ACRES Unconserved	GAP 1	GAP 2	GAP 3	Total Acres	% %UC	%GP1	%GP2	%GP3	Total
Wetland	**100%**	**29%**	**7,936,865**	**587,267**	**891,384**	**1,836,623**	**11,252,139**	**71%**	**5%**	**8%**	**16%**	**100%**
Floodplain / Riparian	**100%**	**26%**	**684,611**	**35,657**	**49,934**	**153,238**	**923,440**	**74%**	**4%**	**5%**	**17%**	**100%**
Large River Floodplain		0%										
CT	0%	32%	2,728		254	1,042	4,024	68%	0%	6%	26%	100%
DC	0%	96%	4		0	85	89	4%	0%	0%	96%	100%
DE	0%	60%	32		0	48	81	40%	0%	1%	60%	100%
MA	1%	41%	5,890	197	2,782	1,185	10,054	59%	2%	28%	12%	100%
MD	1%	49%	4,072	26	288	3,573	7,960	51%	0%	4%	45%	100%
ME	30%	25%	197,227	8,713	10,046	48,545	264,532	75%	3%	4%	18%	100%
NH	2%	23%	13,067	619	979	2,349	17,014	77%	4%	6%	14%	100%
NJ	1%	59%	3,988		2,871	2,983	9,842	41%	0%	29%	30%	100%
NY	32%	27%	203,701	19,192	17,120	39,927	279,939	73%	7%	6%	14%	100%
PA	11%	22%	75,943	2,133	1,950	17,480	97,506	78%	2%	2%	18%	100%
RI	0%	12%	17			2	19	88%	0%	0%	12%	100%
VA	15%	18%	107,953	2,270	3,390	18,824	132,435	82%	2%	3%	14%	100%
VT	6%	36%	33,783	2,456	7,016	9,309	52,564	64%	5%	13%	18%	100%
WV	1%	15%	10,142	6	182	1,557	11,887	85%	0%	2%	13%	100%
Coastal Plain Floodplain Swamps		0%										
DC	0%	100%				1	1	0%	0%	0%	100%	100%
DE	0%	39%	464	1	10	287	762	61%	0%	1%	38%	100%
MA	0%	0%	3				3	100%	0%	0%	0%	100%
MD	0%	32%	10,030	26	1,239	3,468	14,763	68%	0%	8%	23%	100%
NJ	0%	36%	4,001		1,288	1,009	6,298	64%	0%	20%	16%	100%
NY	0%	43%	334		222	30	587	57%	0%	38%	5%	100%
PA	0%	22%	594		13	152	759	78%	0%	2%	20%	100%
VA	0%	14%	10,639	18	282	1,381	12,320	86%	0%	2%	11%	100%
Tidal Wetland	**100%**	**47%**	**627,009**	**45,680**	**293,201**	**223,156**	**1,189,046**	**53%**	**4%**	**25%**	**19%**	**100%**
Tidal Marsh		0%										
CT	2%	37%	11,910	582	2,410	4,043	18,944	63%	3%	13%	21%	100%
DC	0%	52%	58			62	120	48%	0%	0%	52%	100%
DE	7%	61%	33,354	6,045	21,357	24,624	85,380	39%	7%	25%	29%	100%
MA	6%	44%	37,729	1,786	12,631	15,019	67,166	56%	3%	19%	22%	100%
MD	21%	46%	133,131	519	24,609	87,528	245,788	54%	0%	10%	36%	100%
ME	3%	31%	23,563	252	4,705	5,424	33,945	69%	1%	14%	16%	100%
NH	1%	24%	5,461	307	299	1,149	7,216	76%	4%	4%	16%	100%
NJ	19%	66%	78,637	10,873	124,489	14,318	228,317	34%	5%	55%	6%	100%
NY	4%	27%	35,432		9,412	4,025	48,869	73%	0%	19%	8%	100%
PA	0%	32%	1,107	417	39	74	1,637	68%	25%	2%	5%	100%
RI	1%	30%	6,035	57	2,221	267	8,580	70%	1%	26%	3%	100%
VA	20%	45%	127,880	19,513	59,768	27,122	234,283	55%	8%	26%	12%	100%
Tidal Swamp		0%										
DC	0%	89%	9			72	81	11%	0%	0%	89%	100%
DE	1%	38%	7,197	500	963	2,903	11,563	62%	4%	8%	25%	100%
MA	0%	100%				2	2	0%	0%	0%	100%	100%
MD	7%	39%	51,385	754	10,609	21,264	84,012	61%	1%	13%	25%	100%
NJ	4%	47%	21,922	846	14,337	4,621	41,726	53%	2%	34%	11%	100%
NY	0%	38%	930		379	199	1,507	62%	0%	25%	13%	100%
PA	0%	17%	1,065	113	46	54	1,278	83%	9%	4%	4%	100%
VA	6%	27%	50,203	3,116	4,928	10,385	68,633	73%	5%	7%	15%	100%

Non-Forested Habitat: Distribution and Protection

The Northeast is a forested region and non-forested upland habitats are relatively rare. They form and persist in localized environmental conditions that are distinctly different from the surrounding landscape. The factors can be edaphic, ecologic or reflect past disturbances such as:

Edaphic

- Nutrient poor shallow-to-bedrock soil (outcrops, summit shrub, glade, barren),
- Shifting sand (beach, dune),
- Steep unstable slopes (cliff and talus)
- High elevation cold exposed summits (alpine).

Disturbance

- Abandoned mowed grasslands (ruderal grasslands)
- Recently burned areas (pine barrens, sandplain grasslands)

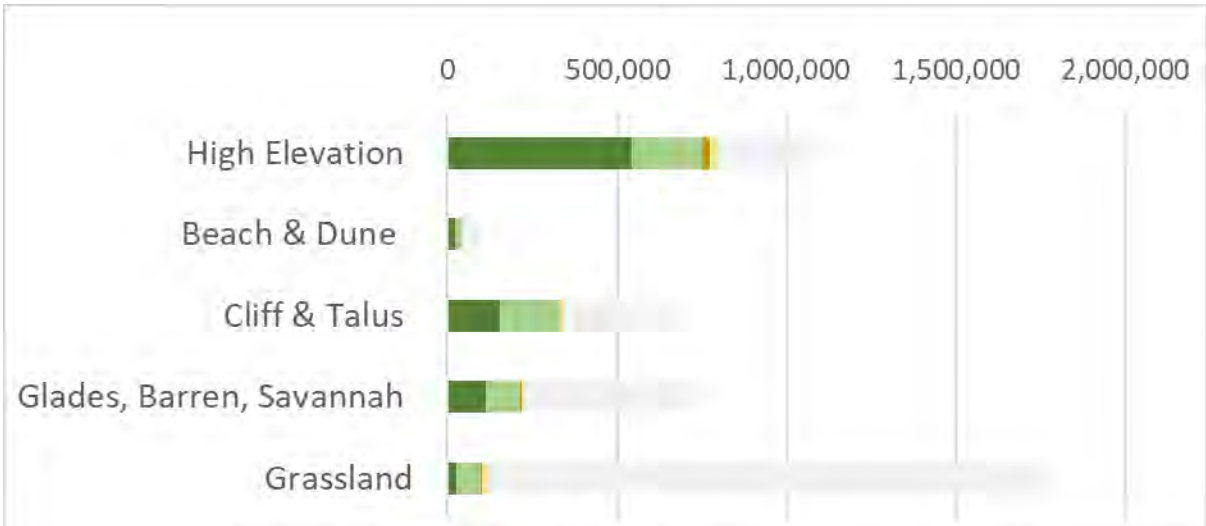
These condition or processes tend to occur in discrete patches where the dominance of trees is limited allowing diverse grass, herb and shrub communities to develop. Non-forested habitats tend to have high plant diversity and host some of New England's rarest species.

In this section we examine the non-forested habitats with respect to their conservation status and recent conservation trends by overlaying the conserved lands dataset on the NETHM. Users should keep in mind that many of these patch-forming habitats are very small and difficult to map accurately. Additionally, the disturbance dependent types are ephemeral and subject to change over time. Although this overlay can reveal some actual trends, the occurrences should be ground-checked for more accurate information.

It is helpful to cross check the edaphically defined habitats with the geophysical setting it is associated with (Table 5.19) as the trend for the individual habitat is likely to follow the trend for the setting. For example, the calcareous cliffs mapped in the NETHP appear to be well conserved (38%) but they occur within a geophysical setting the is highly converted and still losing ground.

Results of the habitat overlay correspond closely to the geophysical analysis. High elevation habitats comprise over 750,000 thousand acres of conservation land including 50,000 new acres in the last decade (Figure 5.17). That includes almost 100% of the northeast Alpine habitat (Figure 18). Beach and dune habitats were mostly conserved before 2001 when large coastal National Wildlife Refuges were established. These systems are now threatened by sea level rise and recent conservation activity has been minimal (but see climate change chapter).

Figure 5.17. Conservation Status of Non-Forested Habitats by Acres. The colors show the conservation status across all years, with the last decade highlighted in brown and tan. A breakdown my percent and individual habitat is shown in Figure 18.

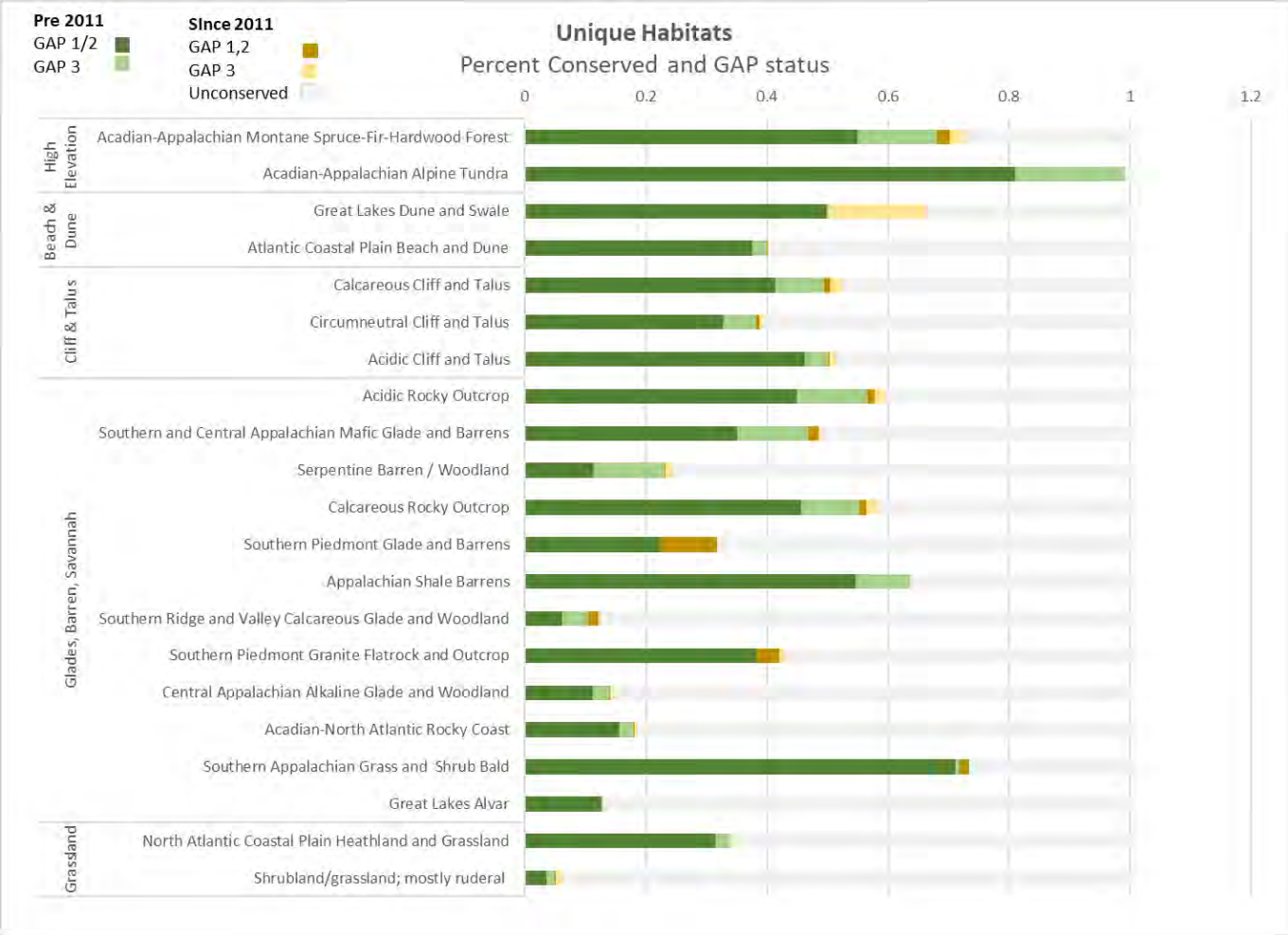


	Grassland	Glades, Barren, Savannah	Cliff & Talus	Beach & Dune	High Elevation
GAP1&2 Pre2001	18,436	93,825	140,078	21,750	475,336
GAP1&2 Pre2011	7,455	17,009	14,765	1,379	65,748
GAP 3 Pre 2001	53,948	76,597	161,217	15,525	128,778
GAP 3 Pre 2011	15,985	25,027	14,030	937	80,158
GAP1&2 2012-2022	3,255	3,942	2,940	55	22,264
GAP 3 2012-2022	20,085	7,770	7,717	452	27,265
UnSecured	1,647,167	504,212	333,946	58,354	296,493

Cliff and talus communities account for 240,000 acres of conserved habitat with 10,000 of that conserved in the last decade (Figure 5.17) This translates to almost 50% of the habitat being conserved. Glades, Barrens and Savannahs account for about the same acreage as cliffs but are not as well conserved although slightly more we put under conservation during the last decade (Figure 5.18). This is a mixed collection of small habitat types including two types of rocky outcrops which are over 50% conserved and three types of calcareous glades and alvars which are less than 20% conserved. Shale barrens and Southern Appalachian grass balds have the highest level of conservation with both over 60%.

Grasslands are the most problematic habitat in the non-forested group. Small edaphic and sometimes fire-dependent grasslands of the coastal plain have over 30% of their habitat under conservation. The region's more widespread grasslands (1.79 million acres) are classified as ruderal habitat, being comprised of pastures, abandoned fields, recently cut forests or recent cool burns. Five percent of that is under conservation but it is not known whether the intents of the owners or easement holders are to maintain that land as grassland or allow it to convert to forest.

Figure 5.18. Conservation of Non-Forested Habitat by Percent Conserved and Individual Habitat Type



Chapter 5: References

Anderson, M.G., and C.E. Ferree. 2010. Conserving the Stage: climate change and the geophysical underpinnings of species diversity. PLoSONE July (5): 7 e11554: http://dx.plos.org/10.1371/journal.pone.0011554.

Anderson, M.G. and Weaver, K.J. 2015. Enduring Features for Conservation. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA.

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2012 Resilient Sites for Terrestrial Conservation in the Northeast and Mid-Atlantic Region. The Nature Conservancy, Eastern Conservation Science. 168 pp

Comer, P., D. Faber-Langendoen, R. Evans, S. Gawler, C. Josse, G. Kittel, S. Menard, M. Pyne, M. Reid, K. Schulz, K. Snow, and J. Teague. 2003. Ecological Systems of the United States: A Working Classification of U.S. Terrestrial Systems. NatureServe, Arlington, Virginia.

Dewitz, J., and U.S. Geological Survey, 2021, National Land Cover Database (NLCD) 2019 Products (ver. 2.0, June 2021): U.S. Geological Survey data release, https://doi.org/10.5066/P9KZCM54.

Ferree, C and M. G. Anderson. 2013. A Map of Terrestrial Habitats of the Northeastern United States: Methods and Approach. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA. https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terres trial/habitatmap/Pages/default.aspx

Gawler, S. C. 2008. Northeastern Terrestrial Wildlife Habitat Classification. Report to the Virginia Department of Game and Inland Fisheries on behalf of the Northeast Association of Fishand Wildlife Agencies and the National Fish and Wildlife Foundation. NatureServe, Boston, Massachusetts. 102 pp. http://rcngrants.org/project-final-reports?page=1.

The Nature Conservancy. 2022. Eastern U.S. Conservation Lands. Various scales. Compiled from multiple sources.

Appendix 5.1: Crosswalk Tables linking Northeast Lexicon, Individual Habitats and Geophysical Settings

Forested Upland Habitats

Table 5.1.1. Crosswalk between the Northeast Lexicon Project and the NETHM forest types

		Elevation			Geology								
LEXICON	HABITAT	Very High Elevation	High Elevation	Coastal	Shale	Sedimentary	Granite	Mafic	Calcareous	Moderately Calcareous	Serpentine	Sand	Loam
Forest: Northern Hardwood	Appalachian (Hemlock)-Northern Hardwood Forest					1	1						
	Laurentian-Acadian Northern Hardwood Forest					1	1						
	Laurentian-Acadian Northern Pine-(Oak) Forest					1	1						
	Laurentian-Acadian Pine-Hemlock-Hardwood Forest					1	1						
	Laurentian-Acadian Red Oak-Northern Hardwood Forest					1	1						
	North-Central Interior Beech-Maple Forest					1	1						
	Northeastern Coastal and Interior Pine-Oak Forest			1								1	
	South-Central Interior Mesophytic Forest								1	1			
	Southern and Central Appalachian Cove Forest								1	1			
	Southern Appalachian Northern Hardwood Forest				1	1	1		1				
	Southern Atlantic Coastal Plain Mesic Hardwood Forest											1	1
	Southern Piedmont Mesic Forest						1						1
Forest: Boreal	Acadian Low Elevation Spruce-Fir-Hardwood Forest					1	1	1					
	Acadian Sub-boreal Spruce Flat					1	1						
	Acadian-Appalachian Montane Spruce-Fir-Hardwood Forest		1				1	1					
	Boreal Highland/Northern Balsam Fir Forest					1	1	1					
	Central and Southern Appalachian Spruce-Fir Forest		1			1	1						
	Cold Temperate Northern/Higher Elevation Conifer Forest					1							
Forest: Oak-Pine	Allegheny-Cumberland Dry Oak Forest and Woodland					1				1			
	Central and Southern Appalachian Montane Oak Forest		1			1	1						
	Central Appalachian Pine-Oak Rocky Woodland					1	1						
	Coastal Plain Maritime Forest			1								1	
	Dry Oak-Pine Forest, Central Apps and Southern Piedmont					1	1	1					
	Glacial Marine and Lake Mesic Clayplain Forest												
	North Atlantic Coastal Plain Hardwood Forest											1	
	Northeastern Interior Dry-Mesic Oak Forest					1	1						
	Piedmont Hardpan Woodland and Forest						1	1					
	Southern Appalachian Montane Pine Forest and Woodland					1	1						
	Southern Appalachian Oak Forest					1	1						
	Southern Ridge and Valley / Cumberland Dry Calcareous Forest								1	1			
	Coastal Plain Maritime Forest			1								1	
	Southern Appalachian Low Elevation Pine Forest					1							
	Southern Atlantic Coastal Plain Upland Longleaf Pine Woodland											1	
Forest: Ruderal	Early Seral (Intolerant) Forest-- Canada												
	Old Field Forest												
	Plantation Forest												

Non-Forested Upland Habitats

Table 5.1.2. Crosswalk between the Northeast Lexicon Project and the NETHM non-forested habitats.

		Elevation			Geology									Soil				
LEXICON	HABITAT	Very High Elevation	High Elevation	Coastal	Shale	Sedimentary	Granite	Mafic	Calcareous	Moderately Calcareous	Serpentine	Sand	Loam	Silt	Muck	Enriched	Peat
Agricultural	Agriculture																
Alpine	Acadian-Appalachian Alpine Tundra	1															
Cliff and Talus	Acidic Cliff and Talus						1	1									
	Calcareous Cliff and Talus								1	1							
	Circumneutral Cliff and Talus									1							
Glade, Barren and Savanna	North Atlantic Coastal Plain Pitch Pine Barrens											1					
	Northeastern Interior Pine Barrens											1					
	Appalachian Shale Barrens				1												
	Central Appalachian Alkaline Glade and Woodland								1	1							
	Great Lakes Alvar								1	1							
	Serpentine Barren / Woodland										1						
	Southern and Central Appalachian Mafic Glade and Barrens							1									
	Southern Piedmont Glade and Barrens						1	1									
	Southern Ridge and Valley Calcareous Glade and Woodland								1	1							
Beach and Dune	Atlantic Coastal Plain Beach and Dune											1					
	Great Lakes Dune and Swale											1					
Grassland & Shrubland	North Atlantic Coastal Plain Heathland and Grassland											1					
	Shrubland/grassland; mostly ruderal shrublands, regenerating clearcuts					1	1	1									
Outcrop & Summit Scrub	Acidic Rocky Outcrop						1										
	Calcareous Rocky Outcrop								1	1							
	Southern Appalachian Grass and Shrub Bald					1	1										
	Southern Piedmont Granite Flatrock and Outcrop						1										
	Acadian-North Atlantic Rocky Coast						1										
Urban/Suburban Built	Developed																
Upland Total		1	3		1	10	10	1	8	1	2	10	2	1			

Wetland Habitats

Table 5.1.3. Crosswalk between the Northeast Lexicon Project and the NETHM wetland habitats.

CLASS		Soil						Topography		
LEXICON	HABITAT	Sand	Loam	Silt	Muck	Enriched	Peat	Floodplain	Riparian	Tidal
Basin Wetland	Atlantic Coastal Plain Blackwater/Brownwater Stream Flood	1								
	Central Atlantic Coastal Plain Non-riverine Swamp and Wet	1								
	North Atlantic Coastal Plain Basin Swamp and Wet Hardwoc	1								
	North Atlantic Coastal Plain Pitch Pine Lowland	1								
	Glacial Marine and Lake Wet Clayplain Forest			1						
	North-Central Interior Wet Flatwoods			1						
	Piedmont Upland Depression Swamp			1						
	Laurentian-Acadian Freshwater Marsh				1					
	Piedmont-Coastal Plain Freshwater Marsh				1					
	North-Central Appalachian Acidic Swamp				1					
	Northern Appalachian-Acadian Conifer-Hardwood Acidic Swamp				1					
	Laurentian-Acadian Wet Meadow-Shrub Swamp				1					
	Piedmont-Coastal Plain Shrub Swamp				1					
	Central Interior Highlands and Appalachian Sinkhole and Depression Pond					1				
	Laurentian-Acadian Alkaline Conifer-Hardwood Swamp					1				
	North-Central Interior and Appalachian Rich Swamp					1				
	Laurentian-Acadian Alkaline Fen					1				
	North Atlantic Coastal Plain Basin Peat Swamp						1			
	Atlantic Coastal Plain Northern Bog						1			
	Atlantic Coastal Plain Peatland Pocosin and Canebrake						1			
	Acadian Maritime Bog						1			
	Boreal-Laurentian Bog						1			
	Boreal-Laurentian-Acadian Acidic Basin Fen						1			
	Atlantic Coastal Plain Northern Bog						1			
	North-Central Interior and Appalachian Acidic Peatland						1			
	High Allegheny Headwater Wetland									
Floodplain / Riparian	Riparian Forest, southeast Virginia								1	
	Southern Piedmont Lake Floodplain Forest							1		
	Laurentian-Acadian Large River Floodplain							1		
	North-Central Appalachian Large River Floodplain							1		
	North-Central Interior Large River Floodplain							1		
	Piedmont-Coastal Plain Large River Floodplain							1		
Tidal Wetland	Atlantic Coastal Plain Embayed Region Tidal Freshwater/Brackish Marsh									1
	Tidal Salt Marsh, Estuarine Marsh									1
	Coastal Plain Tidal Swamp									1
Wetland Total		6		3	6	4	9	5	2	3

Appendix 5.2: Geophysical Settings and Preferential Species

Table 5.2.1. Preferential Species for Sand and other Coarse-Grained Sediments. The table gives examples of the 295 total species.

Coarse Sand						
Vascular plant	**Common Name**	**IV**	**% AE**	**RANK**	**Count**
Dicot					
Helianthemum dumosum	Bushy Rockrose	138.9	0.88	G3	158
Linum intercursum	Sandplain Flax	125.6	0.84	G4	149
Coreopsis rosea	Rose Coreopsis	115.1	0.62	G3	185
Polygonum glaucum	Seabeach knotweed	102.5	0.63	G3	164
Sabatia kennedyana	Plymouth Gentian	91.16	0.43	G3	212
Stachys hyssopifolia	Hyssop-leaved Hedge-nettle	81.41	0.59	G4	137
Amelanchier nantucketensis	Nantucket Juneberry	79.44	0.74	G3	108
Bidens bidentoides	Delmarva Beggar-ticks	46.35	0.49	G3	95
Amaranthus pumilus	Seabeach Amaranth	44.01	0.77	G2	57
Gentiana autumnalis	Pine Barren Gentian	41.85	0.93	G3	45
Monocot					
Helonias bullata	Swamp Pink	139.9	0.70	G3	201
Rhynchospora scirpoides	Bald Rush, Beak-rush	85.11	0.67	G4	127
Sagittaria teres	Quill-leaf Arrowhead	64.11	0.50	G3	127
Muhlenbergia torreyana	Pine Barren Smoke Grass	51.15	0.93	G3	55
Juncus caesariensis	New Jersey Rush	50.08	0.89	G2	56
Rhynchospora knieskernii	Knieskern's Beaked-rush	49.29	0.93	G2	53
Eriocaulon parkeri	Estuary Hatpins	45.83	0.35	G3	131
Scleria reticularis	Nut-rush	45.67	0.38	G3	119
Lachnanthes caroliana	Carolina Redroot	44.66	0.72	G4	62
Narthecium americanum	Bog Asphodel	42.71	0.91	G2	47
Ferns					
Schizae pusilla	Curly Grass Fern	41.85	0.93	G3	45
Thelypteris simulata	Bog Fern	9.34	0.25	G4	38
Isoetes hyemalis	Winter Quillwort	6.16	0.51	G2	12
Vertebrates					
Herptiles					
Hyla andersonii	Pine Barrens Treefrog	465	0.93	G4	500
Ambystoma mabeei	Mabee's salamander	11.88	0.74	G4	16
Necturus punctatus	Dwarf Waterdog	5.3	0.53	G4	10
Crotalus horridus pop. 2	Timber Rattlesnake - Coastal Plain Popu	24.83	0.80	G4	31
Mammals					
Corynorhinus rafinesquii macrotis	Rafinesque's eastern big-eared bat	24.9	0.83	G3	30
Fish					
Etheostoma vitreum	Glassy Darter	13.74	0.76	G4	18
Enneacanthus chaetodon	Blackbanded Sunfish	7.37	0.82	G4	9
Invertebrates					
Insects					
Enallagma recurvatum	Pine Barrens Bluet	71.62	0.53	G3	134
Papaipema sulphurata	Decodon Stem Borer Moth	52.05	0.61	G2	85
Neonympha helicta	Helicta Satyr	49.29	0.93	G3	53
Enallagma pictum	Scarlet Bluet	46	0.46	G3	100
Enallagma laterale	New England Bluet	43.35	0.22	G3	195
Apharetra dentata	A noctuid moth	41.96	0.58	G4	72
Catocala herodias gerhardi	Gerhard's Underwing Moth	37.73	0.62	G3	61
Psectraglaea carnosa	Pink Sallow	36.17	0.52	G3	69
Callophrys irus	Frosted elfin	31.15	0.12	G3	255
Oncocnemis riparia	A noctuid moth	25.69	0.78	G4	33

Table 5.2.2. Preferential Species for Calcareous Bedrock areas. The table gives examples of the 255 total preferential G1-G4 species.

Calcareous						
Vascular plant	**Common Name**	**IV**	**% AE**	**RANK**	**Count**
Dicot					
Salix serissima	Autumn Willow	48.28	0.50	G4	96
Paxistima canbyi	Canby's Mountain-lover	27.73	0.45	G2	61
Clematis addisonii	Addison's Leatherflower	27.62	0.81	G2	34
Arabis patens	Spreading Rockcress	26.43	0.52	G3	51
Echinacea laevigata	Smooth Coneflower	23.78	0.52	G2	46
Delphinium exaltatum	Tall Larkspur	23.55	0.67	G3	35
Helenium virginicum	Virginia Sneezeweed	21.32	0.89	G2	24
Penstemon hirsutus	Hairy Beardtongue	18.83	0.61	G4	31
Lithospermum latifolium	American Gromwell	18.5	0.37	G4	50
Actaea racemosa	Black Cohosh	18.25	0.73	G4	25
Euphorbia purpurea	Darlington's Glade Spurge	17.73	0.29	G3	61
Monocot					
Cypripedium reginae	Showy Lady's-slipper	78.26	0.43	G4	182
Potamogeton hillii	Hill's Pondweed	75.53	0.62	G3	121
Carex grayi	Asa Gray's Sedge	66.97	0.52	G4	129
Carex trichocarpa	Hairy Sedge	59.72	0.57	G4	104
Carex schweinitzii	Schweinitz' Sedge	58.88	0.51	G3	116
Carex tetanica	Rigid Sedge	53.28	0.56	G4	96
Carex formosa	Handsome Sedge	52.77	0.59	G4	89
Carex sterilis	Dioecious Sedge	35.19	0.42	G4	83
Trillium nivale	Snow Trillium	34.61	0.45	G4	77
Cypripedium arietinum	Ram's Head Lady's-slipper	34.07	0.34	G3	99
Vertebrates					
Fish					
Notropis ariommus	Popeye Shiner	20.06	0.48	G3	42
Acipenser fulvescens	Lake Sturgeon	17.97	0.62	G3	29
Notropis anogenus	Pugnose Shiner	10.95	0.73	G3	15
Mammals					
Myotis sodalis	Indiana Bat	89.05	0.31	G2	285
Myotis leibii	Eastern Small-footed Myotis	74.43	0.30	G3	251
Myotis grisescens	Gray Myotis	8.09	0.62	G3	13
Herptiles					
Ambystoma jeffersonianum	Jefferson Salamander	97.41	0.29	G4	337
Clemmys muhlenbergii	Bog Tutle	79.59	0.49	G3	163
Invertebrates					
Anthropods					
Pseudotremia fulgida	Greenbrier Valley Cave Millipede	22.97	0.79	G3	29
Trichopetalum weyeriensis	Grand Caverns Blind Cave Millipede	18.39	0.80	G3	23
Kleptochthonius henroti	Greenbrier Valley Cave Pseudoscorpion	10.09	0.78	G2	13
Trichopetalum whitei	Luray Caverns Blind Cave Millipede	10.02	0.72	G3	14
Insects					
Stylurus scudderi	Zebra Clubtail	41.78	0.29	G4	146
Pseudanophthalmus grandis	A Cave Beetle	36.85	0.82	G3	45
Calephelis borealis	Northern Metalmark	30.38	0.46	G3	66
Euphyes dion	Dion Skipper	28.78	0.63	G4	46
Mussel					
Alasmidonta undulata	Triangle Floater	67.76	0.16	G4	432
Io fluvialis	Spiny Riversnail	22.13	0.54	G2	41
Fontigens tartarea	Organ Cavesnail	17.32	0.72	G2	24
Alasmidonta heterodon	Dwarf Wedge Mussel	16.04	0.13	G1	128

Table 5.2.3. Preferential Species for Acidic Sedimentary Bedrock areas. The table gives examples of the 159 total preferential G1-G4 species.

Acidic Sedimentary						
Vascular plant	**Common Name**	**IV**	**% AE**	**RANK**	**Count**
Dicot					
Actaea podocarpa	Mountain Bugbane	22.2	0.25	G4	90
Solidago uliginosa	Bog Goldenrod	21.8	0.36	G4	60
Plantago cordata	Heartleaf Plantain	19.22	0.33	G4	59
Solidago simplex var. racemosa	Lake Ontario Goldenrod	15.88	0.44	G3	36
Astragalus alpinus	Alpine Milk-vetch	13.34	0.58	G3	23
Lobelia dortmanna	Water Lobelia	13.08	0.50	G4	26
Heuchera alba	White Alumroot	12.62	0.32	G2	39
Salix myricoides	Blueleaf Willow	12.04	0.32	G4	38
Sorbus decora	Northern Mountain-ash	10.88	0.30	G4	36
Astragalus alpinus var. brunetianus	Alpine Milkvetch	10.6	0.53	G3	20
Monocot					
Stenanthium gramineum	Eastern Featherbells	36.7	0.32	G4	115
Trisetum melicoides	Bristle Grass	12.98	0.42	G4	31
Carex squarrosa	Squarrose Sedge	12.1	0.27	G4	45
Cleistes bifaria	Spreading Pogonia	10.82	0.37	G4	29
Spiranthes casei	Case's Ladies'-tresses	8.18	0.39	G4	21
Carex aestivalis	Summer Sedge	7.84	0.16	G4	48
Juncus militaris	Bayonet Rush	7.12	0.51	G4	14
Carex ormostachya	Necklace Spike Sedge	6.86	0.40	G4	17
Lygodium palmatum	Climbing Fern	65.26	0.26	G4	247
Asplenium pinnatifidum	Lobed Spleenwort	20.06	0.35	G4	57
Ferns					
Asplenium bradleyi	Bradley's Spleenwort	8.5	0.34	G4	25
Vertebrates					
Herptiles					
Aneides aeneus	Green Salamander	72.22	0.45	G3	159
Plethodon nettingi	Cheat Mountain Salamander	41.98	0.52	G2	81
Plethodon punctatus	Cow Knob Salamander	26.26	0.56	G3	47
Plethodon sherando	Big Levels Salamander	5.7	0.38	G2	15
Crotalus horridus	Timber Rattlesnake	117	0.16	G4	738
Sistrurus catenatus catenatus	Eastern Massasauga	27.7	0.43	G3	65
Mammals					
Neotoma magister	Allegheny Woodrat	117.5	0.24	G3	494
Sylvilagus obscurus	Appalachian Cottontail	19.16	0.37	G4	52
Sorex dispar	Rock Shrew	15.74	0.30	G4	53
Microtus chrotorrhinus	Rock Vole	6.56	0.21	G4	32
Fish					
Etheostoma tippecanoe	Tippecanoe Darter	9.5	0.38	G3	25
Etheostoma maculatum	Spotted Darter	7.34	0.32	G2	23
Clinostomus elongatus	Redside Dace	5.7	0.38	G3	15
Invertebrates					
Insects					
Stylurus amnicola	Riverine Clubtail	19.16	0.37	G4	52
Lycaena epixanthe	Bog Copper	16.22	0.27	G4	59
Cicindela patruela	Barrens Tiger Beetle	13.04	0.34	G3	38
Lanthus parvulus	Northern Pygmy Clubtail	12.46	0.34	G4	37
Ophiogomphus mainensis	Maine Snaketail	10.08	0.39	G4	26
Mussels					
Cambarus veteranus	A Crayfish	39.44	0.58	G2	68
Stygobromus pizzinii	Pizzini's Cave Amphipod	8.24	0.29	G3	28
Fusconaia subrotunda	Longsolid	20.58	0.40	G3	51
Epioblasma torulosa rangiana	Northern Riffleshell	18.04	0.47	G2	38
Quadrula cylindrica	Rabbitsfoot	16.56	0.52	G3	32

Table 5.2.4. Preferential Species for Moderately Calcareous Bedrock areas. The table gives examples of the 135 total preferential G1-G4 species.

Moderately Calcareous						
Vascular plant	**Common Name**	**IV**	**% AE**	**RANK**	**Count**
Dicot					
Panax quinquefolius	American Ginseng	68.54	0.17	G3	394
Viola appalachiensis	Appalachian Blue Violet	36.63	0.39	G3	93
Polemonium vanbruntiae	Bog Jacob's-ladder	20.01	0.18	G3	111
Aconitum reclinatum	White Monkshood	19.14	0.35	G3	54
Scutellaria saxatilis	Rock Skullcap	14.42	0.23	G3	62
Lathyrus ochroleucus	Pale Vetchling	13.31	0.32	G4	41
Aconitum uncinatum	Blue Monkshood	12.31	0.30	G4	41
Polygonum robustius	Robust Knotweed	11.02	0.50	G4	22
Cardamine rotundifolia	American Bittercress	10.01	0.91	G4	11
Ceratophyllum echinatum	Prickly Hornwort	9.66	0.37	G4	26
Monocot					
Carex oronensis	Orono Sedge	27.51	0.45	G2	61
Platanthera hookeri	Hooker Orchis	16.2	0.14	G4	120
Carex Lupuliformis	False Hop Sedge	14.12	0.11	G3	132
Scirpus pedicellatus	Stalked Bulrush	10.48	0.37	G4	28
Potamogeton vaseyi	A Pondweed	9.9	0.11	G4	90
Cyperus houghtonii	Houghton's Umbrella-sedge	9.13	0.21	G4	43
Listera australis	Southern Twayblade	7.84	0.33	G3	24
Ferns					
Botrychium oneidense	Blunt-lobe Grape Fern	25.34	0.34	G4	74
Isoetes engelmannii	Appalachian Quillwort	11.29	0.59	G4	19
Vertebrates					
Fish					
Ichthyomyzon bdellium	Ohio Lamprey	38.89	0.49	G3	79
Etheostoma percnurum	Duskytail Darter	20.75	0.83	G1	25
Percina macrocephala	Longhead Darter	16.77	0.36	G3	47
Percina copelandi	Channel Darter	16.06	0.24	G4	66
Mammals					
Myotis septentrionalis	Northern Myotis	54.99	0.14	G4	389
Sylvilagus transitionalis	New England Cottontail	29.95	0.21	G3	145
Herptiles					
Cryptobranchus alleganiensis	Hellbender	36.47	0.31	G3	117
Emydoidea blandingii	Blanding's Turtle	249.5	0.20	G4	1261
Glyptemys insculpta	Wood Turtle	159.6	0.07	G3	2427
Clonophis kirtlandii	Kirtland's Snake	5.1	0.51	G2	10
Invertebrates					
Anthropods					
Nesticus tennesseensis	A Cave Cobweb Spider	11.56	0.72	G3	16
Insects					
Lycaeides melissa samuelis	Karner Blue	43.1	0.39	G2	110
Tachopteryx thoreyi	Gray Petaltail	18.07	0.23	G4	77
Pieris virginiensis	West Virginia White	12.04	0.27	G3	44
Rhionaeschna mutata	Spatterdock Darner	9.34	0.13	G4	74
Mussel					
Pleurobema oviforme	Tennessee Clubshell	62.46	0.59	G2	106
Fusconaia barnesiana	Tennessee Pigtoe	56.93	0.46	G2	123
Alasmidonta varicosa	Brook Floater	53.37	0.17	G3	307
Lampsilis cariosa	Yellow Lampmussel	45.61	0.12	G3	371

Table 5.2.5. Preferential Species for Acidic Granitic Bedrock areas. The table gives examples of the 112 total preferential G1-G4 species.

Granitic						
Vascular plant	**Common Name**	**IV**	**% AE**	**RANK**	**Count**
Dicot					
Hottonia inflata	Featherfoil	30.32	0.20	G4	148
Utricularia resupinata	Northeastern Bladderwort	23.4	0.39	G4	60
Hudsonia ericoides	Golden Heather	15.64	0.74	G4	21
Minuartia glabra	Appalachian Sandwort	14.68	0.19	G4	77
Cardamine micranthera	Small Anthered-bittercress	13.28	0.32	G2	42
Geum peckii	Mountain Avens	12.92	0.34	G2	38
Vaccinium boreale	Alpine Blueberry	12.88	0.23	G4	57
Atriplex glabriuscula	Smoothish Orache	12.04	0.39	G4	31
Corydalis sempervirens	Pale Corydalis	11.44	0.72	G4	16
Paronychia argyrocoma var. albimontana	Silverling	10.44	0.65	G3	16
Monocot					
Isotria medeoloides	Small whorled poginia	40.28	0.21	G2	192
Potamogeton confervoides	Algae-like Pondweed	37.92	0.27	G3	138
Arethusa bulbosa	Arethusa	37.08	0.20	G4	187
Scirpus longii	Long's Bulrush	33.08	0.38	G2	87
Triphora trianthophora	Nodding Pogonia	25.36	0.20	G3	129
Calamagrostis pickeringii	Pickering's Reed Bentgrass	19.56	0.58	G4	34
Carex wiegandii	Wiegand Sedge	14.96	0.22	G3	69
Rhynchospora macrostachya	Large-spiked Beak-rush	11.64	0.55	G4	21
Potamogeton bicupulatus	Snail-seed Pondweed	7.92	0.21	G4	38
Carex cumulata	Piled up Sedge	7.72	0.13	G4	58
Cyperus granitophilus	Granite-loving Flatsedge	5.04	0.84	G3	6
Ferns					
Isoetes acadiensis	Acadian Quillwort	6.24	0.57	G3	11
Vertebrates					
Fish					
Phenacobius teretulus	Kanawha Minnow	23.32	0.49	G3	48
Notropis bifrenatus	Bridle Shiner	21.92	0.10	G3	213
Percina rex	Roanoke Logperch	5.92	0.16	G1	38
Herptiles					
Plethodon hubrichti	Peaks of Otter Salamander	9.24	0.84	G2	11
Invertebrates					
Insects					
Williamsonia lintneri	Ringed Bog Haunter	51.2	0.49	G2	105
Zanclognatha martha	Pine Barrens Zanclognatha	19.12	0.28	G4	68
Callophrys hesseli	Hessel's hairstreak	15.88	0.28	G3	57
Neonympha mitchellii	Mitchell's Satyr	15.16	0.63	G2	24
Williamsonia fletcheri	Ebony Boghaunter	9.92	0.16	G3	63
Somatochlora georgiana	Coppery Emerald	7.92	0.61	G3	13
Mussel					
Margaritifera margaritifera	Eastern Pearlshell	15.36	0.19	G4	79

Table 5.2.6. Preferential Species for Mafic or Intermediate Bedrock areas. The table gives examples of the 57 total preferential G1-G4 species.

Mafic						
Vascular plant		**Common Name**	**IV**	**% AE**	**RANK**	**Count**
Dicot						
	Houstonia longifolia	Longleaf Bluet	25.62	0.35	G4	73
	Pycnanthemum torrei	Torrey's Mountainmint	18.58	0.33	G2	57
	Hydrastis canadensis	Golden Seal	17.12	0.17	G4	98
	Limosella australis	Mudwort	14.5	0.19	G4	75
	Juglans cinerea	Butternut	14.26	0.11	G3	129
	Bidens eatonii	Eaton's Beggarticks	13.54	0.33	G2	41
	Ranunculus allegheniensis	Allegheny Crowfoot	10.72	0.28	G4	38
	Pycnanthemum clinopodioides	Basil Mountainmint	10.48	0.25	G1	42
	Megalodonta beckii	Beck Water-marigold	10.38	0.13	G4	77
	Adlumia fungosa	Allegheny Vine	10.12	0.10	G4	98
Monocot						
	Carex polymorpha	(variable) Sedge	25.74	0.21	G3	121
	Platanthera flava	Pale Green Orchis	9.34	0.15	G4	61
	Carex meadii	Mead's Sedge	6.84	0.19	G4	36
	Poa fernaldiana	Wavy Bluegrass	6.32	0.23	G2	28
	Paspalum laeve	Field Beadgrass	5.92	0.33	G4	18
	Triglochin gaspensis	Gaspe Arrow-grass	5.64	0.94	G3	6
	Dryopteris goldiana	Goldie's Fern	20.34	0.13	G4	161
Ferns						
	Huperzia appalachiana	Appalachian Fir-clubmoss	16.18	0.34	G4	47
Invertebrates						
Insects						
	Gomphus abbreviatus	Spine-crowned Clubtail	9.88	0.10	G3	102
Mussels						
	Ligumia nasuta	Eastern Pond Mussel	13.18	0.07	G4	197

Table 5.2.7. Preferential Species for Acidic Shale Bedrock areas. The table gives examples of the 38 total preferential G1-G4 species.

Acidic Shale							
Vascular plant (43)			**Common Name**	**IV**	**% AE**	**RANK**	**Count**
	Dicot (26)						
		Trifolium virginicum	Kate's Mountain Clover	149.03	0.87	G3	171
		Arabis serotina	Shale Barren Rockcress	69.63	0.77	G2	91
		Oenothera argillicola	Shale Barren Evening-primrose	61.58	0.58	G3	106
		Taenidia montana	Mountain Parsley	38.03	0.54	G3	71
		Phlox buckleyi	Swordleaf Phlox	27.22	0.50	G2	54
		Prunus alleghaniensis	Alleghany Plum	19.19	0.23	G4	83
		Penstemon canescens	Gray Beardtongue	19.13	0.47	G4	41
		Clematis viticaulis	Millboro Leatherflower	15.74	0.87	G2	18
		Helianthus laevigatus	Smooth Sunflower	14.74	0.82	G4	18
		Scutellaria parvula var. missouriensis	Shale Barren Skullcap	10.11	0.37	T4	27
		Antennaria virginica	Shale Barren Pussytoes	8.6	0.43	G4	20
	Monocot (10)						
		Allium oxyphilum	Lillydale Onion	16.04	0.57	G2	28
Vertebrates							
	Fish						
		Notropis semperasper	Roughhead Shiner	28.62	0.84	G2	34
		Noturus gilberti	Orangefin Madtom	5.39	0.23	G2	23
Invertebrates							
	Insect						
		Euchloe olympia	Olympia Marble	40.52	0.63	G4	64
		Pyrgus wyandot	Appalachian grizzled skipper	20.76	0.65	G1	32
	Mussel						
		Pleurobema collina	James Spinymussel	176.47	0.63	G1	279
		Elliptio lanceolata	Yellow Lance	21.89	0.30	G2	73
		Elliptio producta	Atlantic Spike	9.46	0.43	G3	22
		Fusconaia masoni	Atlantic Pigtoe	8.9	0.30	G2	30

Table 5.2.8. Preferential Species for Ultramafic Bedrock areas. The table gives examples of the 18 total preferential G1-G4 species.

Ultramafic						
Vascular plant		**Common Name**	**IV**	**% AE**	**RANK**	**Count**
Dicot						
	Symphyotrichum depauperatum	Serpentine Aster	42.9	0.89	G2	48
	Talinum teretifolium	Roundleaf Fameflower	26.92	0.69	G4	39
	Moehringia macrophylla	Largeleaf Sandwort	19.95	0.74	G45	27
	Packera anonyma	Small's Ragwort	14.95	0.65	G45	23
	Sanguisorba canadensis	Canada Burnet	10.89	0.19	G45	56
	Ageratina aromatica	Lesser Snakeroot	6.92	0.17	G45	40
	Helenium brevifolium	Shortleaf Sneezeweed	5.97	0.40	G4	15
Monocot						
	Fimbristylis annua	Annual Fimbry	14.96	0.68	G45	22
	Dichanthelium oligosanthes	Heller's Witchgrass	12.92	0.32	G45	41
	Sporobolus heterolepis	Northern Dropseed	8.946	0.33	G45	27
	Deschampsia cespitosa	Tufted Hairgrass	8.942	0.31	G45	29
	Lilium grayi	Gray's Lily	5.94	0.20	G3	30
Ferns						
	Adiantum viridimontanum	Green Mountain Maidenhair-fern	6.986	1.00	G2	7
Invertebrates						
Insects						
	Anthocharis midea	Falcate Orangetip	5.98	0.60	G4	10

Table 5.2.9. Preferential Species for Fine-grained Mud and Silt Deep Surficial Sediment. The table gives examples of the 10 total preferential G1-G4 species.

Fine Sediment						
Vascular plant		**Common Name**	**IV**	**% AE**	**RANK**	**Count**
Dicot						
	Kalmia angustifolia	Sheep Laurel	24.3	0.71	G45	34
	Verbena scabra	Sandpaper Vervain	11.05	0.58	G45	19
	Lilaeopsis carolinensis	Carolina Lilaeopsis	10.35	0.80	G3	13
	Stewartia ovata	Mountain Camellia	9.1	0.51	G4	18
	Lobelia elongata	Elongated Lobelia	6.65	0.95	G4	7
Monocot						
	Rhynchospora alba	White Beakrush	7.1	0.39	G45	18
	Schoenoplectus subterminalis	Water Bulrush	6.4	0.12	G4	52
Vertebrates						
Herptiles						
	Siren intermedia	Lesser Siren	9.25	0.62	G45	15
	Crotalus horridus atricaudatus	Canebrake Rattlesnake	5.45	0.50	G45	11

Table 5.2.10. Preferential Species for the Very High Elevation zone (>3600'). The table gives examples of the 31preferential G1-G4 species. It has the highest density of preferential species in the Northeast.

>3600' Very High Elevation						
Vascular plant (19)		**Common Name**	**IV**	**% AE**	**RANK**	**Count**
	Dicot					
	Vaccinium boreale	Alpine Blueberry	39.86	0.70	G4	57
	Betula minor	Dwarf White Birch	25.93	0.93	G3	28
	Geum peckii	Mountain Avens	23.91	0.63	G2	38
	Solidago cutleri	Cutler's Alpine Goldenrod	17.95	0.94	G4	19
	Prenanthes boottii	Boott's Rattlesnake Root	15.96	0.94	G2	17
	Heuchera alba	White Alumroot	15.9	0.41	G2	39
	Ilex collina	Long-stalk Holly	12.93	0.45	G3	29
	Monocot					
	Poa fernaldiana	Wavy Bluegrass	25.93	0.93	G2	28
Vertebrates						
	Herptiles (5)					
	Plethodon nettingi	Cheat Mountain Salamander	63.8	0.79	G2	81
	Plethodon punctatus	Cow Knob Salamander	25.88	0.55	G3	47
	Birds (1)					
	Catharus bicknelli	Bicknell's Thrush	51.77	0.54	G4	95

Table 5.2.11. Preferential Species for the High Elevation zone (2500'-3600'). The table gives examples of the 72 preferential G1-G4 species.

2500' to 3600' High Elevation						
Vascular plant (35)		**Common Name**	**IV**	**% AE**	**RANK**	**Count**
	Dicot					
	Trifolium stoloniferum	Running Buffalo Clover	35.93	0.63	G3	57
	Aconitum reclinatum	White Monkshood	30.98	0.57	G3	54
	Vaccinium macrocarpon	Large Cranberry	22.3	0.60	G4	37
	Euphorbia purpurea	Darlington's Glade Spurge	17.85	0.29	G3	61
	Sorbus decora	Northern Mountain-ash	15.32	0.43	G4	36
	Paronychia argyrocoma	Silverling	13.74	0.21	G4	67
	Solidago roanensis	Roan Mountain Goldenrod	11.62	0.58	G4	20
	Monocot					
	Lilium grayi	Gray's Lily	17.43	0.58	G3	30
	Listera smallii	Kidneyleaf Twayblade	15.49	0.57	G4	27
	Cleistes bifaria	Spreading Pogonia	10.45	0.36	G4	29
	Carex aestivalis	Summer Sedge	10.09	0.21	G4	48
	Ferns					
	Huperzia appalachiana	Appalachian Fir-clubmoss	18.11	0.39	G4	47
	Thelypteris simulata	Bog Fern	11.28	0.30	G4	38
Vertebrates						
	Mammals (2)					
	Sylvilagus obscurus	Appalachian Cottontail	16.02	0.31	G4	52
	Sorex dispar	Long-tailed Or Rock Shrew	13	0.25	G4	53
Invertebrates						
	Invertebrates (27)					
	Neonympha mitchellii	Mitchell's Satyr	19.55	0.81	G2	24

Table 5.2.12. Preferential Species for the Coastal zone (0'-20'). The table gives examples of the 177 preferential G1-G4 species

0' to 20' Coastal						
Vascular plant (119)		**Common Name**	**IV**	**% AE**	**RANK**	**Count**
	Dicot					
	Polygonum glaucum	Seabeach knotweed	145.5	0.89	G3	164
	Bidens bidentoides	Delmarva Beggar-ticks	86.47	0.91	G3	95
	Limosella australis	Mudwort	64.64	0.86	G4	75
	Amaranthus pumilus	Seabeach amaranth	52.68	0.92	G2	57
	Plantago cordata	Heartleaf Plantain	49.57	0.84	G4	59
	Helianthemum dumosum	Bushy Rockrose	47.81	0.30	G3	158
	Cardamine longii	Long's Bitter Cress	42.8	0.78	G3	55
	Bidens hyperborea	Estuary Beggarticks	42.21	0.88	G2	48
	Bidens eatonii	Eaton's Beggarticks	38.62	0.94	G2	41
	Amelanchier nantucketensis	Nantucket Juneberry	33.72	0.31	G3	108
	Monocot					
	Eriocaulon parkeri	Estuary Hatpins	117.4	0.90	G3	131
	Sagittaria subulata	River-arrowhead	34.56	0.82	G4	42
	Carex hormathodes	Marsh Straw Sedge	34.38	0.76	G4	45
	Carex mitchelliana	Mitchell's Sedge	34.09	0.68	G3	50
	Rhynchospora scirpoides	Bald Rush, Beak-rush	33.61	0.26	G4	127
	Helonias bullata	Swamp Pink	33.31	0.17	G3	201
	Iris prismatica	Slender Blue Flag	33.29	0.41	G4	81
	Juncus megacephalus	Big-head Rush	23.55	0.94	G4	25
	Phragmites australis ssp. americanus	Common Reed	19.91	0.55	T4	36
	Fuirena pumila	Dwarf Umbrella-grass	16.41	0.21	G4	79
	Ferns					
	Schizaea pusilla	Curly Grass Fern	12.38	0.28	G3	45
Vertebrates						
	Herptiles (10)					
	Caretta caretta	Loggerhead	76.29	0.94	G3	81
	Dermochelys coriacea	Leatherback	15.07	0.94	G2	16
	Crotalus horridus pop. 2	Timber Rattlesnake - Coastal Plain Popula	14.2	0.46	G4	31
	Lepidochelys kempii	Kemp's Or Atlantic Ridley	10.36	0.94	G1	11
	Birds					
	Charadrius melodus	Piping plover	466.9	0.90	G3	518
	Sterna dougallii	Roseate Tern	176.8	0.92	G4	193
	Sternula antillarum	Least Tern	172	0.83	G4	207
	Falco peregrinus	Peregrine Falcon	86.55	0.22	G4	386
	Calidris canutus	Red Knot	79.11	0.94	G4	84
	Ammodramus caudacutus	Saltmarsh Sharp-tailed Sparrow	79.06	0.93	G4	85
	Ammodramus maritimus	Seaside Sparrow	40.50	0.94	G4	43
	Rallus elegans	King Rail	24.46	0.31	G4	78
	Laterallus jamaicensis	Black rail	23.43	0.87	G4	27
	Fish					
	Acipenser brevirostrum	Shortnose sturgeon	35.09	0.70	G3	50
	Acipenser oxyrinchus	Atlantic sturgeon	15.01	0.88	G3	17
Invertebrates						
	Invertebrates					
	Papaipema sulphurata	Decodon Stem Borer Moth	24.06	0.28	G2	85
	Problema bulenta	Rare skipper	21.55	0.86	G2	25
	Cicindela puritana	Puritan tiger beetle	10.67	0.27	G1	40
	Euphyes dukesi	Dukes' Skipper	10.36	0.94	G3	11
	Spartiniphaga inops	Spartina Borer	10.24	0.79	G3	13
	Mussel					
	Leptodea ochracea	Tidewater mucket	36.26	0.27	G3	133

Table 5.2.13. Preferential Species for the Cliffs and Steep Slopes. The table gives examples of the preferential G1-G4 species.

Cliff and Steep Slopes							
Vascular plant			**Common Name**	**IV**	**% AE**	**Rank**	**Count**
	Dicot						
		Clematis occidentalis	Purple Clematis	34.72	0.27	G45	128
		Arabis missouriensis	Green Rock-cress	26.56	0.18	G45	144
		Campanula rotundifolia	American Harebell	22.47	0.42	G45	53
		Arabis serotina	Shale Barren Rockcress	22.09	0.24	G2	91
		Solidago simplex var. monticola	Sticky Goldenrod	18.71	0.65	T4	29
		Geum peckii	Mountain Avens	18.62	0.49	G2	38
		Paxistima canbyi	Canby's Mountain-lover	18.39	0.30	G2	61
		Juglans cinerea	Butternut	17.71	0.14	G3	129
		Oenothera argillicola	Shale Barren Evening-primrose	16.94	0.16	G3	106
		Thuja occidentalis	Northern White Cedar	8.48	0.16	G45	52
	Monocot						
		Carex eburnea	Ebony Sedge	17.51	0.36	G45	49
		Carex scirpoidea	Bulrush Sedge	15.61	0.40	G45	39
		Poa fernaldiana	Wavy Bluegrass	14.72	0.53	G2	28
		Luzula spicata	Spiked Woodrush	13.78	0.63	G45	22
		Calamagrostis stricta ssp. inexpansa	Bentgrass	11.59	0.28	GU	41
		Melica nitens	Three-flower Melic Grass	11.53	0.25	G45	47
		Agrostis borealis	Boreal Bentgrass	10.73	0.40	GU	27
		Hierochloe alpina	Alpine Sweet Grass	10.72	0.38	GU	28
		Carex aestivalis	Summer Sedge	10.52	0.22	G4	48
		Milium effusum	Tall Millet Grass	10.28	0.14	G45	72
	Ferns						
		Dryopteris fragrans	Fragrant Cliff Fern	21.48	0.41	G45	52
		Woodsia glabella	Smooth Cliff Fern	17.67	0.54	G45	33
		Huperzia appalachiana	Appalachian Fir-clubmoss	16.53	0.35	G4	47
		Cheilanthes eatonii	Eaton's Lipfern	13.72	0.49	G45	28
		Diplazium pycnocarpon	Glade Fern	12.22	0.16	G45	78
		Pellaea atropurpurea	Purple Cliffbrake	10.53	0.22	G45	47
Vertebrates							
	Birds						
		Falco peregrinus	Peregrine Falcon	127.26	0.34	G4	374
		Aquila chrysaetos	Golden Eagle	18.69	0.60	G45	31
	Mammals						
		Neotoma magister	Allegheny Woodrat	124.06	0.25	G3	494
		Corynorhinus townsendii virginianus	Virginia Big-eared Bat	15.26	0.21	G45	74
		Microtus chrotorrhinus	Rock Vole	8.68	0.27	G4	32
		Sorex dispar	Long-tailed Or Rock Shrew	6.47	0.12	G4	53
	Reptiles						
		Crotalus horridus	Timber Rattlesnake	205.62	0.28		738
		Eumeces anthracinus	Coal Skink	10.46	0.19	G45	54

Appendix 5.3 Other Species names used in the text

Common Name	Standard name
Allegheny Woodrat	*Neotoma magister*
Alpine Azalea	*Loiseleuria procumbens*
Anarta Noctuid Moth	*Anarta melanopa*
Annual Fimbry	*Fimbristylis annua*
Appalachian Azure	*Celastrina neglectamajor*
Appalachian Firmoss	*Huperzia appressa*
Appalachian grizzled skipper	*Pyrgus Wyandot*
Appalachian Trail Lichen	*Ramalina petrina*
Appalachian Woodsia	*Woodsia appalachiana*
Black Rail	*Laterallus jamaicensis*
Black-stem Spleenwort	*Asplenium resiliens*
Bog Copper	*Lycaena epixanthe*
Bog Fern	*Thelypteris simulate*
Bryohaplocladium microphyllum	*Bryohaplocladium microphyllum*
Cambarus crayfish	*Cambarus veteranus*
Carolina sphagnum	*Sphagnum carolinianum*
Cave Salamander	*Eurycea lucifuga*
Cheat Mountain Salamander	*Plethodon netting*
Chowanoke Crayfish	*Orconectes virginiensis*
Coastal Barrens Buckmoth	*Hemileuca maia maia*
Common Loon	*Gavia immer*
Copperbelly Water Snake	*Nerodia erythrogaster neglecta*
Copperhead	*Agkistrodon contortrix*
Creek Heelsplitter	*Lasmigona compressa*
Crested Coralroot	*Hexalectris spicata var. spicata*
Currant Spanworm	*Itame ribearia*
Deer's Hair Sedge	*Trichophorum caespitosum*
Depressed Glyph	*Glyphyalinia virginica*
Eastern Spadefoot	*Scaphiopus holbrookii*
Elongated Lobelia	*Lobelia elongate*
Fence Lizard	*Sceloporus undulates*
Roundleaf fameflower	*Talinum teretifolium*
Golden Darter	*Etheostoma denoncourti*
Gray Myotis	*Myotis grisescens*
Green Mountain madenhair-fern	*Adiantum viridimontanum*
Ground Skink	*Scincella lateralis*
Hart's-tongue Fern	*Asplenium scolopendrium var.americanum*
Holsinger's Cave Isopod	*Caecidotea holsingeri*
Indian Milk-vetch	*Astragalus australis*
Indian's dream	*Aspidotis densa*
Inland Silverside	*Menidia beryllina*
James Spinymussel	*Pleurobema collina*
Joyful Holomelina moth	*Holomelina laeta*
Kanawha Minnow	*Phenacobius teretulus*
Lake Erie Water Snake	*Nerodia sipedon insularum*
Largeleaf Sphagnum	*Sphagnum macrophyllum*
Lilypad Clubtail	*Arigomphus furcifer*
Lined Topminnow	*Fundulus lineolatus*
Loggerhead	*Caretta caretta*

Maritime Shrew	*Sorex maritimensis?*
Mountain Spleenwort	*Asplenium montanum*
Mud Salamander	*Pseudotriton montanus*
Narrowleaf Peatmoss	*Sphagnum angustifolium*
NE beach tiger beetle	*Cicindela patruela consentanea*
New England Siltsnail	*Cincinnatia winkleyi*
Northern Appressed Clubmoss	*Lycopodiella subappressa*
Northern Clearwater Crayfish	*Orconectes propinquus*
Northern flying squirrel	*Glaucomys sabrinus*
Northern Monk's-hood	*Aconitum noveboracense*
Northern Red-bellied Cooter	*Pseudemys rubriventris pop 1*
Northern Redbelly Dace	*Phoxinus eos*
Organ Cavesnail	*Fontigens tartarea*
Pennsylvania ostrich fern	*Matteuccia struthiopteris var. pens*
Peregrine Falcon	*Falco peregrines*
Philadelphia Vireo	*Vireo philadelphicus*
Pine Barren Gentian	*Gentiana autumnalis*
Pink Papershell	*Potamilus ohiensis*
Piping Plover	*Charadrius melodus*
Plains Clubtail	*Gomphus externus*
Prairie Vole	*Microtus ochrogaster*
Price's Cave Isopod	*Caecidotea pricei*
Pseudanophthalmus Cave beetles	*Pseudanophthalmus spp.*
Pseudanophthalmus delicatus	*Pseudanophthalmus delicates*
Purple Sedge	*Carex purpurifera*
Rafinesque's Big-eared Bat	*Corynorhinus rafinesquii*
Red Peatmoss	*Sphagnum rubellum*
Red-breasted Nuthatch	*Sitta Canadensis*
Red-cockaded Woodpecker	*Picoides borealis*
Roughhead shiner	*Notropis semperasper*
Seabeach knotweed	*Polygonum glaucum*
Serpentine aster	*Symphyotrichum depauperatum*
Shalebarren Pussytoes	*Antennaria virginica*
Shenandoah Salamander	*Plethodon Shenandoah*
Silverling	*Paronychia argyrocoma var. albimontana*
Slenderhead Darter	*Percina phoxocephala*
Slimy Salamander	*Plethodon glutinosus*
Slimy Sculpin	*Cottus cognatus*
Small Yellow Lady's-slipper	*Cypripedium calceolus var. parviflo*
Small's ragwort	*Packera anonyma*
Smooth Cliff Brake	*Pellaea glabella ssp. Glabella*
Smooth Softshell	*Apalone mutica*
Southern Leopard Frog	*Rana sphenocephala*
Spiny Riversnail	*Io fluvialis*
Swamp Fly-honeysuckle	*Lonicera oblongifolia*
Tidewater interstitial amphipod	*Stygobromus araeus*
Timber Rattlesnake	*Crotalus horridus*
Virginia Big-eared Bat	*Corynorhinus townsendii virginianus*
Virginia Northern Flying Squirrel	*Glaucomys sabrinus fuscus*
Virginia Pigtoe	*Lexingtonia subplana*
White Mountain Fritillary	*Boloria chariclea montinus*
Wood Turtle	*Glyptemys insculpta*

CHAPTER

Streams and Rivers

6

Condition and Conservation Status

Feb 2023

A. Olivero & M. G. Anderson

Stream and River Conservation: The region contains over 200,000 miles of streams and rivers, draining three major basins and supporting thousands of species. In total, 23% of all stream miles are locally conserved including 18% of critical stream riparian area of which 75% is still in natural cover. However, only 6% of stream miles meet upstream watershed conservation targets needed to achieve integrated protection. Thus 75% of locally protected streams and rivers do not have enough conserved upstream watershed to protect them from accumulated upstream impacts and overall 94% of streams and rivers do not meet integrated protection. Integrated protection varies by stream type with streams (7%) achieving the most followed by rivers (2%), tidal streams and rivers (1%), and big rivers (0%).

Loss versus Conservation: Riparian areas have lost more habitat through conversion (25%) to agriculture and development than has been conserved (18%), equivalent to 1.4 acres converted for every acre conserved. Over the last decade, however, riparian conservation surpassed habitat conversion almost 4 to 1 reversing the historic trend. Eight states have designated Tier 3 Outstanding National Resource Waters that prohibit new or increased discharge and two more states have designated other waters with medium level water quality protection. Three states have instream flow statues and eight have instream flow requirements. Over 1,500 miles of federally designated Wild and Scenic Rivers provide protection for habitat and connectivity.

Connectivity and Hydrologic Alteration: Historically 74% of all stream and river were embedded in huge, connected networks over 5,000 miles. Today, only 3% of miles are in these huge networks. The region's 14,000 dams fragment perennial stream networks into segments averaging 7 dams per 100 miles, not including the 15,000 small dams on tiny headwater streams. As a result, 86% of river miles are in networks less than a quarter of their pre-dam size, and 21% are less than 25 miles long. Further, 48% of streams and rivers are considered significantly altered in their hydrology, with alteration greatest on big rivers (66%). In the last decade, 346 dams have been removed, opening a minimum of 3,500 miles. Accounting for retrofitted or partially passable dams that increases to over 5,000 miles of newly connected stream and river habitat.

Impervious Surfaces and Nutrient Enrichment: All indicators of stream quality decline with increasing watershed imperviousness and nutrient enrichment. Over the last twenty years, streams and rivers highly impacted by impervious surfaces have increased from 21% to 24%, while undisturbed miles were reduced from 40% to 34%. Additionally, 75% of all miles now exceed EPA nitrogen criteria and 94% of all miles exceed EPA phosphorus criteria. Perhaps as a result, only 8% of the region's streams and rivers are predicted to be in good biological condition as measured by their benthic organisms.

Stream Biota: Nearly 500 non-indigenous aquatic species have been observed in the region and over 300, have established populations (mostly fish and plants). Brook trout have been a focus of conservation and 37% of their recognized strongholds have been secured with conservation land. Over the last decade, conservation has surpassed conversion in every identified brook trout strategy area, including in their identified strongholds (179 to 1) and areas to restore persistent populations (54 to 1).

Streams and rivers are flowing water ecosystems. For centuries, people have depended on them for drinking water, food, transportation, recreation, and more. As we work to balance human needs for water with the needs of stream biota, an assessment of their conservation status and condition is imperative. Here we examine these with respect to fragmentation, hydrologic alteration, nutrients, and biota.

Northeast streams and rivers range from tiny headwater streams to huge mainstem tidal rivers. Major streams and river types vary widely in their associated biota and these relationships described in the Northeast Aquatic Habitat Classification (NEAHC, Olivero and Anderson 2008), the Northeast Aquatic Habitat Guide (Anderson et al. 2013), and Eastern U.S. Stream Classification (McManamay et al. 2018).

Stream and rivers can be grouped into size classes based on their upstream drainage area which correlates with predictable changes in velocity, sediment, and biotic composition as they grow (Vannote et al. 1980, Figure 6.1.). For this report, we crosswalked the classes from the NEAHC to the three SWAP 2022 habitat lexicon target reporting types: Streams & Rivers, Big Rivers, and Tidal Streams & Rivers (Table 6.1.)

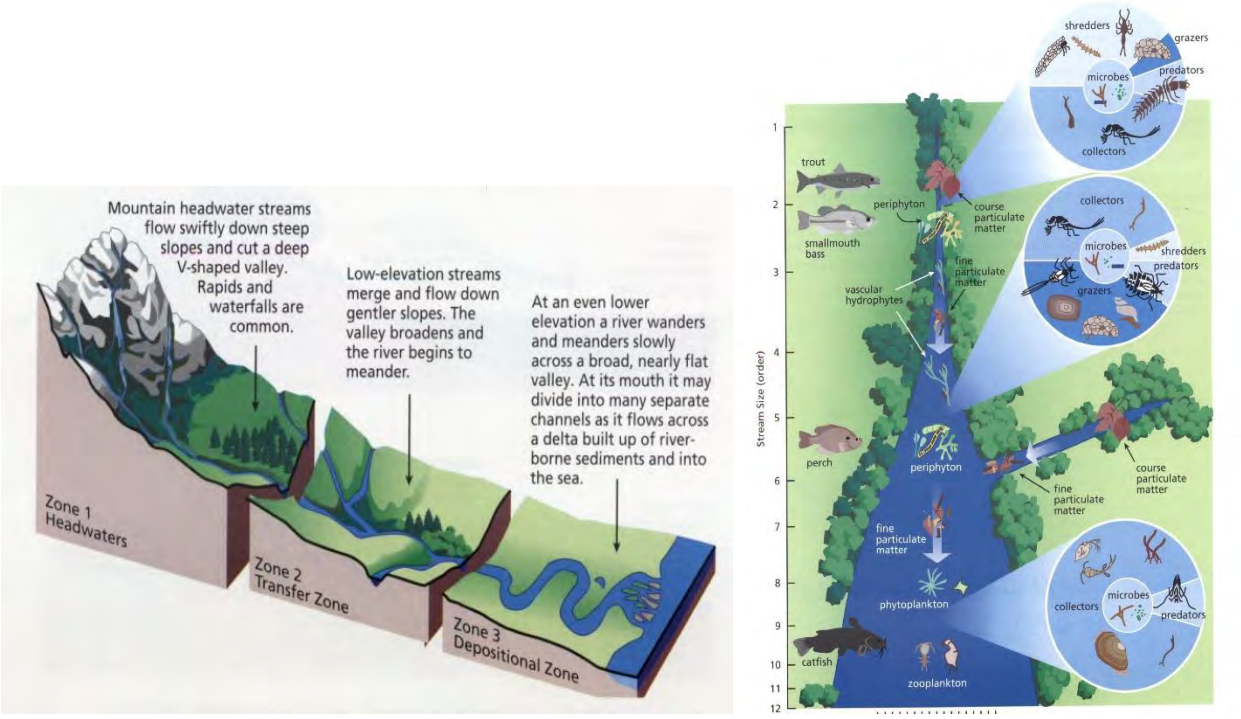
Table 6.1. Stream and River Size Classes

Lexicon Aquatic Habitat Types		NEAHC Habitat Name	Upstream Drainage Area
Streams & Rivers	Streams	Headwater	<10 sq.km
		Creek	10-100 sq.km.
	Rivers	Small Tributary	100-500 sq.km
		Medium Tributary	500-2,500 sq.km
		Mainstem River	2,500-10,000 sq.km
Big Rivers		Freshwater and Tidal Large to Great Rivers	>10,000 sq.km
Tidal Streams & Rivers		Tidal Streams	<100 sq.km.
		Tidal Rivers	100-10,000 sq.km

As streams increase in size, they increase in fish diversity and their species composition changes (Vannote et al., 1980). In this region, fish of small, cold, clear streams with rocky substrates include brook trout and slimy sculpin. In larger streams, cool water fish communities develop that include species such as blacknose dace, golden shiner, and white sucker. As rivers broaden and flatten, warm water fish communities occur until, in the lower tidal sections of large rivers the fish communities include a variety of anadromous, diadromous, and estuarine species (Anderson et al. 2013). Size based freshwater ecosystems further subdivide into variants based on variation in gradient, geology, and temperature class.

The biota associated with the physical variation is described in the full Northeast Stream Classification and Habitat Guide (Anderson et al. 2013). The region's freshwater ecosystems support over 300 species of freshwater and anadromous fish, over 100 species of freshwater mussels, over 100 species of freshwater snails, 36 species of crayfish, 91 species of amphibians, over 500 caddisfly, mayfly, stonefly, dragonfly or damselfly species, and a myriad of aquatic plants, algae, sponges, worms, other invertebrates and microscopic life (NatureServe 2022).

Figure 6. 1. River Continuum Concept (Vannote et al. 1980).



Basemap**:** We used the national dataset Medium Resolution 1:100,000 National Hydrography Dataset NHDPlusV21 data (USGS 2016) to map the extent of river and stream habitats and quantify the abundance of each type. The USGS National Hydrography Dataset (NHD) is a comprehensive national hydrography basemap that includes naturally occurring and constructed bodies of surface water. Its standard unique reach identifiers (COMID) relate to multiple federal and state databases used for reporting in the following sections of this chapter and in many other regional and national contexts.

Our analysis of distribution and trends is based on all streams and rivers with an *upstream drainage area of one square mile or larger.* Smaller streams are often intermittent and inconsistently mapped in the source data (e.g.,1:100,000 USGS topo quads) from which the NHD Medium Resolution was developed. This mapping threshold has been used in other regional scale studies (Anderson et al. 2013, Martin et al. 2017) to provide consistent and comparable metrics across the region's 14 states. As a result, the total miles of smallest headwater streams may be an underestimate in some places. Additionally, our estimate of river length do not include miles of the lakes, reservoirs, and ponds that some rivers pass through. These lentic systems are treated separately in the Lakes and Ponds chapter. The exception to this, are connectivity metrics in this chapter where we do add the centerlines for lotic systems to measure the length of the connected "freshwater network" between dams.

Distribution and Abundance

The region contains over 200,000 miles of streams and rivers that drain three major basins, the North Atlantic, Great Lakes, or Ohio-Mississippian (Map 6.1). Major river systems include the Penobscot, Kennebec, Merrimack, Connecticut, Hudson, Delaware, Susquehanna, Potomac, James, Roanoke, Allegheny, Monongahela, New River, and Ohio River.

The area includes portions of six freshwater ecoregions (Map 6.1, Abell et al. 2008).

1. Laurentian Great lakes,
2. Northeast US and Southeast Canada Atlantic Drainages,
3. Chesapeake Bay,
4. Teays-Old Ohio,
5. Appalachian Piedmont,
6. Tennessee.

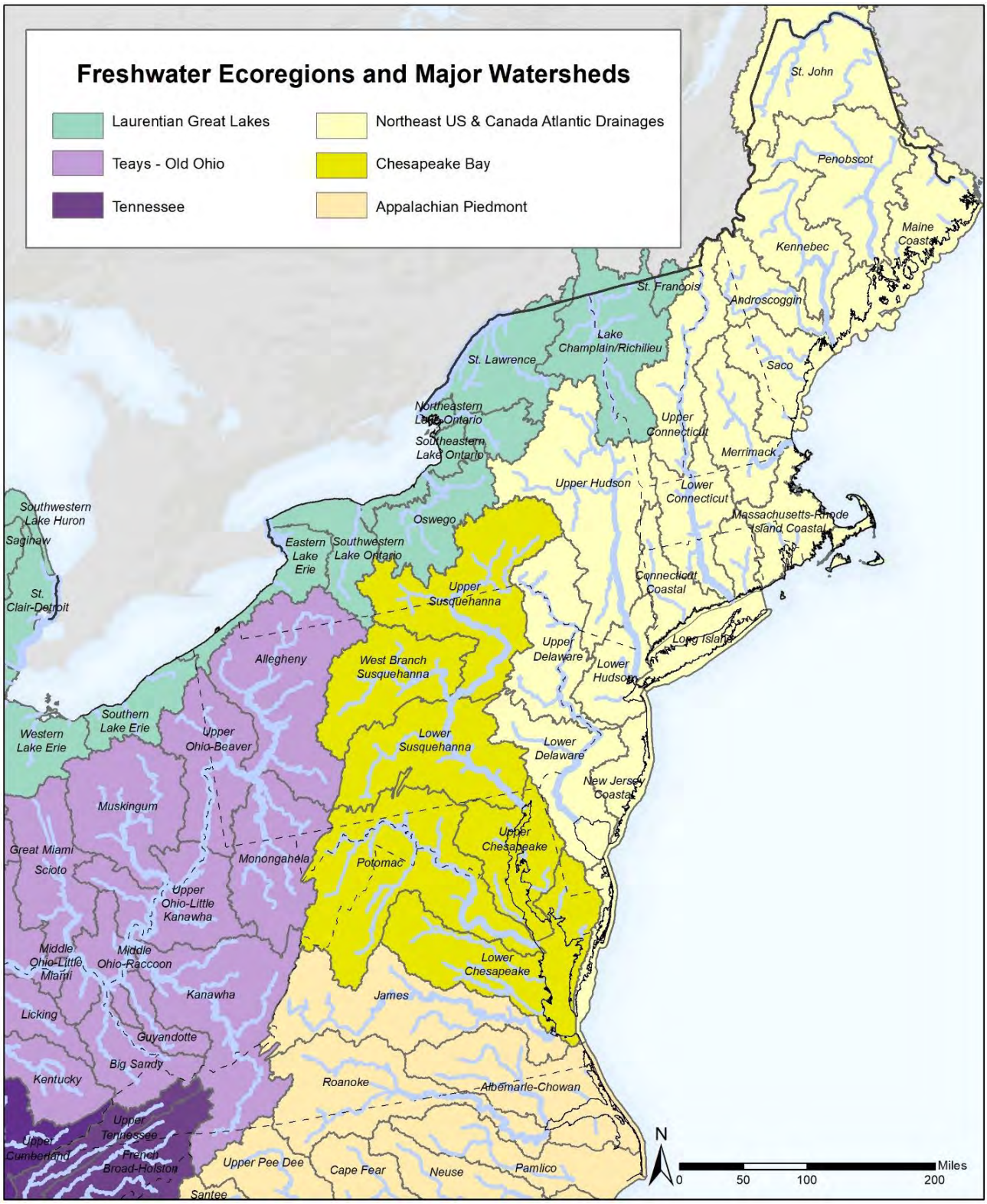
Only the Chesapeake Bay Ecoregions is fully within the NEAFWA region. The ecoregions differ in their freshwater fauna, physiography, and major river systems (Abell et al. 2008). The region is subdivided into 49 6-digit hydrologic units (HUC6) representing USGS delineated watersheds. Thirty-nine of these are primarily within the Northeast states and ten cross into adjacent states not covered here.

Headwater and creeks, make up 80% of all stream miles in the region. Small to mainstem rivers account for another 15% and tidal streams and rivers make up 4%. Big rivers account for 1% (Table 6.2, Map 6.2).

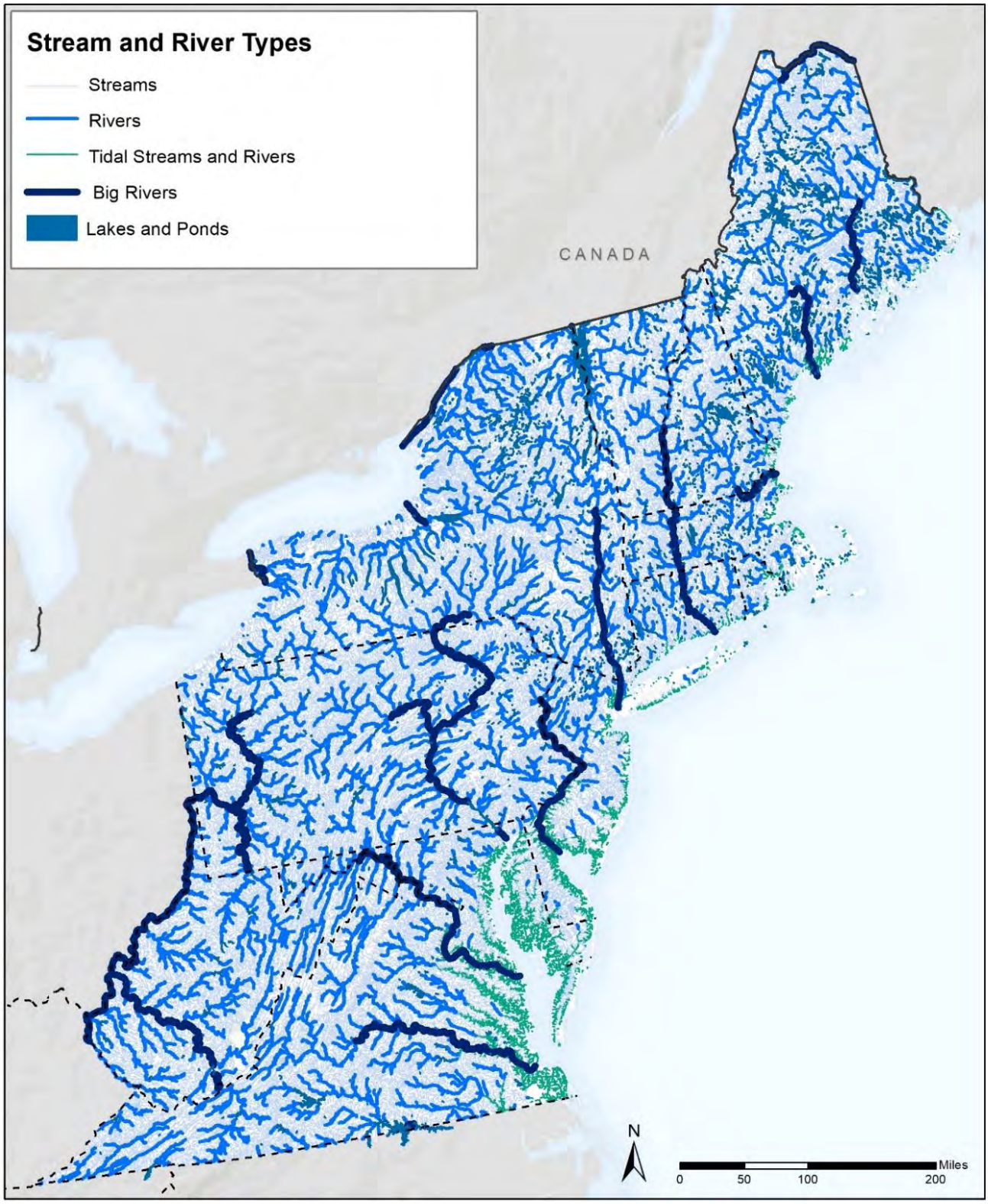
Table 6.2. Miles of Stream and River Types by State and Region *(Source NHD Medium Resolution 1:100,000). All stream and river arcs with >1 sq.mi. drainage area)*

MILES AND TYPES	CT	DC	DE	MA	MD	ME	NH	NJ	NY	PA	RI	VA	VT	WV	Total Miles
Headwaters	1,869	5	802	2,590	4,004	9,287	3,151	2,540	18,072	19,926	380	15,434	2,270	10,576	90,907
Creeks	1,470	3	383	1,967	2,182	9,021	2,605	1,870	15,307	14,063	217	11,290	3,067	7,268	70,712
Total Streams	**3,339**	**8**	**1,185**	**4,557**	**6,186**	**18,308**	**5,756**	**4,410**	**33,379**	**33,989**	**597**	**26,725**	**5,337**	**17,843**	**161,619**
Small Rivers	289	9	31	516	489	1,946	664	453	3,534	3,741	52	3,058	751	2,199	17,733
Medium Rivers	163		10	242	174	858	253	66	1,817	1,562	32	1,584	347	1,289	8,398
Mainstem Rivers	15				30	507	157	20	637	604		620	77	520	3,188
Total Rivers	**467**	**9**	**42**	**758**	**693**	**3,312**	**1,075**	**540**	**5,988**	**5,907**	**84**	**5,261**	**1,175**	**4,009**	**29,319**
1. TOTAL STREAMS AND RIVERS	**3,806**	**17**	**1,226**	**5,315**	**6,879**	**21,620**	**6,831**	**4,950**	**39,367**	**39,895**	**681**	**31,986**	**6,512**	**21,852**	**190,938**
Freshwater Big Rivers	10			89	70	191	45	38	189	642		146	41	517	1,976
Tidal Big Rivers	60	5	23	28	61	69		53	165	30		168			662
2. TOTAL BIG RIVERS	**69**	**5**	**23**	**117**	**131**	**260**	**45**	**90**	**354**	**673**	**0**	**314**	**41**	**517**	**2,638**
Tidal Streams	125	4	458	221	1,771	338	47	750	223	17	32	2,165			6,152
Tidal Rivers	80	8	126	86	632	170	26	332	67	34	28	679			2,268
3. TOTAL TIDAL STREAMS AND RIVERS	205	12	583	307	2,403	509	73	1,082	291	51	60	2,845	0	0	8,420
NORTHEAST TOTAL ALL STREAM AND RIVER TYPES	**4,081**	**35**	**1,833**	**5,739**	**9,413**	**22,388**	**6,949**	**6,122**	**40,011**	**40,619**	**740**	**35,144**	**6,552**	**22,370**	**201,996**

Map 6.1. Freshwater ecoregions and major rivers of the northeast United States.



Map 6.2. Streams and River Types. Major habitat types used in this report include 1. Streams (<100 sq.km drainage), 2. Rivers (100 sq.km – 10,000 sq.km), 3. Big Rivers (> 10,000 sq.km), and 4. Tidal Streams and Rivers.



Conservation Status of Streams and Rivers

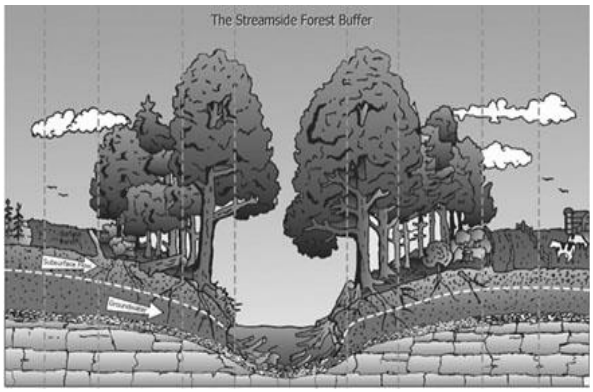
Conservation status is a measure of how well protected ecosystems are against future threats like conversion, fragmentation, or degradation. We define conservation as the establishment and implementation of mechanisms that help freshwater systems avoid future impacts to key ecological attributes for 25 years or more, have a high probability of renewal and enforceability, or have completely alleviated the potential for a future threat (Higgins et al. 2021). Key ecological attributes include habitat, water quality, hydrologic regime, and biotic composition (Karr 1991, Higgins et al. 2021). Assessing the degree of protection involves translating land conservation and policy to spatial extent. For this study we were able to assess three attributes, habitat conservation and water quality protection at a stream reach level, and flow protection at the state level.

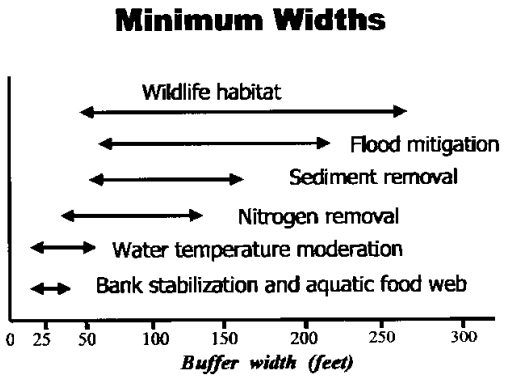
Habitat Conservation in the Riparian Zone

The riparian zone is the land area directly adjacent to a stream or river and subject to its influence. This dynamic zone is an ecologically rich environment supporting many rare and common species and numerous natural communities. Vegetated riparian zones also support adjacent aquatic systems through bank stabilization, water temperature moderation, nutrient filtering, and they are important sources of dissolved particulate and coarse organic matter (Figure 6. 2).

In this section, we assessed the riparian zone of each stream and river by creating a standard 100 m (~300 ft.) buffer on either side of each stream and river centerline line and/or 100 m landward from both shorelines of wider rivers mapped as polygons in the NHD basemap. The 100 m distance was chosen to encompass a broad range of the types of riparian functions noted for eastern riparian zones as one moves landward from the water interface (Palone et al. 1997).

Figure 6. 2. Riparian Zone Conceptual Model (Welsch 1991, Palone et al. 1997).





Land Cover Change in the Riparian Zone

Natural vegetated buffers along streams provide a suite of benefits to aquatic systems, while agricultural and urban development in the riparian zone is associated with elevated levels of nitrogen, phosphorus, sediment, pesticides, and bacteria in streams. We calculated the amount of agriculture and developed land within each 100 m riparian buffer zone by overlaying the 2011 and 2019 National Land Cover dataset (Dewitz and U.S. Geological Survey 2021).

Results of the overlay indicate that 75% of stream riparian land is in natural cover, 13% in agriculture, and 12% in developed cover (Table 6.3). The amount of riparian land in natural cover decreased with increasing stream size from a high of 76% for streams to a low of 64% for big rivers. Development showed the opposite pattern from natural cover, increasing from a low of 11% for headwaters to a high of 27% for big rivers. The percent of agricultural cover had a narrow range of variation across stream sizes, from a high of 13% for streams and rivers to low of 7% for tidal streams and rivers. New England and New York (80%) had slightly more natural riparian areas than the Mid-Atlantic (72%) and slightly less agriculture 11% vs. 14%). The pattern was similar for development: New England (10%), Mid-Atlantic (13%).

Table 6.3. Acres of Riparian Land by Cover Type and Conservation Status

Stratification	Agr. Acres	Dev. Acres	GAP 1 and 2 Acres	GAP 3 Acres	Unconserved Natural Acres	Total Acres
Tidal Streams & Rivers	-38,428	-99,262	50,326	71,678	272,686	532,379
Streams	-1,634,884	-1,359,216	641,517	1,590,091	7,246,420	12,472,128
Rivers	-275,923	-292,401	111,351	245,302	1,207,100	2,132,077
Big Rivers	-15,977	-46,253	11,161	21,865	75,842	171,099
NORTHEAST REGION	-1,965,213	-1,797,132	814,354	1,928,937	8,802,048	15,307,683
MID-ATLANTIC SUBREGION	-1,261,310	-1,162,910	306,261	1,108,790	4,933,107	8,772,378
NEW ENGLAND SUBREGION	-703,903	-634,222	508,093	820,148	3,868,941	6,535,305

Conservation in the Riparian Zone

To evaluate the conservation land in the nearshore riparian zone, we overlaid the TNC 2022 Conservation Lands data set on the 100 m riparian buffer zone. Results indicate that over 2.7 million acres of riparian buffer land was conserved, equivalent to 18% of all the riparian land in the region. Most of this (81%) was associated with small headwaters and creeks, which makes sense as these numerically dominate the region. Nearly 6% of riparian land was in GAP 1-2 land conserved for nature. New England and New York had 20% of their riparian land conserved with 8% conserved for nature, and the Mid-Atlantic had 16% conserved with 4% conserved for nature.

The **Conservation Risk Index (CRI)** is a measurement of the amount of natural land converted to development or agriculture in relation to the amount of land conserved, allowing us to evaluate if conservation is outpacing the loss to agricultural or developed land. CRI is calculated as the amount of agriculture and developed land divided by the amount of GAP 1-3 conservation land, and the stricter Nature Risk Index (NRI) is similar only divided solely by GAP 1-2 land conserved for nature. A ratio greater than one indicates more habitat loss than conserved and a ratio less than one indicates more conservation than conversion to development or agriculture.

Results across all streams and rivers indicate that riparian land was 25% converted to development or agriculture and 18% conserved, equivalent to 1.4 acres converted for every 1 acre conserved (CRI = 1.4, Table 6.4, Figure 6. 3). CRI was highest big rivers (1.9), followed by rivers (1.6), streams (1.3) and nearly equal in tidal streams and rivers (1.1). Big rivers had the highest overall loss to conversion (36%), whiles tidal streams and rivers had the largest proportion conserved (23%).

NRI ratios measuring conservation for nature (GAP 1-2) were much higher, with a regional average of 5 acres converted for every 1 acre conserved for nature (NRI = 4.6). Tidal rivers had the lowest NRI (2.7) while streams (4.7), rivers (5.1), and big rivers (5.6) had values at or above the regional mean (Table 6.4).

The Mid-Atlantic (1.7) had a higher CRI ratio than New England and New York (1.0). A few states such as ME, NH, and MA had ratios less than one indicating more conservation than conversion in the riparian zone. The NRI ratio showed similar patterns with the MidAtlantic (7.9) being higher than New England and New York (2.6) (Table 6.2, Figure 6. 3).

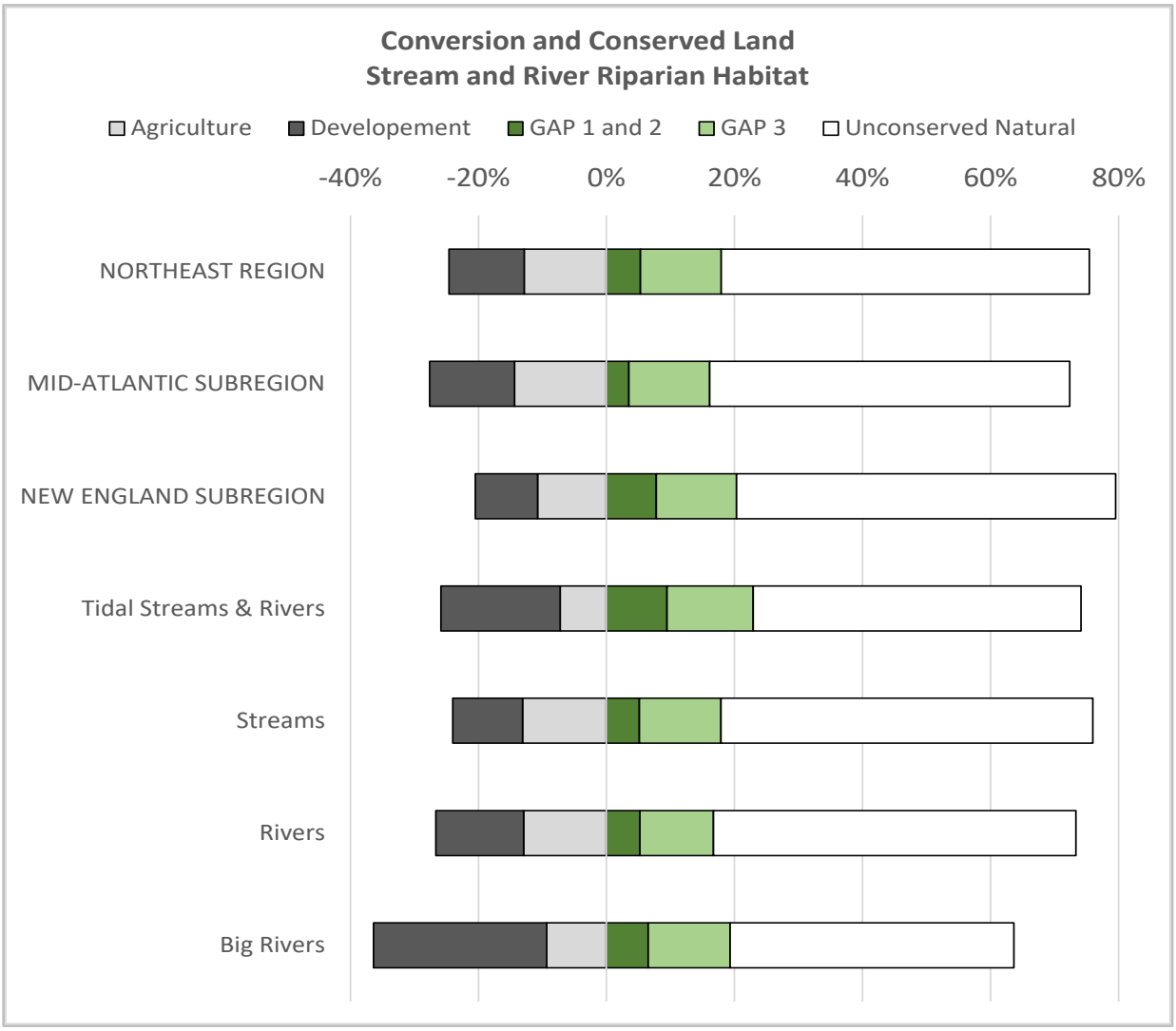
Table 6.4. Conservation Risk Index (CR) and% of Riparian Land Cover and Conservation Land

Stratification	Percent Converted (Dev & Ag)	Percent Protected (GAP 1 & 2)	Percent Conserved (GAP 1-3)	CRI	NRI
Tidal Streams & Rivers	25.9	9.5	22.9	1.1	2.7
Streams	24.0	5.1	17.9	1.3	4.7
Rivers	26.7	5.2	16.7	1.6	5.1
Big Rivers	36.4	6.5	19.3	1.9	5.6
NORTHEAST REGION	24.6	5.3	17.9	1.4	4.6
MID-ATLANTIC SUBREGION	27.6	3.5	16.1	1.7	7.9
NEW ENGLAND SUBREGION	20.5	7.8	20.3	1.0	2.6

Recent Trends in Riparian Shoreline Conservation

Over the last decade (2012-2022) there are some encouraging trends in riparian conservation. During this period conservation surpassed habitat conversion almost 4 to 1. Over 208,000 acres of riparian land was conserved and only 58,000 converted (CRI = 0.3), equivalent to 0.3 acres converted for every one conserved (Table 6.5, Figure 6. 4). The Mid-Atlantic (0.4) had a higher CRI ratio than New England and New York (0.1) but both were far below one. This pattern held true within every state except three: NY, DE, WV (Map 6.3). Although the trend is in the right direction, is has not yet reversed the overall trend of more habitat conversion than conservation in the riparian zone, and the way these two factors are distributed has stayed similar across stream and river types (Figure 6.4),

Figure 6. 3. The distribution of riparian land cover and conservation by stream type. In this chart, each bar represents the total area of riparian land in the habitat type. Land to the left of the center bar has been converted to development or agriculture; land to right of the center bar remains unconverted. Unconverted land is apportioned by conservation status and the% unconserved.

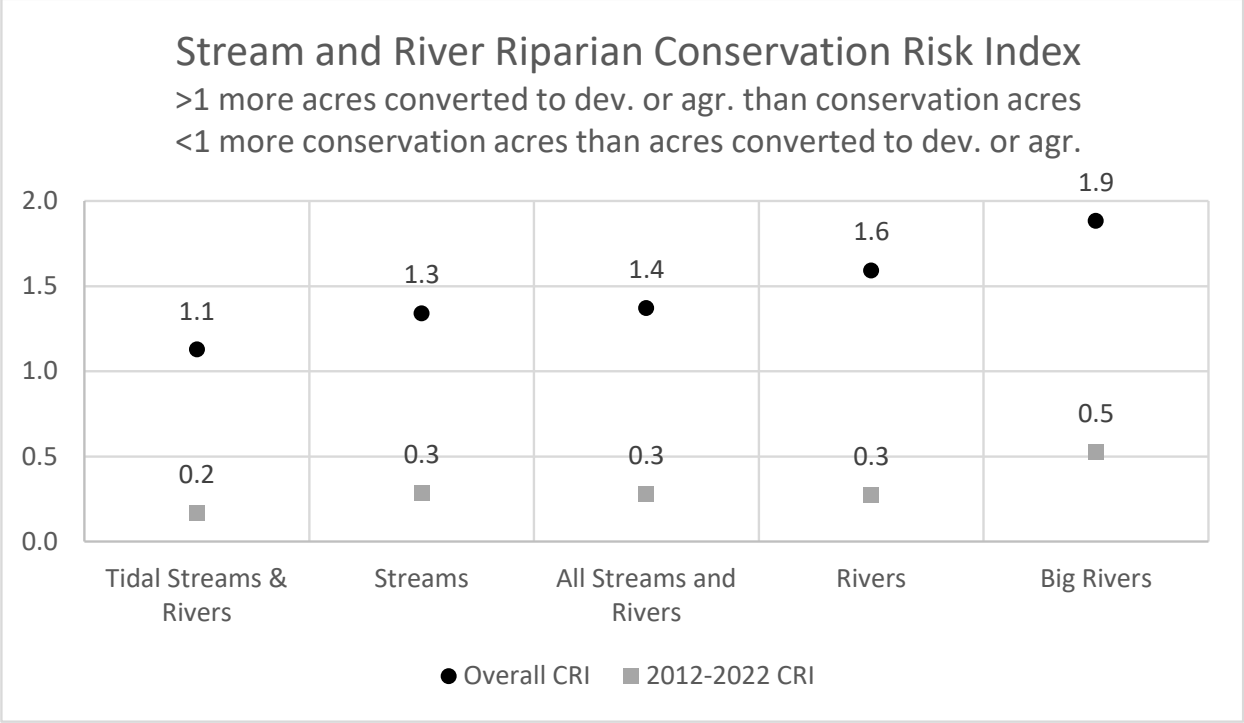


.

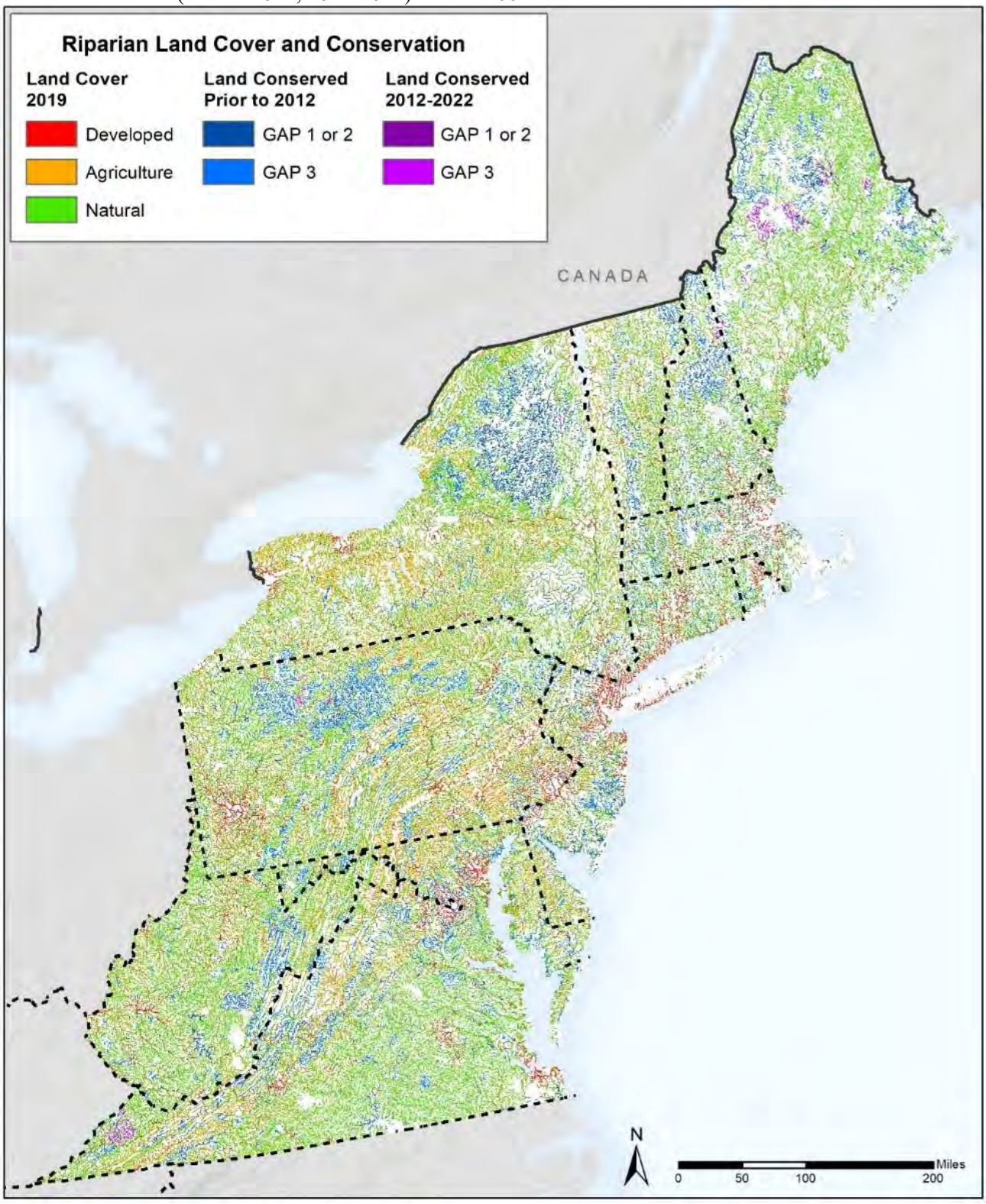
Table 6.5. Recent Trends 2012-2022. Conservation and Conservation in the Riparian Zone

Stratification	2012-2022 Loss Acres (Dev & Ag)	2012-2022 Conserved Acres	% of Total Area Lost 2012-2022	% of Total Area Conserved 2012-2022	2012-2022 CRI
Tidal Streams & Rivers	-1,599	9,470	0.3	1.8	0.2
Streams	-48,030	169,046	0.4	1.4	0.3
Rivers	-7,893	28,875	0.4	1.4	0.3
Big Rivers	-727	1,386	0.4	0.8	0.5
NORTHEAST REGION	-58,249	208,777	0.4	1.4	0.3
MID-ATLANTIC SUBREGION	-43,602	107,046	0.5	1.2	0.4
NEW ENGLAND SUBREGION	-14,647	101,731	0.2	1.6	0.1

Figure 6. 4. Conservation Risk Index (CRI): Overall and Last Decade. The CRI ratio represents the percent of habitat converted in the riparian buffer divided by the percent conserved. The CRI for all years compared to the CRI for the last decade only show that that although conservation is now outpacing habitat conversion, overall the riparian zone still has more land converted than conserved.



Map 6.3. Riparian Land Cover and Conservation. Riparian Land Cover (NLCD 2019) and Conservation Land (Before 2012, 2012-2022) Within 100m of Stream and Rivers

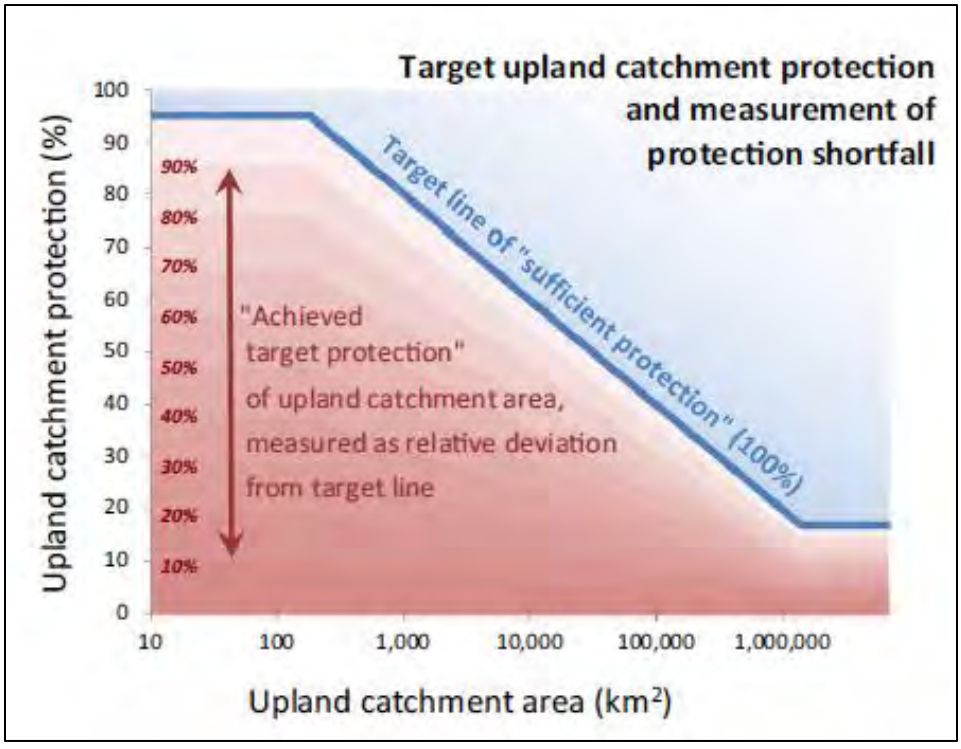


Integrated Protection Index

Miles of Streams and Rivers Achieving Local and Upstream Conservation Land Targets

In 2017, Abell and colleagues introduced an ***Integrated Protection Index (IPI)*** (Abell et al. (2017), which accounts for the protection of given reach as a function of both the *local protection*, the reach falling within conservation land, *and the degree of watershed conservation within a reach's upstream catchment*. The index asks the question: do our streams and rivers not only have local protection, but enough conserved upstream watershed area to likely protect them from the accumulated impacts of activities happening in their upstream watersheds. In the index, conserved reaches are assigned a target level of upstream watershed protection based on their upstream catchment size. For example, a small headwater stream might need 95% of its catchment conserved, while a very large river might need only 20% of its catchment conserved (Figure 6. 5). IPI can be used to determines how many rivers are meeting both their local and watershed goals.

Figure 6.5. Calculation of 'achieved target protection (From Abell et al. 2017). Once an area-based target line has been defined (blue line), every individual river reach can be assessed as to how far it deviates from the target (based on its individual values for 'upland protection' and catchment area).



We defined "locally conserved" as any NHDPlus flowline that intersected a conserved land (GAP 1-3). The boundaries of the region's conservation lands were expanded by 90 m to adjust for differing scales in the source data. The amount of conservation land upstream of every flowline was then accumulated and converted to a percent of the total upstream drainage area. All upstream calculations were based only on the upstream drainage area geography for which we had conservation land data. That is, drainage areas outside of the US or the 14 state NEAFWA footprint were not included in the 2022 calculations.

Following Abell et al. (2017), the "target area for upstream watershed conservation to achieve sufficient protection was calculated for every flowline as:

*Target Percentage = 100-((LOG10(watershed area [km2])-2)*20)*

This relationship is then capped at 95% at the high end and 17% at the low end to yield the declining line that will reach 100% at 100 km2 and 20% at 1 million km2. The IPI was then calculated for each locally protected stream reach by dividing the current percent of upstream conservation land by the target percentage and multiplying by 100. For example, if the target upstream watershed conservation for a stream reach was 80% and the actual upstream conservation was 20%, its IPI is 25 reflecting that it achieves 25% of its protection target.

Applying the IPI calculations to the region's streams and rivers revealed that although 23% of all streams and rivers miles in the region are locally protected, only 6% meet the upstream protection target amount to be considered achieving integrated protection. This highlights that nearly 75% of locally protected streams and rivers (17% out of 23%) do not have enough upstream conserved watershed area to protect them from accumulated impacts of activities that could happen in their upstream watersheds and overall 94% of all streams and rivers do not achieve integrated protection. Nearly 14% of locally protected reaches are getting close to reaching their upstream conservation target (IPI 80-99%). If these were counted as achieving their upstream target, the percentage of streams and rivers in the region achieving integrated protection would increase from 6% to 9%. However, most locally protected reaches are quite far from meeting their upstream watershed conservation land targets**,** as 49% meet less than 60% of target and 35% meet less than 40% of the target.

New England and New York (8%) has more miles achieving integrated protection than the Mid Atlantic (4%). Streams (7%) achieved more integrated protection than rivers (2%) or tidal streams and rivers (1%) and no big rivers meet integrated protection targets (Table 6.6)

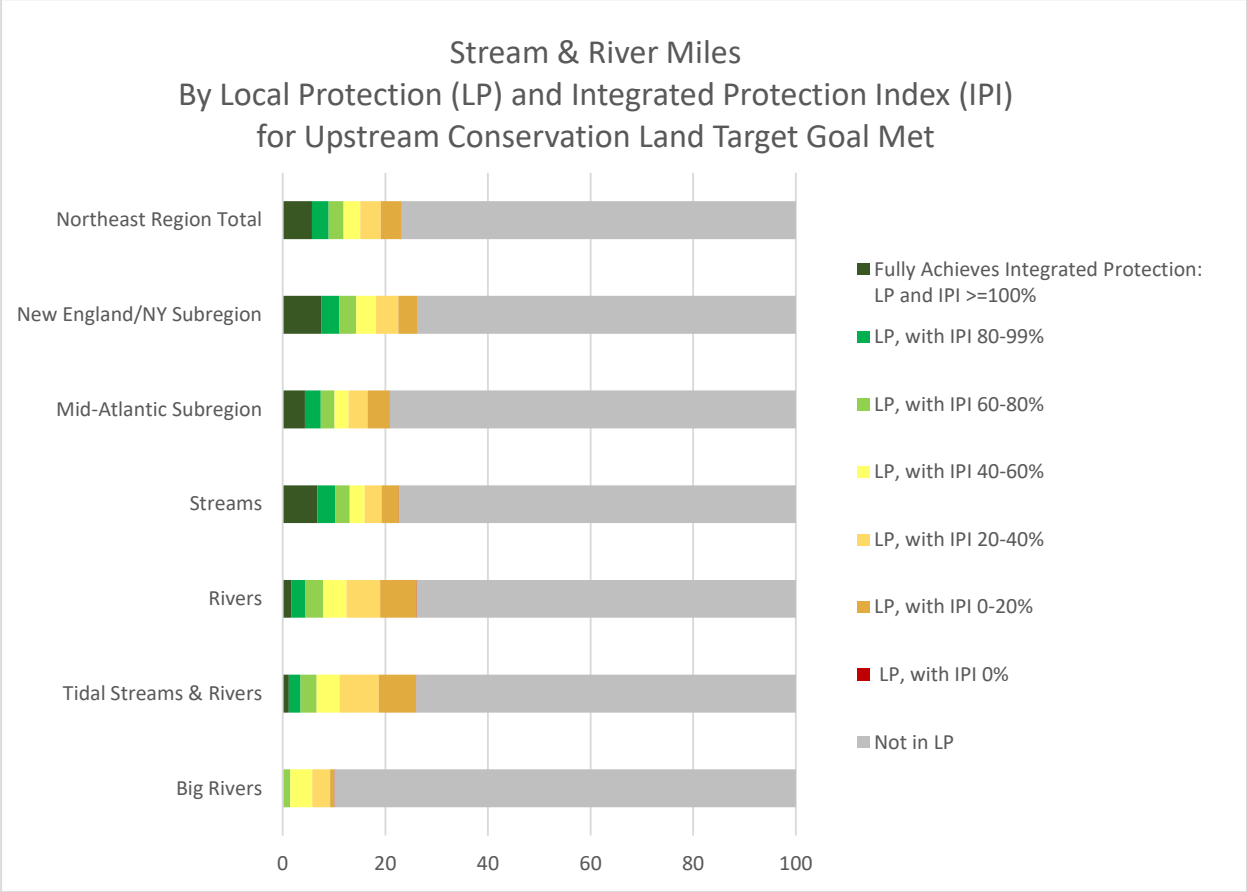
Table 6.6. Streams and Rivers by Integrated Protection Index Class.

Percent of all streams and rivers	Total Miles	Not in Local Protection	Locally Protected (LP): In GAP 1-3 land	FULLY ACHIEVING INTEGRATED PROTECTION: Locally Protected (LP) & Integrated Protection Index (IPI) Meets >= 100% of Upstream Conservation Land Target	LP, with IPI Upstream Target Met 80-99%	LP, with IPI Upstream Target Met 60 - 80%	LP, with IPI Upstream Target Met 40 - 60%	LP, with IPI Upstream Target Met 20 - 40%	LP, with IPI Upstream Target Met 1 - 20%	LP, with IPI Upstream Target Met 0%	% of Population that Increased to Local Protection 2012-2022	% of Population that Increased to Fully Achieving Integrated Protection 2012-2022
Big Rivers	2,638	90	10	0	0	1	4	3	1	0	0.3	0.0
Tidal Streams & Rivers	8,420	74	26	1	2	3	4	8	7	0	2.3	0.0
Rivers	29,319	74	26	2	3	3	5	7	7	0	2.3	0.1
Streams	161,619	77	23	7	3	3	3	3	3	0	1.9	0.5
Northeast Region Total	201,996	77	23	6	3	3	3	4	4	0	1.9	0.4
New England/NY Subregion	86,460	74	26	8	3	3	4	4	4	0	2.0	0.8
Mid-Atlantic Subregion	115,536	79	21	4	3	3	3	4	4	0	1.9	0.2

Miles of all streams and rivers:	Total Miles	Not in Local Protection	Locally Protected (LP): In GAP 1-3 land	FULLY ACHIEVING INTEGRATED PROTECTION: Locally Protected (LP) & Integrated Protection Index (IPI) Meets >= 100% of Upstream Conservation Land Target	LP, with IPI Upstream Target Met 80-99%	LP, with IPI Upstream Target Met 60 - 80%	LP, with IPI Upstream Target Met 40 - 60%	LP, with IPI Upstream Target Met 20 - 40%	LP, with IPI Upstream Target Met 1 - 20%	LP, with IPI Upstream Target Met 0%	Miles that Increased to Local Protection 2012-2022	Miles that Increased to Fully Achieving Integrated Protection 2012-2022
Big Rivers	2,638	2,372	266	0	2	37	113	92	22	0	8	0
Tidal Streams & Rivers	8,420	6,231	2,189	100	192	265	375	642	614	2	192	1
Rivers	29,319	21,657	7,662	474	831	992	1,339	1,935	2,090	1	681	35
Streams	161,619	125,032	36,587	10,959	5,517	4,616	4,707	5,391	5,371	26	3049	845
Northeast Region Total	201,996	155,292	46,704	11,533	6,542	5,910	6,533	8,060	8,097	30	3930	881
New England/NY Subregion	86,460	63,791	22,669	6,569	2,977	2,815	3,359	3,733	3,194	23	1727	660
Mid-Atlantic Subregion	115,536	91,501	24,035	4,965	3,565	3,095	3,174	4,327	4,902	7	2203	222

Local protection did not vary much between stream types (23%-26%) except big rivers which remained the type with both the lowest local protection (10%) the least integrated protection, and as we found previously the most conservation risk in their riparian zone.

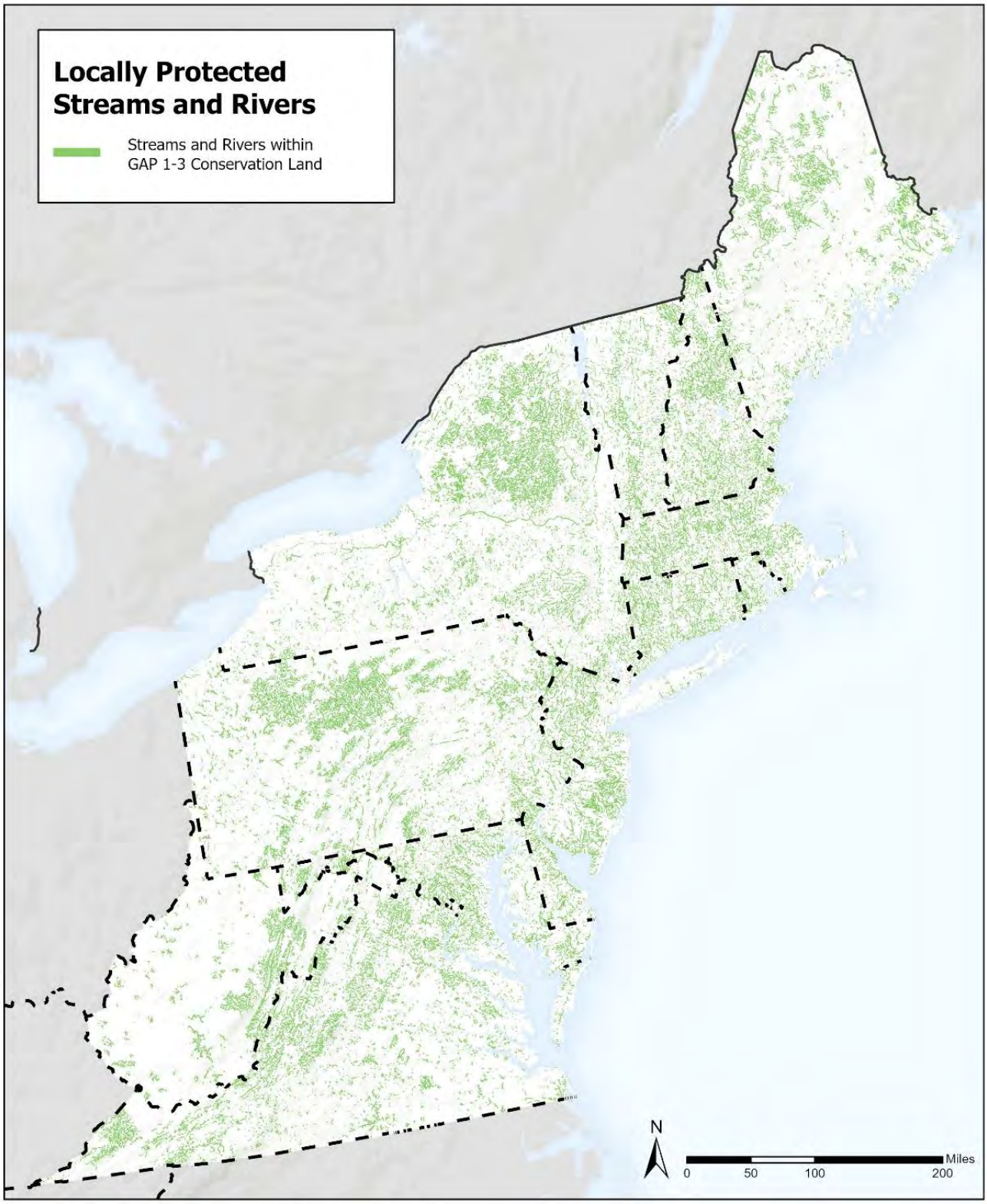
Figure 6.6. Streams and Rivers by Integrated Protection Class. The distribution of scores among the locally conserved streams (colors) and the proportion of streams that do not have local protection (grey)



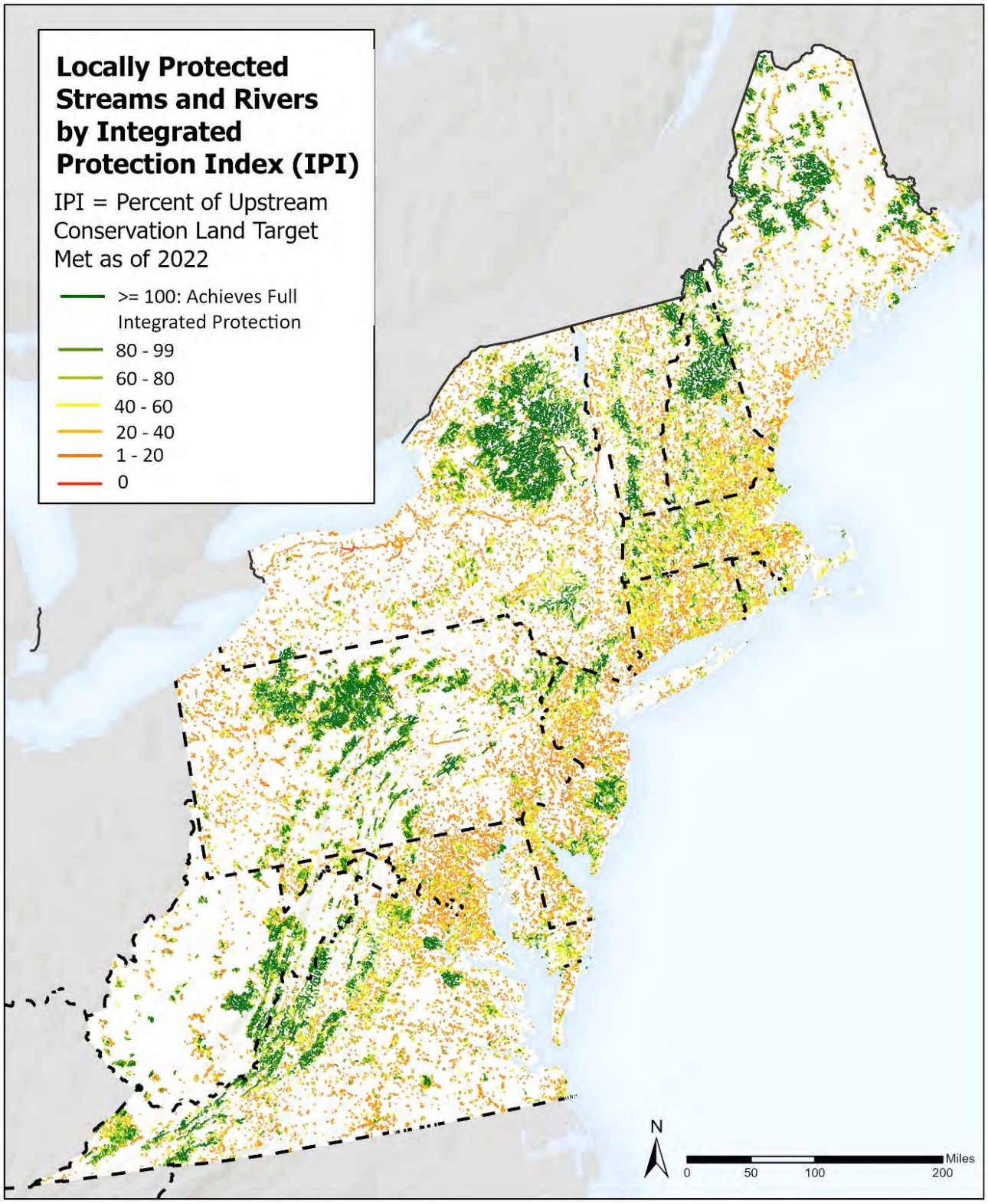
The following map series displays patterns in local protection (LP) and integrated protection (IPI).

- Map 6.5 Identifies the streams and rivers that occur on conservation land
- Map 6.6 Calculates the watershed level conservation for each reach and compares it to the target
- Map 6.7 Identifies streams and rivers systems that fully meet both local and watershed conservation goals.

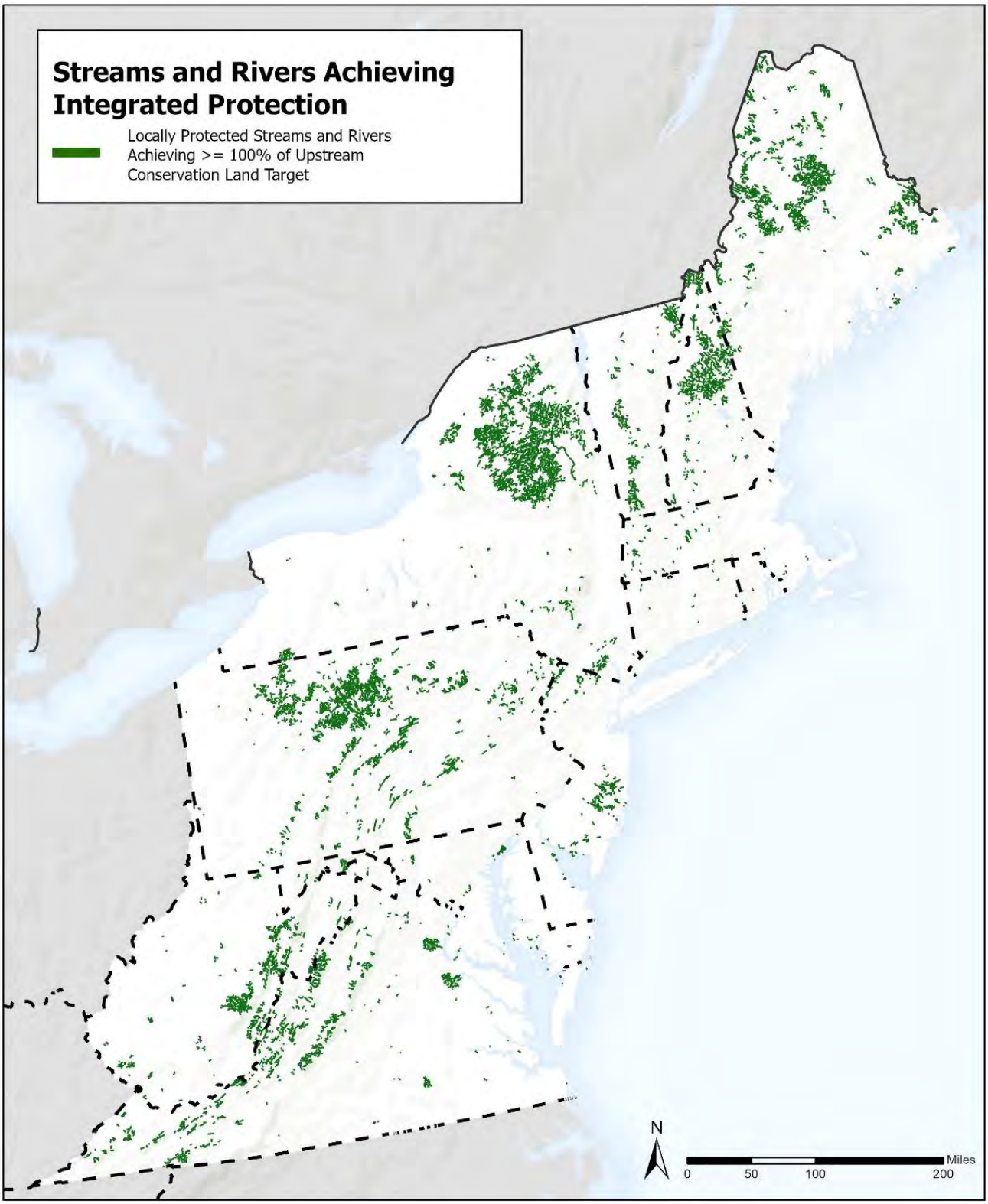
Map 6.4. Locally Conserved Streams and Rivers. This shows the portion of every stream and river that occurs on conservation land.



Map 6.5. Locally Conserved Streams and Rivers by their Integrated Protection Index. The IPI shows what percentage of the upstream watershed conservation targets are met for each locally conserved reach.



Map 6.6. Rivers Achieving Full Integrated Protection. These streams and rivers are both locally protected and meet their upstream watershed integrated protection conservation targets.



Water Quality Protection

Clean Water Act Protection: Outstanding National Resource Waters

The Clean Water Act regulations section 40 CFR 131.12(a)(3) reads: "Where high quality waters constitute an outstanding National resource, such as waters of National and State parks and wildlife refuges and waters of exceptional recreational or ecological significance, that water quality shall be maintained and protected." According to the US Environmental Protection Agency's Water Quality Standards Handbook (US EPA 2012), Outstanding National Resource Waters (ONRWs) provide the highest level of protection under the Clean Water Acts antidegradation policy by prohibiting any new or increased discharge to ONRWs or their tributaries that would lower the water quality. This designation is determined by each state for high quality waters and those of exceptional ecological significance.

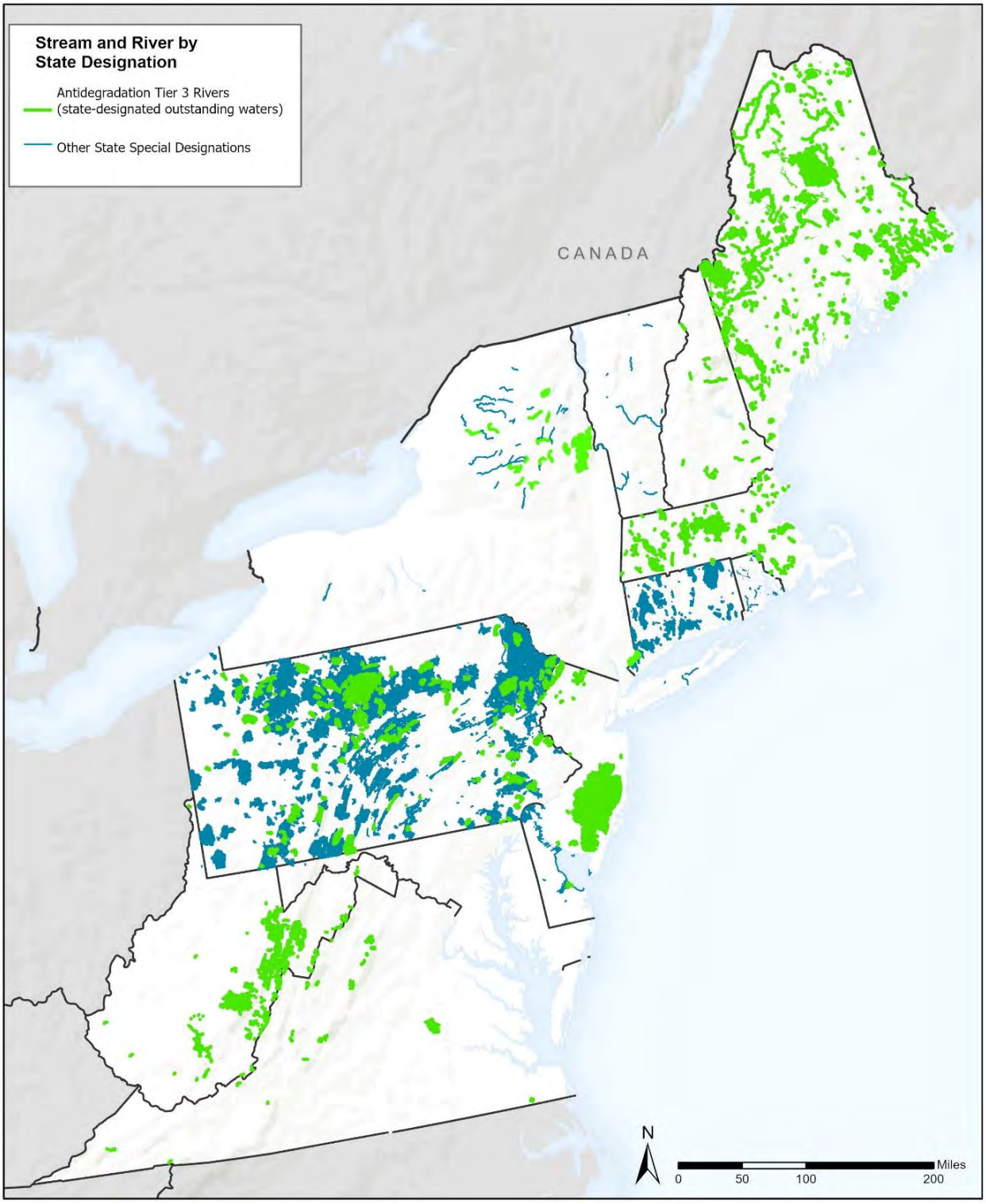
While all states are required to have antidegradation rules consistent with the federal regulations in their state water quality standards, they have discretion to designate ONRWs. Table 6.7 summarizes the status of these designations. ONRWs are often referred to as Tier 3 in state designations and in guidance from EPA. Some states also have designated high quality waters that cannot be degraded without review of practicable alternatives and preventing adverse social and/or economic impacts if the water quality change is not allowed. We have said that those other state designations provide a medium level of protection for water quality.

We compiled and reviewed the spatial distribution of these policies (Table 6.7, Map 6.7, Map 6.8) and found that eight states have designated Tier 3 ONRWs where antidegradation policies in the Clean Water Acts prohibit any new or increased discharge to the river or their tributaries that would lower the water quality. Two more states have designated other waters with a medium level of water quality protection.

Table 6.7. Tier 3 (high) and other state designations (medium) protections for water quality.

State	Tier 3 waters identified	Other state designation?	Other state designation type	Other state designation protection category	Other state designation: reason for protection
Connecticut	No	yes	AA water quality	medium	water quality
Delaware	yes	yes	ERES	medium	water quality
Maine	yes	no			
Maryland	no	yes	Tier II - high quality	low	water quality
Massachusetts	yes	no	Has category Special Resource Waters in its regs but no stream so	medium	water quality
New Hampshire	yes	no			
New Jersey	yes				
New York	yes	yes	State Scenic rivers	medium	water quality, habitat protection
Pennsylvania	yes	yes	HQ waters	medium	water quality
Rhode Island	no	yes	Rhode Island Special Protection Resource	medium	
Vermont	no	yes	Outstanding Resource Waters - have to maintain their qualities	medium	water quality
Virginia	yes	no			
West Virginia	yes	no			

Map 6.7. Tier 3 (high) and other State Designations (medium) Protections for Water Quality.



Connectivity Protection

Wild and Scenic River Designations

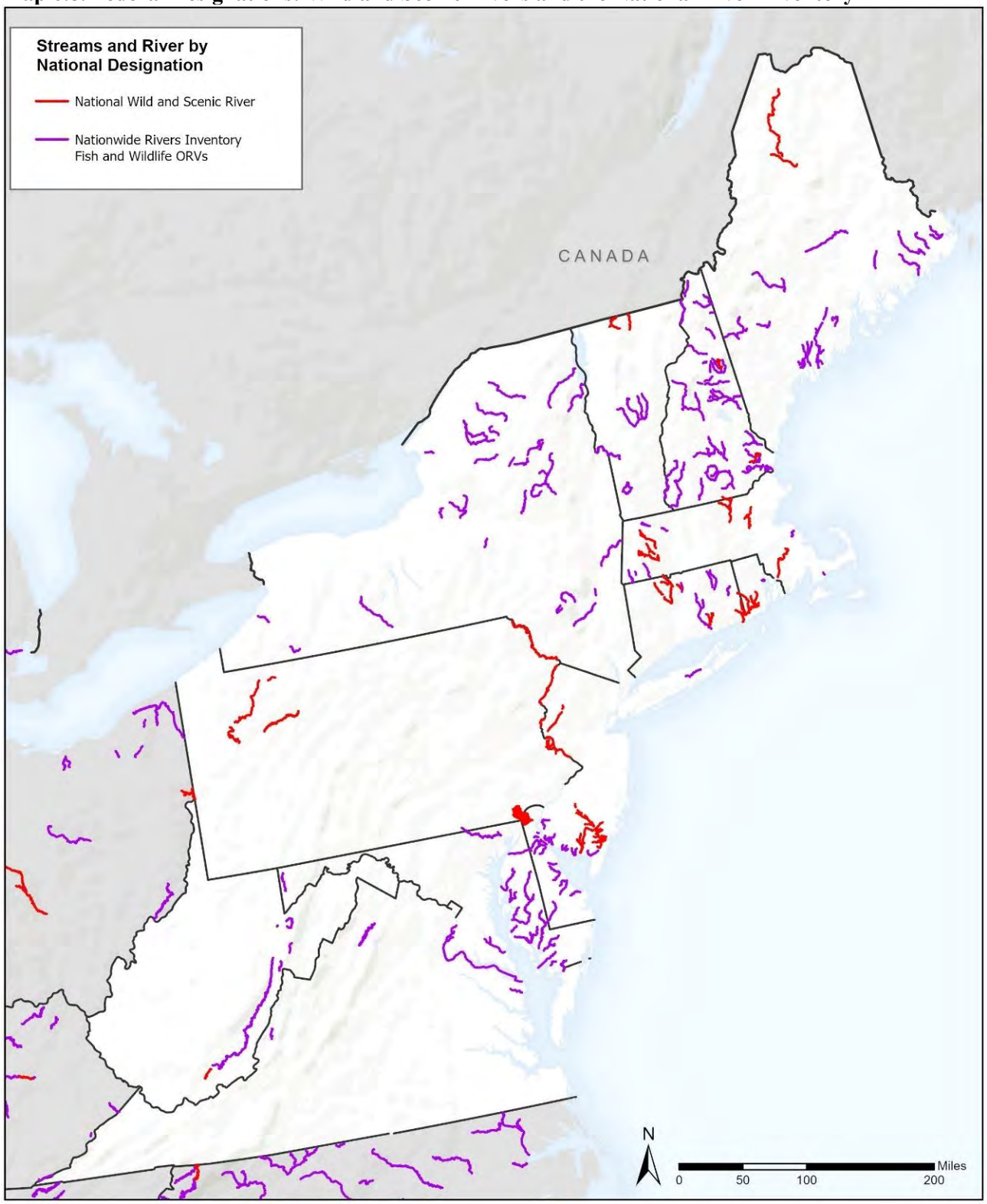
Wild and Scenic Rivers are federally protected for habitat, connectivity and water quality. Congress created the National Wild and Scenic Rivers System in 1968 (Public Law 90-542; 16 U.S.C. 1271 et seq.) with the purpose to preserve rivers with outstanding natural, cultural and recreational values. The Act calls for these rivers to "be preserved in free-flowing condition" and that their immediate environments (approximately .25 - .5 miles along the corridor) to be protected. While providing a high level of protection to the designated reach, the Act only governs federal actions, specifically, it prohibits federal support for actions such as the construction of dams or other instream activities that would harm the river's free-flowing condition, water quality, or outstanding resource values.

We compiled and mapped the Wild and Scenic Rivers for the Northeast and found that 1,528 miles of rivers have been designated in the region (Map 6.8, Table 6.8). Because these rivers must be designated by an act of Congress, less than one half of one percent of the rivers of the United States have this protection (NPS 2022). The National Park Service maintains a database of rivers called the National River Inventory that list rivers with Outstandingly Remarkable Values (ORV). These rivers could be eligible for Wild and Scenic designation but have not been acted on. Federal actions that could adversely impact these ORVs require consultation with the NPS before approval. In the Northeast 4,630 miles have been identified by the National River Inventory (Map 6.8).

Table 6.8. Northeast Wild and Scenic Rivers

Wild and Scenic River Name	STATE	Miles
Allagash Wild and Scenic River	Maine	105
Allegheny Wild and Scenic River	Pennsylvania	92
Bluestone Wild and Scenic River	West Virginia	14
Clarion Wild and Scenic River	Pennsylvania	53
Delaware (Lower) Wild and Scenic River	Pennsylvania	70
Delaware (Middle) Wild and Scenic River	Pennsylvania, New Jersey	41
Delaware (Upper) Wild and Scenic River	New York, Pennsylvania	74
Eightmile Wild and Scenic River	Connecticut	25
Great Egg Harbor Wild and Scenic River	New Jersey	148
Lamprey Wild and Scenic River	New Hampshire	23
Little Beaver Creek Wild and Scenic River	Ohio	32
Lower Farmington River and Salmon Brook Wild and Scenic River	Connecticut	63
Maurice Wild and Scenic River	New Jersey	48
Missisquoi & Trout Wild and Scenic River	Vermont	46
Musconetcong Wild and Scenic River	New Jersey	25
Nashua,Squannacook,and Nissitissit Wild and Scenic Rivers	Massachusetts and New Hampshire	52
Sudbury, Assabet and Concord Wild and Scenic River	Massachusetts	31
Taunton Wild and Scenic River	Massachusetts	38
West Branch Farmington Wild and Scenic River	Connecticut	14
Westfield Wild and Scenic River	Massachusetts	86
White Clay Wild and Scenic River	Delaware, Pennsylvania	210
Wildcate Wild and Scenic River	New Hampshire	16
Wood-Pawcatuck Watershed Wild and Scenic River	Rhode Island and Connecticut	221

Map 6.8. Federal Designations: Wild and Scenic Rivers and the National River Inventory



Flow Protection

A natural flow regime is integral to the health of every freshwater ecosystem (Poff et al. 1997). We reviewed state water policy documents to determine if water withdrawals require consideration of instream flow for ecological values.

We found that three states have specific instream flow statues and another eight have some instream flow requirements such as water permits. Two states have no flow laws, statues, or permits required for water allocation (Table 6.9).

Table 6.9. Levels of flow protection for northeast states.

No flow laws or statutes, no permit required for water allocation	Some instream flow requirements, i.e., water permits	Specific instream flow statutes
Rhode Island	Delaware	Connecticut (2019)
West Virginia	Maine	Massachusetts (2014)
	Maryland	*New Hampshire (2108)
	New Jersey	
	New York	
	Pennsylvania	
	Vermont	
	Virginia	

*Partially implemented – 2 of 19 eligible rivers have specific flows.

CONDITION: Fragmentation: Dam Distribution, Size, and Purpose

Isolation and habitat alterations due to damming has been linked to the significant decline over the last 50 year in many North American fish and mussels (Fausch et al. 2002, Pringel et al 2000, Busch et al. 1998). In addition to blocking the movement of stream biota, dams significantly alter the biological, chemical and physical properties of rivers. Water control and release can significantly alter the timing, velocity, and volume of flows. In the artificial slack-water reservoir habitat behind dams, changes in the water temperature, chemical composition, dissolved oxygen levels, and physical habitat creates conditions unsuitable to riverine biota. Reduction in sediment transport as particles are trapped behind dams also negatively affect downstream channel beds, floodplains, deltas, and coastal wetlands (Allan 1995).

The size, purpose, and operation of dams affects their relative impact on river systems. For example, larger dams can hold more water volume and are greater impediments to riverine species movement. Lower "run-of-the-river" dams are thought to have smaller adverse effects because they create a smaller slack water upstream area and release water at the rate it enters the reservoir. Impacts associated with major types of dams are summarized below (from Richter and Thomas 2007).

Dam Type and Impacts

Hydropower dams: Hydroelectric dams store water and replace a stream's natural hydrology with artificial flow regimes designed to meet daily and seasonal energy demands. Although many small hydropower dams are operated as "run-of-the-river" facilities, larger hydropower dams can store large volumes of water and are associated with significant negative riverine impacts. Episodes of power generation and high flow releases are generally followed by periods in which dam water releases may be largely or completely curtailed to allow the reservoir to refill. The rapid fluctuations in water levels associated with hydropower daily and seasonal operations can cause considerable ecological damage, as it can leave slow-moving aquatic animals such as mussels stranded when levels drop,or sweep them away when levels rise too quickly. In addition to the elimination of small floods and creating an altered flow regime, the hydroelectric generators turbine blades directly kill fish that get swept into them as they move downstream.

Water supply dams: Water supply dams are designed to capture a significant proportion of high flow events and release water according to water demands. These dams can completely rearrange seasonal patterns of water flow, such as when wet-season flows are stored for release in the dry season to support irrigated agriculture. In addition to reduced downstream flows during periods of storage, depending on diversion and release methods, river flows may become unnaturally high during periods when stored water is being released for downstream uses. These high flows can cause channel scouring, downcutting, erosion, and severe disruption to life cycles of aquatic and riparian organisms.

Flood control dams: Flood control dams collect and store water during floods and gradually release it at a later date at a lower discharge level. The general effect of a flood control dam is to reduce the peak flow, eliminate small floods and eliminate all but the most extreme large floods. This regulation of flow has severe negative impacts on floodplain and riparian ecosystems which require both small and large flood inundation for their maintenance. Riverine ecosystems are also negatively impacted by loss of peak flood flows and artificially long moderate-high flow pulses as flood control dams gradually discharge water stored during flood peaks.

Recreation dams: Recreational dams create impoundments within a river or maintain a constant high water level within an existing natural lake. These reservoirs serve as swimming, boating, and fishing places for people. In New England and New York, many of these dams are located on existing natural lakes, while in the mid-Atlantic most create new reservoirs which replace riverine habitat. Many recreation dams also have a secondary purpose such as flood control or water supply.

Northeast Dam Dataset:

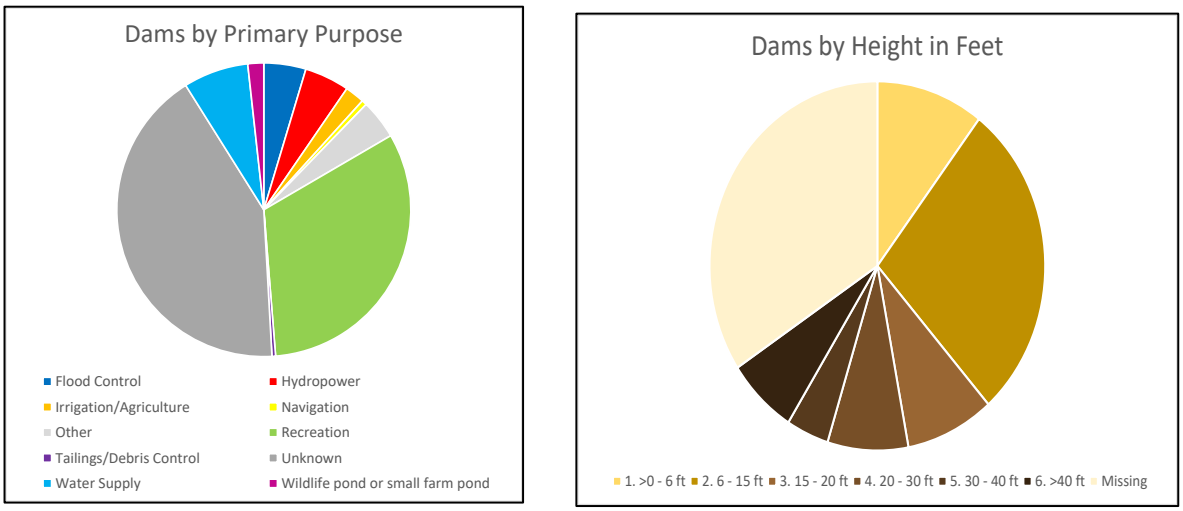
Dams in the region were assessed using an updated regional dam dataset revised in 2022 by The Nature Conservancy. This dataset was based on the Northeast Connectivity Project's compilation of dams (Martin and Levine 2017, Martin 2019) which compiled dam locations in the 14 northeast states from multiple state and federal data sources and spatially linked the dams to the correct flowline in the USGS NHD-Plus 1:100,000 hydrography dataset. The data development method is fully described in Martin and Levine (2017). Primary steps included 1) snapping each state's dams to the NHD flowlines, 2) coding the dams for prioritization for manual review, 3) manual error checking of the prioritized dams, 4) returning the data to the states for expert review, and 5) re-incorporated the state edits into the final spatially rectified dataset. The northeast dam data was revised during 2022 by TNC to integrate additions from updated inventories, deletions of incorrect data, and deletions of dam removals. This review included quality control for correct integration of the National Anthropogenic Barrier Database beta 2.0, integration of Southeast Aquatic Resource Partnership dam data in the Southern Appalachian ecoregion, deletions of dams noted in the American Rivers dam removal database through end of 2021, and review by TNC state scientists.

Dataset attributes were updated when possible, with a focus on key fields such as dam type, height, and passability. Not all dams are a complete barrier to aquatic organism passage and key effort was made to update and improve the coding of partially passable dams. Dams with fish passage structures, navigation locks, and very small dams that are submerged at high flows are all examples of dams that can allow for the movement of some species under certain conditions. Partially passable dams were specifically defined as those where there was presence of locks, presence of a fish passage facility, those with a height greater than zero feet and less than two feet, and those that were identified as partially passable by state and TNC program scientists. Information on locks came from the U.S. Army Corps' National Inventory of Dams (NID, https://nid.sec.usace.army.mil/). Dam height was taken from the source data attributes (NID or other source data). Data on fish passage facilities came primarily from the USGS Fishways Database compiled dataset 2022 version (https://doi.org/10.5066/P9IB1GWS) or local knowledge.

The TNC compiled 2022 regional dam dataset shows 29,583 dams for the northeast states, and the true number of dams is likely even higher given dams on the smallest headwater streams are still inconsistently inventoried and mapped from state to state. For consistency in analysis and to match the consistent hydrography used for this and previous reports (Anderson and Olivero, 2013, Martin and Levine 2017), only the 13,898 dams located on streams greater than 1 sq.mi. in drainage area were included in the following statistics and analysis.

Dam Type and Size: The dams in the northeast had a variety of primary purposes; the most common was recreation followed by water supply, hydroelectric, and flood control dams (Figure 6. 7, Map 6.9). The New England and New York subregion had more hydroelectric dams than the Mid-Atlantic which had a higher percentage of irrigation and tailings dams, along with flood control and water supply dams. Hydroelectric dams had the highest normal and maximum storage capacity and recreational dams the lowest, while flood control dams had a large difference between normal and maximum storage, with their maximum storage being almost three times their normal storage. The highest dams in the region were flood control dams, followed by water supply, hydroelectric, and recreational. There were 946 very high dams over 40 feet (Map 6.9) while 38% were less than 15ft tall.

Figure 6. 7. Northeast Dams by Primary Purpose and Height

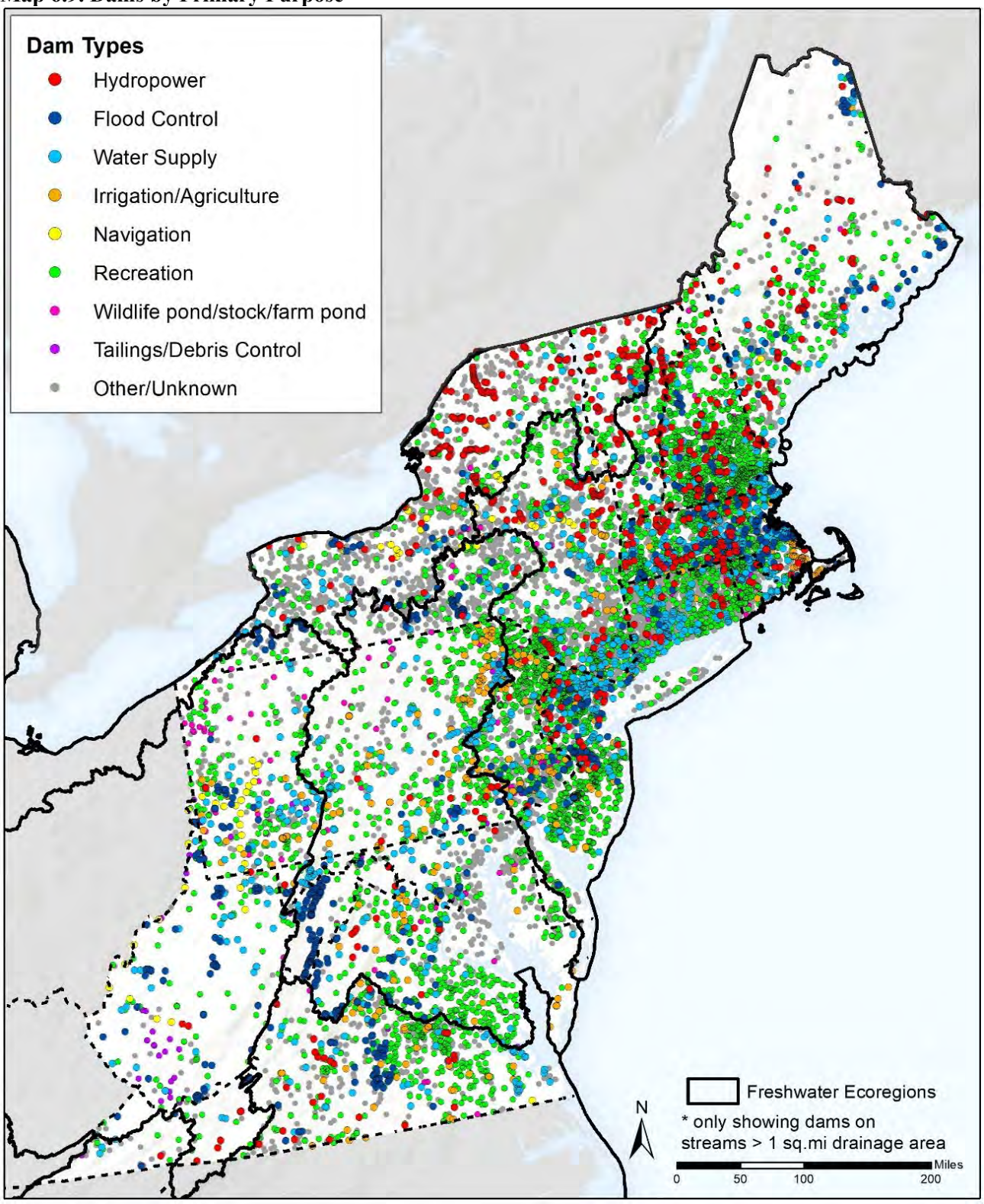


Across all dams, 80% were located on streams, 16% on rivers, 4% on tidal streams and rivers and 1% on big rivers (Table 6.10). Dam density across all streams and rivers was on average 7 dams for every 100 miles. The density of dams in New England and New York was 2.5 times the density in the Mid-Atlantic. Hydroelectric and navigation dams had their highest density on rivers while the density of recreational and irrigation dams was highest on the streams (Table 6.X.).

Table 6.10. Number, primary purpose, and density dams. This table summarizes the types and number of dams by stream type and region.

Number of Dams	Flood Control	Hydropower	Irrigation	Navigation	Other	Recreation	Tailings	Unknown	Water Supply	Wildlife or farm pond	Total
Big Rivers	2	28		33	1	4	1	8	3		80
Rivers	94	524	12	30	143	331	6	900	128	39	2207
Streams	531	130	272	11	425	3898	46	4716	828	197	11054
Tidal Streams & Rivers	16	4	13	4	32	233	2	209	37	7	557
NORTHEAST	643	686	297	78	601	4466	55	5833	996	243	13898
Mid-Atlantic	351	104	218	31	96	2040	51	1462	390	110	4853
New England/NY	292	582	79	47	505	2426	4	4371	606	133	9045
Density/100 miles	Flood Control	Hydropower	Irrigation	Navigation	Other	Recreation	Tailings	Unknown	Water Supply	Wildlife or farm pond	Total/100 miles
Big Rivers	0.1	1.1	0.0	1.3	0.0	0.2	0.0	0.3	0.1	0.0	3.0
Rivers	0.3	1.8	0.0	0.1	0.5	1.1	0.0	3.1	0.4	0.1	7.5
Streams	0.3	0.1	0.2	0.0	0.3	2.4	0.0	2.9	0.5	0.1	6.8
Tidal Streams & Rivers	0.2	0.0	0.2	0.0	0.4	2.8	0.0	2.5	0.4	0.1	6.6
NORTHEAST	0.3	0.3	0.1	0.0	0.3	2.2	0.0	2.9	0.5	0.1	6.9
Mid-Atlantic	0.3	0.1	0.2	0.0	0.1	1.8	0.0	1.3	0.3	0.1	4.2
New England/NY	0.3	0.7	0.1	0.1	0.6	2.8	0.0	5.1	0.7	0.2	10.5

Map 6.9. Dams by Primary Purpose



Passability:

We identified 693 dams (5%) as partially passable (Map 6.10, Table 6.11). These were found across a variety of primary purposes including 15% of hydropower dams, 7% of flood control dams, and over 70% of navigation dams in the region. The density of partially passable dams is highest on big rivers and tidal systems which may reflect efforts to provide passability for anadromous fish.

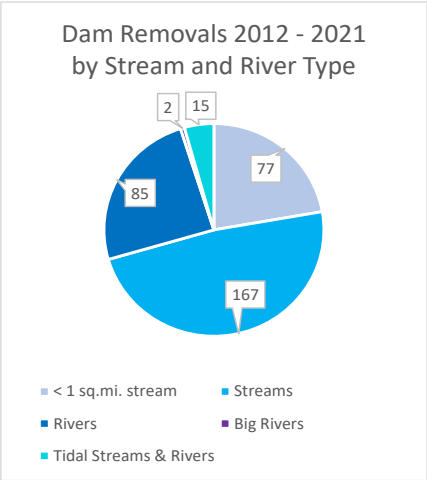
Table 6.11. Partially Passable Dams: Number, primary purpose, and density. Summarizes patterns of dams identified as partially passable on streams

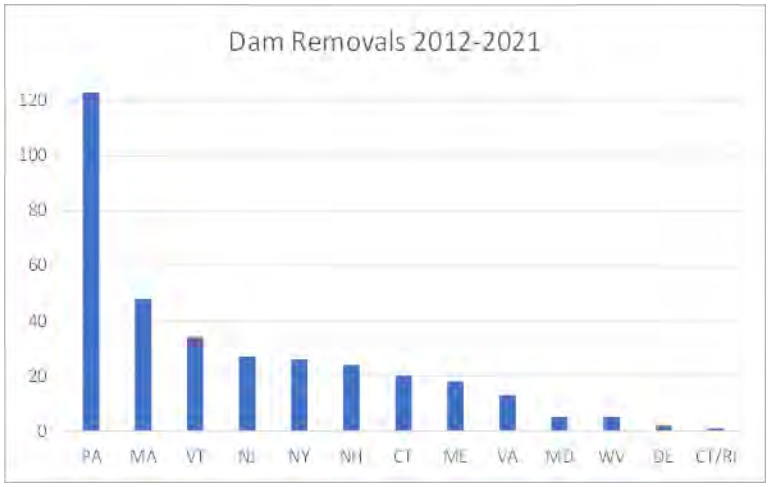
Partially Passable Dams	Flood Con	Hydropow	Irrigation	Navigatio	Other	Recreatio	Unknown	Water Sup	Wildlife o	Total	# Passable/100 miles
Big Rivers		11		33			3	1		48	1.8
Rivers	13	89		20	18	31	60	15	1	247	0.8
Streams	25	4	11	2	34	91	124	22	5	318	0.2
Tidal Streams and Rivers	4	2	2	2	9	32	21	7	1	80	1.0
Grand Total	42	106	13	57	61	154	208	45	7	693	0.3

Dam Removals:

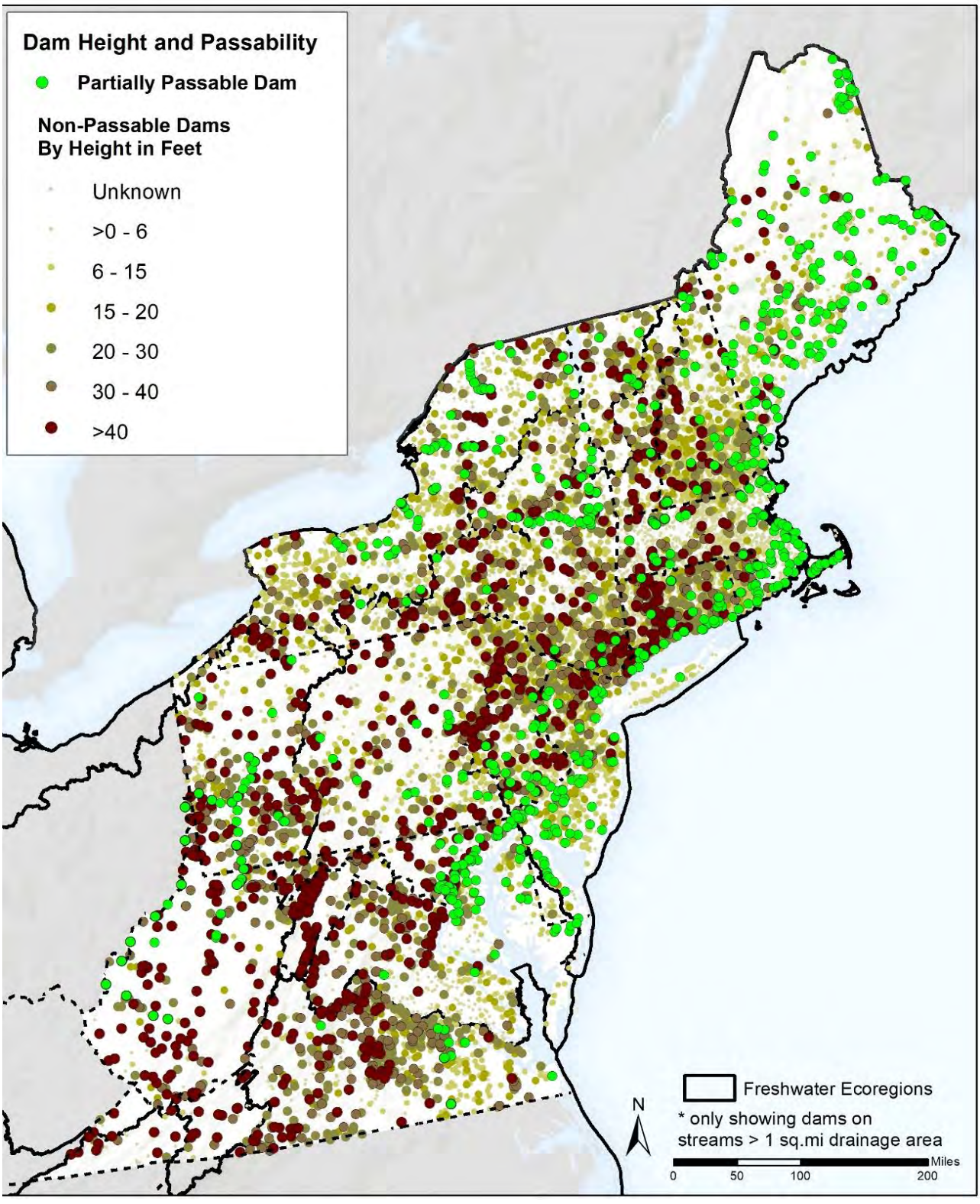
The American Rivers Dams Removal database (American Rivers, 2022) documented the removal over the last decade 2012-2021 of 346 dams in the region (Map 6.11). Pennsylvania, Massachusetts, and Vermont all removed more than 30 dams, with Pennsylvania removing 123 structures (Figure 6. 8). Of the dams removed, 70% were located on streams, 25% on rivers, 5% on tidal streams and rivers, and only 2 were located on big rivers; these were the Great Works and Veazie Dam on the Penobscot River.

Figure 6.8. Number of Dam Removals by State 2012-2021

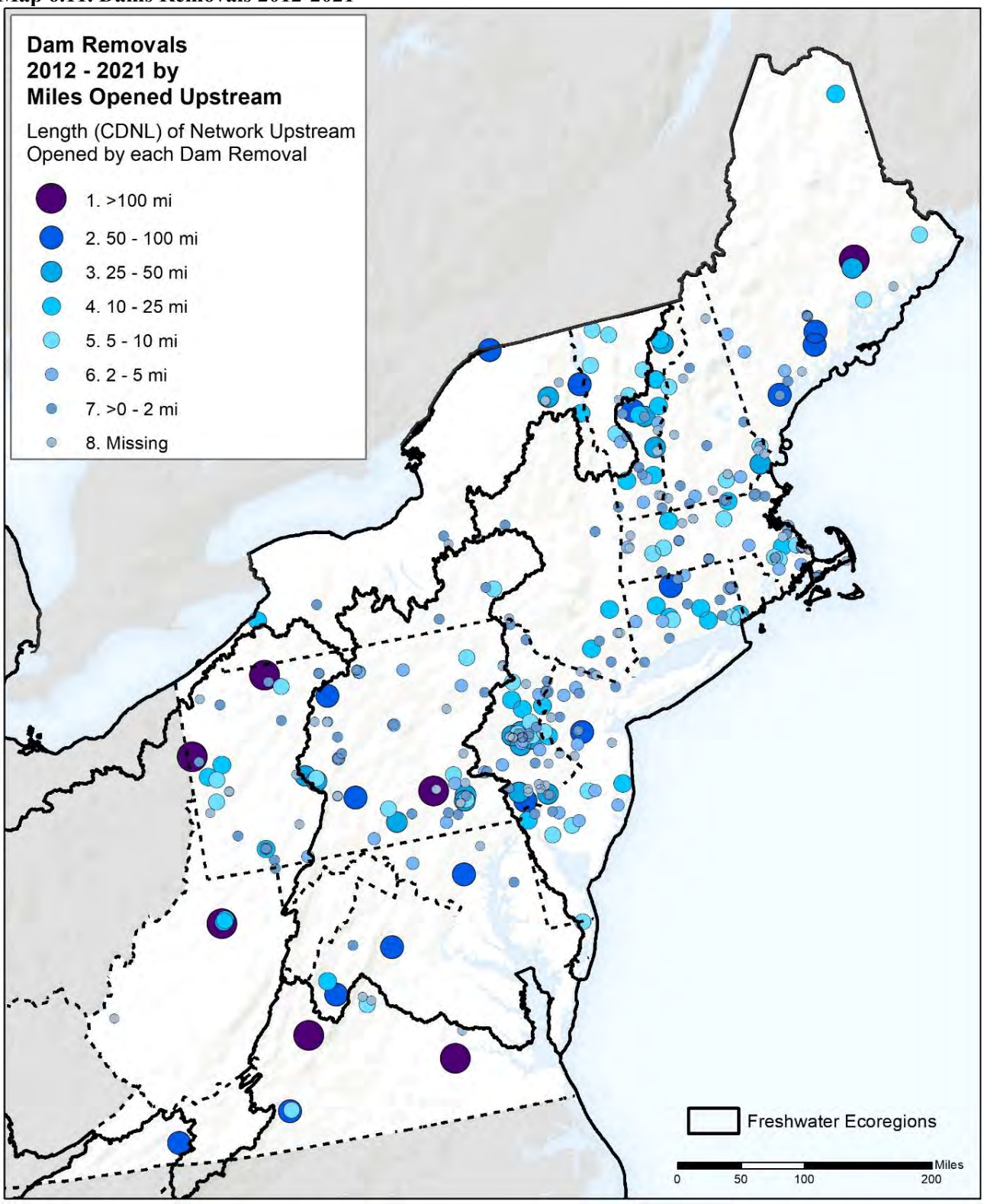




Map 6.10. Dams by Height and Passability



Map 6.11. Dams Removals 2012-2021



Miles Reopened

Removed dams that had been located on streams (> 1 sq.mi. drainage area) and rivers were run through a network analysis to quantify the length of upstream habitat opened by these dam removals. Summarizing the miles of the network directly upstream of these 269 dams, shows removing these dams collectively made accessible a minimum of 3,657 miles. Partially passable dams in the newly accessible upstream network expanded that accessibility to 4,965 miles (cumulative discounted network length, CDNL). (Map 6.11, Table 6.12). This is an incredible gain for freshwater species. The miles opened is also certainly even larger because 77 dams were located on very small headwater streams not included in our analysis.

Table 6.12. Dam Removal and Miles of Reopened Stream Network by State and Year. Summarizes patterns of dams identified as partially passable on streams (source data American Rivers)

State	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total # Dams	Sum of Upstream Network Length (CDNL) Opened
CT	2		1	5	4	2	1	2	1	2	20	178
CT/RI				1							1	19
DE			1					1			2	15
MA	9	3	5	2	5	9	5	1	6	3	48	145
MD	1		1	1			1	1			5	91
ME	2	4	1		1	2	3	3	1	1	18	1,227
NH	3	1	2	2	5	1	1	6	2	1	24	54
NJ	2	4	4	1	2	3	3	1	1	6	27	163
NY	5	1	1	3	4		3	1	6	2	26	243
PA	10	17	17	21	9	16	7	15	4	7	123	1,551
VA	1	1	1	2	2	3		1	2		13	741
VT	2	3	2	1	1	6	4	6	3	6	34	323
WV					3			2			5	216
Grand Total	37	34	36	39	36	42	28	40	26	28	346	4,966

The ten dams that opened up the most miles in the last decade are listed in Table 6.13 along with links to more information about these particular projects. Ninety percent of the top ten were located on large mainstem or big rivers and eighty percent were in the Mid-Atlantic. Only one dam on the list was on a small river, reinforcing the idea that dam removals on larger rivers usually open up more total miles given network connectivity.

.

Table 6.13. Top 10 Dam Removals in the last Decade by Miles Opened Upstream

	State	Dam Name	Year Removed	River	City	Upstream Network CDNL Length in Miles: Newly Accessible Habitat Made Available	Link to Project Information
1	ME	Great Works Dam	2012	Penobscot River	Old Town	940	https://www.nature.org/en-us/about-us/where-we-work/united-states/maine/stories-in-maine/restoring-the-penobscot-river/
2	PA	SunRay (Hospital) Dam	2014	Conewango Creek	North Warren	479	https://www.timesobserver.com/news/local-news/2014/08/conewango-creek-dam-removed/
3	VA	Jordan's Point Dam	2019	Maury	City of Lexington/Rockbridge County	324	https://roanoke.com/news/virginia/jordans-point-dam-removed-from-maury-river-in-lexington/article_64b04958-f16a-50d7-a4e0-533ad71fbd0f.html
4	WV	West Milford Dam	2016	West Fork River	West Milford, Harrison Cty	180	https://wvmetronews.com/2016/03/21/dam-removal-begins-along-west-fork-river-in-harrison-county/
5	PA	Orr's Bridge Dam	2019	Conodoguinet Creek	Hampden Township	155	https://cumberlink.com/news/local/hampden-township-residents-ask-for-authorities-to-re-engage-after-bureaucratic-conflict-over-rock-dam/article_bd2471b6-d7f0-5a16-afa4-8de1211c5345.html
6	VA	Harvell Dam	2014	Appomattox River	Petersburg	140	https://www.fws.gov/project/harvell-dam-removal-appomattox-river-virginia
7	PA	Pulaski Mills Dam	2015	Shenango River	Pulaski/Lawrence	108	https://www.ncnewsonline.com/news/dam-removed-from-shenango-river-in-pulaski/article_42a6cc1e-840c-11e5-9cfb-0f74e3bd7443.html
8	NY	Saw Mill Dam	2015	Bouquet River	Willsboro	82	https://www.adirondackdailyenterprise.com/opinion/columns/adirondack-gadabout-outdoors-by-joe-hackett/2015/10/dam-removal-clears-the-way-for-migrating-fish/
9	MD	Bloede Dam	2018	Patapsco River	Elkridge	77	https://dnr.maryland.gov/fisheries/pages/fishpassage/bloede.aspx
10	PA	Trough Creek Dam	2013	Great Trough Creek	Todd Twp, Huntingdon County	76	https://s3.amazonaws.com/american-rivers-website/wp-content/uploads/2019/07/03135819/DamsRemoved_1999-2018.pdf

Connected River Networks

Connectivity within a network of streams and rivers is essential to healthy freshwater ecosystems. Key benefits include:

- Permits freshwater species to move throughout the network to find the best feeding and spawning conditions
- Enables individuals to colonize, recolonize, and migrate to locations where conditions are more suitable for survival during times of stress
- Facilitates maintenance of metapopulations and accompanying genetic diversity
- Enables water flow, sediment and large woody debris transport, and nutrient regimes to function naturally

Key freshwater biota benefiting from more connected stream networks include the following:

Diadromous Fish: Diadromous fish exploit both freshwater and saltwater habitats. The distance traveled to do this varies widely among the species. Rainbow smelt live their entire life within about a mile of the coast while Atlantic salmon spawn in headwater streams hundreds of miles inland. Diadromous fish species of the northeast include alewife, American eel, American shad, Atlantic salmon, Atlantic sturgeon, Atlantic tomcod, blueback herring, hickory shad, rainbow smelt, searun trout, and shortnose sturgeon. Dams have caused the loss of access to 91% of stream habitat within the historic unrestricted range of diadromous fishes in New England from Maine to Connecticut (Busch et al. 1998).

Resident Freshwater Fish: Many resident freshwater fish species exhibit freshwater migrations and move significant distances within the stream network for feeding, seasonal refuge, and life stage segregation. This includes native eastern freshwater fish species such as: suckers, redhorses, brook trout, fallfish, yellow perch, bullhead, and pickerel (Nedeau 2006).

Freshwater Mussels: Many freshwater mussels are dependent upon migratory fishes as hosts for their parasitic larvae (Neves et al. 1997, Vaughn and Taylor 1999). Dams and the loss of migratory fish have been linked to mussel population declines and local mussel population extirpations (Watters 1996). By blocking fish movements, dams have eliminated host fish availability in reaches otherwise supportive to mussel populations.



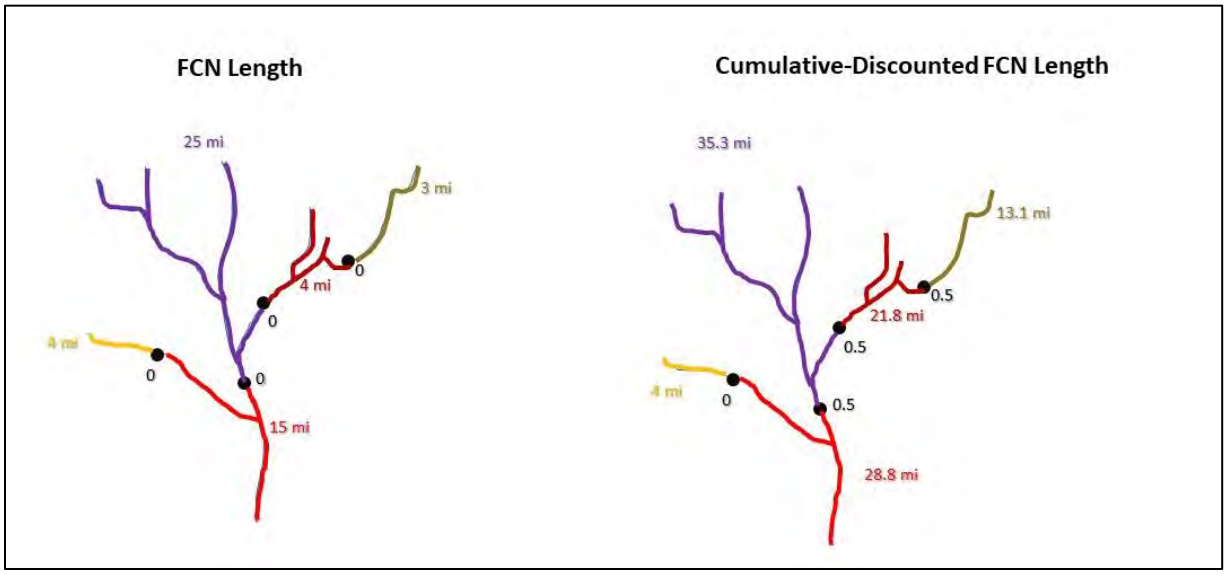
Northern Riffleshell from French Creek, PA (D. Crabtree, TNC PAFO

Plants and Floodplain Ecosystems: Floodplain ecosystems depend on stream connectivity for natural flows to remove vegetative encroachment on floodplains, maintain sediment and nutrient regimes, and disperse seeds. Dams disrupt the dispersal of emergent and submerged floras whose spores or seeds are waterborne (Jansson et al. 2000).

Climate Change: Climate change is creating shifts in the temperature, water quantity and flow regimes of our river systems creating suitable habitat in new places and reducing suitability of others. In response, freshwater species need to explore, disperse, and establish in new region of their network.

Methods: We defined a ***functionally connected network (FCN)*** as the set of connected stream-river-lake-pond segments bounded by dams and/or the topmost extent of headwater streams. Dams were from the updated 2022 dataset described earlier and streams were from the previously described NHDPlus V21. We included all reaches with at least 1 sq.mi. drainage area to focus our results on a consistent set of perennial connected features. Centerlines through connected lakes were also included in this analysis to preserve network connectivity through waterbodies. Road-stream crossings and waterfalls were not used as barriers due to uncertainty as to whether these features were barriers to movement for most species, at all times of the year, and because of inconsistencies in mapping these features across the region. The original FCN network length before dams was also generated using the coasts and the topmost extent of headwater streams as bounding features.

Figure 6. 9: Functionally Connected Network (FCN) Length. The network on the left is comprised of five FCN each bounded by a dam, upper headwaters or river mouth. Each network has a total length that reflects all the available tributaries and connected freshwater habitat. When a dam is removed, two FCN can fuse to create one longer FCN. If the network is bounded by passable dams the length gets a weighted and proportional increase (cumulative-discounted network length) that is less than if the dam was actually removed, but reflects the partial passability of the dams



Creating the FCNs and measuring their length revealed that the region's network of 214,000 miles of streams, rivers and interconnected lakes are fragmented into almost 30,000 FCNs with 20% of them less than 25 miles in length (Table 6.14A). Current network are longer networks in the Mid-Atlantic region and shorter throughout much of New England, New York, and New Jersey (Map 6.12), perhaps reflecting dam building activity in colonial and pre-industrial settlement time periods. Similar patterns are seen by freshwater ecoregion with FCNs in the Northeast US Atlantic Drainages and Great Lakes/St. Lawrence being mostly less than 25 miles long. The Appalachian Piedmont, Chesapeake Bay, and Ohio/Tennessee have a much larger percentage of FCNs (over 40%) over 500 miles long. The Ohio/Tennessee has the highest proportion of FCNs over 1000 miles long and is the only ecoregion with any networks over 5,000 miles long.

Table 6.14. Distribution of (A) Current Network Lengths and (B) Original Network Lengths

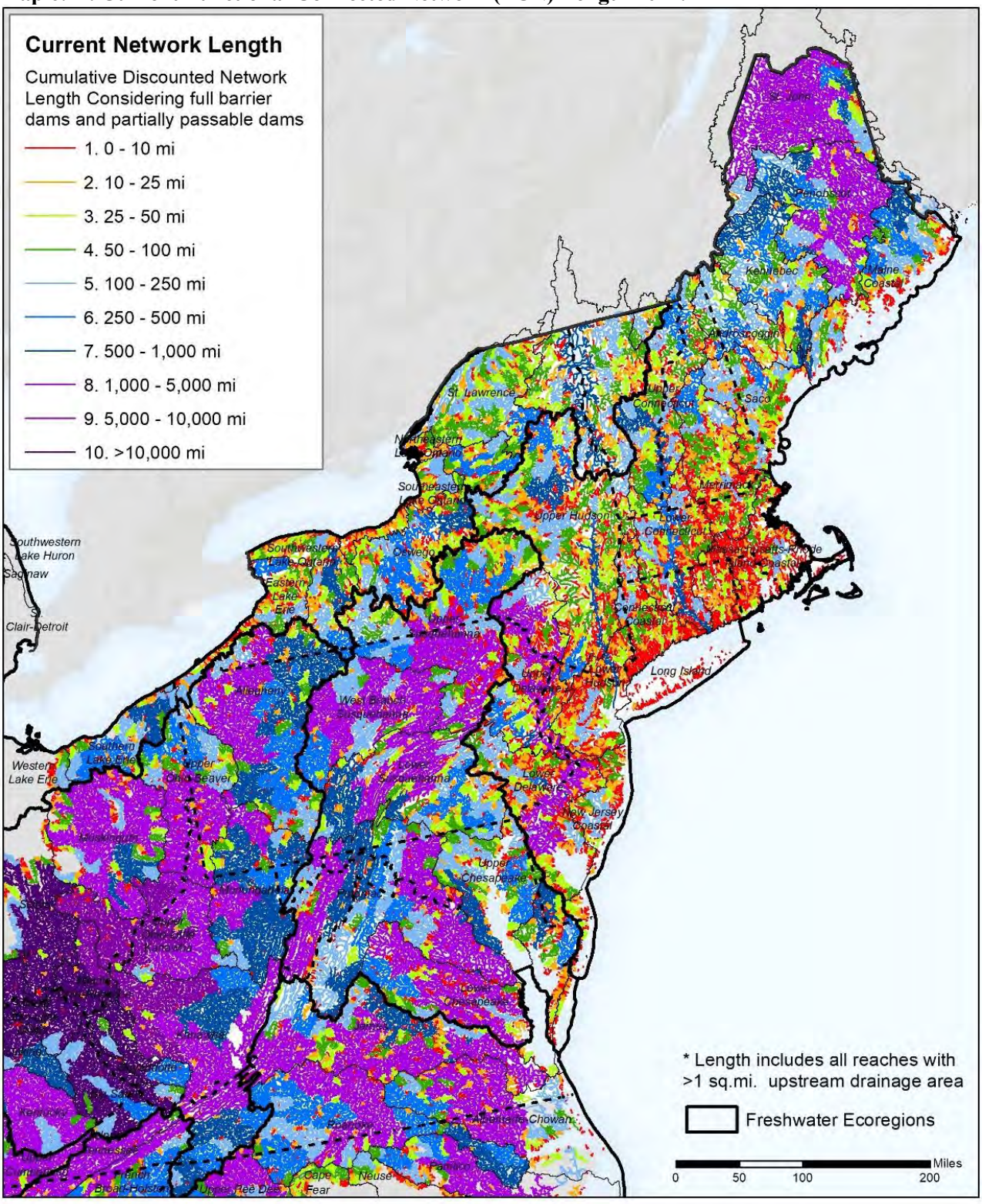
(A) Current Network Length Distribution

Current Network Length (CDNL)	Miles in Class										
	1. 0 - 10 mi	2. 10 - 25 mi	3. 25 - 50 mi	4. 50 - 100 mi	5. 100 - 250 mi	6. 250 - 500 mi	7. 500 - 1,000 mi	8. 1,000 - 5,000 mi	9. 5,000 - 10,000 mi	10. >10,000 mi	Total Miles
Appalachian Piedmont	1,182	1,052	719	889	2,129	3,125	894	8,851			18,840
Chesapeake Bay	3,728	2,818	3,174	3,639	8,387	6,371	4,906	17,300			50,323
Great Lakes/St. Lawrence	3,269	4,218	4,306	3,930	5,378	2,949	2,105				26,155
Northeast Atlantic Drainages	15,657	9,785	8,076	8,200	11,718	6,434	4,651	11,351			75,872
Ohio/Tennessee	1,319	1,056	1,082	1,555	2,880	5,132	8,990	14,288	3,873	2,587	42,764
NORTHEAST REGION	25,155	18,930	17,358	18,213	30,492	24,010	21,545	51,790	3,873	2,587	213,954
MID-ATLANTIC SUBREGION	9,224	6,857	5,905	6,004	14,024	13,958	14,451	41,931	3,873	2,587	118,815
NEW ENGLAND/NY SUBREGION	15,932	12,072	11,453	12,209	16,467	10,052	7,095	9,859			95,139
	Percent in Class										
	1. 0 - 10 mi	2. 10 - 25 mi	3. 25 - 50 mi	4. 50 - 100 mi	5. 100 - 250 mi	6. 250 - 500 mi	7. 500 - 1,000 mi	8. 1,000 - 5,000 mi	9. 5,000 - 10,000 mi	10. >10,000 mi	
Appalachian Piedmont	6.3	5.6	3.8	4.7	11.3	16.6	4.7	47.0	0.0	0.0	
Chesapeake Bay	7.4	5.6	6.3	7.2	16.7	12.7	9.7	34.4	0.0	0.0	
Great Lakes/St. Lawrence	12.5	16.1	16.5	15.0	20.6	11.3	8.0	0.0	0.0	0.0	
Northeast Atlantic Drainages	20.6	12.9	10.6	10.8	15.4	8.5	6.1	15.0	0.0	0.0	
Ohio/Tennessee	3.1	2.5	2.5	3.6	6.7	12.0	21.0	33.4	9.1	6.1	
NORTHEAST REGION	11.8	8.8	8.1	8.5	14.3	11.2	10.1	24.2	1.8	1.2	
MID-ATLANTIC SUBREGION	7.8	5.8	5.0	5.1	11.8	11.7	12.2	35.3	3.3	2.2	
NEW ENGLAND/NY SUBREGION	16.7	12.7	12.0	12.8	17.3	10.6	7.5	10.4	0.0	0.0	

(B) Original Network Length before Dams Distribution

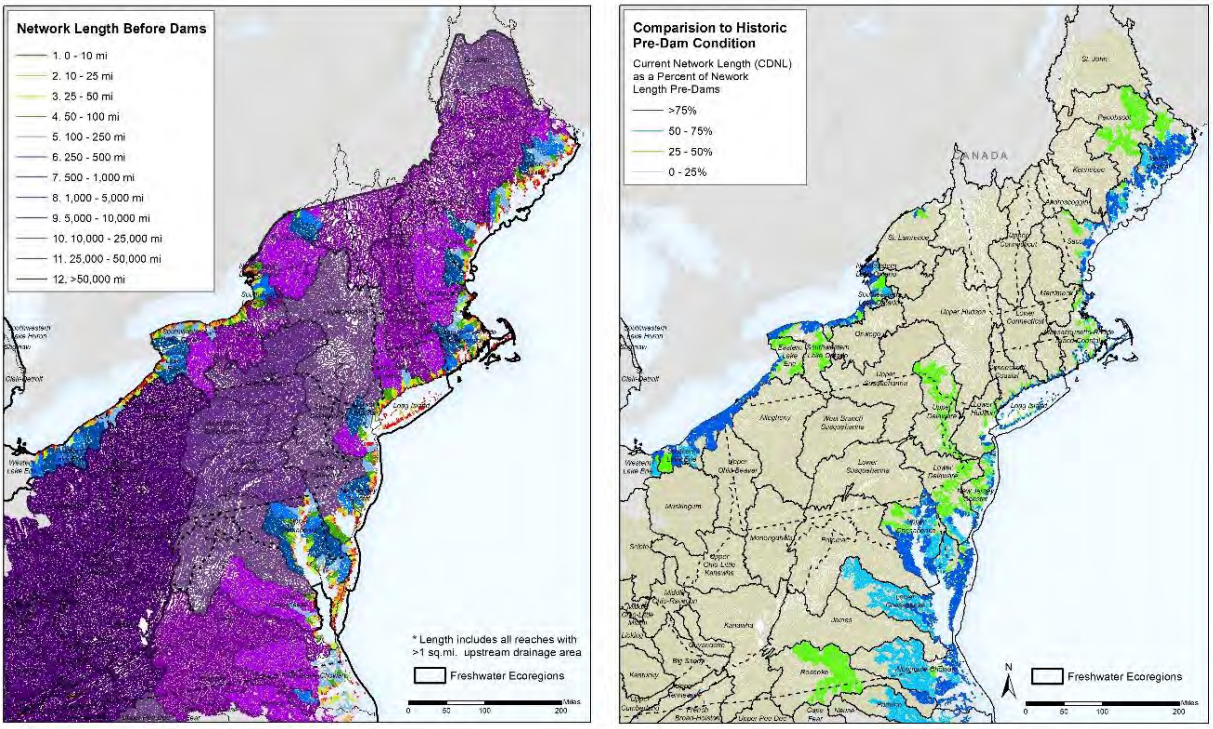
Original Network Length Before Dams	Miles in Class												
	1. 0 - 10 mi	2. 10 - 25 mi	3. 25 - 50 mi	4. 50 - 100 mi	5. 100 - 250 mi	6. 250 - 500 mi	7. 500 - 1,000 mi	8. 1,000 - 5,000 mi	9. 5,000 - 10,000 mi	10. 10,000 - 25,000 mi	11. 25,000 - 50,000 mi	12. >50,000 mi	Grand Total
Appalachian Piedmont	16	17		1	204			3,478	15,014	110			18,840
Chesapeake Bay	284	518	395	668	787	1,281	3,032	4,811	1	13,137	25,408		50,323
Great Lakes/St. Lawrence	485	588	723	626	1,164	1,592	2,136	8,336	10,505	0			26,155
Northeast Atlantic Drainages	1,573	1,223	1,214	2,009	2,177	2,247	4,212	10,914	23,055	27,249			75,872
Ohio/Tennessee	13	13										42,738	42,764
NORTHEAST REGION	2,370	2,359	2,331	3,304	4,332	5,119	9,380	27,540	48,576	40,495	25,408	42,738	213,954
MID-ATLANTIC SUBREGION	752	1,071	694	1,438	1,854	1,849	4,299	9,393	15,016	21,726	19,595	41,127	118,815
NEW ENGLAND/NY SUBREGION	1,618	1,288	1,638	1,866	2,478	3,270	5,082	18,146	33,560	18,769	5,813	1,611	95,139
	Percent in Class												
	1. 0 - 10 mi	2. 10 - 25 mi	3. 25 - 50 mi	4. 50 - 100 mi	5. 100 - 250 mi	6. 250 - 500 mi	7. 500 - 1,000 mi	8. 1,000 - 5,000 mi	9. 5,000 - 10,000 mi	10. 10,000 - 25,000 mi	11. 25,000 - 50,000 mi	12. >50,000 mi	
Appalachian Piedmont	0.1	0.1	0.0	0.0	1.1	0.0	0.0	18.5	79.7	0.6	0.0	0.0	
Chesapeake Bay	0.6	1.0	0.8	1.3	1.6	2.5	6.0	9.6	0.0	26.1	50.5	0.0	
Great Lakes/St. Lawrence	1.9	2.2	2.8	2.4	4.4	6.1	8.2	31.9	40.2	0.0	0.0	0.0	
Northeast Atlantic Drainages	2.1	1.6	1.6	2.6	2.9	3.0	5.6	14.4	30.4	35.9	0.0	0.0	
Ohio/Tennessee	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9	
NORTHEAST REGION	1.1	1.1	1.1	1.5	2.0	2.4	4.4	12.9	22.7	18.9	11.9	20.0	
MID-ATLANTIC SUBREGION	0.6	0.9	0.6	1.2	1.6	1.6	3.6	7.9	12.6	18.3	16.5	34.6	
NEW ENGLAND/NY SUBREGION	1.7	1.4	1.7	2.0	2.6	3.4	5.3	19.1	35.3	19.7	6.1	1.7	

Map 6.12. Current Functional Connected Network (FCN) Length 2022.



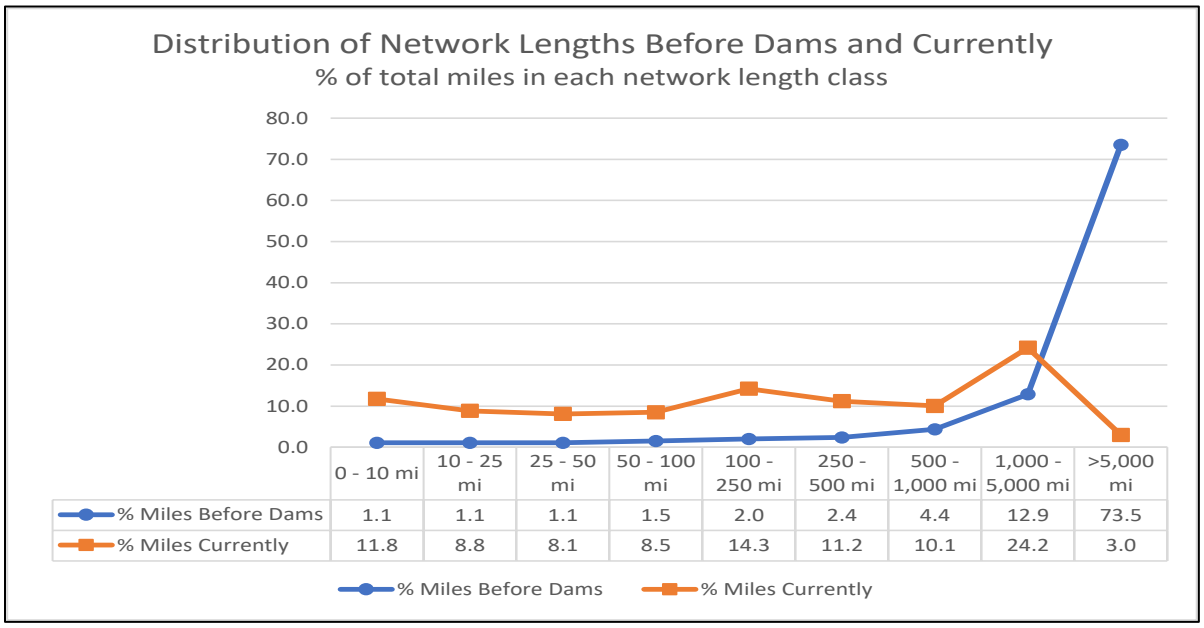
For context, we created a map and table showing the sizes of the original FCN if there were no dams creating barriers to movement (Table 6.14B, Map 6.13). Although relatively long networks can still be found in the Ohio/Tennessee Ecoregion, Chesapeake Bay Ecoregion, Appalachian Piedmont Ecoregion, the Delaware River mainstem, and northern Maine, in general networks have decreased dramatically in size from their historic pre-dam conditions. Even given the dam removals and improvements in partial passability in the last decade, graphing the distribution of stream and river miles historically and currently by network size class shows a striking loss of large networks and a corresponding shift in the distribution to much smaller networks (Figure 6. 10).

Map 6.13. Comparing Current Network Length to Network Length Before Dams



Historically, 74% of all stream miles in the region were embedded in very large networks over 5,000 miles long and today only 3% of miles are in these very large length networks. Conversely, only 2% of miles historically were in networks less than 25 miles long, while today 21% of miles are in these small networks (Table 6.13). In New England and New York, 91% of all miles were originally found in networks over 500 miles long and currently only 37% of the subregion's miles are found in these sized networks.

Figure 6. 10. Distribution of Current and Historic Network Lengths



	0 - 10 mi	10 - 25 mi	25 - 50 mi	50 - 100 mi	100 - 250 mi	250 - 500 mi	500 - 1,000 mi	1,000 - 5,000 mi	>5,000 mi
% Miles Before Dams	1.1	1.1	1.1	1.5	2.0	2.4	4.4	12.9	73.5
% Miles Currently	11.8	8.8	8.1	8.5	14.3	11.2	10.1	24.2	3.0

Compared to historic conditions, 86% of miles in the region are in networks less than a quarter of their pre-dam size (Table 6.15). This includes 100% of networks in the Ohio/Tennessee basin which were once part of the gigantic Mississippi drainage basin. Even ecoregions with naturally smaller networks, or networks connected to the ocean and great lakes coasts have a similar pattern with 77-84% of miles now in networks less than a quarter of their pre-dam size. Today only 4% of miles are found in networks that are at least 75% of their original size (Table 6.14). Many of these are clustered along the Atlantic or Great Lakes coasts in low gradient, naturally small river systems where often the physical settings was less ideal for dam building given the hydraulic head.

Overall, these results highlight the pervasive impact dams have had on reducing connectivity in Northeast freshwater systems. We have lost not only our largest networks, but there has been a massive reduction in the size of nearly all networks, and a large increase of very small networks. Again we applaud the last decades' 346 dam removals and the newly opened 4,965 miles of river and stream habitat.

Table 6.15. Current Network Length as a Percentage of its Original Pre-Dam Length

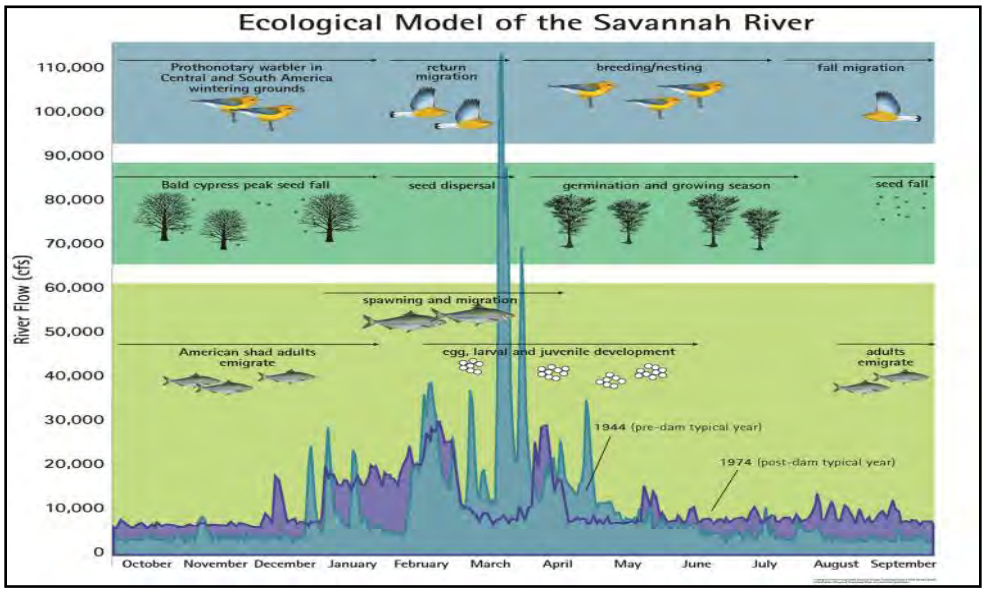
Current Network Length (CDNL) as a Percent of Original Length of Nework Before Dams	Miles in Class					Percentage in Class			
	1. >75%	2. 50 - 75%	3. 25 - 50%	4. 0 - 25%	Grand Total	1. >75%	2. 50 - 75%	3. 25 - 50%	4. 0 - 25%
Appalachian Piedmont	177	1,868	2,360	14,435	18,840	1	10	13	77
Chesapeake Bay	3,020	4,518	736	42,049	50,323	6	9	1	84
Great Lakes/St. Lawrence	1,860	502	2,089	21,703	26,155	7	2	8	83
Northeast Atlantic Drainages	3,593	1,780	8,055	62,443	75,872	5	2	11	82
Ohio/Tennessee	25			42,739	42,764	0	0	0	100
NORTHEAST REGION	8,674	8,668	13,241	183,370	213,954	4	4	6	86
MID-ATLANTIC SUBREGION	4,399	6,916	6,409	101,090	118,815	4	6	5	85
NEW ENGLAND/NY SUBREGION	4,275	1,752	6,832	82,280	95,139	4	2	7	86

Hydrologic Alteration

Flow is the essence of a stream or river, the "master variable" that structures the physical habitat both in the channel and on the adjacent floodplain (Poff et al. 1997). The natural timing, magnitude, and frequency of stream flow influences the evolutionary adaptations of river biota and controls many physical and chemical processes. High flows shape the stream channel, move sediment, and deposit silt-laden floodwaters on adjacent floodplains, replenishing the soil, and creating feeding and nursery grounds for fish. Low flows define the smallest habitat area available to stream biota during the year. Riparian species have evolved to complete their life histories when water is available and are adapted to the natural flow fluctuations (Allan 1995, Figure 6. 11).

Lotic ecosystems have been highly impacted by the human manipulation and alteration of natural stream flows. Roughly 50% of rivers and streams across the world are hydrologically altered from their natural state, including 80% of streams and rivers in the conterminous US (McManamay et al, 2022). Alterations in the northeast are often due to dams which alter the storage and release of water. Their hydrological impacts may be described based on their designated purposes. Hydropower dams hold and release water in response to or following the demand for energy. Water supply dams are characterized by extended low flows as reservoirs capture upstream inflows. Large recreational reservoirs often function similarly, as they capture all upstream inflows until the reservoir is full, at which point outflows equal inflows. Flood control dam management results in increased flow stability and decreased high flow events. (Richter and Thomas 2007).

Figure 6. 11. Ecological functions and hydrograph before (blue) and after (purple) damming. Kelly Applegate, TNC GAFO used with permission.



Hydrologic flows are also altered by impervious surface runoff which increases flashiness, water withdrawals for agriculture leading to low flows in summer growing season, and municipal water withdrawals and returns which can both decrease and increase baseflows depending on the pattern of extraction and return (Eng et al. 2019). Several northeast rivers such as the Connecticut (Kennedy et al. 2018) and Delaware (DePhilip, M. and T. Moberg. 2013) have been studied to document the extent of their high flow alteration, identify causes, and possible remediation.

Until recently, it has been challenging to comprehensively map and model the extent of flow alterations across large geographies. In 2022, McManamay and colleagues published an innovative method to comprehensively map a Hydrologic Alteration Index (HAI) for the coterminous U.S. (McManamay et al. 2022). The HAI index reports the degree of separation between the current flow regime of streams and rivers and that of reference streams within the same hydrologic class. It used reference and non-reference gages, over 110 hydrologic metrics, multidimensional measures of hydrologic regime, a principal components analysis, and a Random Forest Models to predict flows at ungaged locations for all NHD Medium Resolution flowlines using natural and human landscape characteristics. The resultant HAI ranges from 0−1, with 0 being unaltered reference condition. Anthropogenic variables with highest relative importance in predicting flow alteration included dam related variables followed by urban land use, agriculture, a disturbance index, discharge points, and energy sector withdrawals (power plants) in that order.

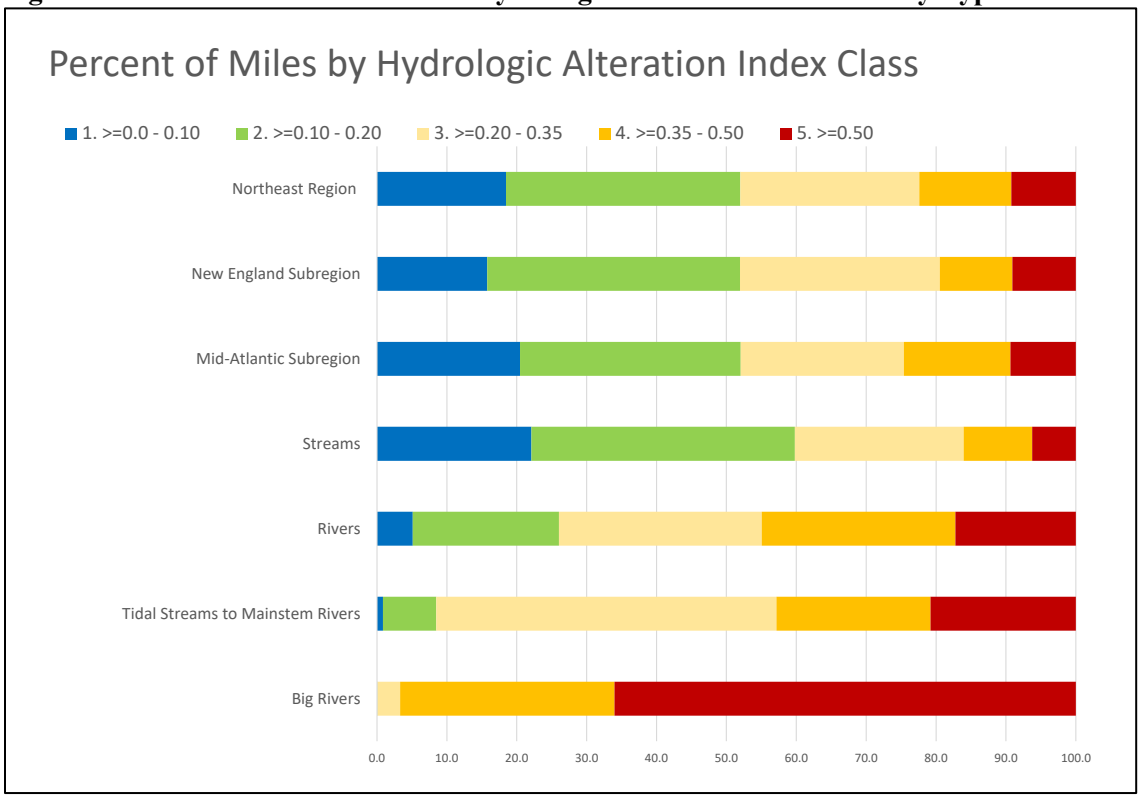
Mapping the HAI for the northeast (Map 6.14, Table 6.16, Figure 6. 12) reveals that the majority of stream and river miles are expected to show signs of hydrologic alteration, with larger rivers showing higher levels of alteration. Thresholds for reporting hydrologic alteration vary, with McManamay et al 2020 using a 20% threshold of change in hydrologic indices from reference conditions to report significant hydrologic alteration (HAI values >= 0.2) , while some other studies report finding impacts at a 10% alteration from reference condition threshold (Carlisle et al, 2011). Using the HAI index and the most conservative threshold of 10% alteration, 82% of stream and river miles in the northeast are altered, and 48% meet the higher threshold of being altered at 20% compared to reference conditions.

For Big Rivers the alteration threshold makes no difference as 100% are altered at either the 10% or 20% reference condition (Table 6.15). Tidal streams and rivers also show very high levels of alteration with 99 and 92% respectively altered using the 10% or 20% threshold. For rivers (small to mainstem), the HAI data shows 95% altered 10% from reference and 74% altered 20% from reference. Headwater and creek streams come in as least altered, with 78% showing some alteration at 10% and only 40% showing alteration 20% or more from reference condition. Applying only the most severely altered class (>50% HIA), 66% of Big River miles fall in this class, 21% of tidal streams and rivers, 17% rivers, and 6% of streams. Across all types 9% of stream and river miles fall in the most severely impacted class.

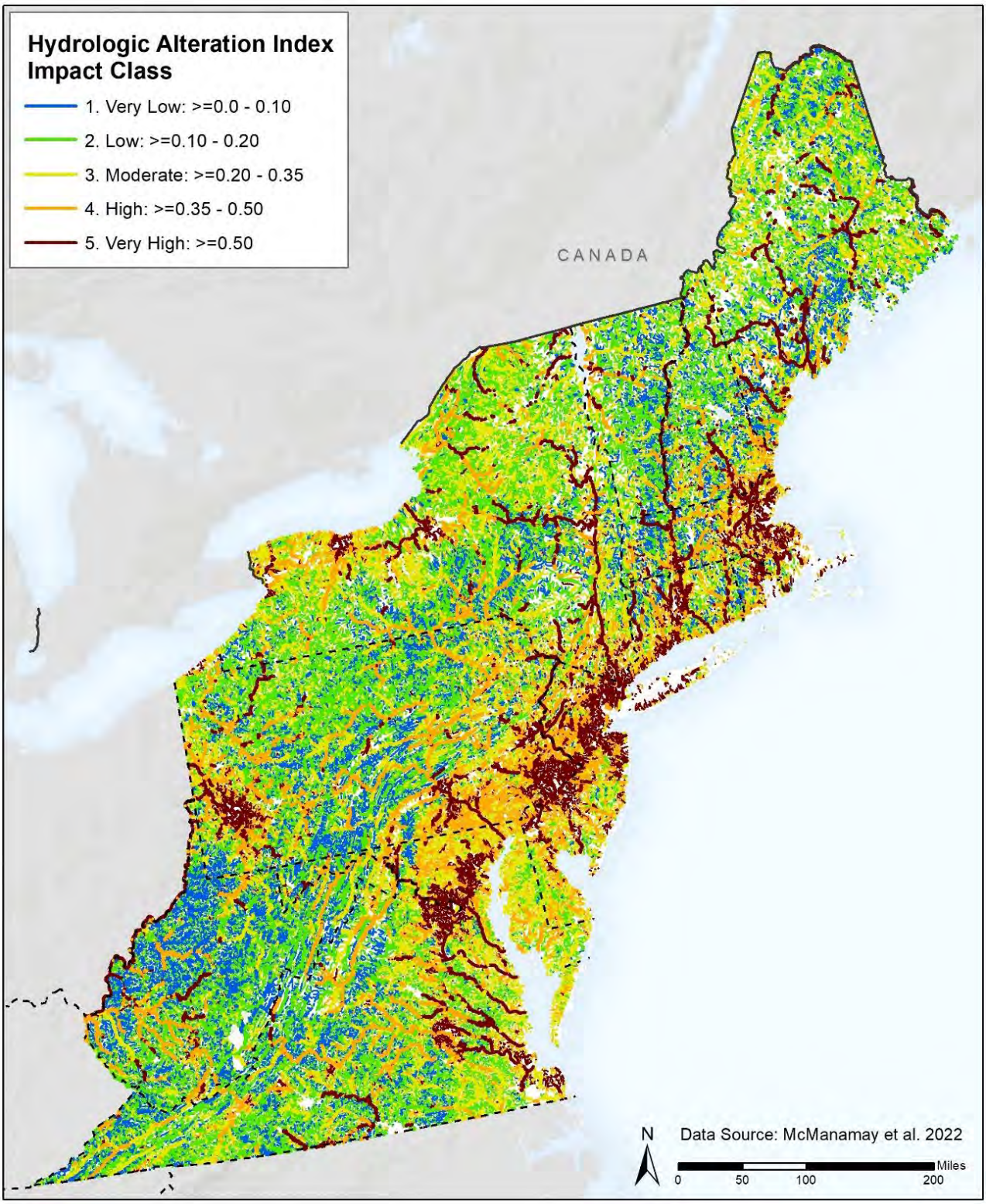
Table 6.16. Percent of miles in each hydrologic alteration index class by stream and river type

	% HAI Class 1. >=0.0 - 0.10	% HAI Class 2. >=0.10 - 0.20	% HAI Class 3. >=0.20 - 0.35	% HAI Class 4. >=0.35 - 0.50	% HAI Class 5. >=0.50
Streams	22	38	24	10	6
Rivers	5	21	29	28	17
Tidal Streams & Rivers	1	8	49	22	21
Big Rivers	0	0	3	31	66
New England-NY Region	16	36	29	10	9
Mid-Atlantic Region	20	32	23	15	9
Northeast Region	18	34	26	13	9

Figure 6. 12. Percent of Miles in each Hydrologic Alteration Index class by Type and Subregion.



Map 6.14. Index of Hydrologic Alteration Impacts (HAI. McManamay et al. 2022)



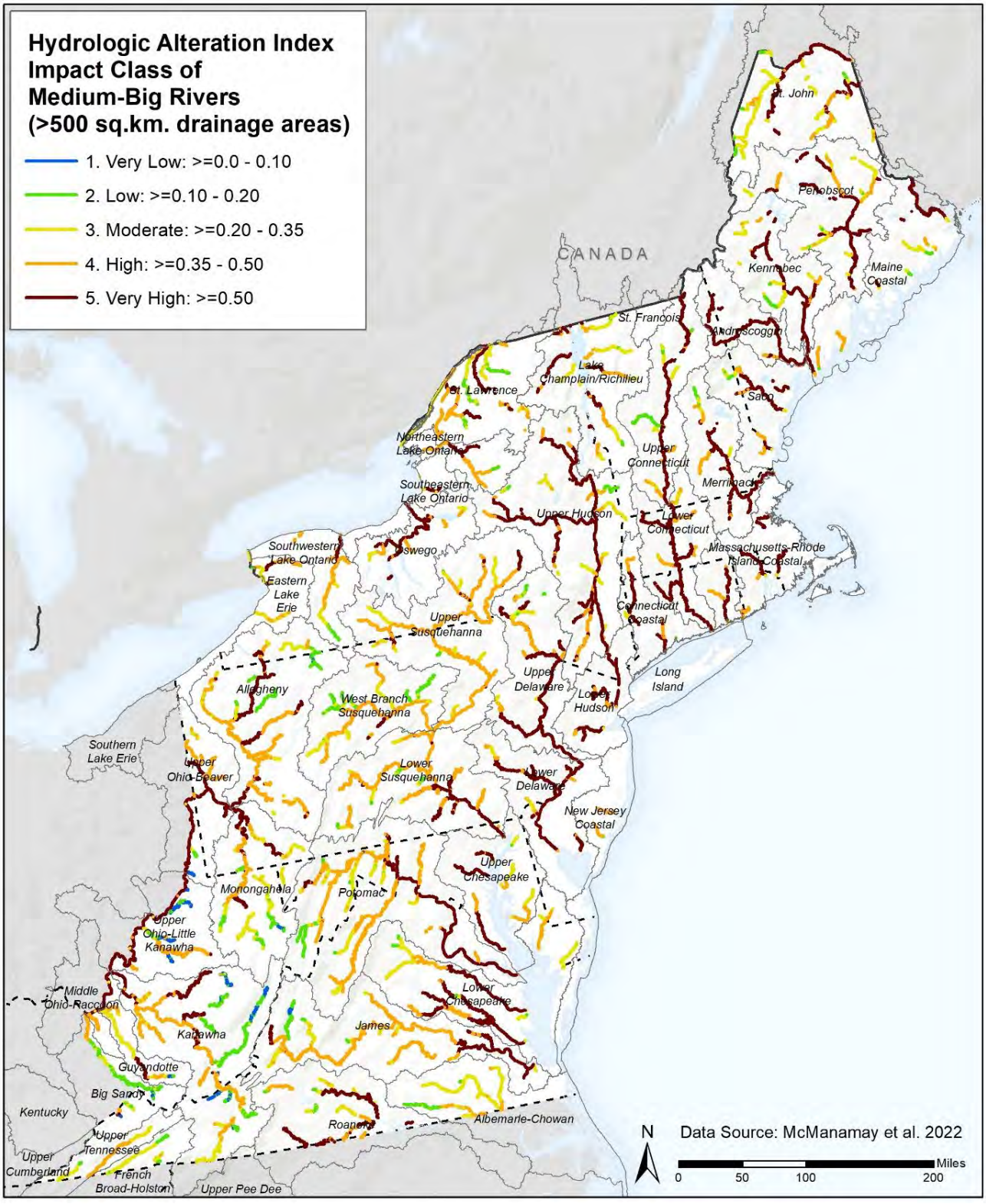
Considering only our familiar Medium-Big rivers with over 500 sq.km. drainage area (Map 6.15) almost every lower mainstems river entering the Atlantic Ocean scores as severely altered as does the Ohio River mainstem. Medium-big rivers of the Mid-Atlantic have fewer miles (28%) in the most impacted class (HAI 50%), while New England-NY has a higher percentage (48%) in the most impacted class.

Summarizing the above rivers by name within HUC6 watersheds (See Appendix for full list) shows that only 28 out of 460 have over 75% of their total length in the relatively unaltered class (HAI <20%). This includes the following short list of most hydrologically intact larger rivers that are particularly rare and outstanding among larger rivers in our region (Table 6.17). Most of these are found in the Mid-Atlantic region, including many in the Teays-Old Ohio freshwater ecoregion and a few in the Appalachian Piedmont, Chesapeake Bay, and Tennessee ecoregions. The longest is the Greenbrier River in the Kanawa river basin with 136 miles of hydrologically intact river. Second is the Cow Pasture River in the James river basin. Only one river in the North Atlantic Freshwater Ecoregion met the 75% criteria – the White River of the Upper Connecticut. No rivers in the Great Lakes ecoregion met the 75% criteria.

Table 6.17. List of Most Hydrologically Intact Medium-Big Rivers by HUC6 Watershed. These named rivers (>500 sq.km upstream drainage area and at least 2 miles long) have more than 75% of their total length in the least altered class (HAI <0.2).

Freshwater Ecoregion	HUC6 Watershed	River Name	Total Miles	% in Least Impacted Top 2 Classes (<0.2 HAI)
Appalachian Piedmont	Albemarle-Chowan	Stony Creek	4	100
Appalachian Piedmont	James	Calfpasture River	3	100
Appalachian Piedmont	James	Cowpasture River	63	95
Chesapeake Bay	Lower Susquehanna	Dunning Creek	3	98
Chesapeake Bay	Lower Susquehanna	Tuscarora Creek	13	93
Chesapeake Bay	Potomac	North Fork South Branch Potomac River	20	99
Northeast US Atlantic Drainages	Upper Connecticut	White River	36	97
Teays - Old Ohio	Allegheny	Oswayo Creek	7	95
Teays - Old Ohio	Allegheny	Potato Creek	5	100
Teays - Old Ohio	Allegheny	Tionesta Creek	33	95
Teays - Old Ohio	Big Sandy	Dry Fork	11	99
Teays - Old Ohio	Kanawha	Big Reed Island Creek	16	97
Teays - Old Ohio	Kanawha	Greenbrier River	136	98
Teays - Old Ohio	Kanawha	Indian Creek	3	100
Teays - Old Ohio	Kanawha	Meadow River	31	95
Teays - Old Ohio	Kanawha	Walker Creek	24	99
Teays - Old Ohio	Kanawha	Wolf Creek	16	98
Teays - Old Ohio	Monongahela	Black Fork	4	100
Teays - Old Ohio	Monongahela	Dry Fork	14	100
Teays - Old Ohio	Monongahela	Dunkard Creek	15	86
Teays - Old Ohio	Monongahela	Shavers Fork	7	99
Teays - Old Ohio	Upper Ohio-Beaver	Fish Creek	14	100
Teays - Old Ohio	Upper Ohio-Little Kanawha	Fishing Creek	6	91
Teays - Old Ohio	Upper Ohio-Little Kanawha	Hughes River	14	100
Teays - Old Ohio	Upper Ohio-Little Kanawha	Middle Island Creek	50	100
Teays - Old Ohio	Upper Ohio-Little Kanawha	South Fork Hughes River	15	100
Teays - Old Ohio	Upper Ohio-Little Kanawha	West Fork Little Kanawha River	14	98
Tennessee	French Broad-Holston	South Fork Holston River	4	100

Map 6.15. Hydrologic Alteration Index Impacts for Medium-Big Rivers



Impervious Surfaces

Impervious surfaces are substrates, like asphalt or concrete, incapable of being penetrated by water. Impervious surfaces prevent the natural pattern of rainwater soaking into the ground and slowly seeping into streams. Instead, the rainwater accumulates and flows rapidly overland. This harms streams in important ways:

- **Water Quantity:** Storm drains deliver large volumes of water to streams much faster than would occur naturally, resulting in flooding and bank erosion. Flows peak more rapidly during storms, and peak flows are higher and more frequent. Lack of groundwater recharge during rain events leads to lower daily base flows.
- **Channel Habitat:** Stream channels become wider, less stable, and less complex. Stream inhabitants are stressed, displaced, or killed by fast moving water and the debris, sediment, and disturbed channel habitat it brings.
- **Water Quality:** Pollutants (gasoline, oil, fertilizers, etc.) accumulate on impervious surfaces and are washed into the streams.
- **Water Temperature:** During warm weather, rain that falls on impervious surfaces becomes superheated and can stress or kill stream inhabitants.

All indicators of stream quality relative to biotic condition, hydrologic integrity, and water quality, decline with increasing watershed imperviousness. Research suggests that aquatic systems become seriously impacted when watershed impervious cover exceeds 10% (CWP 2003) and show significant declines in many stream taxa at levels of impervious surface as low as 0.5 to 2% of the watershed. Serious 40-45% declines in regional steam biodiversity (invertebrates, fish, amphibians) have been found at watershed imperviousness greater than 3% (King and Baker 2010) based on the National Land Cover Impervious Dataset (NLCD 2001-2019).

To examine impervious surface impacts in the region, we used data available from the US EPA StreamCat database (https://www.epa.gov/national-aquatic-resource-surveys/streamcat-dataset) which provides the upstream watershed percent imperviousness for each NHD Plus reach based on the reprocessed and consistently calibrated NLCD impervious dataset (Hill et al. 2016, StreamCat 2022). We grouped all stream and river reaches into one of four impact reporting categories using thresholds published by King and Baker (2010) and used in our previous report (Anderson and Olivero Sheldon 2011).

- Class 1: Undisturbed-Very low impacts: 0 < 0.5% impervious.
- Class 2: Low impacts: >=0.5-2% impervious.
- Class 3: Moderately impacted: >=2-10% impervious.
- Class 4: Highly impacted: >=10% impervious.

Applying the categories to the northeast region revealed that 34% of total stream and river miles were undisturbed, 42% had low impacts, 18% were moderately impacted and 7% were highly impacted (Map 6.16, Figure 6. 13, Table 6.18). The percent of miles falling in the undisturbed class decreased with increasing stream size from a high of 38% in streams to a low of 6% for big rivers (Table 6.18). The percent of highly impacted miles was 23% for tidal streams, 6% for streams, 3% for rivers, and 0% for big rivers. The latter is likely due to the fact that big river watersheds were so huge that the effects of impervious surfaces in one area may be offset by the presence of natural cover in another. The highly impacted tidal streams and rivers makes sense because coastal areas tend to be densely populated with development in the small upstream drainages of these tidal systems.

Map 6.16. Streams and rivers by upstream impervious surfaces impact class (NLCD 2019)

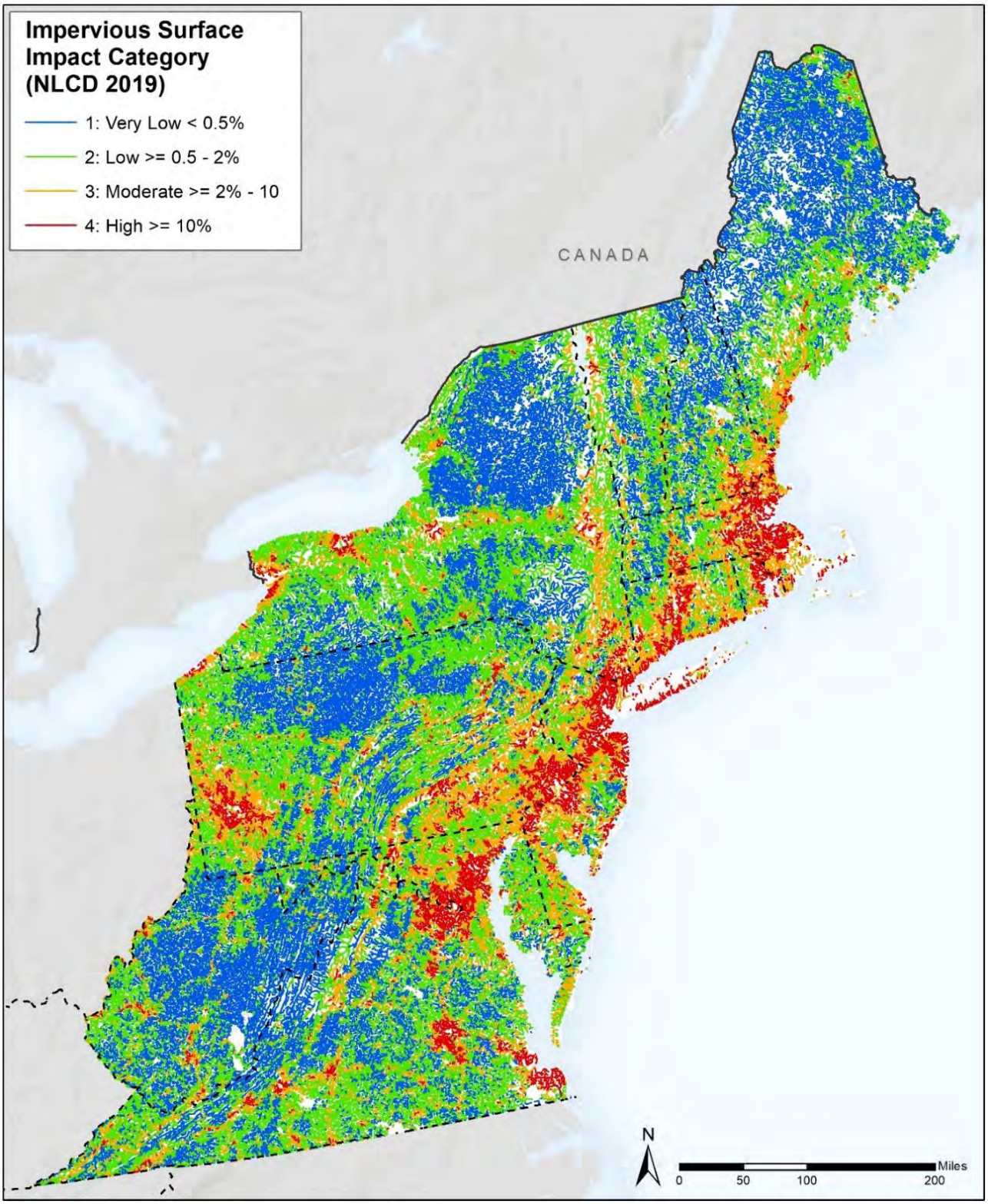


Figure 6. 13. Percent of Stream Miles by Upstream Impervious Surface Class. In this chart, each bar represents the total miles of the habitat type or subregion. Different colors represent the percent of stream miles in the impact class: 1) Undisturbed, 2) Low Impacts, 3) Moderately Impacted, 4) Highly Impacted.

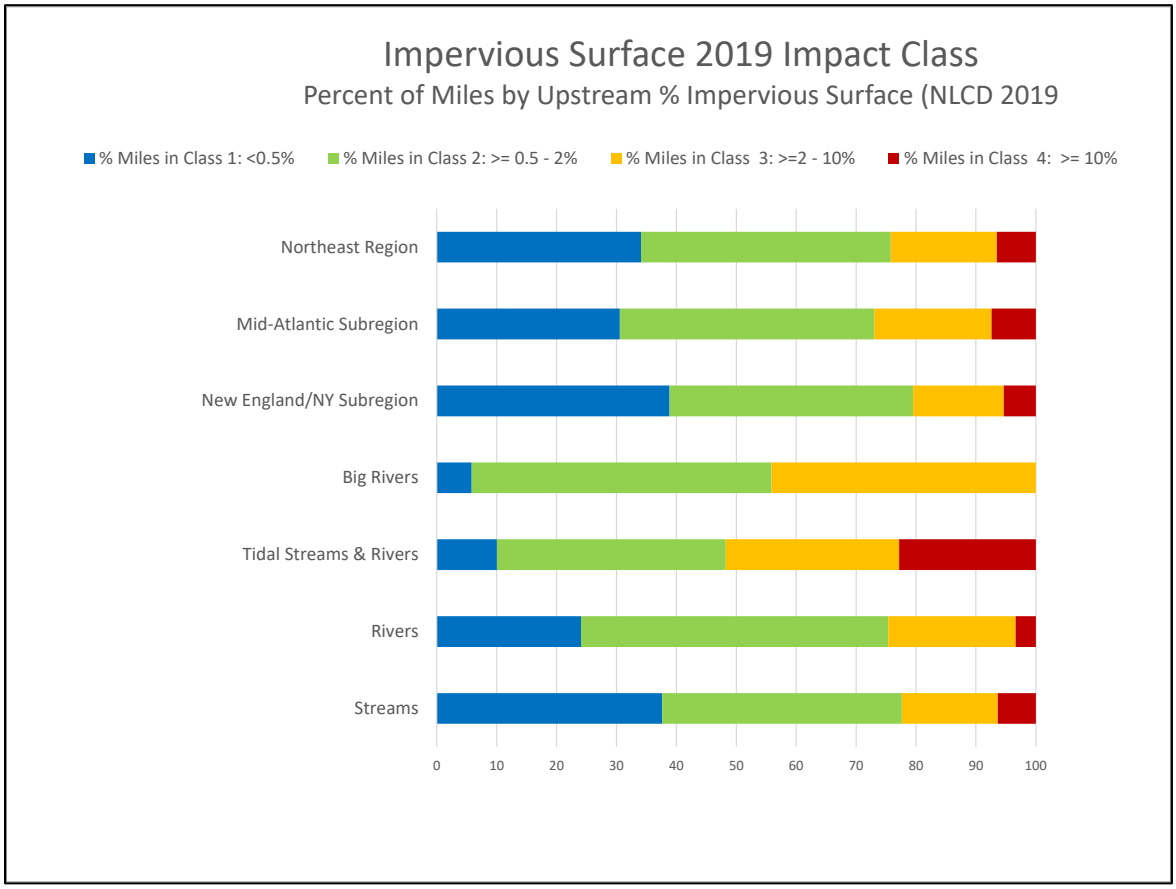


Table 6.18. Percent of Total Mile in each Impervious Surface Class. The classes are 1) Undisturbed, 2) Low Impacts, 3) Moderately Impacted, 4) Highly Impacted.

Upstream Percent Impervious Surfaces 2019 Impact Classes	% Miles in Class 1: <0.5%	% Miles in Class 2: >= 0.5 - 2%	% Miles in Class 3: >=2 - 10%	% Miles in Class 4: >= 10%
Streams	38	40	16	6
Rivers	24	51	21	3
Tidal Streams & Rivers	10	38	29	23
Big Rivers	6	50	44	0
New England/NY Subregion	39	41	15	5
Mid-Atlantic Subregion	31	42	20	7
Northeast Region	34	42	18	7

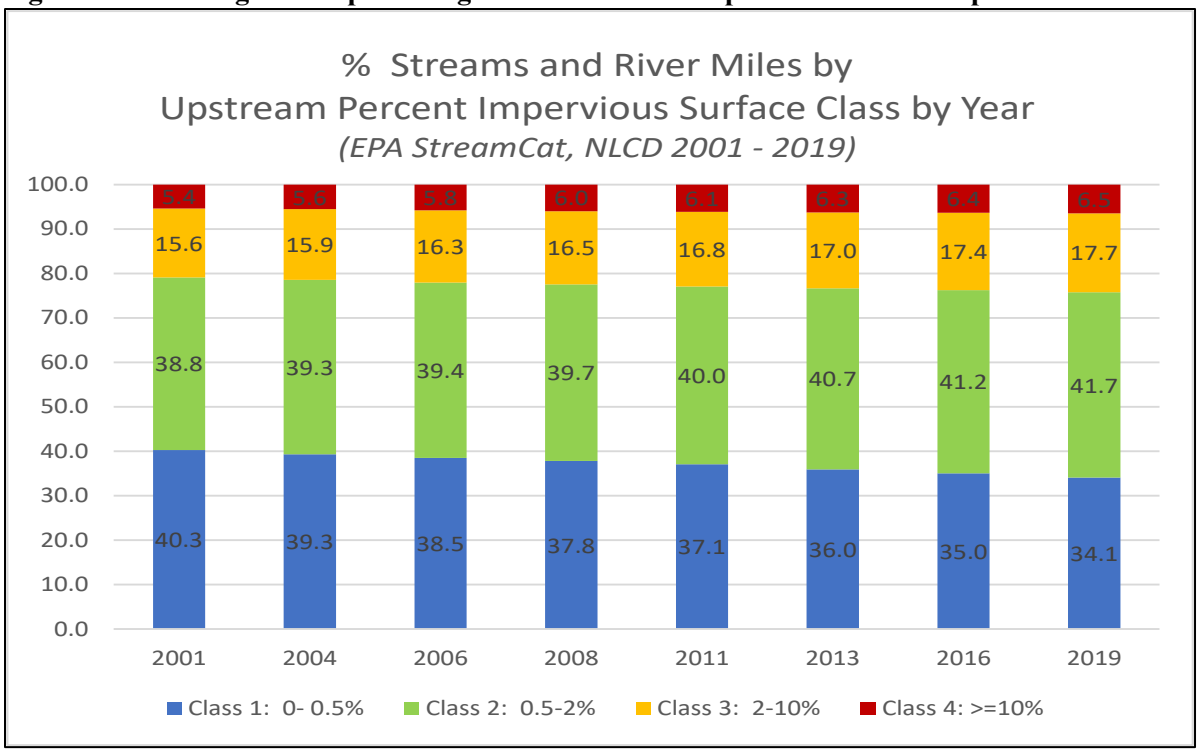
New-England and New York had 39% of its miles in the undisturbed class and the Mid-Atlantic had 31%, however the Mid-Atlantic also had the most impacted miles (7%, Figure 6. 13). Impacts largely track development with CT, DC, RI, NJ and MA all having more than 20% of their miles in the high impact class, while more rural states like ME, WV, NH, VT had over 25% in the undisturbed class.

Recent Trends in Impervious Surfaces.

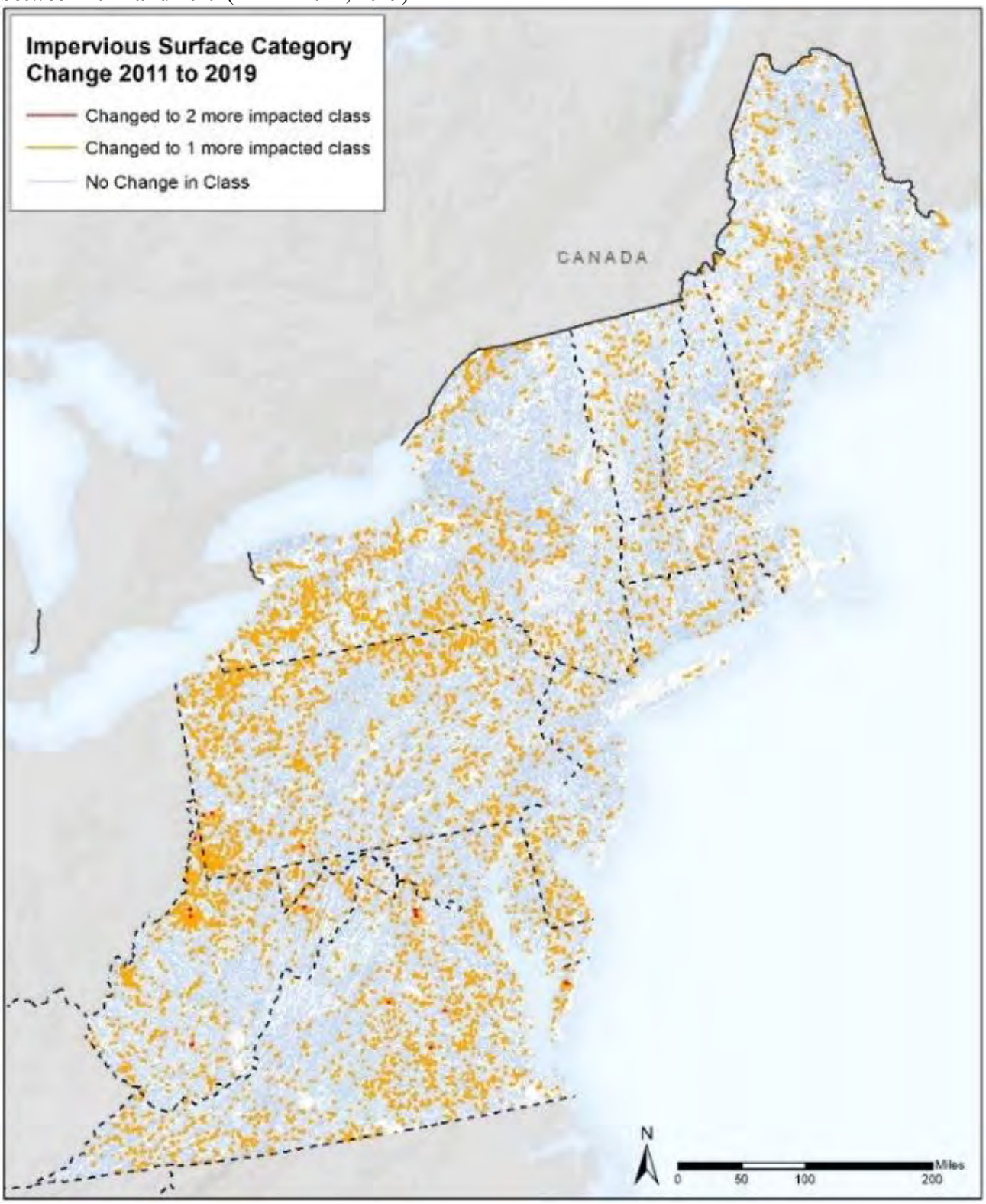
Over the last two decades (2001-2019) impervious surfaces have continued to increase consistent with the expansion of development and suburban sprawl in the northeast (Figure 6. 14). The undisturbed class was no longer the majority after 2004 and the two most highly impacted classes collectively grew from 21% to 24% of all miles between 2001 and 2019. Overall, 11% of the total miles changed to a more impacted class in 2019 compared to their class in 2001.

Within the last decade (2011-2019), 5% of all stream and river miles moved to a more impacted class; 4% of river miles, 5% of stream miles, 4% of tidal systems, and 2% of big river miles. The reaches that changed to a more impacted class in the last decade were widely dispersed across the region with only lands under conservation or very remote and mountainous areas seeing no change (Map 6.17). The Mid-Atlantic states were slightly more impacted by increasing imperviousness with 4-8% of miles changing to a more impacted class compared to 2-4% in New England and New York. Given that once areas are developed into impervious surface it is very hard to return them to a natural state, effort should be made to reduce further loss of land to impervious surfaces to prevent the further degradation and loss of intact stream and river ecosystems.

Figure 6. 14. Change in the percentage of miles in each impervious surface impact class 2001-2019.



Map 6.17. Stream reaches with change to a more impacted upstream impervious surfaces class between 2011 and 2019 (NLCD 2011, 2019)



Nutrient Enrichment

Recent studies suggest most U.S. streams and rivers have higher levels of nitrogen and phosphorus than is recommended (Manning et al. 2020). Although nutrients are a natural part of aquatic ecosystems, human activity has increased nitrogen and phosphorus levels in streams and rivers. At high levels, nutrients can lead to excessive algal growth which can harm water quality, alter food webs and resources, decrease the oxygen that fish and other aquatic life need to survive, and contribute to hypoxia in coastal waters.

Nitrogen is most likely to come from high rates of atmospheric deposition from the burning of fossil fuels or from agriculture and fertilizer application. Agriculture is noted as a substantial source of nitrogen to streams in the Northeast, particularly in the mid-Atlantic region (Ator, 2019). Urban and atmospheric sources also contribute substantial nitrogen to streams throughout the Northeast and most of the nitrogen to streams in New England. Increased phosphorus is more commonly the result of sewage waste, increased soil erosion, and urban runoff. More than one-half of the phosphorus reaching streams in the northeast is contributed by wastewater point sources or urban nonpoint sources (Ator 2019). Northeastern streams also receive phosphorus from agriculture and natural mineral sources.

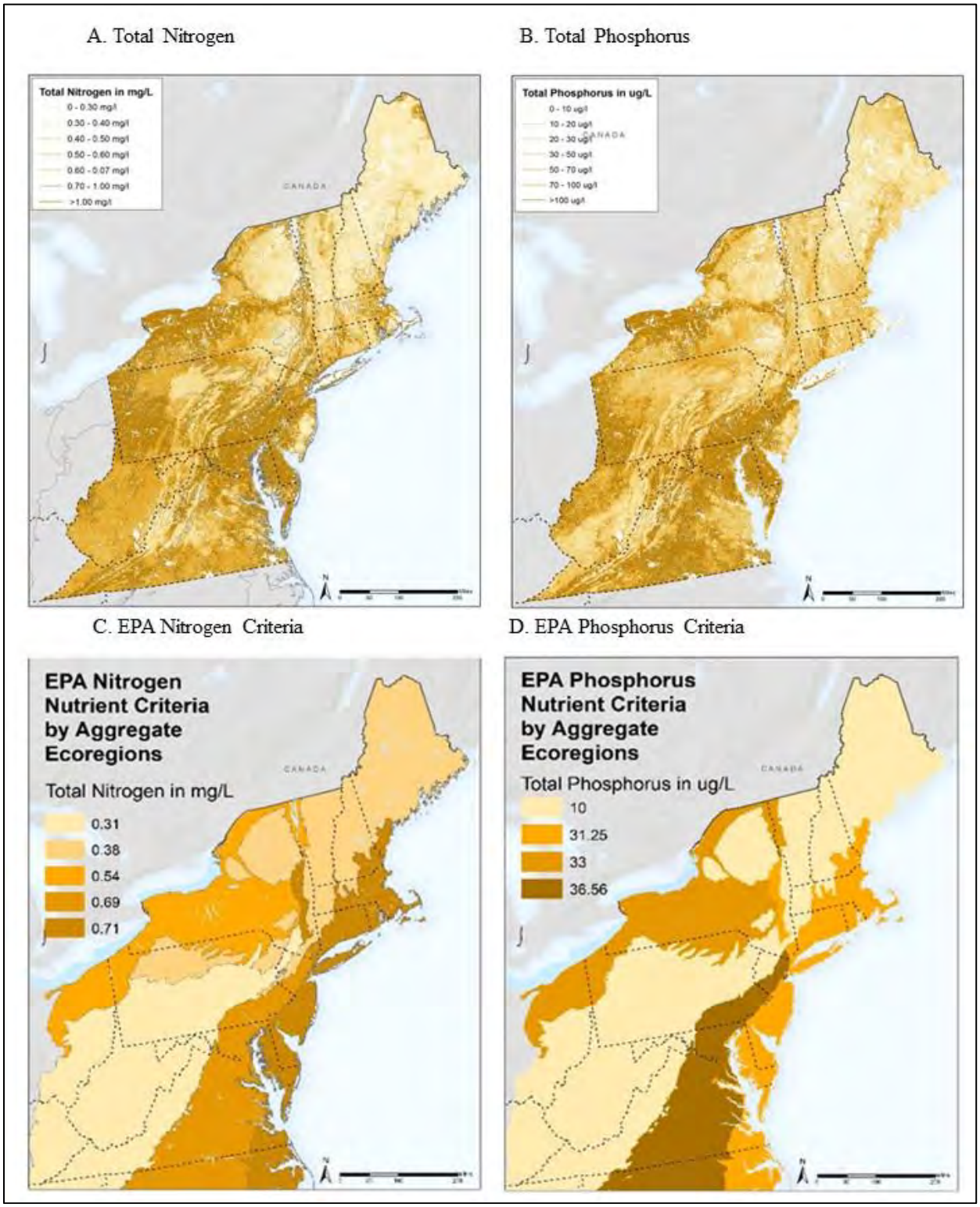
Nutrient enrichment has been listed as the cause of impairment of hundreds of miles of streams, rivers, and waterbodies in the northeast as reported to the EPA under the Integrated Report (IR) and Clean Water Act Sections 303(d) and 305(b). Based on the most recent EPA ATTAINS Water Quality Assessment dataset (https://www.epa.gov/waterdata/get-data-access-public-attains-data; Aug 9, 2022), every northeast state has reported impaired waters due to nutrients and/or closely related impairment causes such as agal blooms and low dissolved oxygen. These include:

- Many rivers draining into the Chesapeake Bay or Delaware Bay,
- Areas of northern VA such as the South Fork Shenandoah River,
- Areas of western PA in the Western Allegheny Plateau,
- Areas of NY such as tributaries of Lake Ontario and NYC's East River and Bronx River,
- CT's Housatonic River, Quinnipiac River, Thames River,
- MA's Merrimack River, Nashua River, Assabet, Blackstone, Charles, and Taunton River,
- RI's Providence River,
- NH's tributaries of Great Bay,
- VT's lower tributaries of Lake Champlain,
- ME's Mousam, Lower Androscoggin, Sabattus River, and Prestile Stream.

Although not all waters in the northeast states have been sampled for water quality impairment as part of state and EPA water quality monitoring, the USGS SPARROW Models provide an additional assessment of nutrient loads in streams and allow fully comprehensive mapping of nutrient impacts. The SPARROW models use spatially comprehensive geospatial data in a calibrated model to predict water-quality conditions at unmonitored stream locations. The most recent SPARROW model provides an estimated nutrient load for each NHD Medium Resolution reach, as of circa 2012 (USGS, 2019).

We combined the SPARROW Northeast (Ator 2019), Mid-West (Hoos and Roland 2019), and Southeast (Robertson and Saad 2019) outputs to cover the entire NEAFWA geography and summarized patterns in total upstream accumulated nitrogen and phosphorous for streams and rivers. In SPARROW, concentration (*Accumulated load/Accumulated flow*) should be interpreted as concentration weighted by mean-annual flow. Results highlight higher nutrient loads around agriculture and urban areas (Map 6.18).

Map 6.18. Stream and River Reaches by Total Nitrogen and Phosphorus. This shows total nitrogen (A) and phosphorus (B) by stream reach and EPA nitrogen (C) and phosphorus (D) criteria by ecoregion.



We compared the SPARROW nutrient loads to the EPA Nutrient Criteria by Aggregate Ecoregions to evaluate where nutrients are potentially elevated beyond reference condition thresholds. Although most states to not have formal nutrient criteria in their water quality standards, EPA provides recommended nutrient criteria for rivers and streams by ecoregion across the country (Map 6.19). The recommended criteria are not laws or regulations but provide specific guidance that states and tribes may use as a starting point for the criteria for their water quality standards. (https://www.epa.gov/nutrient-policy-data/ecoregional-nutrient-criteria-rivers-and-streams**)**.

Results show 75% of stream and river miles in the northeast exceeded EPA Nitrogen recommended criteria for their aggregate nutrient ecoregion. Much fewer streams and rivers meet the EPA Phosphorus baseline criteria, with 94% of miles exceeding the phosphorus criteria including 98% in the Mid-Atlantic and 90% in New England and New York. Patterns are slightly better for nitrogen with 92% exceeding in the Mid-Atlantic and 54% in New England and New York. Levels of exceedance again follow dominant patterns in agriculture and urban land use.

At the most extreme levels, the top two reporting classes in Map 6.19, the spatial pattens begin to highlight many of the same surface waters reported as highly impaired by nutrients via 303d and 305b reporting. Overall, in the northeast 21% of all streams and rivers fall in these highest two impact categories for nitrogen (exceedance > 1mg/l) and phosphorus (exceedance > 100 ug/l). In the Mid-Atlantic it is 27% for nitrogen and 29% for phosphorus, while in New England and New York it is 13% for nitrogen and 10% for phosphorus. The highest proportion of miles in the highest impact classes for nitrogen include tidal streams and rivers at 36%, followed by streams at 21%, rivers at 19% and big rivers at 12%. For phosphorus it is tidal streams and rivers at 33%, streams at 21%, big rivers at 19% and rivers at 17% (Map 6.19).

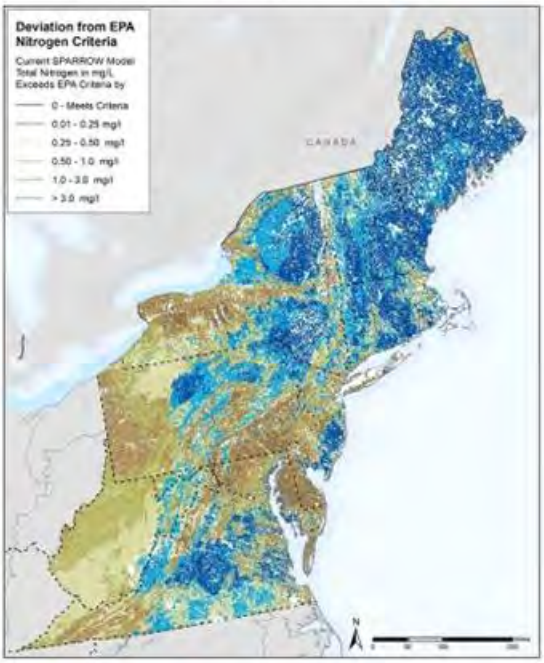
Table 6.19. Nitrogen and Phosphorus Exceedance by Percent Steam Miles: How much the current nutrient load exceeds the EPA suggested criteria by percent of total stream miles.

Nitrogen	%Miles in N Class 1: 0 mg/l: Meets Criteria %	%Miles in N Exceedance Class 2. >0 - 0.25 mg/l	%Miles in N Exceedance Class 3. >0.25 - 0.50 mg/l	%Miles in N Exceedance Class 4. >0.50 - 1 mg/l	%Miles in N Exceedance Class 5. >1 - 3 mg/l	%Miles in N Exceedance Class 6. > 3 mg/l
Big Rivers	21	15	13	39	12	0
Rivers	24	18	18	20	17	3
Streams	25	19	17	19	16	5
Tidal Streams & Rivers	25	14	10	15	26	10
New England/NY Subregion	46	22	9	10	10	3
Mid-Atlantic Subregion	8	16	23	26	21	6
Northeast Region	25	19	17	19	16	5

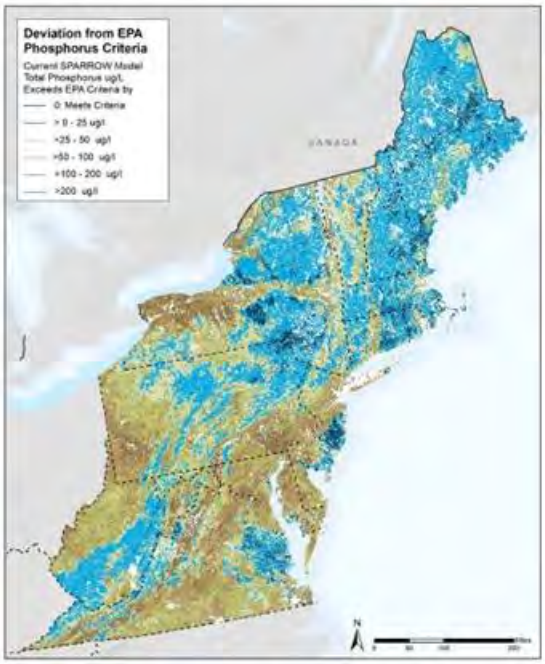
Phosphorus	%Miles in P Class % 1: 0 ug/l: Meets Criteria %	%Miles in P Exceedance Class 2. >0 - 25 ug/l	%Miles in P Exceedance Class 3. >25 - 50 ug/l	%Miles in P Exceedance Class 4. >50 - 100 ug/l	%Miles in P Exceedance Class 5. >100 - 200 ug/l	%Miles in P Exceedance Class 6. > 200 ug/l
Big Rivers	4	21	22	34	19	0
Rivers	7	31	20	24	13	4
Streams	5	35	18	21	15	6
Tidal Streams & Rivers	11	22	14	21	24	9
New England/NY Subregion	10	51	18	10	6	4
Mid-Atlantic Subregion	2	21	17	31	22	6
Northeast Region	6	34	18	22	15	5

Map 6.19. Stream and River Reaches by deviation from EPA Criteria. Map shows the SPARROW model results minus EPA Criteria. Deviations in nitrogen (A) and phosphorus (B) are mapped them summed by stream type and subregon (C & D).

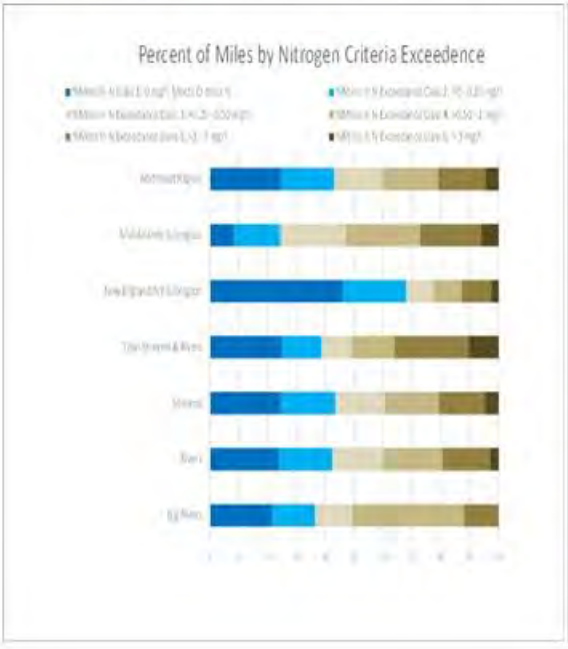
A. Nitrogen: Deviations from EPA



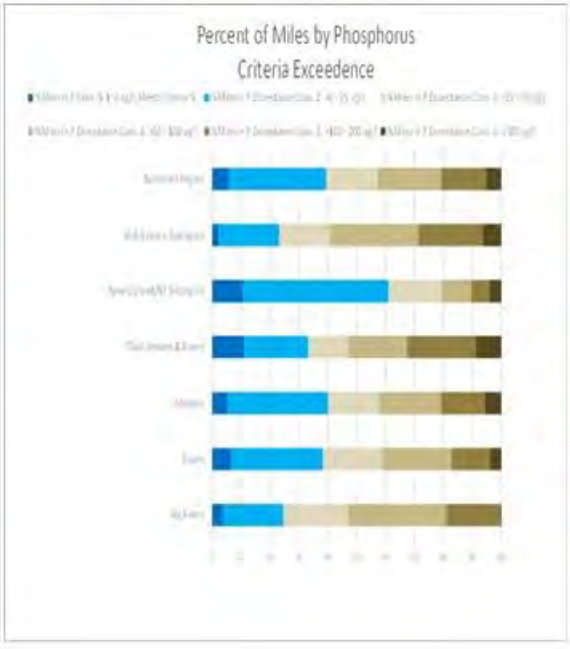
B. Phosphorus: Deviations from EPA



C. Nitrogen Deviations by Type & Subregion



D. Phosphorus Deviations by Type and Subregion



BIOTIC CONDITION: Benthic Macroinvertebrate Index

Although we don't know exactly how landscape variables affect instream biota, the biological condition of streams and rivers can be assessed directly by analyzing the characteristics of the benthic organism communities. These characteristics include the composition and relative abundance of key macro-invertebrates that reflect the quality of their environment and respond to human disturbance in predictable ways. The EPA's NSR Benthic Invertebrate Multimetric Index (BMMI) is a multi-metric measure that integrates across many indices describing the benthic community including: taxonomic richness, composition, and diversity, habits and feeding groups, and pollution tolerance. The index is widely used by state and federal agencies to assess the ecological quality of streams, and it has been incorporated into the water quality criteria regulations of some state agencies.

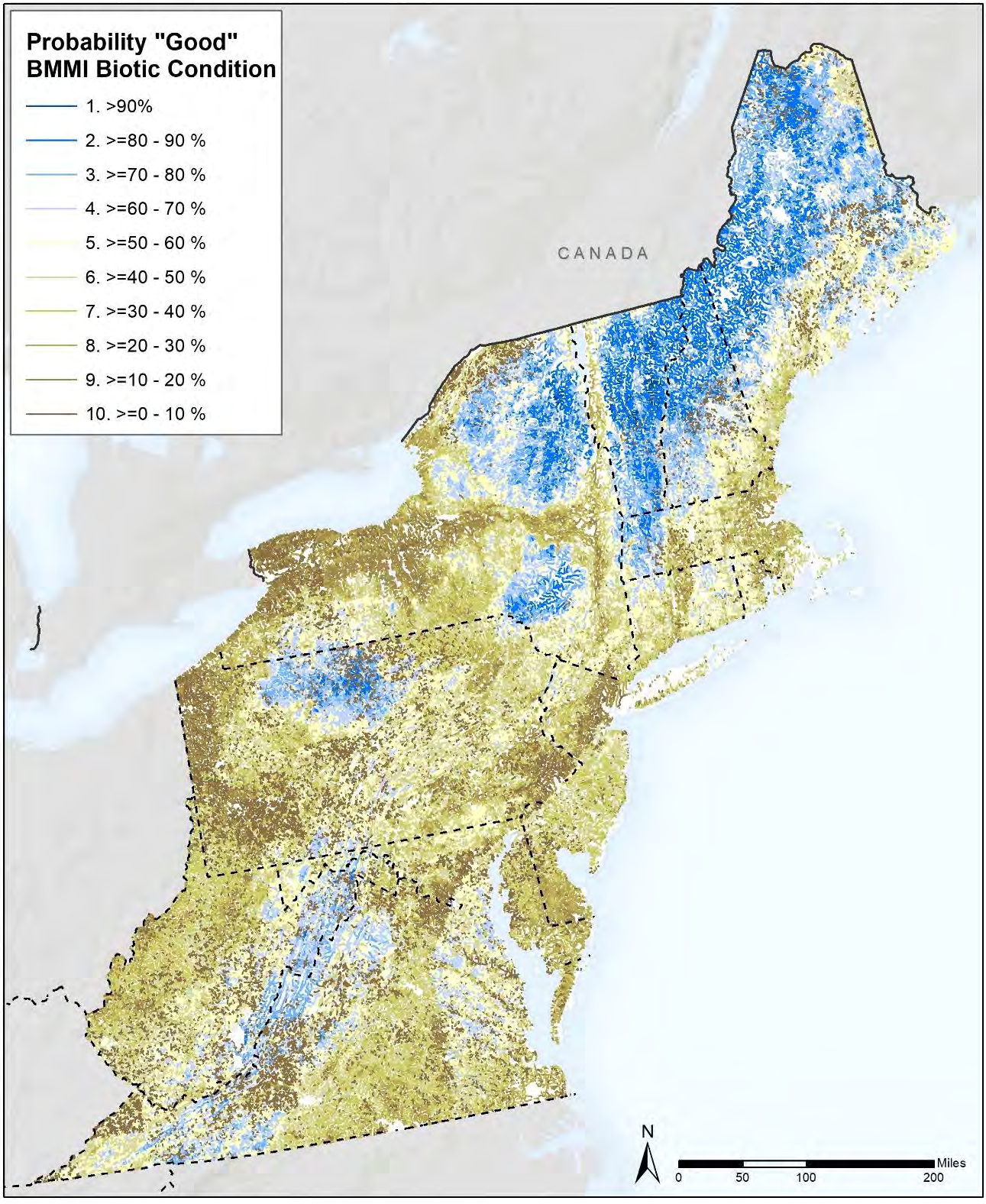
Although only a small number of sites are regularly monitored and assessed for BMMI, the EPA released a new model (Hill et al., 2017) that predicts for every NHD Plus reach the probability that the reach is in good BBMI biological condition. These probabilities were generated using a random forest model developed from BMMI data for known sample locations and a variety of local and landscape GIS predictor variables which were used to estimate the probability at unsampled locations.

Mapping the predicted BBMI (Hill et al. 2017) for the Northeast shows that only 5% of it streams and rivers have an 80% probability of having a good benthic index, distributed as 13% in New England and New York and 1% in the Mid-Atlantic (Table 6.20, Map 6.20, Figure 6. 14) . Streams (6%) and rivers (5%) have a larger proportion in the more intact probabilities than big rivers (1%) or tidal systems (1%). Lowering the threshold for the region does not alter the results much: 8% have a 70% probability of having good BBMI.

Table 6.20. Distribution of each Benthic Invertebrate Multimetric Index (BMMI) Probability Class. In this table the rows are the percent of stream miles in the probability class. For example, row 1 and column 1 show that 0% of tidal streams and rivers are predicted to be in the BMMI 90% class.

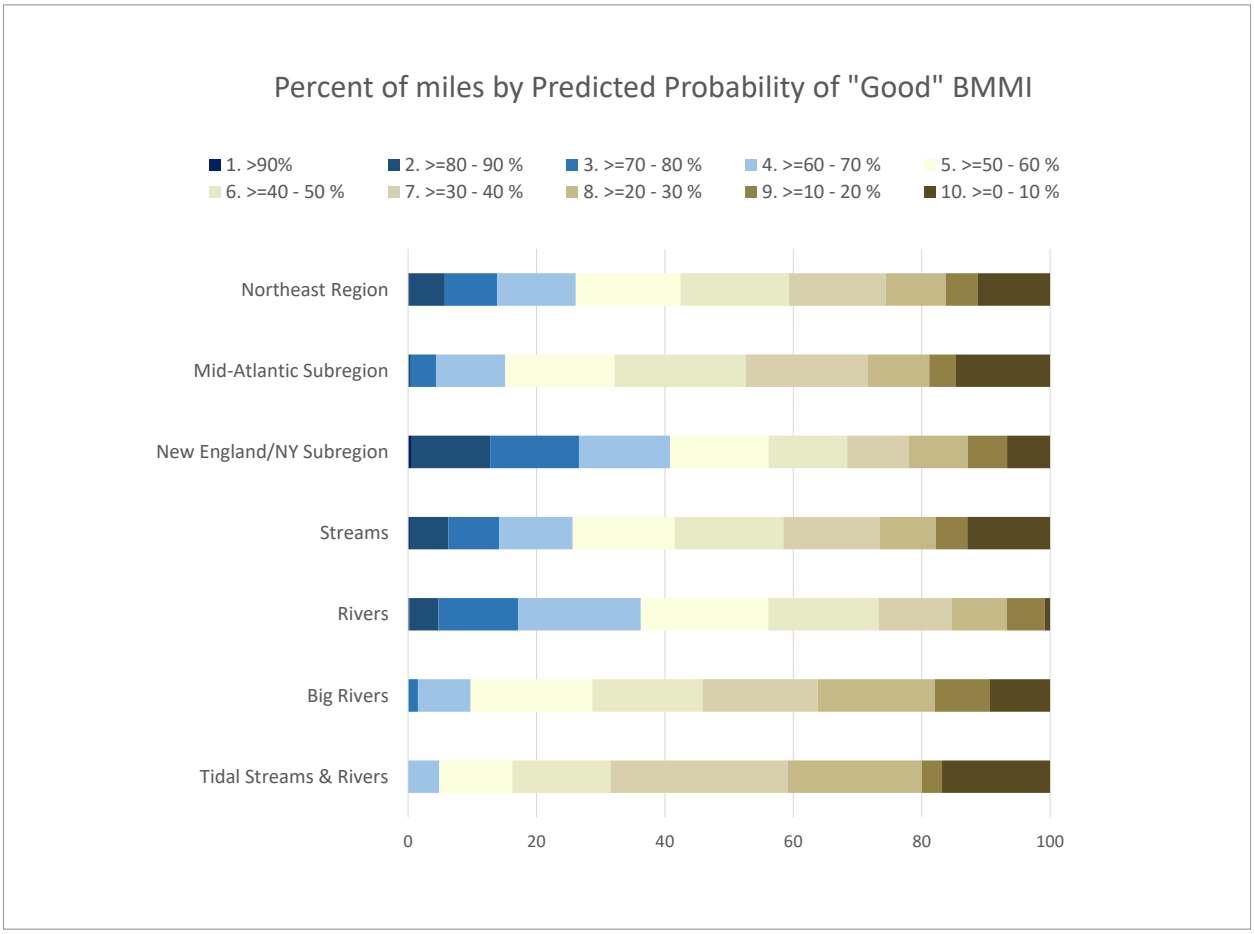
	1. >90%	2. >=80 - 90 %	3. >=70 - 80 %	4. >=60 - 70 %	5. >=50 - 60 %	6. >=40 - 50 %	7. >=30 - 40 %	8. >=20 - 30 %	9. >=10 - 20 %	10. >=0 - 10 %
Tidal Streams & Rivers	0	0	0	5	11	15	28	21	3	17
Big Rivers	0	0	2	8	19	17	18	18	9	9
Rivers	0	5	12	19	20	17	11	9	6	1
Streams	0	6	8	11	16	17	15	9	5	13
New England/NY Subregion	1	12	14	14	15	12	10	9	6	7
Mid-Atlantic Subregion	0	0	4	11	17	20	19	10	4	15
Northeast Region	0	5	8	12	16	17	15	9	5	11

Map 6.20. Probability of Good BMMI Biotic Condition. (Hill et al., 2017)



.

Figure 6. 14. Percent of miles by Predicted Probability of Good BMMI



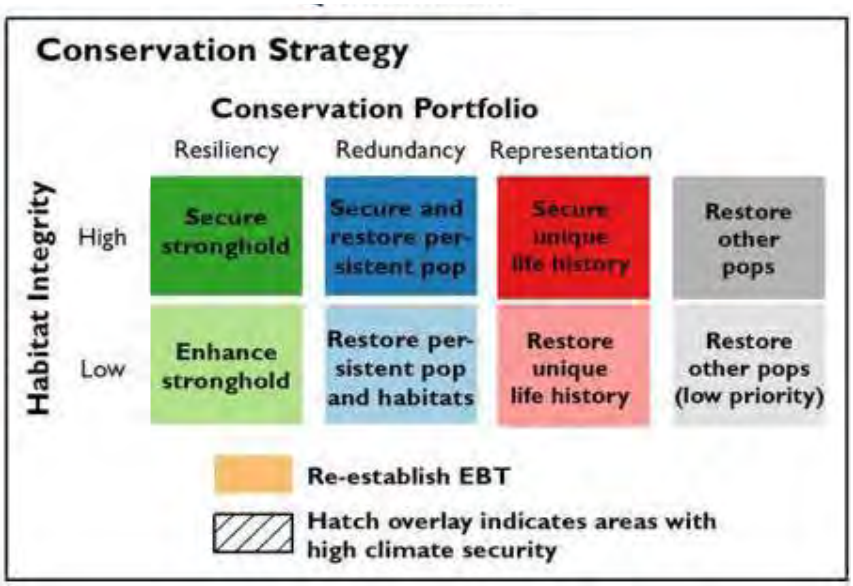
Brook Trout

Within their eastern range in the United States, brook trout (*Salvelinus fontinalis* or EBT) are a primary species of conservation concern. Trout Unlimited developed a widely recognized Conservation Strategy area map for Brook Trout Conservation in the eastern U.S. (Fesenmyer et al. 2017) based on data related eastern brook trout populations, their habitats, and threats to those habitats.

The mapped Conservation Strategies (Figure 6. 15, Map 6.21, Table 6.21) are based on combining a Brook Trout Conservation Portfolio Score with a Habitat Condition Score. The Portfolio Score characterized each contiguous brook trout population "patch" for its resiliency to disturbances, likelihood of demographic persistence, and representation of genetic, life history, and geographic diversity. The Habitat Integrity Score provides a measure of habitat quality and the magnitude of habitat restoration need for each population. The categories are further described, per Fesenmyer et al. 2017 in Table 6.21.

To assess progress towards this strategy, we overlaid the Brook Trout Conservation Strategy areas (Map 6.21) with the 2022 Conservation Lands and National Land Cover 2019 and 2011 datasets. This allowed us to generate the Conservation Risk Index (CRI) and Nature Risk Index (NRI) described previously in the section on conservation status for each brook trout category. The CRI and NRI measure if conservation is outpacing the conversion to agricultural or developed land. It is defined as the amount of permanent conversion (agriculture and developed land) divided by the amount of permanent conservation (CRI = GAP 1-3, NRI = GAP 1-2) which yields a ratio that when >1 indicates more loss than conservation and when < 0 indicates more conservation than loss of natural habitat.

Figure 6.15: Eastern Brook Trout Conservation Strategies. (Fesenmyer et al. 2017)



Map 6.21. Eastern Brook Trout Conservation Strategy Result (Fesenmyer et al 2017). Legend in Table 6.21 describes each strategy.

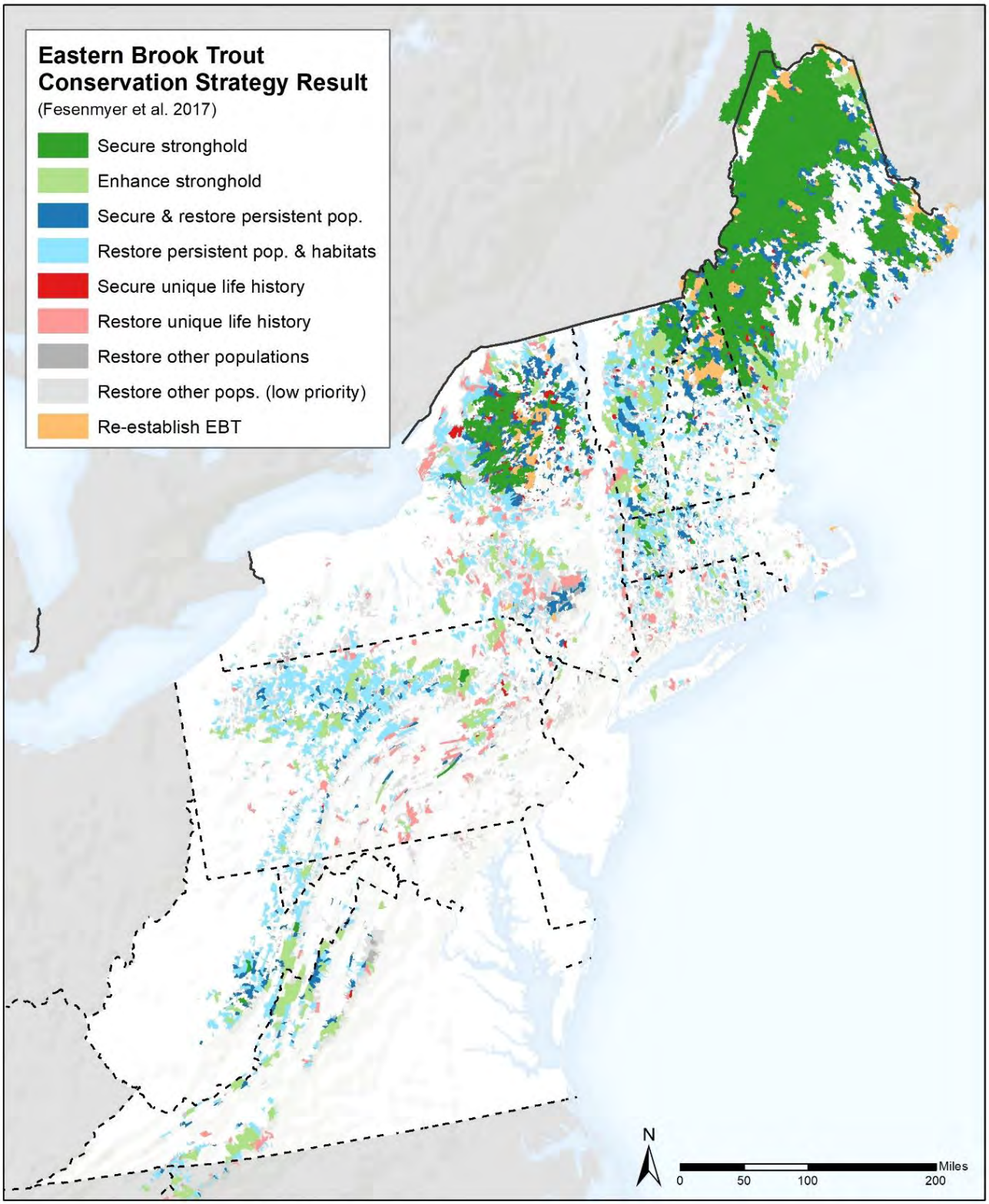


Table 6.21. Legend to Map 6.20 and Description of Eastern Brook Trout Conservation Strategy.
(From Fesenmyer et al. 2017)

• *Secure strongholds* strategy is assigned to resilient patches with high habitat integrity. These patches meet our criteria as strongholds and have relatively few stressors present. Due of overlap in the portfolio categories, these patches also meet redundancy criteria and contain migratory river populations. This category represents an objective – ideally all patches would be in this category, with large interconnected habitats with few acute stressors. Limited restoration action is likely required to secure these populations.
• *Enhance stronghold* is assigned to resilient patches with lower habitat integrity. These patches meet our criteria as strongholds, but have single significant or multiple smaller stressors present – restoration focused on addressing existing stressors within these patches can enhance the strongholds.
• *Secure and restore persistent population* strategy is assigned to redundant patches with high habitat integrity scores. These patches meet our criteria as persistent and have relatively few stressors present – restoration of populations through non-native trout eradication or connectivity enhancements to provide more available habitat for allopatric populations, combined with limited habitat restoration effort could shift these populations to the resilient, stronghold category.
• *Restore persistent populations and habitats* strategy is assigned to redundant patches with low habitat integrity scores. These patches meet our criteria as persistent but have single significant or multiple smaller stressors present – restoration of populations through non-native trout eradication or connectivity enhancements could shift these populations to the resilient, stronghold category, but may require concurrent habitat restoration work.
• *Secure unique life history* strategy is assigned to patches which do not meet portfolio redundancy and resiliency criteria, but which may contain unique life histories (all life histories except resident less productive are considered unique) and have high composite habitat condition scores. Multiple conservation strategies may be necessary within these patches depending on EBT population status or habitat disturbance. River and lake migratory populations offer the best opportunity to shift populations into the redundant category due to their large size and productivity. Anadromous, resident lake/pond, and resident more productive populations may be small, but represent rare and unique life histories.
• *Restore unique life history* strategy is assigned to patches not meeting resiliency or redundancy criteria in the portfolio analysis, but with low habitat integrity scores. These patches may provide some opportunity for population and habitat restoration work to shift to the redundant category.
• *Restore other populations* strategy is assigned to populations that do not meet the resiliency, redundancy, or representation criteria . These populations are largely small allopatric or small to moderately sized sympatric resident EBT populations. Adjacent populations may provide some opportunity for reconnection activities to create additional redundant patches. As new information regarding EBT genetic status or other population attributes, such as population densities, conservation opportunities and needs for these populations may be revealed to be higher priority.
• *Re-establish EBT* is assigned to surrounding or adjacent subwatersheds – those habitats currently unoccupied by EBT – with average composite habitat integrity scores greater than 0.7 and subwatershed-average maximum 30-day average stream temperatures less than 17°C. These subwatersheds may provide an opportunity for reintroducing EBT in locations with minimal habitat restoration need and with lasting value in the face of climate change.

Results of conservation lands and NLCD overlay show that the entire eastern brook trout range was 32% conserved and 12% converted to agriculture or development, equivalent to 0.38 acres of conversion for every acre conserved (CRI=0.38) (Table 6.22 and 6.23, Figure 6.16). Sites for all three securement strategies (strongholds, populations, unique life history) had CRI and NRI scores well below 0 and below the regional mean, indicating good progress already made on conserving these areas and preventing conversion (Table 6.21, Figure 6.16). The lowest CRI (0.09) was for the Secure Strongholds category which covers 13 million acres and has 37% in GAP 1-3 land and 3% developed reflecting 10 times more conservation land than conversion. Although this "secure stronghold" area includes 4.7 million acres of conservation land, there is still much opportunity for further conservation in its nearly 8 million acres of relatively intact unconserved natural lands (Table 6.22 and 6.23). Sites for two restoration strategies - restore brook trout and restore other populations - were also below the mean and seem promising as good restoration areas. Strategies related to "Restore and Enhance" had CRI values above the regional mean.

Over the last decade, conservation has surpassed conversion in every brook trout strategy area. Strongholds targeted for securement had 179 times more conservation than conversion! and securement to restore persistent populations had 54 times more conservation than conversion (Table 6.24).

Table 6.22. Acres of Eastern Brook Trout Conservation Strategies by Land Cover Type and Conservation Status

Conservation Strategy	Agriculture	Developement	GAP 1 and 2	GAP 3	Unconserved Natural	Total Acres
Secure stronghold	-179,453	-236,901	1,557,403	3,197,724	7,840,645	13,012,126
Enhance stronghold	-669,575	-386,553	358,284	1,131,634	3,406,294	5,952,339
Secure & restore persistent pop.	-60,335	-93,248	1,171,546	1,173,842	2,380,118	4,879,089
Restore persistent pop. & habitats	-848,679	-519,372	452,991	2,120,647	5,325,202	9,266,891
Secure unique life history	-1,351	-7,985	121,222	105,208	175,650	411,416
Restore unique life history	-422,697	-233,712	95,120	306,794	1,192,364	2,250,687
Restore other populations	-8,660	-15,895	287,488	368,449	390,743	1,071,235
Restore other pops. (low priority)	-1,047,948	-789,889	386,032	1,181,186	3,906,675	7,311,730
Re-establish EBT	-28,315	-38,337	417,856	286,410	656,242	1,427,161
Northeast Region Total	-3,267,014	-2,321,892	4,847,941	9,871,895	25,273,933	45,582,675

Table 6.23. Eastern Brook Trou Conservation Strategies by Conservation Risk Index (CR) and% of Land Cover and Conservation Land

Conservation Strategy	Percent Converted (Dev & Ag)	Percent Protected (GAP 1 & 2)	Percent Conserved (GAP 1-3)	CRI	NRI
Secure stronghold	3.20	11.97	36.54	0.09	0.27
Enhance stronghold	17.74	6.02	25.03	0.71	2.95
Secure & restore persistent pop.	3.15	24.01	48.07	0.07	0.13
Restore persistent pop. & habitats	14.76	4.89	27.77	0.53	3.02
Secure unique life history	2.27	29.46	55.04	0.04	0.08
Restore unique life history	29.16	4.23	17.86	1.63	6.90
Restore other populations	2.29	26.84	61.23	0.04	0.09
Restore other pops. (low priority)	25.14	5.28	21.43	1.17	4.76
Re-establish EBT	4.67	29.28	49.35	0.09	0.16
Northeast Region Total	12.26	10.64	32.29	0.38	1.15

Figure 6.16. Conversion and Conservation within Eastern Brook Trout Conservation Strategy Areas

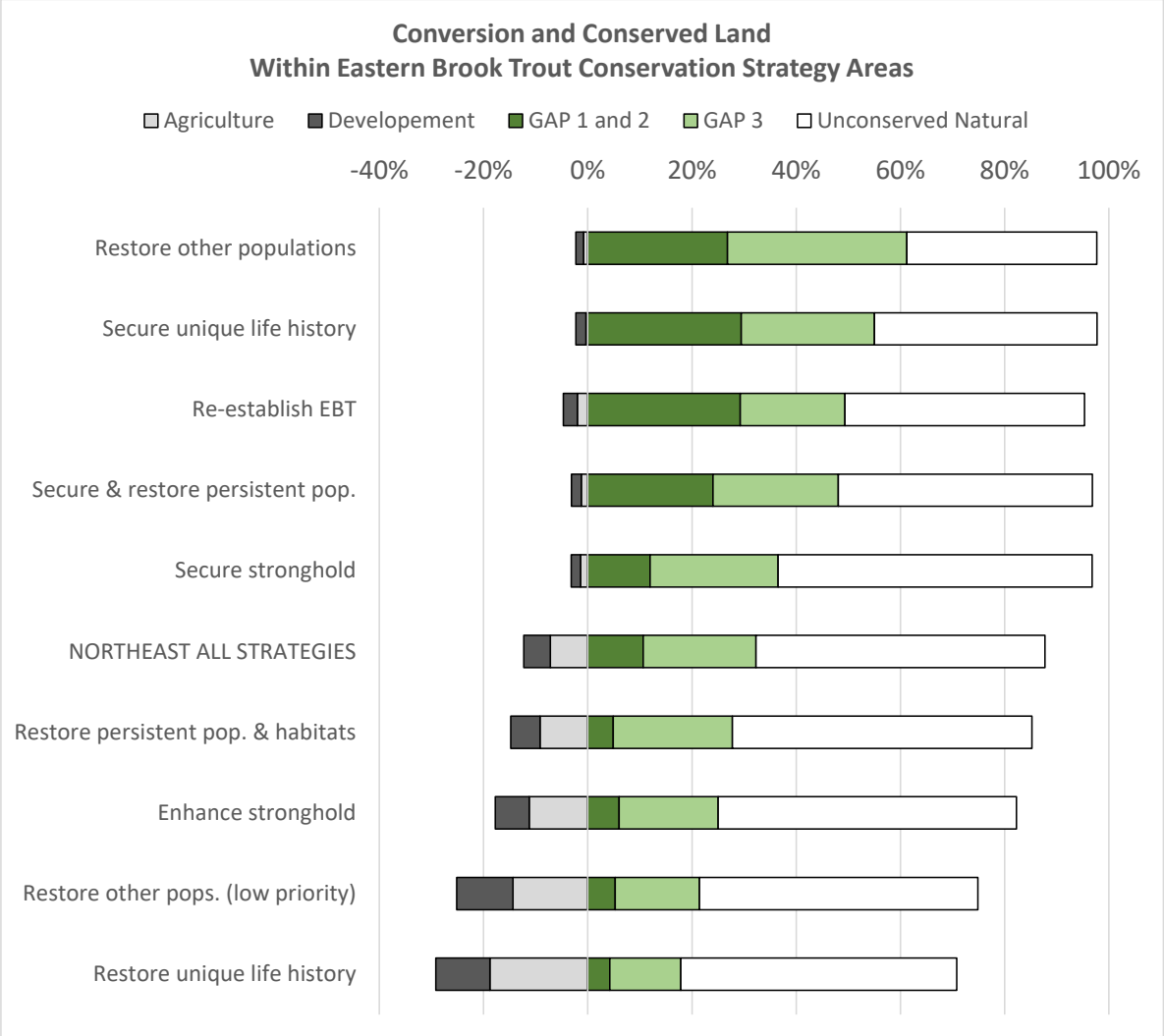


Table 6.24. Eastern Brook Trou Conservation Strategies by Last Decade: Conservation Land and Conservation Risk Index, 2012-2022

Conservation Strategy	2012-2022 Loss Acres	2012-2022 Conserved Acres	% of Total Area Lost 2012-2022	% of Total Area Conserved 2012-2022	2012-2022 CRI
Secure stronghold	3,237	575,896	0.02	4.43	0.01
Enhance stronghold	13,197	57,176	0.22	0.96	0.23
Secure & restore persistent pop.	1,871	101,755	0.04	2.09	0.02
Restore persistent pop. & habitats	21,147	91,173	0.23	0.98	0.23
Secure unique life history	106	2,296	0.03	0.56	0.05
Restore unique life history	10,021	13,108	0.45	0.58	0.76
Restore other populations	325	17,712	0.03	1.65	0.02
Restore other pops. (low priority)	30,038	46,166	0.41	0.63	0.65
Re-establish EBT	680	38,737	0.05	2.71	0.02
Northeast Region Total	80,623	944,018	0.18	2.07	0.09

Non-Indigenous Aquatic Species:

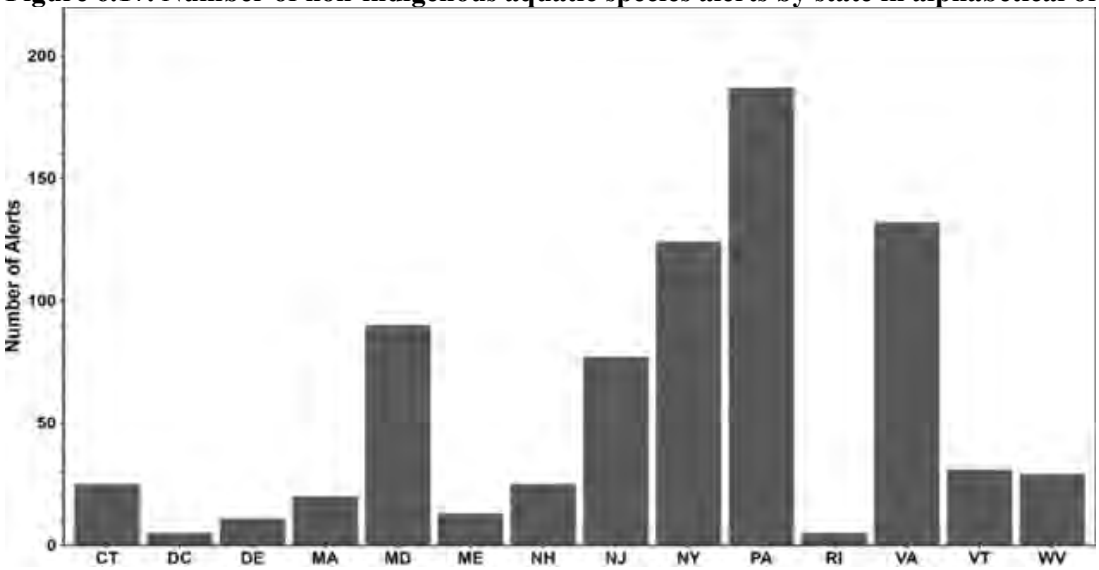
Non-indigenous aquatic species (NAS) are individuals or populations of a species that enter an aquatic ecosystem outside of its historic or native range. They may be vertebrates, invertebrates, plants, or diseases. Invasive NAS may alter ecosystems by preying on natives, competing with natives, hybridizing with natives, or spreading diseases to native species. NAS may be more likely to become established when stream and watershed conditions are degraded.

The most comprehensive survey of NAS is the USGS Non-indigenous Aquatic Species program that maintains a useful website of information (http://nas.er.usgs.gov/queries/). This site was established as a central repository for accurate and spatially referenced biogeographic accounts of NAS, obtained from a variety of sources such as researchers, field biologists, and fishermen**.** Because the reports are opportunistic, rather than based on comprehensive surveying, some states have better reporting than others. The reports are also influenced by publications, or lack thereof, and by news coverage.

Data from NAS was extracted and summarized for the region and subregions by Matthew Neilson, PhD from USGS Nonindigenous Aquatic Species Program, Gainesville, FL as of 1/2023, and we are grateful to him for the charts and summaries in the following section. Information is provided for all NAS species observed and for species established based on population shows evidence of successful reproduction and overwinter survival. The number of alerts in the NAS system regarding new species introductions between 2017-2022 are also provided to show the context of change over the last 5 years.

Results show that nearly 500 non-indigenous aquatic species have been observed in the region and just over 300 have been determined to have established populations (Figure 6.17). By taxa group, over two-thirds of them are fish with the next most common taxa group being plants, followed by crustaceans, mollusks, reptiles, amphibians, and others. The Mid-Atlantic had more NAS fish and plants while New England and New York had more crustaceans and mollusks than the Mid-Atlantic.

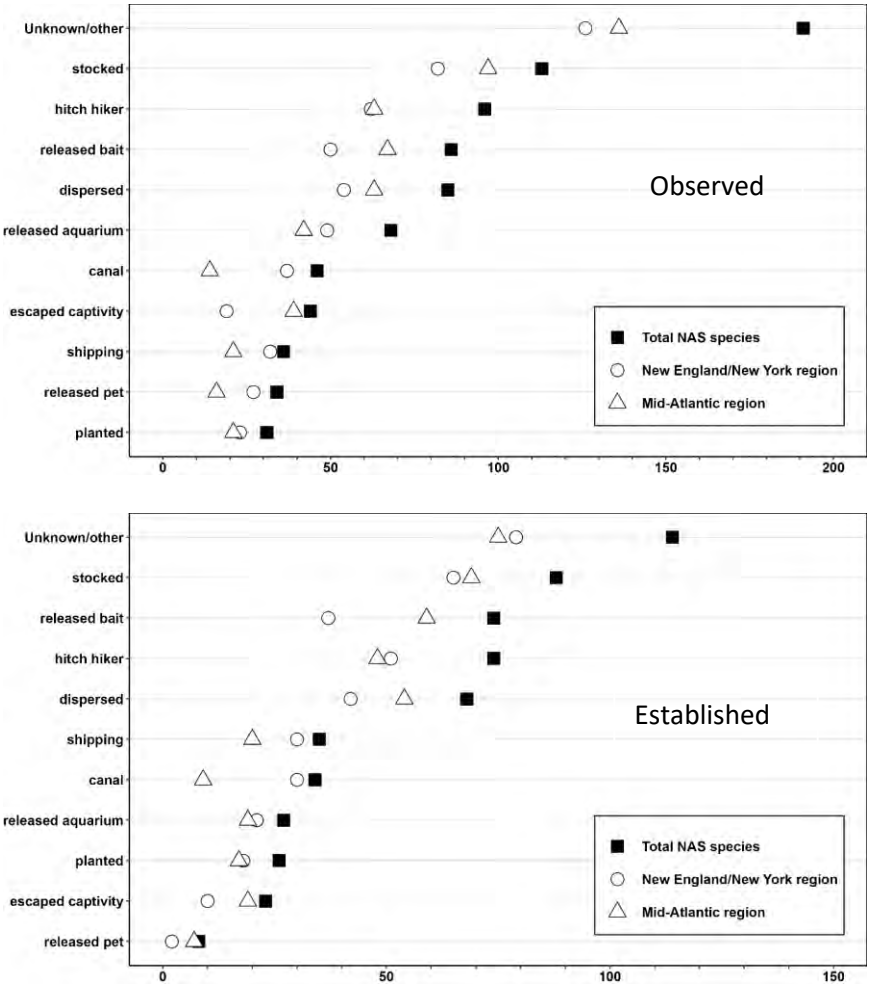
Figure 6.17. Number of non-indigenous aquatic species alerts by state in alphabetical order.



Mapping the results by watershed revealed that there were few areas of the region with less than five NAS established species or ten NAS observed species (Map 6.22). Areas with high number of NAS species include Boston harbor drainages, the middle and lower mainstem Connecticut River, Housatonic, middle to lower Hudson, New York Finger Lakes drainages, lower Delaware, lower Susquehanna, mid to lower Potomac, upper Roanoke, middle-upper New River, and Youghiogheny. Many of these same areas have high numbers of established NAS and high numbers of alerts (Map 6.22)

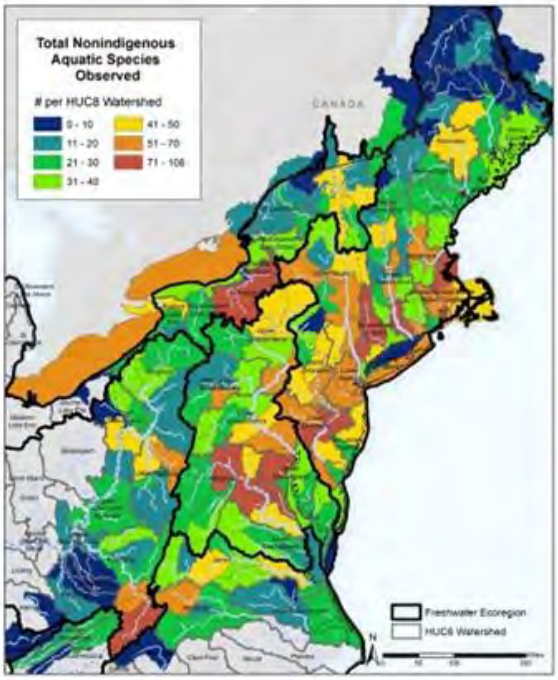
In addition to the presence or establishment of individual species, the NAS program tracks the method of introduction for each species and its location. Summaries of this data (Figure 6.18) show that the source of most introductions are unknown. After that, stocking and released bait are the major pathways of introduction followed by more natural methods of hitch hiker and dispersal (Figure 6.18).

Figure 6.18: Major pathways of non-indigenous aquatic species introductions.

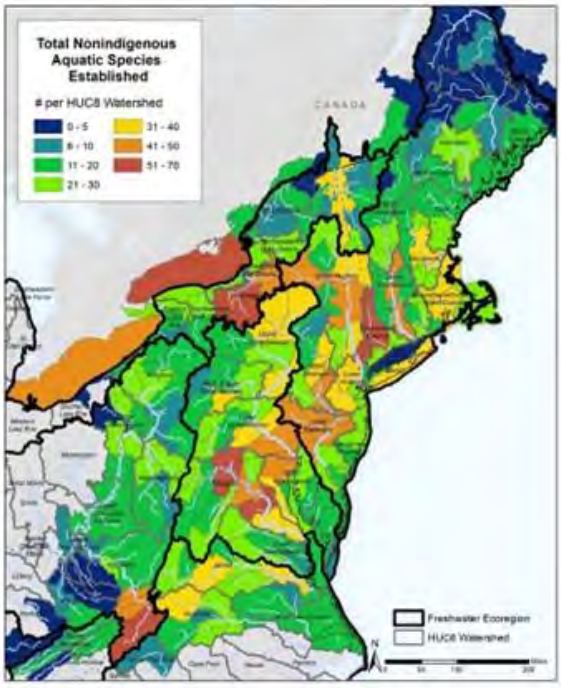


Map 6.22. Total number of non-indigenous aquatic species observed per HUC8 drainage

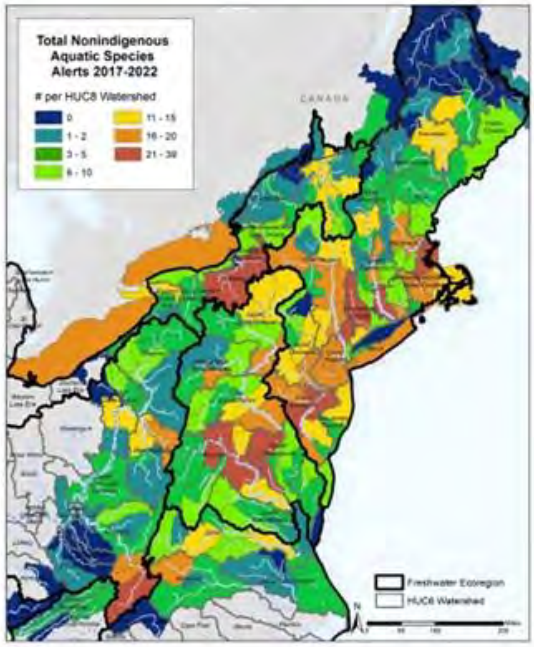
A. Total Number of NAS: Observed



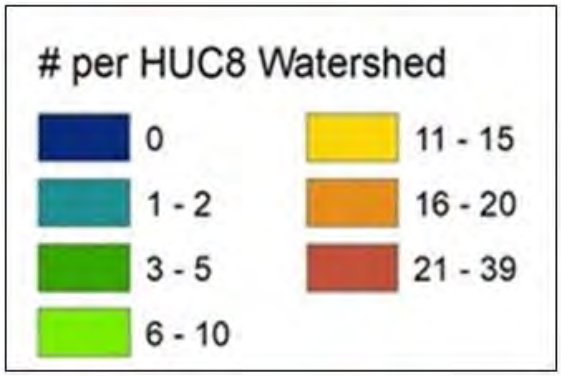
B. Total Number of NAS Established



C. Total Number of NAS Alerts



D. Legend



Chapter 6: References

Abell, R., Thieme, M.L., Revenga, C., Bryer, M., Kottelat, M., Bogutskaya, N., Coad, B., Mandrak, N., Balderas, S.C., Bussing, W. and Stiassny, M.L., 2008. Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation. *BioScience*, *58*(5), pp.403-414.

Abell, R., Lehner, B., Thieme, M. and Linke, S., 2017. Looking beyond the fenceline: Assessing protection gaps for the world's rivers. *Conservation Letters*, *10*(4), pp.384-394.

Allan, J. D. 1995. Stream Ecology: Structure and function of running waters. Kluwer Academic Publishers. Dordrecht, The Netherlands.

Allan, J.D. 2004. Landscapes and riverscapes: The influence of land use on stream ecosystems. Annual Review of Ecology, Evolution and Systematics 35: 257-84.

American Rivers. 2022. Dataset— ARDamRemovalList_figshare_Feb2022. Figshare. Available:https://doi.org/10.6084/m9.figshare.5234068

Anderson, M.G. and A. Olivero Sheldon. 2011. Conservation Status of Fish, Wildlife, and Natural Habitats in the Northeast Landscape: Implementation of the Northeast Monitoring Framework. The Nature Conservancy, Eastern Conservation Science. 289 pp.

Anderson, M.G. M. Clark, C.E. Ferree, A. Jospe, A. Olivero Sheldon and K.J. Weaver. 2013. Northeast Habitat Guides: A companion to the terrestrial and aquatic habitat maps. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA. http://nature.ly/HabitatGuide.

Ator, S.W., 2019, Spatially referenced models of streamflow and nitrogen, phosphorus, and suspended-sediment loads in streams of the Northeastern United States: U.S. Geological Survey Scientific Investigations Report 2019– 5118, 57 p., https://doi.org/10.3133/sir20195118. Associated data for this publication: Ator, S.W., 2019, SPARROW model inputs and simulated streamflow, nutrient and suspended-sediment loads in streams of the Northeastern United States, 2012 base year: U.S. Geological Survey data release, https://doi.org/10.5066/P9NKNVQ

Busch et al. 1998. Evaluating Stream Habitat for Diadromous Fish in Atlantic Coast Watersheds: A Preliminary Assessment. U.S. Fish and Wildlife Service, Lower Great Lakes Fishery Resources Office. Habitat Hotline Atlantic: Issues of Concern for Atlantic Marine Fish Habitat Nov. 1998 Issue No. 27. Atlantic States Marine Fisheries Commission.

Carlisle, D. M., Wolock, D. M. & Meador, M. R. 2011. Alteration of streamflow magnitudes and potential ecological consequences: a multiregional assessment. *Front. Ecol. Environ.* **9**(5), 264–270

Center for Watershed Protection (CWP). 2003. Impacts of Impervious Cover on Aquatic Systems. Watershed Protection Research monograph No. 1.

Cote, D., Kehler, D.G., Bourne, C. and Wiersma, Y.F., 2009. A new measure of longitudinal connectivity for stream networks. *Landscape Ecology*, *24*(1), pp.101-113

DePhilip, M. and T. Moberg. 2010. Ecosystem flow recommendations for the Susquehanna River basin. The Nature Conservancy. Harrisburg, PA.

DePhilip, M. and T. Moberg. 2013. Ecosystem flow recommendations for the Delaware River basin. The Nature Conservancy. Harrisburg, PA.

Dewitz, J., and U.S. Geological Survey, 2021, National Land Cover Database (NLCD) 2019 Products (ver. 2.0, June 2021): U.S. Geological Survey data release, https://doi.org/10.5066/P9KZCM54.

Eng, K., Carlisle, D.M., Grantham, T.E., Wolock, D.M., and Eng, R.L., 2019, Severity and extent of alterations to natural streamflow regimes based on hydrologic metrics in the conterminous United States, 1980–2014: U.S. Geological Survey Scientific Investigations Report 2019–5001, 25 p., https://doi.org/10.3133/sir20195001.

Fesenmyer, K.A., A.L. Haak, S.M. Rummel, M. Mayfield, S.L. McFall, and J.E. Williams. 2017. Eastern Brook Trout Conservation Portfolio, Range-wide Habitat Integrity and Future Security Assessment, and Focal Area Risk and Opportunity Analysis. Final report to National Fish and Wildlife Foundation. Trout Unlimited, Arlington, Virginia.

Fausch, K.D., C.E. Torgensen, C.V. Baxter, H.W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. BioScience 52(6):483-498.

Higgins, J., Zablocki, J., Newsock, A., Krolopp, A., Tabas, P. and Salama, M., 2021. Durable Freshwater Protection: A Framework for Establishing and Maintaining Long-Term Protection for Freshwater Ecosystems and the Values They Sustain. *Sustainability*, [online] 13(4), p.1950. https://doi.org/10.3390/su13041950.

Hill, Ryan A., Marc H. Weber, Scott G. Leibowitz, Anthony R. Olsen, and Darren J. Thornbrugh, 2016. The Stream-Catchment (StreamCat) Dataset: A Database of Watershed Metrics for the Conterminous United States. Journal of the American Water Resources Association (JAWRA) 52:120-128. DOI: 10.1111/1752-1688.12372.

Hill, R.A., Fox, E.W., Leibowitz, S.G., Olsen, A.R., Thornbrugh, D.J. and Weber, M.H., 2017. Predictive mapping of the biotic condition of conterminous US rivers and streams. *Ecological Applications*, *27*(8), pp.2397-2415.

Hoos, A.B., and Roland, V.L. II, 2019, Spatially referenced models of streamflow and nitrogen, phosphorus, and suspended-sediment loads in the Southeastern United States: U.S. Geological Survey Scientific Investigations Report 2019–5135, 87 p., https://doi.org/10.3133/sir20195135. Associated data for this publication: Roland, V.L. II, and Hoos, A.B., 2019, SPARROW model inputs and simulated streamflow, nutrient and suspendedsediment loads in streams of the Southeastern United States, 2012 base year: U.S. Geological Survey data release, https://doi.org/10.5066/P9A682GW.

Janson R., C. Nilsson, B Renofalt. 2000. Fragmentation of riparian floras in rivers with multiple dams. Ecology 81(4):899-903.

Karr, J.R., 1991. Biological integrity: a long-neglected aspect of water resource management. *Ecological applications*, *1*(1), pp.66-84.

Kennedy, K., K. Lutz, C. Hatfield, L. Martin, T. Barker, R. Palmer, L. Detwiler, J. Anleitner, J. Hickey. 2018. The Connecticut River Flow Restoration Study: A watershed-scale assessment of the potential for flow restoration through dam re-operation. The Nature Conservancy, U.S. Army Corps of Engineers, and University of Massachusetts Amherst. Northampton, MA. Available: http://nature.org/ctriverwatershed

King, R.S. and M.W. Baker. 2010. Considerations for analyzing ecological community thresholds in response to anthropogenic environmental gradients. Journal of the North American Benthological Society. **29**(4)**:**998.

McManamay, R.A., Troia, M.J., DeRolph, C.R., Olivero Sheldon, A., Barnett, A.R., Kao, S.C. and Anderson, M.G., 2018. A stream classification system to explore the physical habitat diversity and anthropogenic impacts in riverscapes of the eastern United States. PloS one, 13(6), p.e0198439.

McManamay, R.A., George, R., Morrison, R.R. and Ruddell, B.L., 2022. Mapping hydrologic alteration and ecological consequences in stream reaches of the conterminous United States. Scientific Data, 9(1), p.450.

Manning, D.W., Rosemond, A.D., Benstead, J.P., Bumpers, P.M. and Kominoski, J.S., 2020. Transport of N and P in US streams and rivers differs with land use and between dissolved and particulate forms. Ecological Applications, 30(6), p.e02130.

Maryland DNR. 2012. Maryland Stream Health: How Impervious Surface Impacts Stream Health. http://www.streamhealth.maryland.gov/impervious.asp

Martin, E. H. and J. Levine. 2017. Northeast Aquatic Connectivity Assessment Project - Version 2.0: Assessing the ecological impact of barriers on Northeastern rivers. The Nature Conservancy, Brunswick, Maine. http://maps.freshwaternetwork.org/northeast/

Martin, E.H., 2019. Assessing and prioritizing barriers to aquatic connectivity in the Eastern United States. JAWRA Journal of the American Water Resources Association, 55(2), pp.401-412.

National Park Service. 2023. https://www.rivers.gov/wsr-act.php accessed 2/3/23

NatureServe. 2022. NatureServe Explorer NatureServe, Arlington, Virginia. Available https://explorer.natureserve.org/. (Accessed: Sept. 7, 2022).

Nedeau, E. 2006. Scientific Basis for Road-Stream Crossing Assessments in the Ashuelot River Watershed. Prepared for the New Hampshire Chapter of The Nature Conservancy. 43.p

Neves R.J., A.E. Bogan, J.D. Williams, S.A. Ahlstedt, and P.W. Hartfield. 1997. Status of aquatic mollusks in the southeastern United States: a downward spiral of diversity. In: Aquatic Fauna in Peril: The Southeastern perspective. (eds. GW Benz GW & DE Collins, pp. 45-86. Southeast Aquatic Research Institute, Decatur, GA.

Olivero, A. and M.G. Anderson. 2008. Northeast Aquatic Habitat Classification System. The Nature Conservancy, in Collaboration with the Northeast Association of Fish and Wildlife Agencies. 88p.

Palone, R. and Todd, A. 1997. Chesapeake Bay Riparian Handbook: A Guide for Establishing and Maintaining Riparian Forest Buffers. Chesapeake Bay Program 1997.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E. and Stromberg, J.C., 1997. The natural flow regime. *BioScience*, *47*(11), pp.769-784.

Pringel, C., Freeman, M., and Freeman, B. 2000. Regional Effects of Hydrologic Alteration on Riverine Macrobiota in the New World: Tropical-Temperate Comparisons. BioScience. 50:9:807-823

Richter, B. D., and G. A. Thomas. 2007. Restoring environmental flows by modifying dam operations. Ecology and Society **12**(1): 12. [online] URL: http://www.ecologyandsociety.org/vol12/iss1/art12/

Robertson, D.M., and Saad, D.A., 2019, Spatially referenced models of streamflow and nitrogen, phosphorus, and suspended-sediment loads in streams of the Midwestern United States: U.S. Geological Survey Scientific Investigations Report 2019–5114, 74 p. including 5 appendixes, https://doi.org/10.3133/sir20195114. Associated data for this publication: Saad, D.A., and Robertson,

D.M., 2019, SPARROW model inputs and simulated streamflow, nutrient and suspended-sediment loads in streams of the Midwestern United States, 2012 base year: U.S. Geological Survey data release, https://doi.org/10.5066/P93QMXC9

U.S. Army Corps of Engineers National Inventory of Dams 2022 (NID, https://nid.sec.usace.army.mil/).

U.S. Environmental Protection Agency (EPA). 2012. Water Quality Standards Handbook: Chapter 3: Antidegradation. EPA-823-B-12-002. EPA Office of Water, Office of Science and Technology, Washington, DC. Accessed February 2022. https://www.epa.gov/sites/default/files/2014-10/documents/handbook-chapter4.pdf

U.S. Geological Survey. Fishways Database 2022 (https://doi.org/10.5066/P9IB1GWS)

U.S. Geological Survey, 2016, USGS National Hydrography Dataset (NHD) V21 Downloadable Data Collection - National Geospatial Data Asset (NGDA) National Hydrography Dataset (NHD): USGS - National Geospatial Technical Operations Center (NGTOC): Rolla, MO and Denver, CO, http://nhd.usgs.gov, http://viewer.nationalmap.gov/.

U.S. Geological Survey. 2023. Nonindigenous Aquatic Species Database. Gainesville, Florida. Accessed 1/10/2023.

Vannote, RL,G. W. Minshall, K. W. Cummins, J.R. Sedell, and E. Gushing 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37: 130-137.

Vaughn C.C. and C.M. Taylor. 1999. Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. *Conservation Biology*, 13: 912-920.

Watters G.T. 1996. Small dams as barriers to freshwater mussels (Bivalvia, Unionoida) and their hosts. Biological Conservation. 75:79-85.

Welsch, D.J. 1991. Riparian Forest Buffers. U.S. Forest Service Northeastern Area State & Private Forestry. Radnor, PA. NA-PR-07-91. 20 pages.

CHAPTER

Lakes and Ponds

7

Condition and Conservation Status

Feb 2023

A. Olivero & M. G. Anderson

Lakes and ponds are bodies of standing water with a discernible shoreline. Collectively, the region has over 35,000 lakes and ponds which have a surface area of 2.7 million acres (over twice the area of Delaware). They range in size from small shallow ponds to huge deep lakes over 10,000 acres. Here we review the characteristics of lake and pond systems and examine their loss, degradation, and conservation. We focus on a few key measurable status metrics which are available consistently across the entire geography and allow for comparison between previous time periods and the current state.

Lake and Pond Conservation Status: Of the regions 35,000 lakes and ponds 21% have most of their shoreline conserved. Over the last decade (2012-2022), another 446 waterbodies have joined this group: 300 in New England and New York and 146 in the Mid-Atlantic. Another 800 have shown increased conservation of their shorelines.

Loss and Conservation in the Riparian Zone: Lakes and ponds cover almost three million acres of the region (excluding the three great lakes), creating 1.9 million acres of riparian shoreline habitat critical to wildlife. Of this, 79% is in natural cover and 30% is conserved, while 21% has been converted to development (15%) or agriculture (6%), a ratio of 0.7 acres converted for every one acre conserved. In the past decade (2012-2022) conservation has surpassed conversion by a ratio of 4 to 1.

Shoreline Disturbance Index: Despite the good news about shoreline conservation, 44% of the region's waterbodies have high disturbance impacts in their shoreline buffer zones, reflecting high levels of development, agriculture, and roads in this ecologically sensitive area. Balancing that, 33% are in lowest shoreline disturbance class. Over the two decades (2001-2019) impacts have increased in 36% of waterbodies while 6% have improved, reflecting a reduction in shoreline agriculture.

Impervious Surfaces: Collectively 38% of the region' waterbodies rank very low for impervious surface impacts while 14% rank so high that they are likely experiencing a loss of diversity and an increase in chemical pollutants. Over the last two decades (2001-2019), the number of waterbodies in the two most impacted classes has increased from 32% to 35%. No waterbodies have changed to a lower impact class, highlighting the difficulty in improving impervious surfaces impacts.

Biological and Chemical Indicators: The 2017 National Lake Assessment data shows New England New York and New Jersey with over 50% of their waterbodies showing good biological and nutrient conditions. The Mid-Atlantic had fewer with good biological (12-17%) or nutrient (12-13%) conditions. Over 74% of the region's waterbodies are in good condition for dissolved oxygen..

Waterbody Types and Associated Species

Lakes and ponds provide habitat to thousands of species, the types of which depend on the characteristics of the waterbody. Waterbodies differ substantially in size, depth, shape, location within a stream network and in water properties like clarity, color, pH, nutrient level. These characteristics shape the identity of their flora and fauna, while total surface area is the best predictor of overall species richness.

A wide variety of plant and animal life rely on lakes and ponds for primary habitat. Typical plants range from mosses and algae to specialized rooted plants such as spatterdock, pondweed, duckweed, stonewort, fanwort, hornwort, elodea, water milfoil, lotus and water lily. Standing water supports a wide variety of microscopic animals, worms and insects, the larval stages of midges, mosquitoes, dragonflies, and damselflies, and freshwater snails, mussels, and clams. The rich invertebrate fauna in turn supports a wide range of amphibian, reptiles, fish and birds. In addition to the lake proper, the shoreline habitat provides feeding and breeding areas for great blue heron, black-crowned night heron, green heron, kingfisher, bald eagle, osprey, cormorants, spotted sandpiper, red-winged blackbirds, and mammals such as moose and mink.

Herptiles: mudpuppy, spotted salamander, red-spotted newt, bullfrog, leopard frog, green frog, pickerel frog, eastern painted turtle, Blanding's turtle, common water snake

Fish: bluegill, pumpkinseed, black crappie, golden shiner, yellow perch, chain pickerel, largemouth bass, brown bullhead. **Coldwater fish (deep lakes):** lake trout, brook trout, rainbow smelt, burbot, landlocked Atlantic salmon

Birds: mallard, blue-winged teal, green-winged teal, wood duck, ruddy duck, pied-billed grebe, hooded merganser, bufflehead, common goldeneye, redhead, lesser scaup, and common loon.

In this report, we distinguished between Ponds, Lakes, and Great Lakes (matching the SWAP 2022 habitat lexicon). Ponds are distinct because their shallow depth has a direct influence on the physical components of their ecosystem. Specifically, they are shallow enough to have light penetration throughout, supporting rooted plant growth from shore to shore. Lakes have deep areas without enough light penetration to support plants and are more likely to become temperature stratified in the summer (dimictic). Waterbody size is a gradient within which multiple habitat types exist. Larger lakes typically contain a wide diversity of habitat types and support a broader suite of species (Minns 1989, Tonn & Magnuson 1982). The three Great Lakes in the region, Lake Erie, Ontario, and Champlain are separated from the other lakes and ponds and only a few metrics are reported for them given their extremely large size which make their ecosystems and conditions particularly different.

We map ponds and lakes according to the Northeast Lake and Pond Classification System and dataset (Olivero and Anderson, 2016). This dataset used the NHD Plus V2 Medium Resolution 1:100,000 scale waterbodies as its base and was augmented with waterbodies over 10 acres in size from the high resolution NHD+ dataset and the National Wetlands Inventory. In addition to separating ponds from lakes, we report additional patterns by size class within these two major groups (Table 7.1, Map 7.1). While there are biological differences between small and large lakes, the reporting size classes do not necessarily reflect biologically identified thresholds but is simply a practical way to summarize patterns across lakes and ponds in this region. These size classes match the lake size classes in the original Northeast Aquatic Habitat Classification System (Olivero and Anderson 2008) and those used by New Hampshire DES and Maine DEP. This chapter focuses primarily on the non-Great Lake lentic systems.

Table 7.1. Types of Ponds and Lakes used in this report

PONDS	Small Pond 2-10 acres
	Large Pond > 10 acres
LAKES	Small Lake 2- 100 acres
	Medium Lake 100-1000 acres
	Large Lake 1,000-10,000
	Very Large Lake >10,000
GREAT LAKES	Great Lakes: Erie, Ontario, Champlain

Distribution and Abundance

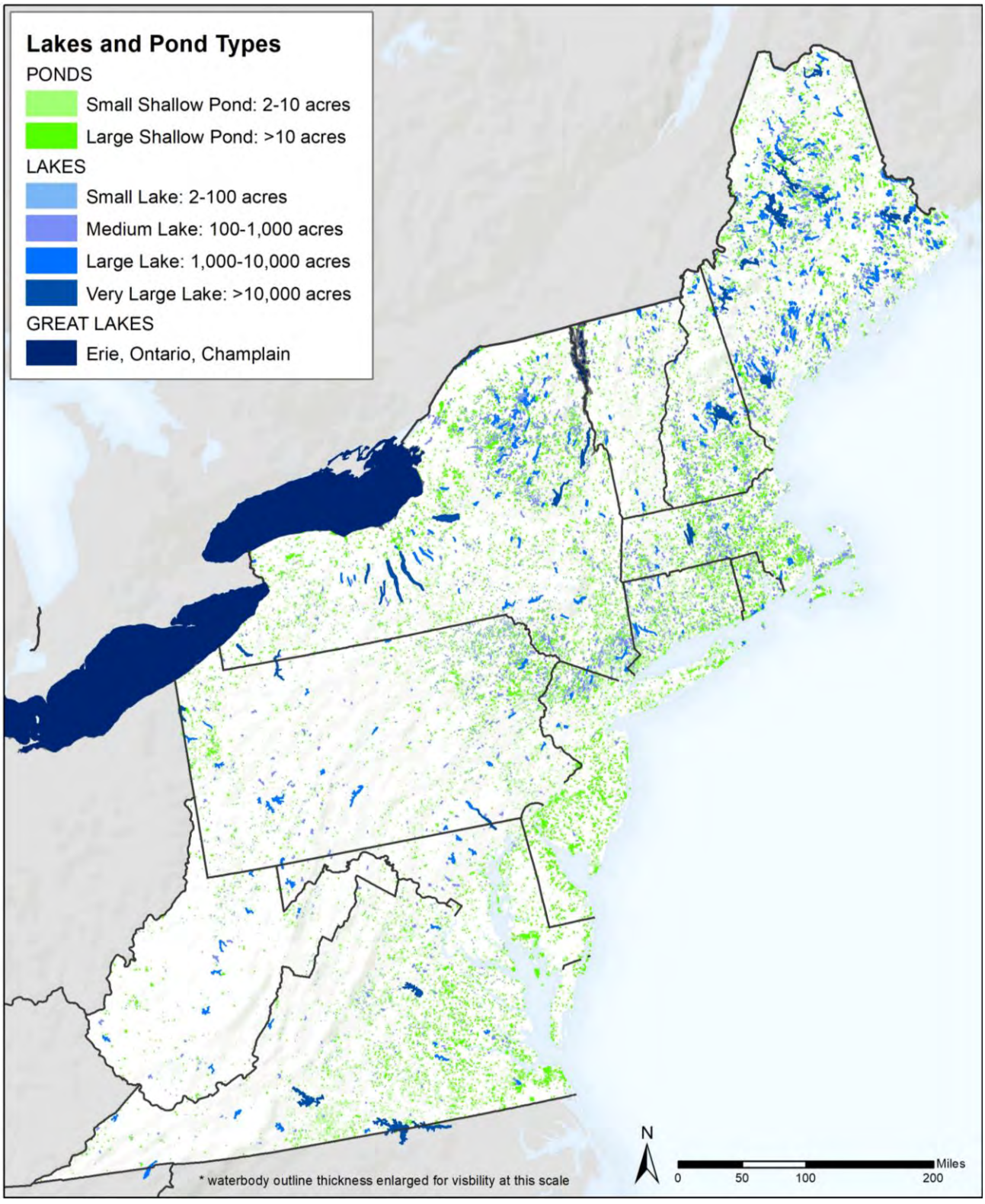
Lakes and ponds are primarily features of the glaciated northern region, with 73% of all lakes found in the New England and New York subregion. (Map 7.1). While the northern region has most of the lakes, the regions 28,000 ponds are more evenly spread among the two sub-regions. Shallow ponds make up nearly 80% of the number of waterbodies in the region, but account for only 21% of the total waterbody area, excluding great lakes.

By size class, the majority of shallow ponds are small (2-10 acres), but shallow ponds over 10 acres in size make up 85% of the total pond area. Likewise, small lakes less than 100 acres in size account for 71% of all lakes, but lakes over 100 acres account for more than half of the total lake surface area. Lakes over 1000 acres in size account for 70% of the total surface area. (Table 7.2)

Table 7.2. Number and acreage of lakes and ponds in the region (also see Map 7.1).

Lake and Pond Types	# New England/NY	# Mid-Atlantic	**Total Number**	**% of Total Number** (excluding Great Lakes)	Acres New England/NY	Acres Mid-Atlantic	**Acres**	**% of Total Area** (excluding Great Lakes)
Small Pond: 2-10 acres	8663	7612	16275	44	45463	37379	82842	3
Large Pond: > 10 acres	7781	4695	12476	34	318089	160664	478754	18
PONDS	16444	12307	28751	79	363553	198043	561596	21
Small Lake: 2- 100 acres	4039	1841	5880	16	119189	46826	166014	6
Medium Lake: 100-1000 acres	1379	250	1629	4	407610	67986	475596	18
Large Lake: 1,000-10,000 acres	254	45	299	1	683188	113421	796609	29
Very Large Lake: >10,000 acres	21	7	28	0	565241	136945	702186	26
LAKES	5693	2143	7836	21	1775227	365178	2140405	79
TOTAL LAKES AND PONDS (excluding Great Lakes)	22,137	14,450	36,587		2,138,779	563,221	2,702,000	

Map 7.1. Lakes and Ponds by Size Class. The region has over 36,000 waterbodies covering 2.7 M acres.



Habitat Conservation of the Shoreline Riparian Zone

The riparian zone is the land directly adjacent to a stream or waterbody. Lakes and ponds with intact riparian habitats are more likely to support healthy biotic populations than lakes that have been deforested by shoreline development (NLA, 2017). Intact riparian areas play a critical role in reducing erosion, filtering nutrients to maintain water quality, supplying needed organic matter and woody debris, providing shade to maintain cooler temperatures, and they provide a suite of other habitat and biodiversity values for fish, wildlife, and other aquatic communities (Palone et al. 1997).

Land Cover of the Riparian Zone

In this section, we assessed the riparian zone by creating a standard 100m (~300 ft.) buffer landward from the shorelines of the lakes and ponds. The 100 m distance was chosen to encompass a broad range of the types of riparian functions noted for eastern riparian zones as one moves landward from the water interface (Palone et al. 1997, Anderson and Olivero, 2011). We calculated the amount of agriculture and developed land within each ~100m riparian buffer zone by overlaying the 2011 and 2019 National Land Cover dataset (Dewitz and U.S. Geological Survey 2021).

Our results show that 1.9 million acres of land is within a waterbody riparian zone. Of that 79% is in natural cover, 6% in agriculture, and 15% in developed cover (Table 7.3). Lakes and pond riparian zones had the same amount of development (15%) but ponds had more agriculture (8%) than lakes (3%). The Great Lakes had the highest amounts of agriculture (15%) and development (29%) in the riparian zone. Loss of natural cover in the riparian zone was least in the large lakes. The Mid-Atlantic states had more agriculture (10%) in the riparian zone than New England and New York (3%).

The above statistics reflect impacts to the entire footprint of waterbody riparian zones. In the condition section of this chapter we report on individual waterbodies to highlight the ones with various levels of conversion to agriculture or development in the riparian zone.

Table 7.3. Acres of Lake and Pond Riparian Land by Cover Type and Conservation Status

Habitat	Agr. Acres	Dev. Acres	GAP 1 and 2 Acres	GAP 3 Acres	Unconserved Natural Acres	Total Acres
Small Pond	-42,103	-61,226	24,990	42,223	178,791	349,333
Large Pond	-37,691	-87,574	73,843	117,363	332,193	648,664
PONDS	**-79,794**	**-148,800**	**98,833**	**159,586**	**510,984**	**997,998**
Small Lake	-10,653	-37,463	31,388	44,070	130,114	253,688
Medium Lake	-4,667	-46,978	25,636	60,919	136,214	274,415
Large Lake	-3,611	-28,059	21,841	76,710	105,930	236,150
Very Large Lake	-3,166	-18,757	7,809	34,012	48,522	112,266
LAKES	**-22,096**	**-131,257**	**86,674**	**215,711**	**420,780**	**876,518**
Great Lakes: Erie, Onatario, Champlain	-4,817	-9,487	1,904	4,151	12,419	32,777
NORTHEAST REGION	**-106,708**	**-289,544**	**187,411**	**379,448**	**944,183**	**1,907,293**
MIDATLANTIC SUBREGION	-63,732	-102,895	38,454	138,050	292,081	635,213
NEW ENGLAND/NY SUBREGION	-42,975	-186,649	148,957	241,397	652,101	1,272,080

,

Conservation of the Riparian Zone

To evaluate the amount of conservation land in the riparian zone, we overlaid the TNC 2022 Conservation Lands data set on the 100m (~300ft) riparian shoreline buffer zone. Results indicate that nearly 567,000 acres (30%) of lake and pond riparian land was under conservation (GAP 1-3) including 10% conserved explicitly for nature (GAP 1-2). This is almost twice as high as for streams and rivers riparian land (18%). The two subregions had a similar overall percentage of conserved land in this zone but New England and New York had more land conserved for nature (12%) than the Mid-Atlantic (6%).

Excluding the great lakes, the lake riparian zone had more conservation land (34%) than did ponds (26%). Larger pond riparian areas were more conserved (29%) than small ponds (19%) perhaps reflecting a bias towards conserving areas with larger amounts of open water for recreation and esthetic values along with biodiversity values. Lakes showed a similar pater with large lakes (42%) having more conservation in the riparian zone than smaller lakes (30%). Detailed assessment of individual waterbodies is described later in the lake securement section where we highlight waterbodies with their entire shorelines conserved.

The Conservation Risk Index (CRI) measures the ratio of habitat lost through conversion to agriculture or development to the amount conserved, where a ratio greater than 1 indicates more habitat lost than conserved and thus greater risk. For the riparian zone we measured CRI as the amount of agriculture and developed land divided by the amount of conserved land (GAP 1-3, Figure 7.1, Table 7.4).

Overall, the collective results show the lake and pond riparian zone to be 21% converted and 30% conserved, indicating 0.7 acres of habitat lost for every one acre conserved (CRI=0.7, Figure 1, Table 7.4). Conservation was greater than habitat loss across all pond and lake types, except small ponds (CRI=1.5) which were slightly more converted than conserved. The great lake class also showed the reverse pattern with 2.4 acres converted for every one acre conserved (CRI =2.4). Excluding the great lakes, lakes had only 0.5 acres lost for every acre conserved (CRI =0.1) whereas the ratio for ponds was almost 1:1 (CRI = 0.9). The pattern reversed when we considered only land conserved explicitly for nature (Gap1-2). This Nature Risk Index (NRI) was greater than one across all types and averaging 2.1 acres converted for every one acre conserved for nature. The NRI was highest for great lakes (7.5) and small ponds (4.1) and lowest for large lakes (1.4). In sum, waterbody riparian lands have more conservation than conversion although most of it is multiple use land.

Considering only the last decade (2011-2022) reveals an encouraging conservation trend (Table 7.5). The regional average (CRI =0.4) indicates that only 0.4 acres of natural lake or pond riparian habitat was converted for every one acre conserved. This was true for both subregions: Mid-Atlantic (CRI = 0.5), New-England and New York (CRI = 0.2). Further patterns by state can be explored with the digital appendix.

Figure 7.1. The distribution of riparian land cover and conservation by lake and pond type. In this chart, each bar represents the total area of riparian land in the habitat type. Land to the left of the center bar has been converted to development or agriculture; land to right of the center bar remains unconverted. Unconverted land is apportioned by conservation status and the % unconserved.

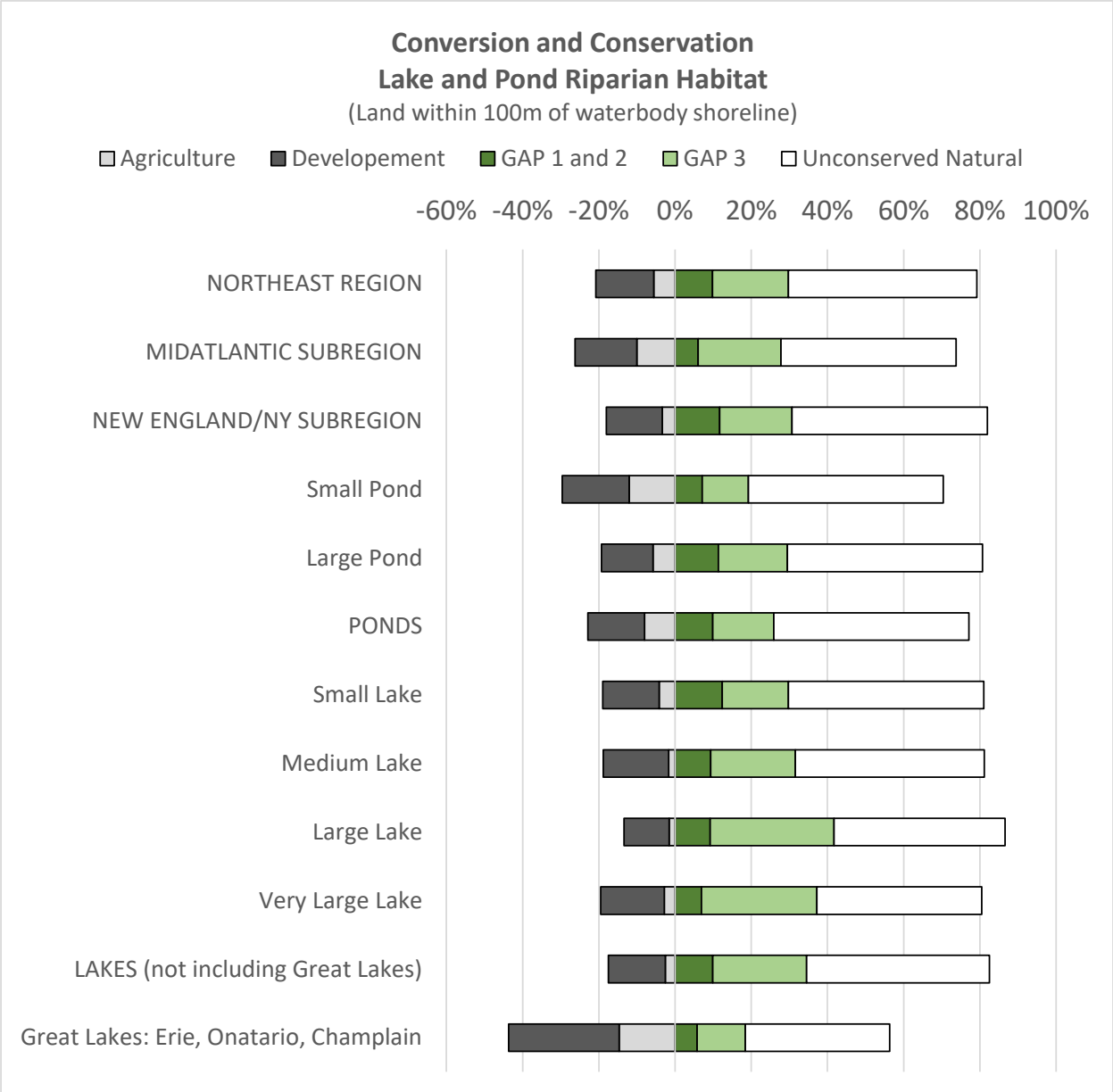


Table 7.4. Conservation Risk Index (CRI) and Nature Risk Index (NRI) for the Lake and Pond Riparian Land

CRI = the ratio of acres converted to development or agriculture to acres conserved (GAP1-3)

NRI = the ratio of acres converted to development or agriculture to acres conserved for nature (GAP1-2)

Habitat	Percent Converted (Dev & Ag)	Percent Protected (GAP 1 & 2)	Percent Conserved (GAP 1-3)	CRI	NRI
Small Pond	29.6	7.2	19.2	1.5	4.1
Large Pond	19.3	11.4	29.5	0.7	1.7
PONDS	**22.9**	**9.9**	**25.9**	**0.9**	**2.3**
Small Lake	19.0	12.4	29.7	0.6	1.5
Medium Lake	18.8	9.3	31.5	0.6	2.0
Large Lake	13.4	9.2	41.7	0.3	1.4
Very Large Lake	19.5	7.0	37.3	0.5	2.8
LAKES	**17.5**	**9.9**	**34.5**	**0.5**	**1.8**
Great Lakes: Erie, Onatario, Champlain	43.6	5.8	18.5	2.4	7.5
NORTHEAST REGION	**20.8**	**9.8**	**29.7**	**0.7**	**2.1**
MIDATLANTIC SUBREGION	26.2	6.1	27.8	0.9	4.3
NEW ENGLAND/NY SUBREGION	18.1	11.7	30.7	0.6	1.5

Table 7.5. Last Decade (2012-2022): Lake and Pond Riparian Conservation Land and Conservation Risk Index Negative number indicate habitat lost. CRI = the ratio of acres converted to development or agriculture to acres conserved (GAP1-3)

Habitat	2012-2022 Loss Acres (Dev & Ag)	2012-2022 Conserved Acres	% of Total Area Lost 2012-2022	% of Total Area Conserved 2012-2022	2012-2022 CRI
Small Pond	-1,995	5,033	1.4	0.4	0.6
Large Pond	-2,431	9,516	1.5	0.3	0.4
PONDS	**-4,426**	**14,550**	**1.5**	**0.3**	**0.4**
Small Lake	-763	2,660	1.0	0.3	0.3
Medium Lake	-561	3,660	1.3	0.2	0.2
Large Lake	-426	3,231	1.4	0.1	0.2
Very Large Lake	-359	1,335	1.2	0.3	0.3
LAKES	**-2,109**	**10,885**	**1.2**	**0.2**	**0.2**
Great Lakes: Erie, Onatario, Champlain	-148	776	2.4	0.2	0.5
NORTHEAST REGION	**-6,683**	**26,211**	**1.4**	**0.3**	**0.4**
MIDATLANTIC SUBREGION	-3,820	7,551	1.2	0.5	0.6
NEW ENGLAND/NY SUBREGION	-2,863	18,660	1.5	0.2	0.2

Conservation Status of Individual Lakes and Ponds

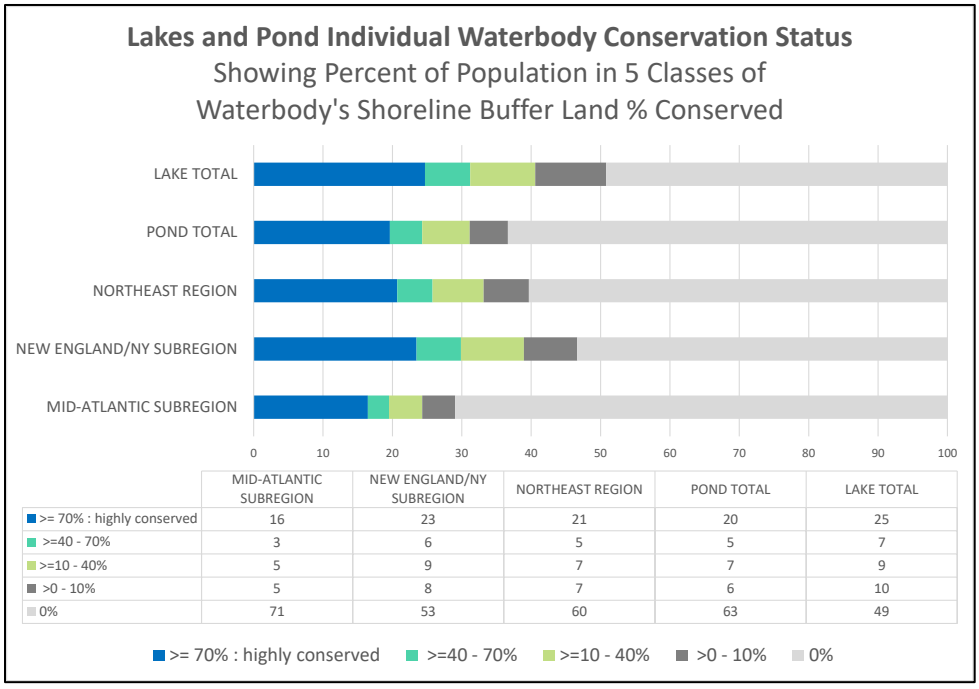
The conservation land in the lake/pond riparian habitat zone across the region is not distributed evenly across every waterbody in the region. For example, although 30% of this habitat type is conserved, not every waterbody has 30% of its riparian land conserved. To access which waterbodies were embedded in conservation land and had nearly their entire individual lake's riparian zone conserved, we quantified the amount and percent of conserved land (GAP 1-3) within the shoreline buffer (100m) of every individual waterbody.

To display the results, we placed individual waterbodies were into one of five 5 categories of conservation status (Map 7.2, Table 7.6) as follows:

- High = >70% of their shoreline buffer land in conservation,
- Moderate = 40-70% of shoreline buffer land in conservation,
- Low = 10-40% of their shoreline buffer land in conservation
- Very Low = >0-10% of their shoreline buffer land in conservation
- None = no conservation land in shoreline buffer.

Overall, 21% of all lakes and ponds scored high for conservation in their shoreline buffer, 5% scored moderate, 7% scored low, 7% scored very low and 60% had no conservation (Figure 7.2, Map 7.2, Table 7.6). Lakes scored slightly better, with 25% in the high class, and 49% had no conservation. Ponds were slightly less conserved, with 20% in the high class, and 63% with no conservation. New England and New York had more waterbodies with conserved riparian areas with 23% in the high class, compared to the Mid-Atlantic with 16% in the high class.

Figure 7.2. Lake and Pond Individual Waterbody Conservation Status: Showing Percent of a population (bar) falling in each of 5 classes based on the percent of an individual waterbody's 100m buffer land which is falling in conservation GAP 1-3 status.



	MID-ATLANTIC SUBREGION	NEW ENGLAND/NY SUBREGION	NORTHEAST REGION	POND TOTAL	LAKE TOTAL
>= 70% : highly conserved	16	23	21	20	25
>=40 - 70%	3	6	5	5	7
>=10 - 40%	5	9	7	7	9
>0 - 10%	5	8	7	6	10
0%	71	53	60	63	49

Map 7.2. Lake and Ponds by their Individual Waterbody Conservation Status. Conservation status for a waterbody is based on the percentage of its 100m shoreline buffer land that is under GAP 1-3 status conservation.

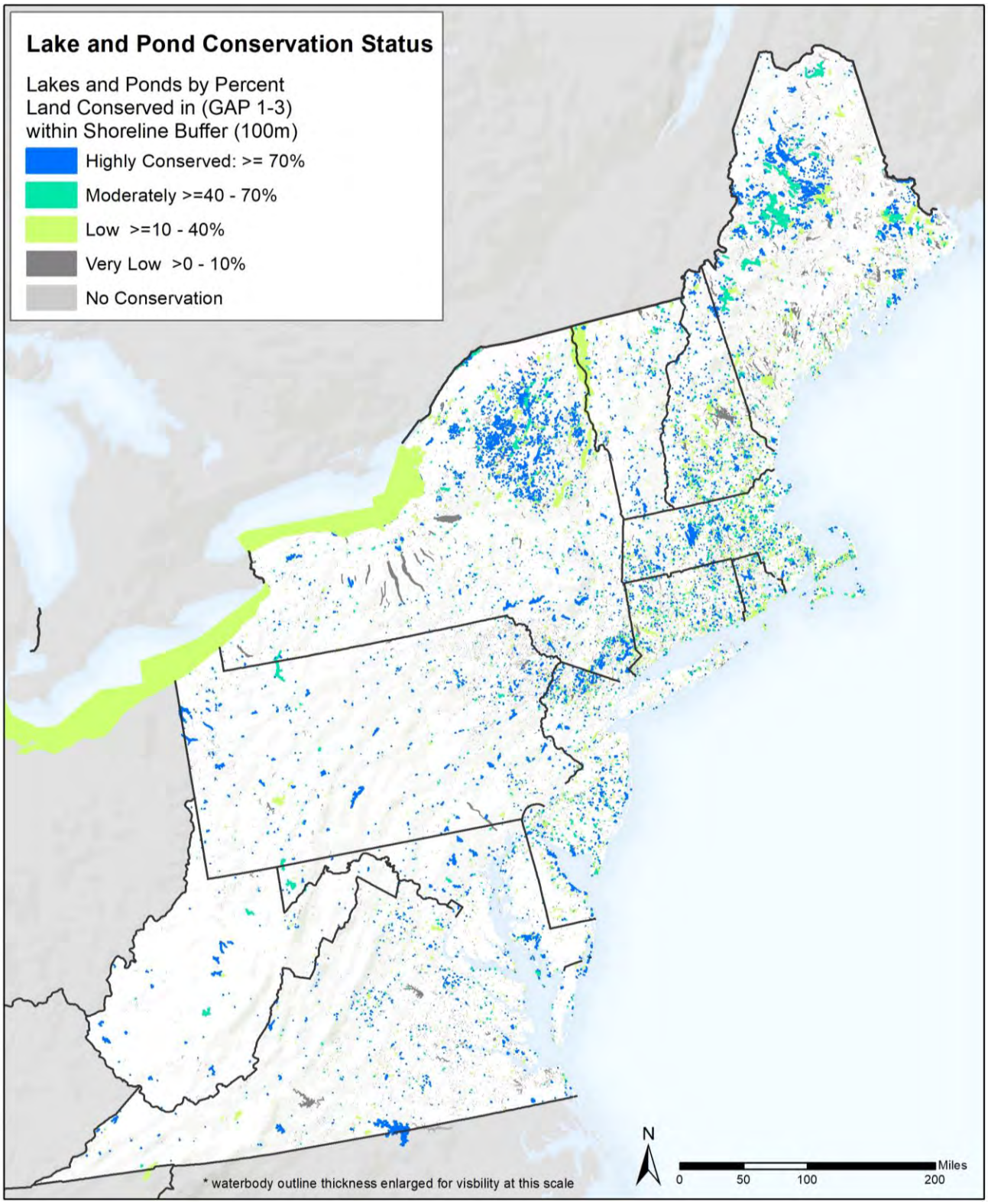


Table 7.6. Lakes and Ponds by Individual Waterbody Conservation Status

Individual Waterbody Conservation Status: Shoreline Buffer (100m) Land Area in Conservation Land GAP 1-3	1. Highly Conserved: >= 70% Waterbody's buffer land conserved		2. Moderately Conserved >=40 - 70%		3. Low Conservation >=10 - 40%		4. Very Low Conservation >0 - 10%		5. No Conservation		Total	
	Acres	Count	Acres	Count	Acres	Count	Acres	Count	Acres	Count	Acres	Count
1. Small Pond	14,541	2,686	3,275	615	4,803	900	3,875	741	56,348	11,333	82,842	16,275
2. Large Pond	129,225	2,958	33,346	729	60,634	1,063	48,671	846	206,878	6,880	478,754	12,476
POND TOTAL	**143,766**	**5,644**	**36,621**	**1,344**	**65,437**	**1,963**	**52,546**	**1,587**		**18,213**	**561,596**	**28,751**
3. Small Lake	42,722	1,454	11,709	359	15,029	444	14,052	400	82,501	3,223	166,014	5,880
4. Medium Lake	115,703	392	33,332	108	69,943	233	99,131	314	157,486	582	475,596	1,629
5. Large Lake	209,532	85	95,931	36	162,535	52	231,515	77	97,095	49	796,609	299
6. Very Large Lake	95,496	4	209,290	8	113,621	5	264,030	10	19,748	1	702,186	28
LAKE TOTAL	**463,453**	**1,935**	**350,263**	**511**	**361,129**	**734**	**608,729**	**801**		**3,855**	**2,140,405**	**7,836**
NORTHEAST REGION	**607,219**	**7,579**	**386,884**	**1,855**	**426,566**	**2,697**	**661,274**	**2,388**	**620,057**	**22,068**	**2,702,000**	**36,587**
MID-ATLANTIC SUBREGION	198,620	2,378	40,353	443	44,249	689	101,514	684	178,484	10,256	563,221	14,450
NEW ENGLAND/NY SUBREGION	408,599	5,201	346,531	1,412	382,317	2,008	559,760	1,704	441,572	11,812	2,138,779	22,137

We assessed the location of the waterbodies with high levels of conservation to understand the current distribution and the gaps (Map 7.3, Figure 7.3, Table 7.7). Across lake size classes large lakes over 1000 acres have the highest (28%) conserved shoreline, except for the very largest lakes over 10,000 acres which have the lowest (14%) as it is rare to find these huge waterbodies fully within conservation lands.

The most conserved groups, by size and subregion, include large, medium and very large lakes of the Mid-Atlantic, and small lakes of New England and New York (Figure 7.3, Table 7.7). This is partly explained by the fact that the Mid-Atlantic has fewer numbers of large waterbodies than New England and New York, and many of these serve as water supply and key recreational areas around which conservation lands have been developed. The least conserved lake and pond size types include very large lakes of New England and New York, small ponds, and small lakes of the Mid-Atlantic.

Recent Trends in Riparian Shoreline Conservation

Conservation in the last decade (2012-2022) shows promising trends, as 446 waterbodies moved into the highest category (>70% conserved) based on new conservation in their riparian shoreline (Table 7.7). This includes 300 waterbodies in New England and New York and 146 in the Mid-Atlantic. These newly conserved lakes and ponds make up 6% of the total conserved waterbodies. They are widely distributed across the regions (Map 7.4) with some in every state but West Virginia. Maine, Virginia, Massachusetts and New Hampshire showed the highest gains with over 40 newly conserved waterbodies in each of these states. Most of the newly conserved waterbodies are ponds which made up 83% of the total number gained. Small lakes (54) and medium lakes (21) account for fewer of the newly conserved waterbodies but a large% of the total area gained. Only two large lakes, Bald Mountain Pond, Maine, and Alcove Reservoir, New York, moved into the highly conserved category in the last decade.

In addition to the highly conserved shorelines, over 800 waterbodies showed over 10% increased conservation within the shoreline buffer zone in the last decade including 454 that increased between 50-69%. The latter got close to, but not quite over, the 70% threshold we set for being counted as “highly conserved”.

Map 7.3. Highly Conserved Lakes and Ponds. Showing lakes and ponds with >70% of their shoreline buffer (100m) land in >= 70% GAP 1-3 Conservation Land

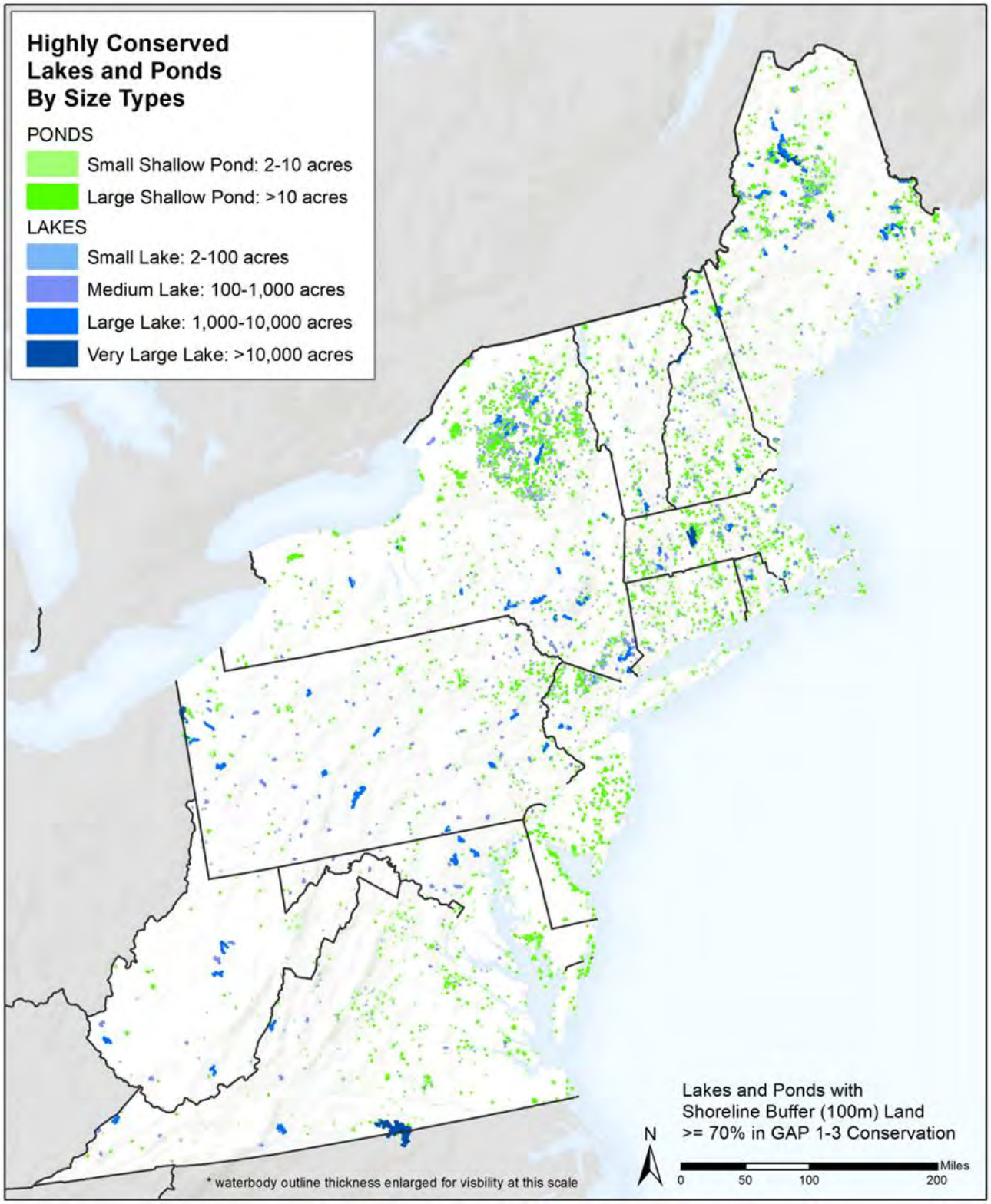


Figure 7.3. Highly Secured Lakes and Pond by Type and Subregion

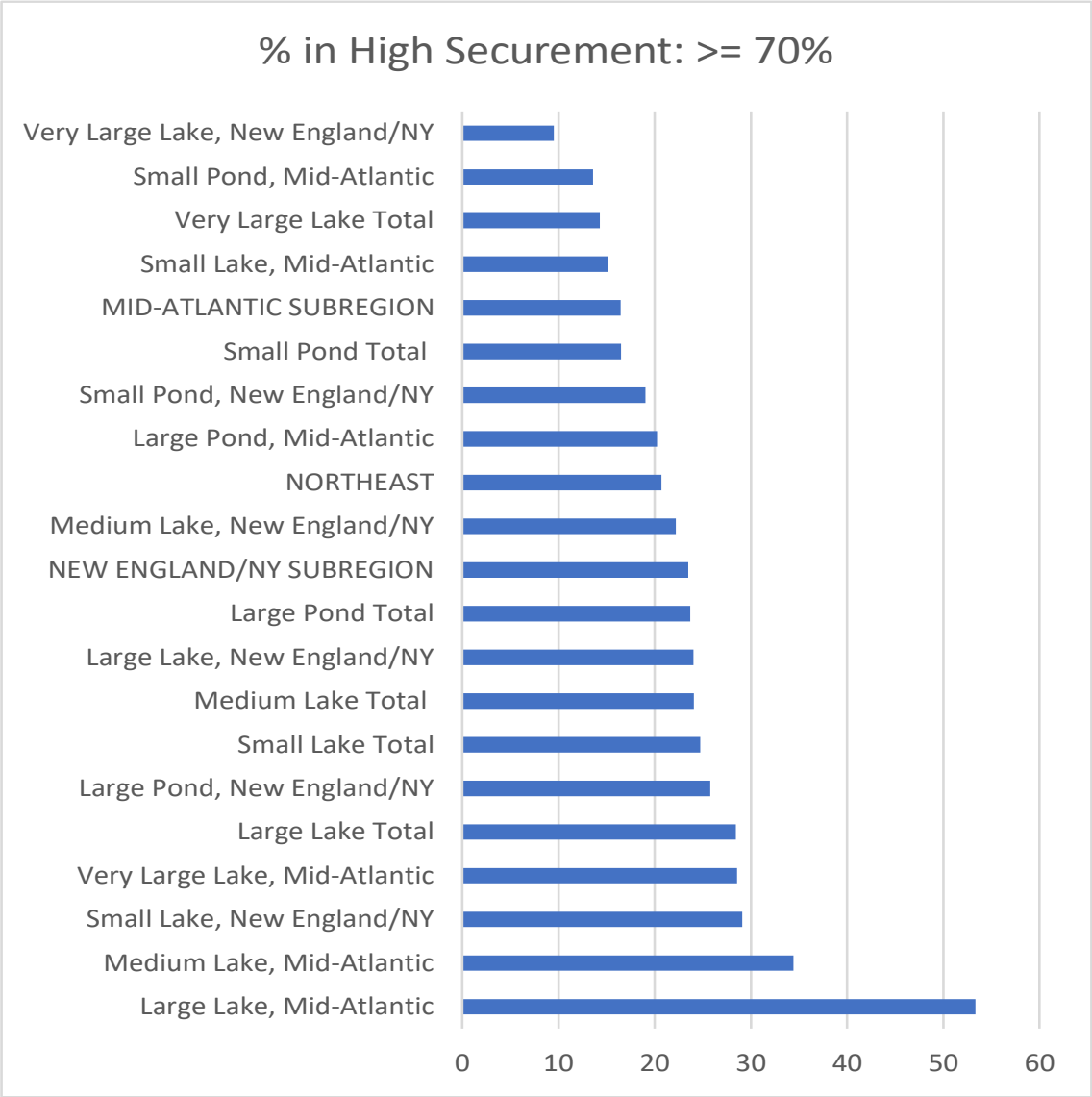
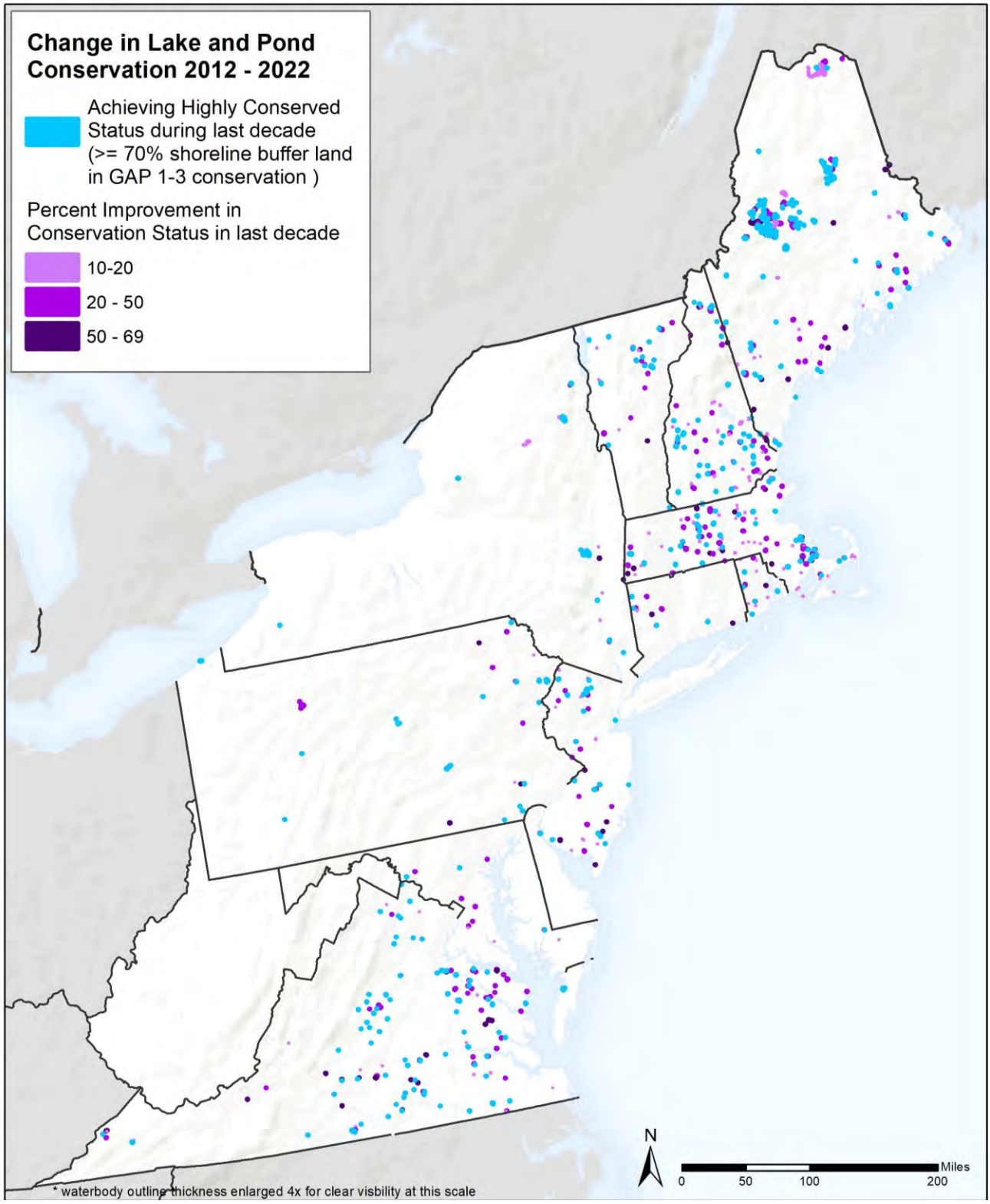


Table 7.7. Highly Secured Lakes and Pond by Type and Subregion.

Pond and Lake Types by Subregion	Total #	# in High Securement: >= 70%	% in High Securement: >= 70%	# entering High Securement Class between 2012 and 2022
1. Small Pond, Mid-Atlantic	7612	1036	14	77
1. Small Pond, New England/NY	8663	1650	19	121
1. Small Pond Total	16275	2686	17	198
2. Large Pond, Mid-Atlantic	4695	951	20	52
2. Large Pond, New England/NY	7781	2007	26	119
2. Large Pond Total	12476	2958	24	171
3. Small Lake, Mid-Atlantic	1841	279	15	11
3. Small Lake, New England/NY	4039	1175	29	43
3. Small Lake Total	5880	1454	25	54
4. Medium Lake, Mid-Atlantic	250	86	34	6
4. Medium Lake, New England/NY	1379	306	22	15
4. Medium Lake Total	1629	392	24	21
5. Large Lake, Mid-Atlantic	45	24	53	
5. Large Lake, New England/NY	254	61	24	2
5. Large Lake Total	299	85	28	2
6. Very Large Lake, Mid-Atlantic	7	2	29	
6. Very Large Lake, New England/NY	21	2	10	
6. Very Large Lake Total	28	4	14	
NORTHEAST	36587	7579	21	446
MID-ATLANTIC SUBREGION	14,450	2,378	16	146
NEW ENGLAND/NY SUBREGION	22,137	5,201	23	300

Map 7.4. Change in Conserved Lakes and Ponds in the last decade. Showing lakes and ponds meeting highly conserved status between 2012-2022, along with other lakes and ponds that had an increase in conservation lands in the last decade.



Lake Condition: Shoreline Disturbance

Shoreline development adds impervious surfaces, piers, wells, septic systems, and lawns along the edge of a waterbody. Removing native vegetation can decrease food and shelter for native species, increase erosion, and impervious surface runoff increases delivery of fertilizers, excess nutrients, pesticides and other pollutants into the lake or pond. Shoreline development has been linked to a number of changes in aquatic biota and ecosystems including measurable declines in fish abundance and diversity, loss of amphibian diversity, and avoidance by loons and some other waterfowl (Capiella and Schueler 2004, CLUE 2004).

The National Lake Assessment (NLA) uses "Lakeshore disturbance" as a key physical habitat assessment metric to evaluate lake and pond condition. In our previous Northeast Conservation Status report (Anderson and Olivero-Sheldon, 2011) we developed a landcover based shoreline disturbance index using a regression analysis to link GIS measurements of development to NLA field sampled lakeshore disturbance values. The field-measured scores had a statistically significant relationship to the GIS-based impact index (R squared = 0.56, $p < 0.0001$, log scale) and three reporting class thresholds were created to replicate the three reporting classes used in the NLA assessment.

We repeat here the calculation of that GIS based shoreline disturbance index, this time using a time sequence of NLCD 2001, 2011, and 2019 land cover to detect trends in disturbance on lands within the 100 m lakeshore buffer zone. Only lands consistently classified as land (not water) across all time periods were included for consistency in total land assessment area.

We use a numeric impact index that sums the percent of development and agriculture in the buffer zone (NLCD cover classes 81/82, 21/22, 23/24) and weights the categories to reflect the degree of impact as follows:

*SDI = 0.5 * % agriculture + 0.75* % low intensity development+ 1.0* % high intensity development*

The Shoreline Development Impact index (SDI) ranges from 100 for a lake with its shoreline zone completely developed, to 0 where the shoreline zone is completely composed of natural cover types. Reporting classes are as follows (Anderson and Olivero-Sheldon, 2011)

1. Low disturbance: SDI 0 < 3.7 (mean 1.3)
2. Moderate disturbance: SDI >= 3.7 < 15.0 (mean 8.4)
3. High disturbance: SDI >=15.0 (mean 26.2)

Applying the index to the region's waterbodies indicates that 33% fall in the low disturbance class, 23% in the moderate disturbance class, and 44% in the high disturbance class. (Figure 7.4, Table 7.8, Map 7.5). Lakes had fewer waterbodies in the high disturbance class (41%) than ponds (45%) Similarly, New England and New York also had fewer waterbodies in the high disturbance class (37%) than the Mid Atlantic (55%). Small ponds had a high level of shoreline impacts (51%), possibly reflecting their dispersed distribution often within suburban neighborhoods and agricultural landscapes. Very large lakes had 54% in the high disturbance class reflecting recreational development along their shorelines.

Map 7.5. Lakes and Ponds by Disturbance Class.

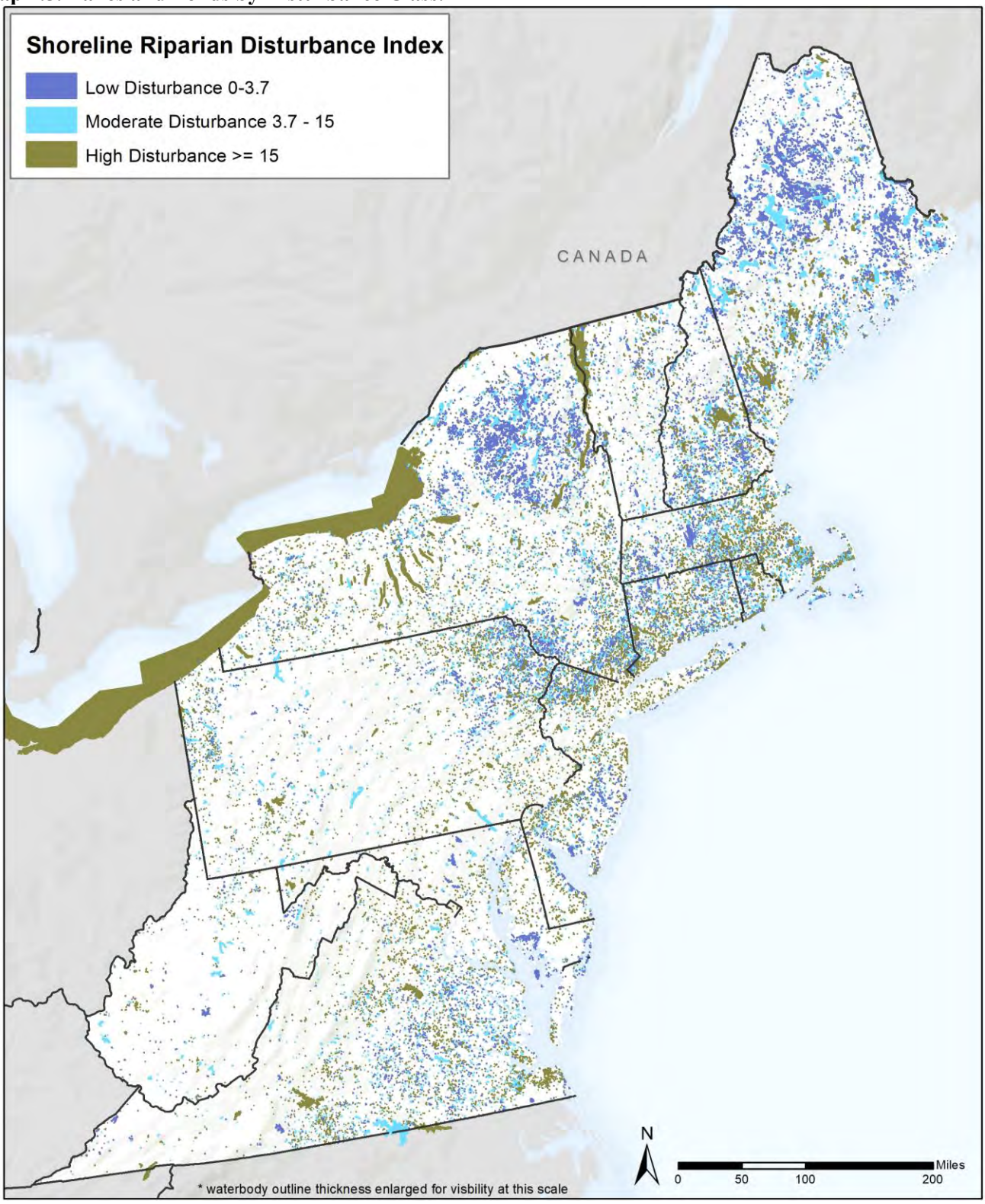


Figure 7.4. The percentage lakes and ponds that fall within each shoreline disturbance class.

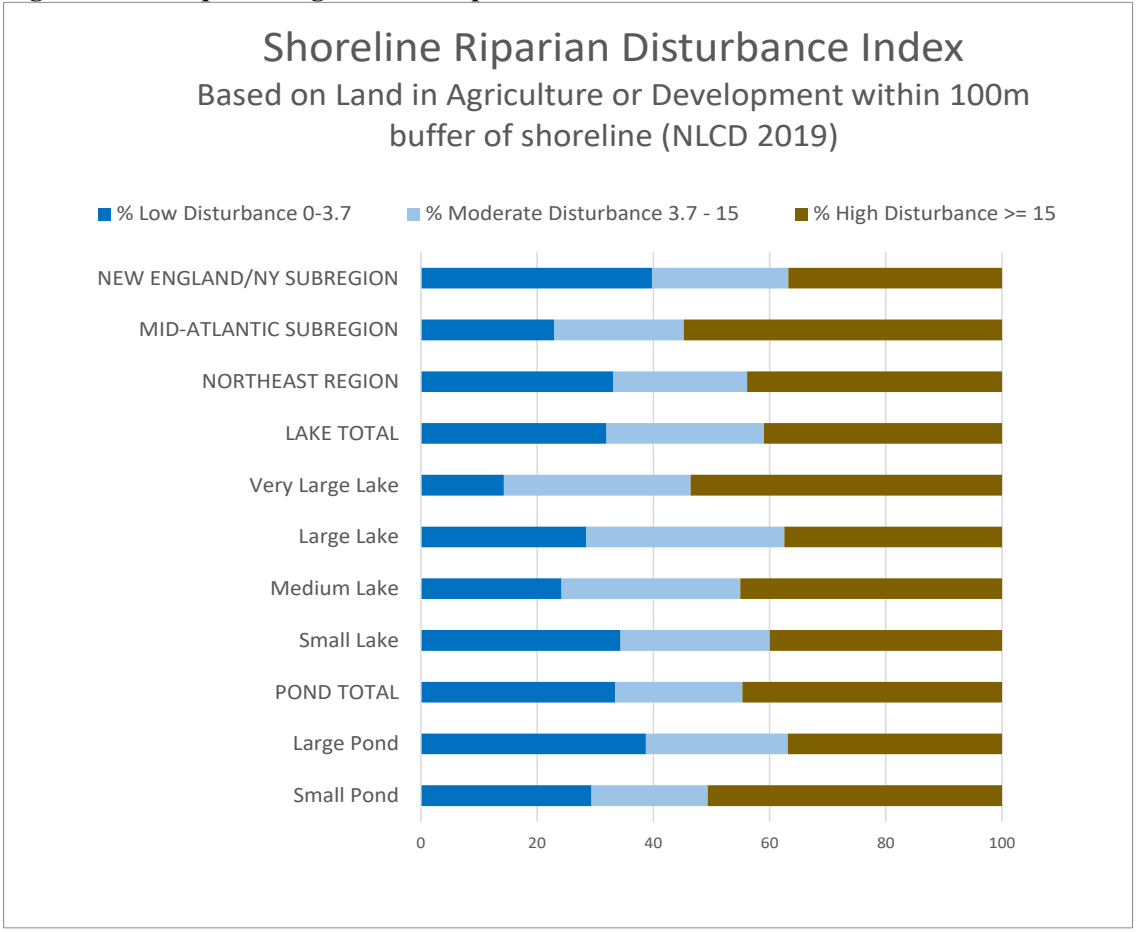


Table 7.8. The percentage and number lakes and ponds that fall within each shoreline disturbance class.

Shoreline Riparian Disturbance Index	% Low Disturbance 0-3.7	% Moderate Disturbance 3.7 - 15	% High Disturbance >= 15	# Low Disturbance 0-3.7	# Moderate Disturbance 3.7 - 15	# High Disturbance >= 15	# Waterbodies Total
Small Pond	29	20	51	4,780	3,251	8,244	16,275
Large Pond	39	24	37	4,830	3,049	4,597	12,476
POND TOTAL	33	22	45	9,610	6,300	12,841	28,751
Small Lake	34	26	40	2,019	1,511	2,350	5,880
Medium Lake	24	31	45	394	501	734	1,629
Large Lake	28	34	37	85	102	112	299
Very Large Lake	14	32	54	4	9	15	28
LAKE TOTAL	32	27	41	2,502	2,123	3,211	7,836
NORTHEAST REGION	33	23	44	12,112	8,423	16,052	36,587
MID-ATLANTIC SUBREGION	23	22	55	3,309	3,228	7,913	14,450
NEW ENGLAND/NY SUBREGION	40	23	37	8,803	5,195	8,139	22,137

We found strong correspondence between the highly conserved lakes and ponds (>70% conserved shoreline) and low shoreline disturbance index, with 65% falling in the low disturbance category. However, 35% fell in the moderate or high shoreline disturbance category suggesting that intense development may be present along the unconserved portion of the shore (<30%) or perhaps some fragmentation in the multi-use conservation lands. Waterbodies with less than 70% of their shoreline conserved had only 25% in the low impact category and nearly four times as many in the high disturbance category.

Recent Trends in Shoreline Disturbance

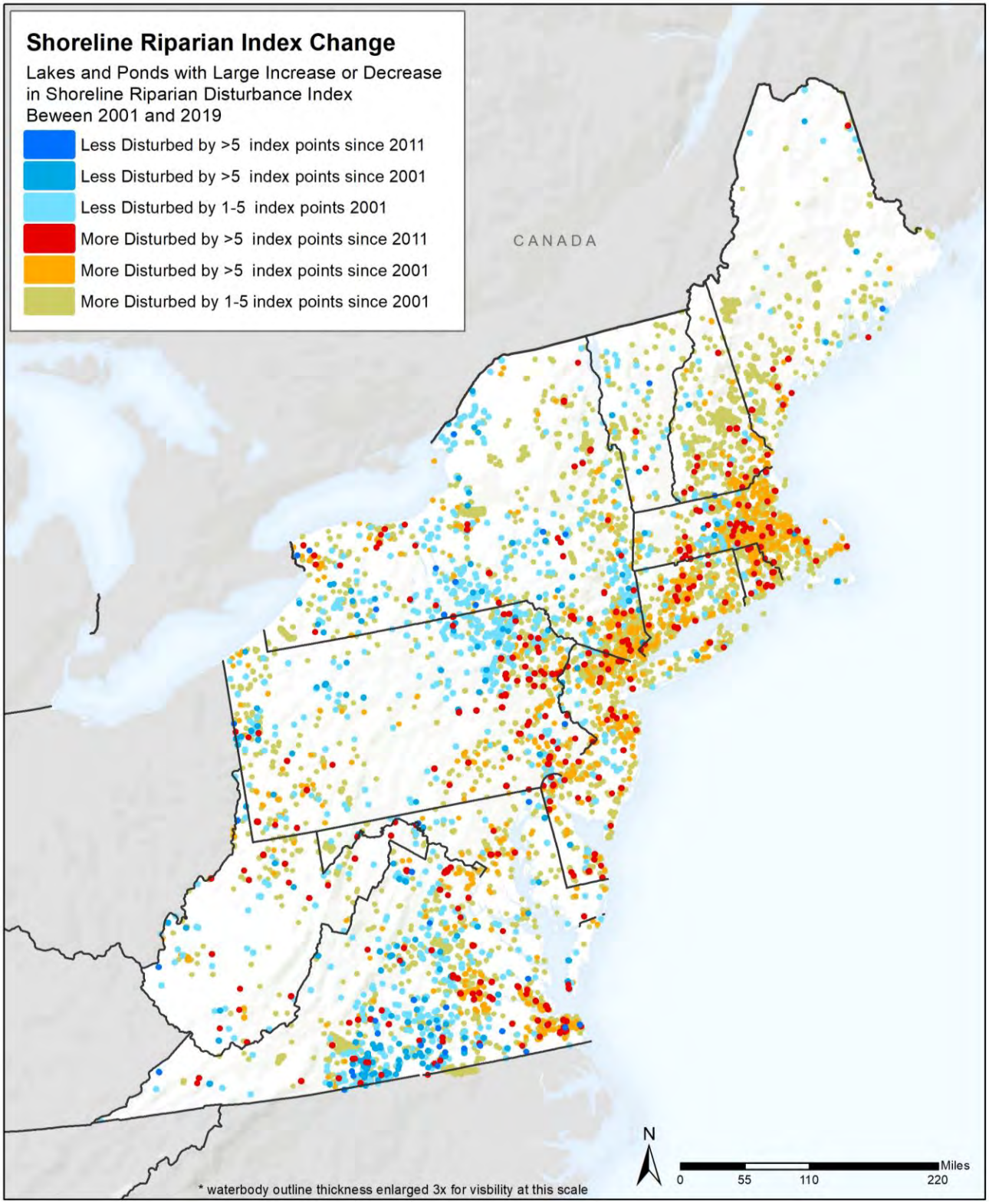
Over the last 20 years (2001-2022) habitat conversion in the shoreline has continued, and 36% of the region's lakes and ponds (13,182 waterbodies) had a higher shoreline disturbance index in 2019 than in 2001. Although 796 remained in the low shoreline disturbance category despite small increases in agriculture or development, many saw more extensive changes in their shoreline disturbance index. Since 2001, 235 waterbodies changed from a low to moderate disturbance class, 488 moved into the high disturbance class, and many other decreased in score but remained in the same class. Overall 4% of waterbodies have had increased disturbance at a level raising their index value by >5 points and another 9% have had increased disturbance at a level raising their index by >1 point (Map 7.6, Table 7.9). In total, 13% waterbodies that increased in disturbance have change over 1 point (9%) or 5 points (4%). The waterbodies that changed at over 5 points (red and orange in Map 7.6) are spread across the region but appear closer to suburban areas and major road corridors. Those waterbodies that have had the most change (>5 points) since 2011 (red on Map 7.6) represent 1% of all waterbodies (Table 7.9), with a higher percentage in the Mid-Atlantic where 1.6% of all waterbodies are in this more recent high disturbance change class.

A small group of 2,261 lakes and ponds (6%) improved in their shoreline disturbance index since 2001. Of these 1,187 improved over one point and 227 (17 lakes and 210 ponds) improved over five points (Map 7.6, blue points, Table 7.9). Land use data indicates that these improvements are mostly due to less agriculture.

Table 7.9. Lakes and ponds that have had a large change in their shoreline disturbance index 2001-2019.

Lakes and Ponds with Large Increase or Decrease in Shoreline Riparian Disturbance Index Beween 2001 and 2019		# More Disturbed by >5 index points since 2011	# More Disturbed by >5 index points since 2001	# More Disturbed by >1-5 index points since 2001	Total # of More Disturbed Classes	# Less Disturbed by >5 index points since 2011	# Improved, Less Disturbed >5 points since 2001	# Less Disturbed by >1-5 index points since 2001	Total #of Less Disturbed Classes	Total # of Waterbodies
Mid-Atlantic	Pond	208	437	1122	1767	27	128	523	678	12307
	Lake	21	57	252	330	2	10	89	101	2143
Mid-Atlantic Subregion		229	494	1374	2097	29	138	612	779	14450
New England/NY	Pond	119	515	1267	1901	12	43	286	341	16444
	Lake	31	124	602	757	1	4	62	67	5693
New England/NY Subregion		150	639	1869	2658	13	47	348	408	22137
POND TOTAL		327	952	2389	3668	39	171	809	1019	28751
LAKE TOTAL		52	181	854	1087	3	14	151	168	7836
NORTHEAST TOTAL		379	1133	3243	4755	42	185	960	1187	36587
Lakes and Ponds with Large Increase or Decrease in Shoreline Riparian Disturbance Index Beween 2001 and 2019		% More Disturbed by >5 index points since 2011	% More Disturbed by >5 index points since 2001	% More Disturbed by >1-5 index points since 2001	% In Total of More Disturbed Classes	% Less Disturbed by >5 index points since 2011	% Improved, Less Disturbed >5 points since 2001	% Less Disturbed by >1-5 index points since 2001	% In Total of Less Disturbed Classes	
Mid-Atlantic	Pond	1.7	3.6	9.1	14.4	0.2	1.0	4.2	5.5	
	Lake	1.0	2.7	11.8	15.4	0.1	0.5	4.2	4.7	
Mid-Atlantic Subregion		1.6	3.4	9.5	14.5	0.2	1.0	4.2	5.4	
New England/NY	Pond	0.7	3.1	7.7	11.6	0.1	0.3	1.7	2.1	
	Lake	0.5	2.2	10.6	13.3	0.0	0.1	1.1	1.2	
New England/NY Subregion		0.7	2.9	8.4	12.0	0.1	0.2	1.6	1.8	
POND TOTAL		1.1	3.3	8.3	12.8	0.1	0.6	2.8	3.5	
LAKE TOTAL		0.7	2.3	10.9	13.9	0.0	0.2	1.9	2.1	
NORTHEAST TOTAL		1.0	3.1	8.9	13.0	0.1	0.5	2.6	3.2	

Map 7.6. Lakes and Ponds by Shoreline Disturbance Index Change. This map highlights lakes and ponds that have had a large increase or decrease in their shoreline riparian disturbance index between 2001 and 2019.



Lake Condition: Impervious Surfaces

Lake and pond ecosystems are influenced by upstream terrestrial processes given their low landscape position and the upstream flow paths of both ground and surface waters that contribute to their volume. The proportion of impervious surfaces (e.g. roads, parking lots, driveways) in a lake's upstream watershed has been associated with the degradation of water quality, ecological processes, and loss of diversity (CWP, 2003). Reduced infiltration of rainwater leads to more frequent overland flow and increased sediment loading. Chemical pollution also tends to be higher in areas with higher impervious surfaces (Dugan et al. 2017). Although less research has been done on lakes than on streams, many studies have found detectable impacts on aquatic biota at impervious surface levels above 10% of the upstream watershed area, while others have detected significant impacts and loss of taxa at levels lower levels of 2% of the watershed or even 0.5% (Southerland and Stranko 2008, King and Baker 2010).

In the previous Northeast Conservation Status report (Anderson and Olivero-Sheldon, 2011), the 2001 NLCD impervious surface dataset was used to assess the upstream impacts on lakes and ponds. We repeat that metric in this study using data available from the US EPA LakeCat database which provides the upstream watershed percent imperviousness for each NHD-Plus V2.1 waterbody based on the reprocessed and consistently calibrated National Land Cover Impervious Surface Datasets 2001-2019, (Hill et al. 2018, LakeCat imperviousness dataset 1/7/2023). Only lakes and ponds in the source NHD-Plus V2.1 medium resolution dataset linked to LakeCat were included in this analysis. This excluded a number of smaller lakes (28) and ponds (4,105) in our regional dataset that had come from finer scale waterbody datasets such as NWI and other sources.

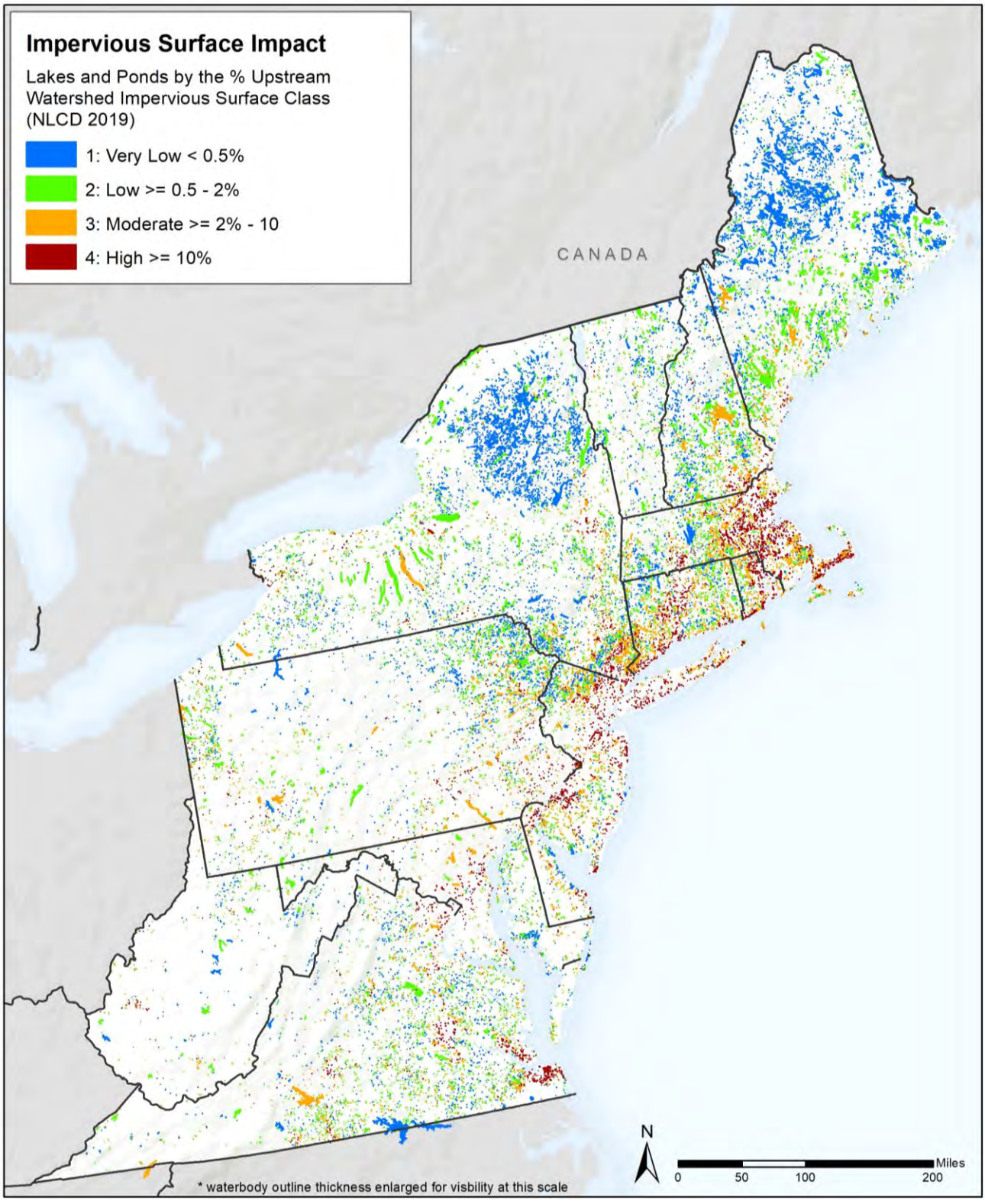
We grouped each lake or pond into one of four impervious impact categories guided by the thresholds found in King and Baker (2010) and as used in the 2011 regional Conservation Status report (Anderson and Olivero-Sheldon 2011).

- Class 1: Undisturbed or Least impacts: 0 < 0.5% impervious.
- Class 2: Low impacts: >=0.5-2% impervious.
- Class 3: Moderately impacted: >=2-10% impervious.
- Class 4: Highly impacted: >=10% impervious.

The results revealed that in 2019, 38% of all lakes and ponds were in the least impacted impervious surface impact category and 26% were in the next least impacted class (Map 7.7, Figure 7.5, Table 7.10). Conversely, 14% were in the most highly impacted class and 21% in the next most impacted class. Lakes had more waterbodies in the least impacted class (43%) than ponds (37%) and similarly ponds had more waterbodies in the highest impact class (16%) than lakes (9%), highlighting that ponds with their smaller watersheds were more sensitive to impervious impacts. Large and very large lakes had the most occurrences in the least impacted class (46%).

New England and New York had more lakes and ponds in the least impacted class (43%) than the Mid-Atlantic (30%, Map 7.7, Table 7.10). The two subregions had quite similar amounts in the most impacted class with 16% in the Mid-Atlantic and 14% in New England and New York. The states of Maine, Vermont, New Hampshire, New York, and Pennsylvania all had less than 10% of both their lakes and ponds in the most severely impact class. New Jersey, Virginia, and West Virginia had less than 10% of their lakes in the most severely impact class.

Map 7.7. Lakes and Ponds by Impervious Surface Impact Class (NLCD 2019)



.

Figure 7.5. Percentage of Lakes and Ponds by Upstream Impervious Class 2019

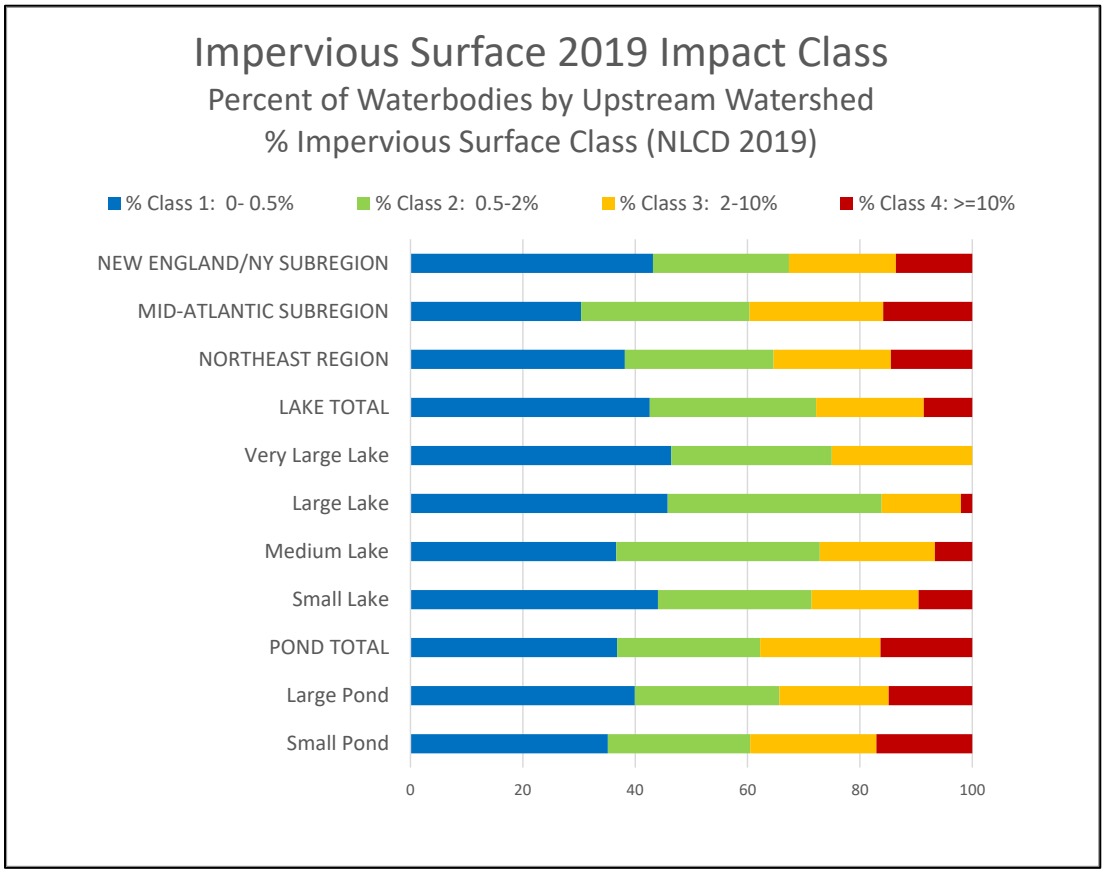


Table 7.10. Number and % of Lakes and Ponds by Upstream Impervious Class 2019

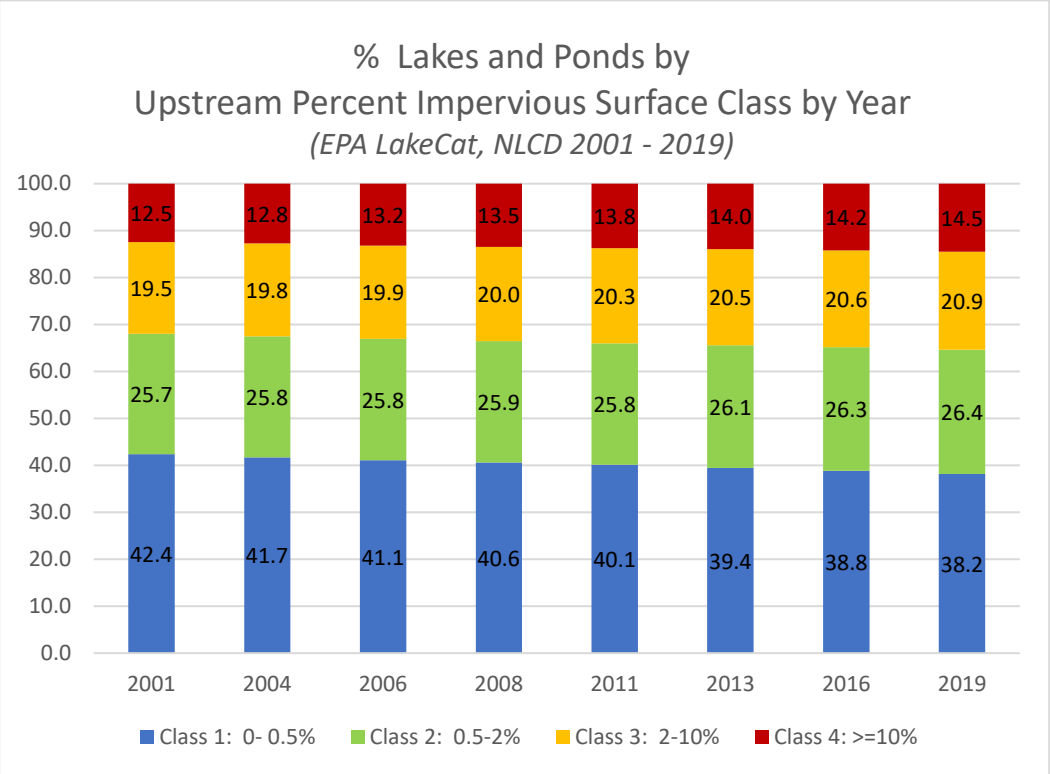
Percent Upstream Watershed Imperviousness (2019)	% Class 1: 0- 0.5%	% Class 2: 0.5-2%	% Class 3: 2-10%	% Class 4: >=10%	# Class 1: 0-0.5%	# Class 2: 0.5-2%	# Class 3: 2-10%	# Class 4: >=10%	# Waterbodies Total
Small Pond	35	25	22	17	5,699	4,101	3,639	2,770	16,209
Large Pond	40	26	19	15	3,368	2,171	1,641	1,257	8,437
POND TOTAL	37	25	21	16	9,067	6,272	5,280	4,027	24,646
Small Lake	44	27	19	10	2,582	1,603	1,115	562	5,862
Medium Lake	37	36	20	7	594	587	332	108	1,621
Large Lake	46	38	14	2	136	113	42	6	297
Very Large Lake	46	29	25	0	13	8	7		28
LAKE TOTAL	43	30	19	9	3,325	2,311	1,496	676	7,808
NORTHEAST REGION	38	26	21	14	12,392	8,583	6,776	4,703	32,454
MID-ATLANTIC SUBREGION	30	30	24	16	3,828	3,780	2,996	2,002	12,606
NEW ENGLAND/NY SUBREGION	43	24	19	14	8,564	4,803	3,780	2,701	19,848

Recent Trends in Impervious Surfaces

Over the last two decades (2001-2019), impervious surfaces have increased consistent with the expansion of development and suburban sprawl in the northeast. The two most impacted classes each grew from 32% in 2001 to 35% of all lakes and ponds in 2019 (Figure 7.6). Considering the last decade 2011-2019, in total 4% of all lakes and ponds were in a more impacted class in 2019 compared to their class in 2011. Effected waterbodies are widely distributed across the region with only lands under conservation very remote and mountainous areas seeing no change (Map 7.8, Table 7.11). No waterbodies changed to a lower impervious surface class, highlighting how difficult it is to remediate impervious surfaces.

There was good correspondence between the highly conserved lakes and ponds (>70% conserved shoreline) and low impervious surfaces, with 66% falling in the lowest disturbance category in 2019, much higher than the regional average (38%). Overall, 85% of highly secured lakes had less than 2% impervious surfaces upstream. There were, however 289 highly secured lakes (4%) that fell in the highly impacted class. They highlight that although these waterbodies may be locally situated within conservation land, their upstream watersheds can still have significant amounts of impervious surfaces, along with possible negative effects on the biota and ecosystem. These 289 lakes and ponds however make up just 6% of the total 4,703 waterbodies in the most highly impacted impervious class.

Figure 7.6. Percent of Lakes and Ponds by Impervious Surface Impact Class 2001-2019



Map 7.8. Lakes and Ponds by Change in Impervious Surface Impact Class (NLCD 2019)

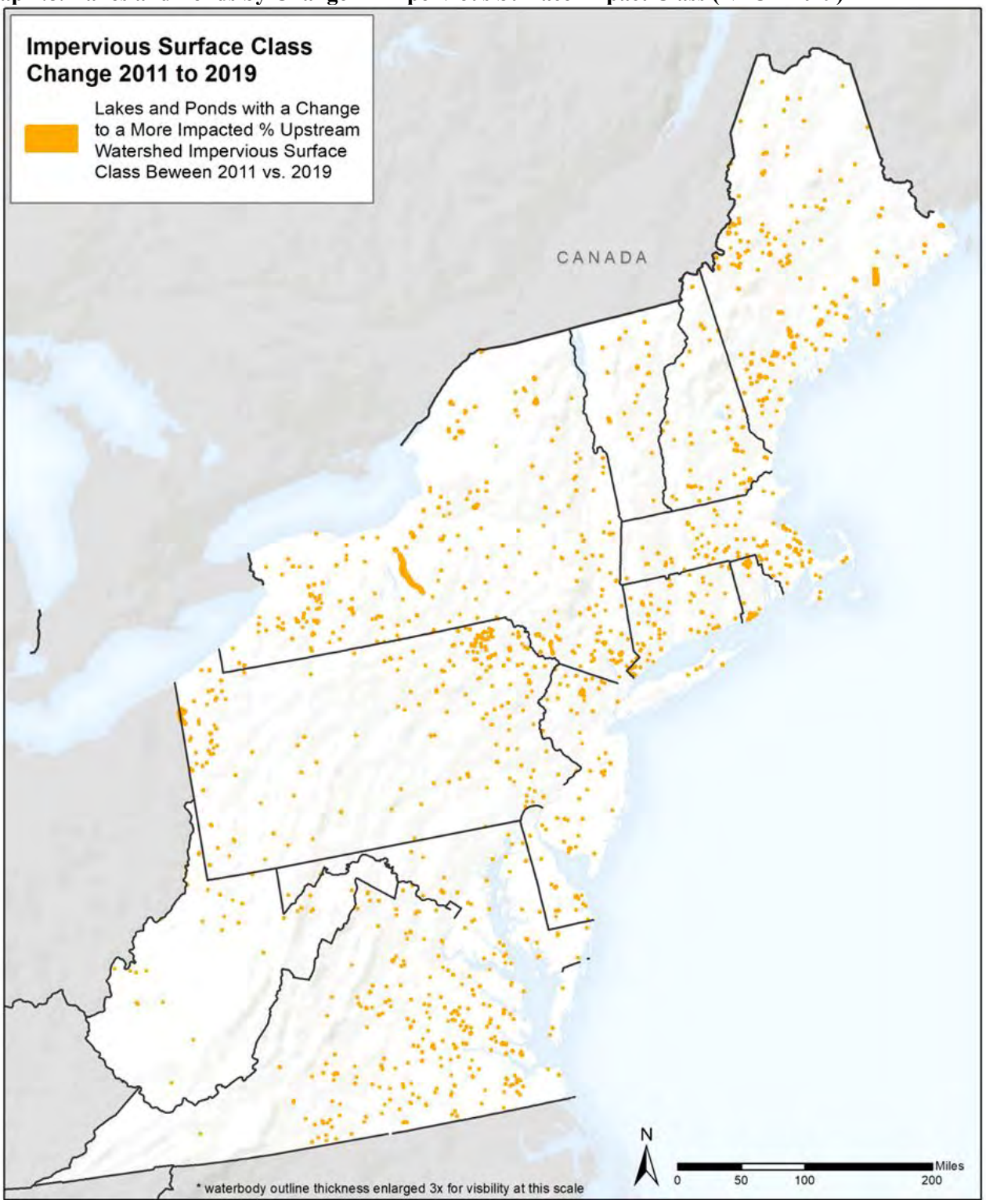


Table 7.11. Number and Percent of Lakes and Ponds by Impervious Surface Impact Class Change 2011-2019

Lakes and Ponds with a Change to More Impacted % Upstream Watershed Impervious Surface Class Beween 2011 vs. 2019		# Waterbodies Changed	Total Population of Waterbodies	% of Waterbodies Changed to a more impacted class
Mid-Atlantic	1. Pond	470	10,473	4.5
	2. Lake	112	2,133	5.3
Mid-Atlantic Total		582	12,606	4.6
New England/NY	1. Pond	481	14,173	3.4
	2. Lake	188	5,675	3.3
New England/NY Total		669	19,848	3.4
NORTHEAST TOTAL		1,251	32,454	3.9

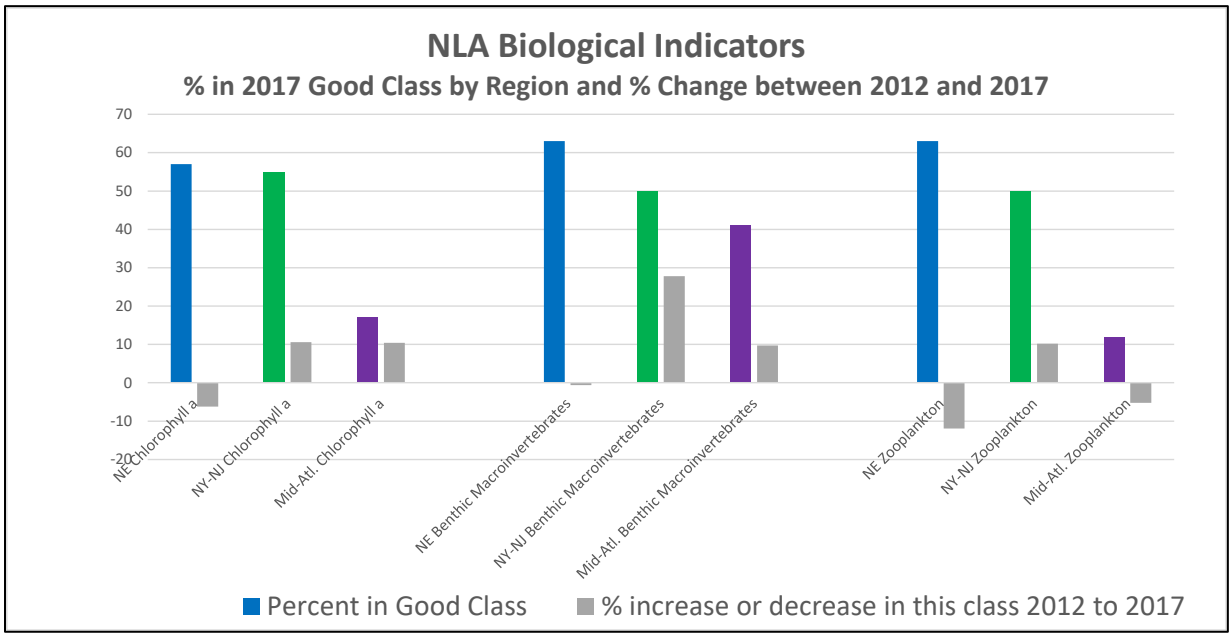
Lake Condition: National Lake Assessment

The National Lakes Assessment (NLA) is a statistical survey of the condition of our nation's lakes, ponds, and reservoirs. It is designed to "provide information on the extent of lakes that support healthy biological condition and recreation, estimate how widespread major stressors are that impact lake quality, and provide insight into whether lakes nationwide are getting cleaner" (USEPA, 2022). The assessment develops ecoregion specific condition criteria for a variety of biological, chemical, and physical metrics and places sampled waterbodies into categories of good, fair, and poor condition for each metric.

The NLA has consistently sampled a small population of 140 lakes in the northeast at repeated intervals. We report here a summary of three key biological, chemical, and physical metrics (Table 7.12) using the EPA National Lake Assessment Dashboard which provides the percent of waterbodies falling in good, fair, and poor from the most recent 2017 survey, along with the change between the results of the 2012 survey. The NLA dashboard does not allow reporting at state levels due to small sample sizes, but does provide summaries by EPA regions, ecoregions, and water resource regions. The full dashboard reports for this region can be found at the end of this chapter.
https://nationallakesassessment.epa.gov/dashboard/?&view=indicator&studypop=al&subpop=epa+region+1&label=pe&condition=good&diff=2v3

For the biological indicators of chlorophyll a, benthic macroinvertebrates, and zooplankton (Figure 7.7), the data suggest that both New England and New York/New Jersey have over 50% of waterbodies in the good biological condition class for all three metrics, while the Mid-Atlantic has 12% in good zooplankton condition, 17% in good chlorophyll condition and 41% in good benthic macroinvertebrate condition. Although change between 2012 and 2017 was not statistically significant, the New York-New Jersey region did show some improvement with more waterbodies in the good class in 2017 for all metrics. New England showed a small decrease in all metrics, and the Mid-Atlantic showed increases for chlorophyll and benthic macroinvertebrates and a decrease for zooplankton.

Figure 7.7: NLA 2017 Biological Indicators. The figure shows the percent of waterbodies > 1 ha (2.47 acre) scoring in "Good Condition" for each metric for the 3 geographic regions in 2017. The change in the percent of lakes categorized as Good Condition between 2012 and 2017 is shown by the gray bar to represent if more (+) or less (-) percent of lakes categorized as Good Condition in 2017.



Chemical indicators show a large percentage of waterbodies in good condition with respect to dissolved oxygen, ranging from 74% in New England to over 90% in New York, New Jersey and the Mid-Atlantic. Nitrogen and phosphorus are in good condition for roughly half the waterbodies in New England, New York and New Jersey, and 12-13% for the Mid-Atlantic. Between 2012 and 2017, New England had a significant 37% decrease in the number of waterbodies in good condition for nitrogen. New England also showed larger but non-significant declines in oxygen and phosphorus than the Mid Atlantic which had very small increases or decreases. The decrease in the number of waterbodies scoring in good condition for oxygen, nitrogen, and phosphorus will be important to monitor.

Physical habitat variables of lakeshore disturbance, riparian vegetation cover, and habitat complexity based on the sampled waterbodies show patterns similar to our spatially comprehensive analysis presented earlier. In general, less than half of waterbodies score in good condition (compared to 33% in our GIS analysis). Only 5% of Mid-Atlantic lakes scored in good condition for lakeshore disturbance compared to our 23%. New England, New York and New Jersey were relatively similar in lakeshore disturbance and riparian vegetation cover with 37-54% of waterbodies in good condition for these metrics, and New York scoring particularly high for habitat complexity. Change was relatively consistent between 2012-2017 for each geographic regions with all three indicators improving for New York and New Jersey but decreasing for New England. The Mid Atlantic decreased for lakeshore disturbance and habitat complexity but increased slightly for riparian vegetation cover.

Figure 7.8: NLA 2017 Chemical Indicators The figure shows the percent of waterbodies scoring in "Good Condition" for each indicator in each geographic region in 2017. Change in the percent of lakes in Good Condition between 2012 and 2017 is shown by the gray bar to represent if more (+) or less (-) lakes changed in 2017.

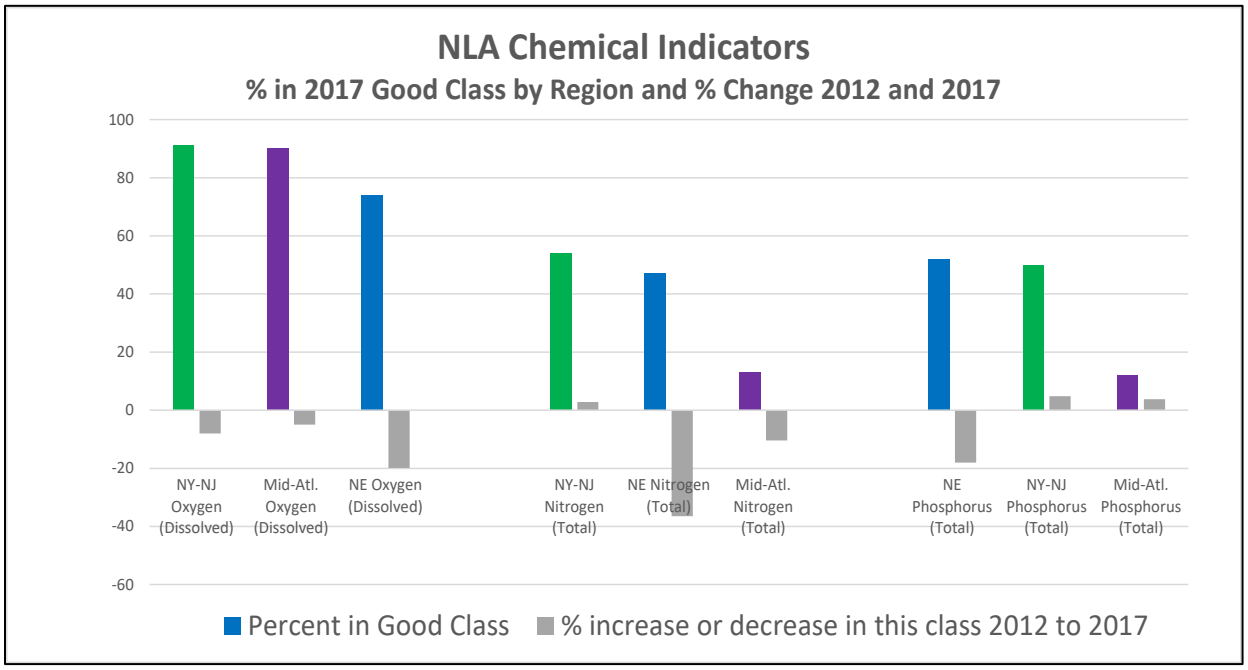


Figure 7.9: NLA 2017 Physical Indicators. The figure shows the percent of waterbodies scoring in "Good Condition" for each indicator in each geographic region in 2017. Change in the percent of lakes in Good Condition between 2012 and 2017 is shown by the gray bar to represent if more (+) or less (-) lakes changed in 2017.

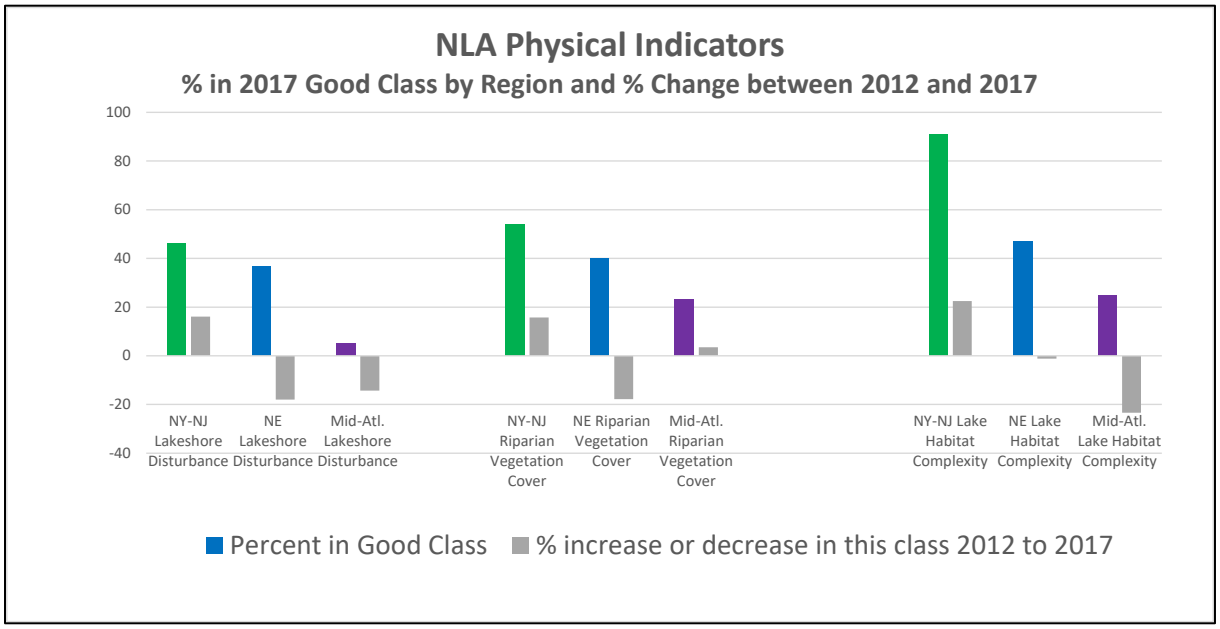


Table 7.12: Summary of Select 2017 National Lake Assessment Biological, Chemical, and Physical Condition Metrics.

All lakes >1 hectare (2.47 acres)		2017 Percent of Total			Change from 2012 2017		
		Good	Fair	Poor	Good	Fair	Poor
New England		% in each class			% in each class increase or decreased by X		
Biological Indicators	Chlorophyll a	57	8	35	-6.2	-11.6	17.9
	Benthic Macroinvertebrates	63	7	30	-0.6	-9.3	13.9
	Zooplankton	63	11	27	-11.9	-5.1	17
Chemical Indicators	Oxygen (Dissolved)	74	2	24	-19.9	-3.8	23.8
	Nitrogen (Total)	47	24	29	-36.5	11.2	25.3
	Phosphorus (Total)	52	18	30	-18	-2.9	20.9
Physical Indicators	Lake Habitat Complexity	47	38	15	-1.2	10.3	-9.1
	Lakeshore Disturbance	37	57	7	-18	13.8	4.2
	Riparian Vegetation Cover	40	55	5	-17.8	34.7	-16.9
NY-NJ							
Biological Indicators	Chlorophyll a	55	2	44	10.6	-14.4	3.8
	Benthic Macroinvertebrates	50	40	7	27.8	22.2	-31.3
	Zooplankton	50	43	8	10.2	-7.8	-2.5
Chemical Indicators	Oxygen (Dissolved)	91	8	2	-8	7.5	1
	Nitrogen (Total)	54	1	44	2.8	-4.1	1.4
	Phosphorus (Total)	50	5	45	4.8	-1.8	-3.1
Physical Indicators	Lake Habitat Complexity	91	2	6	22.5	-13	-9.5
	Lakeshore Disturbance	46	46	9	16.1	-16.5	0.3
	Riparian Vegetation Cover	54	41	4	15.7	4.5	-20.2
Mid-Atlantic							
Biological Indicators	Chlorophyll a	17	3	80	10.4	-17	6.6
	Benthic Macroinvertebrates	41	50	9	9.7	29.3	-33.7
	Zooplankton	12	56	27	-5.2	26.9	-26.3
Chemical Indicators	Oxygen (Dissolved)	90	7	3	-5	5.3	1
	Nitrogen (Total)	13	13	74	-10.4	-5.6	16
	Phosphorus (Total)	12	13	75	3.8	8.5	-12.2
Physical Indicators	Lake Habitat Complexity	25	50	25	-23.4	16.5	6.9
	Lakeshore Disturbance	5	79	16	-14.3	17.7	-3.4
	Riparian Vegetation Cover	23	54	24	3.5	19.4	-22.9

orange = Indicates statistically significant difference (95% confidence) between time periods compared

Chapter 7: References

Anderson, M.G. and A. Olivero Sheldon. 2011. Conservation Status of Fish, Wildlife, and Natural Habitats in the Northeast Landscape: Implementation of the Northeast Monitoring Framework. The Nature Conservancy, Eastern Conservation Science. 289 pp.

Capiella, K., and T. Schueler. 2004. Crafting a lake protection ordinance. Technical Article in Urban Lake Management :751-768.

Center for Land Use Education (CLUE) 2004. Shoreland_Development_Density_and_Impervious_Surfaces. College of Natural Resources at the University of Wisconsin - Stevens Point and the University of Wisconsin - Madison Division of Extension https://www3.uwsp.edu/cnr-ap/clue/Documents/Water/Shoreland_Development_Density_and_Impervious_Surfaces.pdf p.19

Center for Watershed Protection (CWP). 2003. Impacts of Impervious Cover on Aquatic Systems. Watershed Protection Research monograph No. 1.

Dewitz, J., and U.S. Geological Survey, 2021, National Land Cover Database (NLCD) 2019

Products (ver. 2.0, June 2021): U.S. Geological Survey data release, https://doi.org/10.5066/P9KZCM54

Dugan, H.A., Bartlett, S.L., Burke, S.M., Doubek, J.P., Krivak-Tetley, F.E., Skaff, N.K., Summers, J.C., Farrell, K.J., McCullough, I.M., Morales-Williams, A.M. and Roberts, D.C., 2017. Salting our freshwater lakes. Proceedings of the National Academy of Sciences, 114(17), pp.4453-4458.

Hill, Ryan A., Marc H. Weber, Rick Debbout, Scott G. Leibowitz, Anthony R. Olsen. 2018. The Lake-Catchment (LakeCat) Dataset: characterizing landscape features for lake basins within the conterminous USA. Freshwater Science doi:10.1086/697966. LakeCat imperviousness dataset 1/7/2023)

Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan. 2004. Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing.

Janson R., C. Nilsson, B Renofalt. 2000. Fragmentation of riparian floras in rivers with multiple dams. Ecology **81**(4)**:**899-903.

Jiffry, F. 1984. Loss of freshwater shellfish and some ecological impacts after water drawdown in Lake Sebasticook. MS thesis edition. University of Maine, Orono,

King, R. S. and M.W. Baker. 2010. Considerations for analyzing ecological community thresholds in response to anthropogenic environmental gradients. Journal of the North American Benthological Society. **29**(4)**:**998.

Minns, C. K. 1989. Factors Affecting Fish Species Richness in Ontario Lakes. Transactions of the American Fisheries Society **118**(5)**:**533-545.

Olivero, A. P., and M. G. Anderson. 2008. Northeast Aquatic Habitat Classification System. The Nature Conservancy, in Collaboration with the Northeast Asssociation of Fish and Wildlife Agencies.

Olivero-Sheldon, A. and M.G. Anderson. 2016. Northeast Lake and Pond Classification System. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA.

Palone, R. and Todd, A. 1997. Chesapeake Bay Riparian Handbook: A Guide for Establishing and Maintaining Riparian Forest Buffers. Chesapeake Bay Program 1997.

Silk, N., and K. Ciruna. 2005. A Practioner's Guide to Freshwater Biodiversity Conservation. Island Press., Washington, DC.

Southerland, M. T., and S. A. Stranko. 2008. Fragmentation of riparian amphibian distributions by urban sprawl in Maryland, USA. in J. C. Mitchell, R. E. Jung Brown and B. Bartholomew, editors. Urban Herpetology. Society for the Study of Amphibians and Reptiles, Salt Lake City, Utah.

Stranko, S. A., R.H. Hilderbrand, R.P. Morgan III, M.W. Staley, A.J. Becker, A. Roseberry-Lincoln, E.S. Perry, and P.T. Jacobson. 2008. Brook trout declines with land cover and temperature changes in Maryland. North American Journal of Fisheries Management **28**(4)**:**1223-1232.

The Nature Conservancy. 2009. Eastern U.S. Secured Lands. Various scales. Compiled from multiple sources.

The Nature Conservancy. 2022. Eastern U.S. Conservation Lands. Various scales. Compiled from multiple sources.

The Nature Conservancy. 2011. Northeast Regional Dam Dataset Version 3/1/2011. The Nature Conservancy Eastern Conservation Science Office. Boston, MA.

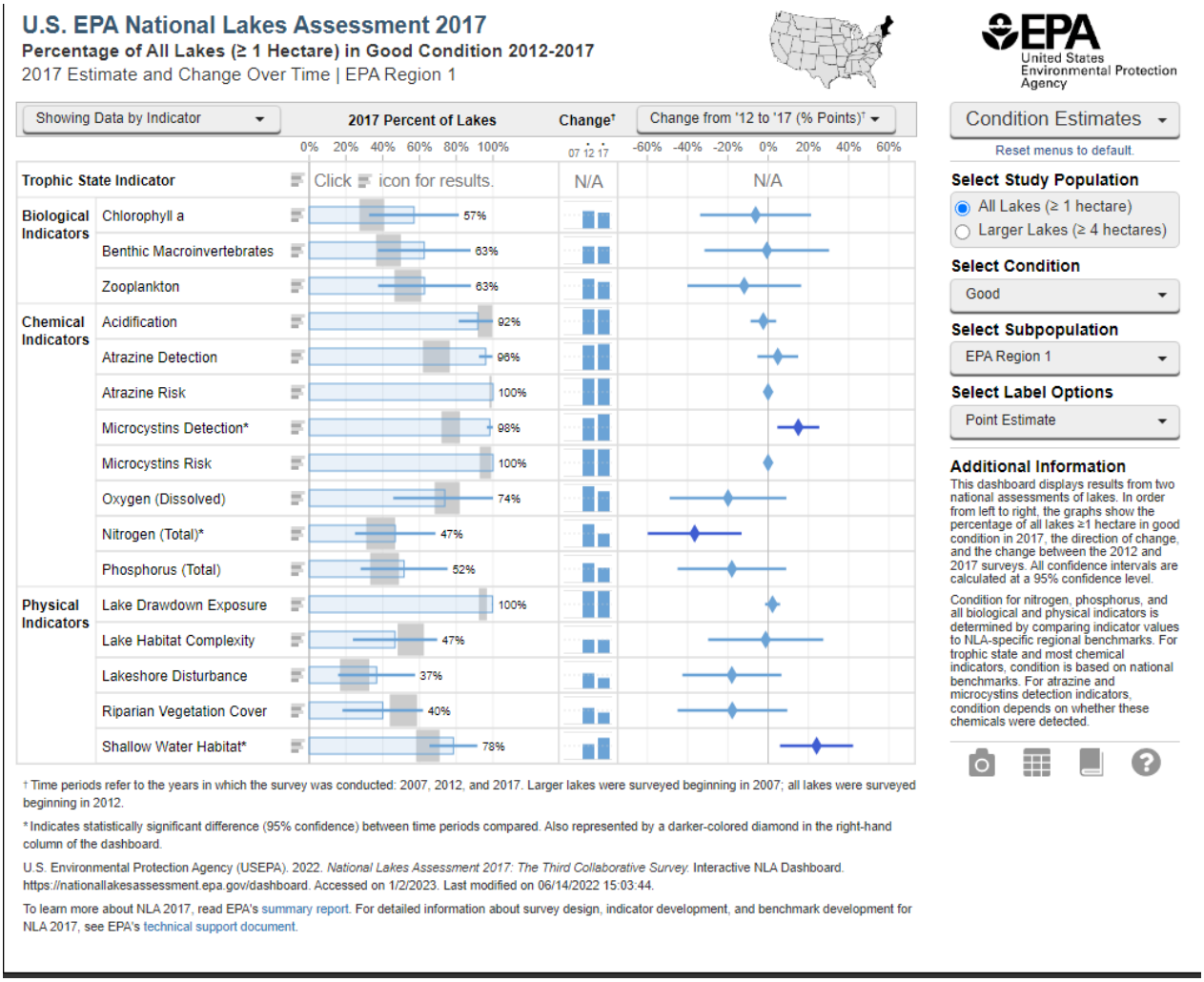
Tonn, W. M., and J. J. Magnuson. 1982. Patterns in the species composition and richness of fish assemblages in northern wisconsin lakes. Ecology **63**(4)**:**1149-1166.

U.S. Environmental Protection Agency. 2022. National Lakes Assessment 2017: Technical Support Document. EPA 841-R-22-001. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development. https://www.epa.gov/national-aquatic- resource-surveys/national-lakes-assessment-2017-technical-support-document

U.S. Geological Survey, 2016, USGS National Hydrography Dataset (NHD) V21 Downloadable Data Collection - National Geospatial Data Asset (NGDA) National Hydrography Dataset (NHD): USGS - National Geospatial Technical Operations Center (NGTOC): Rolla, MO and Denver, CO, http://nhd.usgs.gov, http://viewer.nationalmap.gov/.

Appendix 7.1. All 2017 National Lake Assessment Metrics by Region and Condition Class

EPA National Lake Assessment Dashboard for EPA region 1 (New England), EPA Region 2 (NY-NJ), and EPA Region
https://nationallakesassessment.epa.gov/dashboard/?&view=indicator&studypop=al&subpop=epa+region+1&label=pe&condition=good&diff=2v3



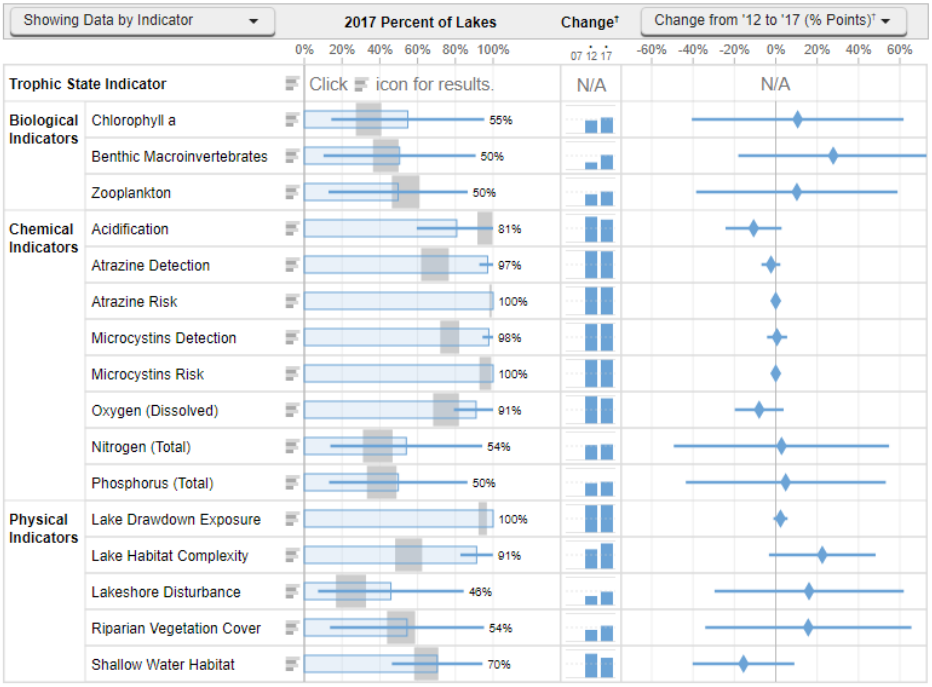
U.S. EPA National Lakes Assessment 2017

Percentage of All Lakes (≥ 1 Hectare) in Good Condition 2012-2017

2017 Estimate and Change Over Time | EPA Region 2



United States Environmental Protection Agency



† Time periods refer to the years in which the survey was conducted: 2007, 2012, and 2017. Larger lakes were surveyed beginning in 2007; all lakes were surveyed beginning in 2012.

* Indicates statistically significant difference (95% confidence) between time periods compared. Also represented by a darker-colored diamond in the right-hand column of the dashboard.

U.S. Environmental Protection Agency (USEPA). 2022. *National Lakes Assessment 2017: The Third Collaborative Survey.* Interactive NLA Dashboard. https://nationallakesassessment.epa.gov/dashboard. Accessed on 1/2/2023. Last modified on 06/14/2022 15:03:44.

To learn more about NLA 2017, read EPA's summary report. For detailed information about survey design, indicator development, and benchmark development for NLA 2017, see EPA's technical support document.

Condition Estimates

Reset menus to default.

Select Study Population

- (•) All Lakes (≥ 1 hectare)
- ( ) Larger Lakes (≥ 4 hectares)

Select Condition

Good

Select Subpopulation

EPA Region 2

Select Label Options

Point Estimate

Additional Information

This dashboard displays results from two national assessments of lakes. In order from left to right, the graphs show the percentage of all lakes ≥1 hectare in good condition in 2017, the direction of change, and the change between the 2012 and 2017 surveys. All confidence intervals are calculated at a 95% confidence level.

Condition for nitrogen, phosphorus, and all biological and physical indicators is determined by comparing indicator values to NLA-specific regional benchmarks. For trophic state and most chemical indicators, condition is based on national benchmarks. For atrazine and microcystins detection indicators, condition depends on whether these chemicals were detected.

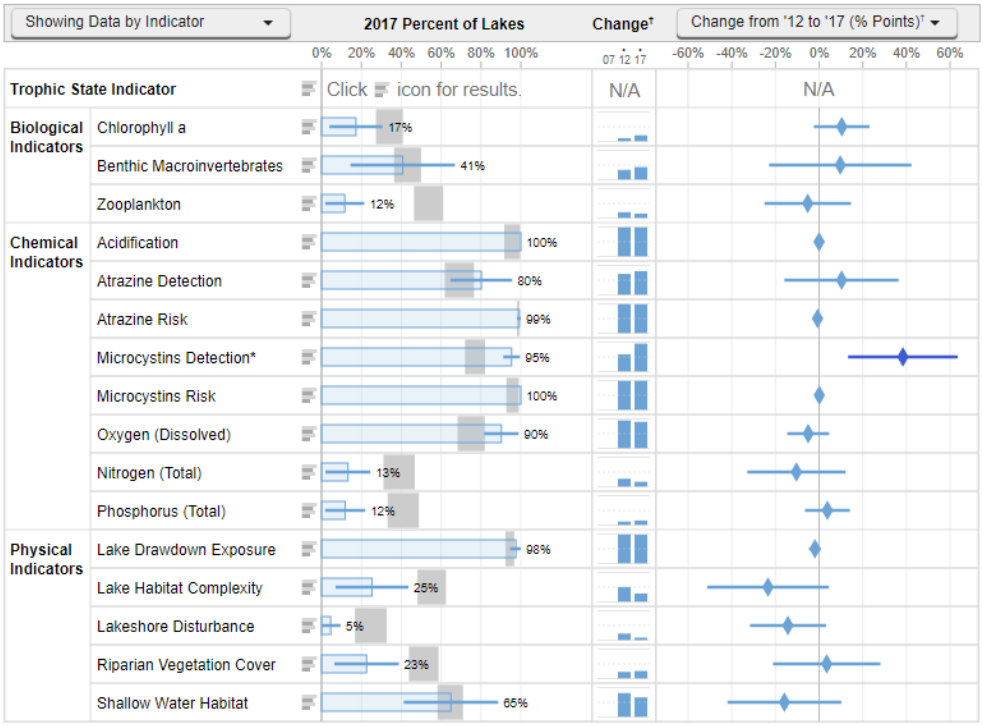
U.S. EPA National Lakes Assessment 2017

Percentage of All Lakes (≥ 1 Hectare) in Good Condition 2012-2017

2017 Estimate and Change Over Time | EPA Region 3



United States Environmental Protection Agency



Condition Estimates

Reset menus to default.

Select Study Population

- (•) All Lakes (≥ 1 hectare)
- ( ) Larger Lakes (≥ 4 hectares)

Select Condition

Good

Select Subpopulation

EPA Region 3

Select Label Options

Point Estimate

Additional Information

This dashboard displays results from two national assessments of lakes. In order from left to right, the graphs show the percentage of all lakes ≥1 hectare in good condition in 2017, the direction of change, and the change between the 2012 and 2017 surveys. All confidence intervals are calculated at a 95% confidence level.

Condition for nitrogen, phosphorus, and all biological and physical indicators is determined by comparing indicator values to NLA-specific regional benchmarks. For trophic state and most chemical indicators, condition is based on national benchmarks. For atrazine and microcystins detection indicators, condition depends on whether these chemicals were detected.

† Time periods refer to the years in which the survey was conducted: 2007, 2012, and 2017. Larger lakes were surveyed beginning in 2007; all lakes were surveyed beginning in 2012.

* Indicates statistically significant difference (95% confidence) between time periods compared. Also represented by a darker-colored diamond in the right-hand column of the dashboard.

U.S. Environmental Protection Agency (USEPA). 2022. *National Lakes Assessment 2017: The Third Collaborative Survey.* Interactive NLA Dashboard. https://nationallakesassessment.epa.gov/dashboard. Accessed on 1/2/2023. Last modified on 06/14/2022 15:03:44.

To learn more about NLA 2017, read EPA's summary report. For detailed information about survey design, indicator development, and benchmark development for NLA 2017, see EPA's technical support document.

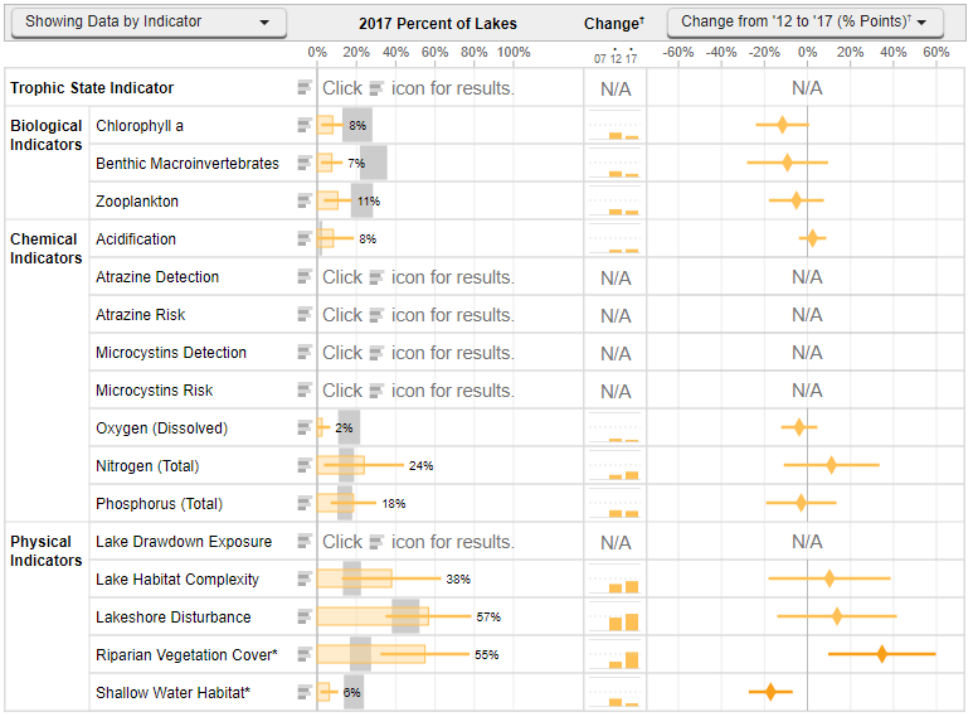
U.S. EPA National Lakes Assessment 2017

Percentage of All Lakes (≥ 1 Hectare) in Fair Condition 2012-2017

2017 Estimate and Change Over Time | EPA Region 1



United States Environmental Protection Agency



Condition Estimates

Reset menus to default.

Select Study Population

- (●) All Lakes (≥ 1 hectare)
- ( ) Larger Lakes (≥ 4 hectares)

Select Condition

Fair

Select Subpopulation

EPA Region 1

Select Label Options

Point Estimate

Additional Information

This dashboard displays results from two national assessments of lakes. In order from left to right, the graphs show the percentage of all lakes ≥1 hectare in fair condition in 2017, the direction of change, and the change between the 2012 and 2017 surveys. All confidence intervals are calculated at a 95% confidence level.

Condition for nitrogen, phosphorus, and all biological and physical indicators is determined by comparing indicator values to NLA-specific regional benchmarks. For trophic state and most chemical indicators, condition is based on national benchmarks. For atrazine and microcystins detection indicators, condition depends on whether these chemicals were detected.

† Time periods refer to the years in which the survey was conducted: 2007, 2012, and 2017. Larger lakes were surveyed beginning in 2007; all lakes were surveyed beginning in 2012.

* Indicates statistically significant difference (95% confidence) between time periods compared. Also represented by a darker-colored diamond in the right-hand column of the dashboard.

U.S. Environmental Protection Agency (USEPA). 2022. *National Lakes Assessment 2017: The Third Collaborative Survey.* Interactive NLA Dashboard. https://nationallakesassessment.epa.gov/dashboard. Accessed on 1/2/2023. Last modified on 06/14/2022 15:03:44.

To learn more about NLA 2017, read EPA's summary report. For detailed information about survey design, indicator development, and benchmark development for NLA 2017, see EPA's technical support document.

U.S. EPA National Lakes Assessment 2017

Percentage of All Lakes (≥ 1 Hectare) in Fair Condition 2012-2017

2017 Estimate and Change Over Time | EPA Region 2



United States Environmental Protection Agency

Showing Data by Indicator | 2017 Percent of Lakes | Change† | Change from '12 to '17 (% Points)†

		2017 Percent of Lakes (0% 20% 40% 60% 80% 100%)	Change† (07 12 17)	Change from '12 to '17 (% Points)† (-60% -40% -20% 0% 20% 40% 60%)
Trophic State Indicator		Click icon for results.	N/A	N/A
Biological Indicators	Chlorophyll a	2%		
	Benthic Macroinvertebrates	40%		
	Zooplankton	43%		
Chemical Indicators	Acidification	19%		
	Atrazine Detection	Click icon for results.	N/A	N/A
	Atrazine Risk	Click icon for results.	N/A	N/A
	Microcystins Detection	Click icon for results.	N/A	N/A
	Microcystins Risk	Click icon for results.	N/A	N/A
	Oxygen (Dissolved)	8%		
	Nitrogen (Total)	1%		
	Phosphorus (Total)	5%		
Physical Indicators	Lake Drawdown Exposure	Click icon for results.	N/A	N/A
	Lake Habitat Complexity	2%		
	Lakeshore Disturbance	46%		
	Riparian Vegetation Cover	41%		
	Shallow Water Habitat	26%		

† Time periods refer to the years in which the survey was conducted: 2007, 2012, and 2017. Larger lakes were surveyed beginning in 2007; all lakes were surveyed beginning in 2012.

* Indicates statistically significant difference (95% confidence) between time periods compared. Also represented by a darker-colored diamond in the right-hand column of the dashboard.

U.S. Environmental Protection Agency (USEPA). 2022. *National Lakes Assessment 2017: The Third Collaborative Survey.* Interactive NLA Dashboard. https://nationallakesassessment.epa.gov/dashboard. Accessed on 1/2/2023. Last modified on 06/14/2022 15:03:44.

To learn more about NLA 2017, read EPA's summary report. For detailed information about survey design, indicator development, and benchmark development for NLA 2017, see EPA's technical support document.

Condition Estimates

Reset menus to default.

Select Study Population

- (●) All Lakes (≥ 1 hectare)
- ( ) Larger Lakes (≥ 4 hectares)

Select Condition

Fair

Select Subpopulation

EPA Region 2

Select Label Options

Point Estimate

Additional Information

This dashboard displays results from two national assessments of lakes. In order from left to right, the graphs show the percentage of all lakes ≥1 hectare in fair condition in 2017, the direction of change, and the change between the 2012 and 2017 surveys. All confidence intervals are calculated at a 95% confidence level.

Condition for nitrogen, phosphorus, and all biological and physical indicators is determined by comparing indicator values to NLA-specific regional benchmarks. For trophic state and most chemical indicators, condition is based on national benchmarks. For atrazine and microcystins detection indicators, condition depends on whether these chemicals were detected.

U.S. EPA National Lakes Assessment 2017

Percentage of All Lakes (≥ 1 Hectare) in Fair Condition 2012-2017

2017 Estimate and Change Over Time | EPA Region 3



EPA United States Environmental Protection Agency

Showing Data by Indicator | 2017 Percent of Lakes | Change† | Change from '12 to '17 (% Points)†

		2017 Percent of Lakes (0% 20% 40% 60% 80% 100%)	Change† (07 12 17)	Change from '12 to '17 (% Points)† (-60% -40% -20% 0% 20% 40% 60%)
Trophic State Indicator		Click icon for results.	N/A	N/A
Biological Indicators	Chlorophyll a	3%		
	Benthic Macroinvertebrates	50%		
	Zooplankton	56%		
Chemical Indicators	Acidification	0% (No Observed Lakes)		
	Atrazine Detection	Click icon for results.	N/A	N/A
	Atrazine Risk	Click icon for results.	N/A	N/A
	Microcystins Detection	Click icon for results.	N/A	N/A
	Microcystins Risk	Click icon for results.	N/A	N/A
	Oxygen (Dissolved)	7%		
	Nitrogen (Total)	13%		
	Phosphorus (Total)	13%		
Physical Indicators	Lake Drawdown Exposure	Click icon for results.	N/A	N/A
	Lake Habitat Complexity	50%		
	Lakeshore Disturbance	79%		
	Riparian Vegetation Cover	54%		
	Shallow Water Habitat	17%		

† Time periods refer to the years in which the survey was conducted: 2007, 2012, and 2017. Larger lakes were surveyed beginning in 2007; all lakes were surveyed beginning in 2012.

* Indicates statistically significant difference (95% confidence) between time periods compared. Also represented by a darker-colored diamond in the right-hand column of the dashboard.

U.S. Environmental Protection Agency (USEPA). 2022. *National Lakes Assessment 2017: The Third Collaborative Survey.* Interactive NLA Dashboard. https://nationallakesassessment.epa.gov/dashboard. Accessed on 1/2/2023. Last modified on 06/14/2022 15:03:44.

To learn more about NLA 2017, read EPA's summary report. For detailed information about survey design, indicator development, and benchmark development for NLA 2017, see EPA's technical support document.

Condition Estimates

Reset menus to default.

Select Study Population

- (•) All Lakes (≥ 1 hectare)
- ( ) Larger Lakes (≥ 4 hectares)

Select Condition

Fair

Select Subpopulation

EPA Region 3

Select Label Options

Point Estimate

Additional Information

This dashboard displays results from two national assessments of lakes. In order from left to right, the graphs show the percentage of all lakes ≥1 hectare in fair condition in 2017, the direction of change, and the change between the 2012 and 2017 surveys. All confidence intervals are calculated at a 95% confidence level.

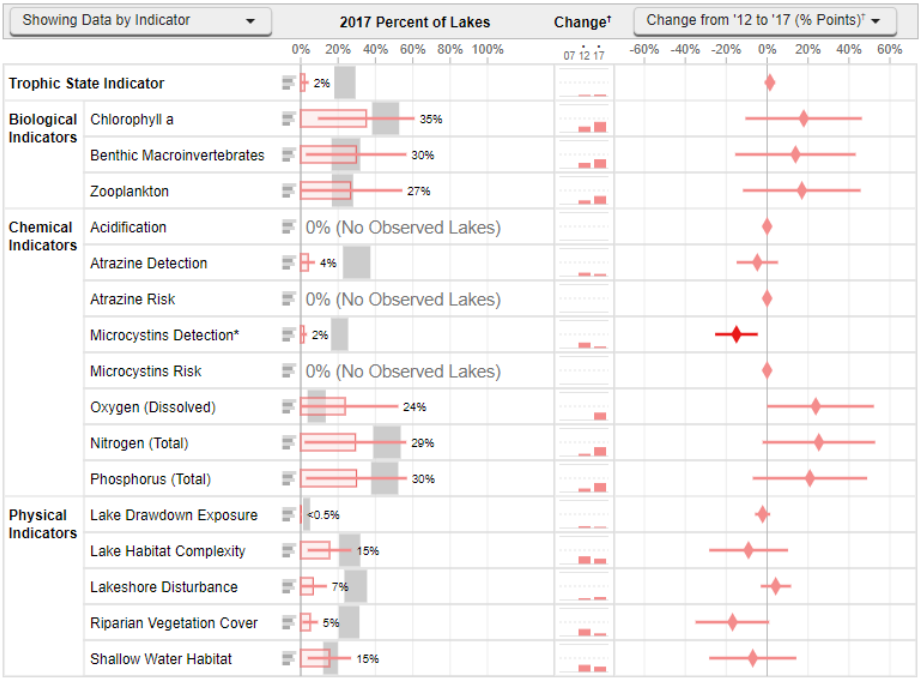
Condition for nitrogen, phosphorus, and all biological and physical indicators is determined by comparing indicator values to NLA-specific regional benchmarks. For trophic state and most chemical indicators, condition is based on national benchmarks. For atrazine and microcystins detection indicators, condition depends on whether these chemicals were detected.

U.S. EPA National Lakes Assessment 2017

Percentage of All Lakes (≥ 1 Hectare) in Poor Condition 2012-2017

2017 Estimate and Change Over Time | EPA Region 1





† Time periods refer to the years in which the survey was conducted: 2007, 2012, and 2017. Larger lakes were surveyed beginning in 2007; all lakes were surveyed beginning in 2012.

* Indicates statistically significant difference (95% confidence) between time periods compared. Also represented by a darker-colored diamond in the right-hand column of the dashboard.

U.S. Environmental Protection Agency (USEPA). 2022. *National Lakes Assessment 2017: The Third Collaborative Survey.* Interactive NLA Dashboard. https://nationallakesassessment.epa.gov/dashboard. Accessed on 3/2/2023. Last modified on 10/27/2022 09:19:04.

To learn more about NLA 2017, read EPA's summary report. For detailed information about survey design, indicator development, and benchmark development for NLA 2017, see EPA's technical support document.

EPA United States Environmental Protection Agency

Condition Estimates

Reset menus to default.

Select Study Population

- (•) All Lakes (≥ 1 hectare)
- ( ) Larger Lakes (≥ 4 hectares)

Select Condition

Poor

Select Subpopulation

EPA Region 1

Select Label Options

Point Estimate

Additional Information

This dashboard displays results from two national assessments of lakes. In order from left to right, the graphs show the percentage of all lakes ≥1 hectare in poor condition in 2017, the direction of change, and the change between the 2012 and 2017 surveys. All confidence intervals are calculated at a 95% confidence level.

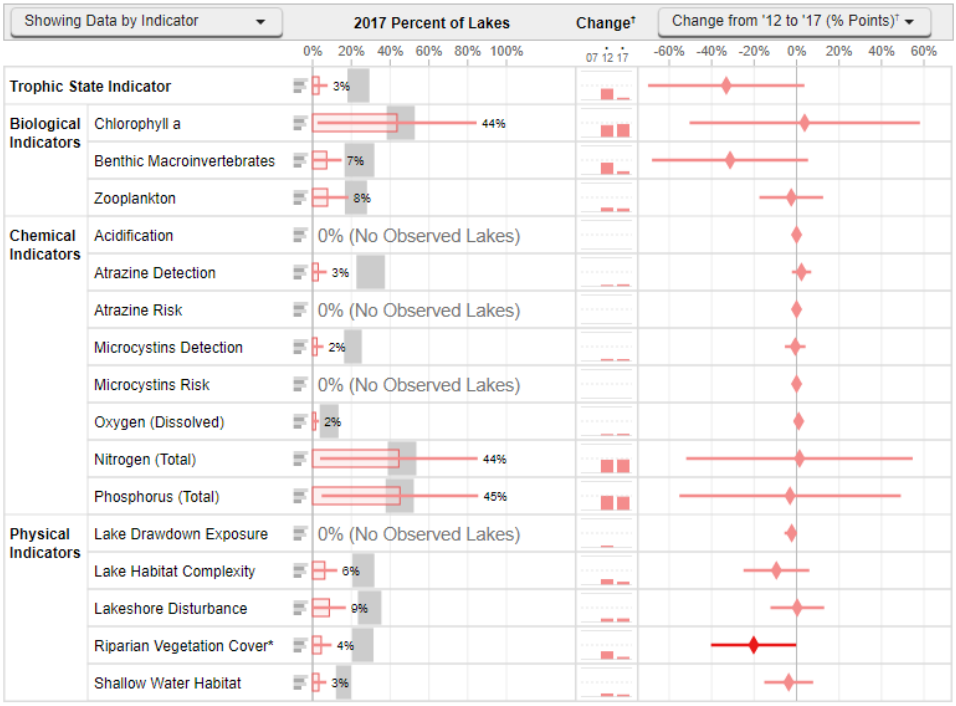
Condition for nitrogen, phosphorus, and all biological and physical indicators is determined by comparing indicator values to NLA-specific regional benchmarks. For trophic state and most chemical indicators, condition is based on national benchmarks. For atrazine and microcystins detection indicators, condition depends on whether these chemicals were detected.

U.S. EPA National Lakes Assessment 2017

Percentage of All Lakes (≥ 1 Hectare) in Poor Condition 2012-2017

2017 Estimate and Change Over Time | EPA Region 2





† Time periods refer to the years in which the survey was conducted: 2007, 2012, and 2017. Larger lakes were surveyed beginning in 2007; all lakes were surveyed beginning in 2012.

* Indicates statistically significant difference (95% confidence) between time periods compared. Also represented by a darker-colored diamond in the right-hand column of the dashboard.

U.S. Environmental Protection Agency (USEPA). 2022. *National Lakes Assessment 2017: The Third Collaborative Survey.* Interactive NLA Dashboard. https://nationallakesassessment.epa.gov/dashboard. Accessed on 1/2/2023. Last modified on 06/14/2022 15:03:44.

To learn more about NLA 2017, read EPA's summary report. For detailed information about survey design, indicator development, and benchmark development for NLA 2017, see EPA's technical support document.

EPA United States Environmental Protection Agency

Condition Estimates

Reset menus to default.

Select Study Population

- (●) All Lakes (≥ 1 hectare)
- ( ) Larger Lakes (≥ 4 hectares)

Select Condition

Poor

Select Subpopulation

EPA Region 2

Select Label Options

Point Estimate

Additional Information

This dashboard displays results from two national assessments of lakes. In order from left to right, the graphs show the percentage of all lakes ≥1 hectare in poor condition in 2017, the direction of change, and the change between the 2012 and 2017 surveys. All confidence intervals are calculated at a 95% confidence level.

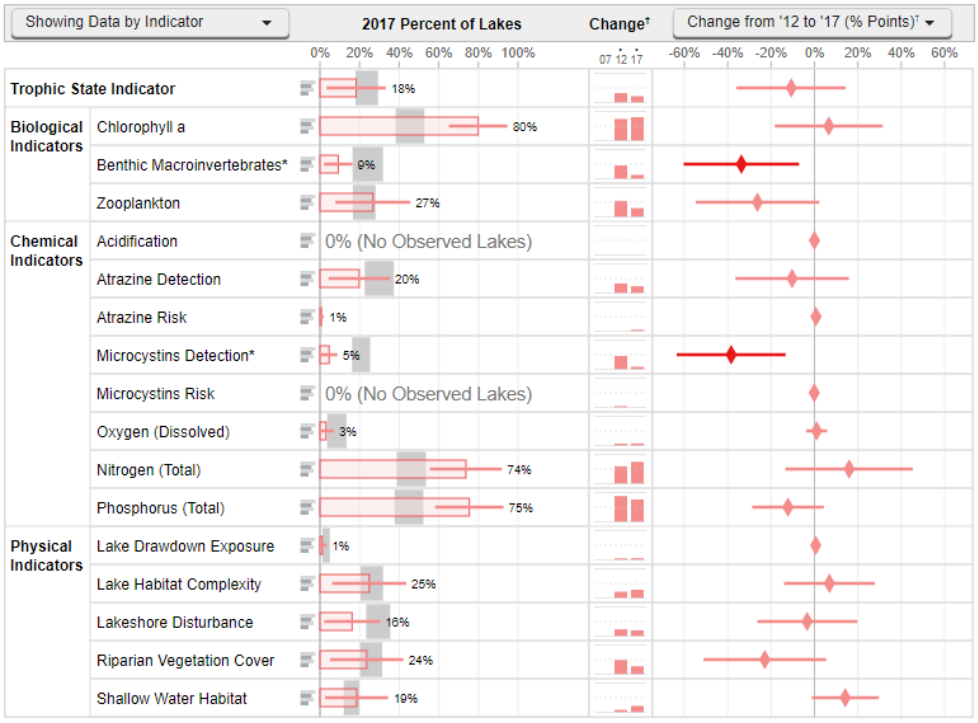
Condition for nitrogen, phosphorus, and all biological and physical indicators is determined by comparing indicator values to NLA-specific regional benchmarks. For trophic state and most chemical indicators, condition is based on national benchmarks. For atrazine and microcystins detection indicators, condition depends on whether these chemicals were detected.

U.S. EPA National Lakes Assessment 2017

Percentage of All Lakes (≥ 1 Hectare) in Poor Condition 2012-2017

2017 Estimate and Change Over Time | EPA Region 3





† Time periods refer to the years in which the survey was conducted: 2007, 2012, and 2017. Larger lakes were surveyed beginning in 2007; all lakes were surveyed beginning in 2012.

* Indicates statistically significant difference (95% confidence) between time periods compared. Also represented by a darker-colored diamond in the right-hand column of the dashboard.

U.S. Environmental Protection Agency (USEPA). 2022. *National Lakes Assessment 2017: The Third Collaborative Survey.* Interactive NLA Dashboard. https://nationallakesassessment.epa.gov/dashboard. Accessed on 1/2/2023. Last modified on 06/14/2022 15:03:44.

To learn more about NLA 2017, read EPA's summary report. For detailed information about survey design, indicator development, and benchmark development for NLA 2017, see EPA's technical support document.

EPA United States Environmental Protection Agency

Condition Estimates

Reset menus to default.

Select Study Population

- (•) All Lakes (≥ 1 hectare)
- ( ) Larger Lakes (≥ 4 hectares)

Select Condition

Poor

Select Subpopulation

EPA Region 3

Select Label Options

Point Estimate

Additional Information

This dashboard displays results from two national assessments of lakes. In order from left to right, the graphs show the percentage of all lakes ≥1 hectare in poor condition in 2017, the direction of change, and the change between the 2012 and 2017 surveys. All confidence intervals are calculated at a 95% confidence level.

Condition for nitrogen, phosphorus, and all biological and physical indicators is determined by comparing indicator values to NLA-specific regional benchmarks. For trophic state and most chemical indicators, condition is based on national benchmarks. For atrazine and microcystins detection indicators, condition depends on whether these chemicals were detected.

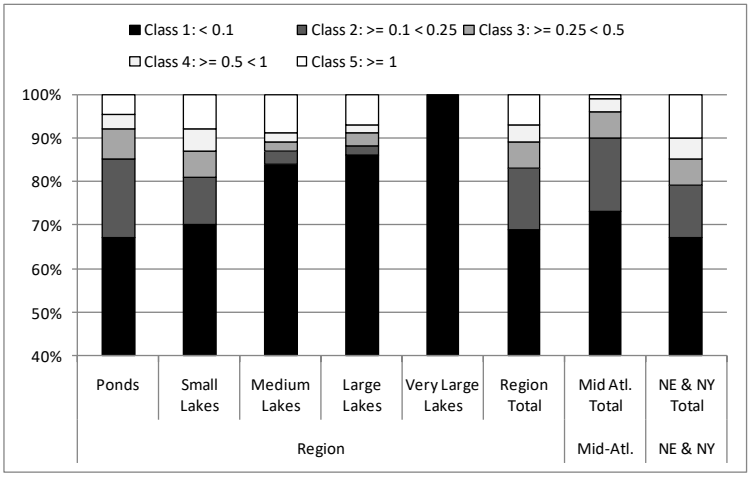
Appendix 7.2. Additional Metrics, 2011. *With approval of the project steering committee, we chose to focus our 2022 analysis on the highest priority metrics, those we expected to see more change in, and/or that were not covered in other recent reports (e.g. birds). These metrics are from the previous 2011 Conservation Status of Fish, Wildlife and Natural Habitats in the Northeast Landscape report (Anderson and Olivero-Sheldon 2011). They may be of interest to some readers looking for additional information on lakes and ponds.*

Isolation from Roads: Access to a lake from a road or trail is correlated with the loss of native species, and with the presence of non-native species (Silk and Ciruna 2004). Field surveys to document the presence of non-indigenous species in lakes only cover a handful of the lakes and ponds in the region, so we used the minimum distance from a mapped road as an estimate of potential introductions. We assumed that the more difficult the lake is to access, the less likely it is to contain non-indigenous species, as the primary entry point for many lake exotics are citizens seeking to create a local sport fishery, inadvertently transporting species attached to boats or discarding excess bait.

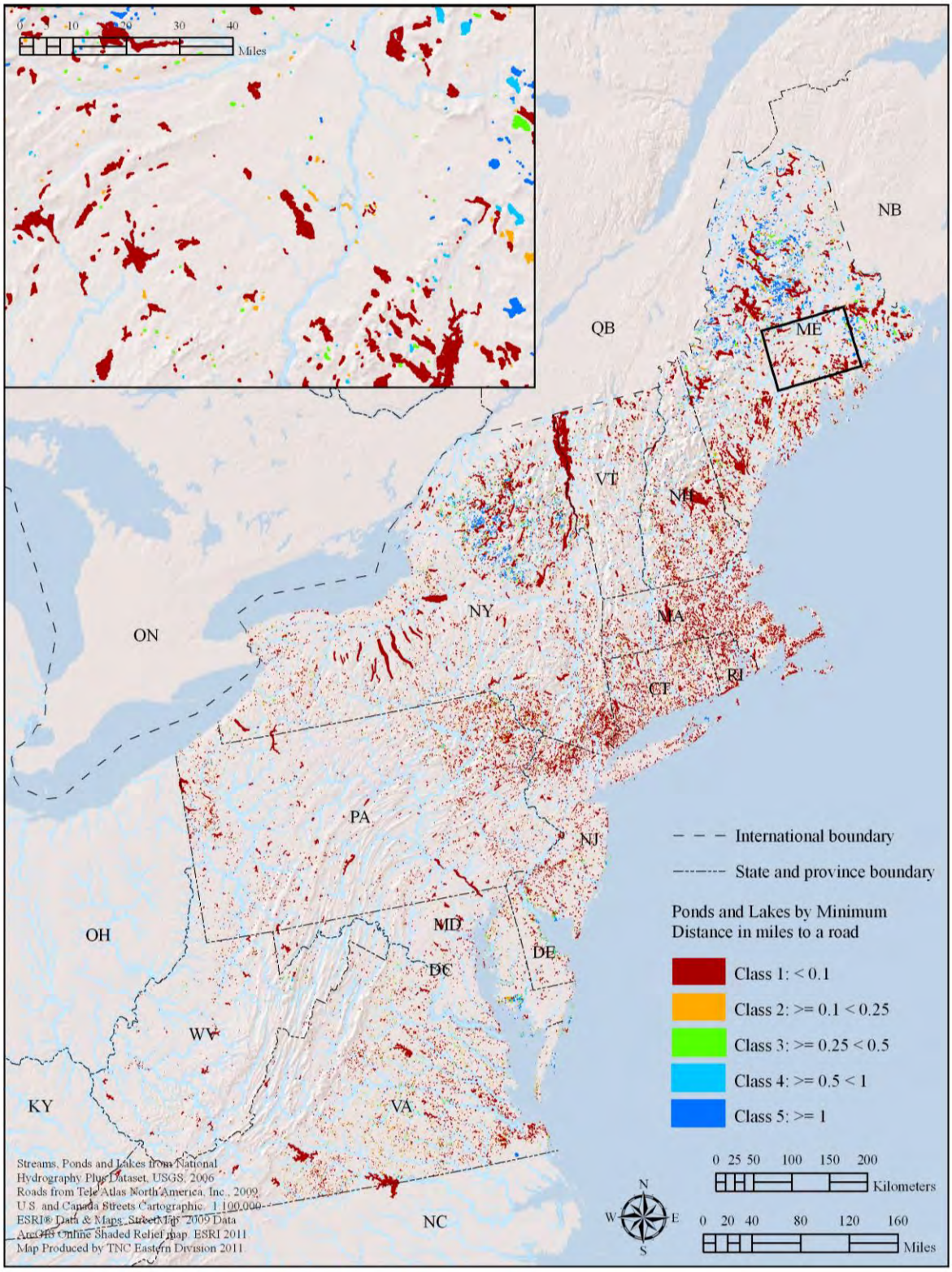
For each waterbody, we tabulated the distance to the nearest road including major highway, local thoroughfares, neighborhood connectors, and rural roads. Four-wheel drive roads and other trails were not included due to inconsistencies in their mapping across the region in the source dataset. Source data sets are described in the appendix A (Tele Atlas North America, Inc. 2009).

The results indicated that ponds and lakes in this region were highly accessible to people; 83 percent were within a quarter mile of a road and 69 percent were within one-tenth of a mile. Only 11 percent of lakes in the region were more than a half mile from a road and only 7 percent were greater than a mile from a road (Figure 7.2.1, Map 7.2.1). The Mid-Atlantic had fewer remote lakes with only 4 percent being more than one-half mile from a road compared to 15 percent for New England and New York. The larger the lake, the closer roads were to it: regionally 67 percent of ponds, 70 percent of small lakes, 84 percent of medium lakes, 86 percent of large lakes, and 100 percent of very large lakes have a road within one-tenth of a mile (Figure 7.2.1). This pattern was found in both sub-regions.

Figure 7.2.1. The proportion of each lake type in each distance to road class (in miles). Few lakes and ponds are over 1 mile from a road (Class 5, 7 percent). Most are less than one tenth mile from a road (Class 1, 69 percent).



Map 7.2.1. Ponds and lakes by minimum distance (in miles) to a road.



Presence of Dams: Dams within formerly natural lakes or reservoirs have been linked to significant negative ecological impacts on both plant and animal communities (see Vaux 2005, Jiffry 1984, Jansson et al 2000). Dams alter lake habitat by augmenting or reducing water levels depending on the operation of the inflow and outflow dams; impounded lakes also often experience altered temperature, oxygen, and sedimentation regimes. Further, dams that fragment connected networks of streams and lakes disrupt the natural dispersal patterns of many aquatic plant and animals. For example, dams have resulted in a substantial reduction in the amount of lake spawning habitat for diadromous species (such as alewife) and migratory freshwater species (such as brook trout).

To evaluate the impacts of dams, we compiled a database of dams for the entire region using a variety of state sources (see data sources) and queried the database for any lake with a dam within 500 m. This buffer distance was necessary to account for spatial inconsistencies between the mapped dams and the lakes upon which they were located, and it allowed us to consider the adverse effect a nearby dam might have on a lake upstream or downstream from it.

Results of the analysis indicate that 17 percent of all lakes and ponds in the region have a dam directly upstream or downstream. The percentage of dammed waterbodies increases as the lakes increase in size, only 11 percent of ponds are dammed but 70 percent of very large lakes have a dam directly associated with it (Figure 7.2.2, Table 7.2.1).

Figure 7.2.2. The percentage of lakes and ponds in the region with a dam directly upstream or downstream.

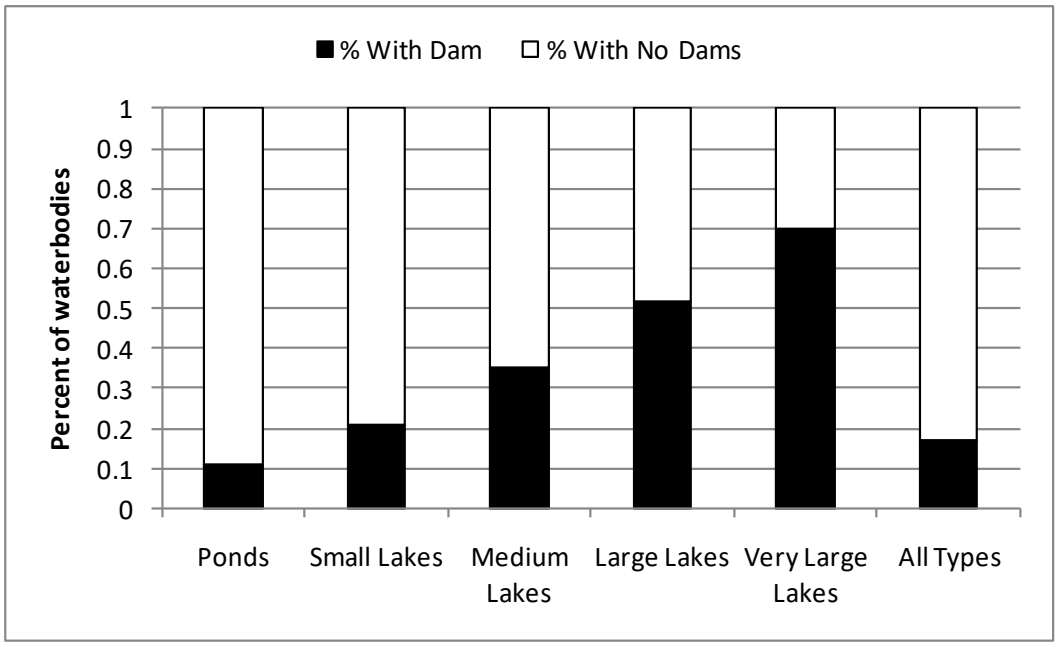


Table 7.2.1. The percentage of lakes with upstream or downstream dams, arranged by type and sub-region.

	Region		Mid-Atlantic		New England & New York	
	% With No Dams	% With Dams	% With No Dams	% With Dams	% With No Dams	% With Dams
Ponds	89%	11%	92%	8%	87%	13%
Small Lakes	79%	21%	75%	25%	82%	18%
Medium Lakes	65%	35%	53%	47%	67%	33%
Large Lakes	48%	52%	44%	56%	48%	52%
Very Large Lakes	30%	70%	33%	67%	29%	71%
Totals	83%	17%	85%	15%	82%	18%

Presence of Dams: Dams within formerly natural lakes or reservoirs have been linked to significant negative ecological impacts on both plant and animal communities (see Vaux 2005, Jiffry 1984, Jansson et al 2000). Dams alter lake habitat by augmenting or reducing water levels depending on the operation of the inflow and outflow dams; impounded lakes also often experience altered temperature, oxygen, and sedimentation regimes. Further, dams that fragment connected networks of streams and lakes disrupt the natural dispersal patterns of many aquatic plant and animals. For example, dams have resulted in a substantial reduction in the amount of lake spawning habitat for diadromous species (such as alewife) and migratory freshwater species (such as brook trout).

To evaluate the impacts of dams, we compiled a database of dams for the entire region using a variety of state sources (see data sources) and queried the database for any lake with a dam within 500 m. This buffer distance was necessary to account for spatial inconsistencies between the mapped dams and the lakes upon which they were located, and it allowed us to consider the adverse effect a nearby dam might have on a lake upstream or downstream from it.

Results of the analysis indicate that 17 percent of all lakes and ponds in the region have a dam directly upstream or downstream. The percentage of dammed waterbodies increases as the lakes increase in size, only 11 percent of ponds are dammed but 70 percent of very large lakes have a dam directly associated with it (Figure 7.2.3, Table 7.2.2).

Figure 7.2.3. The percentage of lakes and ponds in the region with a dam directly upstream or downstream.

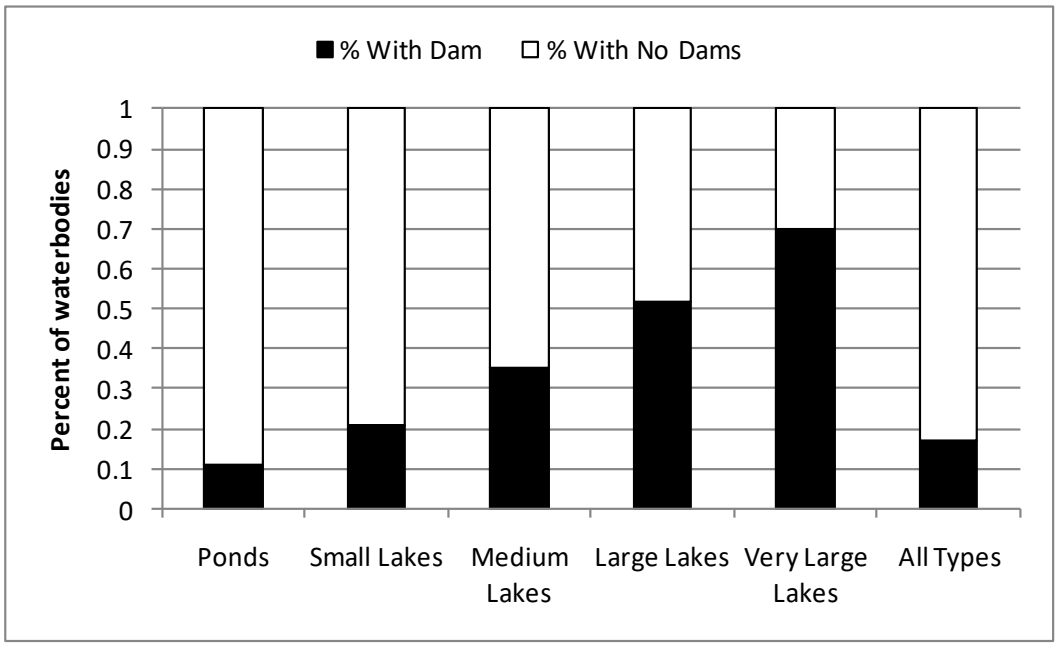


Table 7.2.2. The percentage of lakes with upstream or downstream dams, arranged by type and sub-region.

	Region		Mid-Atlantic		New England & New York	
	% With No Dams	% With Dams	% With No Dams	% With Dams	% With No Dams	% With Dams
Ponds	89%	11%	92%	8%	87%	13%
Small Lakes	79%	21%	75%	25%	82%	18%
Medium Lakes	65%	35%	53%	47%	67%	33%
Large Lakes	48%	52%	44%	56%	48%	52%
Very Large Lakes	30%	70%	33%	67%	29%	71%
Totals	83%	17%	85%	15%	82%	18%

CHAPTER

Climate Resilience

8

Characteristics and Conservation Status

Feb 2023

M. G. Anderson, M. Clark, and A. Olivero

Motivated by declines in biodiversity exacerbated by climate change, The Nature Conservancy has worked with over 287 scientists to identify and map the characteristics and places that provide climate resilient land for species while supporting dynamic shifts in ranges and changes in ecosystem composition. In this chapter, we review those characteristics - representation, site resilience, connectivity, biodiversity value, and carbon – and overlay each map with the 2022 conservation lands to assess the conservation status of each. We end the chapter with a look at where the region stands towards meeting the 2020 America the Beautiful initiative and Global 30 by 30 goals

Climate Resilient Sites: The region's existing conservation lands are already strongly focused on sites with connected microclimates that buffer plants and wildlife from the direct effects of climate change. Conserved forests and wetlands score twice as high for site resilience when compared to unconserved ones, and those on GAP 1 land score higher than 84% of their counterparts in the ecoregion. Lands conserved before 2001 score substantially higher for site resilience than recent conservation lands.

Marsh Migration Space: Tidal marsh is one of our most conserved habitats, but projections suggest we could lose over 75% due to inundation from sea level rise, unless they can migrate landward. Using an independent study that identified 640,000 acres of critical marsh migration space, we found that 37% it is already conserved, as is 61% of the resilient marshes adjacent to the migration space. More conservation, as well as good management is needed to ensure these marshes can migrate.

Connectivity and Flow: As the climate changes, nature is beginning to rearrange. We assessed how the current conservation lands facilitate the flow of nature, using a wall-to-wall analysis to simulate the gradual movement of species in response to climatic gradients across a human-modified landscape. We found forests and wetlands already carried more flow than 69% of the region, and that conserved forests and wetlands had even higher flow density.

Recognized Biodiversity Value: State Wildlife Agencies and The Nature Conservancy have identified and mapped a portfolio of opportunity areas that represent the best places to conserve the regions wildlife, habitats, and other biodiversity. We found that 41% of them are now conserved.

30 by 30, Biodiversity, and Carbon: Scientists and world leaders have challenged us to conserve 30% of the country by 2030 to sustain biodiversity and critical services. In the U.S., over 280 scientists, led by The Nature Conservancy have mapped a national blueprint for such conservation that covers 36% of the northeast. To date, 38% of the network is conserved (19% of the region's area) safeguarding an estimated 1.8 billion metric tons of carbon.

Introduction

The goal of this section is to explore the characteristics of land that build resilience to climate change, assess their distribution in the northeast, and take stock of their conservation status. This section is meant to be used along with The Nature Conservancy's (TNC) Resilient Land Mapping Tool (https://maps.tnc.org/resilientland/) where users can view, and explore the individual datasets, and quantify the properties of places that interest them. Each authoritative dataset can also be downloaded from TNC's Center for Resilient Conservation Science (CRCS) website (https://crcs.tnc.org/). Links to all the published papers and geographic reports appears in Appendix 1. This introduction is extracted from Anderson et al. (2023).

Biodiversity Loss and Climate Change: Over the last decade (2012-2022) it has become alarmingly clear that conservationists are not winning the battle to sustain biological diversity in the US. Despite broad public support and unprecedented bipartisan agreement on Earth Day 1970, followed by landmark environmental laws, expanded regulatory efforts, and the establishment of hundreds of private conservation organizations, the species and ecosystems that characterize our natural world continue to decline. In North America, the abundance of birds has fallen 29% since 1970; 32% of insect taxa are in decline; and 56% of mammalian carnivore and ungulates have shown notable range contractions since 1950 (Rosenberg et al. 2019; Crossley et al. 2020; Liebert and Ripple 2004). Amphibians have declined an average of 33% since 2002 (Muths 2012). Of the 51,936 species of plants, vertebrates, and macroinvertebrates tracked by NatureServe for the conterminous United States, 9% are ranked vulnerable, 12% imperiled, and 1% possibly extinct (NatureServe 2022).

Changes in climate are exacerbating species declines, especially for small, isolated populations. As temperature and moisture regimes change, species ranges are shifting with speed and magnitude unprecedented in recent millennia. In the eastern United States, trees have shifted their centers of distribution 10 km north and 11 km west per decade since 1980. Southern bird ranges have shifted northward by an average of 23.5 km per decade (Fei et al. 2017). These changes are on par with global shifts of 10 km north and 11 m upslope per decade across taxa groups (Chen 2011). While the adaptive strategy of moving has worked in ancient times of rapid climate change, the modern landscape is heavily fragmented by roads, development, industrial agriculture, commercial forestry, and energy infrastructure, making it difficult for species populations to move and find new suitable habitat.

Land and water conservation efforts have the capacity to reverse these trends when strategically located and enabled by the necessary investments. In North America, billions of dollars spent on wetland restoration and management, combined with more stringent hunting regulations, have reversed bird-abundance declines in wetlands (Rosenberg et al. 2019). Globally, conservation investment from 1996 to 2008 reduced the extinction risk for mammals and birds by a median value of 29% (Brondizio 2019). However, as climate change drives changes in species distributions and ecosystem composition, conservation plans based on current biodiversity patterns may become less effective at sustaining species. In particular, the current configuration of protected areas may fail to adequately provide access to the diverse climatic conditions needed for species populations to persist amid changing regional climates and to the connections needed for nature to rearrange.

In recognition of these twin crises, the Convention on Biological Diversity (CBD 2020) Target 2 calls for the global protection of well-connected and effective systems of protected areas covering at least 30% of the planet and focused on biodiversity. Similarly in the United States, the Biden-Harris Administration has launched America the Beautiful, a call to work together to conserve, connect, and restore 30 percent of our lands and waters by 2030, not only for nature but for the sake of our economy, our health, and our well-being (Biden Administration 2021). These initiatives inspire people to act and challenge us to coordinate our actions to conserve nature and maintain a habitable planet.

From a science perspective, the key to sustaining biodiversity lies not in the 30%, although that number gets all the attention, but in the basic principles expressed in the CBD language as a representative, well-connected, effective, and biodiverse network.

Climate Resilience and Conservation

Conservation: The Northeast region has a long history of public and private conservation. In this section we assess the relationship between climate resilience factors and conservation land by overlaying the 2022 TNC conserved lands dataset (described in the Conservation Lands chapter) on maps of resilience factors:

- Site Resilience
- Marsh Migration Space
- Connectivity and Flow
- Recognized Biodiversity
- Resilient & Connected Network
- Carbon

For each section we explain the significance of the concept to resilience, explain our data sources and analysis, and review the results. Terminology for the conservation lands is shown in the box on the right.

Conservation Land Terminology

Conserved (GAP 1-3): The land is permanently secured against conversion to development.

Conserved for Nature (GAP 1): The land is conserved for nature and natural processes.

Conserved for Nature (GAP 2): The land is conserved for nature with management.

Conserved for Multiple Uses (GAP 3): The land is secured AND the intent of the management is for multiple uses, including forest management. This land may provide implicit conservation value such as connectivity or providing stream buffers.

CRI = Conservation Risk Index = %Conv / %GAP1-3

NRI = Nature Risk Index = % Conv / %GAP 1-2

Site Resilience

Site resilience is the capacity of a site to support biological diversity and ecological functions even as the biotic composition changes in response to climate change (Anderson et al. 2014). If adequately conserved, resilient sites are expected to sustain their species and communities for a longer time, and have a slower turnover rate, than less resilient sites.

As climate change drives rapid shifts in species distributions, land and water conservation based on current biodiversity patterns may become less effective in sustaining diversity. Resilient sites are places where microclimatic buffering allows species to persist longer, utilizing local climatic variability, slowing the rate of turnover, and helping species flourish under a changing climate. These natural strongholds also improve connectivity because thriving populations create dispersal pressure, the engine that powers movement across the landscape. The characteristics that create climatic options are features of the land (topography, aspect, hydrology, elevation), which ensures that that site will benefit biodiversity under many future climate scenarios.

Assessing Site Resilience

We used the TNC resilience data which estimates a site resilience score for every 30 m cell in the region as a function of **landscape diversity** that creates persistent microclimates, and **local connectedness** that ensures access to the microclimates (Map 8.1). Detailed methods on how these factors were mapped and integrated into a resilience score may be found in Anderson et al. 2014. Anderson et al. 2023, Anderson et al. 2012). You can explore and download the data on TNC's Climate Resilience webiste.

Landscape Diversity: Resilient sites are those that provide resident species the maximum opportunity to respond on-site to climate change and slow down the rate of change and transition as new species arrive and establish. Evidence continues to grow that spatial heterogeneity in microclimates creates such opportunities and represents an important buffer for species in response to climate change (Weiss et al. 1988; Willis and Bhagwat 2009; Dobrowski 2010; Suggitt. et al. 2018). As precipitation and temperature patterns change, organisms disperse along moisture and temperature gradients, to stay within their preferred climatic regimes. Having a greater diversity of microclimates, resilient sites are likely to offer microsites that species find suitable for establishment and growth. Thus, the variety of microclimates present in a landscape is positively correlated with the capacity of the site to maintain species. Landscape diversity was modeled from a 30 m landform model using topography, elevation, land position, slope, aspect, moisture accumulation, and existing wetlands,

Local Connectedness: The local connectedness metric is a measure of the hardness of barriers, the connectedness of natural cover, and the arrangement of land uses, summed into an integrated metric (Anderson et al. 2014). It is not species specific but defined by the permeability of the landscape measured as the degree to which regional landscapes, encompassing a variety of natural, semi-natural, and developed land cover types, will sustain ecological processes and are conducive to the movement of many types of organisms (Meiklejohn et al. 2010). Local connectedness was modeled using a resistance grid created from 30 m spatial information on roads, powerlines, energy infrastructure, industrial forest, commercial agriculture and more, with each feature assigned a weight reflecting its relative resistance to the movement of native wildlife and plants.

The two metrics were assessed separately and then combined equally into a resilience score (Map 8.1).

Map 8.1. Site Resilience. The map shows the areas in the region that have the most connected microclimates relative to their ecoregions and geophysical setting.

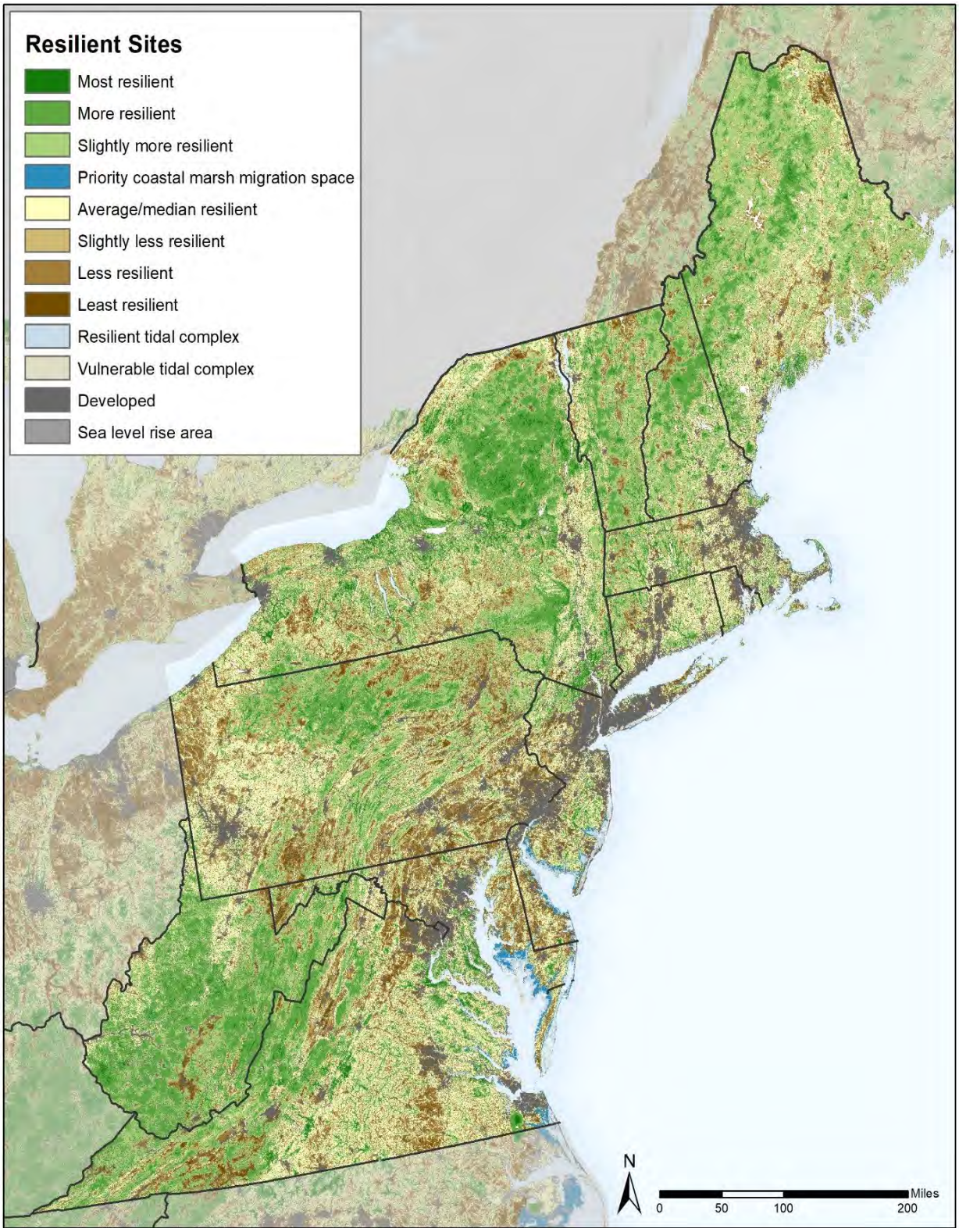
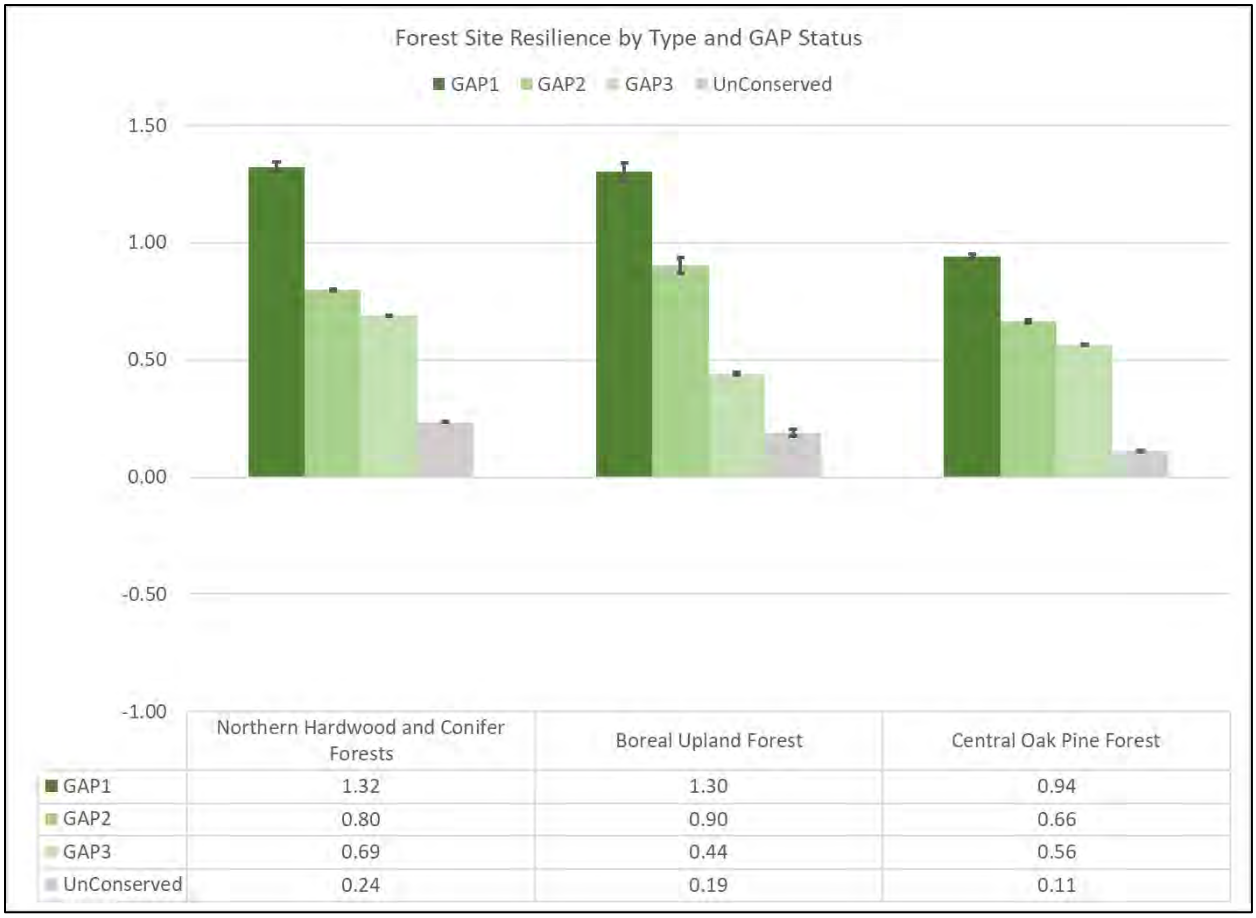


Figure 8.1. Site Resilience by Forest Type and GAP status. The chart shows the average resilience score for each forest type within each class of conservation land (See Forest Chapter). Scores are in standard deviations relative to the mean score of the ecoregion where the forest occurs.



	Northern Hardwood and Conifer Forests	Boreal Upland Forest	Central Oak Pine Forest
GAP1	1.32	1.30	0.94
GAP2	0.80	0.90	0.66
GAP3	0.69	0.44	0.56
UnConserved	0.24	0.19	0.11

Looking only at unconserved forest (grey columns), all three forest types had mean resilience scores slightly higher than the average for the region (Figure 8.1): Northern Hardwood (0.24 SD), Boreal Upland (0.19) and Oak-Pine (0.11). Forests on conservation land scored considerably better for resilience, with those on GAP 1 scoring higher than 84% of the region (>1 SD). GAP 3 multiple use lands scored lower but were still above 69% of the region (> 0.5 SD). GAP 2 were intermediate.

Wetlands showed a very similar pattern (Figure 8.2). For unconserved wetlands (grey), alluvial wetlands scored considerably higher than other types (>0.5 SD), probably reflecting their characteristic setting adjacent to flowing streams and rivers. Woody basin wetlands scored close to the average for the region, and emergent wetland scored a little below average (-0.06 SD). Although basin wetlands are low in topographic diversity, they make up for it by collecting and storing water, a moderator of local climate.

Wetlands occurring on conservation land scored considerably higher, with those on GAP 1 scoring well above 1 SD and better than 84% of the region. Wetlands on GAP 3 multiple use lands scored lower but still above 69% of the region (> 0.5 SD) while wetlands on GAP 2 land scored intermediate between GAP 1 and GAP 3.

Figure 8.2: Site Resilience by Wetland Type and GAP status. The chart shows the average resilience score for each wetland type within each class of conservation land. Scores are in standard deviations relative to the mean score of the ecoregion where the wetland occurs.

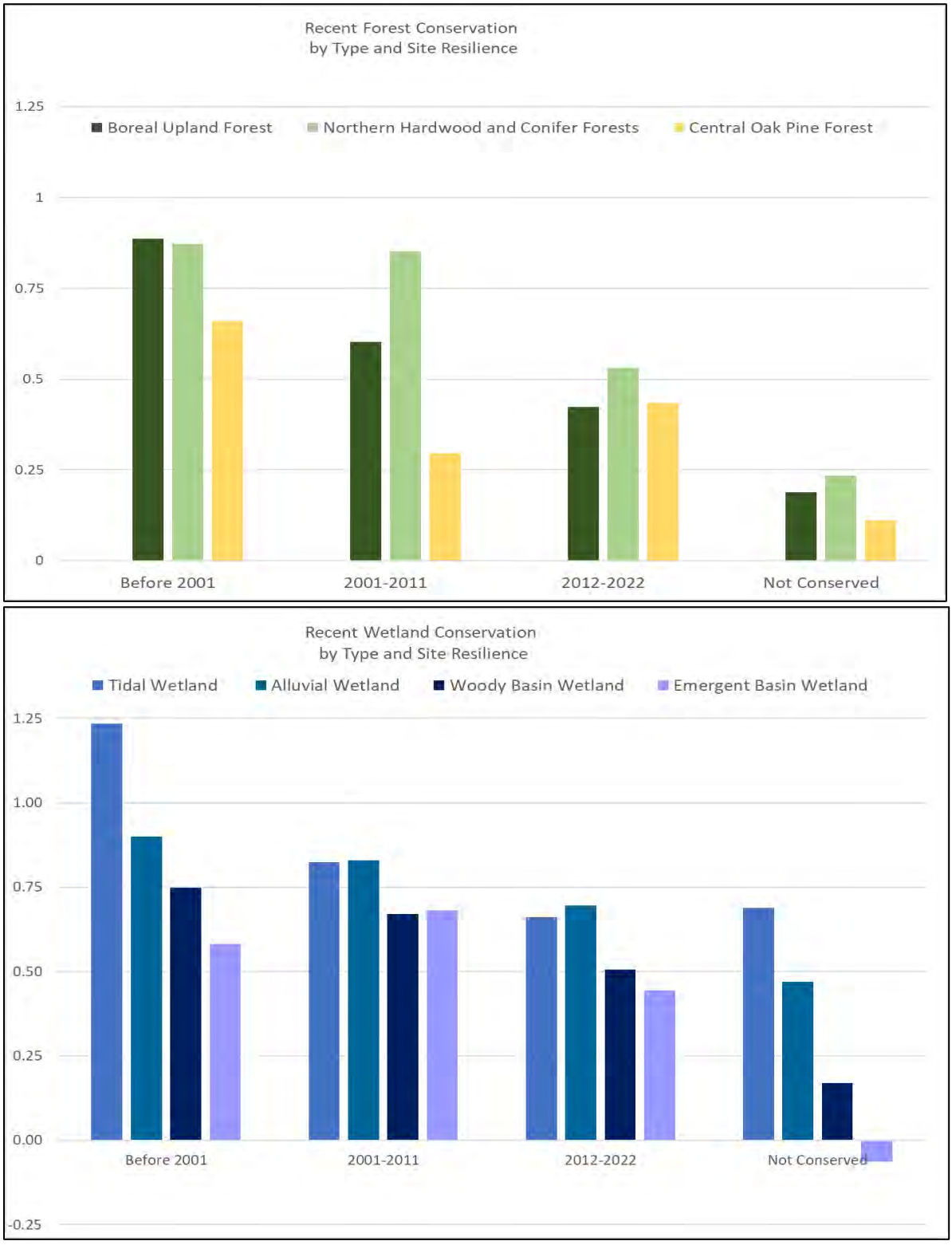


	Alluvial Wetland	Woody Basin Wetland	Emergent Basin Wetland
GAP1	1.26	1.15	1.16
GAP2	0.89	0.87	0.45
GAP3	0.77	0.54	0.52
UnConserved	0.47	0.17	-0.06

The higher resilience scores for conserved forest and wetland reflected both higher landscape diversity and greater connectedness. Landscape diversity scores consistently from GAP1 to unconserved (0.72 to -0.04 SD for forest, 0.73 to 0.25 SD for wetland.) Local connectedness which also decreased consistently from GAP 1 to unconserved (1.65 to 0.31 SD for forest, 1.68 to 0.19 SD for wetland). As the local connectedness scores spanned a greater range, they account for most of the variation in resilience scores. The results suggest that conservation has preserved, maintained, or improved the local connectedness of forests and wetlands boosting their resilience.

It is hard to determine if conservation lands continue to rank higher for resilience because they were selected for better condition and more microclimatic diversity, or if they have improved in resilience from being conserved. As an ecosystem matures or recovers from disturbance it becomes more connected, and its local connectedness score can increase. Looking across time, there is unequivocal evidence that recently conserved conservation lands score lower for site resilience than the older ones, and this pattern is apparent in both terrestrial and wetland conservation lands (Figure 8.3). Compared to the unconserved land, recent forest conservation lands still score higher on average (0.46 SD vs 0.18 SD), but not as high as last decades (0.58 SD) and only half as high as conservation before 2001 (0.81 SD). Wetlands show the same trend suggesting that conservation lands improve over time, or conversely that the overall landscape has degraded over time. Likely is it a little of both.

Figure 8.3: Resilience Score and Conservation Year. These charts show the relationship between resilience score and when the conservation took place for both forest (upper) and wetland (lower) habitats.



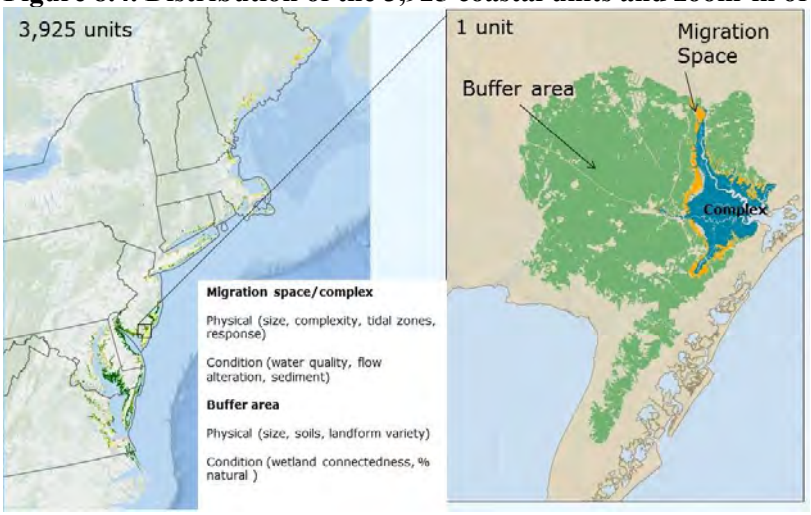
Tidal Wetland and Migration Space

Climate change threatens to alter the ecology of coasts in the Northeastern US. Rising sea levels combined with changing temperature and precipitation regimes threaten to rearrange or destroy habitat and creates novel conditions for the fish and wildlife that inhabit the coastal zone. For this reason, we assessed tidal wetland separately using different data sources.

Coastal areas provide critical habitat for wildlife and are home to more than 40 percent of the U.S. population, but sea levels are rising, and coastal sites vary widely in their ability to accommodate such change. The Nature Conservancy in partnership with 35 scientists from USFW, NOAA, and State Agencies evaluated over 3,000 coastal sites along the Atlantic Seaboard for their capacity to sustain biodiversity and natural services under increasing inundation from sea level rise. Each site received a resilience "score" based on the likelihood that its coastal habitats can and will migrate to adjacent lowlands. A coastal site was considered more resilient if it had more options for adapting to, or accommodating risk, and more vulnerable if it had less options.

Areas with the right combination of characteristics (Figure 8.4) should support native species longer by offering more climatic options to current occupants. Conservation of these resilient sites is critical if we are to sustain nature's diversity and benefits into the future.

Figure 8.4. Distribution of the 3,925 coastal units and zoom-in of a single unit.



We overlaid TNC's Northeast Resilient Coastal Sites dataset with the 2022 conservation lands data to evaluate how well we have conserved resilient marshes and their migration space.

Details on the mapping methods, analysis, and web tools can be found below:

- Northeast: Resilient Coastal Sites for Conservation: Report
- Northeast Resilient Coastal Sites – Strategy Map
- Northeast: Resilient Coastal Sites – Web Map
- Northeast: Resilient Coastal Sites for Conservation - Website

Map 8.2. Resilient Coastal Sites. This map shows a zoom-in for Delaware and Chesapeake Bay, two areas that support a lot of resilient tidal marsh with ample marsh migration space.

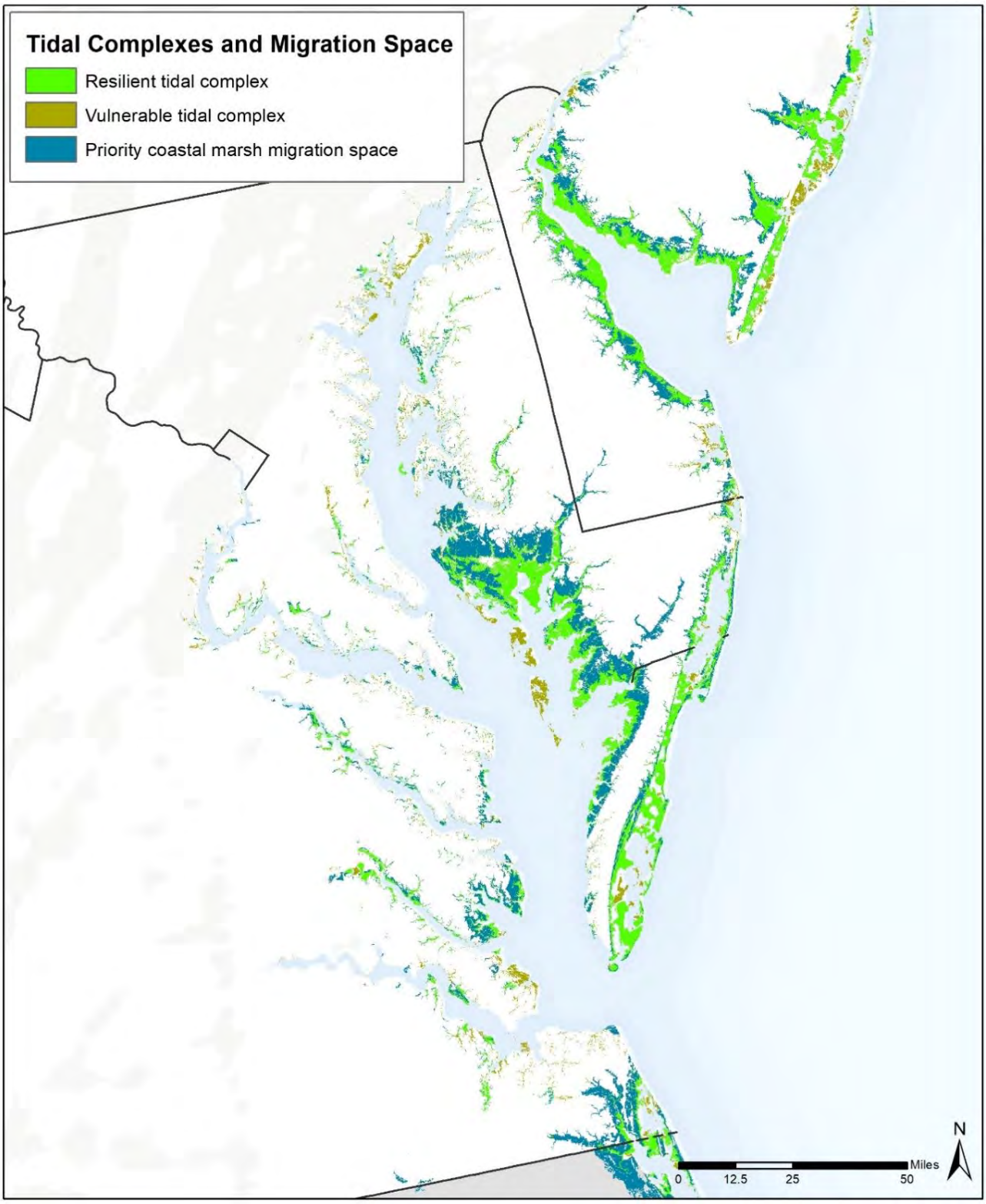
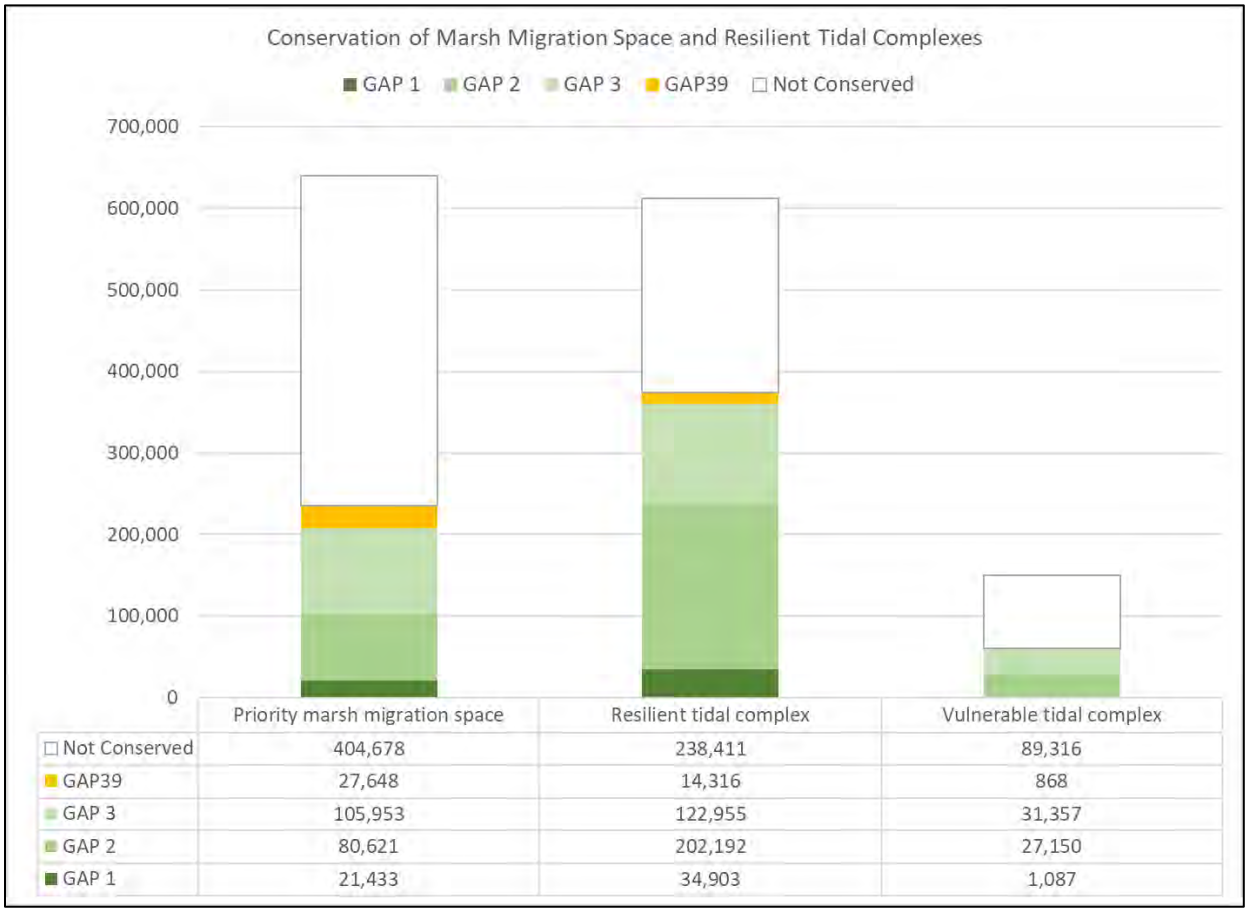


Figure 8.5: Resilient Coastal Sites and Conservation. The chart shows the amount of conversation land for three critical features: 1) Priority Marsh Migration Space: physically suitable land adjacent to an existing tidal marsh that is likely to facilitate and support new marsh in the future as sea levels rise. 2) Resilient tidal complexes: marshes with ample adjacent priority migration space. 3) Vulnerable tidal complexes: tidal marsh systems that do not have adjacent migration space and are likely to diminish as sea level rises. GAP 39 land is a subtype of GAP 3 multiple use land that is focused on farmland.



	Priority marsh migration space	Resilient tidal complex	Vulnerable tidal complex
Not Conserved	404,678	238,411	89,316
GAP39	27,648	14,316	868
GAP 3	105,953	122,955	31,357
GAP 2	80,621	202,192	27,150
GAP 1	21,433	34,903	1,087

The resilient coasts study (Anderson and Barnett 2017) found that with no action, the region could see an estimated 83% loss of existing tidal habitats to severe inundation, yet there are thousands of individual sites where tidal habitats could increase and expand through landward migration, reversing this trend. With conservation and proper management, these resilient sites could offset over 50% of tidal habitat loss, providing critical habitat for wildlife, and buffering people from the effects of storms and floods.

Results of our overlay indicate that the Northeast has 640,000 acres of priority migration space, of which 37% is already conserved (Figure 8.5). This is good news. Tidal marsh is the Northeast's most conserved habitat, but it was uncertain whether we had conserved the critical adjacent migration space that will allow marshes to adapt rising sea levels. The resilient tidal marshes associated with this migration space (middle column) are also well conserved with 61% under some form of conservation. There are also vulnerable sites under conservation (40%) but this is not necessarily a bad thing. Although the vulnerable marshes will likely contract over time, they may still provide suitable habitat for many years for species like salt marsh sparrow as new marsh forms.

Connectivity and Climate Flow

In conservation terms, connectivity refers to actions that maintain or increase the permeability of the landscape allowing species to move and facilitating the rearrangement of ecosystems. Species move to find resources both daily for food and water, and seasonally in migrations that follow changing resources. Adolescents disperse to establish new territories and find mates, and adults move when existing habitat becomes unsuitable. Climate flow refers to connectivity across climate gradients that are most likely to facilitate adaptive movements in response to changing climatic conditions.

Climate change is an ambient change in the condition of the Earth, particularly the temperature and moisture regimes that limit the distribution of many species. In response to new conditions, most species move, leading to changes in community composition or the rearrangement of whole ecosystems. Species persisted under past climatic changes through in situ refugia combined with range shifts to track suitable climates (Gill et al. 2015; Jackson and Overpeck 2000; Krosby et al. 2010). Rapid warming projected for the next century will likely require many species to adapt in a similar way (Moritz and Agudo 2013; Thuiller et al. 2005; Nunez et al. 2013), and many species' ranges are already shifting (Chen et al. 2011; Hitch and Leberg 2007). However, high levels of habitat loss and fragmentation due to anthropogenic activities are isolating populations and creating barriers to species movement that were not present during past periods of rapid climate change (Thomas et al. 2004; Peters and Darling 1985; Corlett and Westcott 2013). Protecting connectivity is essential for effective conservation under climate change, as connectivity facilitates movement and gene flow, bolstering adaptive capacity by maintaining genetic diversity (Hoffmann and Sgro 2011; Sgro et al. 2011; McRae and Beier 2007).

Assessing Connectivity and Climate Flow

We used the TNC Connectivity and Climate Flow dataset which maps the gradual movement of species in response to climatic gradients across a human-modified landscape (Map 8.3, Anderson et al. 2023). The dataset modeled movement potential as a continuous surface based on degree of human modification and geographical climatic gradients using a minor adaptation of the software program, Circuitscape (Shah and McRae 2008). The software models movement as if it was electric current flowing across a surface of mixed resistance which allows for the creation of wall-to-wall connectivity maps that emphasize variations in the density of current flow corresponding to variations in resistance by barriers and roads.

You can view, map, and download the data on TNC Climate Resilience website.

Methods are described in detail in: Anderson, M.G., Barnett, A., Clark, M., Prince, J., Olivero Sheldon, A. and Vickery B. 2016. Resilient and Connected Landscapes for Terrestrial Conservation. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA.

Approach**:** This approach was first developed through a shared grant from USFW North Atlantic LCC. Anderson, M.G. Clark, M. and McRae, B.H. 2015. Permeable Landscape for Climate Change. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA.

The work was guided by a literature review: Maintaining a Landscape that Facilitates Range Shifts

Map 8.3. Connectivity and Climate Flow. This map was created using wall-to-wall Circuitscape to model the gradual movement of species in response to climatic gradients across a human-modified landscape. Areas in dark blue have the highest flow, which may indicate a concentration area or pinch point important for conservation.

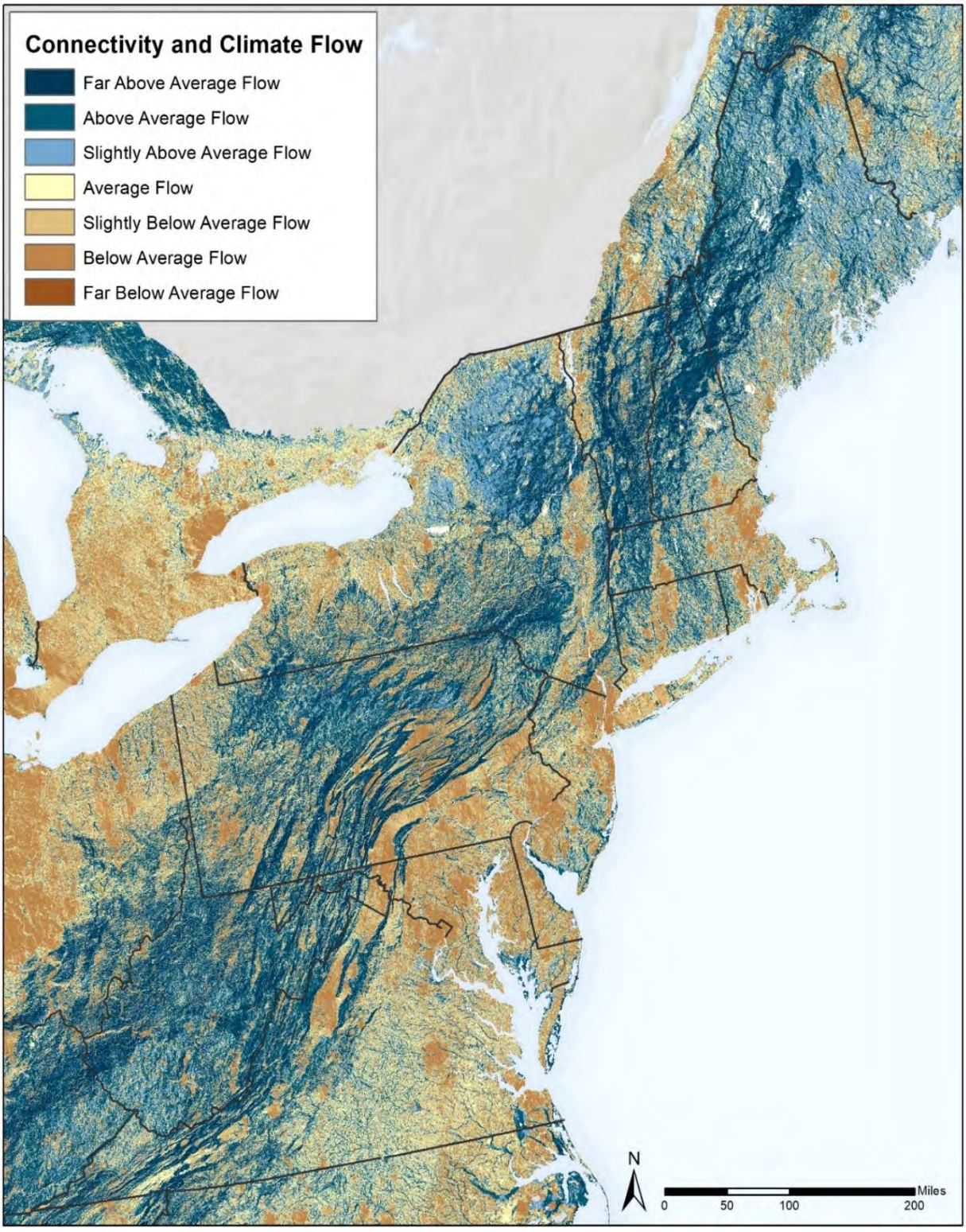
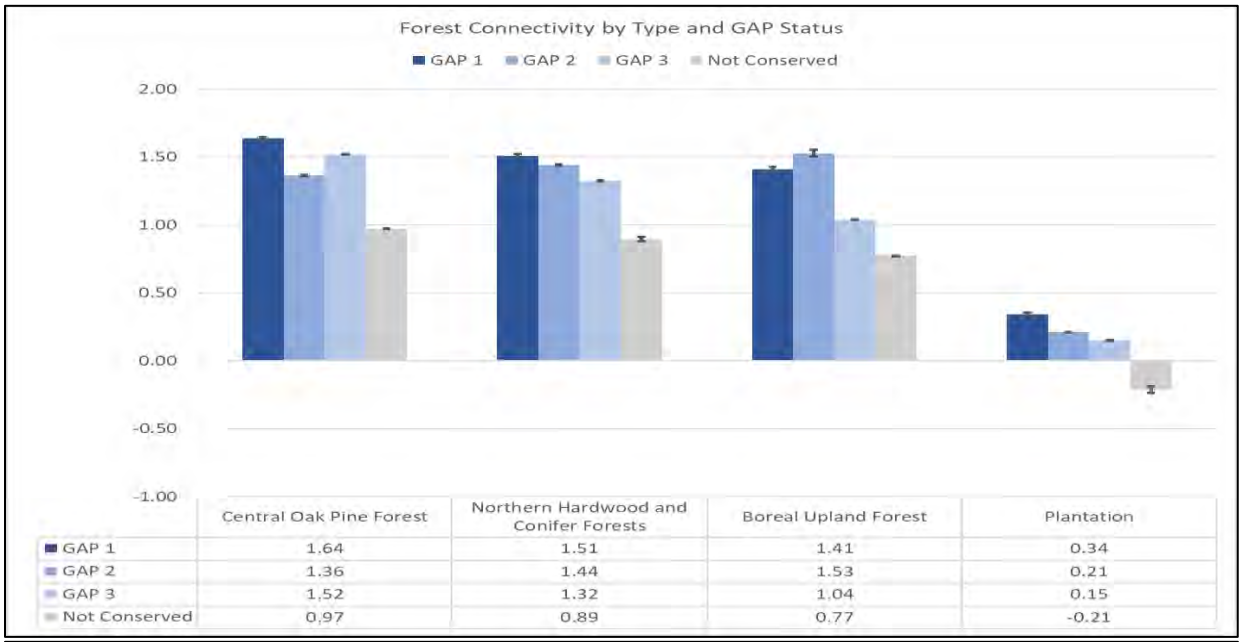
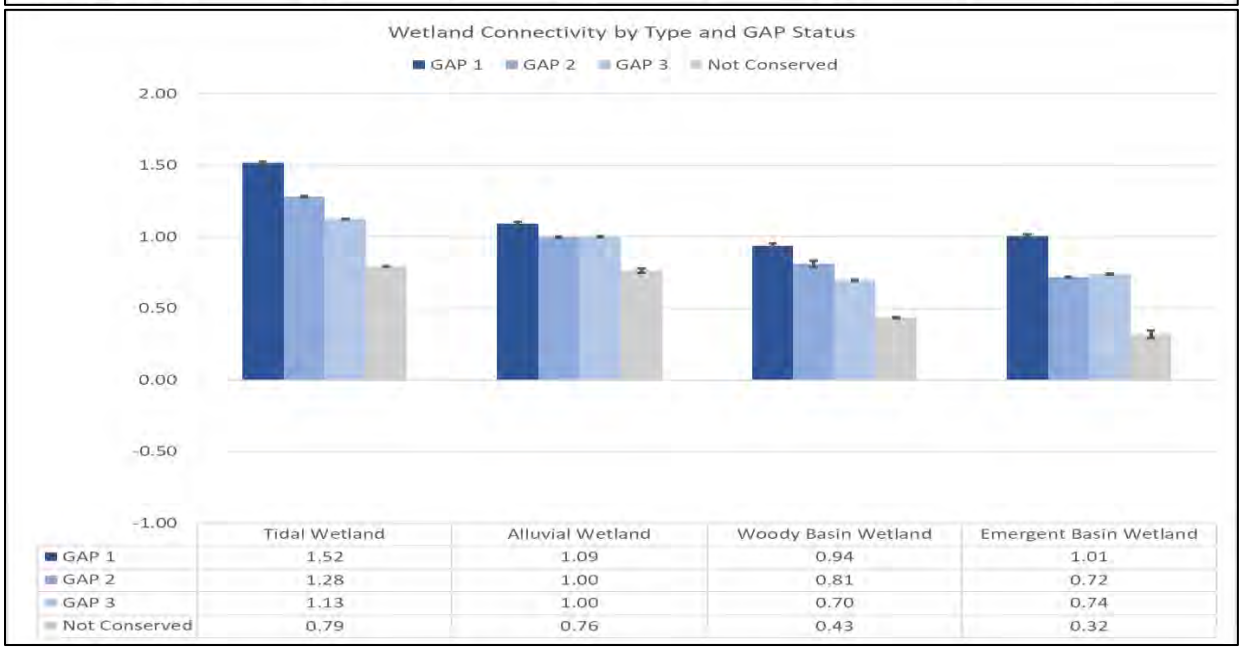


Figure 8.6: Regional Flow by Forest/Wetland Type and GAP Status. These charts show average amount of climate flow per forest or wetland type. Flow patterns are fundamentally spatial. Interpreting them statistically can be challenging because high flow usually indicates channeled and concentrated flow while average flow can be equally high but more diffuse as through a intact landscape.



	Central Oak Pine Forest	Northern Hardwood and Conifer Forests	Boreal Upland Forest	Plantation
GAP 1	1.64	1.51	1.41	0.34
GAP 2	1.36	1.44	1.53	0.21
GAP 3	1.52	1.32	1.04	0.15
Not Conserved	0.97	0.89	0.77	-0.21



	Tidal Wetland	Alluvial Wetland	Woody Basin Wetland	Emergent Basin Wetland
GAP 1	1.52	1.09	0.94	1.01
GAP 2	1.28	1.00	0.81	0.72
GAP 3	1.13	1.00	0.70	0.74
Not Conserved	0.79	0.76	0.43	0.32

Results of the overlay of conservation lands on the flow map (Figure 8.6) suggest that conservation lands tend to have more connectivity and facilitate more climate flow than unconserved land, and flow density correlated with GAP status. Forest tended to have slightly more flow (1.4 SD) than wetlands (0.99 SD) but the differences were not dramatic. Oak-pine forest, had the highest flow among forest types, which likely reflects its being the most intact natural cover in a landscape of mixed fragmentation.

Biodiversity Value

Biodiversity refers to the totality of biological life on earth in all its organized forms: species, communities, and ecosystems (Norse and McManus 1980). Collectively, biodiversity underlies all the earth's life processes and cycling of organic materials. Living plants produce the oxygen we breath, chemicals for medicine, materials for building, and by extracting carbon from the air, they create the sugars, carbohydrates, and fats that form the base of Earth's food webs. Ancient plants and algae are the base of coal and petroleum. Insects, birds, and bats pollinate our crops and are responsible for the colors of flowers. Fungi and invertebrates decompose waste and recycle nutrients, building the healthy productive soils and clean water we need.

In conservation, recognized biodiversity value is usually measure of the quality and condition of wildlife and habitats for their intrinsic worth, such as a viable species population, high quality habitat for breeding, or an intact and compositionally complete example of a community or ecosystem.

Measures of site resilience and connectivity have become integral to identifying places for maintaining nature's dynamics, but to sustain biodiversity, a conservation network must also include sites that support living biotic assemblages of sufficient quality to persist. This includes high-quality ecosystems, communities, and species to ensure that any conservation network is embedded with elements of biodiversity that provide the capacity to adapt.

To identify areas recognized for their biodiversity value, we compiled data from 104 published assessments from two main sources: TNC Ecoregional Assessments and State Wildlife Action Plans (Map 8.4). TNC's portfolio of biodiversity sites was developed through separate ecoregional assessments completed between 1999 and 2010. Each assessment developed a comprehensive list of targets for the ecoregion consisting of rare or specialist species and characteristic natural communities. Natural Heritage Program element occurrences were used to identify multiple locations of each target, and viability criteria were used to rank each occurrence. Representation goals were set based on the distribution, rarity, and spatial pattern of the targets. A spatial portfolio of sites was identified for each ecoregion that aimed to meet representation goals for all viable target occurrences. This resulted in a set of sites that, if conserved, would collectively protect the biological diversity of the ecoregion. The portfolio datasets have a high degree of consistency, as the target lists and sites were reviewed by knowledgeable experts.

We also incorporated sites recognized in 38 state-based wildlife and habitat assessments. The majority were Conservation Opportunity Areas (COAs) mapped as part of each state's Wildlife Action Plan, but where COAs had not been mapped, we also compiled comparable state-wide assessments if they were spatially explicit and had clearly defined terrestrial targets. The state datasets varied widely in terms of conservation targets and expansiveness. Some COAs were identical to the TNC portfolio, while others incorporated different priorities identified through multiple assessments with their own objectives and methods. Most COAs focused on nongame animal species and habitats.

We integrated these two sources into a single map showing which source they were derived from and where they overlap (Map 8.4). Lists of targets are available for each site from the original source reports or TNC data. For this section we overlaid the 2022 conservation land data on the biodiversity map to assess the status of the biodiversity sites.

Map 8.4. Recognized Biodiversity Value.

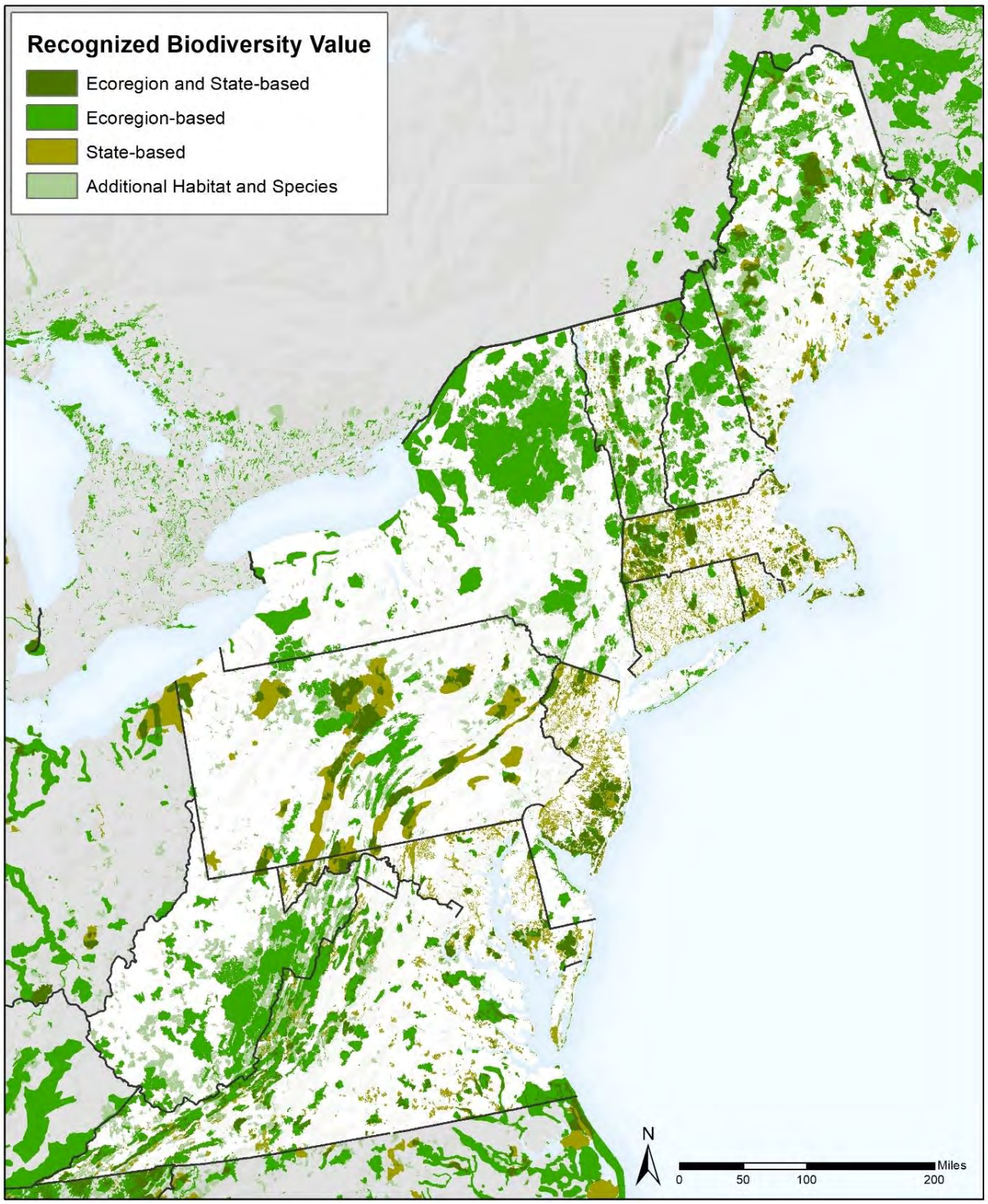
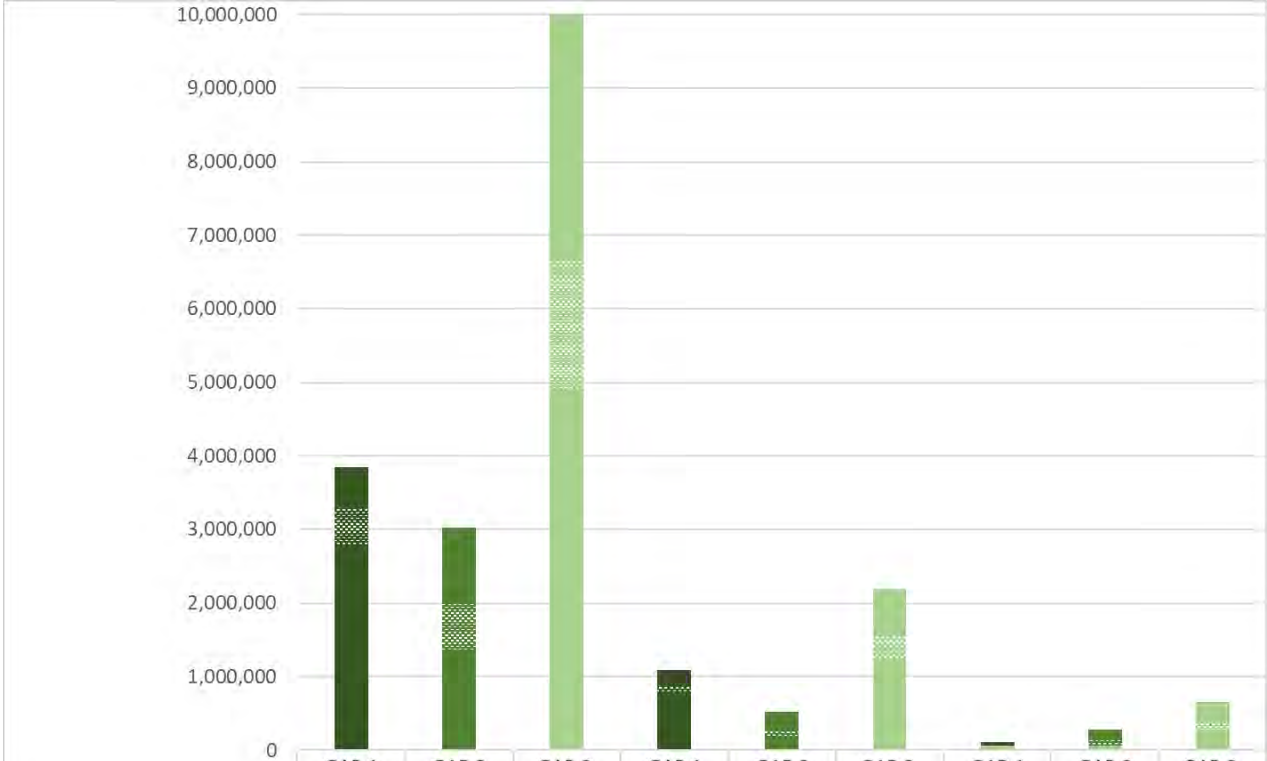


Figure 8.7. Conservation of Biodiversity Areas by GAP status and Decade. The bar show the amount of conservation of biodiversity site were achieved each decade and before 2001. The upper half of the bar corresponds to state-based sites and the lower half to ecoregional sites. The hatched area in the middle shows where the sites overlap



	GAP 1	GAP 2	GAP 3	GAP 1	GAP 2	GAP 3	GAP 1	GAP 2	GAP 3
	Before 2001			Between 2001 and 2011			Between 2012 and 2022		
State-based	566,278	1,034,748	3,506,592	224,363	251,795	660,308	29,301	148,400	278,294
Ecoregion and State-Based	476,084	628,170	1,732,480	77,025	101,390	298,453	20,759	72,694	96,046
Ecoregion-based	2,801,059	1,366,934	4,912,769	792,346	166,967	1,235,689	56,631	60,378	283,923

Almost 22 million acres of conservation has occurred on land recognized for its biodiversity value, including 50% of the conservation achieved in the last decade. Most of the conservation was achieved through multiple use land but together GAP 1 and 2 collectively total about 40% of each time-period, and that ratio has stayed relatively consistent (41%, 42%, 37%).

Resilient and Connected Network

*"*Ensure that at least 30 percent globally of land areas…especially areas of particular importance for biodiversity and its contributions to people, are conserved through *effectively and equitably managed, ecologically representative, and well-connected systems* of protected areas and other effective area-based conservation" - *Convention on Biological Diversity (CBD 2030 Target 2)*

Motivated by declines in biodiversity exacerbated by climate change, The Nature Conservancy identified a network of conservation sites designed to provide resilient habitat for species while supporting dynamic shifts in ranges and changes in ecosystem composition. The 12-year effort to identify and map the network involved 289 scientists in 11 geographic regions and all 50 states. The results identify 34% of the conterminous US and represents all habitats. The intent was to support local, regional, and national-scale conservation decisions in conserving biodiversity. The methods and results for the conterminous U.S. were published in the Proceedings of the National Academy of Science (Anderson et al. 2023, Map 8.6). The supporting science has been published in five peer-reviewed scientific journal articles and 11 geographically specific reports (Appendix 1).

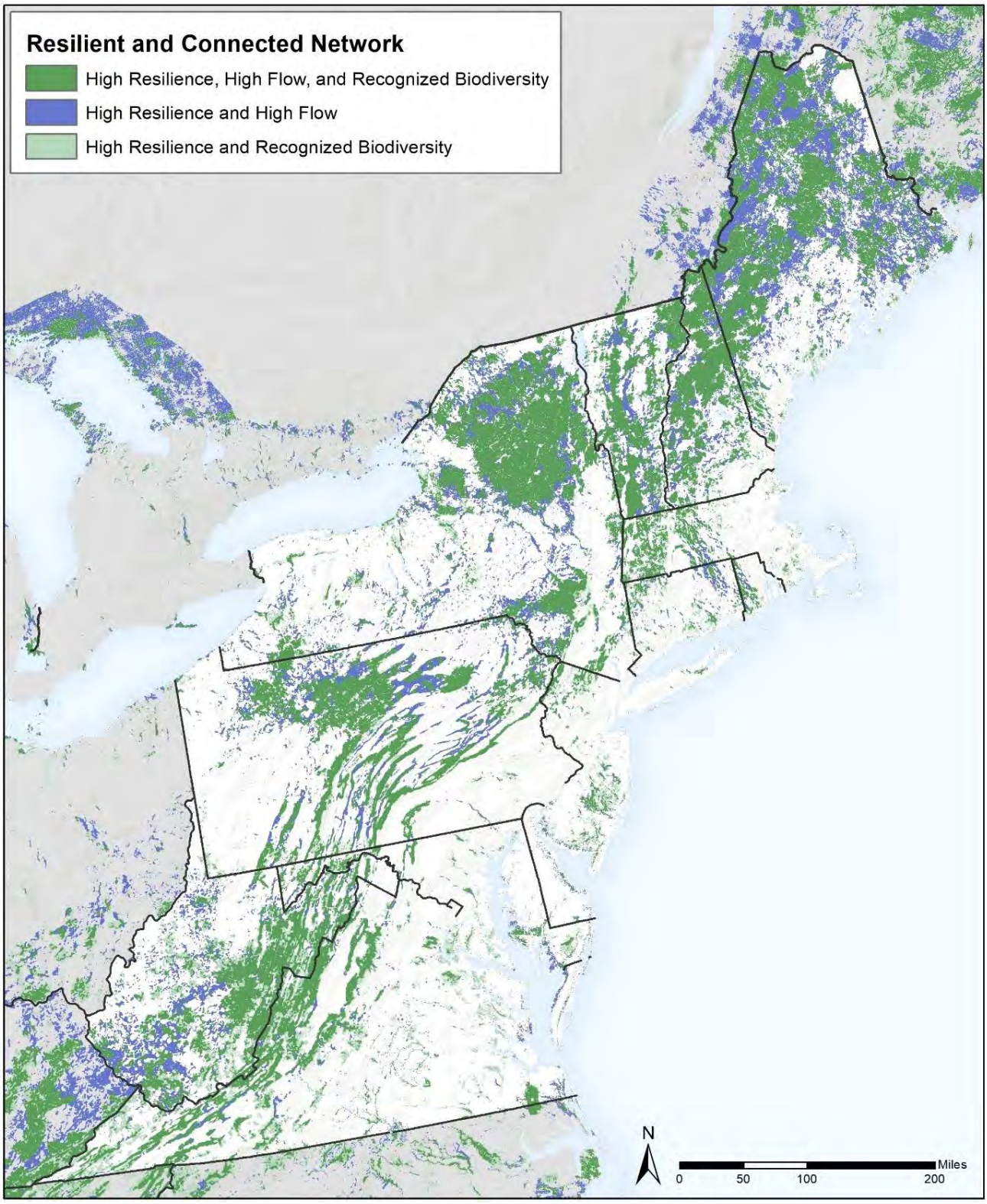
America the Beautiful and 30 by 30

In 2019, nineteen prominent scientists challenged the world to forge a Global Deal for Nature (GDN) in a landmark paper that advanced a science-driven plan to save the diversity and abundance of life on Earth (Dinerstein et al. 2019). The GDN targets 30% of Earth to be formally protected by 2030, plus an additional 20% designated as climate stabilization areas to ensure the temperature change stays below 1.5°C. The authors argue that pairing the GDN and the Paris Climate Agreement would avoid catastrophic climate change, conserve species, and secure essential ecosystem services. In the U.S. the Biden-Harris Administration's America the Beautiful initiative called for the country to work collaboratively to conserve and restore the lands, waters, and wildlife that support and sustain the nation, and to pursue the first-ever national conservation goal – a goal of conserving 30 percent of US lands and waters by 2030 (Biden Administration 2021).

To date, the 30 by 30 calls have not gotten into the specifics of *where*, but for the initiative to sustain the county's wildlife and plants under a changing climate, the places matter. TNC's Resilient and Connected Network can serve as a blueprint for this work because it integrates the key principles of conservation science with the characteristics of resilience and connectivity into a single network. Specifically:

- **Representation**: Sites representing an ecologically meaningful portion of every ecoregion distributed across geophysical settings
- **Site Resilience**: Sites with a high diversity of connected topoclimates linked by natural cover and accessible to species (Map 8.1)
- **Connectivity** and Climate Flow: Sites positioned along climatic gradients within areas of low human modification (Map 8.2 and 8.3)
- **Recognized Biodiversity Value**: Sites supporting biotic assemblages characteristic of their geophysical setting (Map 8.4)
- **Carbon**: The network in the Northeast contains over 4.2 billion metric tons of forest carbon, 51% of the region's carbon (Map 8.7)

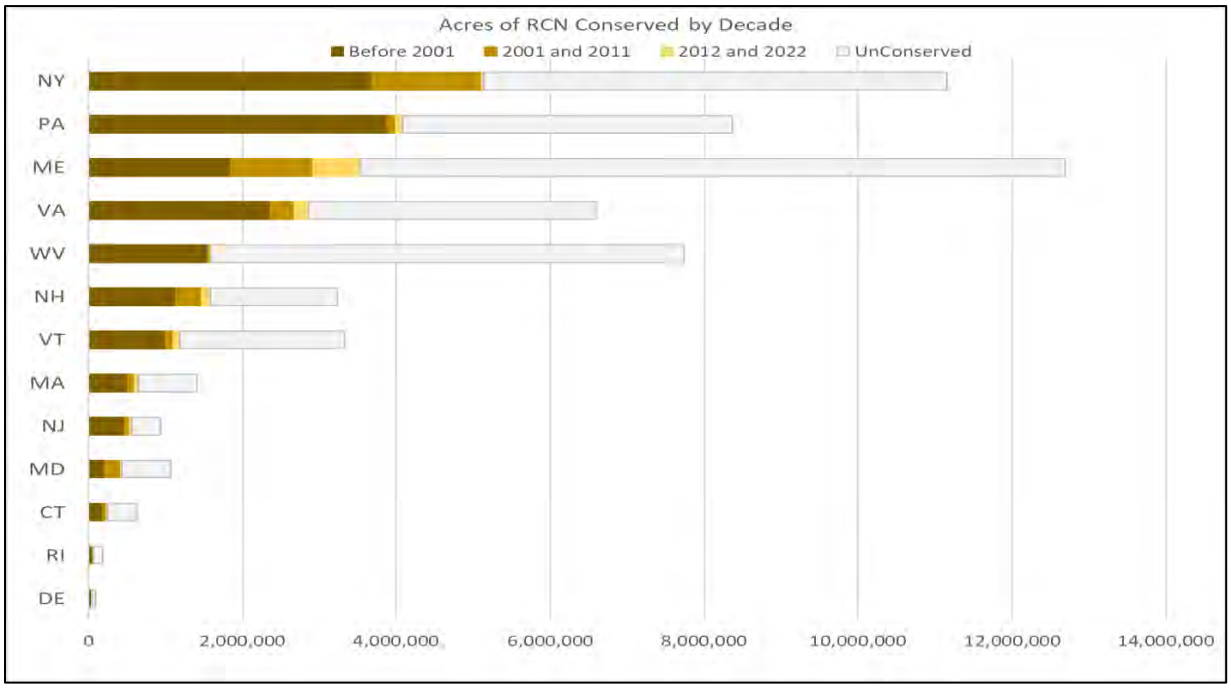
Map 8.5. Resilient and Connected Network The network covers 36 % of the northeast and is designed to provide resilient habitat for species while supporting dynamic shifts in ranges and changes in ecosystem composition.



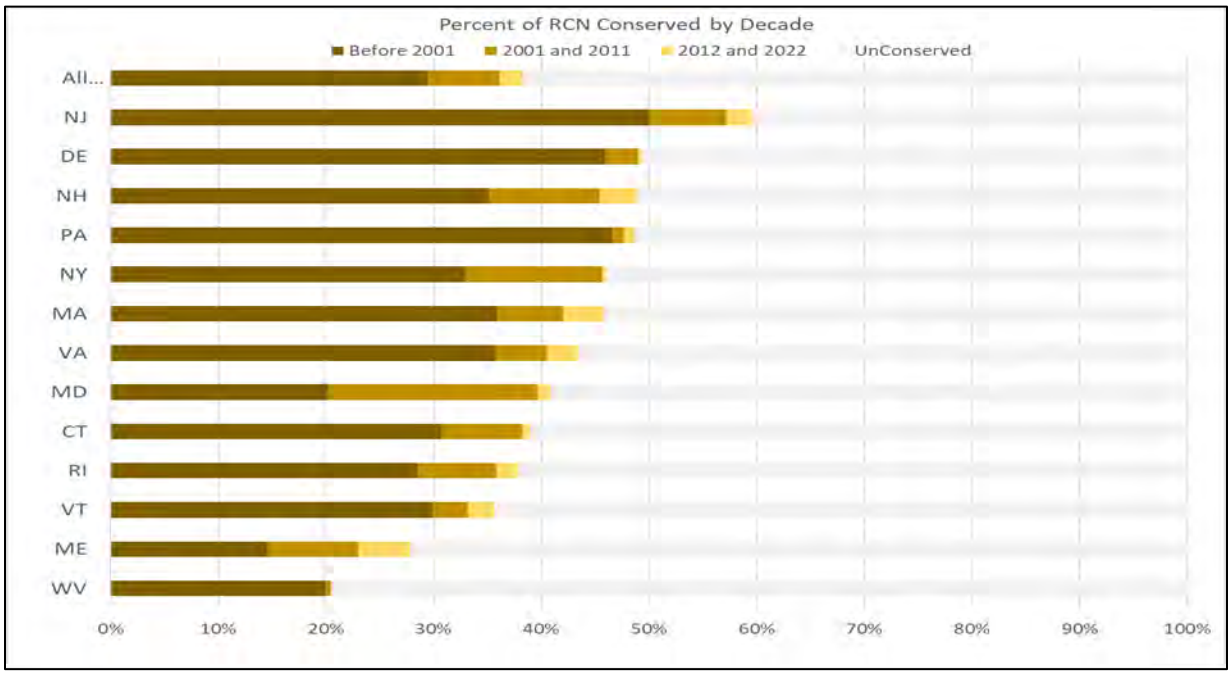
Over 38% of the Resilient and Connected Network is already under conservation from independent efforts by the states (Figure 8.8). Most of that conservation happened before 2001 but in the last decade another 1.2 million conservation acres were added, mostly by private conservation organizations.

Figure 8.8: Conserving the Resilient and Connected Network. Acres of the network vary by state. The two charts show the area conserved in each decade by acres (top) and percent (bottom)

Acres



Percent



Carbon

Carbon is an essential chemical element that underlies all organic compounds like proteins, sugars, carbohydrates, and fats. All plants and animals consist of carbon cells and need to consume carbon to live and grow. Animals consume carbon through eating other sources of it. Plants and algae extract carbon directly out of the air as carbon dioxide (CO^2), releasing the oxygen and converting the carbon to sugars and carbohydrates, which are then transferred throughout the plant and burned or converted to biomass.

To retain a habitable planet for people and nature we must curtail the excessive release of carbon into the atmosphere. Most Intergovernmental Panel on Climate Change (IPCC) scenarios of how we can limit warming to below 2 °C assume large-scale use of carbon dioxide removal methods, plus reductions in greenhouse gas emissions. The cheapest and most mature carbon dioxide removal method is improved land stewardship and conservation (Griscom et al. 2017). Forests, bogs, swamps, marshes, and grasslands are naturally sequester and store carbon and have been doing it for millions of years. Yet confusion persists about the specific set of actions that should be taken to both increase carbon sinks with improved land stewardship and reduce emissions from land use activities. Thus, it has become imperative that we track the carbon implications of our activities. The carbon benefits of land protection and improved management have risen to the forefront of conservation discussions.

Mapping Forest Carbon The estimates of 2010 Forest carbon stock and components -aboveground, coarse woody debris, and soil/other – used in this chapter are from Williams et al. (2021) following methods described for the Southeast US in Gu et al. (2019). They are available for exploration and quantification on the resilient land mapping tool: https://maps.tnc.org/resilientland/

To estimate carbon stock, attributes were determined for all forested 30-m pixels in the conterminous United States. A forest carbon cycle model trained to match Forest Inventory and Analysis (FIA) data was used to predict carbon stocks for 2010 based on site-level attributes of forest type group, years since disturbance, and site productivity class. Results were iterated backward in time to provide continuous, annual reporting of forest carbon dynamics for each pixel. Most prior studies lacked spatial detail on the age of forest stands that persisted in a forested condition during the satellite data era, but this study used remotely sensed biomass to estimate the stand age condition of these persisting, intact forests, distinguishing relatively young stands (e.g., 30 to 50 years old) from older stands.

Mapping results estimate that the region boasts and estimated 9.8 billion metric tons of forest carbon (8,403,294,831 mt) distributed roughly as above-ground (30%), below-ground (50%) and debris (20%) (Map 8.6) According to EPA that is equivalent to 8 billion passenger vehicles driven for one year. The Williams et al (2021) model estimates carbon sequestration by 2050 if those forest grew undisturbed, and although that may be unrealistic under climate change and current harvest patterns, forest growth could potentially add another 1.4 billion metric tons of carbon to the existing stock.

Map 8.6. Estimated Forest Carbon Stocks for 2010. Model from Williams et al 2020.

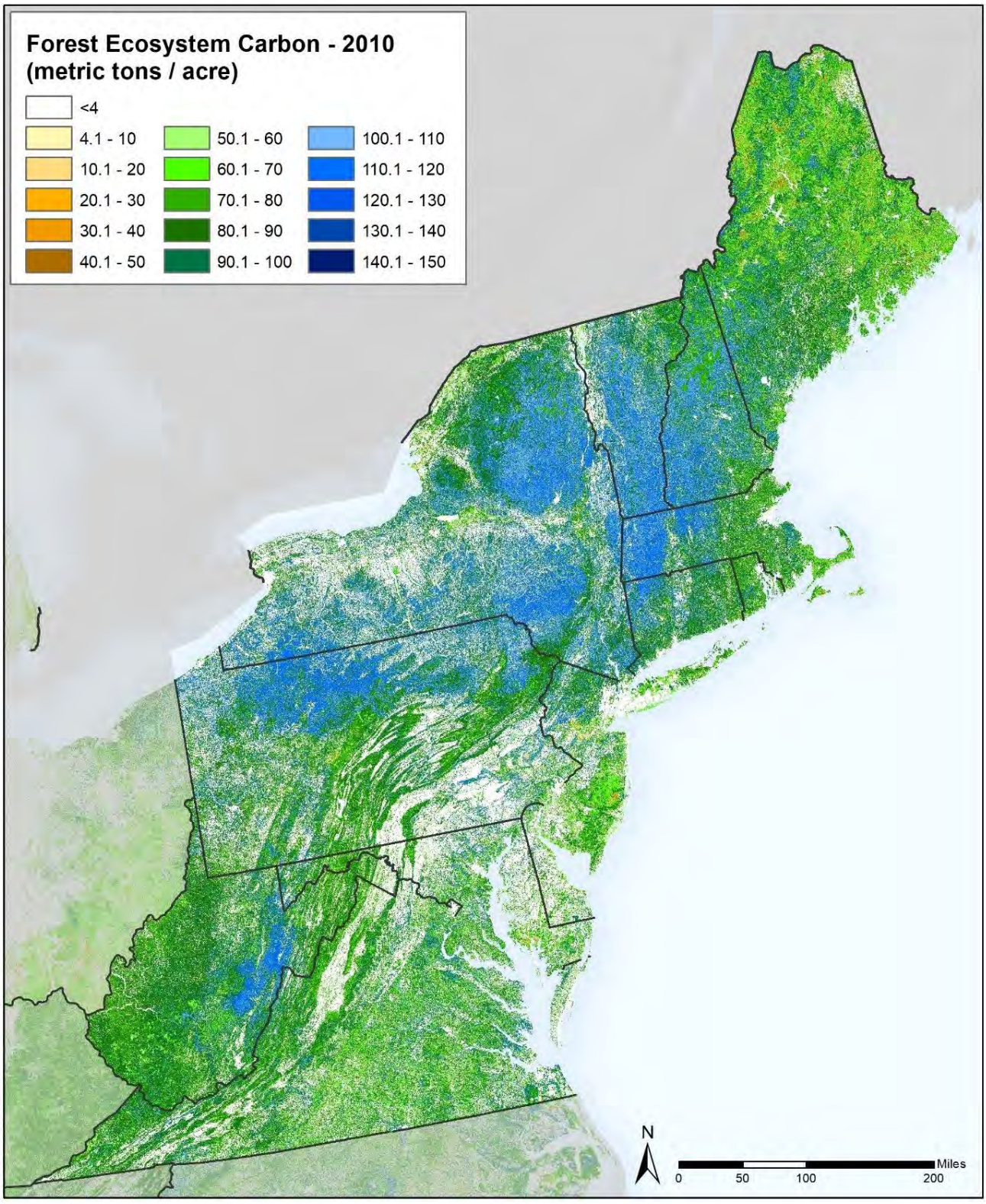
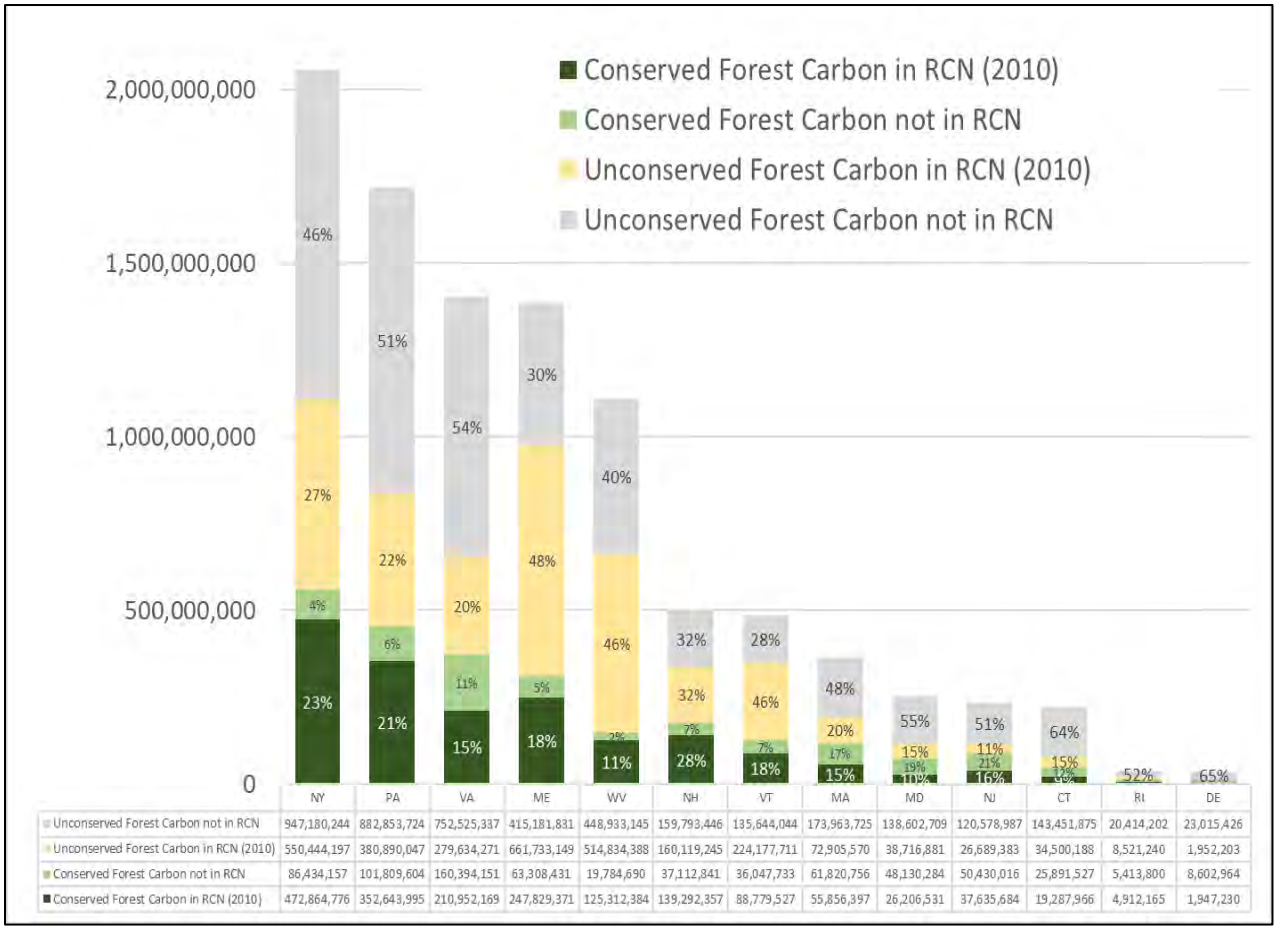


Figure 8.9. Forest Carbon Stocks by State and RCN. Forest carbon stocks vary widely with the size of the state and the amount of forest cover. Most states have already conserved a large proportion of their forest carbon, and most of that was in the RCN.



	NY	PA	VA	ME	WV	NH	VT	MA	MD	NJ	CT	RI	DE
Unconserved Forest Carbon not in RCN	947,180,244	882,853,724	752,525,337	415,181,831	448,933,145	159,793,446	135,644,044	173,963,725	138,602,709	120,578,987	143,451,875	20,414,202	23,015,426
Unconserved Forest Carbon in RCN (2010)	550,444,197	380,890,047	279,634,271	661,733,149	514,834,388	160,119,245	224,177,711	72,905,570	38,716,881	26,689,383	34,500,188	8,521,240	1,952,203
Conserved Forest Carbon not in RCN	86,434,157	101,809,604	160,394,151	63,308,431	19,784,690	37,112,841	36,047,733	61,820,756	48,130,284	50,430,016	25,891,527	5,413,800	8,602,964
Conserved Forest Carbon in RCN (2010)	472,864,776	352,643,995	210,952,169	247,829,371	125,312,384	139,292,357	88,779,527	55,856,397	26,206,531	37,635,684	19,287,966	4,912,165	1,947,230

TNC's Resilient and Connected Network was design using extensive representation goals organized by Ecoregion (ecologically homogenous areas with similar physical conditions). As a result, the network has almost perfect representation of all the country's habitats (99.7%, Anderson et al 2023) with examples chosen for their site resilience, connectivity, and biodiversity value. One consequence of this approach is that the network is unevenly distributed by state. States with several different ecoregions (for example, coastline, river valleys, mountains) may contain more of the RCN than more uniform states. States, however, are the centers of action for conservation and it is instructive to look at how the goals cross state boundaries with an eye toward matching state and ecoregional biodiversity and carbon goals (Figure 8.9).

Carbon is also distributed unevenly across states, but several synergies between carbon and the RCN are apparent. New York for example, has conserved 27% of its estimated 2010 forest carbon stock, with 23% falling within the RCN. Another 27% is available for future conservation that would meet multiple objectives for biodiversity while safeguarding over 500 million metric tons of carbon (Figure 8.8). One characteristic of carbon is that its values are qualitative and interchangeable, whereas the distribution of biodiversity is qualitative with the species composition varying in response to the physical and ecological conditions of the land.

Table 8.1. Percent Conserved by Area, GAP status, RCN and Carbon.

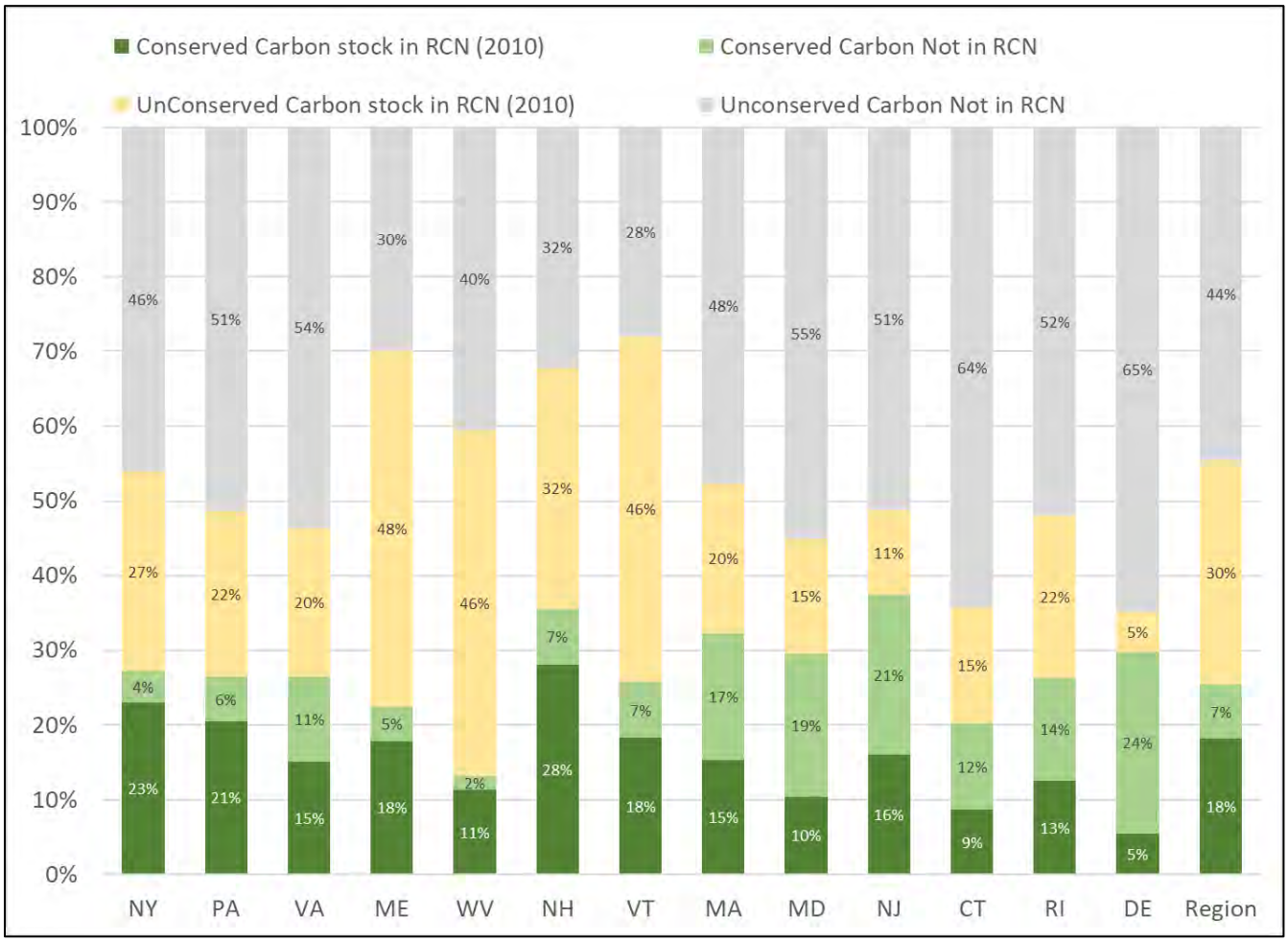
State	% Area GAP 1	% Area GAP 2	% Area GAP 3	% Area Conserved	% RCN Conserved	% Forest Carbon Conserved	Total Acres
CT	1%	4%	12%	17%	39%	20%	3,183,447
DC	0%	0%	20%	20%	100%	42%	39,988
DE	1%	4%	13%	18%	49%	30%	1,266,542
MA	3%	5%	16%	24%	46%	32%	5,200,573
MD	0%	2%	16%	18%	41%	30%	6,351,377
ME	2%	3%	16%	21%	28%	22%	20,824,982
NH	5%	8%	20%	33%	49%	36%	5,931,243
NJ	0%	13%	11%	24%	59%	37%	4,843,101
NY	9%	1%	9%	20%	46%	27%	31,055,902
PA	1%	1%	16%	18%	49%	26%	28,986,981
RI	1%	14%	5%	20%	38%	26%	697,220
VA	2%	3%	12%	17%	43%	26%	25,616,295
VT	3%	2%	16%	22%	36%	26%	6,153,095
WV	1%	2%	9%	11%	21%	13%	15,506,478
Region	3%	3%	13%	19%	38%	25%	**155,657,223**

Conserving America the Beautiful (30 by 30):

There is debate in the conservation community around what counts as "protected". In this report we count all conserved land (GAP 1-3) as contributing (Table 8.1). Scientific analysis has clearly indicated that we need land where the primary purpose is conservation for biodiversity (GAP 1-2) as these are the places where wildlife and plants can find quality breeding habitat and the resource they need to thrive. It also appears these lands improve in resilience and connectedness over time. This report has also shown the immense value of GAP 3 multiple use land in sustaining connectivity and services that benefit species at large scales beyond what has been achieved with GAP 1-2 conservation. Moreover, improved management practices have been shown to have a positive effect on biodiversity, and this is the essential land base for applying those practice. Ideally conservationists would plan collaboratively for a mix of wildlands and woodlands as has been promoted by Wildlands and Woodlands to amplify the benefits of both.

On way to look at achieving 30 by 30 is to assess how each state is doing towards conservation with respect to different footprints: acres, biodiversity as represented by the RCN, and carbon as represented by the total forest carbon stock (Table 8.1). In total, the region has conserved 19% of its area, 38% of the resilient and connected network and 25% of its forest carbon stock. For the most part these targets reinforce each other, but there is still a lot a conservation to be done in each state, particularly in unconserved carbon stock portion of the RCN (Figure 8.10).

Figure 8.10. Reaching 30 by 30: Conserving the Biodiversity and Carbon Footprint This table shows conservation as a percent of the estimated total forest carbon stock in each state. Green areas are already under conservation. The yellow-tan region is the place where conservation could make a difference to biodiversity and carbon.



Chapter 8: References

Anderson, M.G. and Barnett, A. 2017. Resilient Coastal Sites for Conservation in the Northeast and Mid-Atlantic US. The Nature Conservancy, Eastern Conservation Science.

Anderson, M.G., and C.E. Ferree. 2010. Conserving the Stage: climate change and the geophysical underpinnings of species diversity. PLoSONE July (5): 7 e11554: http://dx.plos.org/10.1371/journal.pone.0011554.

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2014. Estimating Climate Resilience for Conservation across Geophysical Settings. Conservation Biology 28 (4) 1523-1739. http://dx.doi.org/10.1111/cobi.12272

Beier, P., Hunter, M.L., Anderson, M.G. 2015. Special Section: Conserving Nature's Stage. Conservation Biology 29 (3) 1523-1739. http://dx.doi.org/10.1111/cobi.12511.

Biden Administration, 2021. Conserving and restoring America the beautiful (Report, US Department of the Interior, Washington, DC, 2021).

Brondizio, E.S. et al. 2019. Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services" (Report, IPBES Secretariat, Bonn, Germany, 2019).

Chen, I.C. et al. 2011. Rapid range shifts of species associated with high levels of climate warming. Science 333, 1024–1026.

Cleland, D.T.; Freeouf, J.A.; Keys, J.E.; Nowacki, G.J.; Carpenter, C.A.; and McNab, W.H. 2007. Ecological Subregions: Sections and Subsections for the conterminous United States. Gen. Tech. Report WO-76D [Map on CD-ROM] (A.M. Sloan, cartographer). Washington, DC: U.S. Department of Agriculture, Forest Service, presentation scale 1:3,500,000; colored.

Comer PJ, Faber-Langendoen D, Evans R, Gawler SC, Josse C, Kittel G, Menard S, Pyne M, Reid M, Schulz K, Snow K, and Teague J. 2003. Ecological Systems of the United States: A Working Classification of U.S. Terrestrial Systems. NatureServe, Arlington, Virginia.

Compton, B. W., K. McGarigal, S. A. Cushman, and L. G. Gamble. 2007. A resistant-kernel model of connectivity for amphibians that breed in vernal pools. Conservation Biology 21:788–799.

Convention on Biological Diversity (CBD), 2020. "Zero draft of the Post-2020 Global Biodiversity Framework" (Report, Secretariat of the Convention on Biological Diversity, Montreal, 2020).

Corlett, R.T. and D.A. Westcott. 2013. Will plant movements keep up with climate change? Trends Ecol. Evol. 28, 482–488.

Crist, P. J., B. Thompson, T. C. Edwards, C. J. Homer, and S. D. Bassett. 1998. Mapping and Categorizing Land Stewardship. A Handbook for Conducting Gap Analysis.

Crossley, M.S., et al. 2020. No net insect abundance and diversity declines across US Long term ecological research sites. Nat. Ecol. Evol. 4, 1368–1376 (2020).

Dewitz, J., 2019, National Land Cover Database (NLCD) 2016 Products: U.S. Geological Survey data release, https://doi.org/10.5066/P96HHBIE.

Dinerstein, E., et al. (2019). A Global Deal for Nature: Guiding principles, milestones, and targets. Sci. Adv. 5, eaaw2869.

Dobrowski, S. Z. 2010. A climatic basis for microrefugia: the influence of terrain on climate. Global Change Biology DOI:10.1111/j.1365-2486.2010.02263x

Fei S., et al. 2017. Divergence of species responses to climate change. Sci. Adv. 3, e1603055 (2017).

Gill J.L. et al., 2015. A 2.5-million-year perspective on coarse-filter strategies for conserving nature's stage. Conserv. Biol. 29, 640–648.

Griscom, B.W., Adams, J., et al. 2017. Natural Climate Solutions. PNAS 114 (44) 11645–11650.

Groves, C.R. 2003. Drafting a Conservation Blueprint: A Practitioner's Guide to Planning for Biodiversity (Island Press, Washington, DC).

Groves, C.R., Game, E.T., Anderson, M.G., Cross, M, Enquist, C, Ferdana, Z, Girvetx, E, Gondor, A, Hall, K.R>, Higgins, J., Marshall, R, Popper, K, Schill, S, and S.L. Shafer. 2012. Incorporating climate change into systematic conservation planning, Biodiversity and Conservation 20 (1). https://adapt.nd.edu/resources/275/download/Groves_ClimateChangeinConservationPlanning_2012.pdf

Gu, H., Williams, C. A., Hasler, N., & Zhou, Y. (2019). The carbon balance of the southeastern U.S. Forest sector as driven by recent disturbance trends. Journal of Geophysical Research: Biogeosciences, 124, 2786– 2803. https://doi.org/10.1029/2018JG004841

Guevara, M., C.E. Arroyo-cruz, N. Brunsell, C.O. Cruz-gaistardo, G.M. Domke, J. Equihua, J. Etchevers, D.J. Hayes, T. Hengl, A. Ibelles, K. Johnson, B. de Jong, Z. Libohova, R. Llamas, L. Nave, J.L. Ornelas, F. Paz, R. Ressl, A. Schwartz, S. Wills, and R. Vargas. 2020. Soil Organic Carbon Estimates for 30-cm Depth, Mexico and Conterminous USA, 1991-2011. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1737

Hitch, A.T., and P L. Leberg, 2007. Breeding distributions of North American bird species moving north as a result of climate change. Conserv. Biol. 21, 534–539.

Hoekstra, J. M., Boucher, T.M., Ricketts, T.H., and C. Roberts. 2005. LETTERS: Confronting a biome crisis: Global disparities of habitat loss and protection. Ecology Letters 8(1):23-29.

Hoffmann, A.A and C.M. Sgro. 2011.Climate change and evolutionary adaptation. Nature 470, 479–485

Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan. 2004. Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing.in Science Conference, G. Varoquaux, T. Vaught, J. Millman, Eds. (2008), pp. 62–65.

Jackson, S.T. and J.T. Overpeck, 2000. Responses of plant populations and communities to environmental changes of the late Quaternary. Paleobiology 26, 194–220.

Krosby, M. et al. 2010. Ecological connectivity for a changing climate. Conserv. Biol. 24, 1686–1689 (2010).

LANDFIRE, Biophysical Setting Layer (LC16_BpS_200). LANDFIRE 2016 REMAP LF 2.0.0 (US Department of the Interior, Geological Survey, and US Department of Agriculture, Washington, DC, 2016). https://www.landfire.gov/viewer/ Accessed 11 May 2022

Lawler J.J, Ackerly, D.D., Albano, C.M., Anderson, M.G., Dobrowski, S.Z., Gill, J.L., Heller, N.E., Pressey, R.L., Sanderson, E.W., Weiss, S. B. 2015. The theory behind, and challenges of, conserving nature's stage in a time of rapid change. Conservation Biology 29:618–629. Abstract http://onlinelibrary.wiley.com/doi/10.1111/cobi.12505/full

Liebert, A.S. and W.J. Ripple. 2004. Range contractions of North American carnivores and ungulates. Bioscience 54, 123–138).

McRae, B.H. and P. Beier. 2007. Circuit theory predicts gene flow in plant and animal populations. Proc. Natl. Acad. Sci. U.S.A. 104, 19885–19890.

Meiklejohn, K., R. Ament, and G. Tabor. 2010. Habitat corridors & landscape connectivity: clarifying the terminology. Center for Large Landscape Conservation, New York.

Morelli, T.L. et al. 2020. Climate-change refugia: Biodiversity in the slow lane. Front. Ecol. Environ. 18, 228–234 (2020).

Moritz, C. and R. Agudo, 2013. The future of species under climate change: Resilience or decline? Science 341, 504–508.

Muths, E., 2012. The State of Amphibians in the United States (US Department of the Interior, US Geological Survey, Amphibian Research and Monitoring Initiative.

NatureServe 2022. NatureServe Explorer, accessed 8/2022. https://explorer.natureserve.org/

Norse, E.A., McManus, R.E., 1980. Environmental Quality 1980: The Eleventh Annual Report of the Council on Environmental Quality. Council of Environmental Quality pp. 31–80.

Noss, R F, and Cooperrider, A, 1994, Saving nature's legacy: protecting and restoring biodiversity: Island Press.

Nowacki, G., Spencer, P., Brock, T., Fleming, M., and T. Jorgenson. 2001. United Ecoregions of Alaska. USGS. Open-File Report 2002-297. https://doi.org/10.3133/ofr2002297

Nunez T. et al. 2013. Connectivity planning to address climate change. Conserv. Biol. 27, 407–416

Pelletier, D. Clark, M., Anderson, M.G., Rayfield, B., Wulder, M.A., Cardille, J.A. 2014. Applying Circuit Theory for Corridor Expansion and Management at Regional Scales: Tiling, Pinch Points, and Omnidirectional Connectivity. PLoSONE 9 (1) http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0084135

Peters, R.L. and J.D.S. Darling, 1985. The greenhouse effect and nature reserves. Bioscience 35, 707–717 (1985).

Rosenberg, K.V., et al. 2019. Decline of the North American avifauna. Science 366, 120–124 (2019).

Ruefenacht, B., M.V. Finco, M.D. Nelson, R. Czaplewski, E.H. Helmer, J.A. Blackard, G.R. Holden, A.J. Lister, D. Salajanu, D. Weyermann, and K. Winterberger. 2008. Conterminous U.S. and Alaska Forest Type Mapping Using Forest Inventory and Analysis Data. Photogrammetric Engineering & Remote Sensing 74:1379–1388. https://doi.org/10.14358/PERS.74.11.1379

Sanchez-Bayo, F., and K.A.G. Wyckhuys. 2019. Worldwide decline of the entomofauna: A review of its drivers. Biol. Conserv. 232, 8–27.

Schrodta, F. et al. 2019. To advance sustainable stewardship, we must document not only biodiversity but geodiversity. PNAS 116 (33)16155–16158.

Scott, J. et al., 1993. Gap analysis: A geographic approach to protection of biological diversity. Wildl.Monogr. 57, 1–41 (1993).

Sgro, C.M. et al. 2011. Building evolutionary resilience for conserving biodiversity under climate change. Evol. Appl. 4, 326–337.

Shah, V.B. and B. McRae. 2008. Circuitscape: A tool for landscape ecology" in Proceedings of the 7th Python

Suggitt A.J. et al. 2018. Extinction risk from climate change is reduced by microclimatic buffering. Nat. Clim. Chang. 8, 713–717.

Thomas C.D. et al., 2004. Extinction risk from climate change. Nature 427, 145–148 (2004).

Thuiller, W. et al. 2005. Climate change threats to plant diversity in Europe. Proc. Natl. Acad. Sci. U.S.A. 102, 8245–8250 (2005).

Weiss, S. B., D. D. Murphy, and R. R. White. 1988. Sun, slope, and butterflies: topographic determinants of habitat quality for Euphydryas editha bayensis. Ecology 69:1486–1496.

Williams, C. A., N. Hasler, H. Gu, and Y. Zhou. 2021. Forest Carbon Stocks and Fluxes from the NFCMS, Conterminous USA, 1990-2010. ORNL Distributed Active Archive Center

Willis, K. J., and S. A. Bhagwat. 2009. Biodiversity and climate change. Science 326:806–807.

Appendix 8.1

List of Terrestrial Resilience Study Region Reports

TNC's Resilient and Connected Network (RCN) is a proposed conservation network of representative climate-resilient sites designed to sustain biodiversity and ecological functions into the future under a changing climate. The network was identified and mapped over a 10-year period by scientists in eleven geographic study regions. Methods and results for each region are described in an illustrated report reviewed by members of the steering committee.

All region's resilience reports can be accessed from the Interactive Reports and Resources Map found on http://nature.org/climateresilience or from the individual websites and direct links below.

Eastern U.S. Region: Website
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/resilience/Pages/default.aspx

Resilient and Connected Landscapes: Report
Anderson, M.G., Barnett, A., Clark, M., Prince, J., Olivero Sheldon, A. and Vickery B. 2016. Resilient and Connected Landscapes for Terrestrial Conservation. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA.
http://easterndivision.s3.amazonaws.com/Resilient_and_Connected_Landscapes_For_Terrestial_Conservation.pdf

Resilient Sites: Report
Anderson, M.G., A. Barnett, M. Clark, C. Ferree, A. Olivero Sheldon, J. Prince. 2016. Resilient Sites for Terrestrial Conservation in Eastern North America. The Nature Conservancy, Eastern Conservation Science.
http://easterndivision.s3.amazonaws.com/Resilient_Sites_for_Terrestrial_Conservation.pdf

Webmap: https://omniscape.codefornature.org/#/analysis-tour.

Cameron, D. R., Schloss, C. A., Theobald, D. M., & Morrison, S. A. 2022. A framework to select strategies for conserving and restoring habitat connectivity in complex landscapes. Conservation Science and Practice, 4(6), e12698.
https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/csp2.12698

List of Coastal Resilience Study Region Reports

Coastal Northeast and Mid-Atlantic U.S.

Anderson, M.G. and Barnett, A. 2017. Resilient Coastal Sites for Conservation in the Northeast and Mid-Atlantic U.S.. The Nature Conservancy, Eastern Conservation Science. Boston, MA
View the interactive map, download the data, and read the report at:
https://www.nature.org/resilientcoasts

Published literature by TNC Authors on the Resilience Work.

Anderson, M.G., Clark, M., Olivero, A.P., Barnett, A.R., Hall, K.R., Cornett, M.W., Ahlering, M., Schinel, M., Unasch, B., Schoss, C., Cameron, D.R. (in press 2022). A resilient and connected network of sites to sustain biodiversity under a changing climate. PNAS

Lombard, K., M.G. Anderson, K. Barlow, G. Goodwin, K. Serbesoff-King, N. Sferra, J. Wraithwall (editors). 2021. Managing for Climate Resilience on The Nature Conservancy Preserves and Managed Lands in the eastern United States. The Nature
Conservancy, Center for Resilient Conservation Science. 114 pp.

Anderson, M.G. and Johnson, N. 2016. Maintaining Forest Diversity in a Changing Climate: a geophysical approach, in Sample, V.A., Bixler,R.P. and C. Mille eds. Forest Conservation in the Anthropocene: Science, Policy, and Practice. U of Colorado Press. Boulder. 346 p.
https://www.fs.fed.us/rm/pubs/rmrs_p071/rmrs_p071_273_296.pdf

Anderson MG, Comer PJ, Beier P, Lawler J, Schloss C, Buttrick S, Albano C, Faith D. 2015. Case studies of conservation plans that incorporate geodiversity. Conservation Biology 29 (3) DOI: 10.1111/cobi.12503

Beier, P., Hunter, M.L., Anderson, M.G. 2015. Special Section: Conserving Nature's Stage. Conservation Biology 29 (3) 1523-1739. http://dx.doi.org/10.1111/cobi.12511.

Lawler J.J, Ackerly, D.D., Albano, C.M., Anderson, M.G., Dobrowski, S.Z., Gill, J.L., Heller, N.E., Pressey, R.L., Sanderson, E.W., Weiss, S. B. 2015. The theory behind, and challenges of, conserving nature's stage in a time of rapid change. Conservation Biology 29:618–629. Abstract
http://onlinelibrary.wiley.com/doi/10.1111/cobi.12505/full

Pelletier, D. Clark, M., Anderson, M.G., Rayfield, B., Wulder, M.A., Cardille, J.A. 2014. Applying Circuit Theory for Corridor Expansion and Management at Regional Scales: Tiling, Pinch Points, and Omnidirectional Connectivity. PLoSONE 9 (1)
http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0084135

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2014. Estimating Climate Resilience for Conservation across Geophysical Settings. Conservation Biology 28 (4) 1523-1739.
http://dx.doi.org/10.1111/cobi.12272

Groves, C.R., Game, E.T., Anderson, M.G., Cross, M, Enquist, C, Ferdana, Z, Girvetx, E, Gondor, A, Hall, K.R>, Higgins, J., Marshall, R, Popper, K, Schill, S, and S.L. Shafer. 2012. Incorporating climate change into systematic conservation planning, Biodiversity and Conservation 20 (1).
https://adapt.nd.edu/resources/275/download/Groves_ClimateChangeinConservationPlanning_2012.pdf

Anderson, M.G., and C.E. Ferree. 2010. Conserving the Stage: climate change and the geophysical underpinnings of species diversity. PLoSONE July (5): 7 e11554:
http://dx.plos.org/10.1371/journal.pone.0011554.

SUMMER 2021 • REPORT NO. 23

ISSUES IN ECOLOGY

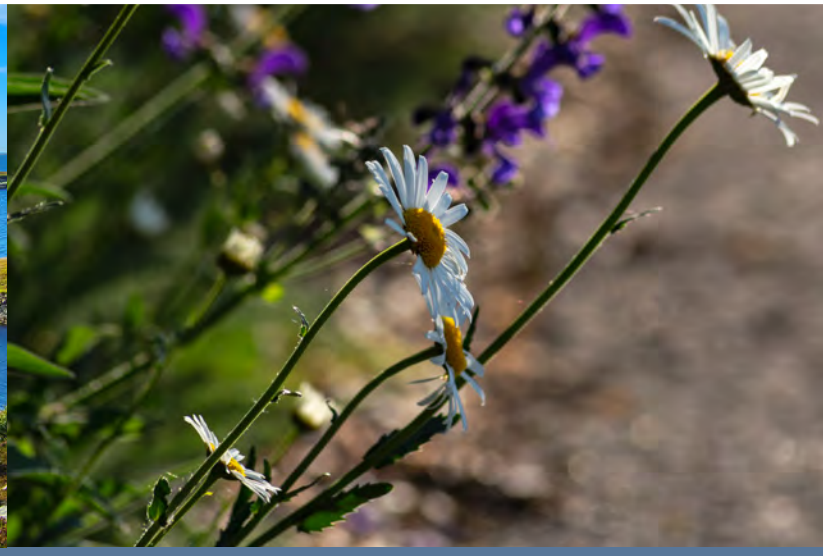
PUBLISHED BY THE ECOLOGICAL SOCIETY OF AMERICA





THE ECOLOGY OF RURAL ROADS: EFFECTS, MANAGEMENT & RESEARCH





esa

Alisa W. Coffin, Douglas S. Ouren, Neil D. Bettez, Luís Borda-de-Água, Amy E. Daniels, Clara Grilo, Jochen A.G. Jaeger, Laetitia M. Navarro, Haiganoush K. Preisler, and Emily S.J. Rauschert

THE ECOLOGY OF RURAL ROADS: EFFECTS, MANAGEMENT, AND RESEARCH

Alisa W. Coffin, Douglas S. Ouren, Neil D. Bettez, Luís Borda-de-Água, Amy E. Daniels, Clara Grilo, Jochen A.G. Jaeger, Laetitia M. Navarro, Haiganoush K. Preisler, and Emily S.J. Rauschert

SUMMARY

Road networks form the basic transportation system for most of the world's inhabitants, stimulating local and regional economies. Scientific advances in recent years have revealed that this vast, growing, planetary construction boom has been occurring mostly in non-urban environments, and most aggressively in developing frontiers of tropical regions. However, even in highly urbanized countries, road networks consist mostly of roads outside of urban areas. To produce a reliable, comprehensive picture of the global road network, scientists have taken advantage of improvements in mapping technologies, including automated detection from satellite imagery and real-time mapping on the ground. Because the extent of the global road network is increasing at a rapid, unprecedented pace, the pervasive and sometimes dramatic impacts on ecosystems and their services in rural areas will continue. The science of road ecology has emerged to quantify these effects and propose solutions to mitigate the detrimental effects of roads and their traffic. This report explains these effects and examines implications of road ecology research for decisions and actions, including some management practices to help mitigate the negative ecological effects of rural roads.

Some of the major ecological effects of roads in rural landscapes include:

- Destruction of habitat, including fragmentation of plant and animal populations.
- Traffic disturbance, including animal-vehicle collisions that reduce populations and/or habitat quality to the point of causing local extinctions.
- Introduction and establishment of invasive and non-native plants and animals that compete with native flora and fauna.
- Pollutants, including hydrocarbons, salts, nitrates, heavy metals, and pesticides, emitted from vehicles, road surface materials, and associated with dust. These pollutants persist in and change the roadside environment, including aquatic habitats (e.g., near-road streams) and downstream aquatic systems (e.g., estuaries).
- Alteration of hydrology: ditches change water movement and infiltration patterns; road structures affect erosion and sedimentation of streambeds; culverts fragment streams altering movement of aquatic fauna.
- Increased access to remote places that, in turn, enables the collateral destruction of habitats, the degradation of ecosystems, and the loss of biodiversity.

Several strategies exist for mitigating the negative effects of roads in rural landscapes. Road ecology can be applied advantageously in transportation policy, planning, and decision making to reduce the impacts of roads by evaluating development alternatives, including whether to build a road, where to build, as well as how and when to build. Such strategies can be applied at continental, regional, or local scales, contributing to the discussion of tradeoffs within a framework of sustainable development. Strategies for mitigating environmental impacts include configuring roads to avoid destroying ecosystems, installing fences to reduce road mortality, creating safe passages for wildlife under and over roads, controlling traffic during critical times for key species, and following best practices for road construction and maintenance.

© The Ecological Society of America • esa.org

Road ecology is a young science that has advanced rapidly in recent years. Thousands of scientific studies have, since the late 1990s, measured various environmental responses to roads and their traffic with the intention of quantifying the extent and magnitude of ecological effects. But, the current challenges to road ecology now involve working with large volumes of data, integrating datasets, and incorporating these data into models. Furthermore, there is a challenge in synthesizing the information across disciplines, for example, combining data on hydrological, chemical, and health effects to understand the depth and range of ecological responses. Therefore, as road ecology matures and addresses these challenges, a much more nuanced and complete understanding of the ecological effects of roads is emerging.

Smaller low-volume rural road systems are not usually as well-mapped or as well-studied as their higher-volume counterparts, yet they constitute the lion's share of the global road network and are at the frontiers where ecological patterns and dynamics strongly influence human activities. Conversely, the characteristics of the road network in these far-flung locations (e.g., how well connected they are) have implications for the future of rural communities and the landscapes in which they are embedded. While these roads offer many benefits to people living in remote rural areas, grappling with rural road impacts and addressing them with solutions for mitigating their negative ecological effects is a priority for road ecology. The community of road ecology scientists is, in cooperation with land managers and decision makers, committed to identifying the problems and evaluating potential solutions to better manage road-related ecological impacts in rural landscapes.

INTRODUCTION

From space, vast webs of human settlements can be seen spanning the planet, and they are almost entirely connected by roads. People have ventured and will continue to go wherever there is a road, and its adjacent land use has likely changed. Roads bring the promise of increased access to natural resources and, in turn, to markets and trade for producers. A road by itself is but a disturbed piece of earth, but when connected with other roads, it becomes a link in a broader network. Road networks can open entire regions to trade, economic development, and new ideas and uses, and people often see roads as signs of progress, so it is no wonder that developing the road network is central to many socio-economic development objectives. Yet roads alter and degrade the scenic and natural value of the landscapes they fragment, undermining potential sources of economic development. Recent independent efforts to map the global road network have resulted in estimates of the global extent of roads that range between 9.1 and 64.3 million kilometers depending on which road map data were used.* Even the most conservative estimate shows sufficient roadway to encircle the Earth's equator over 200 times. This vast human production signifies the vital role transportation infrastructure plays in local and regional economies, but it also constitutes an enormous human footprint with the potential for immense unintended ecological impacts.

Roads indelibly alter landscapes through both space and time. Long after the initial rationale for building a road is gone, its effects can linger, sometimes for centuries; for all intents and purposes, roads permanently change a landscape. For example, remnants of the ancient road systems of southwestern Asia, such as the Royal Road of Persia that linked ancient Susa

*The Global Roads Open Access Data Set (gROADS) v1 (1980-2010) reported 9.1 million km of roads worldwide, while the US Central Intelligence Agency "World Factbook" reported 64.3 million km in 2013.

and Persepolis (Iran) with Sardis (Turkey) in 500 BCE, are still evident today. The most enduring elements of these roads include infrastructure like the historic "Ten-Eyed Bridge" near Diyarbakir, Turkey, crossing the Tigris River. The specific land use influences of such ancient roads are hard to ascertain today, but the Greek historian Herodotus described how they facilitated communications in the Persian Empire, implying swifter and more effective territorial administration. While the evidence of highways may remain, remote unpaved roads tend to be ephemeral. Temporary logging roads, for example, might be used for months or years, but can be rendered practically invisible within a few years or decades.

BOX 1.

WHAT IS A RURAL ROAD?

Most observant travelers would be able to tell whether the road they are traveling on is in the countryside, a suburb, or a town, but the answer to this general question of road definition is not so easy. There is no globally accepted definition of a rural road. The simplest definition is a road in a rural area, which begs the question: What is a rural area?

According to the US Department of Transportation, rural areas are "outside of the FHWA-approved adjusted Census boundaries of small urban and urbanized areas." Based on the measure of population density used by the US Bureau of Census, over 96 percent of the conterminous US is rural. The US Federal Highway Administration reported that, in 2018, about 2.9 million miles (4.7 million km) of public roads that receive federal highway funding in the US (including D.C., Alaska, Hawaii and US Territories) were rural—roughly 70 percent of the public road system; of that, 1.27 million miles (2 million km), were unpaved rural roads, roughly 30 percent of all public roads in the US.



Roads are often classified by function—for example, as limited-access highways, arterials, collectors, and local roads. Rural roads can also be defined in terms of the landscapes they bisect, whether farms, forests, mountains, or deserts. Roads have also been classified by the connecting roles they play; rural roads have been defined as connecting farms to villages and villages to markets.

A related term is "low-volume roads", roads with a low average annual daily traffic volume, often considered less than 1000 vehicles per day. More than 80 percent of all US roads are low volume, a proportion that is consistent for many national road networks.

While these roads form the critical infrastructure for people living in rural areas, level of use does not always equate to whether a road is "rural." There are many low-volume roads in urbanized areas, and conversely, there are many higher-volume roads that traverse rural areas. For example, the Trans-Canada Highway system traverses remote rural areas of Canada carrying high volumes of passenger vehicle and truck traffic. Furthermore, a volume of 1000 vehicles per day can have high impacts. Even traffic volumes of 300 vehicles per day can impact some species.

However they are defined, rural roads are both paved and unpaved. Unpaved roads can be dirt roads or covered by some surfacing material, such as gravel or other stone aggregate. Unimproved roads are dirt roads without surfacing material and no regular maintenance.

For the purpose of this paper, we focus attention on those rural roads that tend to:

1) be farther from cultural centers;

2) be less regularly maintained; and

3) provide the first critical links between population centers and remote land uses such as mining and forestry.

The vast majority of the global road network comprises roads in rural areas, is predominantly low in traffic volume, and mostly unpaved, yet by comparison to highways and paved roads with high traffic volumes, these rural roads have generally been neglected in ecological research (Box 1). The longest rural road networks are in Russia, the United States of America (USA), Australia, China, Brazil, and India, ranging from about 287 thousand kilometers in India to about 517 thousand kilometers in Russia (Figure 1). Countries in Central and Southern Africa tend to have higher proportions of rural versus urban roads than countries in the Americas and Europe, regardless of size. However, with only a few exceptions in smaller, highly urbanized countries like Belgium, the rural proportion of the road network predominates. In the US, where

© The Ecological Society of America • esa.org

road networks are well documented, most public rural roads are labeled as "local" and "minor collector roads" (Figure 2). It is not surprising that most roads in the US are relatively small with low volumes, and this pattern likely describes rural road networks everywhere.

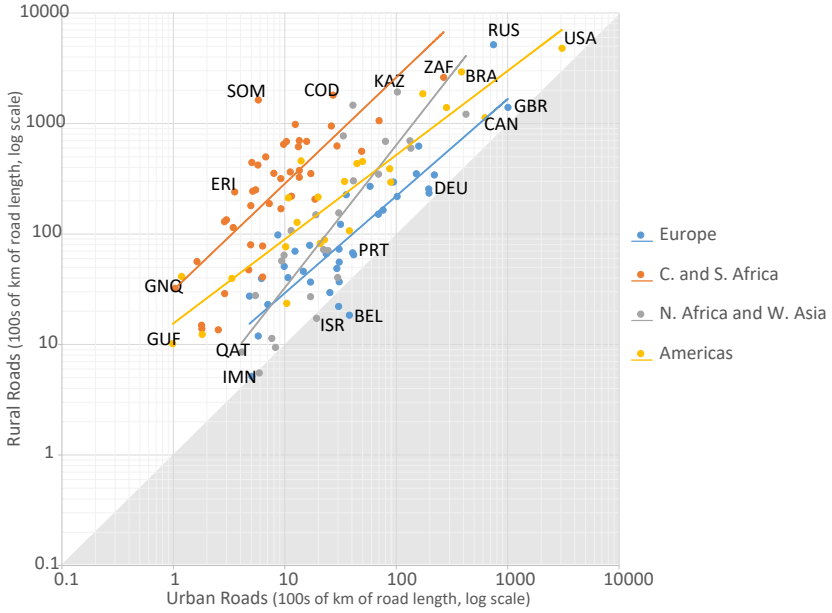


Figure 1. *Urban vs. rural road network extents for various countries, categorized by major geographic regions for Europe, Central and Southern Africa, North Africa and Western Asia, and the Americas, including trend lines for each. Global urban areas were used to differentiate urban vs. rural roads in the global roads data set. In most countries, rural roads predominate the entire network. Country abbreviations: Belgium – BEL, Brazil – BRA, Canada – CAN, Democratic Republic of the Congo – COD, Eritrea – ERI, Germany – DEU, United Kingdom – GBR, Equatorial Guinea – GNQ, French Guyana – GUF, Isle of Man – IMN, Israel – ISR, Kazakhstan – KAZ, Portugal – PRT, Qatar – QAT, Russia – RUS, Somalia – SOM, United States of America – USA, South Africa – ZAF. Data source: Center for International Earth Science Information Network (CIESIN)/ Columbia University, and Information Technology Outreach Services (ITOS)/ University of Georgia. 2013. Global Roads Open Access Data Set, Version 1 (gROADSv1). Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC).*

The global road network reveals a level of human access to the planet that is both extensive and immediate, and in a matter of years new roads and accompanying land use changes appear in tandem to completely transform landscapes (Figure 3). In 2016, an analysis of global roads indicated that, while roadless areas (at least 1 km away from a road) covered 80% of the Earth's terrestrial surface, more than half of these areas are patches of less then 1 square kilometer. Whether driven by resource extraction, colonization, or long-distance trade, building a road through a previously isolated region opens landscapes for further development. The impacts of roads on biodiversity are pervasive; indeed, the cumulative effects of roads have been called the "sleeping giant" of environmental biology.

In this report, we address the following questions about rural roads: What is the state of research into rural road ecology, and what additional research would help land managers mitigate the impacts of rural roads? What are the major effects of rural roads affecting the environment in most bioclimatic zones? What policies and practices can land managers use in planning and building rural roads to minimize ecological impacts? In short, how can we better consider the tradeoffs between social and economic benefits and ecological effects associated with rural road development and use?

The dramatic expansion of scientific research in road ecology in recent decades enables us to answer these questions, and we do so by using a conceptual framework that describes road ecology as central to three "spheres" of road development and use: understanding the ecological effects of roads (effects); informing decisions about transportation, mitigation, and landscape plans (decisions); and helping to enact road design, construction, and use strategies (actions; Figure 4). However, most road ecology research is not designed with a particular focus on rural roads. Therefore, throughout this paper, we ask: "What does the research we review mean in the context of rural roads?" We start with a description of road ecology, including the rise and development of this branch of scientific research. We then describe some major ecological effects of rural roads, including biogeochemical effects, hydrologic and atmospheric effects, effects on invasive species, and effects on wildlife, which are supported by case studies. We follow this with an examination of current national

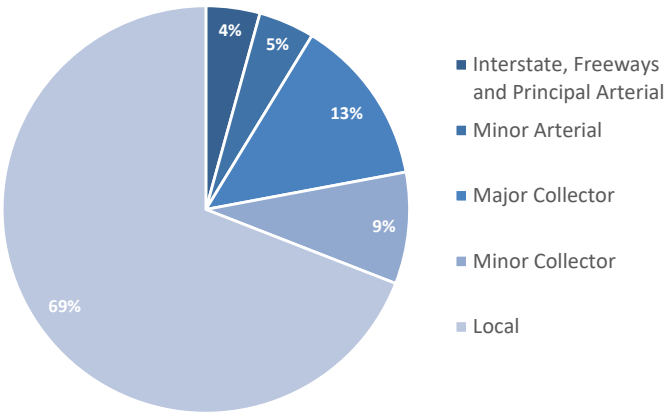


Figure 2. *Proportion of public roads by category in the US in 2018. Local roads and minor collectors constitute almost 80% of all public rural roads in the US, classified by the US Department of Transportation. This proportion has remained steady since 1980. No data has been collected for private rural roads across the entire nation.*

and international policies for rural roads, where such policies have been developed. We describe best management and mitigation practices (BMPs) for the planning, design, and use of rural roads, including a list of BMPs for each of these phases of development. We wrap up the report by discussing current research needs, particularly with respect to rural road networks, and we provide conclusions and recommendations.

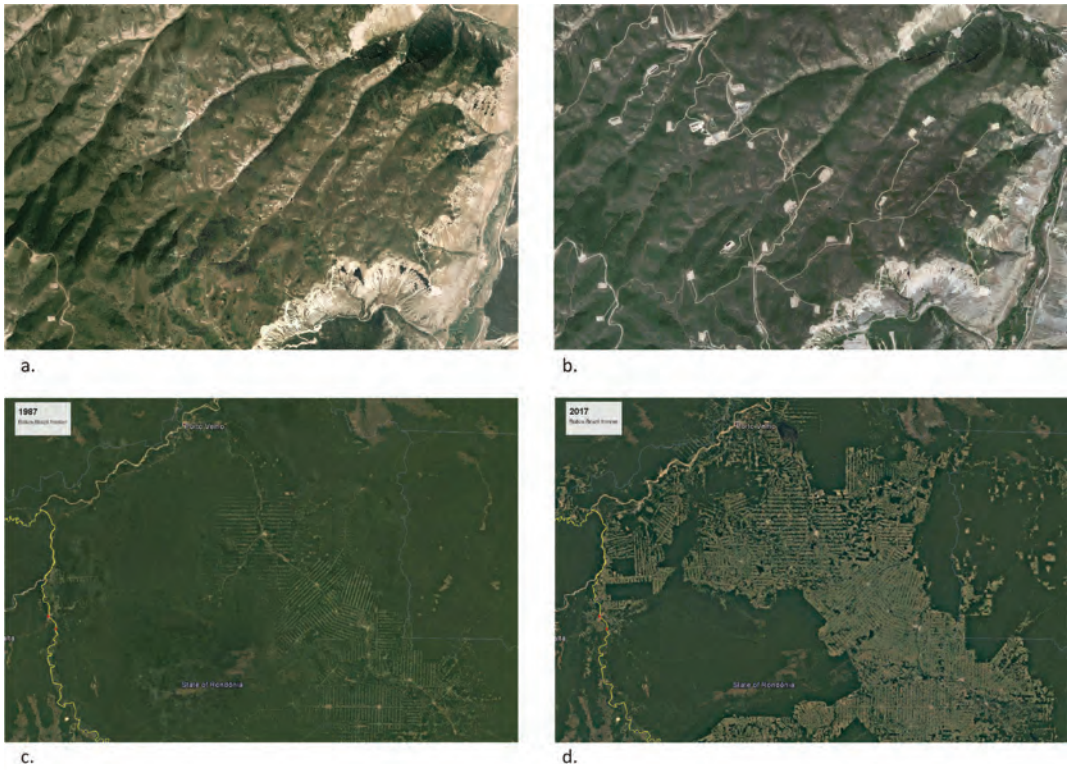


Figure 3. *Imagery showing road networks in rural areas of Colorado, US, in 2005 (a) and 2014 (b), and Rondônia, Brazil, in 1987 (c) and 2017 (d). Colorado road development patterns are indicative of gas and petroleum extraction, while Rondônia configurations show typical "fish bone" patterns of colonization and agricultural expansion. (Imagery provided by Google Earth: USDA, Farm Service Administration, National Agriculture Imagery Program; Landsat / Copernicus).*

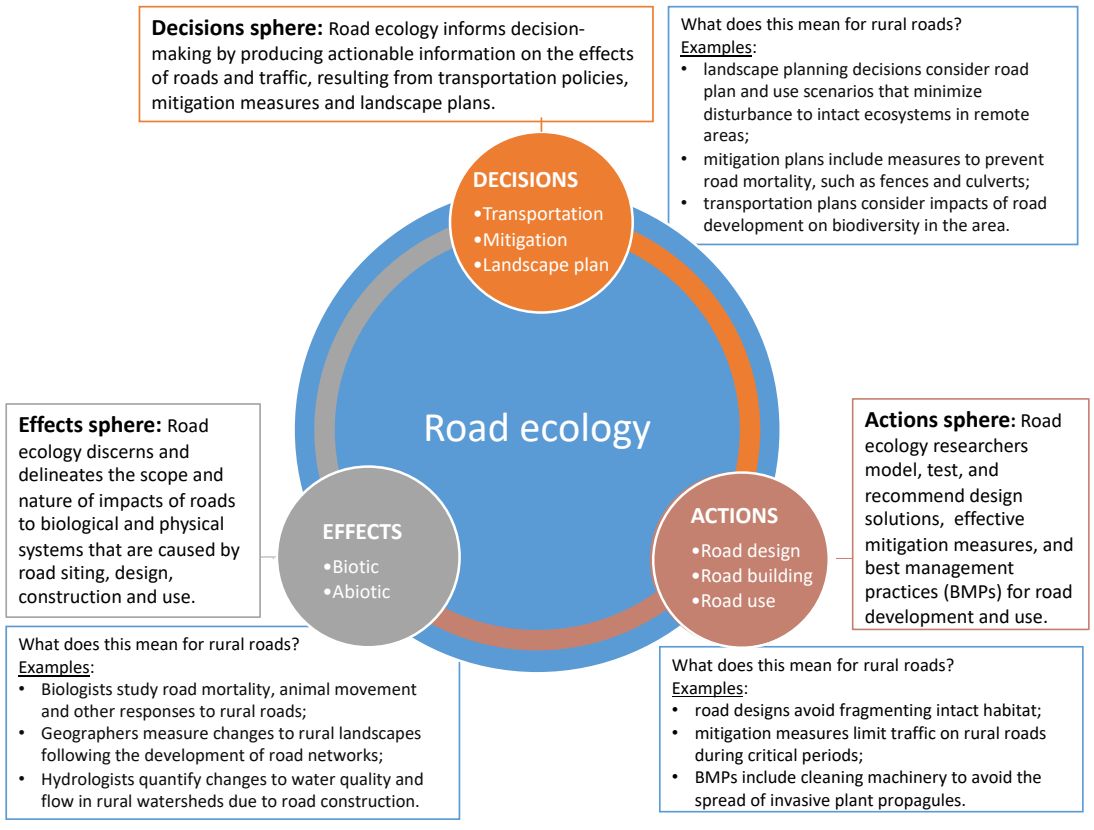


Figure 4. *Graphic showing the relationship of Road Ecology to spheres of decisions, actions, and effects. These relationships form a conceptual framework illustrating the associations of road ecology science and practice with various stages of road system planning, development, and use.*

© The Ecological Society of America • esa.org

THE RISE OF ROAD ECOLOGY

As people came to understand that roads have environmental impacts, a field of research emerged in the early 20th century bringing attention to their detrimental effects. As roads extended across landscapes to accommodate motorized vehicles, biologists noted the inevitable collisions of animals with vehicles. Initial studies were rudimentary, usually designed to help improve highway safety by reducing vehicle collisions with animals. Scientists systematically counted the numbers, species, and locations of vehicle-killed animals.

In 1981, the German vegetation ecologist Heinz Ellenberg and his colleagues first used the term road ecology *(Straßenökologie)* in German, providing a distinctive name to this field of research. Their study emphasized the effects of emissions, road salt, noise, and changes in climatic conditions on vegetation and wildlife and they warned of further fragmentation of landscapes by road construction. They also provided recommendations for reducing the use of herbicides, for the choice of roadside vegetation based on ecological principles, for reducing roadkill, and for reclaiming roads that are no longer needed. Richard T. T. Forman, a US landscape ecologist, and his colleagues translated the term in 1998 for an editorial in Landscape Ecology, in which they referred to the 1981 study by Ellenberg and others. Use of the term in English expanded further following publication in 2003 of the book *Road Ecology: Science and Solutions*.

Road-specific animal mortality studies still comprise most road ecology research; discrete and site specific, the corresponding research entails a well-defined, limited scope of work. Such studies provide useful information on the species affected as well as the timing and locations of collisions. They continue to be instrumental in planning and designing mitigation measures along high-volume roads in rural landscapes. In addition, the rise of citizen science, engaging the public in scientific projects, coupled with web-based data reporting in the last decade has also benefitted the compilation of road-kill events worldwide. Free download smartphone applications illustrate the growing potential to obtain large and geographically extensive datasets with minor costs.

Although traditional animal mortality studies contribute to our understanding of animal-vehicle collisions, they do not explain how strongly collisions with vehicles affect wildlife populations. To do so requires a deeper understanding of animal populations, such as their longevity and reproduction, and broader ecosystem responses of factors like vegetation, which in turn, affect wildlife. Consequently, a growing number of studies have collected information about seasonal, annual, and decadal responses to roads, for example, providing information about animal movements and their relationships to traffic patterns. One such study observed that Rocky Mountain elk avoid trails with all-terrain vehicles but not those with equestrian traffic (Case Study 1). Remote animal tracking, using tags that record or transmit animal positions, along with genetic and observational studies, also reveal the effects of roads on animal behavior.

Other site-specific road-effect studies, such as those examining changes to light, microclimate, dust, pollutants, hydrology, non-native species, and other measurable effects have vastly increased our understanding of how roads affect ecosystem properties and processes, along with local flora and fauna. In fact, the number of road ecology studies has mushroomed over the last two decades (Figure 5), with the number of publications increasing by over 400% since 1996. While this progress is impressive, further research is needed to link road management effects to the behavior of animals over broad temporal and

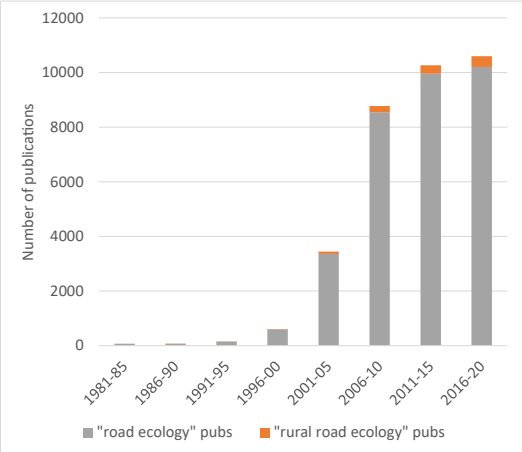


Figure 5. *The volume of English language publications with key words "road" and "ecology" has mushroomed since the publication in 1998 of the first influential papers coining the term "road ecology". The height of the bar indicates the number of publications discovered by a key word search of the EBSCOhost "Environment Complete" database. Although many road ecology studies are executed in rural areas, the proportion of publications explicitly including the term "rural" occurred in about 3% of studies, shown here in orange.*

spatial scales. For example, studies that evaluate the effectiveness of mitigation measures often suffer from limited scope, weak study design, and lack of funding. A recent analysis of mitigation studies noted that incorporating a minimum study duration of four years and comparing conditions before and after the mitigation measure is put in place would improve the evaluation of effectiveness.

TABLE 1. THE EFFECTS OF ROADS AND TRAFFIC ON LANDSCAPES AND ECOSYSTEMS

THEME	ENVIRONMENTAL EFFECTS AT OR NEAR ROADWAYS
Landscape Elements 	• Land occupation for road surface and shoulders • Soil compaction or sealing of soil surface • Alterations to geomorphology (e.g. cuts, embankments, dams, stabilization of slopes) • Removal and alteration of vegetation
Local Climate 	• Modification of temperature conditions (e.g., heating of road surface; increased variability in temperature) • Accumulation of cold air at embankments of roads • Modification of humidity conditions (e.g., lower moisture content in the air due to higher solar radiation and reduced vegetation; stagnant moisture on road shoulders due to soil compaction) • Modification of light conditions • Modification of wind conditions (e.g., due to aisles in forests) • Formation of steep micro-climatic gradients which act as barriers
Emissions 	• Vehicle exhaust, pollutants, fertilizing substances leading to eutrophication (excess nutrients in water bodies lead to excessive plant growth) • Dust and particles emissions (e.g., abrasion from tires and brake linings) • Oil, fuel, etc. (e.g., as a result of traffic accidents) • Road salt and de-icing compounds in higher latitudes and elevations • Noise, depending on vehicular traffic and atmospheric conditions • Visual stimuli; lighting from passing traffic, infrastructure and road associated activities
Water 	• Drainage, faster removal of stormwater, preventing groundwater infiltration • Modification of surface watercourses • Changes to groundwater flows • Water pollution from deposition of emmissions near roads
Flora/Fauna 	• Death of animals caused by vehicle collisions (partially due to animals' attraction to roads) • Formation of a road-effect zone with lower population densities near roads • Higher levels of disturbance and stress, loss of refuges • Fragmentation, reduction, and loss of habitat for many species; creation of new habitat for a few species • Breaking up of animal and plant populations, reduction of biodiversity, loss of species, and extinction • Genetic isolation, inbreeding effects and increased genetic drift, and interruption of the processes of evolutionary development • Disruption of meta-population dynamics, shifts in sex ratios, changes in population structure, and community composition (e.g., predation release through the elimination of large predators) • Barrier effect, filter effect to animal movement (reduced connectivity) • Disruption of seasonal migration pathways, impediment of dispersal, reduced recolonization of empty habitats • Disruption of access to resources that are dispersed across the landscape, modifications of food availability and diet composition (e.g., reduced food availability for bats due to cold-air buildups along road embankments at night) • Increased intrusion and distribution of invasive species • Creation of pathways facilitating the spread of infectious diseases

Source: Jaeger, J. (2003): II-5.3 Landschaftszerschneidung [II-5.3 Landscape dissection]. - In: Konold, W., R.Böcker, U. Hampicke (Eds.) (1999ff.): Handbuch Naturschutz und Landschaftspflege. *11th fascicle11/2003. Ecomed-Verlag, Landsberg, Germany. 30 pp. [handbook arcle]*
Note: Effects of construction sites such as soil excavation and deposition, vibrations, and acoustic and visual disturbances are not included.

© The Ecological Society of America • esa.org

EFFECTS OF RURAL ROADS ON ECOSYSTEMS

Many countries value and protect their rural open spaces as essential to their national character. In her Geographical History of America, Gertrude Stein wrote: "In the United States there is more space where nobody is than where anybody is. That is what makes America what it is." But, in the U.S. and around the world, even the most empty spaces "where nobody is" have roads, and even lightly used roads can have profound cumulative impacts on the environment—through the chemicals they shed, through the watersheds they transect, through the invasive species they introduce, and through the ways they affect wildlife (Table 1). Of particular note are the ecological effects of roads in tropical rainforests, which are substantially different than the effects of roads in other ecoregions. While the ecological impacts described below are not focused on any one ecoregion, the climatic, biological and economic conditions in tropical rainforests exacerbate many of the effects. For example, in the moist tropics, intense rainfall can cause severe erosion of roads resulting in gully formation that not only destroys the road but impacts aquatic ecosystems downstream where the sediment is deposited.

Biogeochemical Effects

Biogeochemical effects include the family of effects caused when chemical elements or substances are transferred to the environment. Roads have biogeochemical impacts when chemicals related to the roads themselves or to the vehicles traveling on them are washed off or deposited along gradients away from the road. Many of these gradients are relatively short (< 200 meters) and most of the deposition is within the first 5-10 meters, but sometimes chemicals are transported much farther by waterways. These chemicals include heavy metals such as zinc (Zn), copper (Cu), cadmium (Cd), lead (Pb), chromium (Cr), manganese (Mn), and nickel (Ni) from engine, tire, and brake wear; salts such as sodium chloride (NaCl) and calcium chloride (CaCl) from deicing and dust control; gases such as nitrogen oxides (NO_x) and ammonia (NH_3) from exhaust emissions; and hydrocarbons such as polycyclic aromatic hydrocarbons (PAHs). For example, in a comparison of European studies, researchers found higher than background median levels of Cd, Cr, Cu, Ni, Pb, and Zn in the 0-5 m area closest to the road, some of which were strongly correlated with lower soil pH. However, these studies were focused primarily on roads with high traffic volumes, with higher volume roads having higher variability and median concentrations of metals. Therefore, it could be expected that metal concentrations would be lower along lower-volume roads. The impact of chemicals in the environment varies, but many cannot be broken down by micro-organisms. Therefore, their persistent, long-term toxicity to plants, animals and people is of concern.

The road itself is a source of dust, sediments, and particulates, which have biogeochemical effects. Surface aggregates (mixtures of crushed rock or gravel) are frequently used on dirt and gravel roads to create a safe surface for driving. Both through direct runoff and through the creation of dust, the effects of the aggregate may be felt far beyond the road itself, altering soil pH and affecting vegetation. For example, higher pH of soil adjacent to limestone-aggregate surfaced roads likely helped invasive Japanese stiltgrass become established along roadsides (Figure 6).

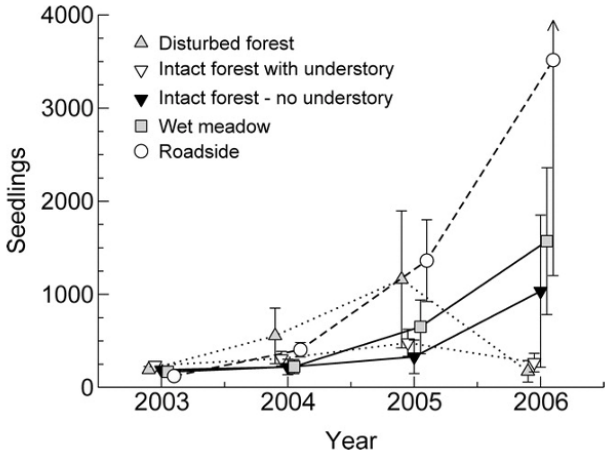


Figure 6. *Seedling recruitment of Japanese stiltgrass (Microstegium vimineum) was higher in patches adjacent to roads which were associated with higher levels of pH in the soil. (Source: Nord, Andrea N., David A. Mortensen, and Emily S. J. Rauschert. 2010. Environmental Factors Influence Early Population Growth of Japanese Stiltgrass [Microstegium vimineum].* Invasive Plant Science and Management *3:17-25.)*

Numerous studies have examined the heavy metals associated with roads, measuring their content in storm water runoff and in roadside soils. For example, research on roadsides of the Qinghai-Tibet Plateau of China found that the concentration of heavy metals in roadside soils depended on traffic density, varied with terrain and wind, and decreased exponentially with distance from the road, usually reaching background levels within 50 meters. In Australia, scientists found further contamination when road sediments and dust containing heavy metals washed into nearby streams, resulting in higher heavy metal concentrations in stream sediments. In another study, researchers discovered higher concentrations of heavy metals in the first 10 meters of roadside grasses, contaminating potential food sources for livestock and wildlife.

Other chemicals associated with vehicles, such as emissions and organic pollutants, also increase in quantity with more traffic. Incomplete fuel combustion, along with tire wear and road surface abrasion, are sources of these chemicals. Nitrogen (NO_x and NH_3) emitted in vehicle exhaust lands on the road and washes into local streams where it impacts the availability of plant nutrients in soils, affects nearby plant species composition, and contributes to pollution in aquatic systems, potentially at much greater distances. For most rural areas, roads with low traffic volumes are often free of noxious roadside emissions. However, for some rural roads, such as those associated with active mines or wells which can experience periodic heavy traffic by trucks, such contaminants are a problem, and require attention and mitigation.

Road managers apply chemicals (e.g., salt) to roads to maintain safe driving conditions, to control dust, and in cold climates to melt ice and snow. A substantial proportion of road salt – 20-63% in one Swedish study – washes off the road and is deposited nearby. Numerous studies describe the environmental effects of road salt, but the impact varies from place to place depending on local factors such as temperature and precipitation, topography, road drainage, and the amount of salt applied. In addition to physically damaging leaves, road salt also inhibits plant growth by changing osmotic stress which reduces their ability to absorb water. Road salt dissolves in water and filters into the soil, where it changes the structure of the soil, decreasing permeability and aeration, altering soil chemistry, and increasing soil pH. Surface runoff carries dissolved salt into nearby lakes and rivers where it increases the sodium and chloride concentrations. Additives to road salt are toxic to many species of plants and animals living in these aquatic ecosystems and can alter aquatic food webs. Below the surface, groundwater laden with road salt has contaminated drinking water supplies. Road salt is corrosive to concrete and metal structures, and it degrades bridge and road infrastructure, liberating and increasing the mobility of heavy metals.

Hydrologic and Atmospheric Effects

Roads change the flow of air and water, and these changes affect the environment. In rural areas, roadways and traffic interact with watersheds and airsheds, causing a variety of effects originating at the road and extending into the surrounding air and landscape, sometimes for hundreds of meters. As described previously, the chemicals associated with roads and their traffic combine with the action of wind and water to extend biogeochemical impacts up to 50 meters away from the road edge, or even much further, depending on terrain and prevailing winds.

Road surfaces and drainage systems affect the movement of surface and subsurface water across the landscape, altering aquatic systems locally and regionally. The road's semi- or impermeable surface area and storm water drainage systems act as conduits to move water off of the road surface as quickly as possible — water that would otherwise infiltrate to replenish groundwater stores and to be used by plants and released back into the atmosphere through evapotranspiration. Quickly channeling water to streams and other water bodies results in higher peak flows and associated flooding. Moving water quickly into road drainage ditches, which

© The Ecological Society of America • esa.org

occupy a relatively small area compared to the entire road surface, creates wetter soil conditions in and near the ditch, especially evident in semi-arid and arid environments where wetland species take advantage of the increased water availability and plant growth is more luxuriant. Erosion from unpaved roads in agricultural and forested areas, used primarily for moving farm and forestry machinery as well as harvested goods, causes sedimentation downstream. The fine sediments produced from roadsides reduce water clarity, change the way water flows, and increases water temperatures, in turn changing aquatic habitat and making smaller rural streams less habitable to aquatic species like trout and salmon which require cold, clear streams with gravel substrates. Watersheds with higher road densities experience more sediment and debris flows where excavated road fill erodes or slides into nearby streams. Road networks that dissect rural headwaters may affect the resilience of aquatic plant and animal communities due to changes to stream networks and the intensity of flood peaks caused by roads.

Where roads intersect drainage networks or run parallel to rivers in valleys, associated bridges, culverts, and roadbeds alter the flow of water and sediment that maintain river habitats, thereby fragmenting and degrading floodplain ecosystems and reducing the benefits of riparian buffer zones. In low-relief areas, such as the Amazon Basin or the Southeastern US, bridges and culverts constrain stream flow, leading to increased velocity that scours stream beds. Additionally, in these low-relief areas, roads on causeways interrupt the sheet flow of water across large areas, causing wetter conditions upstream of roads and drier conditions downstream. This is the case for the Tamiami Trail (US 41) which bisects the Everglades in South Florida, and where, for the last century, these types of changes have, in turn, altered key ecological processes, including fire patterns, nutrient flows, and animal movements. Recently, broad plans to restore the Everglades include ongoing modifications to the Tamiami Trail to restore water flow and ecological connectivity by constructing elevated roads. Where terrain is more rugged, as in mountainous regions of the world, roads are more likely to run parallel to stream and river channels in valleys. There, the roads can form a barrier between the stream channel and floodplain areas running parallel to the stream, preventing water from moving into these typically flooded areas, and altering historical riparian flooding patterns. Roads and their traffic affect the local atmosphere creating a microclimate that dissipates with distance from the road. By displacing vegetation with bare ground or pavement, roads alter the temperature, humidity, amount of incoming solar radiation, light reflectance, and wind speed of the immediate area. As most roads are more open and built-up compared to their surroundings, their microclimates tend to be hotter during the day (cooler at night), drier, brighter, and windier than adjacent areas. Specific conditions vary according to region, season, time of day, and how a road is designed. For example, along an unpaved road in the Central Brazilian Amazon, tree transpiration rates have been higher adjacent to the road than farther away, a consequence of higher air turbulence closer to the road. In addition, this "edge effect" extended further from the road in the dry season than the wet season. While the effects of roads on microclimates may be significant locally, their cumulative effects at broader scales are still unclear. For example, we do not know how microclimatic changes caused by road networks affect soil health, forest production, and biodiversity at regional and landscape scales over time.

While roads themselves are structural features that alter the flow of water and air, the movement of vehicles along roads raises dust, which impacts air quality. Traffic on rural roads is generally light, and many roads in rural areas are unpaved. "Fugitive dust" from traffic on unpaved roads has a range of impacts on health and ecology, especially within the first 20 meters of the road. This fine particulate matter: causes respiratory health problems; makes snow near roads less reflective and causes it to melt sooner; reduces plant productivity by coating leaves; and provides surfaces to which pollutants stick and eventually deposit downwind or downstream.

Effects on Invasive Species

An association between roads and invasive species is well-established and documented. The overall density of roads is associated with the presence of invasive species, and the prevalence of non-native species is generally higher along roads than away from them (Figure 7). Roads create more favorable habitat for invasive species by providing light gaps, dispersal corridors, and reduced competition. In some cases, exotic species, deliberately planted along roadsides to stabilize soil, add to the number of invasive plants along roads.

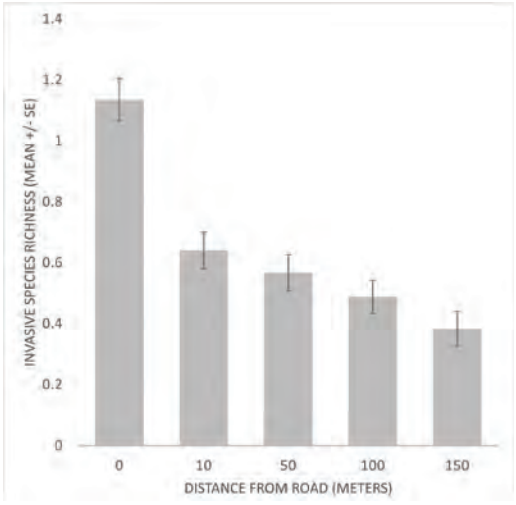


Figure 7. *Richness of invasive species declined with distance from the road, a common outcome of many road ecology/ invasive plant studies. The results shown are from data published in a study by Mortensen, D.A., Rauschert, E.S.J., Nord, A.N., and Jones, B.P. 2009. Forest Roads Facilitate the Spread of Invasive Plants,* Journal of Invasive Plant Science and Management *2: 191-199.*

Plant seeds attach to surfaces and tires of cars, trucks, and equipment used for periodic road maintenance, which means that invasive plant species tend to disperse quickly along rural roads. For example, scotch broom *(Cytisus scoparius)*, once planted to stabilize soils along roads in the western US, now proliferates along roadsides. It outcompetes native vegetation and is now considered invasive (Figure 8).



Figure 8. *Scotch broom in an Oregon landscape, after spreading from a nearby road. Photo: Eric Coombs, Oregon Department of Agriculture).*

Bugwood.org

Most rural road networks are unpaved, and the question of whether or not paving makes a difference to the spread of invasive species has been addressed in a few studies. One study on ragweed (*Ambrosia* spp.) abundance found that it spread and established more readily near paved roads than near unpaved roads. For paved roads, studies generally find higher invasive plant biomass adjacent to roads versus further away; this pattern is less pronounced in unpaved roads. These studies suggest that paving a rural road enhances the spread of some invasive species. However, all rural road networks provide access into remote areas creating opportunities for repeated introductions of these species, contributing to their proliferation.

Although studies about the connections between roads and invasive species have focused mainly on plants, roads also influence the dispersal and redistribution of non-native animals and pathogens. In the southeastern US, red imported fire ants *(Solenopsis invicta)* are commonly found in roadside habitats. Invasive cane toads *(Rhinella marina)* in Australia disperse along roadsides—the higher the road density, the greater the cane toad populations. In the US, invasive insects such as emerald ash borer *(Agrilus planipennis)* and non-native pathogens such as root rot in cedars are spread by vehicles traveling along rural roads. Less directly, when people build roads through remote areas, infectious diseases (e.g., diarrheal pathogens) spread more readily when changes to the environment, that are related to roads, combine to create conditions for increased transmission. These conditions include altered watershed drainage patterns, more intensive land uses with increased human-wildlife contact, and denser human populations accompanied by inadequate sanitation infrastructure.

Effects on Wildlife

Roads affect wildlife in many ways, acting directly when they fragment populations, and indirectly, when they induce changes in animal behavior. The four main mechanisms by which roads affect wildlife populations include:

© The Ecological Society of America • esa.org

(i) decreasing habitat area, fragmenting the remaining area, and reducing habitat quality in adjacent areas;

(ii) increasing mortality caused by vehicle collisions;

(iii) reducing landscape connectivity because roads act as barriers (e.g., some animals avoid roads and do not cross them) and sometimes interrupting seasonal migration routes; and

(iv) subdividing populations into smaller and more vulnerable sub-populations.

To appreciate how these four mechanisms affect wildlife, we need to recognize that some of them influence wildlife immediately and others act over longer time periods. The effect of habitat loss is almost immediate, reduced habitat quality and traffic mortality may take longer, and reduced connectivity longer still. Road systems also affect wildlife at different scales, from the individual to local areas where many individuals of the same species form a group (or population), to regions where multiple populations of this species live. In addition, previously described impacts of roads (e.g., biogeochemical and hydrologic) can also impact wildlife. Although less common, roadsides sometimes provide habitat for certain species, and as mentioned roads are vectors for invasive species.

Habitat fragmentation caused by the presence of roads with traffic increases the edge-to-interior ratio of habitat patches, which in turn, can impair species that need large blocks of habitat or networks of patches linked by movement corridors. A key problem with fragmenting habitat is that it can isolate groups of animals, preventing them from breeding, reducing gene flow, and diminishing their chances for persistence. The use of genetics in road ecology, while so far underutilized, holds much promise for helping researchers understand the effects of roads on wildlife populations. For example, in Australia researchers found that, after analyzing genetic data from squirrel gliders *(Petaurus norfolcensis)*, a road crossing structure effectively restored gene flow in the population within five years of its construction at a point where they had previously observed a barrier to gene flow.

Roads act as barriers, but they can also act as filters, because some individuals or species avoid them, while others do not. For example, prairie voles *(Microtus ochrogaster)* and cotton rats *(Sigmodon hispidus)* in the US were unable to cross roads three meters wide. Road avoidance behavior varies widely by species and depends on the animal's physical traits, the individual's choices, its ability to move in the landscape, and its population density. The timing of traffic conditions is clearly a factor in determining whether an individual will cross a road. For example, bobcats *(Lynx rufus)* and coyotes *(Canis latrans)* observed in Southern California crossed roads to reach patches within their home ranges at times when traffic levels were low. Furthermore, road characteristics matter to many of the animals that cross them. Research on pumas *(Puma concolor)*, a wide-ranging gregarious species, showed that the cats crossed unimproved dirt roads more frequently than improved or hard-surfaced roads. Measuring how animals respond to roads and their traffic is an important area of research in road ecology. In the western US, several studies have examined animal movements using telemetry to monitor behavior relative to roads and traffic. During annual migrations, mule deer *(Odocoileus hemionus)* experience higher rates of mortality at road crossings; Rocky Mountain elk *(Cervus canadensis nelsoni)* avoid all-terrain vehicles (Case Study 1). In the same region, Gunnison sage-grouse *(Centrocercus minimus)* fitted with GPS tracking devices avoided roads; the study mapped their movements in relation to passing vehicles and known breeding grounds, or lek sites (Case Study 2, Figure 9).



Figure 9. *Still image from video (linked below) demonstrating simultaneous tracking of vehicle traffic in relation to the movement of two individual sage grouses. The false color image is an aerial photograph of a landscape in Colorado, with roads shown as black lines, known lek sites outlined in orange, and potential lek sites shown as blue dots. The green line indicates a pulse of monitored road traffic.*

One unresolved debate in road ecology focuses on the relative harm to wildlife of fencing roads versus leaving roads unfenced or using other technologies such as wildlife warning reflectors, intended to interrupt animals' movement onto roads at night when vehicles are present. Research has clarified tradeoffs among them as well as the reasons why particular approaches may be appropriate in different situations (e.g., small rural roads versus high-traffic roads). Interrupting animal movement with fences reduces collisions with cars but fences also interfere with habitat connectivity. The debate focuses on the question under what conditions the isolating effects caused by connectivity interruptions due to animal crossing barriers are worse than the effects of animal mortality caused by vehicle collisions. Those who think of situations in which the latter are worse point out the immediate consequences of mortality, and that, ideally, fences should be used in conjunction with wildlife passages to ameliorate the barrier effect. Furthermore, they emphasize that if roads are not fenced, then animal-vehicle collisions continue, driving populations into decline, regardless of whether the populations are connected across a road. Wildlife warning reflectors, while very cost efficient, are debated because past studies have not demonstrated that they lower animal-vehicle collisions. However, a recent analysis of this work suggested that the research did not fully account for confounding factors, and, as the research was carried out using a variety of methods, further standardized research approaches are needed to assess their effectiveness. The relative importance of one potential solution over another depends to a large extent on the behavior of the focal species in question, the amount of traffic on the road and the land management status of the road area (private or public). In rural areas, low traffic volumes (less than 300 vehicles per day) may not justify the expense of implementing road crossing structures and fencing; however, even traffic volumes of 300 vehicles per day are significant for some species. This can easily be the case in times of amphibian migrations across a rural road, even with rather low traffic volumes. Even then, strategies such as temporary road closures during critical periods may be more suitable for rural roads. Research aimed at resolving these questions for smaller rural roads has yet to be fully developed.

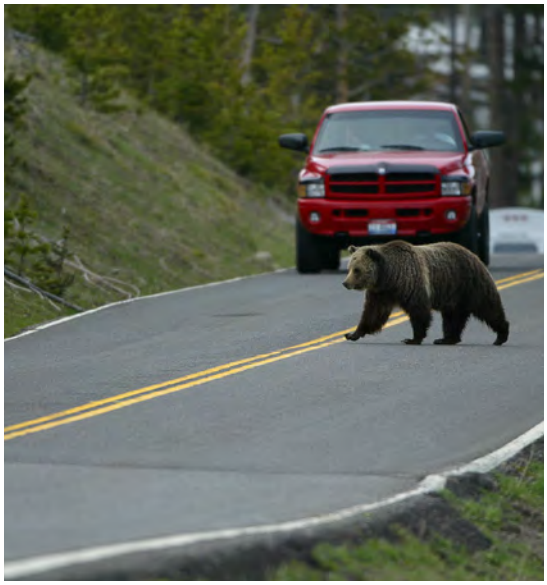


Figure 10. *Bear crossing a road in Montana, US. Photo: Doug Ouren, US Geological Survey.*

In some areas, logging roads have left a legacy of unmanaged human access to remote regions, with severe consequences for wildlife populations. This problem has been particularly marked in tropical regions where roads provide access to poachers of large mammals. In Central Africa, roads have been a major driver of elephant poaching and consequent decline in their populations; and planned road development projects may reduce the economic benefits from ecotourism. Large carnivores are particularly susceptible to the effects of roads in remote areas (Figure 10) because these animals tend to avoid roads and areas near roads, and they are thus affected by the reduced area of viable habitat. As with elephants, carnivores suffer increased levels of poaching where roads enable poachers to gain access. A recent study modeled carnivore population viability across the globe, revealing that numerous carnivores are particularly exposed to the negative effects of roads. The models, which combined road density and available habitat with species traits (e.g., population growth rates) showed that many species, including Iberian lynx *(Lynx pardinus)*, Japanese badger *(Meles anakuma)*, and Japanese marten *(Martes melampus)*, are highly exposed to roads and may be expected to become very rare or disappear in the coming decades.

Even though for most native species roads present challenges to individuals and

© The Ecological Society of America • esa.org

populations, some species benefit from roads. For example, power and fence lines that often accompany roads provide new perches for a variety of raptors. Carrion-feeding species may benefit from animal-vehicle collisions by eating the remains. However, this dynamic is a double-edged sword when they risk getting hit by vehicles themselves. Results from a recent study that modeled animal population responses to changing road densities showed that, for animals attracted to resources from a road, increasing road densities would not necessarily increase their population. A compounding effect occurs when a species' abundance increases in areas with higher road densities due to the lack of predators, also known as "predation release". This is the situation in the case of white-tailed deer *(Odocoileus virginianus)* in the eastern US. There, the lack of large carnivores has allowed deer populations to increase, in turn detrimentally affecting the mix and rejuvenation of trees and understory plants that make up the forests where they live and increasing the frequency and costs of deer-vehicle collisions.

In summary, the effects of roads tend to be generally negative for wildlife, acting as barriers or filters, reducing available habitat, and causing death from vehicle collisions. These impacts to wildlife reverberate over space, from local to regional scales, and over time, from immediate to generational scales. This combination of time and space means that roads can profoundly affect the ability of wildlife at the individual level, the population level, and, ultimately, as a species, to persist.

Landscape and Regional Effects

As networks, the ecological effects of roads extend across broad areas and cause cumulative effects that are poorly described by analyzing one road segment. Taking a landscape perspective of the effects of roads allows scientists to approach the problem more holistically. This perspective requires researchers to pay attention to the broader aspects of the road systems they study like the adjacent land uses, traffic characteristics, and overall road network connections and spatial arrangement. These considerations form the basis for an ecological road network theory, which draws from the fields of landscape ecology and transportation geography.

Landscape ecology can be used to quantify various ecological aspects of landscapes and regions. To measure the cumulative effects of road network development over time, researchers use numerous indicators that describe how the landscape is changing, such as the sizes and shapes of roadless patches and the amount of roadless area. For example, a study in northern Wisconsin, US, over a 50-year period of development, showed that the size of roadless patches decreased and the shape of these patches became more regular as road density increased. Likewise, in the Congo Basin, researchers developed a statistical tool to measure roadless space and found that, over time, logging concession areas all lost roadless space, while national parks did not. Their study, however, was limited to protected areas and logging concessions, so we still lack information about most of the landscape which does not fall into either of those categories. Given that road systems fragment the landscape, indicators that measure levels of connectivity at landscape and regional scales are useful for modeling, measuring, and describing the interactions between roads and the landscape. Even simple measurements of road density and distance from roads can help bracket expected levels of ecological effects in a given region.

As roads develop across regions, they cause changes in land cover, but also appear as a result of changing land uses. Over the last few decades, studies focused on tropical deforestation have found repeatedly that road development is one of the key factors in the predictable patterns of land transformation. In many frontier situations, road development is linked with mining and forestry. Where land is poorly monitored and legal protections are virtually non-existent, roads built for legitimate reasons, such as providing access to national ports of entry, become conduits for illicit activities, like illegal mining, timber extraction, and poaching. Illegal mining, for example, occurs when government controls over an area are weak and individuals or groups informally mine without permits, leading to changes in settlement patterns and land use in remote areas. Eventually, as transportation

costs decline, the region becomes more attractive to farmers and ranchers, and the forests or grasslands give way to agriculture, extending hundreds of meters from the road. Consequently, more roads are built to provide more access to more intensively used land, and ultimately, the entire landscape is transformed. In the Amazon Basin, where deforestation has long been observed, a combination of political and economic policies has been driving these destructive transformations.

DECISIONS AND ACTIONS: POLICY AND BEST PRACTICES FOR RURAL ROADS

As road ecology research continues to develop, transportation policies increasingly incorporate principles of landscape ecology and adaptive management into guidelines for road development and management. Resources about road ecology, from scientific papers that provide reflective questions (Figure 11), to handbooks and guides, are increasingly available to transportation planners and managers. However, much of the recently gained knowledge about the cumulative effects of roads on plant and animal populations has yet to be incorporated into decisions and translated into actions, especially those effects occurring at broader spatial and temporal scales. Because transportation policies exist at national, subnational, and local levels, incorporating knowledge from road ecology into policy and practice requires engagement with many different institutions. Where those institutions lack sufficient resources or capacity to function effectively, the job is that much harder. In tropical and subtropical countries, large rural road networks combine with biodiversity hotspots to produce some of the most strategic opportunities for "high-return" mitigation, where relatively simple measures to avoid or correct the negative impacts of roads can make a big difference for conservation. However, it is often the case that these are places where governance operates with limited capacity, and centralized institutions are far-removed from the road-building frontier. Therefore, road ecology adoption in planning and management

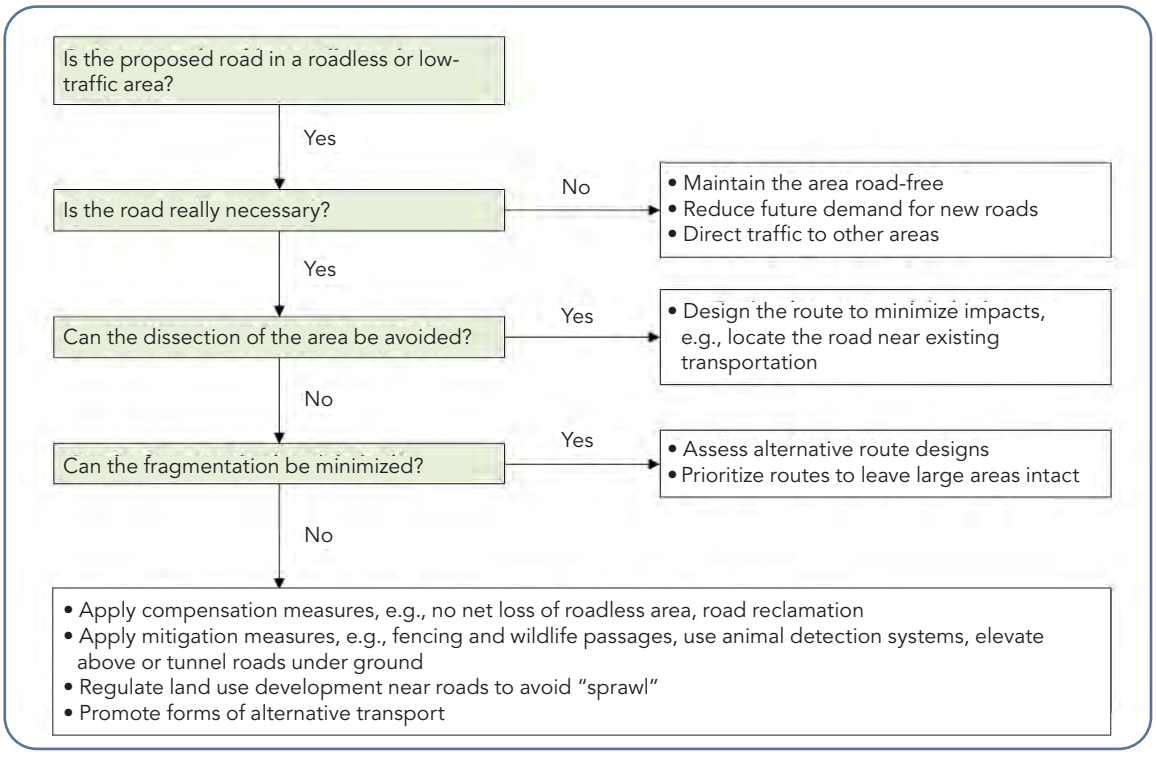


Figure 11. *Four main questions to ask when planning a road project in roadless or low-traffic areas. (Source: adapted from Selva* et al. *2015. "Why Keep Areas Road-Free? The Importance of Roadless Areas" in eds R. van der Ree, D. J. Smith, and C. Grilo.* Handbook of Road Ecology. *John Wiley & Sons)*

© The Ecological Society of America • esa.org

policies is less well developed. This situation underscores the importance of the implementation of ecological "best practices" for road development in these regions.

Policy Approaches in the United States and the European Union

The most notable examples of transportation and land policy taking advantage of road ecology science are in industrialized countries, including recent changes to transportation policies in the United States (US) and the European Union (EU). Historically, rural transportation management policies failed to consider broader, landscape-scale dynamics related to cumulative ecological effects of rural road network development and use. Typical project-based, fine-scale decision processes gradually impact and cumulatively alter landscapes, i.e., a "death by a thousand cuts." Policy solutions that incorporate broad-scale landscape ecological approaches are found to be more effective in managing the spatially diffuse effects of roads on regional- or continental-scale ecosystem processes. Solutions may, for example, prioritize conservation areas where the development of roads would fundamentally alter regional ecological processes, such as animal migrations or basin-wide flood patterns. Incorporating environmental standards in the planning, design, development, and maintenance of roads is squarely in the public's interest, providing for consideration of the long-term effects of rural road systems on natural resources and biodiversity. Most transportation development agencies maintain some level of environmental standards in their policies and procedures. In one case, the US Federal Highway Administration and its Sustainable Highways Initiative provide numerous publications and tools to aid transportation planners in the development of highways and roads. However, in the US, a variety of governmental agencies at the state, county, and municipal levels are also responsible for rural road policy and can enforce their own rules, creating sometimes complex multi-layered decision processes. Globally, the extent to which the standards used by transportation departments have effectively integrated road ecology solutions is an open question, as no comprehensive review of such standards exists. Therefore, this is an area of potentially valuable research.

The US Forest Service (USFS) manages extensive areas of land including thousands of kilometers of low-volume rural roads. In the late 1990s, due to the increasing use of USFS lands for recreation, insufficient funding available to maintain the existing road system, and a growing body of scientific evidence about the ecological impacts of roads, the USFS turned its attention to road management policy. In 2001 the USFS published its "Roadless Area Conservation Rule" that fundamentally changed its longstanding approach to managing the roughly 58.5 million acres (236.7 thousand km^2) of inventoried roadless areas, or one-third of the nation's federal system of national forests and grasslands. Rather than managing road development via independent land management plans for each national forest, the rule encompasses the whole system of USFS-managed land and prohibits most road construction and reconstruction, as well as timber harvest in inventoried roadless areas. More than a decade of litigation put in question the rule's implementation, and during that period, a state-led petition process resulted in two state rules (Colorado and Idaho) with greater flexibility than the original rule's prohibitions. Most recently, a rule was adopted for the Tongass National Forest (Alaska) exempting it from the 2001 Roadless Rule. But as of 2012, the rule still stands as the law of the land for most of the states.**

Another USFS policy that mitigates road impacts and stands to reduce mounting

**On October 1, 2012 the Supreme Court declined to review the Tenth Circuit Court of Appeals ruling to uphold the original 2001 rule. The rule does not necessarily apply in Idaho and Colorado where state-specific rules were finalized in 2008 and 2012, respectively, under the state petition process. On October 29, 2020, the USDA adopted a specific rule exempting the Tongass National Forest from the 2001 Roadless Rule (www.federalregister.gov/d/2020-23984). For more information: https://www.fs.usda.gov/roadmain/roadless/home.

costs related to road maintenance was the 2005 Travel Management Rule. It curbs unrestricted motorized access by designating when and where motorized vehicle use is permitted. In the past, unbounded motorized use within national forests resulted in the proliferation of user-created routes—up to tens of thousands of kilometers across the country, though no definitive inventory exists. In sum, the rule provides a way to find opportunities to reduce the total number and length of open roads—not insignificant given that USFS manages more kilometers of roads than any other entity in the nation.

In the EU, few initiatives specifically restrict road development in natural areas or aim to protect roadless or low-traffic areas. The EU conservation policy is mostly based on the Natura 2000 network. It consists of "Special Protection Areas" and "Special Areas of Conservation" following the "Birds Directive" and "Habitats Directive", respectively (79/409/EEC and 92/43/EEC). However, a large proportion of Natura 2000 sites are either located in proximity to major transportation infrastructures or may potentially be affected by the future development of the European transport network since the level of the standards of protection are often too weak to avoid further habitat fragmentation, as various recent examples have shown. Many legal instruments in Europe aim to protect wildlife habitat connectivity, ecosystem processes, or ecosystem integrity; but none currently considers roadless or low-traffic areas as a conservation target.

In recent years, policy in the EU has shifted from species and habitat protection to approaches encompassing broader ecological conservation measures. For example, Germany's 2009 Federal Nature Conservation Act established that "traffic and energy infrastructure and similar projects shall be integrated so that fragmentation and consumption of the landscape as well as ecological impairment is avoided or reduced to a minimum." Germany is the first European country where data on the distribution and size of low-traffic areas have become available. To support landscape assessments, the German Federal Agency for Nature Conservation developed the concept of areas unfragmented by traffic (UAT). The UATs are areas greater than 100 km^2 that are free of higher volume roads (>1000 vehicles/day – a volume much higher than the ecological thresholds described earlier), railroads, human settlements, airports and channels. The first inventory in 2008 identified about 9 million ha of UATs in Germany, of which only a quarter are protected under European Directives. Most low-traffic areas (75%) are outside of the Natura 2000 network and thus remain without protection.

Another example of a policy designed to address road impacts in a relatively large-scale, holistic way is aimed to reduce fragmentation in the Swiss Alps. The "Alpine Article" in the Swiss Federal constitution (Article 84) limits the capacity of trans-alpine road transportation (i.e. "must not be increased") and demands a shift to railway transportation for goods. The 2003 Carpathian Convention signed by seven countries addresses regulations of traffic impacts and development and encourages the parties to develop sustainable transportation policies. However, neither the EU nor most national laws currently recognize the significance of areas with low levels of fragmentation by roads in their conservation policies. Even this choice example of a policy that considers the sustainability of transportation faces a challenge incorporating scientific understanding about the enormity of global road network impacts. To focus attention on this gap in legal frameworks, participants at the 2014 international conference of the Infrastructure and Ecology Network Europe (IENE 2014) unequivocally called for a "pan-European strategy to protect roadless areas" that explicitly incorporates these areas "as conservation targets in national and European policy and legislation."

Best Practices for Rural Road Development

Guidelines, specific strategies, and design solutions for rural road networks, to which we refer as a body of "best management practices" (BMPs; Box 2), are in development and codified to varying degrees in different

© The Ecological Society of America • esa.org

places. Institutions charged with creating transportation plans are increasingly cognizant of emerging best management practices in the planning, design, construction, and maintenance of both new and existing roads.

Road network development occurs in phases beginning with planning and design, then construction, and lastly, maintenance, during which ecological solutions can be included. This process is typical with new roads and reinitiated wherever existing road networks evolve to meet the changing socio-economic demands of a region. Sometimes roads are finally decommissioned and, increasingly, such roads undergo a process of ecological restoration. Going forward, decisions to decommission certain roads, and not to build others, will likely include assessments of the projected impacts of climate change compounding the ecological effects of a road and its traffic. While direct ecological impacts are clearly associated with the construction and maintenance phases, the planning and design phase may offer the best, most cost-effective opportunities for avoiding or minimizing deleterious ecological effects. This is particularly true in rural areas, where road development, existence, and use are most likely to alter or affect ecosystems.

Asking the right questions at the planning and design stage (Figure 11) can help guide the decision and planning processes to evaluate alternative solutions for road development, avoiding unnecessarily negative effects. If road-related impacts cannot be avoided then they must be addressed through mitigation, which can sometimes be expensive. Roadway designs to mitigate habitat fragmentation effects on wildlife are becoming more common, as shown in the 2016 NOVA documentary "Wild Ways," produced by WGBH Boston (www.pbs.org/wgbh/nova). In protected areas, land management agencies have greater authority to enact traffic management plans that limit the traffic on roads and can do so temporarily or permanently. Monitoring traffic patterns in protected areas is a critical step in being able to evaluate not only the effectiveness of public traffic management plans, but also the traffic associated with land management itself, which, as noted in Case Study 3, may also contribute to road-related disturbances.

RESEARCH NEEDS FOR ROAD ECOLOGY

Road ecology research is reaching new levels of maturity with increased focus at international levels. It is not uncommon to see attention given to major impacts caused by highways bisecting landscapes, especially where the presence of endangered species causes notable concern. The consequences of this growth in road ecology research and synthesis are already being seen in the ways organizations develop and manage roads in the protected areas they manage. For example, public lands agencies may decommission or temporarily close roads, limiting motorized access to some areas to protect sensitive species and landscapes. Although researchers have collected increasingly broad information on how roads affect animal behavior and populations, many unanswered questions remain. Chief among them are uncertainties about the complex interactions among roads and their use, animal behavior and wildlife abundance, and landscapes modified by roads. Researchers seek answers about how these factors impact genetic pools, species assemblages, and evolutionary processes of animals over many decades. For example, scientific research evaluating the ecological effects of permanent and seasonal road closure, and the cumulative benefits of such actions is rare. Suitable study designs that can address these research needs, especially considering climate change scenarios, are required.

Data and Analysis Needs for Rural Road Ecology

Data about road networks and their use by traffic, along with analytic methods to measure, simulate, and evaluate ecological responses to roads are the building blocks of road ecology. Data streams of these types are often high volume, and the methods to analyze them require specialized knowledge,

BOX 2. ECOLOGICAL BEST MANAGEMENT PRACTICES FOR MITIGATING THE IMPACTS OF ROADS

Best management practices (BMPs) are strategies and actions that aim to provide balanced solutions to complex environmental problems. Typically, these involve direct measures taken to ameliorate potentially harmful activities as they occur, such as using hay bales or textile fences along drainage channels to lessen the pollution of waterways from sediment eroding during construction. However, avoiding ecological effects by restricting, limiting, or prohibiting road development is also part of the BMP toolkit. This includes the option of avoiding road construction projects with insufficient budgets to follow through with design, construction, and management practices that incorporate mitigation measures and their maintenance. Mitigation typically consists of a three-pronged approach to address environmental impacts, including avoidance, minimization, and compensation. This framework provides a useful way to think about BMPs for road networks. A common example of mitigation for the effects of roads on wildlife entails the design and construction of crossing structures to connect habitat patches and facilitate the safe passage of animals. Structures include both those aboveground, via overpasses and fencing, and belowground, via specially designed culverts or tunnel passages. Other designs for mitigating road impacts on wildlife include wildlife crossing detection devices, perch deterrents on power lines and fences, and restoration of areas significantly altered by roads and their use.

The report "Low-Volume Road Engineering: Best Management Practices Field Guide," by G. Keller and J. Sherar, provides an excellent overview for BMPs for roads typically encountered in rural environments, and following their "recommended practices" offers the best opportunity to protect ecosystems in these cases. Likewise, the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on the Environment offers guidelines for transportation planners and designers to assess environmental impacts of road development projects. The following is a bulleted list of BMPs applicable to different phases of road development taken from field guides and other sources. These are not exhaustive but complement the recommended practices described in the above-mentioned sources. While not explicitly listed for each phase, following environmental BMPs published by organizations like AASHTO as a minimum specification for road projects at every stage would provide the best available solution for managing road related ecological impacts.

1) PLANNING AND DESIGN PHASE BMPS

Environmental considerations should be included from the early stages of road project planning and design, supporting decisions about if and where new roads will be built, or existing roads redeveloped. Thorough assessments should consider the project context and use ecological planning and sustainable design principles to minimize negative environmental effects.

Consider the context.

- Identify quantitative levels of fragmentation and/or indices of roadless areas in the surrounding landscape (e.g., road density).
- Synchronize with wider regional ecological objectives for the protection of regional ecosystem dynamics, such as the preservation and management of low-traffic or roadless areas.
- Maintain wildlife habitat and wildlife movement corridors, identify and maintain existing corridor networks.
- Avoid or minimize habitat fragmentation caused by roads.
- Preserve intact roadless areas through careful planning and design, for example, by "bundling" roads and thereby clustering road impacts.

Use ecological planning methods to support decisions in locating and aligning new roads or in improving or realigning existing roads.

- Conduct inventories of biological and cultural resources in the proposed rights-of-way and those that might be affected in the surrounding landscape.
- Conduct mapping to accurately establish a baseline inventory of existing roads.
- Analyze existing and potential wildlife-traffic conflicts and water and air quality problems.
- Consider alternative scenarios that minimize ecological effects.

along with innovation and creativity to combine them with rigorous clarity.

The breakneck speed at which remote sensing and geospatial analysis have advanced has brought us much closer than we were a decade ago to having accurate road maps of appropriate extent that are essential if we are to quantify the ecological effects of roads. For studies of large areas, promising new mapping technologies use such methods as automated detection and "crowd sourcing" to collect and provide freely available fine scale road data at unprecedented spatial extents

© The Ecological Society of America • esa.org

- Develop and incorporate "traffic calming" approaches that identify rural areas where road network traffic is reduced by re-routing traffic to trunk roads, possibly downgrading or closing some existing roads.
- Where impacts are anticipated, establish goals for their mitigation.

Use sustainable landscape design and engineering principles for roadway design. In addition to published BMPs, consider the following:

- Align roads to minimize disruptions, such as to surface and subsurface water flows and fish movement.
- Buffer areas adjacent to roads for the management of storm water runoff and the attenuation of dust and noise.
- Reduce road width wherever possible to minimize habitat disturbance.
- Plant native plants for road edge stabilization and maintenance, avoiding the introduction of invasive plants.
- Slow and manage the flow of storm water runoff using swales and retention basins that prevent scouring and the direct introduction of road silt and pollutants into natural drainage systems.
- Incorporate best options for structures that facilitate safe wildlife crossings such as fish passages, fences, and under- or overpasses.
- Use design and engineering standards for sight distance with the goal of reducing animal-vehicle collisions, such as reducing the design speed.
- Minimize the generation of noise and dust by specifying low impact surfacing materials.
- Reduce glare and excessive light with low-glare energy efficient lighting standards and reflective paints.

2) CONSTRUCTION PHASE BMPS

When road construction occurs, land is transformed into transportation links. Careful planning and management of the construction process can help to limit the negative effects of road development. High quality construction standards include planning and mitigating for construction-related impacts. In addition to published BMPs for road construction, consider the following:

- Limit construction areas to clearly identified zones within the right-of-way.
- In remote areas, limit poaching by road-building crews by providing sufficient provisions and discouraging poaching.
- Incorporate erosion control measures such as silt fences.
- Clean road building equipment and machinery prior to entering a new area to avoid the spread of invasive species as "hitch-hikers".
- Incorporate safety management plans, including chemical spill protection and response measures.
- Minimize the generation of dust.
- Remove and properly dispose of waste from the construction zone.

3) MAINTENANCE AND MANAGEMENT PHASE BMPS

Roadway maintenance and management activities cause chronic disturbances to the roadside environment. Management BMPs focus on minimizing negative effects and adapting to changing circumstances. In addition to published BMPs for environmental mitigation, consider the following road maintenance BMPs:

- After establishing thoughtful baselines, monitor the effects of roads on wildlife, plant communities, and water and air quality, periodically evaluating the effectiveness of mitigation measures, e.g., monitoring if roadkill hotspots have shifted.
- Adapt management solutions to meet environmental goals as conditions vary.
- Establish road and roadside management specifications and maintenance schedules that are minimally disruptive to wildlife and natural processes, avoiding the use of pollutants wherever possible.
- Consider temporary or permanent road closures for critical areas and during critical times (e.g., breeding or migration seasons) to minimize wildlife-traffic conflicts and reduce animal-vehicle collisions.

(e.g., www.openstreetmap.org). Although it is still difficult to find complete, well-documented, accurate maps of rural road networks, the road-mapping "terrain" has been shifting dramatically in recent years. The establishment of global navigation satellite systems, combined with the proliferation of low-cost cellular service in rural areas around the world is making it possible to locate remote roads with adequate precision, accelerating the road mapping process. In addition, high performance computing systems implementing "artificial intelligence" systems are becoming very

adept at automatically detecting roads in satellite images of ever-increasing clarity. In the past, insightful map librarians or cartographers sometimes archived datasets, but until recently archiving was not a standard (or even common) part of the research process. As with map creation, archiving historical datasets has become much more tractable with the conversion to digital mapping systems. For example, regularly archived snapshots of the global roads dataset from 2013 onward, produced by the OpenStreetMap Foundation's community of mappers, are now freely available to download from their data repository (www.openstreetmap.org).

Although these developments will undoubtedly support road ecology science, there are still significant challenges related to the quality and accuracy of road datasets that limit road ecology research, often in the very places where this research could be most impactful, such as poorly mapped forests or savannahs, where the effects of road construction on endangered wildlife are most severe. The reliability of road datasets varies from one place to the next, and with few clear standards or systematic assessments about their accuracy, spatially explicit measurements of uncertainty are unavailable. This situation is especially problematic in regions where mapping resources are scarce, which are often less populated areas and development frontiers, and where the need for road ecology studies may be most critical. These issues stymie road ecology researchers who commonly use historic and current road network maps as "before and after" datasets to model environmental changes. It remains difficult for researchers to acquire accurate road maps that portray smaller, low-volume rural roads at more than one point in time. This is due to the high costs of creating such datasets, combined with the lack of universal mapping standards that address issues of scale, accuracy, and road features.

Road network maps provide critical spatial information about location, but they do not readily provide critical information about traffic patterns. Traffic pattern data, maintained by local and regional transportation authorities, are more common in urban and suburban areas, and on toll roads, where traffic is monitored and measured. Studies documenting traffic patterns along rural roads are virtually nonexistent. Since so much of the impact of rural roads depends on the volume and timing of traffic, understanding the actual patterns of road use through time in these regions is critical to assessing their impacts.

Whereas road network maps and traffic data help us to understand the pressures of roads on surrounding ecosystems, measurements of air, water, soils, plants, and animals provide the critical information about responses. Live animal responses are often measured using telemetry, with GPS tracking devices that allow for indirect and near constant monitoring of animal movements relative to vehicles and traffic. The volume of data produced by such studies is substantial, and the data analysis requirements are, likewise, formidable. However, while statistical expertise is in high demand and hard to come by, the availability of statistical modeling tools to support ecologists in animal movement studies is developing quickly.

Research Gaps and Frontiers in Rural Road Ecology

An important gap in road ecology research is understanding the cumulative effects of rural roads and their traffic on ecosystems and landscapes. Roedenbeck *et al.* (2007) pose five research questions that aim to identify the effects of roads on wildlife population persistence at the landscape scale (Figure 12). They further outline an experimental framework for increasing the strength of conclusions about causes and effects in road ecology research, both to advance knowledge in the field, and for applying that knowledge to real-world planning of transportation systems. They point out the need for well-designed experiments that document effects before and after the development of roads or the installation of mitigation measures, and that include control sites for comparing purposeful observations and data collection across road and non-road areas that are otherwise similar (so-called BACI design).

© The Ecological Society of America • esa.org

Another gap in road ecology research is understanding the thresholds in road density, at which wildlife populations decline, and the response times of wildlife populations to habitat loss, increased mortality, and reduced connectivity. There is a time lag between road construction and wildlife population responses. After this time lag, the population is smaller and more vulnerable to extinction. The overall response may take several decades and is likely to depend on the road network density. The response times for most species are not known, although related to the species' generation time, and this realization is important for environmental impact assessment (EIA) because it implies that the decline and loss of populations could continue for several decades after road construction. The term 'extinction debt' denotes the number of populations that will go extinct because of changes that have already occurred in the landscape. Thus, EIA and landscape conservation planning should consider the effects of land use on animal survival and movement and the associated response times. Related to this is the question of our ability to reverse potential negative impacts during this lag period. Reversing the impacts is a major effort that involves not only stopping the impacts, but also restoring the ecosystem. While we have some ideas about population lag times and extinction debts based on current research, this is an important area of research where new approaches coupling genetics, mapping, and computer modeling can improve those estimates and help inform our understanding about cumulative effects of roads and the potential efficacy of mitigation measures.

An explicit evaluation of road network configuration strategies that modify road density versus strategies that modify traffic volumes in real landscapes is an urgent research priority. For example, is it less harmful to wildlife to accommodate a growth in vehicle numbers by upgrading existing roads to carry higher volumes of traffic or to increase the total length of roads in the network? Under either strategy, road mortality rates increase, but it is far from intuitive which one results in lower increase in mortality, lower habitat loss, lower reduction in connectivity, etc. Such questions could be asked of any one of the many effects described earlier, such as hydrologic and atmospheric consequences. Ecological modelling can make important contributions to address such landscape-scale questions since experimental approaches are not usually feasible at this scale.

QUESTION 1

Under what circumstances do roads affect population persistence?

QUESTION 2

What is the relative importance of road effects vs. other impacts on population persistence?

QUESTION 3

Under what circumstances can road effects be mitigated?

QUESTION 4

What is the relative importance of the different mechanisms by which roads affect population persistence?

QUESTION 5

Under what circumstances do road networks affect population persistence at the landscape scale?

Building on the understanding that road ecology has produced about issues such as population fragmentation, and the chemical and physical effects of roads and their traffic, road ecology research is now at a stage where it needs comprehensive, integrated approaches with coordinated efforts between ecologists and transportation agencies to produce more useful research results with greater scientific merit. Harmonizing the spatial and temporal scales of the many kinds of data involved in road ecology research is a key priority for moving forward. This includes matching the scales of road building and projected traffic volumes with questions about species distributions, air and water quality, and animal behavior and mortality. Toward this end, a data collection protocol that is executable and useful for rural transportation agencies, while meeting scientific rigor for ecological studies, would help advance the practical application of

Figure 12. *Five questions to identify relative effects of roads on wildlife population persistence. (Source: Roedenbeck, I. A., Fahrig, L., Findlay, C. S., Houlahan, J. E., Jaeger, J. A. G., Klar, N., Kramer-Schadt, S. and Grift van der, E. A. (2007) 'The Rauischholzhausen agenda for road ecology',* Ecology and Society, *12 (1):11.*

road ecology. Such a protocol that identifies minimum data collection standards, with a common set of terms for rural road networks, could help standardize the datasets across broad regions so that effects of roads can be properly compared and assessed over time.

CONCLUSIONS AND RECOMMENDATIONS

Road networks and their traffic result in multiple long-term ecological effects as demonstrated in numerous detailed scientific studies. While people need roads for access to resources, roads have far-reaching consequences for the ecology of rural landscapes. The construction and maintenance of road networks are among the most expensive human land use investments; moreover, the full costs of road development are much higher, because they include the value of "externalities"— lost or diminished ecosystem services such as biodiversity and water filtration. The challenge is to plan and manage rural landscapes to minimize the need for rural roads and to mitigate their adverse effects on rural ecosystems, a goal which underpins regional economies.

Road ecology provides a useful ontology of road systems for describing the scope and nature of road impacts; modeling, designing, and testing strategies and solutions for impact mitigation; and producing actionable information for making decisions about road networks (Figure 4). Before building a road, it is vital to take into consideration both the short- and long-term ecological effects of that road, including its use and its maintenance and to consider alternatives, including the no-road option. Mitigation measures might appear costly, but over time they can be the most cost-effective approach to road development through the savings they bring by preventing accidents and sustaining ecosystem services. During the planning and design phases, adopting road development approaches that aim to sustain the full value and the long-term ecological integrity of those places will likely better serve the interests of people living in rural landscapes.

For roads already in use, mitigation measures can be implemented to retrofit and reduce road impacts. They include design, management, and maintenance solutions. Such measures have the benefit of reducing effects of roads on ecological systems while also improving the safety of existing roads and reducing the unnecessary damages caused by animal-vehicle collisions. For higher-trafficked and paved rural roads, design solutions can be considered to manage wildlife movement, such as fencing and crossing structures, and to manage storm water runoff, such as retention basins. For lightly traveled rural roads, mitigation measures could begin with surveying the potentially affected ecosystems and taxa, along with the locations, conditions, and use of existing roads, to assess their impact, and use the information to propose targeted, creative management approaches for impact reduction. Research suggests that customizing the application of mitigation to the needs of species that are negatively affected by roads is most effective. Examples of such approaches might include measures to limit access to certain places, or during particular times of the year, to minimize the negative effects on wildlife.

Human society has created an ingenious system of transportation that allows coordinated and unfettered access to the Earth's land surface, but scientific research shows that there are multiple long-term ecological impacts of the growing global road network, most of which is in rural areas. To sustainably manage such a system, equally ingenious strategies need to be devised and implemented. Numerous approaches are already available for mitigating adverse ecological effects of rural roads, including best management practices, but barriers preventing their implementation exist including a lack of knowledge; a lack of will to implement unfamiliar or seemingly costly measures; a lack of care for the environment and future generations; and, in many regions, a lack of resources and capacity for governance. It is essential to educate citizens, drivers, and land managers alike about the true costs of roads, including their cumulative ecological impacts, and best management practices for mitigating their negative effects. Effectively translating this information into action could result in land use policy tools and management actions that are rooted in science, thus promoting a more holistic and sustainable approach to road development and management.

© The Ecological Society of America • esa.org

CASE STUDY 1

Elk Response to Recreational Activities on Rural Roads

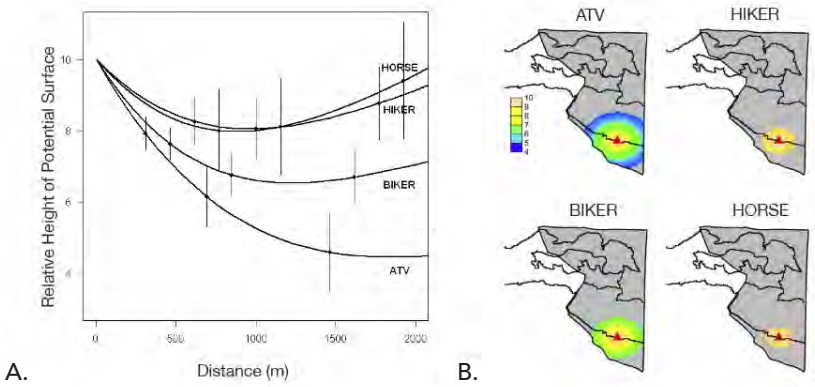


Figure 13. *Elk avoidance of four activities on rural roads: hiking (HIKER) and riding all terrain vehicles (ATV), bicycles (BIKER), and horses (HORSE). The slope of the curve (A) reflects strength of avoidance. Fine perpendicular lines show approximately 95-percent confidence bounds. Estimated potential surfaces (B) when human disturbance was located at the red triangle, showed by far the strongest avoidance was for ATV users, with the weakest for horseback riders. (Source: Preisler, H.K., A.A. Ager, M.J. Wisdom. 2013. Analyzing animal movement patterns using potential functions.* Ecosphere: *4[3]:art32.)*

Use of rural roads impacts wildlife when traffic and human presence cause disruptions, fragmenting habitats periodically. Using GPS technology, researchers in Oregon (USA) tracked Rocky Mountain elk *(Cervus canadensis nelsoni)* responses to recreational activities on rural roads. For four years, they tracked four kinds of recreational activities: hiking, riding bicycles, riding horses, and riding all-terrain vehicles (ATVs). They measured the reaction of elk by estimating a "potential surface", a statistical concept that describes the movement of animals as a space-time surface with points of attraction (e.g., foraging areas) and points of repulsion (e.g., disturbance caused by a vehicle). A mathematical equation was used to model the movement of the elk. That equation describes the strength of repulsion or avoidance as a function of distance to activity; the steeper the estimated function, the stronger the repulsion. The results showed that, on average, elk moved away when they were within a few hundred yards from any disturbances, but that "repulsion" was strongest for ATVs, with some repulsion observed up to 1 kilometer away. On the other hand, for horseback riders, the repulsion effect was only observed up to about 200m (Figure 13).

CASE STUDY 2

Gunnison Sage Grouse Responses to the Motorized use of Rural Roads

A growing number of studies collect information about seasonal, annual, and decadal changes in ecosystem responses to roads, providing information about animal movements and traffic patterns. Researchers in western Colorado conducted a study showing the effects of motor vehicles on rural roads on habitat use by Gunnison sage-grouse *(Centrocercus minimus)*. The Gunnison sage-grouse (GUSG), a threatened species protected by the Endangered Species Act, is in decline with less than 5000 individuals remaining in the wild. Researchers established a vehicle monitoring network, collecting data on date and time of vehicle use as well as vehicle type, speed, and direction of travel, to study how the intensity of motorized use relate to GUSG habitat use and movements. The monitoring network has been in operation for six years, includes seven monitoring sites, and has counted more than 25,000 vehicles. The researchers also fitted 13 GUSG with GPS collars to monitor their habitat use and movements, or resource selection, in relation to motor vehicle use. Results of this project as they relate to motorized use of rural roads have shown a clear distinction between the effects of roads with "continuous" use and those roads with "infrequent" use. For continuous use roads (greater than two vehicles per day), GUSG resource selection increased within increasing distance from the road, up to over a kilometer away. This was compared with infrequently used roads (less

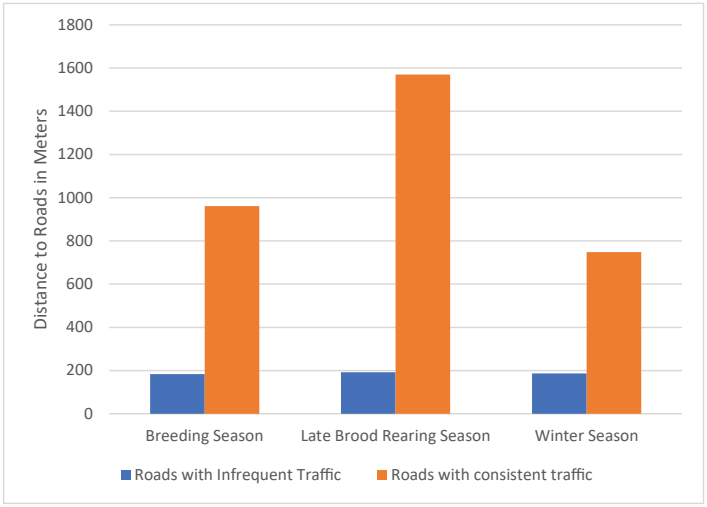


Figure 14. *Gunnison sage grouse seasonal distance to roads showing the effect of roads with consistent traffic and those with infrequent traffic.*

than or equal to two vehicles per day) where resource selection occurred within ~200 m from roads. All roads, and their effects, are indeed not equal (Figure 14); throughout the year, GUSG will keep their distance from roads with relatively low but consistent traffic, as opposed to roads with extremely low and infrequent use. The effect of traffic is especially strong during late brood season, when birds are fully engaged in raising their young.

CASE STUDY 3

Vehicle Trails in the Doñana Natural Area, Spain

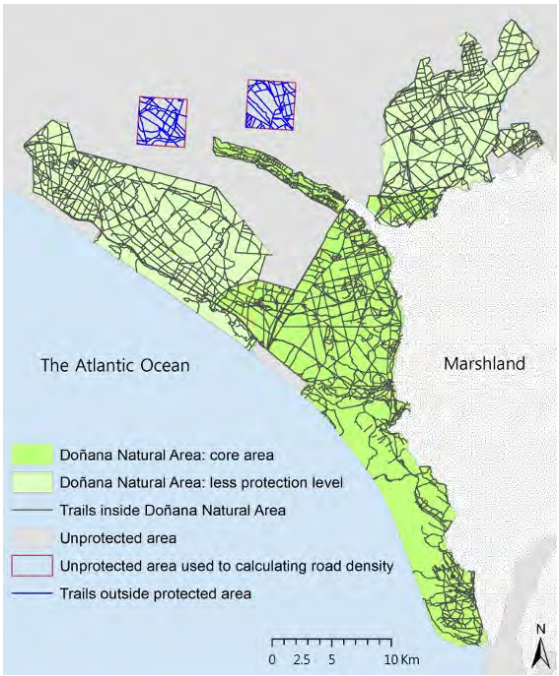


Figure 15. *Map of Doñana Natural Area, Spain. Core natural areas had just as many if not more trails within the protected area for scientific monitoring activities. (Source: Román J, A Barón, E Revilla. 2010. Evaluación de los efectos del tránsito a motor sobre especies y comunidades de interés en el Espacio Natural de Doñana. Consejería de Medio Ambiente, Junta deAndalucía y Estación Biológica de Doñana CSIC. 236 pp.)*

One of the areas in Europe with the lowest density of paved roads is the Doñana Natural Area in southwestern Spain (543 km^2). Parts of it are open to the public, but access is severely restricted in the core area (Figure 15), suggesting that the Natural Area would be an excellent location as a roadless "control" for use in road ecology studies. Therefore, the public agency in charge of conservation (Consejería de Medio Ambiente, Junta de Andalucía) and a research institute (Estación Biológica de Doñana) conducted a research project to evaluate the role of unpaved roads and vehicle trails in the area. However, the agency found that the protected area holds more than 2000 km of vehicle trails occupying four percent of the surface area, with a density of 4 km km^{-2}. But, while access to the Doñana protected area is restricted, trail density is highest in the core area where it doubled from 1956 to 2010, and the lowest densities are in unprotected areas. Furthermore, traffic intensity is highest in the area with the most protection. This increased traffic intensity is due to higher levels of management, conservation, and research activities in the core area. Results from this work show that land management activities, in and of themselves, have impacts, often with consequences for the conservation of many species and communities, including several vegetation types considered high-priority habitats in the Doñana Natural Area.

© The Ecological Society of America • esa.org

ACKNOWLEDGEMENTS

This paper grew out of an organized session at the 2010 annual meeting of the Ecological Society of America entitled "Road networks and environmental change," where the invited presenters agreed to develop a manuscript for Issues in Ecology focused on the ecological effects of rural roads. We are very grateful to the editors at the ESA for supporting this project over its long period of development. We acknowledge the financial support of: US Geological Survey and USDA. We also acknowledge the support of: the US Geological Survey, in particular Mendenhall Postdoctoral Fellowship Program and Rama Kotra, along with the leadership and staff at the Fort Collins Science Center and the Rocky Mountain Geographic Science Center; Tim Strickland and the Southeast Area leadership of the USDA Agricultural Research Service for their Agency review; William Lange, Duncan McKinley, Susan Cook-Patton, and Hutch Brown of the USDA Forest Service Research and Development Washington Office, for their assistance with and contributions to the manuscript. LBA was financed by Portuguese national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P.,under the Norma Transitória - DL57/2016/CP1440/CT0022.

ABOUT THE SCIENTISTS

Alisa W. Coffin*
Southeast Watershed Research Laboratory, USDA Agricultural Research Service, Tifton, GA 31794, USA

Douglas S. Ouren
Emeritus, Fort Collins Science Center, US Geological Survey, Fort Collins, CO 80524, USA

Neil D. Bettez
Cary Institute of Ecosystem Studies, Millbrook, NY 12545 USA

Luís Borda-de-Água
CIBIO/InBio, Centro de Investigação em Biodiversidade e Recursos Genéticos, Laboratório Associado, Universidade do Porto, Campus Agrário de Vairão, 4485-661 Vairão, Portugal

CIBIO/InBio, Centro de Investigação em Biodiversidade e Recursos Genéticos, Laboratório Associado, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisbon, Portugal

Amy E. Daniels
Independent Consultant, Rua Mondlane, Luanda, Angola

Clara Grilo
CESAM – Centre for Environmental and Marine Studies, Faculdade de Ciências da Universidade de Lisboa, C2, 2.3.03 1749-016 Lisboa, Portugal

Jochen A.G. Jaeger
Concordia University Montreal, Department of Geography, Planning and Environment, Montreal, Quebec, H3G 1M8, Canada

Laetitia M. Navarro
German Center for Integrative Biodiversity Research, 04103 Leipzig, Germany

Haiganoush K. Preisler
Retired. Pacific Southwest Research Station, USDA Forest Service, Albany, CA, 94710 USA

Emily S.J. Rauschert
Department of Biological, Geological and Environmental Sciences, Cleveland State University, Cleveland, OH 44115, USA

* Corresponding author: Alisa W. Coffin, Research Ecologist, USDA-ARS, 2316 Rainwater Road, PO Box 748, Tifton, GA, 31793; phone: 229-386-3665; email: alisa.coffin@ars.usda.gov

FURTHER READING LIST

AASHTO Highway Subcommittee on Design Task Force for Environmental Design, editor. 1991. A Guide for Transportation Landscape and Environmental Design. American Association of State Highway and Transportation Officials, Washington, DC.

Balkenhol N., and L.P. Waits. 2009. Molecular road ecology: exploring the potential of genetics for investigating transportation impacts on wildlife. *Molecular Ecology* **18**(20): 4151-64.

Borda-de-Água L. , L. Navarro, C. Gavinhos, and H.M. Pereira. 2011. Spatio-temporal impacts of roads on the persistence of populations: analytic and numerical approaches. *Landscape Ecology* **26**: 253–265.

Borda-de-Água L., C. Grilo, and H.M. Pereira. 2014. Modeling the impact of road mortality on barn owl (Tyto alba) populations using age-structured models. *Ecological Modelling* **276**: 29–37.

Brundige, J. (Director). 2016. "Wild Ways." In *NOVA*, aired on April 20, 2016. Produced by WGBH, Boston, MA.

Ceia-Hasse A., L. Borda-de-Água, C. Grilo, and H.M. Pereira. 2017. Global exposure of carnivores to roads. *Global Ecology and Biogeography* **26**: 592-600.

Ellenberg, H., K. Müller, and T. Stottele, T. 1981. Straßen-Ökologie: Auswirkungen von Autobahnen und Straßen auf Ökosysteme deutscher Landschaften [Road ecology: Effects of motorways and roads on ecosystems in German landscapes.]. Ökologie und Straße: Broschürenreihe der deutschen Straßenliga [Ecology and road: Pamphlet series of the German Road League], Ausgabe [Issue] **3**: 19–122.

Fahrig, L., and T. Rytwinski. 2009. Effects of Roads on Animal Abundance: an Empirical Review and Synthesis. *Ecology and Society* **14** (1):21.

Faiz, A. 2012. The Promise of Rural Roads: Review of the Role of Low-Volume Roads in Rural Connectivity, Poverty Reduction, Crisis Management, and Livability. Transportation Resaerch Circular E-C167. Transportation Research Board of the National Academies, Washington, DC.

Forman, R.T.T., and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics **29**: 207–232.

Forman, R.T.T., D. Sperling, J.A. Bissonette, A.P. Clevenger, C.D. Cutshall, V.H. Dale, L. Fahrig, R. France, C.R. Goldman, K. Heanue, J.A. Jones, F.J. Swanson, T. Turrentine, and T.C. Winter. 2003. *Road ecology: Science and solutions*. Island Press, Washington, DC.

Haddad, N. M. 2015. Corridors for people, corridors for nature. *Science* **350**: 1166-1167.

Ibisch, P. L., M. T. Hoffmann, S. Kreft, G. Pe'er, V. Kati, L. Biber-Freudenberger, D. A. DellaSala, M. M. Vale, P. R. Hobson, and N. Selva. 2016. A global map of roadless areas and their conservation status. *Science* **354**: 1423-1427,

IENE (Infra Eco Network Europe). 2015. Protect remaining roadless areas: The IENE 2014 declaration. *Nature Conservation* **11**: 1-4.

Keller, G., and J. Sherar. 2003. Low-volume roads engineering: Best management practices field guide. US Department of Agriculture, US Agency for International Development.

Kleinschroth, F., J. R. Healey, S. Gourlet-Fleury, F. Mortier, and R. S. Stoica. 2017. Effects of logging on roadless space in intact forest landscapes of the Congo Basin. *Conservation Biology* **31**:469-480.

Kuussaari, M., R. Bommarco, R.K. Heikkinen, A. Helm, J. Krauss, R. Lindborg, E. Öckinger, M. Pärtel, J. Pino, F. Rodà, C. Stefanescu, T. Teder, M. Zobel, and I. Steffan-Dewenter. 2009. Extinction debt: A challenge for biodiversity conservation. *Trends in Ecology and Evolution* **24**: 564–571.

© The Ecological Society of America • esa.org

Laurance, W.F.; M. Goosem, and S.G.W. Laurance. 2009. Impacts of roads and linear clearings on tropical forests. *Trends in Ecology and Evolution*, **24**, 659-669.

Laurance, W.F.; M.J. Campbell, M. Alamgir, M.I. Mahmoud. 2017. Road expansion and the fate of Africa's tropical forests. *Frontiers in Ecology and Evolution*, **5** (75).

National Research Council. 2005. Assessing and managing the ecological impacts of paved roads. The National Academies Press, Washington, DC.

Olson, D.D., J.A. Bissonette, P.C. Cramer, A.D. Green, S.T. Davis, P.J. Jackson, and D.C. Coster. 2014. Monitoring Wildlife-Vehicle Collisions in the Information Age: How Smartphones Can Improve Data Collection. *PLoS ONE* **9**(6): e98613.

Roedenbeck, I. A., L. Fahrig, C. S. Findlay, J. E. Houlahan, J.A.G. Jaeger, N. Klar, S. Kramer-Schadt, and E. A. van der Grift. 2007. The Rauischholzhausen agenda for road ecology. *Ecology and Society* **12**: 11.

Rytwinski, T., K. Soanes, J.A.G. Jaeger, L. Fahrig, C.S. Findlay, J. Houlahan, R. van der Ree, E.A. van der Grift. 2016. How effective is road mitigation at reducing road-kill? A meta-analysis. *PLoS ONE* **11**(11): e0166941. doi: 10.1371/journal.pone.0166941. Online: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0166941.

Spanowicz, A.G., F.Z. Teixeira, F.Z., and J. A. G. Jaeger. 2020. An adaptive plan for prioritizing road sections for fencing to reduce animal mortality. *Conservation Biology*, 34(5):1210-1220. doi.org/10.1111/cobi.13502

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* **14**:18-30.

van der Grift, E. A., R. van der Ree, L. Fahrig, S. Findlay, J. Houlahan, J.A.G. Jaeger, N. Klar, L.F. Madrinan, and L. Olson. 2013. Evaluating the effectiveness of road mitigation measures. *Biodiversity and Conservation* **22**:425-448.

van der Ree, R., D.J. Smith, and C. Grilo. 2015. Handbook of Road Ecology. Wiley-Blackwell, Hoboken, NJ.

van Strien, M. J., K. W. Axhausen, I. Dubernet, A. Guisan, A. Grêt-Regamey, A. Khiali-Miab, D. O. Ortiz-Rodríguez, and R. Holderegger. 2018. Models of Coupled Settlement and Habitat Networks for Biodiversity Conservation: Conceptual Framework, Implementation and Potential Applications. *Frontiers in Ecology and Evolution* **6**:41.

BIBLIOGRAPHY

AASHTO. 2001a. Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT less than or equal to 400). Washington, D.C.

AASHTO. 2001b. A Policy of Geometric Design of Highways and Streets. American Association of State Highway Transportation Officials, Washington, D.C.

AASHTO Highway Subcommittee on Design Task Force for Environmental Design, editor. 1991. A Guide for Transportation Landscape and Environmental Design. American Association of State Highway and Transportation Officials, Washington, DC.

Allan, J. D., and M. M. Castillo. 2007. Stream Ecology: Structure and function of running waters. 2 edition. Springer Netherlands.

Almeida-Neto, M., G. Machado, R. Pinto-da-Rocha, and A. A. Giaretta. 2006. Harvestman (Arachnida : Opiliones) species distribution along three Neotropical elevational gradients: an alternative rescue effect to explain Rapoport's rule? *Journal of Biogeography* **33**:361-375.

Angold, P. G. 1997. The impact of a road upon adjacent heathland vegetation: Effects on plant species composition. *Journal of Applied Ecology* **34**:409-417.

Balkenhol, N., and L. P. Waits. 2009. Molecular road ecology: exploring the potential of genetics for investigating transportation impacts on wildlife. *Molecular Ecology* **18**:4151-4164.

Ballesteros-Mejia, L., I. J. Kitching, W. Jetz, P. Nagel, and J. Beck. 2013. Mapping the biodiversity of tropical insects: species richness and inventory completeness of African sphingid moths. *Global Ecology and Biogeography* **22**:586-595.

Barbosa, N. P. U., G. W. Fernandes, M. A. A. Carneiro, and L. A. C. Junior. 2010. Distribution of non-native invasive species and soil properties in proximity to paved roads and unpaved roads in a quartzitic mountainous grassland of southeastern Brazil (rupestrian fields). *Biological Invasions* **12**:3745-3755.

Benten, A., P. Annighöfer, and T. Vor. 2018. Wildlife Warning Reflectors' Potential to Mitigate Wildlife-Vehicle Collisions—A Review on the Evaluation Methods. *Frontiers in Ecology and Evolution* **6**.

Bezborodov, G. A., D. K. Shadmanov, R. T. Mirhashimov, T. Yuldashev, A. S. Qureshi, A. D. Noble, and M. Qadir. 2010. Mulching and water quality effects on soil salinity and sodicity dynamics and cotton productivity in Central Asia. *Agriculture Ecosystems & Environment* **138**:95-102.

Blanton, P., and W. A. Marcus. 2009. Railroads, roads and lateral disconnection in the river landscapes of the continental United States. *Geomorphology* **112**:212-227.

Blomqvist, G., and E.-L. Johansson. 1999. Airborne spreading and deposition of de-icing salt — a case study. *Science of The Total Environment* **235**:161-168.

Borda-de-Água, L., C. Grilo, and H. M. Pereira. 2014. Modeling the impact of road mortality on barn owl (Tyto alba) populations using age-structured models. *Ecological Modelling* **276**:29-37.

Borda-de-Água, L., L. Navarro, C. Gavinhos, and H. M. Pereira. 2011. Spatio-temporal impacts of roads on the persistence of populations: analytic and numerical approaches. *Landscape Ecology* **26**:253-265.

Brown, G. P., B. L. Phillips, J. K. Webb, and R. Shine. 2006. Toad on the road: Use of roads as dispersal corridors by cane toads (Bufo marinus) at an invasion front in tropical Australia. *Biological Conservation* **133**:88-94.

Brunen, B., C. Daguet, and J. A. G. Jaeger. 2020. What attributes are relevant for drainage culverts to serve as efficient road crossing structures for mammals? *Journal of Environmental Management* **268**:110423.

Ceia-Hasse, A., L. Borda-de-Água, C. Grilo, and H. M. Pereira. 2017. Global exposure of carnivores to roads. *Global Ecology and Biogeography* **26**:592-600.

Coffin, A. W. 2007. From roadkill to road ecology: A review of the ecological effects of roads. *Journal of Transport Geography* **15**:396-406.

Coffin, A. W. 2010. Environmental Impacts of Roads. Encyclopedia of Geography. Sage Publications. Sage Publications, Thousand Oaks, USA.

Cornish, P. M. 2001. The effects of roading, harvesting and forest regeneration on streamwater turbidity levels in a moist eucalypt forest. *Forest Ecology and Management* **15**2:293-312.

© The Ecological Society of America • esa.org

Dark, S. J. 2004. The biogeography of invasive alien plants in California: an application of GIS and spatial regression analysis. *Diversity and Distributions* **10**:1-9.

Davidson, E. A., K. E. Savage, N. D. Bettez, R. M. Marino, and R. W. Howarth. 2010. Nitrogen in Runoff from Residential Roads in a Coastal Area. *Water Air and Soil Pollution* **210**:3-13.

Diseker, E. G., and J. M. Sheridan. 1971. Predicting Sediment Yield from Roadbanks. Transactions of the ASAE **14**:102-0105.

Dunlap, D. W. 1987. Development of grass-seeding specifications for use on Texas highway rights-of-way. Proceedings of Conference XVII International Erosion Control Association **18**:161-172.

Dunne, T., and L. B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company, New York.

Eisenberg, J. N. S., W. Cevallos, K. Ponce, K. Levy, S. J. Bates, J. C. Scott, A. Hubbard, N. Vieira, P. Endara, M. Espinel, G. Trueba, L. W. Riley, and J. Trostle. 2006. Environmental change and infectious disease: How new roads affect the transmission of diarrheal pathogens in rural Ecuador. Proceedings of the National Academy of Sciences **103**:19460-19465.

Ellenberg, H. K., K. Müller, and T. Stottele. 1981. Straßen-Ökologie: Auswirkungen von Autobahnen und Straßen auf Ökosysteme deutscher Landschaften [Road ecology: Effects of motorways and roads on ecosystems in German landscapes.]. Ökologie und Straße: Broschürenreihe der deutschen Strassenliga [Ecology and road: Pamphlet series of the German Road League] Ausgabe [Issue] **3**:19-122.

Fahrig, L., and T. Rytwinski. 2009. Effects of roads on animal abundance: an empirical review and synthesis. *Ecology and Society* **14** (1):21.

Faiz, A. 2012. The promise of rural roads: Review of the role of low-volume roads in rural connectivity, poverty reduction, crisis management, and livability. Transportation Research Circular.

Farmer, A. M. 1993. The effects of dust on vegetation: A review. *Environmental Pollution* **79**:63-75.

Fay, L., and X. Shi. 2012. Environmental Impacts of Chemicals for Snow and Ice Control: State of the Knowledge. *Water, Air, & Soil Pollution* **223**:2751-2770.

Forman, R. T. T. 1998. Road ecology: A solution for the giant embracing us. *Landscape Ecology* 13:III-V.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* **29**:207-232.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road Ecology: Science and Solutions*. Island Press, Washington, DC.

Forsyth, A. R., K. A. Bubb, and M. E. Cox. 2006. Runoff, sediment loss and water quality from forest roads in a southeast Queensland coastal plain Pinus plantation. *Forest Ecology and Management* **221**:194-206.

Forys, E. A., C. Allen, and D. P. Wojcik. 2002. Influence of the proximity and amount of human development and roads on the occurrence of the red imported fire ant in the lower Florida Keys. *Biological Conservation* **108**:27-33.

Freudenberger, L., P. R. Hobson, S. Rupic, G. Pe'er, M. Schluck, J. Sauermann, S. Kreft, N. Selva, and P. L. Ibisch. 2013. Spatial road disturbance index (SPROADI) for conservation planning: a novel landscape index, demonstrated for the State of Brandenburg, Germany. *Landscape Ecology* **28**:1353-1369.

Haddad, N. M. 2015. Corridors for people, corridors for nature. *Science* **350**:1166-1167.

Haddad, N. M., L. A. Brudvig, J. Clobert, K. F. Davies, A. Gonzalez, R. D. Holt, T. E. Lovejoy, J. O. Sexton, M. P. Austin, C. D. Collins, W. M. Cook, E. I. Damschen, R. M. Ewers, B. L. Foster, C. N. Jenkins, A. J. King, W. F. Laurance, D. J. Levey, C. R. Margules, B. A. Melbourne, A. O. Nicholls, J. L. Orrock, D.-X. Song, and J. R. Townshend. 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances* **1**.

Hawbaker, T. J., and V. C. Radeloff. 2004. Roads and landscape pattern in northern Wisconsin based on a comparison of four road data sources. *Conservation Biology* **18**:1233-1244.

Hawbaker, T. J., V. C. Radeloff, M. K. Clayton, R. B. Hammer, and C. E. Gonzalez-Abraham. 2006. Road Development, Housing Growth, And Landscape Fragmentation In Northern Wisconsin: 1937–1999. *Ecological Applications* **16**:1222-1237.

Heffernan, J. B., P. A. Soranno, M. J. Angilletta Jr, L. B. Buckley, D. S. Gruner, T. H. Keitt, J. R. Kellner, J. S. Kominoski, A. V. Rocha, J. Xiao, T. K. Harms, S. J. Goring, L. E. Koenig, W. H. McDowell, H. Powell, A. D. Richardson, C. A. Stow, R. Vargas, and K. C. Weathers. 2014. Macrosystems ecology: understanding ecological patterns and processes at continental scales. *Frontiers in Ecology and the Environment* **12**:5-14.

Huling, E. E., and T. C. Hollocher. 1972. Groundwater Contamination by Road Salt: Steady-State Concentrations in East Central Massachusetts. *Science* **176**:288-290.

Ibisch, P. L., M. T. Hoffmann, S. Kreft, G. Pe'er, V. Kati, L. Biber-Freudenberger, D. A. DellaSala, M. M. Vale, P. R. Hobson, and N. Selva. 2016. A global map of roadless areas and their conservation status. *Science* **354**:1423-1427.

IENE, 2015. Protect remaining roadless areas: The IENE 2014 declaration. *Nature Conservation* **11**:1-4.

Jaeger, J. A. G. 2000. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. *Landscape Ecology* **15**:115-130.

Jaeger, J. A. G., R. Bertiller, C. Schwick, K. Müller, C. Steinmeier, K. C. Ewald, and J. Ghazoul. 2008. Implementing landscape fragmentation as an indicator in the Swiss monitoring system of sustainable development (Monet). *Journal of Environmental Management* **88**:737-751.

Jaeger, J. A. G., J. Bowman, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber, and K. T. von Toschanowitz. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. *Ecological Modelling* **185**:329-348.

Joly, M., P. Bertrand, R. Y. Gbangou, M. C. White, J. Dube, and C. Lavoie. 2011. Paving the Way for Invasive Species: Road Type and the Spread of Common Ragweed (Ambrosia artemisiifolia). *Environmental Management* **48**:514-522.

Jones, J. A., F. J. Swanson, B. C. Wemple, and K. U. Snyder. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. *Conservation Biology* **14**:76-85.

Jordán-López, A., L. Martínez-Zavala, and N. Bellinfante. 2009. Impact of different parts of unpaved forest roads on runoff and sediment yield in a Mediterranean area. *Science of The Total Environment* **407**:937-944.

Jordán, A., and L. Martínez-Zavala. 2008. Soil loss and runoff rates on unpaved forest roads in southern Spain after simulated rainfall. *Forest Ecology and Management* **255**:913-919.

Jules, E. S., M. J. Kauffman, W. D. Ritts, and A. L. Carroll. 2002. Spread of an invasive pathogen over a variable landscape: A nonnative root rot on Port Orford cedar. *Ecology* **83**:3167-3181.

Karasin, B., Ibrahim, and E. Isik. 2016. Protection of Ten-Eyed Bridge in Diyarbakir. Budownictwo I *Architectura* **15**:87-94.

Keller, G., and J. Sherar. 2003. Low-Volume Roads Engineering: Best Management Practices Field Guide. Page 158. U.S. Department of Agriculture, U.S. Agency for International Development.

Kleinschroth, F., and J. R. Healey. 2017. Impacts of logging roads on tropical forests. *Biotropica* **49**:620-635.

Kleinschroth, F., J. R. Healey, S. Gourlet-Fleury, F. Mortier, and R. S. Stoica. 2017. Effects of logging on roadless space in intact forest landscapes of the Congo Basin. *Conservation Biology* **31**:469-480.

Kramer, M. G. 2013. Our Built and Natural Environments: A Technical Review of the Interactions Among Land Use, Transportation, and Environmental Quality.in E. P. Agency, editor. Government Printing Office, Washington, DC.

Kunert, N., L. M. T. Aparecido, N. Higuchi, J. d. Santos, and S. Trumbore. 2015. Higher tree transpiration due to road-associated edge effects in a tropical moist lowland forest. *Agricultural and Forest Meteorology* **213**:183-192.

Kuussaari, M., R. Bommarco, R. K. Heikkinen, A. Helm, J. Krauss, R. Lindborg, E. Öckinger, M. Pärtel, J. Pino, and F. Roda. 2009. Extinction debt: a challenge for biodiversity conservation. *Trends in Ecology & Evolution* **24**:564-571.

Laurance, W. F. 2013. Rapid Land-Use Change and its Impacts on Tropical Biodiversity. Pages 189-199 Ecosystems and Land Use Change. American Geophysical Union.

Laurance, W. F., M. J. Campbell, M. Alamgir, and M. I. Mahmoud. 2017. Road Expansion and the Fate of Africa's Tropical Forests. *Frontiers in Ecology and Evolution* **5**.

Laurance, W. F., G. R. Clements, S. Sloan, C. S. O/'Connell, N. D. Mueller, M. Goosem, O. Venter, D. P. Edwards, B. Phalan, A. Balmford, R. Van Der Ree, and I. B. Arrea. 2014. A global strategy for road building. *Nature* **513**:229-232.

Laurance, W. F., B. M. Croes, L. Tchignoumba, S. A. Lahm, A. Alonso, M. E. Lee, P. Campbell, and C. Ondzeano. 2006. Impacts of Roads and Hunting on Central African Rainforest Mammals. *Conservation Biology* **20**:1251-1261.

Laurance, W. F., M. Goosem, and S. G. W. Laurance. 2009. Impacts of roads and linear clearings on tropical forests. *Trends in Ecology & Evolution* **24**:659-669.

Lonsdale, W. M., and A. M. Lane. 1994. Tourist Vehicles as Vectors of Weed Seeds in Kakadu-National-Park, Northern Australia. *Biological Conservation* **69**:277-283.

© The Ecological Society of America • esa.org

Mathisen, K., A. Wójcicki, and Z. Borowski. 2018. Effects of forest roads on oak trees via cervid habitat use and browsing.

Mertens, B., R. Poccard-Chapuis, M. G. Piketty, A. E. Lacques, and A. Venturieri. 2002. Crossing spatial analyses and livestock economics to understand deforestation processes in the Brazilian Amazon: The case of Sao Felix do Xingu in South Para. *Agricultural Economics* **27**:269-294.

Mortensen, D. A., E. S. J. Rauschert, A. N. Nord, and B. P. Jones. 2009. The role of roads in plant invasions. *Invasive Plant Science and Management* **2**:191-199.

Moser, B., J. Jaeger, U. Tappeiner, E. Tasser, and B. Eiselt. 2007. Modification of the effective mesh size for measuring landscape fragmentation to solve the boundary problem. *Landscape Ecology* **22**:447-459.

National Research Council (U.S.). Committee on Ecological Impacts of Road Density. 2005. Assessing and managing the ecological impacts of paved roads. National Academies Press, Washington, D.C.

Nord, A. N., D. A. Mortensen, and E. S. J. Rauschert. 2010. Environmental Factors Influence Early Population Growth of Japanese Stiltgrass (Microstegium vimineum). *Invasive Plant Science and Management* **3**:17-25.

Olson, D. D., J. A. Bissonette, P. C. Cramer, A. D. Green, S. T. Davis, P. J. Jackson, and D. C. Coster. 2014. Monitoring Wildlife-Vehicle Collisions in the Information Age: How Smartphones Can Improve Data Collection. *PLOS ONE* 9:e98613.

Ouren, D. S., R. D. Watts, and A. W. Coffin. 2010. Beyond the pavement: Scientific methods for quantifying ecological responses to off-highway vehicle use. 95th ESA Annual Meeting, Pittsburgh, PA.

Pratt, C., and B. G. Lottermoser. 2007. Mobilisation of traffic-derived trace metals from road corridors into coastal stream and estuarine sediments, Cairns, northern Australia. *Environmental Geology* **52**:437-448.

Preisler, H. K., A. A. Ager, and M. J. Wisdom. 2013. Analyzing animal movement patterns using potential functions. *Ecosphere* **4**:art32.

Psaralexi, M. K., N.-E. P. Votsi, N. Selva, A. D. Mazaris, and J. D. Pantis. 2017. Importance of Roadless Areas for the European Conservation Network. *Frontiers in Ecology and Evolution* **5**:(2).

Ramakrishna, D. M., and T. Viraraghavan. 2005. Environmental Impact of Chemical Deicers – A Review. *Water, Air, and Soil Pollution* **166**:49-63.

Rauschert, E. S. J., D. A. Mortensen, O. N. Bjornstad, and A. N. Nord. 2008. The spread of Microstegium vimineum (Japanese stiltgrass), an invasive weed. 93rd Annual Meeting of the Ecological Society of America, Milwaukee, WI.

Rew, L., M. Taper, F. Pollnac, T. Brummer, and H. Balbach. 2010. Dispersal of plant propagules by vehicles.in Society for Range Management and Weed Science Society of America, Denver, Colorado.

Roedenbeck, I. A., L. Fahrig, C. S. Findlay, J. E. Houlahan, J. A. G. Jaeger, N. Klar, S. Kramer-Schadt, and E. A. Grift van der. 2007. The Rauischholzhausen agenda for road ecology. *Ecology and Society* **12**:11.

Rytwinski, T., and L. Fahrig. 2013. Why are some animal populations unaffected or positively affected by roads? *Oecologia* **173**:1143-1156.

Rytwinski, T., K. Soanes, J. A. G. Jaeger, L. Fahrig, C. S. Findlay, J. Houlahan, R. van der Ree, and E. A. van der Grift. 2016. How Effective Is Road Mitigation at Reducing Road-Kill? A Meta-Analysis. *PLOS ONE* **11**:e0166941.

Rytwinski, T., R. van der Ree, G. M. Cunnington, L. Fahrig, C. S. Findlay, J. Houlahan, J. A. G. Jaeger, K. Soanes, and E. A. van der Grift. 2015. Experimental study designs to improve the evaluation of road mitigation measures for wildlife. J*ournal of Environmental Management* **154**:48-64.

Schuler, M. S., W. D. Hintz, D. K. Jones, L. A. Lind, B. M. Mattes, A. B. Stoler, K. A. Sudol, and R. A. Relyea. 2017. How common road salts and organic additives alter freshwater food webs: in search of safer alternatives. *Journal of Applied Ecology* **54**:1353-1361.

Selva, N., S. Kreft, V. Kati, M. Schluck, B.-G. Jonsson, B. Mihok, H. Okarma, and P. Ibisch. 2011. Roadless and Low-Traffic Areas as Conservation Targets in Europe. *Environmental Management* **48**:865-877.

Selva, N., A. Switalski, S. Kreft, and P. Ibisch. 2015. Why Keep Areas Road-Free? The Importance of Roadless Areas. Pages 16-26 in R. van der Ree, D. J. Smith, and C. Grilo, editors. Handbook of Road Ecology.

Siegert, N. W., D. G. McCullough, A. M. Liebhold, and F. W. Telewski. 2014. Dendrochronological reconstruction of the epicentre and early spread of emerald ash borer in North America. *Diversity and Distributions* **20**:847-858.

Siegert, N. W., R. J. Mercader, and D. G. McCullough. 2015. Spread and dispersal of emerald ash borer (Coleoptera: Buprestidae): estimating the spatial dynamics of a difficult-to-detect invasive forest pest. *The Canadian Entomologist* **147**:338-348.

Smith III, T. J., H. Hudson, M. B. Robblee, G. V. N. Powell, and P. J. Isdale. 1989. Freshwater Flow from the Everglades to Florida Bay: A Historical Reconstruction Based on Flourescent Banding in the Coral Solenastrea bournoni. *Bulletin of Marine Science* **44**:274-282.

Soanes, K., A. C. Taylor, P. Sunnucks, P. A. Vesk, S. Cesarini, and R. van der Ree. 2018. Evaluating the success of wildlife crossing structures using genetic approaches and an experimental design: Lessons from a gliding mammal. *Journal of Applied Ecology* **55**:129-138.

Sollenberger, L. E., K. R. Woodard, J. M. Vendramini, J. E. Erickson, K. A. Langeland, M. K. Mullenix, C. Na, M. S. Castillo, M. Gallo, C. D. Chase, and Y. López. 2014. Invasive Populations of Elephantgrass Differ in Morphological and Growth Characteristics from Clones Selected for Biomass Production. *BioEnergy Research* **7**:1382-1391.

Sosa-Pérez, G., and L. H. MacDonald. 2017. Reductions in road sediment production and road-stream connectivity from two decommissioning treatments. *Forest Ecology and Management* **398**:116-129.

Spanowicz, A. G., and J. A. G. Jaeger. 2019. Measuring landscape connectivity: On the importance of within-patch connectivity. *Landscape Ecology* **34**:2261-2278.

Stiles, J. H., and R. H. Jones. 1998. Distribution of the red imported fire ant, shape Solenopsis invicta, in road and powerline habitats. *Landscape Ecology* **13**:335-346.

Sullivan, J. J., P. A. Williams, S. M. Timmins, and M. C. Smale. 2009. Distribution and spread of environmental weeds along New Zealand roadsides. *New Zealand Journal of Ecology* **33**:190-204.

Sunnucks, P., and N. Balkenhol. 2015. Incorporating Landscape Genetics into Road Ecology. Pages 110-118 in R. van Der Ree, D. J. Smith, and C. Grilo, editors. Handbook of Road Ecology.

Tigas, L. A., D. H. Van Vuren, and R. M. Sauvajot. 2002. Behavioral responses of bobcats and coyotes to habitat fragmentation and corridors in an urban environment. *Biological Conservation* **108**:299-306.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* **14**:18-30.

U.S. Department of Commerce, U.S. Census Bureau, Geography Division. 2014. TIGER/Line Shapefile, 2014, 2010 nation, U.S., 2010 Census Urban Area National.in U.S. Department of Commerce, U.S. Census Bureau, Geography Division, Editor, ftp://ftp2.census.gov/geo/tiger/TIGER2014/UAC/.

Urban, M. C., B. L. Phillips, D. K. Skelly, and R. Shine. 2008. A toad more traveled: The heterogeneous invasion dynamics of cane toads in Australia. *American Naturalist* **171**:E134-E148.

US EPA (US Environmental Protection Agency). 1993. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters., Washington, DC.

van der Grift, E. A., R. van der Ree, L. Fahrig, S. Findlay, J. Houlahan, J. A. G. Jaeger, N. Klar, L. F. Madrinan, and L. Olson. 2013. Evaluating the effectiveness of road mitigation measures. *Biodiversity and Conservation* **22**:425-448.

van der Ree, R., J. A. G. Jaeger, E. A. van der Grift, and A. P. Clevenger. 2011. Special Feature: Effects of Roads and Traffic on Wildlife Populations and Landscape Function. *Ecology and Society* 16(1):48.

van der Ree, R., D. J. Smith, and C. Grilo. 2015. Handbook of Road Ecology. John Wiley & Sons.

van Strien, M., K. Axhausen, I. Dubernet, A. Guisan, A. Grêt-Regamey, A. Khiali-Miab, D. Ortiz Rodriguez, and R. Holderegger. 2018. Models of Coupled Settlement and Habitat Networks for Biodiversity Conservation: Conceptual Framework, Implementation and Potential Applications.

Verburg, P., K. Kok, R. Pontius, and A. Veldkamp. 2008. Modeling Land-Use and Land-Cover Change.

Wang, G., X. Yan, F. Zhang, C. Zeng, and D. Gao. 2014. Traffic-Related Trace Element Accumulation in Roadside Soils and Wild Grasses in the Qinghai-Tibet Plateau, China. *International Journal of Environmental Research and Public Health* **11**:456.

Weiss, S. B. 1999. Cars, cows, and checkerspot butterflies: Nitrogen deposition and management of nutrient-poor grasslands for a threatened species. *Conservation Biology* **13**:1476-1486.

Werkenthin, M., B. Kluge, and G. Wessolek. 2014. Metals in European roadside soils and soil solution – A review. *Environmental Pollution* **189**:98-110.

© The Ecological Society of America • esa.org

Wisdom, M. J., A. A. Ager, H. K. Preisler, N. J. Cimon, and B. K. Johnson. 2004. Effects of off-road recreation on mule deer and elk. Transactions of the 69th North American Wildlife and Natural Resources Conference: 531-550.

Yan, X., D. Gao, F. Zhang, C. Zeng, W. Xiang, and M. Zhang. 2013. Relationships between Heavy Metal Concentrations in Roadside Topsoil and Distance to Road Edge Based on Field Observations in the Qinghai-Tibet Plateau, China. *International Journal of Environmental Research and Public Health* **10**:762.

Zehetner, F., U. Rosenfellner, A. Mentler, and M. H. Gerzabek. 2009. Distribution of Road Salt Residues, Heavy Metals and Polycyclic Aromatic Hydrocarbons across a Highway-Forest Interface. *Water Air and Soil Pollution* **198**:125-132.

Zhang, H., Z. Wang, Y. Zhang, M. Ding, and L. Li. 2015. Identification of traffic-related metals and the effects of different environments on their enrichment in roadside soils along the Qinghai–Tibet highway. *Science of The Total Environment* **521-522**:160-172.

ABOUT ISSUES IN ECOLOGY

Issues in Ecology uses commonly understood language to report the consensus of a panel of scientific experts on issues related to the environment. The text for *Issues in Ecology* is reviewed for technical content by external expert reviewers, and all reports must be approved by the Editor-in-Chief before publication. This report is a publication of the Ecological Society of America. ESA and *Issues in Ecology* editors assume no responsibility for the views expressed by the authors of this report.

EDITOR-IN-CHIEF

Serita Frey, Department of Natural Resources & the Environment, University of New Hampshire, serita.frey@unh.edu

ADVISORY BOARD OF ISSUES IN ECOLOGY

Jessica Fox, Electric Power Research Institute

Noel P. Gurwick, Smithsonian Environmental Research Center

Clarisse Hart, Harvard Forest

Duncan McKinley, USDA Forest Service

Sasha Reed, U.S. Geological Survey

Amanda D. Rodewald, Cornell Lab of Ornithology

Thomas Sisk, Northern Arizona University

ADDITIONAL COPIES

This report and all previous *Issues in Ecology* are available electronically for free at:
https://www.esa.org/publications/issues/

Print copies may be ordered online or by contacting ESA:

Ecological Society of America, 1990 M Street NW, Suite 700, Washington, DC 20036

202-833-8773, esahq@esa.org


esa
ISSUES IN ECOLOGY
ECOLOGICAL SOCIETY OF AMERICA

PNW
Pacific Northwest
Research Station

Science FINDINGS

inside

An Emerging Field: Road Ecology 2
Planning for a Wildlife-Friendly Snoqualmie Pass 3
A Regional Perspective on Animal Movement . . .4
Helping the Critter Cross the Road 5

issue seventy nine / january 2006

"Science affects the way we think together."
Lewis Thomas

HIGHWAYS AND HABITAT: MANAGING HABITAT CONNECTIVITY AND LANDSCAPE PERMEABILITY FOR WILDLIFE



From a wildlife manager's perspective, roads act as barriers to movement and dispersal, often isolating and fragmenting populations .They also introduce pollutants and provide access for humans and development .And then, of course, there are vehicle-animal collisions—a direct source of mortality for countless animals each year .

in sUMMArY

Millions of miles of highway crisscross the United States .Highways fragment the landscape, affecting the distribution of animal populations and limiting the ability of individuals to disperse between those populations .Moreover, animal-vehicle collisions are a serious hazard to wildlife, not to mention people .

Researchers at the PNW Research Station in Wenatchee, Washington, have developed methods to evaluate landscape permeability—the ability of animals to move across the landscape .Using a geographic information system, in conjunction with snow tracking, automatic cameras, and road-kill surveys, they can now identify areas where animals are most likely to cross major highways .These techniques have been adopted by the Washington State Department of Transportation in a massive reconstruction project on Interstate 90 at Snoqualmie Pass .The new stretch of highway is slated to include several wildlife crossing structures .

In addition, the researchers have conducted a regional-scale evaluation of landscape permeability for grizzly bears, wolverines, grey wolves, and lynx in the Pacific Northwest .The analysis identifies highways and other landscape barriers that may fragment populations and limit dispersal opportunities .Their work provides tools that can be used to develop conservation strategies and help identify management priorities for these focal species .

"As transportation-related environmental issues and associated public concern rapidly grow, fortuitously, the science of road system ecology also emerges."

—Richard T. Forman, Professor of Landscape Architecture, Harvard University, and author of *Road Ecology*

It is an ominous feeling to be cruising down the road at 70 miles per hour and see your headlights reflected in the eyes of a deer. Your heart leaps to your throat and you wordlessly beg the animal not to cross. Though there is some relief when you pass, you know the deer is still stuck, and the drivers behind you all face the same hazard. Indeed, the very abundance of carcasses on the highway's shoulder offers proof that many deer don't make it out of the headlights or across the roadway.

There are nearly 4 million miles of roads in the United States and their ecological footprint extends well beyond the pavement. From a wildlife manager's perspective, roads act as barriers to movement and dispersal of wildlife, often isolating and fragmenting populations. They promote human access and development into wildlife habitat, and they introduce a host of pollutants, such as exhaust, pavement de-icers, and oil. Then,

of course, there are the collisions—a direct source of mortality for millions of animals each year.

Awareness of the environmental impacts of roads is increasing, yet information remains scarce. Peter Singleton, an ecologist at the PNW Research Station in Wenatchee, Washington, is among a growing cadre of scientists seeking to understand the interplay between human and animal movement networks.

Singleton's recent work has paired him with transportation engineers at the Washington State Department of Transportation (WSDOT). Together they are trying to understand how Washington's highways, bridges, on- and off-ramps, and other highway structures affect the distribution of animal populations. Their work is leading to new highway construction that integrates animal movement patterns into their design.

"Incorporating highway alignment with an understanding of animal movement can contribute to safer highways for both animals and motorists," says Singleton.

"For example, our work along Interstate 90 in the Snoqualmie Pass Adaptive Management Area, and throughout the Pacific Northwest, has provided several tools that managers can use to create crossing opportunities for animals, help connect isolated populations, and minimize risks to motorists from animal-vehicle collisions," he says.

To identify where human and animal transportation routes overlap, Singleton has used remote cameras, snow tracking, and road-kill surveys. But perhaps his most valuable tool has been a landscape analysis model that maps regional habitat quality and predicts how wildlife will move from one habitat-area to the next.

"Just like human populations, most animals are not uniformly distributed across large landscapes," explains Singleton. "They occur in subpopulations centered in areas of suitable habitat. Ensuring that animals have the opportunity to move across broad landscapes, from one subpopulation to the next, is vital to their long-term viability. It can alleviate many of the negative effects related to genetic isolation and random disturbances, such as wildfires or storms."

Key findings

- The Interstate 90 Snoqualmie Pass wildlife habitat linkage assessment identified five areas of increased landscape permeability. These areas have higher relative levels of animal crossings and are likely candidates for mitigation efforts during the reconstruction project.
- The regional assessment identified eight important fracture zones (areas of reduced landscape permeability) in Washington and Oregon that may be important for populations of wolverine, lynx, grizzly bears, and wolves.
- A geographic information system model that utilizes widely available data to find animal movement routes and wildlife-highway interaction zones was found to correspond well with field data and road-kill surveys.

AN EMERGING FIELD: ROAD ECOLOGY

Landscape ecologists are always talking about the connectivity of wildlife habitat. The idea is straight forward enough—large blocks of habitat are better than fragmented ones. As such, wildlife managers should strive to connect habitat to produce the largest blocks possible. Though Singleton finds no fault with this theory, he prefers to talk about "landscape permeability."

"Connectivity implies uniformity," says Singleton "and we know landscapes are never uniform; instead they are patchworks of habitat types interspersed with various types of barriers. Landscape permeability, on the other hand, describes the amount of resistance animals perceive when navigating across barriers and from one patch to the next."

Barriers come in many forms, and their permeability is, in some respects, in the eye of the beholder. In the case of natural barriers, like rivers or rugged topography, the barrier effect is perceived differently depending on the species in question. To an river otter or mountain goat, these may not be barriers at all. Humanmade barriers are the same way. A deer may easily traverse a rural subdivision, whereas to a wolverine, that same subdivision may be as good as a brick wall.

Highways are the archetypical landscape barrier.

"Few features in the modern landscape have such dramatic influence on human development, landscape change, and habitat fragmentation as highways," says Singleton. Concerns over the impact of roads on ecosystems have led to an emerging academic field: road ecology.

Road ecologists are concerned with the adverse impacts of roads on natural systems at many spatial scales. "At regional scales, it is important to understand how highways can affect the distribution of individual animals between populations," explains Singleton. "At smaller, local scales, it is important to be able to identify specific places where animals are likely to cross highways in order to manage for landscape permeability, provide crossing opportunities for animals, and minimize risks to motorists from animal-vehicle collisions."

science findings is online at:

http://www.fs.fed.us/pnw

The site includes **science Update**—scientific knowledge for pressing decisions about controversial natural resource and environmental issues.

Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

PNW Science Findings is published monthly by:

Pacific Northwest Research Station
USDA Forest Service
P.O. Box 3890
Portland, Oregon 97208
(503) 808-2137

Send new subscriptions and change of address information to pnw_pnwpubs@fs.fed.us

Sherri Richardson Dodge, editor
srichardsondodge@fs.fed.us

Keith Routman, layout
kroutman@fs.fed.us

USDA United States Department of Agriculture

Forest Service

PLANNING FOR A WILDLIFE-FRIENDLY SNOqUALMIE PASS

To drive on Interstate 90 through the breathtaking Cascade Mountains is to straddle a barrier that fragments a uniquely valuable ecosystem. Of particular concern is the Snoqualmie Pass region. In the past few years, Snoqualmie Pass has been the focus of a major land exchange and land acquisition effort by the Forest Service and a variety of nonprofit conservation groups interested in protecting old-growth forests and other biological resources.

Much of this region is managed by the Forest Service and is 1 of 10 regions designated as an adaptive management area (AMA) by the 1994 Northwest Forest Plan. The primary purpose of the AMA is to re-establish habitat connectiveness and permeability for late-successional species.

Interstate 90 at Snoqualmie Pass sees nearly 27,000 vehicles per day and bisects the central Cascades ecosystem, effectively halving the habitat available to many wildlife species.

In response, WSDOT and the PNW Research Station entered into an agreement in 1998 to conduct an assessment of the barrier effects of Interstate 90. Soon after the assessment was started, planning began for a major overhaul of the 15-mile stretch of highway. “It may seem odd for a transportation project, but habitat connectivity is a major emphasis of Interstate 90 reconstruction,” says Randy Giles, a project manager at WSDOT.

Knowing that millions of dollars would be spent on animal crossing structures, WSDOT asked Singleton to identify exactly where along the highway that investment could be best applied.

Singleton and his colleagues developed a unique methodology by using a geographic information system (GIS) to recognize places along the highway corridor with high landscape permeability. “Our model identified areas in the surrounding landscape with the best wildlife habitat and then sought the linkages between them that had the least exposure to unsuitable habitat,” says Singleton. The approach is called “least-cost corridor analysis.”

The model evaluated road and human population density, land cover type, elevation, and slope to highlight places along the highway most likely to have wildlife crossings. They tested the model by using a combination of automatic camera stations, snow tracking surveys, and an analysis of road-kill distributions that looked back 16 years. Through this methodology they identified five areas with greater landscape permeability along the stretch of highway.



Snow tracking, automatic camera stations, and road-kill surveys have been used to identify areas along Interstate 90 in the Snoqualmie Pass region with high animal crossing rates .This information is being used by the Washington State Department of Transportation in a major reconstruction project that includes habitat connectivity as a primary objective .

One of these areas, Easton Hill, was the sight of a tragic accident in 2004 that killed four people when their vehicle collided with an elk and crashed over an embankment.

“Several factors come together to make Easton Hill a hot spot of wildlife activity,” says Singleton. “It is linked to some very high-quality habitat, and there is little human access off the roadway. Also, there is a wide forested median that separates the east- and westbound lanes of traffic, which makes for a shorter cross. What’s more, because of the steep hill, traffic gets clumped up and tends to slow down quite a bit. In fact, it is the only area that my field crews could safely cross when we were conducting snow tracking surveys.”

Easton Hill and the other four areas with high wildlife activity are now likely candidates for mitigation work during the reconstruction project—much of which is still undergoing environmental review. “So far, $387 million have been funded toward the highway project, which includes several wildlife crossing structures—and that’s just for the first 5 miles,” explains Giles.

“As far as Easton Hill goes,” he says, “we are still trying to find the structure that will benefit the widest range of wildlife species. For now, a large forested overpass seems most likely.”



Automatic camera stations were used to test the landscape permeability model developed for the Interstate 90 assessment .Several animals were photographed near the highway, including these black bears .

A REGIONAL PERSPECTIVE ON ANIMAL MOVEMENT

The GIS analysis was very good at locating regions along Snoqualmie Pass with high densities of wildlife. The cameras, snow tracks, and road-kill analysis all confirmed the model's findings. Seeing this, Singleton took the logical next step: he scaled up.

"We modified the landscape permeability model that we developed for the Interstate 90 project and applied it at a regional scale throughout Washington, Oregon, and southern British Columbia," he explains.

Singleton and his colleagues were particularly interested in finding the barriers to long-range movement between large blocks of wilderness found in this region, such as the north Cascades Range, the Selkirk-Columbia Mountains, and the British Columbia Coast Range.

"Understanding patterns of landscape permeability is particularly important for the conservation of species with large home ranges and low-density populations, such as large carnivores," says Singleton. So this time they catered the habitat assessment to the needs of four species: grizzly bear, wolverine, lynx, and grey wolf. All are known to travel long distances, and all are listed as threatened, endangered or are of special concern by the state of Washington.

The analysis identified several fracture zones, which are areas of low permeability separating high-quality habitat areas. In addition to highways, the fracture zones contain recreation and residential development and fragmented forest cover resulting from logging. One fracture zone in southwestern Washington had such low permeability that carnivore populations in the southern Cascades and Olympic Mountains are likely to be completely isolated.

Also of particular concern was landscape permeability for grizzly bears in and out of the north Cascades. The north Cascades area has been identified as a grizzly bear recovery zone and the current population is small and isolated. Female grizzlies, in particular, are known to avoid crossing roads or moving through other human developments. As a result, the long-term viability of grizzly bears in this region is in question.

Singleton's research may offer some help in identifying areas that have the potential to reconnect north Cascades grizzlies to other populations in Canada or the Rocky Mountains.



Transportation engineers are increasingly collaborating with ecologists to design creative wildlife crossing structures .Some are simple oversized culverts, which assist movement for small, low-mobility species like rodents and amphibians; in contrast, others are complex networks of tunnels and grass-covered bridges that facilitate movement of large and small animals .

More immediately, the regional analysis is already helping land managers identify areas where landscape permeability for all carnivores can be improved. "Our results have been incorporated into the WSDOT long-range highway maintenance planning process. This has given them more information and predictability on the issues they are likely to face in implementing future highway projects at regional scales. The WSDOT had been very supportive of this work," says Singleton.

l And MAnAGeMent iMplicAtions

- The geographic information system model developed for this project is a useful tool for land managers and road engineers seeking to find the best location for placing animal crossing structures along major highways.
- Field techniques developed during this research, such as roadside snow tracking, automatic cameras, and road-kill surveys, are useful for evaluating animal movement near highways.
- The analysis of landscape permeability for large carnivores in the Pacific Northwest can be used to develop conservation strategies, contribute to future field survey efforts, and help identify management priorities for these focal species.

HELPING THE CRITTER CROSS THE ROAD

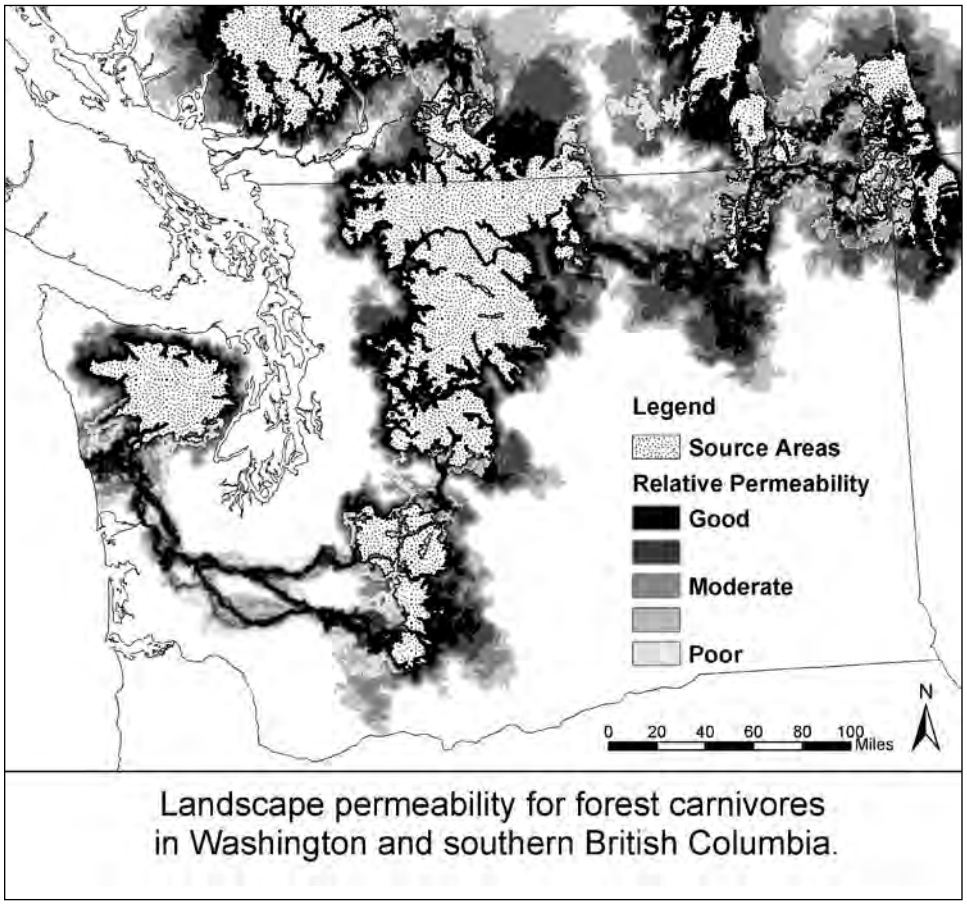
Once land managers know where wildlife crossings are most likely to occur, the question becomes: How can we get them across safely? Increasingly, transportation engineers are collaborating with road ecologists to design creative wildlife crossing structures. Some are as simple as oversized culverts, which assist movement for small, low-mobility species like rodents and amphibians. On the other end of the spectrum, some highways have incorporated complex networks of tunnels and grass-covered bridges.

Engineers on the Trans-Canada Highway in Banff National Park in Alberta have been leaders in developing wildlife-friendly roads. The park contains miles of fencing, all designed to funnel animals toward one of the wildlife tunnels or grass-covered overpasses—some of which are more than 150 feet wide.

Lessons learned in Banff and elsewhere have shown that a primary challenge for road ecologists is finding the right structure for each species. For example, on the Snoqualmie Pass project, Singleton used track plates and automatic cameras to determine if the existing bridges and culverts were allowing animal crossings. He found that mice and chipmunks were readily utilizing these structures, but few other species were using them.

"I was surprised that we didn't see any use of the larger culverts by medium or large carnivores," he says. "We found evidence of one river otter, but that's it."

As the reconstruction project on Interstate 90 unfolds, it will likely include dozens of different animal crossing structures including culverts, bridges, and viaducts. From the sounds of it, Snoqualmie Pass will certainly be more than just another ribbon of highway.



Landscape permeability is particularly important for the viability of species with large home ranges and low density populations, such as large carnivores .Singleton's landscape analysis model produces habitat maps that identify likely movement corridors for wolves, bears, lynx and wolverine .



Matching the appropriate crossing structures to the target species is often an important challenge in managing highways for landscape permeability as highlighted by this automatic camera photo of a deer investigating a tracking plate placed inside a drainage culvert .

"It is a fact, patent to both my dog and myself, that at daybreak I am the sole owner of all the acres I can walk over. It is not only the boundaries that disappear, but also the thought of being bounded."

—Aldo Leopold (1949)

FOR FURTHER READING

Singleton, P.H.; Gaines, W.L.; Lehmkuhl, J.F. 2004. *Landscape permeability for grizzly bear movements in Washington and southwestern British Columbia* .Ursus. 15(1): 90–103.

Singleton, P.H.; Gaines, W.L.; Lehmkuhl, J.F. 2002. *Landscape permeability for large carnivores in Washington: a geographic information system weighted-distance and least-cost corridor assessment* . Res. Pap. PNW-RP-549. Portland, OR: U.S.Department of Agricuture, Forest Service, Pacific Northwest Research Station. 89 p.

Singleton, P.H.; Lehmkuhl, J. 1999. *Assessing wildlife habitat connectivity in the interstate 90 Snoqualmie Pass corridor, Washington* .In: Evink, G.; Garrett, P.; Ziegler, D. Missoula, MT. Proceedings of the 3rd international conference on wildlife ecology and transportation: 75–84.

Singleton, P.H.; Lehmkuhl, J. 2000. *I-90 Snoqualmie Pass wildlife habitat linkage assessment* .Olympia, WA: Washington State Department of Transportation, final report. WA:RD489.1. 97 p.

Writer's profile

Jonathan Thompson is a science writer and ecologist .He lives in Corvallis, Oregon .

Science
FINDINGS

U.S. Department of Agriculture
Pacific Northwest Research Station
333 SW First Avenue
P.O. Box 3890
Portland, OR 97208-3890

Official Business
Penalty for Private Use, $300

PRSRT STD
US POSTAGE
PAID
PORTLAND OR
PERMIT N0 G-40

scientist profile



PETER SINGLETON is an ecologist with the USDA Forest Service, Pacific Northwest Research Station in Wenatchee, WA. He is currently conducting a study of barred owl habitat selection and landscape use patterns in the eastern Cascades. Singleton has also been involved in research on carnivore movement patterns, developing analysis techniques to address habitat connectivity and landscape permeability, assessing the impacts of outdoor recreation on wildlife populations, and modeling the interactions between elk populations and the ecology of meadow and riparian habitats. Singleton holds an M.S. from the University of Montana and a B.S. from The Evergreen State College in Washington.

Singleton can be reached at:

Forestry Sciences Laboratory
1133 N. Western Avenue
Wenatchee, WA 98801
Phone: (509) 664-1732
E-mail: psingleton@fs.fed.us

collABorAtors

John F. Lehmkuhl, USDA Forest Service, Pacific Northwest Research Station

William (Bill) L. Gaines, USDA Forest Service, Pacific Northwest Region

Paul Wagner, Randy Giles, Marion Carey, Washington State Department of Transportation

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communica-tion of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write USDA, Director, Office of Civil Rights, Room 1400 Independence Avenue, SW, Washington, DC 20250-9410 or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

APPLIED ECOLOGY

2015 © The Authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. Distributed under a Creative Commons Attribution License 4.0 (CC BY).
10.1126/sciadv.1500052

Habitat fragmentation and its lasting impact on Earth's ecosystems

Nick M. Haddad,[1]* Lars A. Brudvig,[2] Jean Clobert,[3] Kendi F. Davies,[4] Andrew Gonzalez,[5] Robert D. Holt,[6] Thomas E. Lovejoy,[7] Joseph O. Sexton,[8] Mike P. Austin,[9] Cathy D. Collins,[10] William M. Cook,[11] Ellen I. Damschen,[12] Robert M. Ewers,[13] Bryan L. Foster,[14] Clinton N. Jenkins,[15] Andrew J. King,[9] William F. Laurance,[16] Douglas J. Levey,[17] Chris R. Margules,[18,19] Brett A. Melbourne,[4] A. O. Nicholls,[9,20] John L. Orrock,[12] Dan-Xia Song,[8] John R. Townshend[8]

We conducted an analysis of global forest cover to reveal that 70% of remaining forest is within 1 km of the forest's edge, subject to the degrading effects of fragmentation. A synthesis of fragmentation experiments spanning multiple biomes and scales, five continents, and 35 years demonstrates that habitat fragmentation reduces biodiversity by 13 to 75% and impairs key ecosystem functions by decreasing biomass and altering nutrient cycles. Effects are greatest in the smallest and most isolated fragments, and they magnify with the passage of time. These findings indicate an urgent need for conservation and restoration measures to improve landscape connectivity, which will reduce extinction rates and help maintain ecosystem services.

INTRODUCTION

Destruction and degradation of natural ecosystems are the primary causes of declines in global biodiversity (*1*, *2*). Habitat destruction typically leads to fragmentation, the division of habitat into smaller and more isolated fragments separated by a matrix of human-transformed land cover. The loss of area, increase in isolation, and greater exposure to human land uses along fragment edges initiate long-term changes to the structure and function of the remaining fragments (*3*).

Ecologists agree that habitat destruction is detrimental to the maintenance of biodiversity, but they disagree—often strongly—on the extent to which fragmentation itself is to blame (*4*, *5*). Early hypotheses based on the biogeography of oceanic islands (*6*) provided a theoretical framework to understand fragmentation's effect on extinction in terrestrial landscapes composed of "islands" of natural habitat scattered across a "sea" of human-transformed habitat. Central to the controversy has been a lingering uncertainty about the role of decreased fragment size and increased isolation relative to the widespread and pervasive effects of habitat loss in explaining declines in biodiversity and the degradation of ecosystems (*7*). Observational studies of the effects of fragmentation have often magnified the controversy because inference from nonmanipulative studies is limited to correlation and because they have individually often considered only single aspects of fragmentation (for example, edge, isolation, and area) (*8*). However, together with these correlative observations, experimental studies reveal that fragmentation has multiple simultaneous effects that are interwoven in complex ways and that operate over potentially long time scales (*9*).

Here, we draw on findings of the world's largest and longest-running fragmentation experiments that span 35 years and disparate biomes on five continents. Their rigorous designs and long-term implementation overcome many limitations of observational studies. In particular, by manipulating and isolating individual aspects of fragmentation while controlling for others, and by doing so on entire ecosystems, they provide a powerful way to disentangle cause and effect in fragmented landscapes. Here, we present experimental evidence of unexpected long-term ecological changes caused by habitat fragmentation.

Highlighting one ecosystem type as an example, we first present a global analysis of the fragmentation of forest ecosystems, quantifying for the first time the global hotspots of intensive historical fragmentation. We then synthesize results from the set of long-term experiments conducted in a wide variety of ecosystems to demonstrate consistent impacts of fragmentation, how those impacts change over time, and how they align with predictions from theory and observation. Finally, we identify key knowledge gaps for the next generation of fragmentation experiments.

GLOBAL ANALYSIS OF THE EXTREME MAGNITUDE AND EXTENT OF FRAGMENTATION

New satellite data sets reveal at high resolution how human activities are transforming global ecosystems. Foremost among these observations are those of forest cover because of the high contrast between forest

[1]Department of Biological Sciences, North Carolina State University, Raleigh, NC 27695, USA. [2]Department of Plant Biology, Michigan State University, East Lansing, MI 48824–1312, USA. [3]Station d'Ecologie Expérimentale du CNRS a Moulis USR 2936, Moulis, 09200 Saint-Girons, France. [4]Department of Ecology and Evolutionary Biology, UCB 334, University of Colorado, Boulder, CO 80309, USA. [5]Department of Biology, McGill University, Montreal, Quebec H3A 1B1, Canada. [6]Department of Biology, University of Florida, Gainesville, FL 32611, USA. [7]Department of Environmental Science and Policy, George Mason University, Fairfax, VA 22030, USA. [8]Global Land Cover Facility, Department of Geographical Sciences, University of Maryland, College Park, MD 20702, USA. [9]CSIRO Land and Water Flagship, GPO Box 1700, Canberra, Australian Capital Territory 2601, Australia. [10]Department of Biology, Colby College, 5746 Mayflower Hill, Waterville, ME 04901, USA. [11]Department of Biological Sciences, St. Cloud State University, St. Cloud, MN 56301, USA. [12]Department of Zoology, University of Wisconsin, Madison, WI 53706, USA. [13]Department of Life Sciences, Imperial College London, Silwood Park Campus, Buckhurst Road, Ascot, Berkshire SL5 7PY, UK. [14]Department of Ecology and Evolutionary Biology and Kansas Biological Survey, University of Kansas, 2101 Constant Avenue, Lawrence, KS 66047–3759, USA. [15]Instituto de Pesquisas Ecológicas, Rod. Dom Pedro I, km 47, Caixa Postal 47, Nazaré Paulista, São Paulo 12960-000, Brazil. [16]Centre for Tropical Environmental and Sustainability Science and College of Marine and Environmental Sciences, James Cook University, Cairns, Queensland 4878, Australia. [17]National Science Foundation, Arlington, VA 22230, USA. [18]Centre for Tropical Environmental and Sustainability Science, School of Earth and Environmental Sciences, James Cook University, Cairns 4878, Australia. [19]Research Center for Climate Change, University of Indonesia, Kota Depok, Java Barat 16424, Indonesia. [20]The Institute for Land, Water and Society, Charles Sturt University, Thurgoona Campus, Albury, New South Wales 2640, Australia.
*Corresponding author. E-mail: nick_haddad@ncsu.edu

Downloaded from https://www.science.org on October 21, 2025

and anthropogenic land cover types. Deforestation, which was already widespread in temperate regions in the mid-18th to 20th centuries and increased in the tropics over the past half century, has resulted in the loss of more than a third of all forest cover worldwide (*10*, *11*). Beyond the direct impacts of forest loss and expanding anthropogenic land cover (for example, agricultural fields and urban areas), remnant forests are likely to suffer from being smaller, more isolated, and with a greater area located near the edge of the forest (*12*).

We analyzed the world's first high-resolution map of global tree cover (*13*) to measure the magnitude of forest fragmentation. This analysis revealed that nearly 20% of the world's remaining forest is within 100 m of an edge (Fig. 1, A and B)—in close proximity to agricultural, urban, or other modified environments where impacts on forest ecosystems are most severe (*14*). More than 70% of the world's forests are within 1 km of a forest edge. Thus, most forests are well within the range where human activities, altered microclimate, and nonforest species may influence and degrade forest ecosystems (*15*). The largest contiguous expanses of remaining forests are in the humid tropical regions of the Amazon and Congo River Basins (Fig. 1A). Large areas of more disjunct forest also remain in southeastern Asia, New Guinea, and the boreal biomes.

Historical data enable the study of the process of forest fragmentation over time. We reconstructed the historical forest extent and timing of fragmentation in two forested regions of Brazil that provide a stark contrast in land-use dynamics. The Brazilian Amazon is a rapidly changing frontier (*10*), yet most of its forests remain contiguous and far from an edge despite recent increases in fragmentation (Fig. 1, C and D). In contrast, the Brazilian Atlantic Forest is a largely deforested landscape, cleared for agriculture and logged for timber over the last three centuries (*11*). This remaining forest is dominated by small fragments, with most fragments smaller than 1000 ha and within 1000 m of a forest edge (Fig. 1, E and F) (*16*). In the Brazilian Amazon, the proportion of forest farther than 1 km from the forest edge has decreased from 90% (historical) to 75% (today), and in the Brazilian Atlantic, from 90% to less than 9%.

These two forested regions of Brazil define extremes of the fragmentation process and are representative of the extent of fragmentation in forested landscapes worldwide (Fig. 1), as well as many other biomes including temperate grasslands, savannas, and even aquatic systems (*17*). For example, although a spatial analysis similar to that of forest is not currently possible in grasslands, 37% of the world's grassland eco-regions are classified as "highly fragmented" (*18*, *19*).

Downloaded from https://www.science.org on October 21, 2025

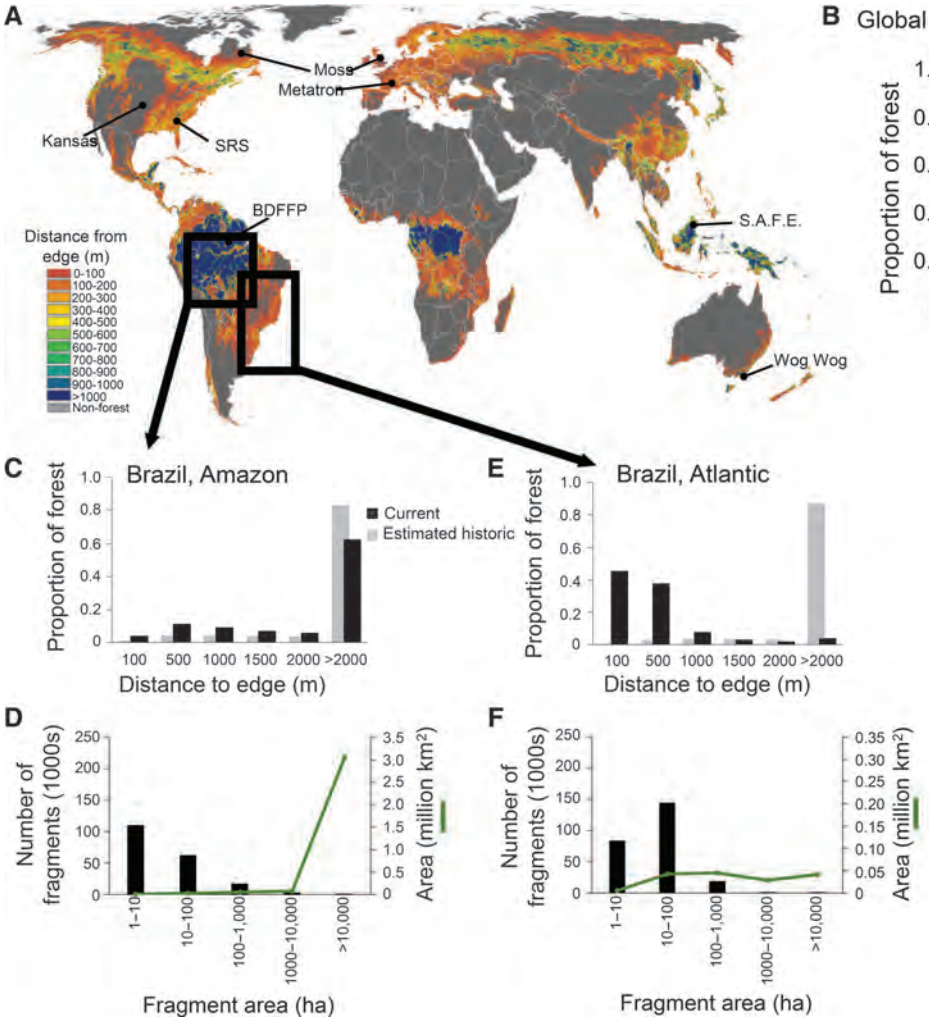


Fig. 1. The global magnitude of forest fragmentation. (**A**) Mean distance to forest edge for forested pixels within each 1-km cell. Lines point to locations of ongoing fragmentation experiments identified and described in Fig. 2. (**B**) Proportion of the world's forest at each distance to the forest edge and the cumulative proportion across increasing distance categories (green line). (**C** and **E**) In the Brazilian Amazon (C) and Atlantic Forests (E), the proportion of forest area at each distance to forest edge for both the current and estimated historic extent of forest. (**D** and **F**) In the Brazilian Amazon (D) and Atlantic Forests (F), the number of fragments and the total area of fragments of that size. The total number of fragments in the smallest bin (1 to 10 ha) is an underestimate in both the Atlantic Forest and Amazon data sets because not all of the very smallest fragments are mapped.

Robust knowledge of how habitat fragmentation affects biodiversity and ecosystem processes is needed if we are to comprehend adequately the implications of this global environmental change.

THE VALUE OF LONG-TERM FRAGMENTATION EXPERIMENTS

Long-term experiments are a powerful tool for understanding the ecological consequences of fragmentation (*20*). Whereas observational studies of fragmented landscapes have yielded important insights (*9*, *21*), they typically lack rigorous controls, replication, randomization, or baseline data. Observational studies have limited ability to isolate the effects of fragmentation from concomitant habitat loss and degradation per se (*4*, *7*, *22*). Remnant fragments are embedded in different types and qualities of surrounding habitat, complicating interpretation because the surrounding habitat also influences biodiversity and ecosystem productivity (*23*).

The long-term fragmentation experiments we analyze here comprise the entire set of ongoing terrestrial long-term experiments. They occur in several biomes (Fig. 2 and Supplementary Materials) and were designed to manipulate specific components of fragmentation—habitat size, isolation, and connectivity—while controlling for confounding factors such as the amount of habitat lost across a landscape (Fig. 2). The largest fragments across these experiments match the size of fragments commonly created by anthropogenic activities (Figs. 1 and 2). Distances to the edge of experimental fragments range to 500 m, encompassing edge distances found in more than half of forests worldwide (Fig. 1B). In each experiment, different fragmentation treatments with replication were established, starting from continuous, nonfragmented landscapes and controlling for background environmental variation either by experimental design (blocking) or by measurement of covariates for use in subsequent analyses. Tests were conducted within fragments that varied experimentally in area or edge, within fragments that were experimentally isolated or connected, or within experimental fragments compared to the same area within continuous habitat. All treatments were replicated. Experiments were created by destroying or creating precise amounts of habitat across replicate landscapes, allowing tests of fragmentation effects independent of habitat loss. The robust

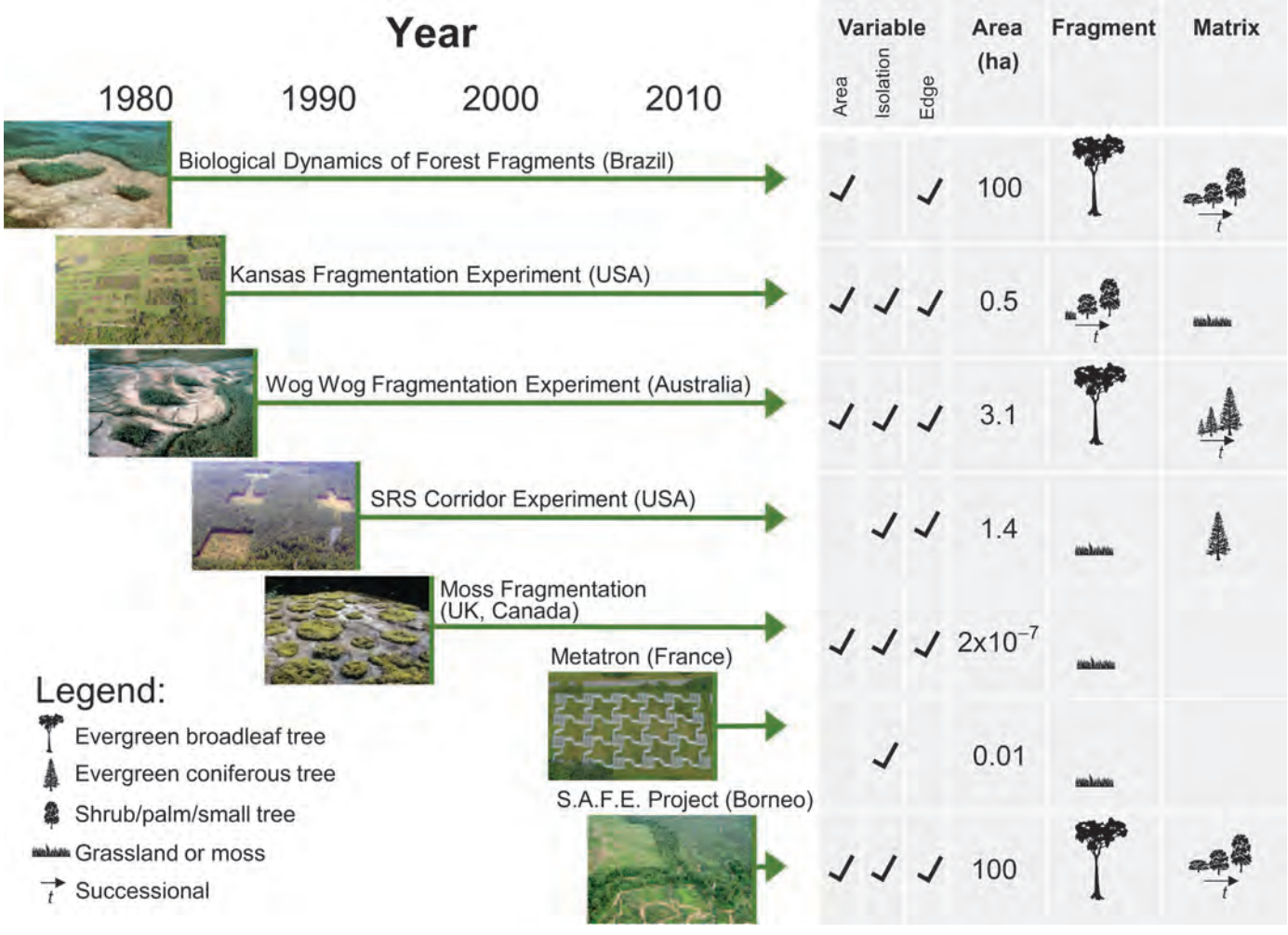


Fig. 2. The world's ongoing fragmentation experiments. All experiments have been running continuously since the time indicated by the start of the associated arrow (with the exception of the moss fragmentation experiment, which represents a series of studies over nearly two decades). The variables under study in each experiment are checked. The area is that of the experiment's largest fragments. Icons under "Fragment" and "Matrix" indicate the dominant community and its relative height, with multiple trees representing succession.

Downloaded from https://www.science.org on October 21, 2025

and comparable experimental designs allow for powerful tests of the mechanisms underpinning the ecological impacts of fragmentation, and the long-term nature of ensuing studies has revealed consistent emergent effects.

These experiments mimic anthropogenic fragmentation; they are whole-ecosystem manipulations in which all species and processes experienced the same treatment (*24*). Emergent responses thus reflect the multiple direct and indirect effects of interacting species and processes. Further, because experimentally fragmented ecosystems are open to fluxes of individuals and resources, fragmentation effects can manifest across multiple levels of ecological organization (Fig. 3). Long-term experiments have the power to detect lagged and/or chronic impacts.

The first fragmentation experiments, now more than three decades old, were created to test effects of fragment area on both species persistence and patterns of immigration, reflecting concern in conservation biology about the role of fragmentation in reducing population sizes below viable levels (*25*) (Fig. 2). Subsequent experiments, created two decades ago, shifted focus to modifying habitat isolation, reflecting recognition of the potential to mitigate negative effects of fragmentation by recreating habitat—specifically with corridors—to increase connectivity among fragments (*26*) (Fig. 2). The newest experiments test emerging questions about potentially deleterious synergies between fragmentation and global changes in climate and land use (Fig. 2).

We synthesized results available 31 January 2014 for all studies within these experiments that were conducted in all treatments and replicates, and tested fragmentation effects on dispersal, abundance, extinction, species richness, community composition, and ecosystem functioning. We first calculated effect sizes of fragmentation as log response ratios (Fig. 3). Data from 76 different studies across the five longest-running experiments were drawn from published and unpublished sources (table S1). We synthesized results according to three fragmentation treatments: reduced fragment area [the focus of Biological Dynamics of Forest Fragments Project (BDFFP), Wog Wog, and Kansas; see Fig. 2 for identifiers of experiments], increased fragment isolation [Savannah River Site (SRS) and Moss], and increased proportion of edge (all experiments). Fragmented treatments were compared directly to non- or less-fragmented habitats that were either larger or connected via structural corridors (table S1).

Strong, consistent, and accumulating effects of habitat fragmentation

Our synthesis revealed strong and consistent responses of organisms and ecosystem processes to fragmentation arising from decreased fragment area, increased isolation, and the creation of habitat edges (Fig. 3).

Community and ecosystem responses emerge from observed responses at the level of populations. Reduced area decreased animal

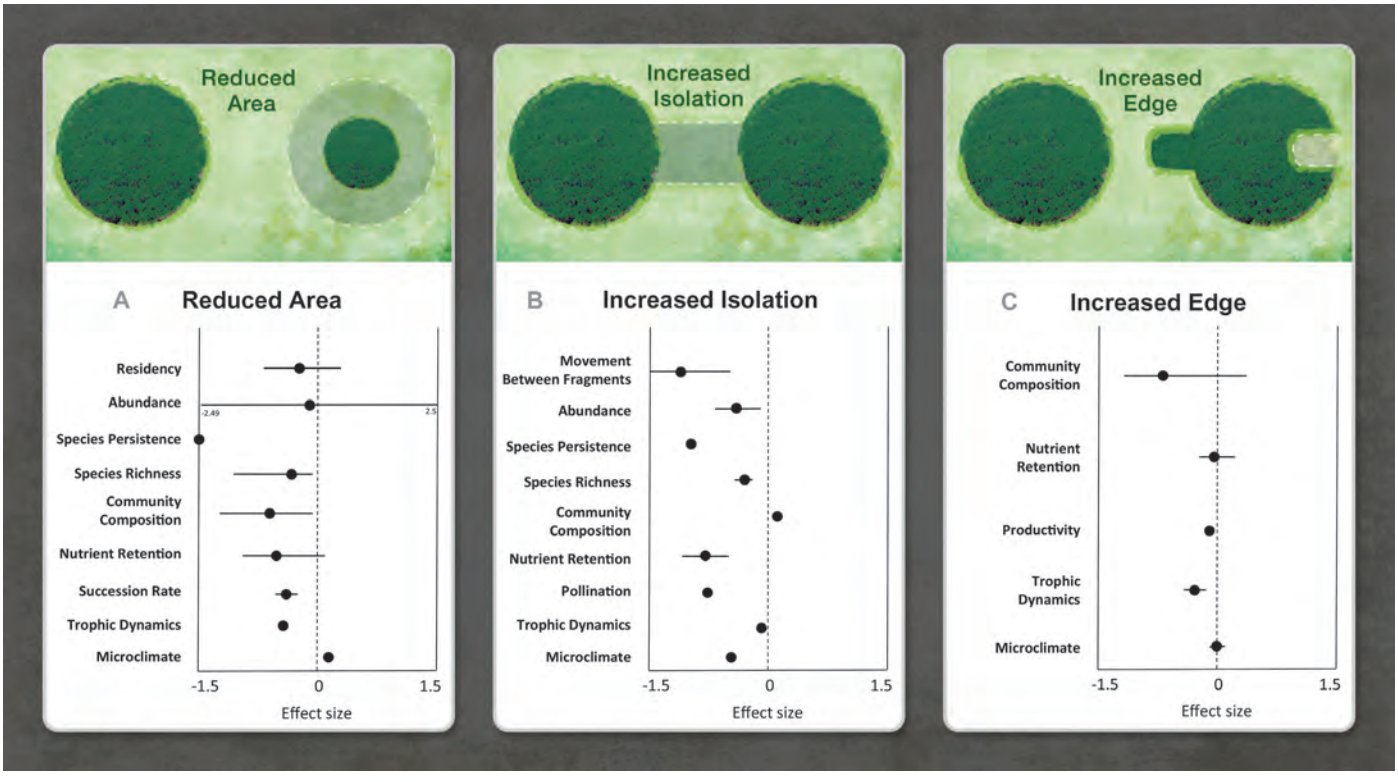


Fig. 3. Fragmentation effects propagate through the whole ecosystem. (**A** to **C**) For each fragmentation treatment [reduced area in BDFFP, Wog Wog, Kansas (A); increased isolation in SRS and Moss (B); and increased edge in all experiments (C)], we summarize major findings for ecological processes at all levels of ecological organization. Each dot represents the mean effect size [computed as log response ratio: ln(mean in more fragmented treatment/mean in non- or less-fragmented treatment)] for an ecological process. Effect sizes are statistical, such that negative or positive values could represent degrading function. Horizontal bars are the range when a dot is represented by more than one study. Details, including individual effect sizes for each study, are reported in table S1.

Downloaded from https://www.science.org on October 21, 2025

residency within fragments, and increased isolation reduced movement among fragments, thus reducing fragment recolonization after local extinction (Fig. 3, A and B). Reduced fragment area and increased fragment isolation generally reduced abundance of birds, mammals, insects, and plants (Fig. 3, A and B). This overall pattern emerged despite complex patterns of increases or declines in abundance of individual species (Fig. 3A) with various proximate causes such as release from competition or predation, shifts in disturbance regimes, or alteration of abiotic factors (*14*, *27*–*29*). Reduced area, increased isolation, and increased proportion of edge habitat reduced seed predation and herbivory, whereas increased proportion of edge caused higher fledgling predation that had the effect of reducing bird fecundity (represented together as trophic dynamics in Fig. 3, A to C). Perhaps because of reduced movement and abundance, the ability of species to persist was lower in smaller and more isolated fragments (Fig. 3, A and B).

As predicted by theory (*6*, *30*, *31*), fragmentation strongly reduced species richness of plants and animals across experiments (Fig. 3, A and B), often changing the composition of entire communities (Fig. 3, A to C). In tropical forests, reduced fragment size and increased proportion of edge habitat caused shifts in the physical environment that led to the loss of large and old trees in favor of pioneer trees (Fig. 3, A and C), with subsequent impacts on the community composition of insects (*32*). In grasslands, fragment size also affected succession rate, such that increased light penetration and altered seed pools in smaller fragments impeded the rate of ecological succession relative to that of larger fragments (*33*) (Fig. 3A).

Consistently, all aspects of fragmentation—reduced fragment area, increased isolation, and increased edge—had degrading effects on a disparate set of core ecosystem functions. Degraded functions included reduced carbon and nitrogen retention (Fig. 3, A to C), productivity (Fig. 3C), and pollination (Fig. 3B).

In summary, across experiments spanning numerous studies and ecosystems, fragmentation consistently degraded ecosystems, reducing species persistence, species richness, nutrient retention, trophic dynamics, and, in more isolated fragments, movement.

Long-term consequences of fragmentation

To synthesize all time series of species richness and ecosystem functioning gathered across experiments, we measured effects of fragmentation over the course of each study. The effect of fragmentation was calculated over time as the proportional change in fragmented relative to non- or less-fragmented treatments (Fig. 4).

In most cases, the large and consistent effects of fragmentation revealed by the experiments were predicted from theory. However, we were struck by the persistence of degradation to biodiversity and ecosystem processes and by the increase in many of the effects over time (Fig. 4). For example, extreme rainfall events at Wog Wog appeared to delay the decline in plant species richness for 5 years after fragmentation. In the Kansas Experiment, a lag of 12 years occurred before fragmentation effects on plant succession were detected. Our results thus reveal long-term and progressive effects of fragmentation and provide support for three processes proposed by recent studies in spatial ecology: extinction debt, immigration lag, and ecosystem function debt (Fig. 4).

First, we found strong evidence for temporal lags in extinction [that is, "extinction debt" (*30*)] in fragments. Species richness of plants, arthropods, and birds sampled in the experiments conducted in mature forest fragments and replicated moss landscapes showed decreases of

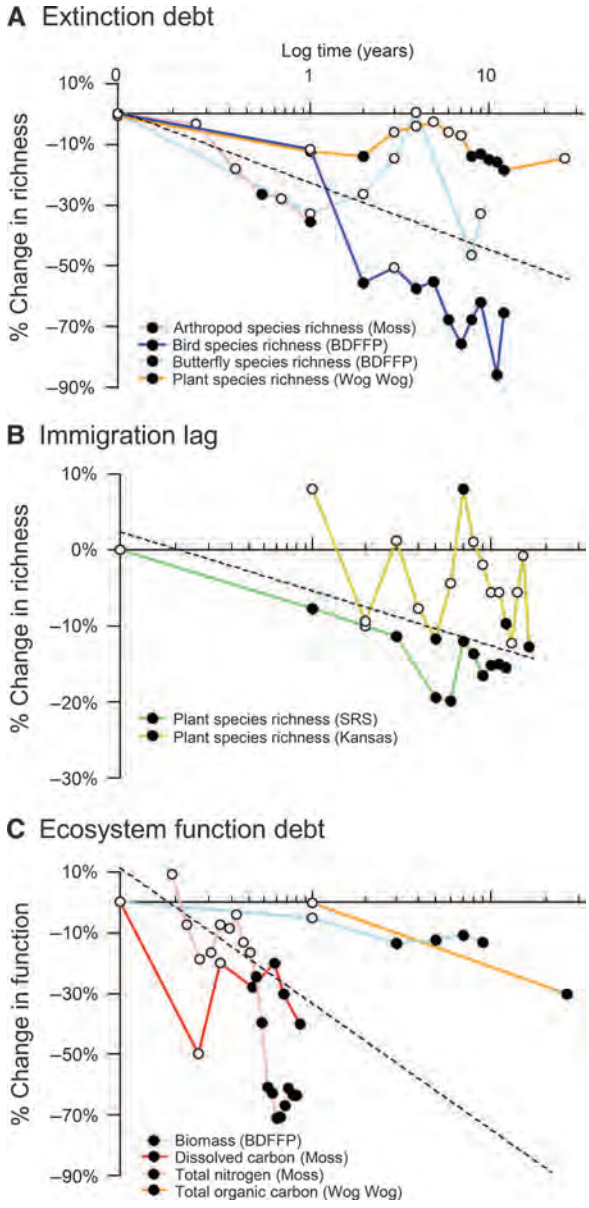


Fig. 4. Delayed effects of fragmentation on ecosystem degradation. (**A**) The extinction debt represents a delayed loss of species due to fragmentation. (**B**) The immigration lag represents differences in species richness caused by smaller fragment area or increased isolation during fragment succession. (**C**) The ecosystem function debt represents delayed changes in ecosystem function due to reduced fragment size or increased isolation. Percent loss is calculated as proportional change in fragmented treatments [for example, (no. of species in fragment − no. of species in control)/(no. of species in control) × 100]. Fragments and controls were either the same area before and after fragmentation, fragments compared to unfragmented controls, or small compared to large fragments. Filled symbols indicate times when fragmentation effects became significant, as determined by the original studies (see table S2). Mean slopes (dashed lines) were estimated using linear mixed (random slopes) models. Mean slope estimates (mean and SE) were as follows: (A) −0.22935 (0.07529); (B) −0.06519 (0.03495); (C) −0.38568 (0.16010).

Downloaded from https://www.science.org on October 21, 2025

20 to 75% after fragmentation (Fig. 4A). Some declines were evident almost immediately after fragmentation, whereas others increased in magnitude over the experiment's duration. Across experiments, average loss was >20% after 1 year, >50% after 10 years, and is still increasing in the longest time series measured (more than two decades). The rate of change appears to be slower in larger fragments [in BDFFP, 50% decline in bird species after 5 years in 1-ha fragments, but after 12 years in 100-ha fragments; in Moss, 40% decline in arthropod species richness of small fragments and 26% reduction in large fragments after 1 year (*34*, *35*)]. As predicted by theory (*36*), the extinction debt appears to take longer to pay in larger fragments.

Second, we observed that reduced richness was coincident with an "immigration lag" (*37*), whereby small or isolated fragments are slower to accumulate species during community assembly (*33*, *38*) (Fig. 4B). Immigration lags were observed in experiments conducted in successional systems that were initiated by creating new habitat fragments, rather than by fragmenting existing habitats. After more than a decade, immigration lags resulted in 5% fewer species after 1 year, and 15% fewer species after 10 years in small or isolated fragments compared to large or connected fragments (Fig. 4B).

Third, we observed an ecosystem function debt caused by fragmentation (*39*) in forest and moss fragments (Fig. 4C). An ecosystem function debt is manifest both as delayed changes in nutrient cycling and as changes to plant and consumer biomass. Loss of function amounted to 30% after 1 year, rising to 80% after a decade in small and isolated fragments when compared to larger and more connected fragments (Fig. 4C). Functional debts can result from biodiversity loss, as when loss of nutrients and reduction in decomposition are caused by simplification of food webs. Alternatively, the impact is exhibited through pathways whereby fragmentation changes biotic (for example, tree density in successional systems) or abiotic conditions (for example, light regimes or humidity) in ways that alter and potentially impair ecosystem function [for example, biomass collapse in fragments; Figs. 3 and 4; altered nitrogen and carbon soil dynamics (*40*)].

A new understanding of the effects of fragmentation

By testing existing theory, experiments play a pivotal role in advancing ideas and developing new theory. We draw on experimental evidence to highlight two ways that the understanding of fragmentation has been enriched by the interplay between long-term experiments and development of theory.

First, island biogeography (*6*) was among the earliest theories to predict extinction and immigration rates and patterns of species richness in isolated biotas, which were later used to predict the effects of fragmentation on these variables. Experiments in continental settings tested the theory and gave rise to fresh perspectives. For example, islands are surrounded by sea, a thoroughly inimical matrix for island-dwelling species. Habitat islands, or fragments, are surrounded by a matrix that may not be so unsuitable for some species. In terms of all of the ecological variables studied in our long-term experiments, our results support the conclusion that ecological dynamics in human-modified fragments are a stark contrast to the dynamics in intact habitats that remain. Observational studies that have devoted more detailed consideration to the countryside within which fragments are embedded explain the diversity of ecological responses in remaining fragments (*41*). At the same time as experiments supported the core predictions of classical theories about effects of fragment size and isolation (Figs. 3 and 4), they spurred and tested new theories such as metacommunity theory (*42*) to account for variation in connectivity and habitat quality within and between fragments (*33*, *43*–*45*), spatial dynamics (*14*, *46*), and spatially varying interspecific interactions (*47*).

Second, experiments have demonstrated that the effects of fragmentation are mediated by variation in traits across species. More realistic predictions of community responses to fragmentation emerged after explicit consideration of species traits such as rarity and trophic levels (*48*, *49*), dispersal mode (*50*–*52*), reproductive mode and life span (*29*, *53*), diet (*54*), and movement behavior (*55*, *56*). Increasingly, the simple theoretical prediction that fragmentation reduces species richness is being modified to account for species identity through models that focus on how species vary in their traits (*4*, *21*, *36*, *48*, *57*, *58*). Consideration of traits may help to interpret variation around the overarching pattern that fragmentation consistently reduces species richness across many species and biomes (Figs. 3 and 4).

A NEW GENERATION OF FRAGMENTATION EXPERIMENTS

New foci are emerging for studying ecosystem fragmentation, including (i) synergies between fragmentation and global changes, (ii) eco-evolutionary responses of species to fragmentation, and (iii) ecological responses to fragmentation in production landscapes—that is, ecosystems whose services are under extreme appropriation by humans (*59*).

First, conclusions from experiments thus far are likely to have been conservative because impacts from other environmental changes have been mostly excluded. Most forms of global change known to reduce population sizes and biodiversity will be exacerbated by fragmentation (*58*, *60*), including climate change (*61*), invasive species (*62*, *63*), hunting (*64*), pollution [including light, noise, and chemicals (*65*)], and altered disturbance regimes (*66*).

More complex experiments with unparalleled control and capacity to simultaneously manipulate fragmentation and other global changes are now under way (*53*). The Metatron, created in 2011 in southern France (*67*), enables ecologists to assess effects of variation in temperature and other abiotic factors in addition to habitat isolation. The SAFE Project is being created in the rainforest of Borneo (*68*) and will embed a fragmentation experiment within a production agricultural plantation in which poaching will occur. Other synergies should be investigated experimentally, including the interaction between fragmentation and hunting, fire, infectious disease outbreaks, or nitrogen deposition. Within these experiments, fragmentation and loss of habitat can then be varied independently.

Second, current experiments have stopped short of examining how fragmentation drives evolution through genetic bottlenecks, ecological traps, changing patterns of selection, inbreeding, drift, and gene flow (*69*–*72*). Extensive fragmentation has occurred over many years, and in some regions over millennia (*11*). Changes caused by fragmentation undoubtedly lead to altered patterns of selection and trait evolution. Evolutionary responses to fragmentation have already been suggested (*73*, *74*), and it is likely that such changes will, in turn, feed back to influence population persistence and ecosystem resilience in fragmented landscapes. Linking long-term experiments with the tools of landscape genetics (*75*) may provide powerful insights into the evolutionary dynamics of species inhabiting fragmented landscapes.

Third, new experiments should address the management of natural habitats in production landscapes by monitoring vegetation, networks of interacting species, and ecosystem services at ecologically relevant

Downloaded from https://www.science.org on October 21, 2025

spatial and temporal scales (*76*–*78*). Some ecosystem services have global consequences, for example, local carbon sequestration affects global atmospheric CO_2. However, in many cases the benefits obtained by people depend on their proximity to habitat fragments (*79*). For example, crop pollination and biological pest control from natural areas adjacent to farms are made available by the very process of habitat fragmentation, bringing people and agriculture closer to those services. Yet, further fragmentation reduces access to many services and ultimately may push landscapes past tipping points, beyond which essential ecosystem services are not merely diminished but lost completely (*80*). This complex relationship creates a double-edged sword, for which locally optimal levels and arrangements of habitat must be sought. New fragmentation experiments should consider how multiple fragments in a landscape interact, creating an ecological network in which the collective benefit of ecosystem services may be greater than the sum of services provided by individual fragments (*81*, *82*). Experimental inferences may then be tested beyond their spatiotemporal domains and, if successful, extrapolated across scales. Such research will be aided by satellite monitoring of ecosystems and human land use across the globe. The most powerful research programs will integrate experiments, observational studies, air- and space-borne imaging, and modeling.

CONCLUSIONS

Fragmentation experiments—some of the largest and longest-running experiments in ecology—provide clear evidence of strong and typically degrading impacts of habitat fragmentation on biodiversity and ecological processes. The findings of these experiments extend to a large fraction of the terrestrial surface of the Earth. Much of the Earth's remaining forest fragments are less than 10 ha in area, and half of the world's forest is within 500 m of the forest edge—areas and distances matched to existing long-term experiments (Figs. 1 and 2) from which consistent effects of fragmentation have emerged (Figs. 3 and 4).

Reduced fragment area, increased isolation, and increased edge initiate changes that percolate through ecosystems (Fig. 3). Fragmentation has the capacity to generate persistent, deleterious, and often unpredicted outcomes, including surprising surges in abundance of some species and the pattern that long temporal scales are required to discern many strong system responses. In light of these conclusions and ongoing debates, we suggest that fragmentation's consistency, pervasiveness, and long-term degrading effect on biodiversity and ecosystem function have not been fully appreciated (*9*).

Without gains in yield and efficiency of agricultural systems (*83*), the expansion of human populations will inevitably continue to reduce and fragment natural areas. The area of Earth's land surface devoted to cropland already occupies 1.53 billion hectares (*83*) and may expand 18% by the middle of this century (*84*), and the area committed to urban centers is predicted to triple to 0.18 billion hectares by 2030 (*85*). The capacity of the surviving forests and other natural habitats to sustain biodiversity and ecosystem services will hinge upon the total amount and quality of habitat left in fragments, their degree of connectivity, and how they are affected by other human-induced perturbations such as climate change and invasive species. Long-term experiments will be even more needed to appreciate, explain, and predict long-term effects. New efforts should work in concert, coordinating a network of experiments across ecosystems and spatial extents.

The effects of current fragmentation will continue to emerge for decades. Extinction debts are likely to come due, although the counteracting immigration debts may never fully be paid. Indeed, the experiments here reveal ongoing losses of biodiversity and ecosystem functioning two decades or longer after fragmentation occurred. Understanding the relationship between transient and long-term dynamics is a substantial challenge that ecologists must tackle, and fragmentation experiments will be central for relating observation to theory.

Experimental results to date show that the effects of fragmentation are strong and markedly consistent across a diverse array of terrestrial systems on five continents. Increasingly, these effects will march in concert with other global changes. New experiments should be coupled with emerging technologies, landscape genetics, and detailed imagery of our planet, and should be coordinated with current ecological theory to understand more deeply the coupled dynamics of ecological and social systems. These insights will be increasingly critical for those responsible for managing and prioritizing areas for preservation and ecological restoration in fragmented landscapes.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/1/2/e1500052/DC1

Materials and Methods

Fig. S1. Map of the BDFFP experiment and location within Brazil.

Fig. S2. Map of the Kansas fragmentation experiment.

Fig. S3. Map of the Wog Wog experiment and location within Australia.

Fig. S4. Map of the SRS experiment showing locations of the eight blocks in the second SRS Corridor Experiment within the SRS, South Carolina, USA.

Fig. S5. Design of the Moss experiment.

Fig. S6. Design of the Metatron experiment with 48 enclosed fragments and adjoining enclosed corridors.

Fig. S7. Map of the SAFE experiment and location within Borneo [after Ewers *et al.* (*68*)].

Table S1. Metadata for Fig. 3 in the main text.

Table S2. Metadata for Fig. 4 in the main text.

REFERENCES AND NOTES

1. H. M. Pereira, P. W. Leadley, V. Proenca, R. Alkemade, J. P. W. Scharlemann, J. F. Fernandez-Manjarres, M. B. Araujo, P. Balvanera, R. Biggs, W. W. L. Cheung, L. Chini, H. D. Cooper, E. L. Gilman, S. Guenette, G. C. Hurtt, H. P. Huntington, G. M. Mace, T. Oberdorff, C. Revenga, P. Rodrigues, R. J. Scholes, U. R. Sumaila, M. Walpole, Scenarios for global biodiversity in the 21st century. *Science* **330**, 1496–1501 (2010).
2. M. R. W. Rands, W. M. Adams, L. Bennun, S. H. M. Butchart, A. Clements, D. Coomes, A. Entwistle, I. Hodge, V. Kapos, J. P. W. Scharlemann, W. J. Sutherland, B. Vira, Biodiversity conservation: Challenges beyond 2010. *Science* **329**, 1298–1303 (2010).
3. D. B. Lindenmayer, J. Fischer, *Habitat Fragmentation and Landscape Change: An Ecological and Conservation Synthesis* (Island Press, Washington, DC, 2006).
4. R. K. Didham, V. Kapos, R. M. Ewers, Rethinking the conceptual foundations of habitat fragmentation research. *Oikos* **121**, 161–170 (2012).
5. L. Fahrig, Rethinking patch size and isolation effects: The habitat amount hypothesis. *J. Biogeogr.* **40**, 1649–1663 (2013).
6. R. H. MacArthur, E. O. Wilson, *The Theory of Island Biogeography* (Princeton University Press, Princeton, NJ, 1967).
7. L. Fahrig, Effects of habitat fragmentation on biodiversity. *Annu. Rev. Ecol. Evol. Syst.* **34**, 487–515 (2003).
8. S. K. Collinge, *The Ecology of Fragmented Landscapes* (The Johns Hopkins University Press, Baltimore, MD, 2009).
9. I. Ibanez, D. S. W. Katz, D. Peltier, S. M. Wolf, B. T. C. Barrie, Assessing the integrated effects of landscape fragmentation on plants and plant communities: The challenge of multiprocess–multiresponse dynamics. *J. Ecol.* **102**, 882–895 (2014).
10. M. C. Hansen, P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, J. R. G. Townshend, High-resolution global maps of 21st-century forest cover change. *Science* **342**, 850–853 (2013).

Downloaded from https://www.science.org on October 21, 2025

11. M. Williams, *Deforesting the Earth: From Prehistory to Global Crisis* (University of Chicago Press, Chicago, 2003).
12. D. Skole, C. Tucker, Tropical deforestation and habitat fragmentation in the Amazon: Satellite data from 1978 to 1988. *Science* **260**, 1905–1910 (1993).
13. J. O. Sexton, X. P. Song, M. Feng, P. Noojipady, A. Anand, C. Q. Huang, D. H. Kim, K. M. Collins, S. Channan, C. DiMiceli, J. R. Townshend, Global, 30-m resolution continuous fields of tree cover: Landsat-based rescaling of MODIS vegetation continuous fields with lidar-based estimates of error. *Int. J. Digital Earth* **6**, 427–448 (2013).
14. W. F. Laurance, T. E. Lovejoy, H. L. Vasconcelos, E. M. Bruna, R. K. Didham, P. C. Stouffer, C. Gascon, R. O. Bierregaard, S. G. Laurance, E. Sampaio, Ecosystem decay of Amazonian forest fragments: A 22-year investigation. *Conserv. Biol.* **16**, 605–618 (2002).
15. E. N. Broadbent, G. P. Asner, M. Keller, D. E. Knapp, P. J. C. Oliveira, J. N. Silva, Forest fragmentation and edge effects from deforestation and selective logging in the Brazilian Amazon. *Biol. Conserv.* **141**, 1745–1757 (2008).
16. M. C. Ribeiro, J. P. Metzger, A. C. Martensen, F. J. Ponzoni, M. M. Hirota, The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. *Biol. Conserv.* **142**, 1141–1153 (2009).
17. T. P. Hughes, D. R. Bellwood, C. Folke, R. S. Steneck, J. Wilson, New paradigms for supporting the resilience of marine ecosystems. *Trends Ecol. Evol.* **20**, 380–386 (2005).
18. T. Ricketts, E. Dinerstein, D. Olson, C. Loucks, W. Eichbaum, K. Kavanagh, P. Hedao, P. Hurley, K. Carney, R. Abell, S. Walters, *A Conservation Assessment of the Terrestrial Ecoregions of North America* (Island Press, Washington, DC, 1999).
19. R. P. White, S. Murray, M. Rohweder, *Grassland Ecosystems* (World Resources Institute, Washington, DC, 2000).
20. K. McGarigal, S. A. Cushman, Comparative evaluation of experimental approaches to the study of habitat fragmentation effects. *Ecol. Appl.* **12**, 335–345 (2002).
21. H. M. Martinson, W. F. Fagan, Trophic disruption: A meta-analysis of how habitat fragmentation affects resource consumption in terrestrial arthropod systems. *Ecol. Lett.* **17**, 1178–1189 (2014).
22. J. I. Watling, M. A. Donnelly, Fragments as islands: A synthesis of faunal responses to habitat patchiness. *Conserv. Biol.* **20**, 1016–1025 (2006).
23. K. M. Flinn, M. Vellend, P. L. Marks, Environmental causes and consequences of forest clearance and agricultural abandonment in central New York, USA. *J. Biogeogr.* **32**, 439–452 (2005).
24. D. A. Saunders, R. J. Hobbs, C. R. Margules, Biological consequences of ecosystem fragmentation: A review. *Conserv. Biol.* **5**, 18–32 (1991).
25. M. E. Soulé, *Viable Populations for Conservation* (Cambridge University Press, Cambridge, UK, 1987).
26. E. O. Wilson, E. O. Willis, in *Ecology and Evolution of Communities*, M. L. Cody, J. M. Diamond, Eds. (The Belknap Press, Cambridge, MA, 1975), pp. 522–534.
27. H. L. Vasconcelos, E. M. Bruna, Arthropod responses to the experimental isolation of Amazonian forest fragments. *Zoologia* **29**, 515–530 (2012).
28. N. M. Haddad, L. A. Brudvig, E. I. Damschen, D. M. Evans, B. L. Johnson, D. J. Levey, J. L. Orrock, J. Resasco, L. L. Sullivan, J. J. Tewksbury, S. A. Wagner, A. J. Weldon, Potential negative ecological effects of corridors. *Conserv. Biol.* **28**, 1178–1187 (2014).
29. C. D. Collins, R. D. Holt, B. L. Foster, Patch size effects on plant species decline in an experimentally fragmented landscape. *Ecology* **90**, 2577–2588 (2009).
30. D. Tilman, R. M. May, C. L. Lehman, M. A. Nowak, Habitat destruction and the extinction debt. *Nature* **371**, 65–66 (1994).
31. I. Hanski, A. Moilanen, M. Gyllenberg, Minimum viable metapopulation size. *Am. Nat.* **147**, 527–541 (1996).
32. W. F. Laurance, P. Delamonica, S. G. Laurance, H. L. Vasconcelos, T. E. Lovejoy, Conservation: Rainforest fragmentation kills big trees. *Nature* **404**, 836 (2000).
33. W. M. Cook, J. Yao, B. L. Foster, R. D. Holt, L. B. Patrick, Secondary succession in an experimentally fragmented landscape: Community patterns across space and time. *Ecology* **86**, 1267–1279 (2005).
34. A. Gonzalez, Community relaxation in fragmented landscapes: The relation between species richness, area and age. *Ecol. Lett.* **3**, 441–448 (2000).
35. G. Ferraz, G. J. Russell, P. C. Stouffer, R. O. Bierregaard, S. L. Pimm, T. E. Lovejoy, Rates of species loss from Amazonian forest fragments. *Proc. Natl. Acad. Sci. U.S.A.* **100**, 14069–14073 (2003).
36. J. L. Orrock, J. I. Watling, Local community size mediates ecological drift and competition in metacommunities. *Proc. Biol. Sci.* **277**, 2185–2191 (2010).
37. S. T. Jackson, D. F. Sax, Balancing biodiversity in a changing environment: Extinction debt, immigration credit and species turnover. *Trends Ecol. Evol.* **25**, 153–160 (2010).
38. J. Clobert, J. F. Le Galliard, J. Cote, S. Meylan, M. Massot, Informed dispersal, heterogeneity in animal dispersal syndromes and the dynamics of spatially structured populations. *Ecol. Lett.* **12**, 197–209 (2009).
39. P. Staddon, Z. Lindo, P. D. Crittenden, F. Gilbert, A. Gonzalez, Connectivity, non-random extinction and ecosystem function in experimental metacommunities. *Ecol. Lett.* **13**, 543–552 (2010).
40. S. A. Billings, E. A. Gaydess, Soil nitrogen and carbon dynamics in a fragmented landscape experiencing forest succession. *Landsc. Ecol.* **23**, 581–593 (2008).
41. C. D. Mendenhall, D. S. Karp, C. F. J. Meyer, E. A. Hadly, G. C. Daily, Predicting biodiversity change and averting collapse in agricultural landscapes. *Nature* **509**, 213–217 (2014).
42. A. Gonzalez, J. H. Lawton, F. S. Gilbert, T. M. Blackburn, I. Evans-Freke, Metapopulation dynamics, abundance, and distribution in a microecosystem. *Science* **281**, 2045–2047 (1998).
43. H. M. Alexander, B. L. Foster, F. Ballantyne, C. D. Collins, J. Antonovics, R. D. Holt, Metapopulations and metacommunities: Combining spatial and temporal perspectives in plant ecology. *J. Ecol.* **100**, 88–103 (2012).
44. C. R. Margules, The Wog Wog habitat fragmentation experiment. *Environ. Conserv.* **19**, 316–325 (1992).
45. E. I. Damschen, L. A. Brudvig, Landscape connectivity strengthens local–regional richness relationships in successional plant communities. *Ecology* **93**, 704–710 (2012).
46. W. M. Cook, K. T. Lane, B. L. Foster, R. D. Holt, Island theory, matrix effects and species richness patterns in habitat fragments. *Ecol. Lett.* **5**, 619–623 (2002).
47. K. F. Davies, B. A. Melbourne, C. R. Margules, Effects of within- and between-patch processes on community dynamics in a fragmentation experiment. *Ecology* **82**, 1830–1846 (2001).
48. K. F. Davies, C. R. Margules, K. F. Lawrence, Which traits of species predict population declines in experimental forest fragments? *Ecology* **81**, 1450–1461 (2000).
49. K. F. Davies, C. R. Margules, J. F. Lawrence, A synergistic effect puts rare, specialized species at greater risk of extinction. *Ecology* **85**, 265–271 (2004).
50. J. Yao, R. D. Holt, P. M. Rich, W. S. Marshall, Woody plant colonization in an experimentally fragmented landscape. *Ecography* **22**, 715–728 (1999).
51. E. I. Damschen, L. A. Brudvig, N. M. Haddad, D. J. Levey, J. L. Orrock, J. J. Tewksbury, The movement ecology and dynamics of plant communities in fragmented landscapes. *Proc. Natl. Acad. Sci. U.S.A.* **105**, 19078–19083 (2008).
52. L. L. Sullivan, B. L. Johnson, L. A. Brudvig, N. M. Haddad, Can dispersal mode predict corridor effects on plant parasites? *Ecology* **92**, 1559–1564 (2011).
53. Z. Lindo, J. Whiteley, A. Gonzalez, Traits explain community disassembly and trophic contraction following experimental environmental change. *Glob. Chang. Biol.* **18**, 2448–2457 (2012).
54. S. A. Boyle, A. T. Smith, Can landscape and species characteristics predict primate presence in forest fragments in the Brazilian Amazon? *Biol. Conserv.* **143**, 1134–1143 (2010).
55. J. E. Diffendorfer, M. S. Gaines, R. D. Holt, Habitat fragmentation and movements of three small mammals (Sigmodon, Microtus, and Peromyscus). *Ecology* **76**, 827–839 (1995).
56. K. S. Van Houtan, S. L. Pimm, J. M. Halley, R. O. Bierregaard Jr., T. E. Lovejoy, Dispersal of Amazonian birds in continuous and fragmented forest. *Ecol. Lett.* **10**, 219–229 (2007).
57. I. Hanski, Extinction debt at different spatial scales. *Anim. Conserv.* **16**, 12–13 (2013).
58. R. Dirzo, H. S. Young, M. Galetti, G. Ceballos, N. J. B. Isaac, B. Collen, Defaunation in the Anthropocene. *Science* **345**, 401–406 (2014).
59. C. Kueffer, C. N. Kaiser-Bunbury, Reconciling conflicting perspectives for biodiversity conservation in the Anthropocene. *Front. Ecol. Environ.* **12**, 131–137 (2014).
60. W. F. Laurance, D. C. Useche, Environmental synergisms and extinctions of tropical species. *Conserv. Biol.* **23**, 1427–1437 (2009).
61. M. Krosby, J. Tewksbury, N. M. Haddad, J. Hoekstra, Ecological connectivity for a changing climate. *Conserv. Biol.* **24**, 1686–1689 (2010).
62. R. K. Didham, J. M. Tylianakis, N. J. Gemmell, T. A. Rand, R. M. Ewers, Interactive effects of habitat modification and species invasion on native species decline. *Trends Ecol. Evol.* **22**, 489–496 (2007).
63. L. Gibson, A. J. Lynam, C. J. A. Bradshaw, F. L. He, D. P. Bickford, D. S. Woodruff, S. Bumrungsri, W. F. Laurance, Near-complete extinction of native small mammal fauna 25 years after forest fragmentation. *Science* **341**, 1508–1510 (2013).
64. C. A. Peres, Synergistic effects of subsistence hunting and habitat fragmentation on Amazonian forest vertebrates. *Conserv. Biol.* **15**, 1490–1505 (2001).
65. K. J. Gaston, T. W. Davies, J. Bennie, J. Hopkins, Review: Reducing the ecological consequences of night-time light pollution: Options and developments. *J. Appl. Ecol.* **49**, 1256–1266 (2012).
66. M. A. Cochrane, W. F. Laurance, Fire as a large-scale edge effect in Amazonian forests. *J. Trop. Ecol.* **18**, 311–325 (2002).
67. D. Legrand, O. Guillaume, M. Baguette, J. Cote, A. Trochet, O. Calvez, S. Zajitschek, F. Zajitschek, J. Lecomte, Q. Benard, J. F. Le Galliard, J. Clobert, The Metatron: An experimental system to study dispersal and metaecosystems for terrestrial organisms. *Nat. Methods* **9**, 828–833 (2012).
68. R. M. Ewers, R. K. Didham, L. Fahrig, G. Ferraz, A. Hector, R. D. Holt, V. Kapos, G. Reynolds, W. Sinun, J. L. Snaddon, E. C. Turner, A large-scale forest fragmentation experiment: The Stability of Altered Forest Ecosystems Project. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **366**, 3292–3302 (2011).
69. A. R. Templeton, K. Shaw, E. Routman, S. K. Davis, The genetic consequences of habitat fragmentation. *Ann. Mo. Bot. Gard.* **77**, 13–27 (1990).
70. A. Young, T. Boyle, T. Brown, The population genetic consequences of habitat fragmentation for plants. *Trends Ecol. Evol.* **11**, 413–418 (1996).

Downloaded from https://www.science.org on October 21, 2025

71. M. S. Gaines, J. E. Diffendorfer, R. H. Tamarin, T. S. Whittam, The effects of habitat fragmentation on the genetic structure of small mammal populations. *J. Hered.* **88**, 294–304 (1997).
72. J. L. Orrock, Conservation corridors affect the fixation of novel alleles. *Conserv. Genet.* **6**, 623–630 (2005).
73. T. Merck, H. Van Dyck, B. Karlsson, O. Leimar, The evolution of movements and behaviour at boundaries in different landscapes: A common arena experiment with butterflies. *Proc. Biol. Sci.* **270**, 1815–1821 (2003).
74. S. P. Ripperger, M. Tschapka, E. K. V. Kalko, B. Rodriguez-Herrera, F. Mayer, Life in a mosaic landscape: Anthropogenic habitat fragmentation affects genetic population structure in a frugivorous bat species. *Conserv. Genet.* **14**, 925–934 (2013).
75. S. Manel, R. Holderegger, Ten years of landscape genetics. *Trends Ecol. Evol.* **28**, 614–621 (2013).
76. M. Keller, D. S. Schimel, W. W. Hargrove, F. M. Hoffman, A continental strategy for the National Ecological Observatory Network. *Front. Ecol. Environ.* **6**, 282–284 (2008).
77. H. Tallis, H. Mooney, S. Andelman, P. Balvanera, W. Cramer, D. Karp, S. Polasky, B. Reyers, T. Ricketts, S. Running, K. Thonicke, B. Tietjen, A. Walz, A global system for monitoring ecosystem service change. *Bioscience* **62**, 977–986 (2012).
78. J. O. Sexton, R. D. Ramsey, D. L. Bartos, Habitone analysis of quaking aspen in the Utah Book Cliffs: Effects of site water demand and conifer cover. *Ecol. Model.* **198**, 301–311 (2006).
79. A. K. Fremier, F. A. J. DeClerck, N. A. Bosque-Perez, N. E. Carmona, R. Hill, T. Joyal, L. Keesecker, P. Z. Klos, A. Martinez-Salinas, R. Niemeyer, A. Sanfiorenzo, K. Welsh, J. D. Wulfhorst, Understanding spatiotemporal lags in ecosystem services to improve incentives. *Bioscience* **63**, 472–482 (2013).
80. T. H. Keitt, Habitat conversion, extinction thresholds, and pollination services in agroecosystems. *Ecol. Appl.* **19**, 1561–1573 (2009).
81. P. Opdam, E. Steingrover, S. van Rooij, Ecological networks: A spatial concept for multi-actor planning of sustainable landscapes. *Landsc. Urban Plan.* **75**, 322–332 (2006).
82. M. Cabeza, A. Moilanen, Design of reserve networks and the persistence of biodiversity. *Trends Ecol. Evol.* **16**, 242–248 (2001).
83. J. A. Foley, N. Ramankutty, K. A. Brauman, E. S. Cassidy, J. S. Gerber, M. Johnston, N. D. Mueller, C. O'Connell, D. K. Ray, P. C. West, C. Balzer, E. M. Bennett, S. R. Carpenter, J. Hill, C. Monfreda, S. Polasky, J. Rockstrom, J. Sheehan, S. Siebert, D. Tilman, D. P. M. Zaks, Solutions for a cultivated planet. *Nature* **478**, 337–342 (2011).
84. D. Tilman, Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. *Proc. Natl. Acad. Sci. U.S.A.* **96**, 5995–6000 (1999).
85. K. C. Seto, B. Guneralp, L. R. Hutyra, Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc. Natl. Acad. Sci. U.S.A.* **109**, 16083–16088 (2012).

Acknowledgments: For comments, we thank R. Dunn, P. Ehrlich, L. Frishkoff, F. Gould, A. Leidner, C. Mendenhall, A. Tal, J. Watling, and the Fukami and Peay labs at Stanford. For symbols in figures, we thank the Integration and Application Network, University of Maryland Center for Environmental Science. **Funding:** R.M.E. is supported by ERC (European Research Council) Project number 281986. A.G. is supported by the Natural Sciences and Engineering Research Council, the Canada Research Chair program, and the Quebec Centre for Biodiversity Science. C.N.J. was supported by the Brazilian agency CAPES through the Ciência Sem Fronteiras program. R.D.H. thanks the University of Florida Foundation. J.C. is supported by the labex TULIP and the ANR Infrastructure grant AnaEE-France. Global forest cover data and analysis were provided under support from the NASA Making Earth System Data Records for Use in Research Environments (MEaSUREs; NNH06ZDA001N) and Land Cover and Land Use Change (NNH07ZDA001N-LCLUC) programs. For long-term support of experiments, we thank the Andrew W. Mellon Foundation (BDFFP); the Kansas Biological Survey and National Science Foundation (NSF) (DEB 01-08302 and DEB-0950100; Kansas Experiment); NSF and U.S. Department of Agriculture Forest Service–Savannah River (SRS Corridor Experiment); NSF DEB 0841892 and Environment and Heritage NSW, Forestry Corporation NSW, and CSIRO Ecosystem Sciences (Wog Wog); and the Sime Darby Foundation (SAFE).

Submitted 15 January 2015
Accepted 17 February 2015
Published 20 March 2015
10.1126/sciadv.1500052

Citation: N. M. Haddad, L. A. Brudvig, J. Clobert, K. F. Davies, A. Gonzalez, R. D. Holt, T. E. Lovejoy, J. O. Sexton, M. P. Austin, C. D. Collins, W. M. Cook, E. I. Damschen, R. M. Ewers, B. L. Foster, C. N. Jenkins, A. J. King, W. F. Laurance, D. J. Levey, C. R. Margules, B. A. Melbourne, A. O. Nicholls, J. L. Orrock, D.-X. Song, J. R. Townshend, Habitat fragmentation and its lasting impact on Earth's ecosystems. *Sci. Adv.* **1**, e1500052 (2015).

Downloaded from https://www.science.org on October 21, 2025

Beginning with HABITAT

Maine Audubon

MaineDOT

CONSERVING WILDLIFE







On and Around Maine's Roads

Maine's wildlife habitat is some of the healthiest and most expansive in the Northeast. It's also threatened by an increasing number of roads.[1]

Over the last 50 years, residential development has spread further and further from cities and towns into rural areas, requiring more roads and contributing to what is commonly referred to as "sprawl." The great majority of new roads are private subdivision and local roads.

What these roads mean for Maine's wildlife is alarming: wildlife-vehicle collisions, commonly known as "road kill," are the number one human cause of wildlife mortality in the United States. They're also the cause of many human injuries and fatalities. And what many people don't realize is that the impacts of roads on wildlife and surrounding habitat occur far beyond the pavement's edge.

The good news is that road planning and building strategies and wildlife-crossing structures can help make Maine roads less dangerous to wildlife and people.

This brochure outlines how Maine's local planning boards, comprehensive planning committees, local public works departments, regional transportation planning groups, and state transportation agencies can use these strategies to improve and maintain Maine's wildlife habitats.

How do roads affect wildlife and habitat?

Roads not only cause wildlife-vehicle collisions, they also fragment and destroy habitat.

A HIGHLY EFFECTIVE network of roads keeps people mobile in the United States, taking us to work and school, to visit with friends and family, and to shop for goods that support our lives. We demand good roads for our safety and convenience, and we've been willing to pay the costs. But what about the hidden costs?

Imagine if someone built a road separating your bedroom and kitchen. For species such as the wide-ranging moose, their "kitchens" (the ponds where they eat aquatic plants in summer) and "bedrooms" (uplands where they rest with their young) are often separated by roads.

Building and using roads often fragments and destroys habitat, and causes some wildlife to avoid it. It also brings humans into the area, with results such as wildlife-vehicle collisions. Roads also bring invasive species and chemical contaminants into the areas surrounding them.

Quite simply, the impact on some wildlife is disastrous. Over time, species sensitive to habitat disruption decrease in number. Fragmented habitat limits natural dispersal of young animals, which leads to a loss of genetic diversity in some animal populations. Numbers of species and individuals decrease overall and, at the extreme, species become locally and regionally extinct.

Estimates show 15 to 20 percent of the land base of the United States suffers ecological impacts from roads, because the effects of roads extend significantly beyond the road and its immediate surrounding area.[2] (See Figure 1.)

Direct Habitat Loss

WILDLIFE HABITAT IS DIRECTLY lost when roadbeds and associated rights-of-ways are constructed. Across the country, approximately 20 million acres (an area about the size of Maine) has been lost from the construction of four million miles of public highways, streets, and rights-of-way.

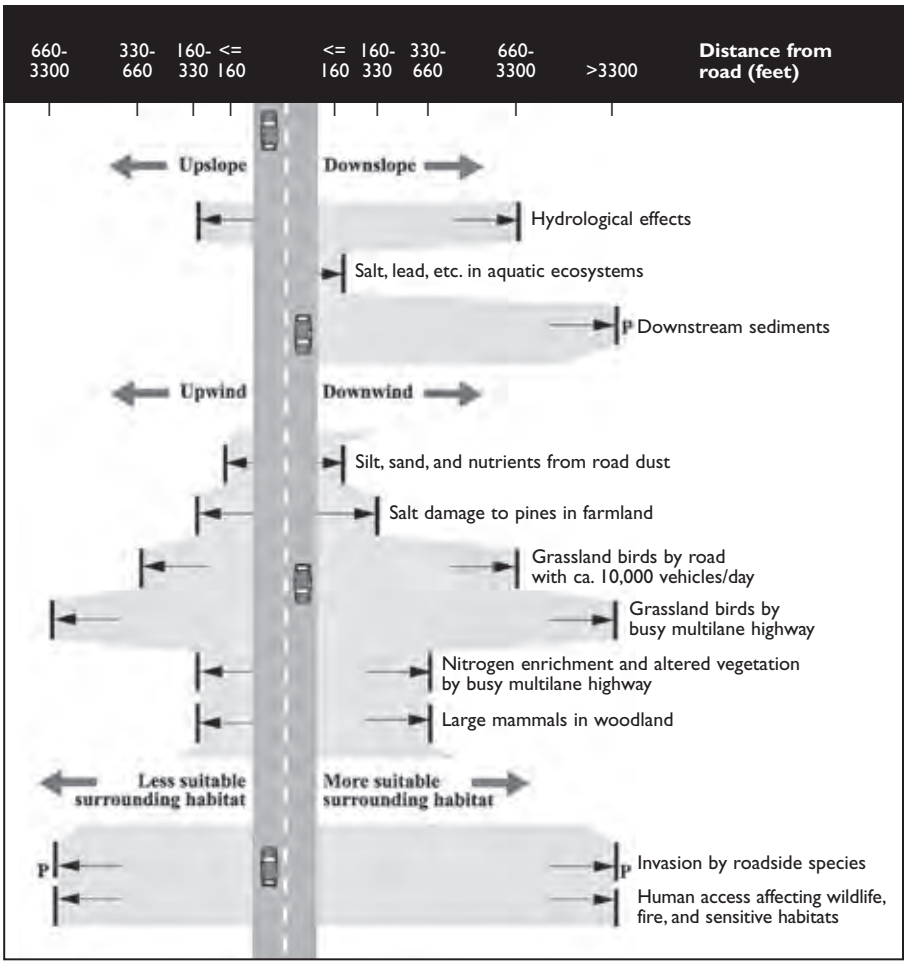


FIGURE 1. Sample distances of road-effect zones that affect wildlife habitat. Gravity (upslope/downslope), wind (upwind/downwind), and behavior or habitat suitability (less/more)—in addition to walls or hills near the road—produce greater effect-distances on one side of the road than on the other. Shaded areas = road-effect zone. Each effect typically extends outward along a stretch of road; (P) = an effect extending from a point on the road.

FROM *ROAD ECOLOGY* BY RICHARD T.T. FORMAN, ET AL. ©2003 ISLAND PRESS. REPRODUCED BY PERMISSION OF ISLAND PRESS, WASHINGTON, D.C.[3]



Bobcats need to move across a large landscape and are likely to disappear from habitat fragmented into smaller areas.

In Maine, the amount of habitat lost to public roads (22,750 miles) is approximately 115,000 acres, more than half the size of Baxter State Park. Roughly one-third of this acreage corresponds with the footprint of Maine's major roadways managed by the Maine Department of Transportation (MaineDOT) and the Maine Turnpike Authority (MTA); the remainder falls within the jurisdiction of Maine's nearly 500 municipalities and its Unorganized Territories. (These numbers don't include the approximately 44,000 miles of private and forestry roads in Maine.) A Maine study found that 210 pairs of breeding birds were displaced from every mile of the four-lane I-95 built in forested habitat. Most displaced birds will not breed successfully since adjacent habitat is usually occupied by other birds that vigorously defend their nesting territories against intruders. The intruders cannot find food or nesting sites. This represents a direct loss of habitat not only for the 210 pairs of breeding birds but also for the next generation of birds that would have lived there, leading to declines in total populations for the region.[4]

Habitat Fragmentation

WHEN A ROAD IS BUILT through large, formerly intact habitat blocks—whether forest, grassland, or wetland—it fragments them into smaller areas and isolates the animals within them. Some wildlife species can continue to thrive in relatively smaller habitat blocks. However, animal species that need to move across a large landscape, such as moose and bobcat, are likely to disappear from smaller habitat areas. Species such as wood thrush and northern parula warblers—which are especially sensitive to habitat changes, increased predation, or human disturbance—are likely to abandon fragmented habitat.

One study of traffic and wildlife showed that no small mammals moved across roads with average annual daily traffic volumes of over 11,000 vehicles per day—comparable to a busy two-lane highway in central Maine.[5]

Isolating animal populations into smaller groups by fragmenting their habitat reduces their genetic diversity and can lead to local extinction, and in some cases listing as an endangered species.

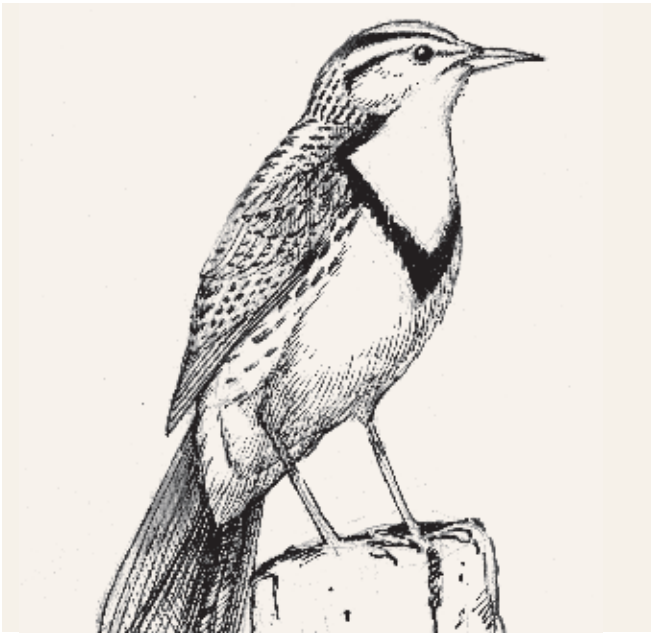
HOW DO ROADS AND TRAFFIC FRAGMENT HABITAT?

- ❑ Roads can create impassable barriers for terrestrial animals because of road width and altered habitat alongside roads.
- ❑ Roads constructed through wetlands and across streams can fragment habitat for aquatic animals.
- ❑ Culverts can restrict connections between habitat for fish and other aquatic animals.
- ❑ Noise, lights, and vehicle movements and emissions can restrict wildlife movement, particularly at high traffic volumes.

Habitat Avoidance

WILDLIFE EXPERTS BELIEVE traffic noise may be a major reason animals avoid habitat near roads. Other factors include visual disturbance, pollutants, and an increased numbers of predators.[6]

Traffic noise may interfere with breeding birds' ability to hear birdsong, which they rely on to attract mates and establish breeding territories. Because noise travels farther in open habitats, a decrease in population density adjacent to roads has been found to be greatest for grassland birds, less for birds in



Grassland birds, such as the meadowlark, may avoid habitat along noisy roads.



Collisions between vehicles and deer pose the greatest hazard for motorists, but do not put the deer population at risk.

deciduous woods, and least for birds in coniferous woods.[7,8,9] Researchers have found that negative impacts on the density and nesting success of grassland birds extend more than a quarter mile from a rural road and more than a half mile from a highly traveled, four-lane highway. [10,11]

Human Access and Land Use

WHEN NEW ROADS INCREASE access to Maine's undeveloped natural areas, they bring new opportunities for human activity such as development, agriculture, logging, mining, and the use of all-terrain vehicles. These activities can degrade, change, or even eliminate wildlife habitat.

New roads intended to alleviate congestion lead to increased residential and commercial development alongside the road, unless access is controlled. Private roads constructed to facilitate practices such as forestry, which may have relatively low impact on wildlife habitat, increase access to remote areas. As recreational use of these remote areas increases, and seasonal and permanent homes are built, road improvements are often expected—posing further threats to wildlife.

Chemical Contamination

CHEMICALS INTRODUCED ALONG roadways from vehicles, deicing salts, road surface wear, and herbicide and pesticide use can pollute wildlife habitat by providing a source of heavy metals, salt, organic pollutants, and excessive nutrients.[12] Such water and soil pollution poses a lethal risk to wildlife that depend on the resources.

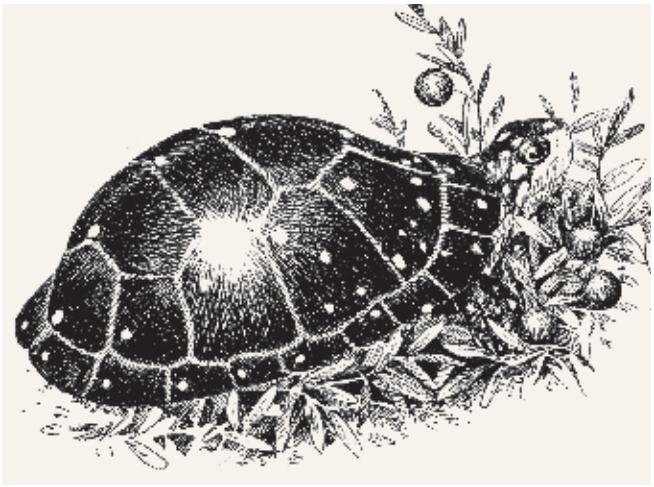
Contamination of soil, plants, and animals extends up to 66 feet from a road, and elevated levels of heavy metals often extend 650 feet or more from the road, occurring at greater concentrations along roads with high traffic volume.[13] Aquatic systems are particularly vulnerable to contamination, which streams may carry over long distances. Road salt, particularly sodium chloride, is toxic to many species of plants, fish, and other aquatic organisms. Increased salt in the water often helps invasive plants grow. In addition, concentrations of salt along roadsides may attract deer and moose, increasing the risk of vehicle collisions.

Wildlife-Vehicle Collisions

THE TYPES AND NUMBER OF animals killed by vehicles is related to road width, traffic volume, and vehicle speed. For example, amphibians and reptiles have the highest mortality rates on two-lane roads with low to moderate amounts of traffic, whereas large and midsize mammals are more susceptible to collisions on two-lane, high-speed roads. Birds and smaller mammals are more at risk from collisions on wider, high-speed highways.[14]

It's important to note that roads through and adjacent to wetlands, ponds, and other waterways have some of the highest road-kill rates.[15,16] With 85 percent of Maine's vertebrate species living in or using these habitats during some or all of the year, the need for animals to move safely from and around them is clear.

Although wildlife-vehicle collisions do not currently put the health of large-mammal populations such as deer and moose at risk, collisions between vehicles and large mammals pose the greatest hazard for motorists in Maine and should be minimized (see table on page 5).



For this spotted turtle, wildlife-vehicle collisions may lead to extinction.

However, for slower-moving species with lower reproduction rates and/or small populations, wildlife-vehicle collisions can be the major factor contributing to extinction. In Maine, this high-risk group includes the endangered Blanding's turtle and threatened spotted turtle, which regularly travel great distances between wetland feeding areas and upland nesting habitat. These turtles, which can live up to 75 years but do not breed until they are about 10 years old, have a very low rate of hatchling survival. Most of the turtles that cross roads are females traveling to and from nest sites.

Maine wildlife population models suggest that unless road kill can be substantially reduced, turtle extinctions in Maine are inevitable. Research that MaineDOT supports in southern Maine around Mount Agamenticus will help scientists and planners better understand the needs of these animals and develop some potential solutions.

Invasive Species

INVASIVE PLANTS AND ANIMALS that are not native to a region can seriously harm wildlife habitats. Invasive species spread rapidly and displace native species by outcompeting them for breeding sites, prey, and other resources. They can disrupt food webs, degrade habitats, and alter wildlife diversity.

Roadside erosion-control plantings, drainage ditches, maintenance and construction fill, automobiles and boats traveling from areas infested by invasive species, and animals traveling along roadways all provide a means for invasive species to disperse. Roadside erosion into wetlands and streams allows invasive species to gain a foothold as native vegetation is scoured or smothered by eroding soils. MaineDOT plants only native species on construction sites to reduce the spread of invasive species in Maine.

Maine Wildlife Species Most Vulnerable to Road Impacts

Species	Type of Road Impact	Reasons for Concern
Moose*	Vehicle collision	*From 2000-2004:* 14 human fatalities 3,391 accidents $83 million economic loss
Deer*	Vehicle collision	*From 2000-2004:* 2 human fatalities 18,289 accidents $62 million economic loss
Wide-ranging mammals: **Moose, Bear, Bobcat, Fisher, Canada lynx**	Road mortality Habitat loss Habitat fragmentation	Species loss on a local level
Riparian mammals: **Mink, Otter**	Habitat fragmentation Blocked riparian passage	Species loss on a local level
Low-reproducing/fairly wide-ranging mammal:** **Porcupine**	Road mortality	Species loss on a local level
Area-sensitive and declining birds:*** **Least flycatcher, Brown creeper, Wood thrush, Veery, Black-and-white warbler, Northern parula warbler, Chestnut-sided warbler, Canada warbler, American redstart, Rose-breasted grosbeak, Rufous-sided towhee, Upland sandpiper, Bobolink, Eastern meadowlark, Grasshopper sparrow, Vesper sparrow**	Habitat fragmentation Habitat avoidance/disturbance	Decline in populations Species loss on a local level
Fish: **Brook trout, American eel, Swamp darter**	Habitat loss/fragmentation Blocked riparian passage Chemical contamination/ sedimentation	Population reduction Species loss on a local level
Slow-moving/slow-reproducing/wide-ranging turtles: **Blanding's turtle, Spotted turtle, Wood turtle, Snapping turtle**	Road mortality Habitat loss	State extinction Species loss on a local level
Amphibians: **Spotted salamanders, Blue-spotted salamanders, Four-toed salamanders, Wood frogs, Leopard frogs**	Road mortality Habitat loss Chemical contamination	Population reduction Species loss on a local level Disease/deformation

* MaineDOT, *Collisions Between Wildlife Species and Motor Vehicles in Maine 2000-04*

** Dan Harrison, personal communication

*** Maine Audubon, *Conserving Wildlife in Maine's Developing Landscape*

Planning and Building for Wildlife Conservation

With careful land-use planning, we can do a great deal to reduce the impacts of roads on Maine's wildlife.

MOVING PEOPLE ACROSS Maine does not have to occur at great cost to wildlife. Through engineering and land-use planning, we can do a great deal at the state, regional, and local levels to enhance public safety and protect wildlife habitat while planning, designing, constructing, and maintaining our transportation networks. The financial cost of these projects and solutions varies widely—from thousands, to hundreds of thousands, to millions of dollars. However, solutions such as wildlife crossings can save human life and property, are used over many decades, and are a relatively small percentage of the cost of highway projects. With advanced planning, some projects may be readily incorporated into new roads, or upgrades and maintenance of existing roads. Others may be beyond the scope of current funding and would require special funding.

Citizen Involvement Can Make a Difference

CITIZENS CAN ENCOURAGE road planning, design, construction, and maintenance that protect wildlife populations, and enhance safety and our quality of life by sharing road and wildlife information with their local planning boards and public works departments. *Beginning with Habitat* maps (see "Need More Information?" on page 8) and this publication about roads and wildlife are a good start.

Participating in planning at the local and regional level ensures that the habitat and transportation sections of a town's comprehensive plan are linked, and reflect habitat and road issues. Each town's comprehensive plan determines its future land-use decisions, including where new roads will be needed to support new growth. To become involved at the local level, attend municipal planning board public hearings on subdivision proposals involving road construction or modification, and request changes to the plan that will benefit wildlife. To become involved on the regional and state level, refer to the guide *Working Together to Build a Better Maine: Participate in the Maine Department of Transportation Planning Process,* available from MaineDOT and at www.maine.gov/mdot/public-involvement/publicinvolvement.php.



Culverts installed to allow brook trout to pass can also be designed to allow small mammals, reptiles, and amphibians to pass under roads.

Road Planning and Construction Strategies

SPECIFIC STEPS CAN BE TAKEN to reduce impacts of roads on wildlife. Many have been used successfully elsewhere and others are being studied around the world. These recommendations were adapted in part from *Road Ecology*, a recent book authored by experts in this science.[17]

PLANNING

1. Use *Beginning with Habitat* maps to identify riparian habitats, high-value plant and animal habitats, and large blocks of undeveloped habitat in a project area. Steer development and road construction away from these important habitats to the greatest extent possible.
2. Where not possible to avoid important habitats, design and construct roads to minimize impacts to sensitive or fragile resources.
3. Develop and adopt town land-use plans and ordinances that promote village and neighborhood centers that reduce the

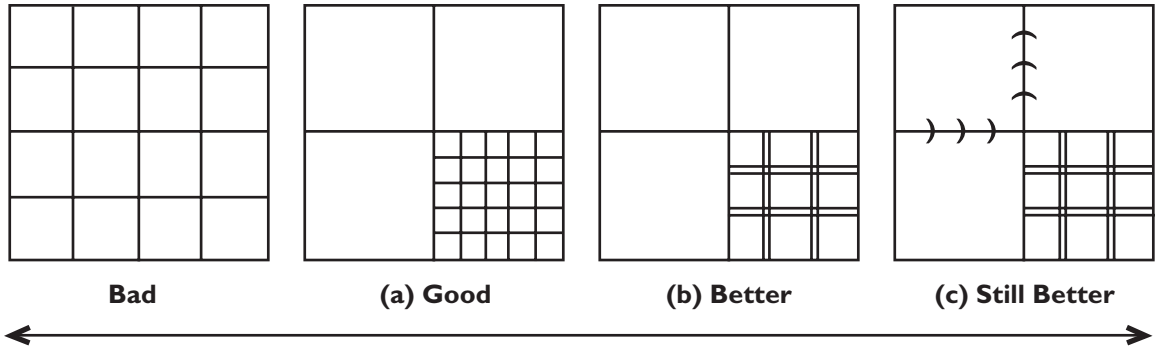


FIGURE 2: A hypothetical road network showing three principles for the ecologically best possible network. The principles: (a) Maintain a few large, roadless natural areas. (b) Concentrate the bulk of traffic onto a small number of large roads. (c) Connect habitat across roads that separate the large natural areas. ⌒ = wildlife crossing
FROM FORMAN, R.T. T. 2006.[18] WITH PERMISSION.

need to drive for daily goods and services; discourage building new roads in rural areas; and prohibit approval of long, dead-end roads. As much as possible, accommodate increasing traffic by upgrading existing major roads instead of developing multiple new minor roads. (See Figure 2.)

4. Minimize the number of breaks for new roads and driveways off main roads in areas of unfragmented and high-value habitat to reduce leapfrog development.
5. Develop a regional map showing where wildlife can travel between large habitat areas separated by roads. Preserve these important wildlife travel routes through local land-use management or wildlife crossing structures. The *Beginning with Habitat* program is developing such information.
6. Identify locations on roadways, culverts, and bridges that can be restored or retrofitted with wildlife crossing structures to improve wildlife movement.
7. Compensate for unavoidable habitat loss and fragmentation by identifying opportunities to purchase and conserve high-value habitat in the region.
8. Site and design roads to reduce runoff of chemicals that can contaminate water and soil. In consultation with MaineDOT, reduce salt use and designate "salt free" zones where appropriate.

CONSTRUCTION

1. Install wildlife underpasses and overpasses (see insert "Wildlife Crossing Structures") along existing roads to reduce habitat fragmentation and travel barriers, particularly in conservation lands, high-value habitat, and areas where wildlife travel.
2. Span streams or design culverts to mimic natural stream conditions so fish and other wildlife can pass under roads.
3. Use soil berms and vegetation as well as road surface improvements to mute noise and reduce other ecological disturbances that traffic creates for wildlife.
4. Use only native species for roadside plantings, erosion control, and slope stabilization. Plant maintenance-free native wildflowers and other plants along roadsides to prevent nonnative plant species from invading.

Wildlife-Friendly Road Planning and Projects Under Way in Maine

DURING ITS PLANNING PROCESS, MaineDOT routinely uses *Beginning with Habitat* and other habitat data to screen projects, as well as field visits to verify natural resources present at project locations. For large projects, such as the highway bypasses around Gorham and Presque Isle, MaineDOT studies not just the roadway but the entire transportation corridor, adjusting the final road alignment where possible to minimize impacts.

Where impacts to important habitats cannot be avoided, MaineDOT mitigates the negative effects of road building by conserving or restoring sites that have similar ecological functions and values. MaineDOT hopes to soon be a primary user of Maine's new "in lieu fee" program that proactively identifies regional sites of statewide value to best meet the goal of habitat mitigation. This program, administrated by Maine's Department of Environmental Protection, will be the first of its kind in New England.

Ten years ago culverts were designed only to pass a stream under a road; today they are also designed to allow passage of fish and wildlife. As of 2006, MaineDOT is building Maine's first large (13-foot-wide by 7-foot-high) concrete box culvert with a shelf inside to let small mammals, reptiles, and amphibians pass. This culvert, also designed to allow brook trout to pass, is on Bog Brook on Route 117 in Buckfield. In Phillips, in an effort to keep moose from bolting onto the road, MaineDOT began in 2006 to experiment with a five-foot-wide blanket of rocks along the shoulder in areas with many moose-vehicle collisions.

Maine Audubon works with MaineDOT and *Beginning with Habitat* to develop outreach materials and promote planning and projects that benefit wildlife and meet Maine citizen's transportation needs.

Literature Cited

1 O'Hara, F. 1997. The Cost of Sprawl. Maine State Planning Office.

2 Forman, R. T.T. & L. E. Alexander. 1998. Roads and Their Major Ecological Effects, Annu. Rev. Ecol. Syst. 29:207-31.

3 Forman, R. T.T. et al., 2003. Road Ecology: Science and Solutions, Island Press, 481 pages.

4 Ferris, C.R. 1979. Effects of Interstate 95 on breeding birds in northern Maine. J. Wildl. Manage. 43:421-27.

5 McGregor, R.,Derrane, S., Bender, D., & Fahrig, L. 2003. The Effect of Traffic Volume on Translocated Small Mammal Movement. In 2003 Proceedings of the International Conf. on Ecology & Trans., ed. by C. L. Irwin, P. Garrett, & K.P. McDermott. Raleigh, NC: Center for Trans. and the Envir., NC State U,

6 Forman & Alexander

7 Forman & Alexander

8 Reijnen, R., R. Foppen, C.T. Braak, & J. Thissen. 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. J. Applied Ecology, 32:187-202.

9 Reijnen, R., R. Foppen, & H. Meeuwsen. 1996. The effects of traffic on the density of breeding birds in dutch agricultural grasslands. Biological Conservation 75: 255-260.

10 Bennett, A.F. 1991. Roads, roadsides and wildlife conservation: a review, In Nature Conservation 2: The Role of Corridors, eds. D. A. Saunders & R. J. Hobbs, Surrey Beatty & Sons, p. 99-117.

11 Van der Zande, W.J. ter Keurs & W.J. Van der Weijden. 1980. The impact of roads on the densities of four bird species in an open field habitat- evidence of a long-distance effect. Biol. Conservation. 18: 299-321.

12 Forman & Alexander

13 Ashley, E. P. & J. T. Robinson. 1996. Road Mortality of Amphibians, Reptiles and Other Wildlife on the Long Point Causeway, Lake Erie, Ontario. The Canadian Field-Naturalist. 110:403-412.

15 Forman & Alexander

16 Forman, R. T.T. et al., 2003. Road Ecology: Science and Solutions, Island Press, 481 pages.

16 Trombulak, S. C. & C. A. Frissell. 2000. Review of Ecological Effects of Roads on Terrestrial and Aquatic Communities, Conservation Biol., 14(1):2000, 18-30.

17 Forman, R. T.T. et al.

18 Forman, R.T.T. 2006. Good and Bad Places for Roads: Effects of Varying Road and Natural Pattern on Habitat Loss, Degradation, and Fragmentation. In Proceedings of the 2005 International Conf. on Ecology & Transportation, ed. By C.L. Irwin, P. Garrett, & K.P. McDermott. Raleigh, NC: Center for Transportation & the Environment, NC State U.

19 Donaldson, B.M. 2006. Use of Highway Underpasses by Large Mammals and Other Wildlife in Virginia and Factors Influencing Their Effectiveness. In Proceedings of the 2005 International Conf. on Ecology & Transportation, ed. By C.L. Irwin, P. Garrett, & K.P. McDermott. Raleigh, NC: Center for Transportation & the Environment, NC State U.

20 Forman, R. T.T. et al.

Need More Information?

Beginning with Habitat: (207) 287-8042, www.beginningwithhabitat.org

Maine Audubon: (207) 781-2330, www.maineaudubon.org

Maine Department of Transportation: (800) 380-7822, www.mainedot.gov

Defenders of Wildlife Habitat and Highways Campaign: www.defenders.org/habitat/highways

Federal Highways: www.fhwa.dot.gov/environment/hconnect

Eco-Logical: www.environment.fhwa.dot.gov/ecological/eco_index.asp

International Conference on Ecology and Transportation: www.icoet.net

River and Steam Continuity Project: www.streamcontinuity.org

Wildlife Crossing Toolkit USDA Forest Service: www.wildlifecrossings.info

Wildlife and Roads: www.wildlifeandroads.org

CREDITS AND ACKNOWLEDGEMENTS

Researched and written by Barbara Charry, Maine Audubon wildlife biologist. All wildlife illustrations by Mark McCollough.

Maine Audubon thanks the Maine Department of Transportation for their support and partnership on this project, as well as the following reviewers: Richard Bostwick, Kathy Fuller, Judy Gates, MaineDOT; John Nordgren, Kendall Foundation; Sally Stockwell, Maine Audubon; Barbara Vickery, The Nature Conservancy; Steve Walker, Beginning with Habitat; Patricia White, Defenders of Wildlife; Elizabeth Hertz, Maine State Planning Office; Sandra Jacobson, USDA Forest Service; and John Lepore, Vermont Agency of Transportation

Maine Audubon, a founding member of the award-winning *Beginning with Habitat* program, thanks its fellow members, Maine Coast Heritage Trust, Maine Department of Inland Fisheries and Wildlife, Maine Natural Areas Program, Maine State Planning Office, The Nature Conservancy, and U.S. Fish and Wildlife Service.

Published 2007. Funded in part by the Maine Department of Transportation.

MAINE AUDUBON

20 Gilsland Farm Rd. ▪ Falmouth, Maine 04105 ▪ (207) 781-2330 ▪ www.maineaudubon.org

Maine Audubon works to conserve Maine's wildlife and wildlife habitat by engaging people of all ages in education, conservation, and action.

Wildlife Crossing Structures

Planning to avoid the need for wildlife crossing structures is the first step. But, in the right locations, wildlife crossing structures can effectively allow animals to move across roads.

BY MAKING IT POSSIBLE for animals to move across roads, wildlife-crossing structures help them maintain access to the different habitats they need and avoid wildlife-vehicle collisions. However, crossings can be expensive and only address some of the problems created by new roads. The first rule is to locate roads in the appropriate places. Wildlife crossing structures should not be used to justify inappropriately located new roads. But retrofitting existing roads, often with minor changes, presents a huge opportunity to reconnect and maintain habitats. Wildlife crossings are an emerging science and new information is rapidly becoming available. Some things to keep in mind are:

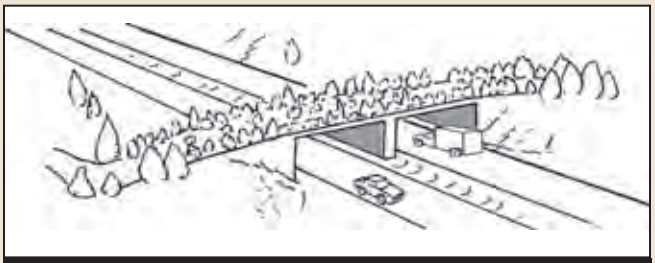
- ❑ Construction projects for wildlife are site specific, and their potential effectiveness needs to be assessed on a case-by-case basis, including up-front and long term maintenance costs.
- ❑ No one-size-fits-all solution exists for wildlife crossing structures; species prefer and adjust differently to various types of structures.
- ❑ Structures, such as fencing and culverts, need regular maintenance to be effective over time.
- ❑ Though some large wildlife crossing structures can be quite expensive, the most effective mitigation measure need not be the most expensive nor the most difficult to achieve.
- ❑ It's more economical to plan wildlife-friendly roadway expansion or major upgrade projects ahead of time than to retrofit an existing roadway.
- ❑ Ongoing resurfacing, bridge and culvert maintenance, and reconstruction often provide excellent cost-effective opportunities to mitigate for wildlife passage.

Crossing structures include directed fencing (barriers), signage, noise barriers, underpasses (small and large), and overpasses. The following illustrations from the United States Department of Agriculture Forest Service's Wildlife Crossings Toolkit show some of the common types and sizes of wildlife passage structures. For more information about wildlife crossing structures, visit www.wildlifecrossings.info.

FENCING

Fencing keeps animals—from deer and moose to frogs and turtles—off roadways while guiding them to designated crossing structures (see "Wildlife Underpasses"). Fencing, when combined with crossing structures such as overpasses or underpasses and escape ramps, is very effective in keeping wildlife off roadways and providing habitat connections. For deer, fences are typically 7 to 10 feet high with fine mesh on the bottom 1 ½ to 3 ½ feet to prevent small animals from getting through. The fence may be buried 8-16 inches to prevent animals from digging under, or folded into an "L" shape that extends away from the base of the fence. Gaps or holes in the fence over 13 inches are enough for deer to get through.

Extensive fencing to keep deer and moose off controlled-access highways can be costly and must be used with escape ramps to allow animals to get out of the right-of-way areas alongside roads. Fencing does not work to keep large animals off urban or rural roads with numerous driveways.



Wildlife Overpass or Green Bridge

WILDLIFE OVERPASSES

A wide range of animals, from insects to large mammals including deer, use wildlife overpasses, or "green bridges," that range in width from 66 to 1,000 feet (most are 98-164 feet). They are designed to resemble natural habitat, with native vegetation and in some cases even small ponds. These are most successful when combined with fencing to keep animals off the road and landscaping around the entrance to provide cover for approaching wildlife. Cost for these structures may be well over $1 million. Two wildlife overpasses are being used successfully over the Trans-Canada Highway in Banff National Park. Wildlife passageways and fencing have reduced wildlife and vehicle collisions by more than 80 percent. Moose, deer, bears, snowshoe hare, marten, and other wildlife use these overpasses. For more details go to the Trans-Canada Highway Twinning Banff National Park of Canada web site, www.pc.go.ca/pn-np/ab/banff/docs/routes.

WILDLIFE UNDERPASSES

Many designs of small passages allow amphibians, reptiles, and small mammals to cross underneath roads. Dry tunnels two feet wide that are designed primarily for small and medium-size

mammals work well and are inexpensive. Culverts designed for amphibians range from 1 to 3 1/3 feet wide to up to 66 feet long. Concrete tunnels with earthen floors are most effective. Trenches, fencing, or curbs can direct animals to the underpass.

Waterway culverts with raised, dry ledges can help animals move along the waterway. These structures may be up to four feet wide and have ledges 1 1/2 feet wide. When replacing a culvert, use an arch shape or consider a span instead of a culvert to include some of the stream bank. Stream simulation is a new approach to culvert design to allow passage of fish and other aquatic animals and which can also be adapted to accommodate terrestrial wildlife. This method avoids constricting the stream channel and maintains the continuity of the stream bottom and hydrolic conditions by construction of a streambed within the culvert.

Large passages range from 6 1/2 to 16 feet wide for most large culverts to more than 330 feet for extended bridges or viaducts. Culvert passages may be made of metal or concrete, be bottomless (having a natural bottom) or continuous, and may be box, circular, arch, or elliptical in shape. Rocks, stumps, and plants may need to be added near the entrance to provide cover for animals moving through the underpass. Many species will use these large passages, including bear, bobcat, and moose. Deer tend to prefer passages that are at least 20 feet wide and 8 feet high with vegetation for cover nearby. The amount of light visible due to the width, height, and length of the tunnel (referred to as "openness ratio") determines whether animals are willing to use the underpass.

When wildlife crossing modifications are added to bridge contruction projects over water, costs can be a small percentage of the overall project budget, starting from $200,000. However, costs can range to over $1 million for wildlife underpass bridges over land. The cost of strategically placed underpasses can be more than matched by the savings from reducing vehicle collisions and loss of human life.[19]

DRIVER WARNINGS

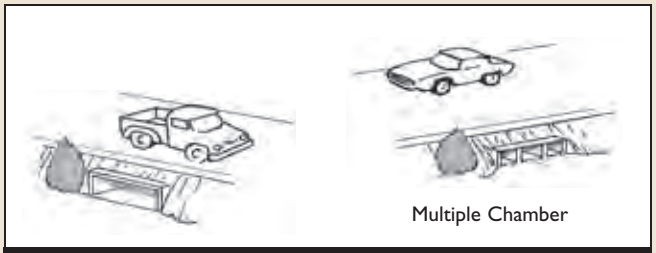
Traditional warning signs, like "Moose Crossing Next 3 Miles," have had limited success preventing collisions with deer and moose. This is unfortunate since slower speeds in areas with high rates of collisions would result in significantly fewer collisions.[20] However, dynamic message signs (electronic signs with changing messages) with wildlife advisory messages are showing promise in reducing motorist speed, particularly at night. Turtle crossing signs are being tested in areas around Maine's Mount Agamenticus with high concentrations of endangered Blanding's and threatened spotted turtles.

NOISE BARRIERS

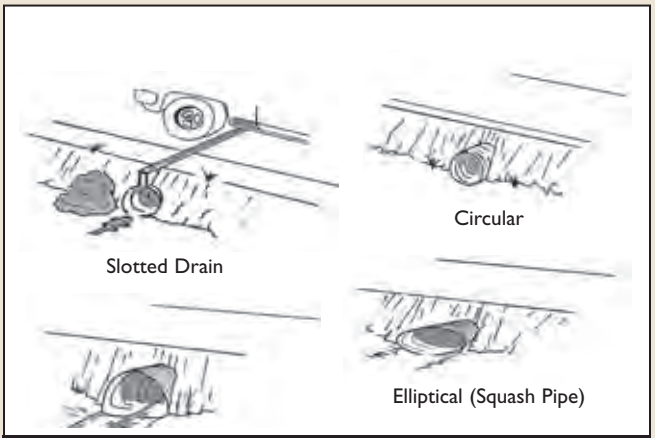
Vegetated earthen berms along roads bordering fields, wetlands, on overpasses, and above underpasses reduce highway noises disturbing to wildlife. They should be used judiciously to make sure they do not cause or exacerbate habitat fragmentation. Trees are natural noise barriers and should be left where they occur next to roads.



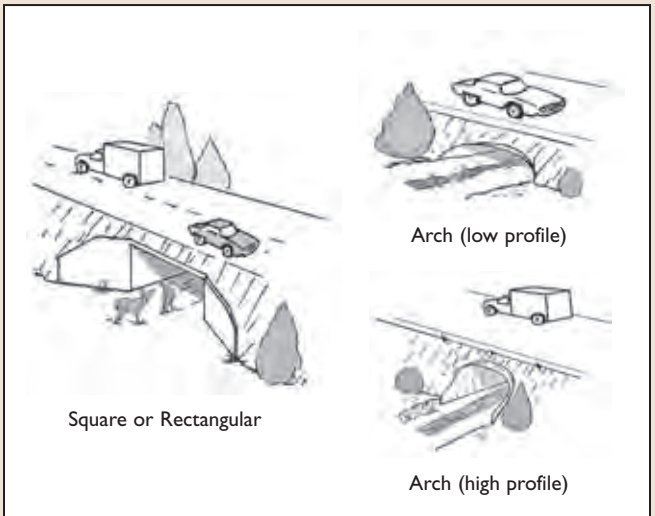
Wildlife Underpass Bridge



Box Culverts



Culverts



Bottomless Culverts

scientific reports

Check for updates

OPEN

The impacts of power transmission and transformation projects on ecological corridors and landscape connectivity: a case study of Shandong province, China

Jianguang Yin[1], Qingquan Wei[1], Dongliang Shao[1], Zhiwei Luo[2]✉ & Ling Ji[2]✉

With the rapid urbanization and electrification in recent years, investment and construction in power infrastructure have been strengthened. Although it has a positive impact on economic development and energy distribution, the ecological and landscape impacts brought by the construction of related auxiliary facilities are often overlooked. To achieve a harmonious relationship between energy development and ecological protection, this study aims at the impacts of power transmission and transformation projects on ecological corridors and landscape connectivity. By coupling the morphological spatial pattern analysis and the least-cost path model, the regional ecological corridors are first constructed. In addition, the influences of power transmission and transformation projects on landscape connectivity can be evaluated and compared. This framework is verified through a case study of Shandong Province in China. The results indicated that power transmission and transformation projects had a significant impact on the migration resistance of landscapes, impeding the formation of ecological corridors for species. Additionally, these projects have exerted a pronounced cutting effect on landscapes, reducing ecological corridor permeability and landscape connectivity. It is crucial to preserve the habitats of major ecological sources while maintaining and developing the ecological nodes along the key ecological corridors. The findings contributed to the harmonization of regional energy planning and ecological protection, providing a reference for the future layout of transmission and transformation project construction and development.

Keywords Power transmission and transformation projects, Morphological spatial pattern analysis, Least-cost path method, Ecological corridor

Power transmission and transformation projects (PTTPs) are a key infrastructure for realizing the efficient transmission of energy from the production place to the consumption place. Following over seven decades of advancement, they have become an indispensable component of China's economic growth and social advancement[1]. As a consequence of economic expansion and urbanization, there has been a considerable increase in demand for electricity from industrial developments and household consumption[2]. This has led to extensive construction of high-voltage and ultra-high-voltage transmission networks and a robust push for inter-regional power transfer initiatives[3]. However, the rapid expansion has not consistently integrated ecological preservation and sustainable development[4]. For example, high-voltage transmission lines and substations typically generate strong electromagnetic fields, and prolonged exposure to electromagnetic radiation can disrupt plant growth, animal migration, and biological reproduction[5]. The construction of PTTPs involves substantial land use, which may lead to soil structure disruption, loss of vegetation, subsequent soil erosion, and desertification. The construction of transmission lines and pylons may destroy the habitats of wildlife, hinder the migration of birds, and reduce biodiversity. The long-term impacts on ecosystems often disrupt regional landscape patterns and create fragmented ecological corridors, potentially posing a serious threat to future energy transition and carbon neutrality goals.

[1]State Grid Shandong Electric Power Research Institute, Jinan 250003, China. [2]School of Economics and Management, Beijing University of Technology, Beijing 100124, China. ✉email: luozwei@126.com; hdjiling@bjut.edu.cn

These ecological disruptions are primarily driven by PTTPs' direct and indirect impacts on landscape connectivity, which are mainly reflected in four interrelated parts: (1) Habitat fragmentation: The construction of PTTPs often results in significant land use changes, fragmenting natural habitats and disrupting the continuity of ecological corridors[6]. This fragmentation impedes the movement of species and the flow of genetic material across landscapes[7]. (2) Ecological barrier effects: High-voltage transmission lines and associated infrastructure act as physical barriers, deterring the migration of terrestrial and avian species[8]. This can lead to reduced habitat connectivity and isolation of populations, further threatening biodiversity[9]. (3) Electromagnetic interference: The electromagnetic fields generated by PTTPs have been shown to disrupt the behavior and reproductive success of certain species[10,11], potentially altering the ecological dynamics critical for corridor functionality. (4) Ecosystem function degradation: The construction and maintenance of PTTPs often result in vegetation removal, soil erosion, and microclimate alterations, which can degrade the supporting ecosystem services necessary for maintaining ecological corridors[12,13]. Field observations substantiate that the migration pathways and habitat connectivity essential for certain species have been significantly disrupted, highlighting the need for strategic planning and mitigation measures in the development of such infrastructure[14,15]. Wildlife individuals may respond to the ecological barriers by altering their behavior, for example, by avoiding crossing landscape sections with power lines[16], reducing predation behaviors in these areas[17], or nesting away from transmission towers[18]. Additionally, the distribution and density of ungulates are influenced by the presence of power lines and associated right-of-way corridors, particularly when they intersect with transportation infrastructure[19]. The biodiversity reduction is not solely attributable to animal migration; it is also constrained by the electromagnetic effects of PTTPs. Studies demonstrate that prolonged exposure to electromagnetic radiation results in a reduction in reproductive success and individual survival rates among animals[20], as well as an elevated probability of enzyme activity mutations in plants[21]. The degradation of ecosystem functions is generally caused by the creation of pathways during construction and the removal of vegetation during maintenance, which may lead to changes in resource availability, microclimate gradients, and biological behaviors within the affected area. Although previous studies have investigated the ecological impacts of PTTPs from various perspectives, including habitat fragmentation, biodiversity loss, and ecosystem function degradation, research addressing the impact of PTTPs on the construction and integrity of ecological corridors remains insufficient. Current studies often focus on the immediate and localized effects of PTTPs on individual species or ecosystems, overlooking the broader implications for regional ecological connectivity. Furthermore, the lack of quantitative assessment of long-term and cumulative impacts of PTTPs on ecological corridors has limited the ability to develop effective mitigation strategies. As regional ecological security becomes increasingly important for sustainable development, understanding and addressing these impacts at a macro-ecological scale is essential for achieving a balance between infrastructure development and ecological conservation.

Currently, the research of ecological disturbance under PTTPs is mainly aimed at ecological modeling, habitat assessment, landscape pattern analysis, and environmental impact assessment. For example, Tarko et al.[22] examined strategies to reduce electric field influence zones and conductor spatial distribution in power lines, employing verified models for electric field and noise assessment. Jin et al.[23] provided the first evaluation of water use and thermal pollution impacts on freshwater biodiversity from electricity production, examining the temporal and spatial dynamics drivers within China's power sector. Li et al.[24] used an impact pathway approach to evaluate the environmental and health benefits of long-distance power transmission, assessed the indirect effects of air pollution, and explored the benefits of existing ultra-high voltage lines. The ecological disturbance analysis in the context of PTTPs was constrained by temporal scale and systematic complexities, with a significant reliance on qualitative assessment. However, despite these advances, research addressing the impact of PTTPs on the construction and integrity of ecological corridors remains insufficient. Current studies often focus on immediate and localized effects, overlooking the broader implications for regional ecological connectivity. Furthermore, the lack of quantitative assessment of long-term and cumulative impacts of PTTPs on ecological corridors has limited the ability to develop effective mitigation strategies.

This not only hampers the ability to comprehensively address the impacts of long-term and cumulative ecological disturbances but also placed new demands on regional ecological planning. The impact of PTTPs involves backtracking of materials above the landscape scale, which is crucial for the construction of ecological corridors, ecosystem functions' maintenance, and regional ecological security[25]. Although ecological degradation has been recognized as an inevitable side effect in the construction of PTTPs, the regional-scale exploration and quantitative assessment of the impacts on ecological corridors and landscapes still lacks.

The research on regional ecological conservation primarily focuses on aspects such as ecosystem service functions[26], biodiversity[27], and ecological security patterns[28]. Ecological security patterns refer to spatial layout schemes constituted by key elements of natural landscapes, including points, lines, and areas, which were significant for protecting regional biodiversity and maintaining the functional integrity of regional ecosystems. Recently, the research orientation for ecological security patterns has shifted from "single-species migration corridors" to a comprehensive study of "ecological corridors and landscape connectivity," essentially forming a research paradigm of " identification of ecological source—construction of resistance surfaces—extraction of ecological corridors"[29,30]. The identification of ecological sources primarily encompasses two aspects: (1) The direct selection of nature reserves, long-standing forest areas, national parks, etc.; (2) The construction of an evaluation system to recognize patches with higher functional value. The Least Cost Path (LCP) model, which has gained recognition for its relative maturity in practical applications, provides an intuitive framework for elucidating the intrinsic relationships governing energy flow within regional ecological patches. The model serves as a robust analytical tool, enabling a clear visualization of the dynamics and pathways through which energy is transferred and distributed among various ecological components. By identifying the most cost-effective pathways for ecological processes, the LCP model offers a strategic approach to understanding and managing the complex interactions within regional ecosystems, thus enhancing the conservation and restoration

efforts in these critical environmental systems. It has been more and more widely applied in research areas such as ecological corridor construction, landscape connectivity analysis, ecological network development, and environmental protection planning[31–33].

To sum up, the potential impacts of landscape fragmentation caused by PTTPs on ecological patterns remain poorly understood. Although an environmental impact assessment is necessary before the construction of PTTPs, the effects on ecological corridors and landscape connectivity are often greatly simplified or even overlooked. To fully understand the impact of PTTPs on the ecological corridors and landscape connectivity, it is necessary to conduct a large-scale ecological impact analysis at the landscape scale. Therefore, it is urgent to clarify the impact on ecological security patterns, ecosystem function maintenance, and regional ecological protection for the rational planning of PTTPs. This comprehensive study helps ensure that PTTPs maximize the protection of local ecosystems while meeting power needs. The primary research objectives are: (1) to simulate the construction of ecological corridors under a variety of influencing factors; (2) to assess the impacts of PTTPs on ecological corridors; (3) to identify important ecological nodes; (4) to explore the impacts of PTTPs on landscape connectivity.

Research area and data sources

Research area overview

Shandong Province is located on the eastern coast of China, bordered by the Yellow Sea to the east and the Bohai Sea to the north. The total area is approximately 157,100 km^2, as shown in Fig. 1. Shandong's diverse landscape includes mountains, plains, and coastal areas, providing a rich variety of ecosystems. The province is home to several ecologically significant areas, including the Yellow River Delta Wetlands, and a globally important habitat for migratory birds, which supports unique biodiversity. These ecological features make Shandong an ideal study area for examining the interplay between infrastructure development and ecological conservation.

By the end of 2023, there were 110,000 km of power transmission and transformation lines in Shandong. The province is connected to the North China and Northeast China power grids through a strong power grid supported by extra-high voltage. This grid is composed of six 1000 kV AC lines, two ± 800 kV DC lines, one ± 660 kV DC line, and four 500 kV lines. The 500 kV and 220 kV ring networks serve as the main framework of the provincial and municipal grids, achieving a 100% electrification rate.

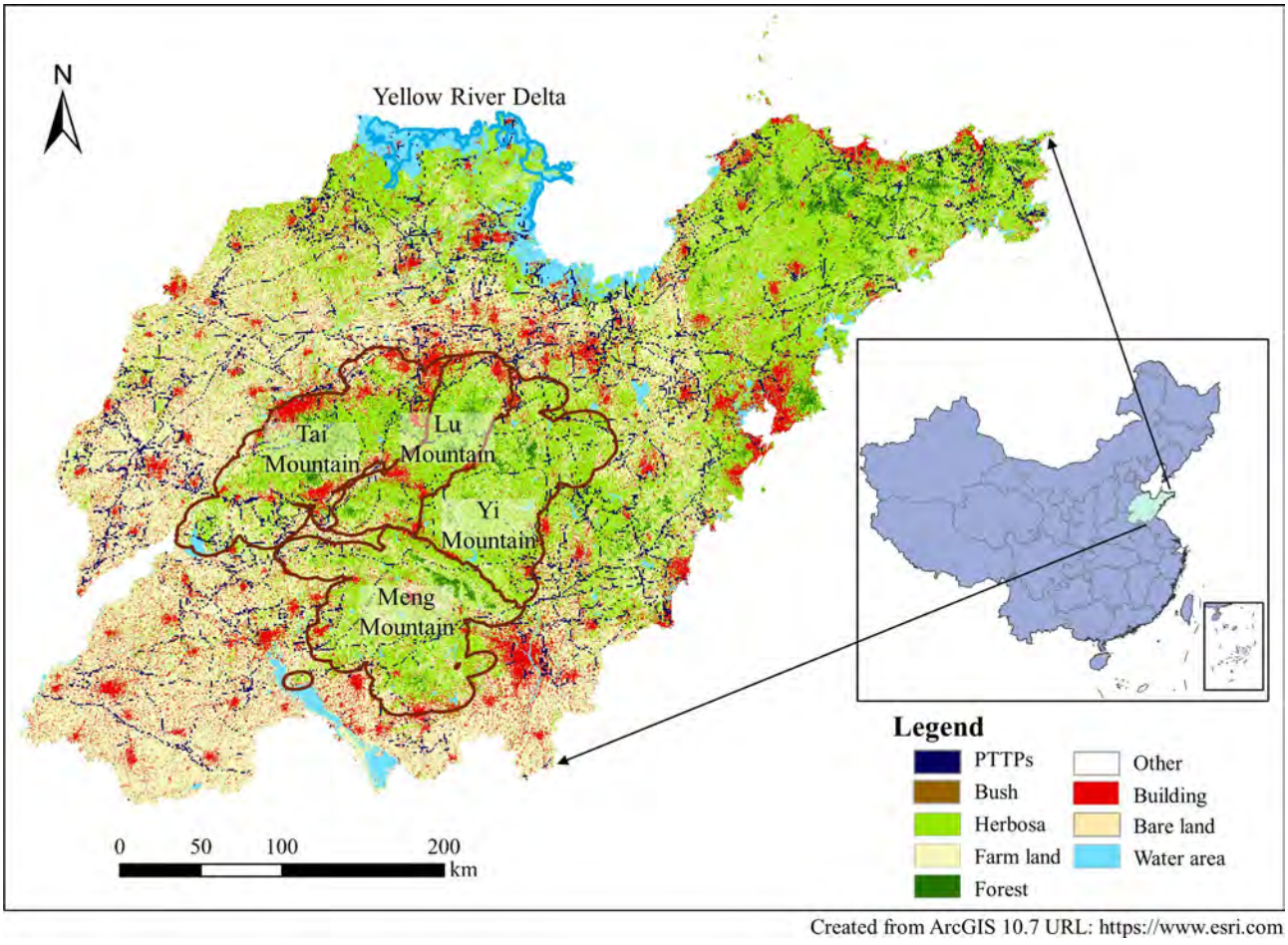


Fig. 1. Location of study area.

In recent years, the construction of PTTPs has expanded due to the rising electricity demand and the rapid development of renewable energy power generation. However, this expansion has also led to significant ecological challenges, such as habitat fragmentation, biodiversity loss, and disruption of ecological corridors. These issues are particularly acute in Shandong due to its high population density, intense industrial activity, and the coexistence of critical ecological zones with major infrastructure developments. Therefore, addressing the balance between power grid expansion and ecological conservation in Shandong is both urgent and representative of broader challenges faced by rapidly developing regions in China.

Data source and processing

Landsat TM images with a 30-m resolution from 2000 to 2020 are obtained from the Geospatial Data Cloud (http://www.gscloud.cn/search). Based on Landsat 8, the Normalized Difference Vegetation Index (NDVI) in 2000 and 2020 were analyzed, respectively. Landsat TM images from 2000 and 2020 are used to identify various land use types. The NDVI measures the difference between near-infrared and red light in pixels to indicate the amount of green vegetation. High NDVI values indicate an abundance of green vegetation within the raster. The Landsat TM Images are processed using Environment for Visualizing Images (ENVI) Version 5.0 (Esri, Redlands, CA) to identify various land use types. The slope and topographic data are obtained from the Global Digital Elevation Model (GDEM) provided by the Geospatial Data Cloud.

Research framework and methods

This paper aims to assess the impact of PTTPs on ecological corridors and landscape connectivity through the LCP model. Figure 2 presents the proposed research framework, which primarily includes the following three steps: (1) identifying the ecological sources by morphological spatial pattern analysis (MSPA); (2) constructing the landscape resistance surface by the Least Cost Distance (LCD) method; (3) identifying ecological corridors by using the LCP approach and considering the already recognized ecological source and resistance surface; (4) evaluating the impacts of PTTPs on the ecological corridors and overall landscape connectivity, including the impacts on corridor patency, length, and connectivity scores.

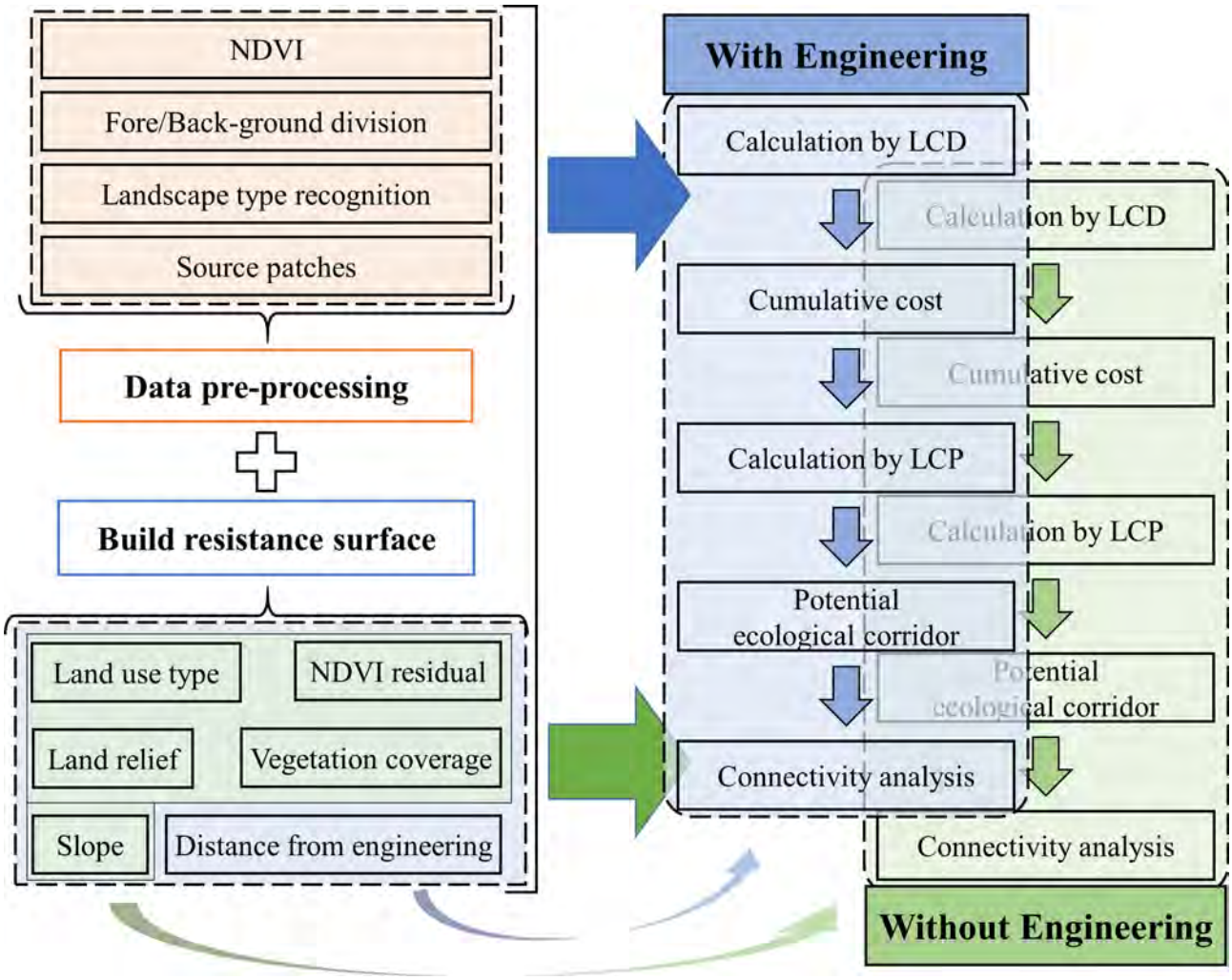


Fig. 2. Research framework of this study.

Identification of ecological sources

Ecological resources are highly valued for their connectivity and ecological services, which serve as the foundation for species habitat and dispersal[34]. In landscape ecology, ecological source patches are the fundamental units that contribute to the development of ecological processes in the landscape[35,36]. TheMSPA approach is a classification method for binarized raster images based on the principles of mathematical morphology. It has the advantages of simplicity and efficiency and is not limited by the research scale[37]. The land cover type is typically used as the primary reference factor[38]. During this process, forest land, grassland, wetland, and water areas are extracted as the foreground, while farmland, sparse vegetation, buildings, and bare land as the background. The edge width is calculated using GuidosToolBox software with the default eight-domain analysis method, resulting in the identification of three pixels, and eight landscape types (i.e. core, islet, perforation, edge, loop, bridge, branch, and background) in the study area. The identification of ecological sources through MSPA has revealed the existence of core patches with high importance indices, which not only provide substantial habitat areas but also serve as vital nodes for species migration and diffusion due to their high connectivity and ecological integrity.

Construction of resistance surface

The spatial diffusion and migration of ecological materials can enhance biodiversity, which is beneficial for maintaining ecosystem stability. However, the convenience of energy flow is influenced by spatial resistance. Therefore, rational construction of an ecological resistance surface is the key to extracting ecological corridors. This process typically involves four steps: (1) determining the resistance factors; (2) analyzing the resistance factor; (3) determining the resistance value; and (4) constructing the resistance surface.

Comprehensive factors should be considered to calculate integrated species migration resistance, usually including land cover, orography, location, and human activities[39,40]. Land cover types can directly affect the quality of habitat; slope and topographic relief influence vegetation growth and the range of biological movement; vegetation coverage can directly reflect the status of regional surface vegetation. In addition, the growth of vegetation is influenced by climate change and human activities. The construction of PTTPs, as a type of human activity, undoubtedly has an impact on vegetation. In order to assess the impact of PTTPs on vegetation, it is necessary to eliminate the influence of climate change from the NDVI data set.

The study evaluates the impact of human activities on vegetation, excluding the impact of climate change, referring to the residual analysis proposed by Evans and Geerken[41]. It involves performing regression analysis on the NDVI of each grid to obtain the predicted value of NDVI, which represents the influence of climate factors on NDVI. The impact of human activities on vegetation is measured by the difference between the actual and predicted value of NDVI, expressed by Eq. (1):

$$\varepsilon = NDVI_{real} - NDVI_{predicted} \tag{1}$$

where $NDVI_{real}$ is the actual NDVI value of the grid, which is obtained by Landsat TM image; $NDVI_{predicted}$ is obtained by the linear regression equation through the predicted value; ε is the NDVI residual value for each grid. $\varepsilon > 0$ indicates positive effects caused by human activity; $\varepsilon = 0$ indicates no effect; $\varepsilon < 0$ indicates a negative effect.

Moreover, the attenuation effect of noise and electromagnetic radiation in the air is primarily dependent on the distance traveled. Thus, the distance from the transmission line can be used to represent the noise electromagnetic radiation, and visual effects. "Technical guidelines for environmental impact assessment of electric power transmission and distribution" by China's Ministry of Ecology and Environment in 2020 mentions that the scope of electromagnetic environmental impact assessment for PTTPs with voltage ratings of 110 kV, 220–330 kV and ≥500 kV are 30 m, 40 m and 50 m respectively[42].

In this paper, 50 m is selected as the threshold of the impact range. In this study, six specific indicators (i.e. land use type, slope, relief degree, green vegetation coverage, NDVI residuals, and distance from PTTPs) are selected to calculate the integrated resistance surface. For the scenario without the PTTPs construction, the distance from PTTPs is excluded, and the weights of the remaining five factors are adjusted proportionally to maintain a total weight of 1. Table 1 displays the resistance values obtained from various degrees of landscape factors' influence on species migration. The resistance value ranges from 1 to 100, with values closer to 1 indicating free migration and values closer to 100 indicating difficult migration. The spatial layer of each influencing factor is synthesized by running ArcGIS 10.7 software for comprehensive analysis. Then, the reclassification tool is used to classify each resistance factor and assign the corresponding resistance value to each landscape unit. Furthermore, the Analytic Hierarchy Process (AHP) is a frequently employed technique for establishing the relative importance of individual resistance factors[43]. This is achieved by soliciting expert input and integrating it with weight assignments. Finally, the resistance surface with and without considering the PTTPs construction can be determined by overlaying these factor layers through the raster calculator.

Establishment of ecological corridor based on LCD and LCP

The landscape process ecological involves the circulation and migration of internal and external materials, energy, and information, as well as the evolution[44]. Landscape theory overcomes the limitations of the traditional concepts by introducing dynamic landscape patterns that reflect the influence of the bidirectional interactions between patterns and processes[45]. To achieve a more profound insight into the dynamics between landscape patterns and ecological processes, and to effectively simulate the movement and dispersion of these processes across landscapes, it is imperative to establish a quantitative methodology that assesses the influence on ecological flows within regional landscapes[46]. Within this framework, the LCP approach emerged as an invaluable instrument.

Factors	Weight (with PTTPs)	Weight (without PTTPs)	Grading	Resistance value
Land use type	0.27	0.32	Forest	1
			Grass	10
			Farmland	50
			Buildings	100
Slope (°)	0.15	0.18	< 8	1
			8–15	10
			15–25	50
			25–5	75
			> 35	100
Relief degree	0.12	0.14	< 25	1
			25–50	10
			50–75	50
			> 75	100
Green vegetation coverage (%)	0.18	0.21	> 75	1
			60–75	10
			45–60	50
			30–45	75
			< 30	100
NDVI residual	0.12	0.14	< − 0.05	1
			0.05–0.05	50
			> 0.05	100
Distance from PTTPs (m)	0.16	–	> 200	1
			50–200	50
			< 50	100

Table 1. Resistance surface weights and values for various landscape factors.

The LCD, or least cost distance represents the most likely path an individual would take when moving between two habitat patches. To account for the various factors that affect species migration, a range of distances is used instead of a single value, resulting in variations in species dispersal distance. In the LCD model, the path of minimum resistance between each node could be determined based on the resistance surface[47]. The resistance distance, derived from the analysis of all potential pathways interlinking two ecological source patches, encapsulates the effective separation distance for species and is frequently employed as a metric to gauge the functional connectivity within a landscape. Additionally, the LCP is a single path that species can use to move between two ecological source patches.

Both the LCD and LCP models are calculated using Eq. (2) in ArcGIS 10.7. The LCD model calculates the cumulative cost of each pixel to the nearest source patch by inputting the source patch and resistance surface. The LCP determines the least cost paths to connect each of the two source patches based on the cumulative cost, which are the potential ecological corridors.

$$LCP = f \min \sum_{j=n}^{t=m} (D_{ij} \times R_i) \tag{2}$$

where f is an unknown positive function reflecting the positive relationship between the minimum resistance at any point in space and its distance to all sources and the characteristics of the landscape substrate; D_{ij} is the spatial distance of the substrate i of a landscape traversed by a species from a source j to a point in space; R_i is the resistance of the landscape i to the movement of a species.

Landscape connectivity evaluation

Landscape connectivity refers to the degree to which the landscape enables or impedes the movement of biological and ecological processes between patches. It considers both structural and functional connectivity, which serves as a critical basis for identifying high-quality corridors. The Integral Index of Connectivity (IIC) and the Probabilistic Index of Connectivity (PC) are currently the primary landscape indices used to assess the level of landscape connectivity.

The IIC is a binary connectivity index that considers the usable area of each habitat segment (intra-segment connectivity), the estimated flow between segments, and those segments that serve as stepping stones or connections to other suitable habitat areas[48]. The PC incorporates richer connectivity modes which are not influenced by neighboring patches. Furthermore, the PC reflects both the structural characteristics of the landscape and the behavioral characteristics of species dispersal, effectively representing the significance of ecological sources and corridors in the landscape pattern.

To assess the impact of PTTPs on the landscape connectivity of ecological sources or ecological corridors, the relative changes in the IIC and the PC could be calculated using the following Eqs. (3) to(5)[49]:

$$IIC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{a_i a_j}{1+nl_{ij}}}{A_L^2} \tag{3}$$

$$PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i \times a_j \times P_{ij}}{A_L^2} \tag{4}$$

$$dI\,(\%) = \frac{I - I_{remove}}{I} \times 100\% \tag{5}$$

where a_i and a_j are the area of each habitat patch; nl_{ij} is the number of links on the shortest path (topological distance) connecting patches i and j; A_L is the total area; P_{ij} is the maximum probability product of all paths between patches i and j. If patches i and j are close enough, the maximum probability path will simply be a step between nodes i and j. If patches i and j are far apart, the path with the greatest probability may consist of multiple patches passing through the middle as "stepping stones/transitions". dI represents the relative change of landscape connectivity caused by the exclusion of a certain ecological source or ecological corridor, I is the landscape connectivity index value (IIC or PC), and I_{remove} is the landscape connectivity index value remaining after the removal of a single ecological source patch or ecological corridor, which can be calculated by software Conefor 2.6.

Results and analysis

Ecological sources identification analysis based on MSPA

Figure 3 presents the spatial landscape type of Shandong Province. The core area (green in Fig. 3) which comprises the intertidal zone and shallow sea wetland of the Yellow River Delta, the Tai Mountain, the Yi Mountain, the Meng Mountain front alluvial plain, and the low hilly area of eastern Shandong Province, accounts for 2.98% of the total ecological landscape area, approximately 9.46×10^3 km^2. The distribution of patches in the core area

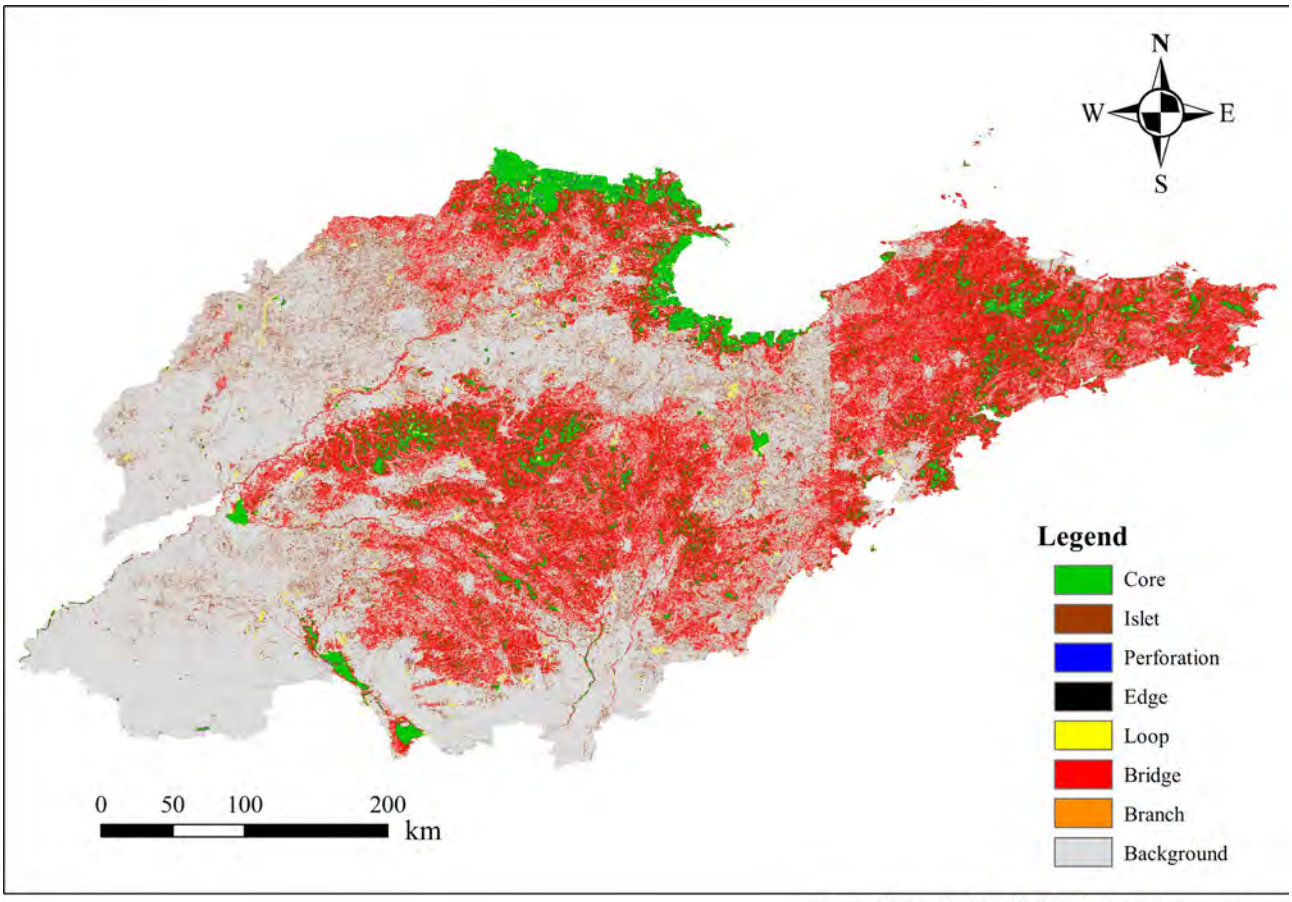


Fig. 3. Spatial distribution of MSPA landscape type in the study area.

was partially concentrated but relatively dispersed. So, it needs to consider the calculation efficiency of resistance surface construction and landscape connectivity.

In previous studies, urban-scale studies have employed a threshold of 10 km^2, while watershed-scale studies have utilized 100 km^2 as the threshold[50,51]. The ecological source patches larger than 80 km^2 in the core area were selected in this study. Based on the MSPA method, a total of 12 ecological sources were identified, as shown in Fig. 4. The bridge area covered approximately 43.61×10^3 km^2, which was 13.73% of the total ecological landscape area. The calculation was based on the selection of three times the pixel edge width when the landscape type was determined, resulting in a landscape structure that was broad and dispersed. The perforation and edge area corresponded to the inner and outer edges of landscape patches, both representing areas within the ecological landscape that exhibited edge effects. They constituted 0.12% and 0.41% of the total area, respectively. The influence of the edge effect was excluded in this study by disregarding the proportionally minor branch lines, which made up only 0.59% of the total area. The islet area represented detached ecological landscape patches that were unconnected and fragmented. These patches demonstrated low connectivity, leading to restricted internal exchange of materials and energy, and comprised only 3.11% of the total area. The loop area facilitated animal movement within the patch, promoting species migration within the core patch, and accounted for 0.29% of the total area.

Ecological resistance surface construction

Based on the distribution of resistance surface values (see Fig. 5), areas with high resistance values were primarily located in mountainous, wetland, coastal, and non-vegetation regions. By comparing the landscape resistance surface before and after the PTTPs, it was evident that the PTTPs had increased the area of the resistance surface with high resistance values in Shandong Province. In addition, it reduced the connectivity between ecological sources, as indicated by the overall increase in LCD values. Before the construction of the PTTPs, the average, minimum, and maximum values of LCD were 30.52, 0.67, and 87.50, respectively. According to the general study, the overall resistance value should rise after adding the influence of the PTTPs. In this study, when we constructed the resistance surface without the PTTPs, we excluded the weight assignment of the landscape factor "Distance from PTTPs", and the weights' sum of the remaining factors was increased to 1 in equal proportions. When considering "Distance from PTTPs", the average and maximum values of LCD decreased to 26.48 and 78.16, respectively, while the minimum value slightly increased to 0.73. The resistance values in the western and northern regions had increased noticeably, while the high resistance values in the central and northeastern

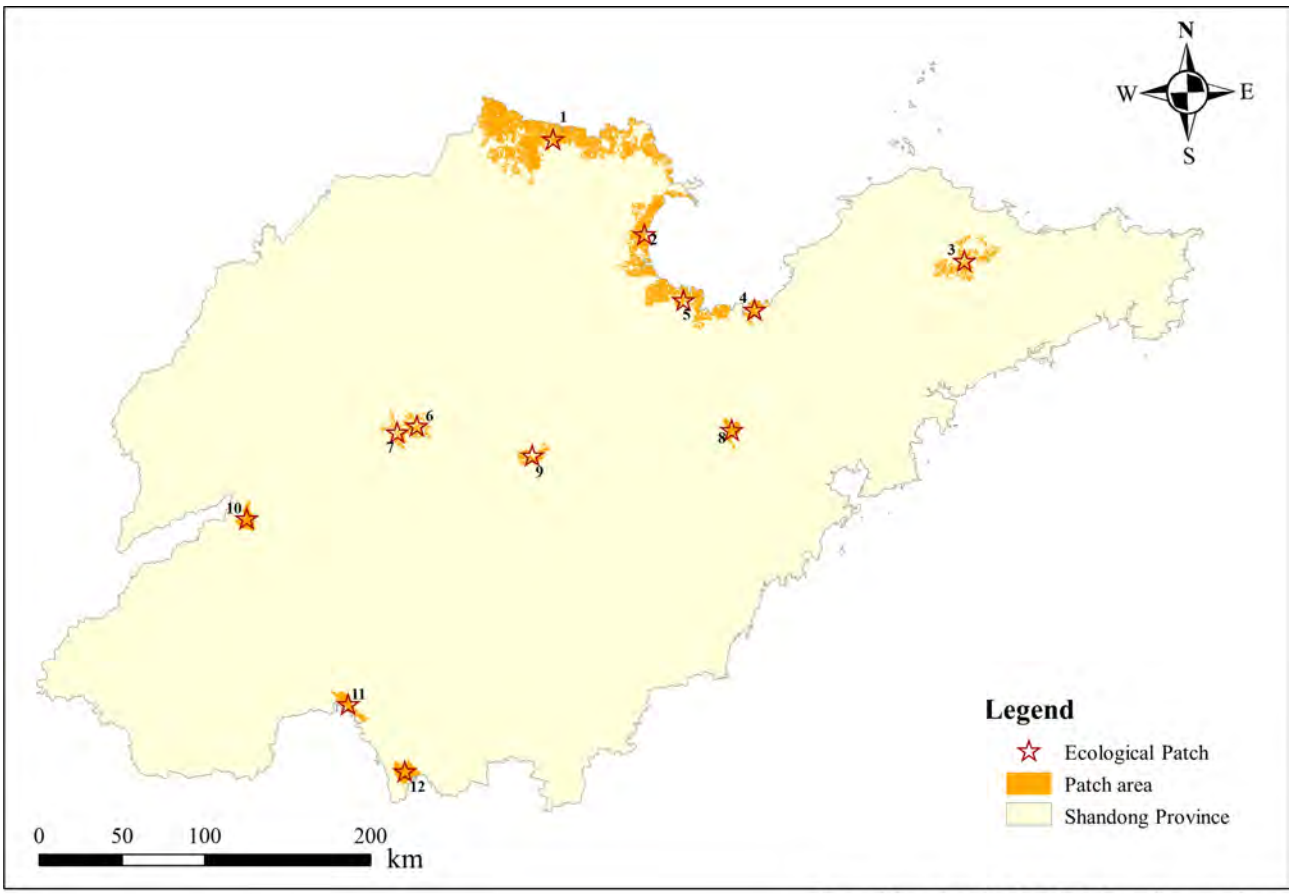


Fig. 4. Spatial distribution of the ecological sources.

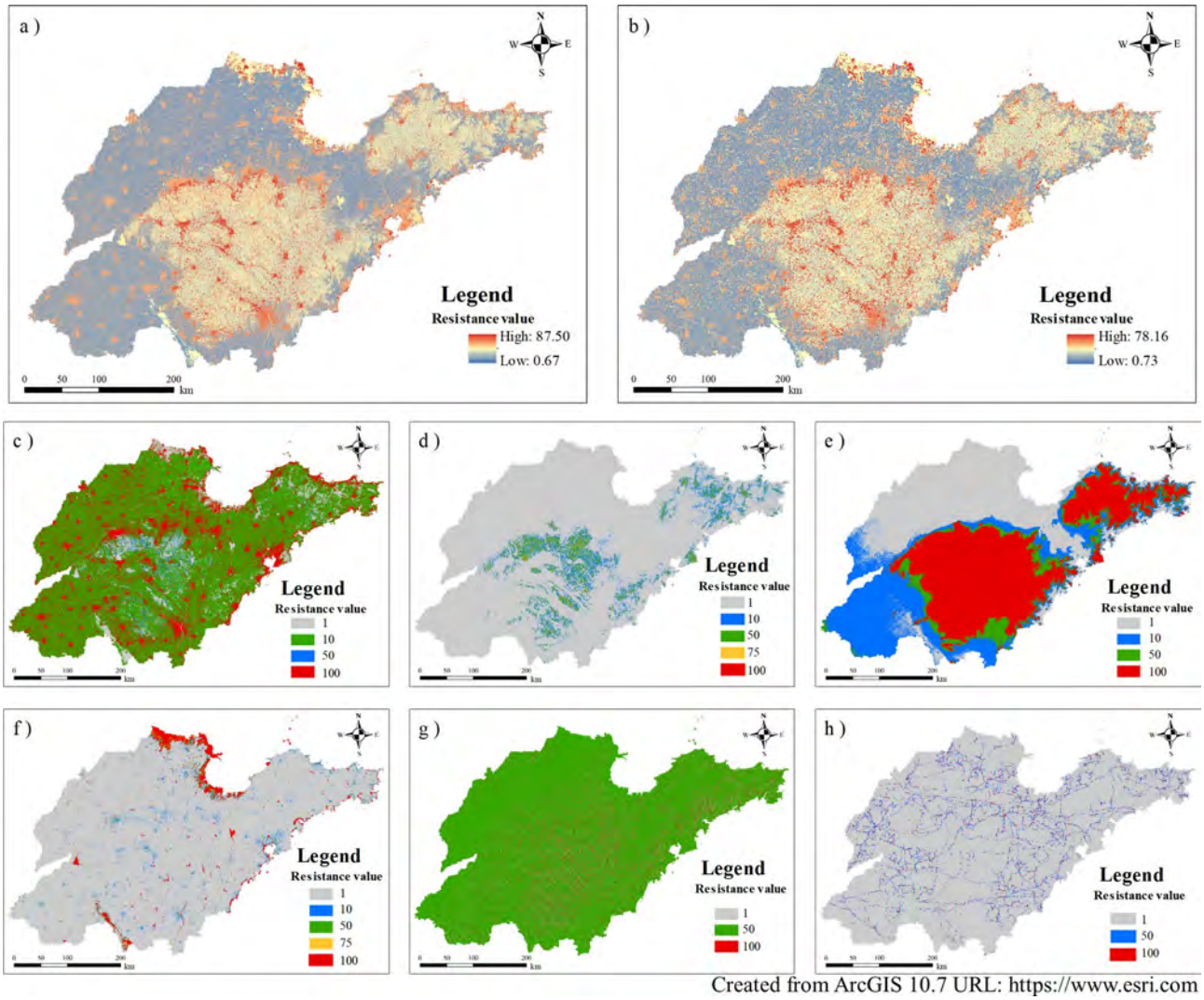


Fig. 5. Resistance surface before and after being affected by PTTPs. (**a**) represents the resistance surface without the influence of PTTPs; (**b**) represents the resistance surface with the influence of PTTPs; (**c**) represents the resistance value of land use type; (**d**) represents the resistance value of slope; (**e**) represents the resistance value of land surface relief; (**f**) represents the resistance value of green vegetation coverage; (**g**) represents the resistance value of NDVI residual; (**h**) represents the resistance value of the PTTPs.

regions had significantly increased. The central part of Shandong was dominated by Tai Mountain, Yi Mountain and Meng Mountain which was a mountainous and hilly region. The eastern part was a low mountainous and hilly region, and the northern part was the Yellow River Delta region. When constructing PTTPs, environmental impact and electromagnetic radiation were typically taken into account, so it was usually carried out in areas far from human activities. This was also corroborated by the resistive surface change observed in the area both before and after the PTTPs.

Ecological corridors extraction

Figure 6 displays the distribution of potential ecological corridors in Shandong Province. The overlap between the ecological corridors with and without the impacts of the PTTPs was mainly distributed in the study area's periphery, including the ecological corridors '10 to 11 to 12 to 8 to 5', '10 to 11 to 12 to 3 to 4', and '3 to 5'. The internal ecological corridors were significantly impacted by the construction of PTTPs, as evidenced by the smaller overlapping area. It is important to consider this impact when planning the path of these corridors. Based on the steps for constructing the least-cost path, the ecological corridor had been divided into 11 parts, each corresponding to the number of least-cost paths between ecological source areas. Ecological corridor 1 connected ecological source 1 to other ecological sources (2, 3, …, 12). Ecological corridor 2 connected ecological source 2 to other ecological sources (3, 4, …, 12). By analogy, ecological corridor 11 connected ecological source 11 to the remaining ecological source (12). The PTTPs resulted in a reduction of the length of most ecological corridors, with only corridors 3, 8, 9, and 10 experiencing an increase in length (see Fig. 7). The total length of ecological corridors had been reduced by 28.48 km. Under the influence of PTTPs, the maximum value of

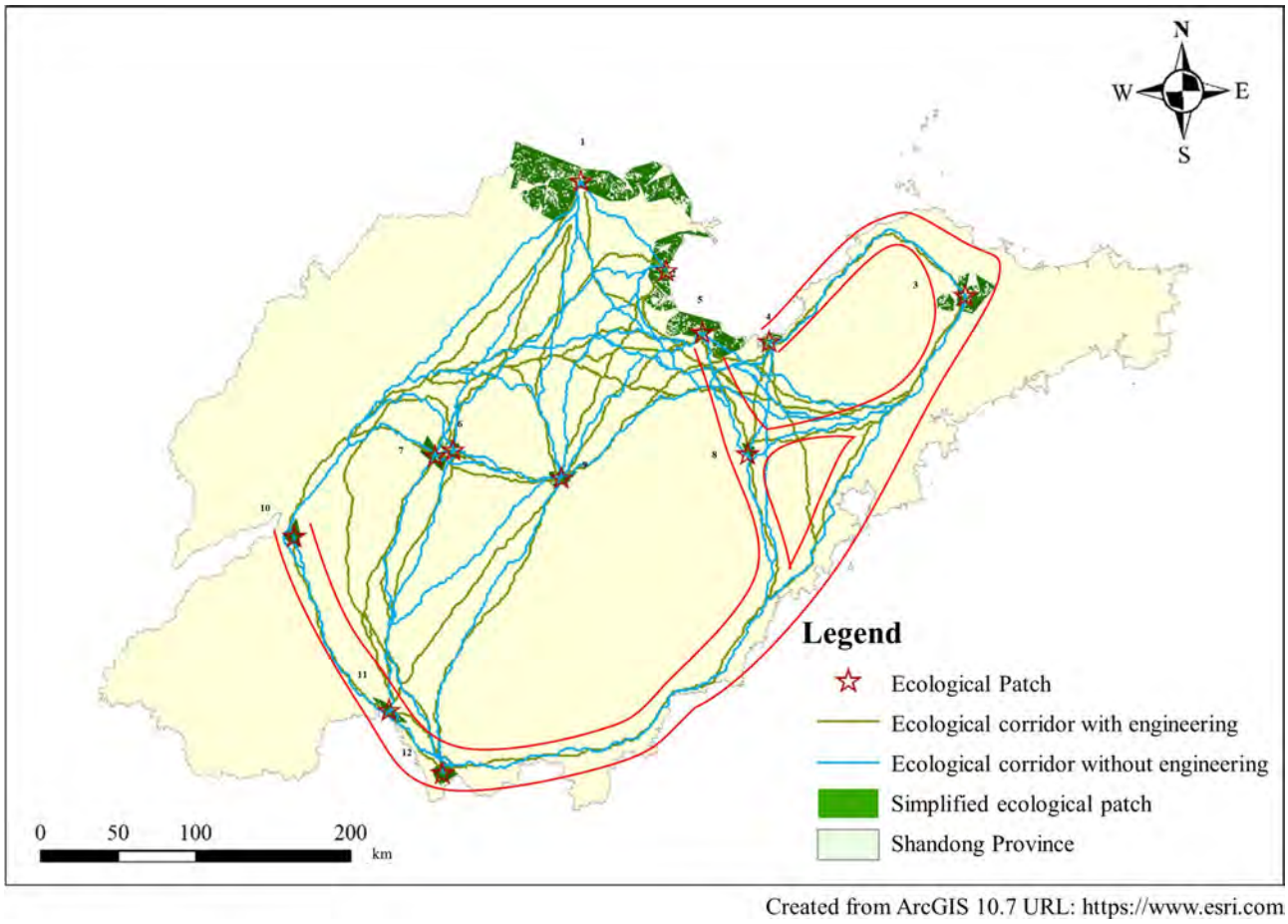


Fig. 6. Spatial distribution of potential ecological corridors in Shandong Province.

ecological corridors 1, 3, and 5 increased by more than 30 km. Conversely, the maximum value of ecological corridor 4 decreased by 65.97 km, while the maximum value of other ecological corridors changed by no more than 10 km.

Ecological nodes identification

Maintaining the stability of the entire ecological corridor network was a pressing issue after the generation of linear ecological corridors. Ecological nodes were crucial complementary components of the ecological corridor system. They improved the landscape connectivity of the ecosystem and were typically distributed in the ecological corridors of extremely vulnerable areas, which played a vital role in consolidating the corridor system. Ecological nodes are crucial habitats for organisms during migration, which identification could improve the success rate of species migration. Additionally, ecological corridors intersecting with areas of high resistance on the cumulative resistance surface are often ecological fracture points, which could negatively impact energy transportation and species migration through the corridor.

Based on the initially identified ecological corridors, the shortest corridors of each two ecological sources were screened as important ecological corridors (including before and after project impacts). In another study conducted in Shandong Province, the mean width of the identified inter-city ecological corridors was found to range from 1.12 to 3.18 km[52]. The width threshold was taken as 2.5 km for the identification of ecological nodes. Key ecological nodes were identified by overlaying critical ecological corridors, both pre-and post-projects impact, with the corresponding cumulative resistance surface. From an examination of Fig. 5a and b, it is evident that the median resistance values of the resistance surfaces are approximately 40, with the range of resistance values exceeding 40 intersecting with the range of ecological corridors basically. Accordingly, 40 has been selected as the threshold value for the resistance surface. The vital ecological nodes and corridors could be delineated by overlaying the pre- and post-project ecological datasets, enabling the identification of areas with significant ecological importance (see Fig. 8).

Vital ecological nodes were primarily situated to the north of ecological source 9 and the southwest of ecological source 7, as depicted in red in Fig. 8. Most of the identified ecological nodes with/without projects were located along ecological corridors that extended from ecological sources 6, 7, and 9 to other ecological sources. The ecological nodes were mainly located within the Taishan Mountain Range due to factors such as slope gradient, land typology, and terrain undulation that were important in constructing the resistance surface.

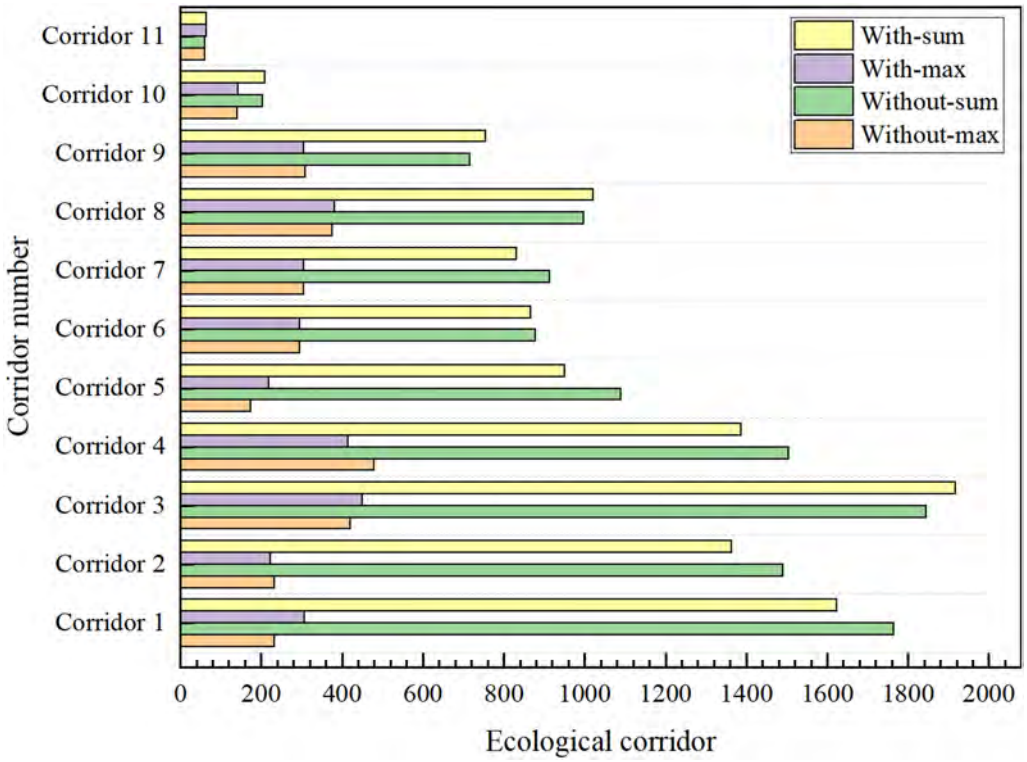


Fig. 7. Length of ecological corridor before and after being affected by the PTTPs.

It was worth noting that the significant ecological nodes had high resistance values due to these parameters. Enhancing the conservation and management of forested areas could help alleviate pressures on ecological nodes that were predominantly forested. At the same time, ecological nodes with built-up areas and agricultural land with significant resistance values were identified as highly sensitive to human interventions. To improve landscape connectivity with ecological sources, it was recommended to restrict developmental and construction activities and establish ecological buffer zones.

Landscape connectivity analysis

To calculate the IIC and PC values for each ecological source, it is necessary to select a suitable connectivity distance threshold. Figure 9 shows that as the connectivity distance threshold increases, the overall PC value also increase. The IIC reached its maximum value of 0.60 when the distance threshold was 200 km. However, the slope of the PC curve decreased as the distance threshold increased. The connectivity distance threshold was typically chosen based on the value corresponding to the maximum slope of the connectivity index curve. In this study, the connectivity distance threshold for the ecological source area was set at 150 km. Using this distance threshold and a connectivity possibility probability of 0.5 as the basic parameters, the landscape connectivity (IIC and PC) of the ecological source area in Shandong Province was calculated, as shown in Table 2. In the study area, ecological source 1 had the largest *d*IIC and *d*PC values, exceeding 76%, due to accounting for 46.53% of all ecological source areas. The top three sources with large areas, namely source 1, source 2, and source 5, had the highest *d*IIC and *d*PC values. Notably, the *d*PC values of source 2 and source 5 were consistently greater than their *d*IIC values.

Figure 10 illustrates the effect of each ecological corridor loss on overall landscape connectivity. Ecological sources 1, 2, and 5 were close to each other in terms of geographical location. Therefore, the loss of ecological corridors '2 to 1' and '5 to 2' had the most significant effect on the *d*PC values, which reduced overall by 8.48% and 6.05%, respectively. The *d*IIC values for the ecological corridors '2 to 1', '5 to 1', '6 to 1', and '12 to 11' were higher contributions, with percentages of 3.62%, 3.24%, 1.81%, and 2.97%, respectively. These results suggested that these four corridors were the primary contributors to the overall landscape connectivity in Shandong Province. The ecological corridors that required special attention were the northern sources (1, 2, and 5), the central source (6), and the southern sources (11 and 12). The PTTPs had the greatest impact on the ecological corridor that connects the central patches (sources No. 6, 7, 8, and 9) and the northern patches (sources No. 1, 2, 3, 4, and 5). Additionally, the ecological corridors between the southwestern patches (sources No. 10, 11, and 12) and the central patches (sources No. 6, 7, and 9) were also affected. The ecological corridors connected by the peripheral patches (sources No. 3, 10, 11, and 12) were largely unaffected by the projects. The PTTPs had a greater impact on the shorter ecological corridor than on the longer one. To summarize, it is important to prioritize the protection of existing ecological corridors and the creation of new ones in suitable ecological source areas.

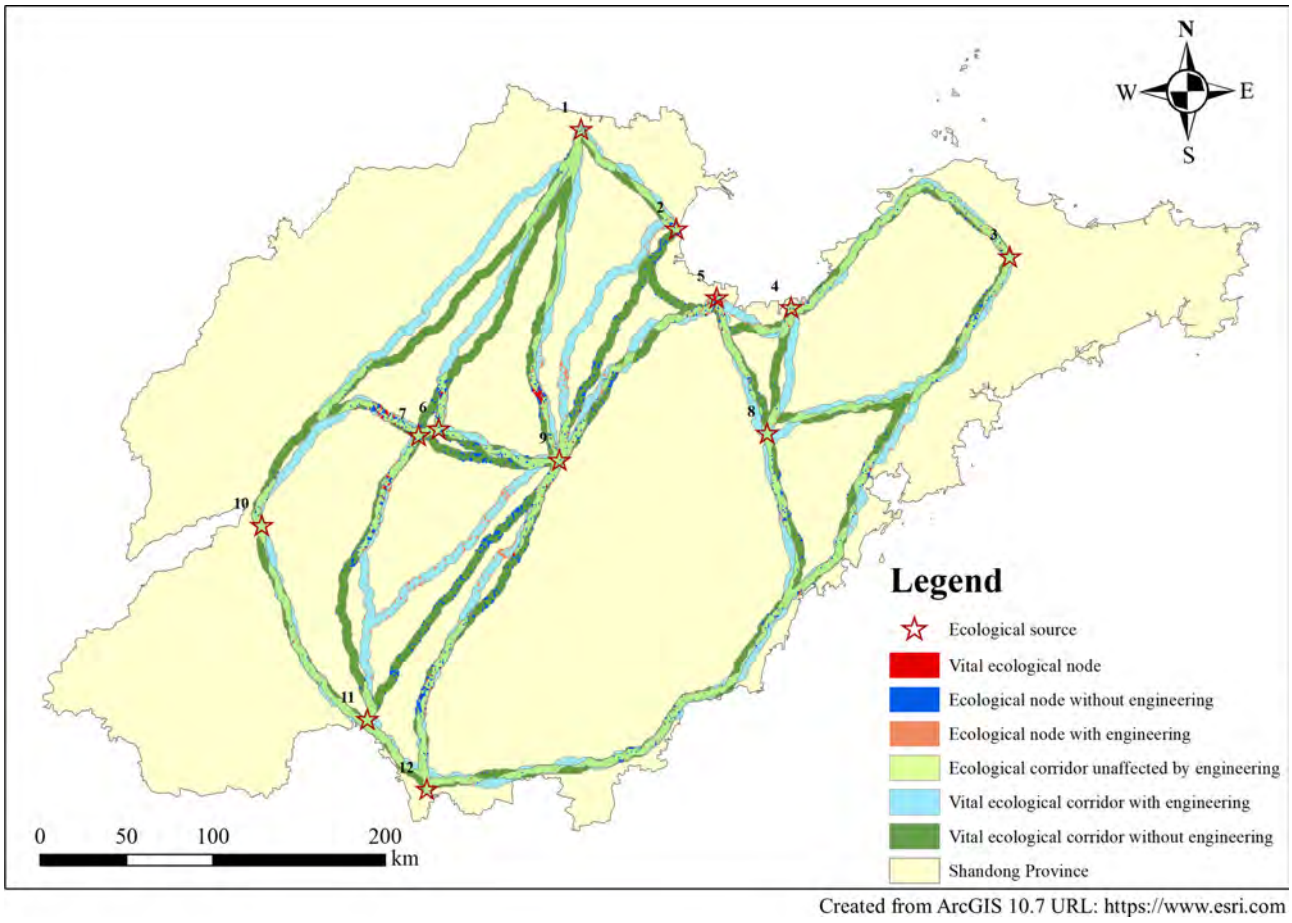


Fig. 8. Spatial distribution of vital ecological nodes and corridors in the study area.

Discussion

The guide of projects' construction by regional ecological corridors

Based on the basic idea of ecological source identification, resistance surface construction, and ecological corridor extraction, this study mapped the potential ecological corridors of Shandong province while considering the impact of PTTPs. A framework for exploring the effect of ecological corridors under the PTTPs was tentatively formed from a provincial perspective. The ecological corridor serves multiple functions, such as protecting biodiversity, filtering pollutants, preventing erosion, and managing floods. Additionally, it provides habitats for wildlife and routes, sources, sinks, barriers, and filters for biological migration[53]. Due to the lack of detailed ecological requirements in previous projects, the continuation of PTTPs from previous years will inevitably have an impact on the breadth and connectivity of existing ecological corridors. For instance, alterations in soil properties, vegetation destruction, light pollution, and local climate impacts have negatively affected ecological corridors where various species migrate[54]. This leads to fragmentation of the ecological network and reduces the quality of ecological network services. The results indicate that the construction of PTTPs has significantly shortened the length of ecological corridors, particularly in areas with high resistance values. Therefore, it is important to ensure that PTTPs avoid potential ecological corridors during construction to promote the synergistic development of these projects and ecological sustainability in Shandong Province.

Specifically, the findings suggest that PTTPs should be rerouted away from key ecological sources and corridors identified in this study, especially in areas with high NDVI residuals and green vegetation coverage, where species connectivity is most sensitive to fragmentation. Additionally, in regions where rerouting is not feasible, adopting "green infrastructure" technologies, such as wildlife passages, green tunnels, and underground cables, is essential to mitigate the negative impacts of PTTPs. Meanwhile, the inclusive approaches are essential for the ethical and effective implementation of PTTPs that intersect with ecological and power transmission concerns. Engaging with a broader range of stakeholders early and continuously, including local communities, environmentalists, and indigenous groups, represents a dynamic and enriching process that integrates various ecological knowledge and cultural wisdom into project planning and construction. By establishing an iterative feedback loop, trust in ecological conservation and a spontaneous sense of stewardship can be fostered through their effective participation in the project's development. The implementing measures such as the development of community outreach plans, participatory workshops, and collaborative monitoring can facilitate and advocate

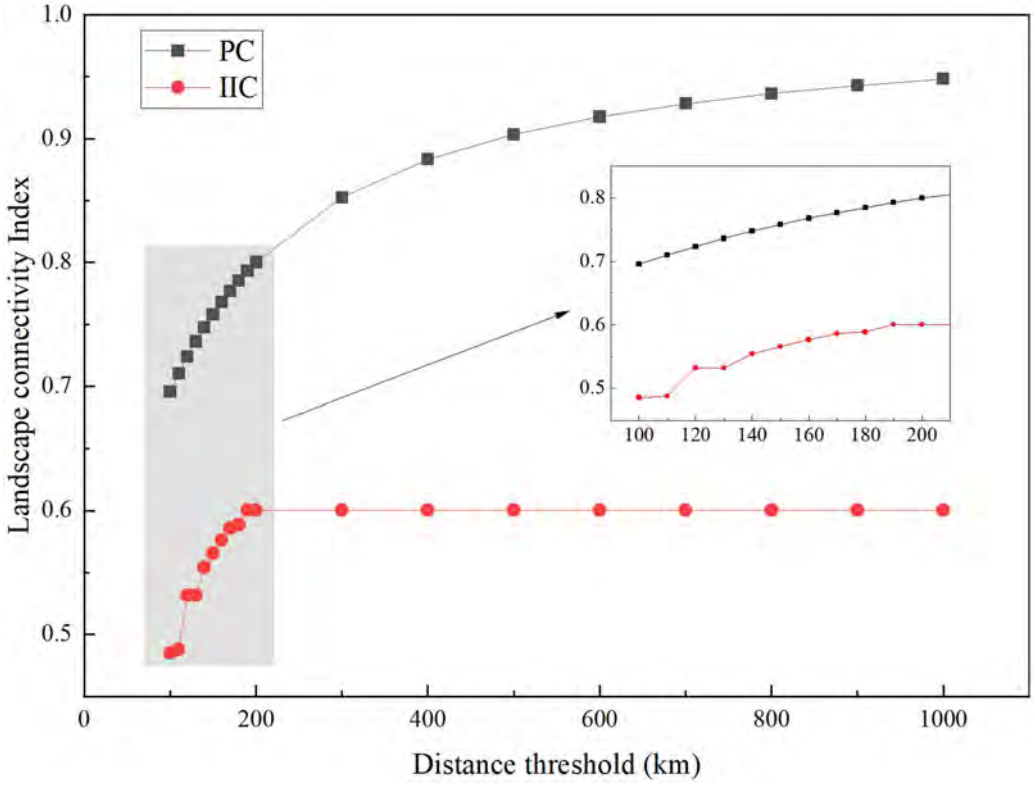


Fig. 9. Changing trend of landscape connectivity index of ecological source area under different distance thresholds.

Source number	Area (km)	Area ratio (%)	*d*IIC (%)	*d*PC (%)
1	1727.91	46.53	76.60	76.74
2	490.06	13.20	21.21	32.56
3	278.60	7.50	9.33	9.91
4	80.39	2.17	3.58	5.32
5	439.06	11.82	19.53	27.28
6	99.56	2.68	5.11	3.84
7	84.59	2.28	2.81	3.26
8	85.37	2.30	3.70	4.14
9	84.15	2.27	3.99	3.89
10	108.55	2.92	3.27	2.77
11	101.44	2.73	5.92	2.38
12	133.69	3.60	3.20	2.95

Table 2. Indicators of landscape connectivity in ecological sources.

for this engagement. Following the establishment of multi-party collaboration, the impact of PTTPs on the construction of ecological corridors and landscape connectivity can be significantly reduced.

The effects of PTTPs on the ecological corridors and landscape connectivity

The infrastructure for the PTTPs consists of transmission lines, substations, transformers, switching facilities, protection equipment, and control equipment. The installation of PTTPs' infrastructure, such as transmission line pillars and towers, can negatively impact the patency, length, and connection strength of ecological corridors. The results demonstrate that the presence of PTTPs has fragmented ecological landscapes, particularly in regions with high relief degrees and steep slopes, where species migration is most constrained. Moreover, constructing the PTTPs will inevitably disrupt the habitats of some species, limit the activity range of some wildlife, and create linear obstacles to their movement patterns. The PTTPs have made a significant impact on the landscape, resulting in species isolation and ecosystem fragmentation. It would bring negative effects on the adaptive and migratory capacity of species, ultimately harming ecosystem integrity and the long-term viability of wildlife[55].

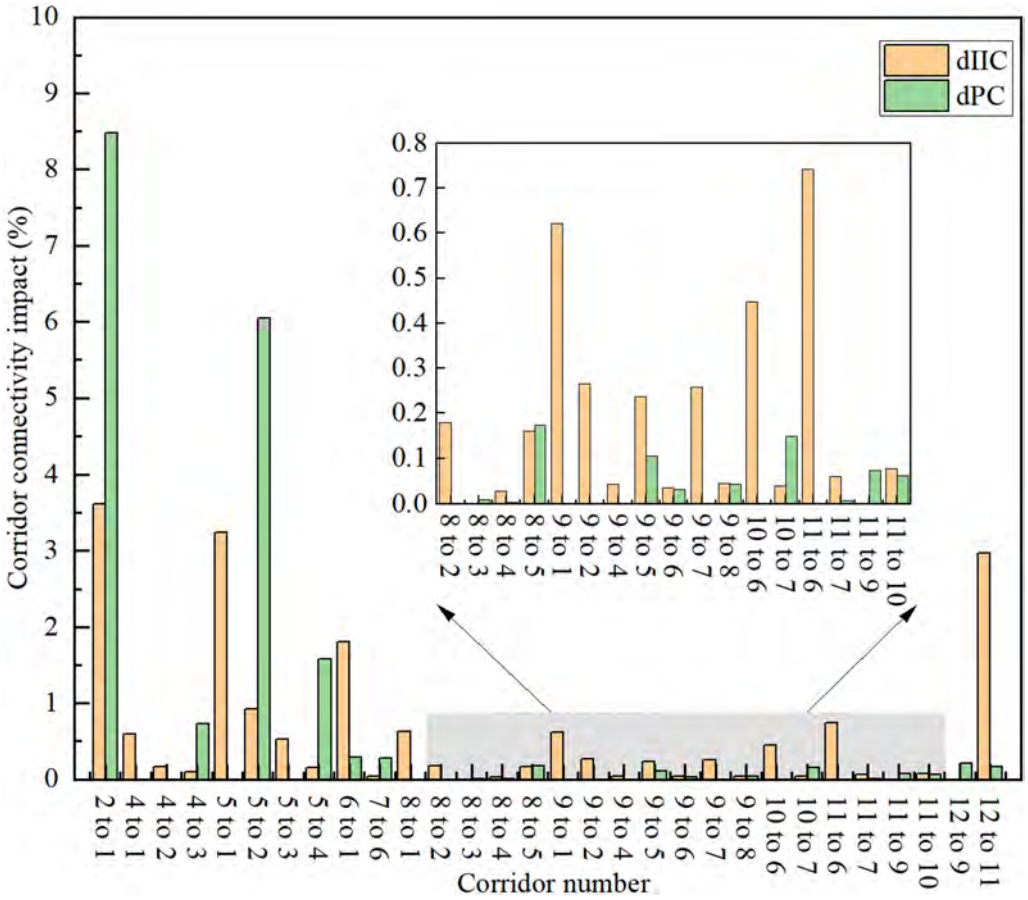


Fig. 10. Effect of each ecological corridor loss on landscape connectivity.

Further, it can alter the orientation of the corridors between the core habitat patches of the landscape, impede the migration and dispersal of species, and decrease the connectivity of the corridors[56].

Previous studies have shown that the length of corridors increased when species were forced to migrate through areas with high resistance. However, our study differed from previous ones in that it considered the impact of PTTPs on the selection of resistance surface factors. This approach mitigated the actual ecological impacts and indirectly avoided the risk of increasing the ecological corridors' length. The PTTPs are spread throughout Shandong Province, so ecological corridors are disrupted by the linear distribution of supports, cables, and other infrastructures. To mitigate the effects of fragmentation isolating the ecological landscapes, the length of most ecological corridors was shortened after considering the impact of PTTPs. It is necessary to adopt "green infrastructure" technologies including wildlife corridors, green tunnels, and underground cables, which help maintain landscape connectivity. It suggests to: reasonably plan construction roads; design specific wildlife corridors in PTTPs that cross ecological corridors; optimize foundation depth and tower head layout; select appropriate cable laying routes, use cable trenches or tunnels, and apply intelligent monitoring systems. It is recommended that these designs be incorporated as standard practice in power transmission projects to minimize fragmentation and effectively protect ecological corridors.

Limitation and future study

The current study has several limitations that should be addressed in future research. First, while we identified the impacts of PTTPs on ecological corridors and landscape connectivity, our analysis was primarily based on spatial modeling and did not include detailed field validation of species migration patterns or habitat use. Incorporating empirical data from ecological monitoring programs would provide a more comprehensive understanding of the actual effects of PTTPs on biodiversity. Second, our resistance surface construction relied on expert input and weight assignments, which may introduce subjectivity. Future studies could explore more objective methods, such as machine learning algorithms or species-specific resistance models, to improve the accuracy of ecological corridor identification.

Furthermore, the current policies aimed at promoting landscape connectivity in the development of energy infrastructure suffer from significant limitations, such as a lack of uniformity, insufficient enforcement, and the absence of specific objectives and adaptability. For instance, policies between different departments may be contradictory, leading to difficulties in implementing ecological protection measures in practice[57]. Additionally, many policies lack inter-departmental and cross-regional coordination mechanisms, resulting in a fragmented

approach during the policy implementation process. Future studies should explore how collaboration between government, industry, and environmental organizations can facilitate the development and implementation of more effective policies. For example, local and regional planning, parks, transport, conservation and climate action agencies can coordinate around green infrastructure and riparian corridors to create communities with high ecological connectivity[58]. This would help ensure that actions and measures in different areas support the maintenance and enhancement of landscape connectivity.

Conclusion

To safeguard regional ecological security, this paper proposed a framework for regional ecological conservation that integrated the MSPA, LCD, and LCP methodologies. Taking Shandong Province in China as a case study, the paper explored the impacts of PTTPs construction on regional ecological corridors and landscape connectivity. The comprehensive approach aimed to provide a strategic perspective for assessing and mitigating the ecological implications of regional PTTPs' developments.

The results of the case study revealed that: (1) A total of 12 ecological source patches were identified, each possessing an area exceeding 80 km^2. (2) When considering the PTTPs, there was a general increase in resistance, coupled with an overall reduction in the length of ecological corridors by 28.48 km. (3) Key ecological nodes were predominantly located in the vicinity of ecological source patches 7 and 9. (4) The absence of critical ecological corridors, specifically '2 to 1', '5 to 1', '6 to 1', and '12 to 11', had a significant impact on the regional landscape connectivity.

In general, to improve regional ecological security, the initial step is to safeguard the habitats of the larger ecological sources 1, 2, 3, and 5. Subsequently, the ecological nodes along the identified important ecological corridors from central ecological sources 6, 7, 8, and 9 should be maintained and constructed. Simultaneously, priority ecological corridors should be subject to stringent management measures to ensure the maintenance and enhancement of the overall landscape connectivity within the region. Ensuring a balance between the construction of power infrastructure and the protection of the ecological environment is key to adaptive management in the future. The implementation of an integrated approach, encompassing adaptive route layouts, ecological corridor planning, sustainable vegetation restoration, and biodiversity conservation measures, can effectively address unforeseen ecological impacts and changing environmental conditions.

The study results can enhance the diversity and accuracy of quantitative evaluation on ecological corridors while offering a new approach to constructing and optimizing regional ecological network patterns.

Data availability

The data supporting the findings of this study are available from the corresponding authors upon reasonable request.

Received: 26 August 2024; Accepted: 20 February 2025
Published online: 25 February 2025

References

1. Yu, X. et al. Integration of tradable green certificates trading and carbon emissions trading: How will Chinese power industry do?. *J. Clean. Prod.* **279**, 123485 (2021).
2. Yuan, J. & Zhao, D. A panel empirical modeling on the driving factors of provincial electricity consumption in China. *Environ. Sci. Pollut. Res.* **29**, 10345–10356 (2022).
3. Oliva, H. S., Muñoz, J., Fredes, F. & Sauma, E. Impact of increasing transmission capacity for a massive integration of renewable energy on the energy and environmental value of distributed generation. *Renew. Energy* **183**, 524–534 (2022).
4. Yuan, J., Lei, Q., Xiong, M., Guo, J. & Hu, Z. The prospective of coal power in China: Will it reach a plateau in the coming decade?. *Energy Policy* **98**, 495–504 (2016).
5. Gajšek, P. et al. Review of studies concerning electromagnetic field (EMF) exposure assessment in Europe: Low frequency fields (50 Hz–100 kHz). *IJERPH* **13**, 875 (2016).
6. Li, X. & Lin, Y. Do high-voltage power transmission lines affect forest landscape and vegetation growth: Evidence from a case for Southeastern of China. *Forests* **10**, 162 (2019).
7. Kohl, M. T. et al. The effects of electric power lines on the breeding ecology of greater sage-grouse. *PLoS ONE* **14**, e0209968 (2019).
8. Biasotto, L. D. & Kindel, A. Power lines and impacts on biodiversity: A systematic review. *Environ. Impact Assess. Rev.* **71**, 110–119 (2018).
9. Richardson, M. L. et al. A review of the impact of pipelines and power lines on biodiversity and strategies for mitigation. *Biodivers. Conserv.* **26**, 1801–1815 (2017).
10. Wyszkowska, J., Kobak, J. & Aonuma, H. Electromagnetic field exposure affects the calling song, phonotaxis, and level of biogenic amines in crickets. *Environ. Sci. Pollut. Res.* **30**, 93255–93268 (2023).
11. Tomás, G., Barba, E., Merino, S. & Martínez, J. Clutch size and egg volume in great tits (Parus major) increase under low intensity electromagnetic fields: A long-term field study. *Environ. Res.* **118**, 40–46 (2012).
12. King, D. I., Chandler, R. B., Collins, J. M., Petersen, W. R. & Lautzenheiser, T. E. Effects of width, edge and habitat on the abundance and nesting success of scrub–shrub birds in powerline corridors. *Biol. Conserv.* **142**, 2672–2680 (2009).
13. Jahn, W., Urban, J. L. & Rein, G. Powerlines and wildfires: Overview, perspectives, and climate change: Could there be more electricity blackouts in the future?. *IEEE Power Energy Mag.* **20**, 16–27 (2022).
14. Oloo, F., Safi, K. & Aryal, J. Predicting migratory corridors of white storks, *Ciconia ciconia*, to enhance sustainable wind energy planning: A data-driven agent-based model. *Sustainability* **10** (2018).
15. Roscioni, F. et al. A modelling approach to infer the effects of wind farms on landscape connectivity for bats. *Landsc. Ecol.* **29**, 891–903 (2014).
16. Colman, J. E., Eftestøl, S., Tsegaye, D., Flydal, K. & Mysterud, A. Is a wind-power plant acting as a barrier for reindeer Rangifer tarandus tarandus movements? (2012).
17. Rieucau, G., Vickery, W. L., Doucet, G. J. & Laquerre, B. An innovative use of white-tailed deer (*Odocoileus virginianus*) foraging behaviour in impact studies. **85** (2007).
18. Dinkins, J. B., Conover, M. R., Kirol, C. P., Beck, J. L. & Frey, S. N. Greater Sage-Grouse (*Centrocercus urophasianus*) select habitat based on avian predators, landscape composition, and anthropogenic features. *The Condor* (2014).

19. Bartzke, G. S., May, R., Bevanger, K., Stokke, S. & Røskaft, E. The effects of power lines on ungulates and implications for power line routing and rights-of-way management.
20. Fernie, K. J. & Reynolds, S. J. The effects of electromagnetic fields from power lines on avian reproductive biology and physiology: A review. *J. Toxicol. Environ. Health Part B* **8**, 127–140 (2005).
21. Mahmoodbr, M., Beebr, O. & Subramaniam, M. Effects of electromagnetic field on the nitrogen, protein and chlorophyllcontent and peroxidase enzyme activity in oil palm (*Elaeis guineensis* Jacq.) leaves. *Emir. J. Food Agric.* **25**, 471 (2013).
22. Tarko, R., Kochanowicz, K., Nowak, W., Szpyra, W. & Wszołek, T. Reduction of the environmental impact of electric field generated by high voltage power transmission lines. *Energies* **14**, 6388 (2021).
23. Jin, Y., Behrens, P., Tukker, A. & Scherer, L. Biodiversity loss from freshwater use for China's electricity generation. *Environ. Sci. Technol.* **56**, 3277–3287 (2022).
24. Zhang, F., Jia, Y., Liu, X., Li, T. & Gao, Q. Application of MSPA-MCR models to construct ecological security pattern in the basin: A case study of Dawen River basin. *Ecol. Indic.* **160**, 111887 (2024).
25. Skarin, A., Nellemann, C., Rönnegård, L., Sandström, P. & Lundqvist, H. Wind farm construction impacts reindeer migration and movement corridors. *Landsc. Ecol.* **30**, 1527–1540 (2015).
26. Weiskopf, S. R. et al. A conceptual framework to integrate biodiversity, ecosystem function, and ecosystem service models. *BioScience* **72**, 1062–1073 (2022).
27. Rey, P. J. et al. Landscape-moderated biodiversity effects of ground herb cover in olive groves: Implications for regional biodiversity conservation. *Agric. Ecosyst. Environ.* **277**, 61–73 (2019).
28. Lu, J., Jiao, S., Han, Z. & Yin, J. Promoting ecological restoration of deeply urbanized hilly areas: A multi-scale ecological networks approach. *Ecol. Indic.* **154**, 110655 (2023).
29. Liu, W., Xu, H., Zhang, X. & Jiang, W. Green infrastructure network identification at a regional scale: The case of Nanjing metropolitan area, China. *Forests* **13**, 735 (2022).
30. Wang, J., Rienow, A., David, M. & Albert, C. Green infrastructure connectivity analysis across spatiotemporal scales: A transferable approach in the Ruhr Metropolitan Area, Germany. *Sci. Total Environ.* **813**, 152463 (2022).
31. Avon, C. & Bergès, L. Prioritization of habitat patches for landscape connectivity conservation differs between least-cost and resistance distances. *Landsc. Ecol.* **31**, 1551–1565 (2016).
32. Barrows, C. W., Fleming, K. D. & Allen, M. F. Identifying habitat linkages to maintain connectivity for corridor dwellers in a fragmented landscape. *J. Wildl. Manag.* **75**, 682–691 (2011).
33. Rabinowitz, A. & Zeller, K. A. A range-wide model of landscape connectivity and conservation for the jaguar, *Panthera onca*. *Biol. Conserv.* **143**, 939–945 (2010).
34. Xu, Z. et al. Construction of international important wetland white-headed crane ecological corridor in Chongming Dongtan, China. *Ecol. Indic.* **149**, 110156 (2023).
35. Botequilha Leitão, A. & Ahern, J. Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landsc. Urban Plan.* **59**, 65–93 (2002).
36. Sun, R., Xie, W. & Chen, L. A landscape connectivity model to quantify contributions of heat sources and sinks in urban regions. *Landsc. Urban Plan.* **178**, 43–50 (2018).
37. Vogt, P. et al. Mapping landscape corridors. *Ecol. Indic.* **7**, 481–488 (2007).
38. Jiménez-Alfaro, B., Chytrý, M., Mucina, L., Grace, J. B. & Rejmánek, M. Disentangling vegetation diversity from climate–energy and habitat heterogeneity for explaining animal geographic patterns. *Ecol. Evol.* **6**, 1515–1526 (2016).
39. Lin, Q. et al. Remotely sensed ecological protection redline and security pattern construction: A comparative analysis of Pingtan (China) and Durban (South Africa). *Remote Sens.* **13**, 2865 (2021).
40. Shen, Z. et al. A static and dynamic coupling approach for maintaining ecological networks connectivity in rapid urbanization contexts. *J. Clean. Prod.* **369**, 133375 (2022).
41. Evans, J. & Geerken, R. Discrimination between climate and human-induced dryland degradation. *J. Arid Environ.* **57**, 535–554 (2004).
42. 环境影响评价技术导则-输变电工程.
43. Li, J. & Zhang, Y. Construction and optimization of wilderness networks in the southwest border biodiversity tropical areas based on naturalness and connectivity. Preprint at https://doi.org/10.21203/rs.3.rs-3931927/v1 (2024).
44. Klunder, G. The search for the most eco-efficient strategies for sustainable housing construction; Dutch lessons. *J. Hous. Built Environ.* **19**, 111–126 (2004).
45. Chen, L., Fu, B. & Zhao, W. Source-sink landscape theory and its ecological significance. *Front. Biol. China* **3**, 131–136 (2008).
46. Chetkiewicz, C.-L.B. & Boyce, M. S. Use of resource selection functions to identify conservation corridors. *J. Appl. Ecol.* **46**, 1036–1047 (2009).
47. Adriaensen, F. et al. The application of 'least-cost' modelling as a functional landscape model. *Landsc. Urban Plan.* **64**, 233–247 (2003).
48. Grande, T. O., Aguiar, L. M. S. & Machado, R. B. Heating a biodiversity hotspot: connectivity is more important than remaining habitat. *Landsc. Ecol.* **35**, 639–657 (2020).
49. Saura, S. & Pascual-Hortal, L. A new habitat availability index to integrate connectivity in landscape conservation planning: Comparison with existing indices and application to a case study. *Landsc. Urban Plan.* **83**, 91–103 (2007).
50. Peng, B., Yang, J., Li, Y. & Zhang, S. Land-use optimization based on ecological security pattern—A case study of Baicheng, Northeast China. *Remote Sens.* **15**, 5671 (2023).
51. Wang, Y., Zhang, L. & Song, Y. Study on the construction of the ecological security pattern of the Lancang river basin (Yunnan section) based on InVEST-MSPA-circuit theory. *Sustainability* **15**, 477 (2022).
52. Zhai, T. & Huang, L. Linking MSPA and circuit theory to identify the spatial range of ecological networks and its priority areas for conservation and restoration in urban agglomeration. *Front. Ecol. Evol.* **10**, 828979 (2022).
53. Hou, Q. et al. Smart city oriented ecological corridor layout of Sanshui River Basin in arid area of Loess Plateau. *Sustain. Energy Technol. Assess.* **44**, 100993 (2021).
54. Su, J., Yin, H. & Kong, F. Ecological networks in response to climate change and the human footprint in the Yangtze River Delta urban agglomeration, China. *Landsc. Ecol.* **36**, 2095–2112 (2021).
55. Ewers, R. M. & Didham, R. K. Confounding factors in the detection of species responses to habitat fragmentation. *Biol. Rev.* **81**, 117–142 (2006).
56. Kuvlesky, W. P. Jr. et al. Wind energy development and wildlife conservation: Challenges and opportunities. *J. Wildlife Manag.* **71**, 2487–2498 (2007).
57. Vermunt, D. A. Towards biodiversity conservation in natural resource-intensive sectors: Understanding dynamics of social-ecological transformations: (Utrecht University, 2022). https://doi.org/10.33540/968.
58. Newell, R., Dale, A. & Lister, N.-M. An integrated climate-biodiversity framework to improve planning and policy: An application to wildlife crossings and landscape connectivity. *Ecol. Soc.* (2022).

Acknowledgements

We thank State Grid Shandong Electric Power Research Institute for giving financial support for this study. In addition, we would like to thank the anonymous reviewers who have helped to improve the paper.

Author contributions

Conceptualization, Z.L. and L.J.; methodology, J.Y.; software, Z.L.; validation, Z.L., Q.W. and D.S.; formal analysis, Z.L. and J.L.; investigation, J.Y.; resources, Q.W.; data curation, Z.L.; writing—original draft preparation, Z.L.; writing—review and editing, J.Y. and L.J.; All authors have read and agreed to the published version of the manuscript.

Funding

This work was supported by the Research Program of State Grid Shandong Electric Power Research Institute (No. 2023A-133).

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to Z.L. or L.J.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open Access This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

© The Author(s) 2025





MAINE'S WILDLIFE ACTION PLAN

Prepared by

Maine Department of Inland Fisheries Wildlife

in collaboration with

Maine's Conservation Partners
September 2015





MAINE DEPARTMENT OF INLAND FISHERIES AND WILDLIFE

The Department of Inland Fisheries and Wildlife is established to preserve, protect and enhance the inland fisheries and wildife resources of the State; encourage the wise use of these resources; ensure coordinated planning for the future use and preservation of these resources, and provide for effective management of these resources.

Maine Department of Inland Fisheries and Wildlife
41 State House Station
284 State Street
Augusta, ME 04333
207-287-5202

RECOMMENDED CITATION

Maine Dept. of Inland Fisheries and Wildlife. 2015. Maine's wildlife action plan. Maine Dept. of Inland Fisheries and Wildlife, Augusta, ME.

PROJECT FUNDING

Development of Maine's Wildlife Action Plan was supported by

- Maine's Endangered and Nongame Wildlife Fund ("Chickadee Checkoff" and "Loon Plate" contributions) administered by the Maine Dept. of Inland Fisheries and Wildlife

- Wildlife and Sports Fisheries Restoration funds (State Wildlife Grants, Pittman - Robertson Federal Aid in Wildlife Restoration, and Dingell - Johnson Federal Aid in Sport Fish Restoration) administered by the U.S. Fish and Wildlife Service

We are indebted to the donations of time and resources by Maine's Plan partners and citizens.

COVER PHOTO CREDITS

Humpback Whale (*Megaptera novaeangliae;* SGCN Priority 1 + Federal/State Endangered) – © John, Hyde, Wild Things Photography
Golden Eagle (*Aquila chrysaetos*; SGCN Priority 2 + State Endangered – © Terry Heitz, Avian Haven Wildlife Rehabilitation Clinic
Boreal Snaketail Dragonfly (*Ophiogomphus colubrinus*); SGCN Priority 1 + State Threatened – © John Abbott
Wood Turtle (*Glyptemys insculpta*); SGCN Priority 1 + State Special Concern) – © Jonathan Mays, Maine Department of Inland Fisheries and Wildlife
Brook Trout (*Salvelinus fontinalis*, SGCN Priority 3 + Maine "heritage" species) - © Merry Gallagher, Maine Department of Inland Fisheries and Wildlife
New England Cottontail (*Sylvilagus transitionalis*; SGCN Priority 1 + State Endangered) – Tom Barnes, U.S. Fish and Wildlife Service

Acknowledgements

The preparation of Maine's 2015 Wildlife Action Plan could not have been accomplished without the assistance of many devoted individuals who contributed their expertise and passion to this effort. It is risky to recognize individuals -- someone may inadvertently be omitted. Nevertheless, we feel compelled to make an honest attempt to identify all who made significant contributions.

The Maine Dept. of Inland Fisheries and Wildlife (MDIFW) cannot adequately express its gratitude to Maine's Conservation Partners -- 158 individuals representing 102 unique organizations and members of the public (Element 7/8, Table 7/8-2) -- for their contributions. Many graciously eked out time from their busy schedules to attend five day-long partner meetings, shaping Elements 1-5 of the 2015 Action Plan. They provided criticism, inspiration, and encouragement.

We extend our deep appreciation to those serving on the Wildlife Action Plan Steering Committee. They served as "mission control" during the past year, meeting monthly to monitor the overall accomplishment of the Action Plan, providing invaluable insight. They reviewed MDIFW's proposed strategies for developing the Action Plan prior to implementation with the Conservation Partners, assisted with planning Partner meeting agendas and presentations, and perhaps most importantly, helped us distill key suggestions for Action Plan improvement from among diverse Partner feedback.

2015 Maine Wildlife Action Plan Steering Committee

Barry Burgason - Maine Forest Products Council
Tom Doak - Small Woodland Owners Association of Maine
Molly Docherty - Maine Natural Areas Program
Claire Enterline - Maine Dept. of Marine Resources
Tim Glidden - Maine Coast Heritage Trust
Mitch Hartley - U.S. Fish and Wildlife Service
Emily Norton - Maine Coastal Program
Jeff Norment - Natural Resources Conservation Service, U.S. Dept. of Agriculture
Sally Stockwell - Maine Audubon Society
Angela Twitchell - Brunswick-Topsham Land Trust
Jed Wright - U.S. Fish and Wildlife Service
Barbara Vickery - The Nature Conservancy

Judy Camuso, Amanda Shearin, Nate Webb, Charlie Todd, Phillip deMaynadier, and Mark Stadler, all from MDIFW, provided technical, administrative, and logistical support to the Steering Committee.

MDIFW is grateful to staff from the Maine Dept. of Marine Resources (MDMR), the Maine Natural Areas Program (MNAP), and MDIFW who served on the Wildlife Action Plan Coordination Team. The team met bi-weekly through many long months managing the development of the Action Plan and coordinating with the Steering Committee and Conservation Partners to ensure that all were involved in its timely preparation.

2015 Maine Wildlife Action Plan Coordination Team

Judy Camuso - Wildlife Division Director, MDIFW
Andy Cutko - Ecologist, MNAP
Phillip deMaynadier - Wildlife Biologist, MDIFW
Claire Enterline - Fishery Biologist, MDMR
Amanda Shearin - Wildlife Planner and Biologist, MDIFW
Mark Stadler - Wildlife Action Plan Coordinator, MDIFW (retired)
Charlie Todd - Endangered and Threatened Species Coordinator, MDIFW
Nate Webb - Special Projects Biologist, MDIFW

Members of the Coordination Team served as the principle authors of the Action Plan, taking on the daunting task of filling in the details and share ultimate responsibility for its content. We greatly appreciate their contributions.

Element 1	Phillip deMaynadier, Claire Enterline, Charlie Todd
Element 2	Andy Cutko, Emily Norton, Slade Moore (Maine Coastal Program)
Element 3	Nate Webb
Element 4	Amanda Shearin
Elements 5/6	Amanda Shearin, Nate Webb
Elements 7/8	Amanda Shearin, Mark Stadler

We thank Ray "Bucky" Owen for authoring the Action Plan's Foreword. His dedication to fish and wildlife conservation in Maine is legendary.

Staff from MDIFW and MDMR compiled the lists of wildlife species and updated the 2005 process for identifying Species of Greatest Conservation Need (SGCN). MDIFW bird staff specialists included Brad Allen, Lindsay Tudor, Tom Hodgman, Danielle D'Auria, Erynn Call, and Kelsey Sullivan. MDIFW herpetofauna and invertebrate specialists included Phillip deMaynadier, Beth Swartz, and Derek Yorks. MDIFW mammal staff specialists included Wally Jakubas, Jen Vashon, and Cory Mosby. Merry Gallagher provided MDIFW fish expertise. Claire Enterline and Emily Norton compiled MDMR's SGCN tables with invaluable guidance from MDMR biologists Margaret Hunter (marine invertebrates), Sally Sherman (groundfish, skates), Erin Summers (whales, porpoise, turtles), Jason Overlock (Atlantic Salmon), and Gail Wippelhauser (diadromous fish). Thomas Trott from Suffolk University (marine invertebrates) and James Sulikowski from the University of New England (sharks and skates) shared their expertise. All members of the MDIFW Habitat Group made major contributions: Jason Czapiga developed Maine's SWAP database and generated all SGCN, habitat, and stressor data reports; Don Katnik produced the SGCN distribution maps; Mary-Ellen Wickett aided database design and website management; and Amy Meehan assisted in GIS graphics. Don Katnik, Jason Czapiga, Andy Cutko, Merry Gallagher, Claire Enterline, Emily Norton, and Slade Moore developed and fine-tuned Maine's habitat data. All provided critical review of this document as it was developed.

We are grateful for the thoughtful suggestions and observations submitted by Conservation Partners, Maine citizens, and individuals residing outside of Maine during the public comment period.

Our appreciation to Bob Stratton and Barbara Vickery who provided critical review of the first draft and to Diana Harper who compiled the first draft of the Action Plan and who also formatted and compiled the final document.

We thank MaryEllen Wicket, Jason Czapiga, and Ralph Brissette for website support.

Key MDIFW administrators - Chandler Woodcock, Jim Connolly, Judy Camuso, Shawn Haskell, and Mike Brown - demonstrated an early and steadfast commitment to the development of the Action Plan, making it the highest priority for all involved and by providing comments, suggestions, and guidance.

Finally, we wish to recognize Dee Blanton and Mitch Hartley of the USFWS, for providing guidance and encouragement along the way – thank you. SWAP coordinators and state agency representatives throughout the Northeast Association of Fish and Wildlife Agencies shared Plan development and regional coordination strategies.

Maine's 2015 Wildlife Action Plan is a testament to the dedication, passion, tenacity, and expertise of all who made it possible. It was an honor and privilege to work with all of the Conservation Partners involved, and we look forward to fruitful collaboration during the Plan's *implementation* from 2015 through 2025.

Table of Contents

Acknowledgements i

Table of Contents 1
- Element 1: Species of Greatest Conservation Need 2
- Element 2: Key Habitats and Natural Communities 3
- Element 3: Problems Affecting SGCN and Their Habitats 4
- Element 4: Conservation Actions 5
- Element 5: Monitoring 6
- Element 6: Periodic Review 6
- Element 7: Coordination with Partners 7
- Element 8: Public Participation 7

Foreword 8

Introduction 10
- Welcome to Maine 10
- State Authority for Wildlife and Fisheries Management 11
- The State Wildlife Grant Program 12
- The Value of Maine's Wildlife Action Plan 13
- Roadmap to the Plan's Eight Elements 14
- Key to Acronyms 15
- Literature Cited and References 16

Executive Summary 18
- Introduction 18
- Element 1: Species of Greatest Conservation Need 19
- Element 2: Key Habitats and Natural Communities 19
- Element 3: Problems Affecting SGCN and Their Habitats 20
- Element 4: Conservation Actions 21
- Element 5: Monitoring 21
- Element 6: Periodic Review 21
- Element 7: Coordination with Partners 22
- Element 8: Public Participation 22

ELEMENT 1: SPECIES OF GREATEST CONSERVATION NEED

1.0 Abstract....1

1.1 Introduction....2

1.2 Significant Changes from Maine's 2005 Plan....3

1.3 An Overview of Maine's Fauna and SGCN....4
1.3.1 Mammals (Non-Marine)....5
1.3.2 Birds....7
1.3.3 Reptiles and Amphibians....10
1.3.4 Freshwater (Non-Diadromous) Fish....11
1.3.5 Inland and Freshwater Invertebrates....12
1.3.6 Marine Fauna (Except Birds)....16

1.4 Distribution of Maine's SGCN and Associated Habitats....19
1.4.1 Methodology for Mapping Element 1 – SGCN Distributions....20
1.4.2 Methodology for Mapping Element 2 – Habitats....20
1.4.3 Species Conservation Range Maps....21
1.4.4 SGCN Distribution Synthesis....22

1.5 Designation Criteria for Maine's SGCN - 2015....26
1.5.1 Priority 1 (Highest Priority) SGCN....26
1.5.2 Priority 2 (High Priority) SGCN....27
1.5.3 Priority 3 (Moderate Priority) SGCN....28

1.6 Maine's 2015 SGCN....31

1.7 Literature Cited and References....60

1.8 Appendices....64

ELEMENT 2: KEY HABITATS AND NATURAL COMMUNITIES

2.0 Abstract....1

2.1 Significant Changes from Maine's 2005 Plan....1

2.2 Landscape Overview of Maine....2
2.2.1 Climate....3
2.2.2 Physiography....3

2.3 Habitat Classifications....4
2.3.1 Northeast Terrestrial Habitat Classification System....4
2.3.2 Coastal and Marine Classification System....7

2.4 Coastal and Marine Ecosystems....9

2.5 Freshwater Aquatic Ecosystems....10

2.6 Terrestrial and Wetland Ecosystems....11

2.7 Conservation Land in Maine....13

2.8 Importance of Habitats to SGCN....15

2.9 Maine Flora AND Exemplary Natural Communities....18

2.10 Focus Areas of Ecological Significance....19

2.11 Literature Cited and References....21

ELEMENT 3: PROBLEMS AFFECTING SGCN AND THEIR HABITATS

3.0 Abstract 1

3.1 Introduction 2
3.1.1 Significant Differences from Maine's 2005 Plan 2
3.1.2 Assigning Stressors – General Considerations 3
3.1.3 Stressor Classification and Characteristics 3
3.1.4 Assigning and Prioritizing Stressors for SGCN 10
3.1.5 Assigning Stressors for Habitats 10

3.2 Stressors to SGCN 11

3.3 Stressorts to Habitats 17

3.4 Literature Cited and References 19

ELEMENT 4: CONSERVATION ACTIONS

4.0 Abstract....1

4.1 Introduction....2
4.1.1 Significant Differences from Maine's 2005 Plan....2
4.1.2 General Considerations for Development of Conservation Actions....3

4.2 SGCN Conservation Actions....6
4.2.1 SGCN Action Background....6
4.2.2 Development of SGCN Conservation Actions....6
4.2.3 Summary of SGCN Conservation Actions....7

4.3 Habitat Conservation Actions....36
4.3.1 Habitat Action Background....36
4.3.2 Development of Habitat Conservation Actions....36
4.3.3 Summary of Habitat Conservation Actions....41
4.3.4 Development of Habitat Themes....84

4.4 Programmatic Conservation Actions....90

4.5 An Approach to Prioritizing Conservation Efforts....93
4.5.1 Uses for Prioritization Considerations....93
4.5.2 Potential Criteria for Prioritizing Conservation Actions....93

4.6 Literature Cited....95

ELEMENT 5: MONITORING

ELEMENT 6: PERIODIC REVIEW

5/6.0 Abstract 1

5/6.1 Introduction 1
5/6.1.1 Significant Differences from Maine's 2005 Plan 1

5/6.2 Monitoring SGCN 2
5/6.2.1 Birds 3
5/6.2.2 Reptile, Amphibians, and Invertebrates 16
5/6.2.3 Inland Fish 17
5/6.2.4 Mammals 17
5/6.2.5 Marine Fauna 30

5/6.3 Monitoring SGCN Habitats 41
5/6.3.1 Statewide Habitat and Conservation Action Monitoring 46

5/6.4 Progammatic Monitoring 48

5/6.5 Plans for Revision 50

5/6.6 Literature Cited and References 51

ELEMENT 7: COORDINATION WITH PARTNERS

ELEMENT 8: PUBLIC PARTICIPATION

7/8.0 Abstract....1

7/8.1 Introduction....1
7/8.1.1 Significant Differences from Maine's 2005 Plan....2

7/8.2 Action Plan Coordination Team / Action Plan Steering committee....3
7/8.2.1 Action Plan Coordination Team....3
7/8.2.2 Action Plan Steering Committee....4
7/8.2.3 SWAP Review and Update Charter....5

7/8.3 Coordination with Conservation Partners....5
7/8.3.1 Coordination with Federal Partners....9
7/8.3.2 Coordination with State Partners....9
7/8.3.3 Coordination with Tribal Partners....9
7/8.3.4 Coordination with Public and Local Partners, Including Non-governmental Organizations....9

7/8.4 Public Engagement....27
7/8.4.1 Public Presentations....27
7/8.4.2 Brochure....27
7/8.4.3 Peer Review....27
7/8.4.4 Maine Action Plan Webpage....28
7/8.4.5 Email Correspondence....28
7/8.4.6 30-Day Comment Period....28

7/8.5 Public and Partner Engagement During Plan Implementations....37

7/8.6 Literature Cited and References....40

7/8.7 Appendices....41

Foreword

It is difficult to believe that it has been 10 years since Maine's first Wildlife Action Plan was written. Initiated in 2001, the State Wildlife Grants Program allocated funds to states that have an approved Plan. These funds, matched by state dollars, provide ongoing support for monitoring, research, management, and habitat protection for Species of Greatest Conservation Need (SGCN), many of which are species of special concern or threatened and endangered. Most of these species lack financial support except through special programs, such as the Federal Endangered Species Act, or state programs such as the Chickadee Check-Off or the Loon Plate, both of which are unpredictable and declining sources of revenue.

Maine contains a wealth of ecosystems from the spruce forests of the north to vast coastal areas; from high mountains to thousands of lakes, ponds, and streams. This diversity of ecosystems supports thousands of associated species. It is the wealth of this diversity and its conservation that this plan addresses in detail.

The climate gradient in Maine, spanning four degrees of latitude, is equal to that extending from Poland to northern Finland, a distance covering 20 degrees of latitude; it is no wonder that we are blessed with such a diversity of species. Numerous species, such as the New England Cottontail, reach their northern range limit in central or southern Maine, while others, such as the Canada Lynx, are restricted to northern Maine.

The leadership of the Maine Department of Inland Fisheries and Wildlife (MDIFW) and its Steering Committee in developing this Plan has been superb. Their ability to bring together scores of participants ranging from state and federal agencies, Native Americans, and a wide diversity of NGOs, testifies to their leadership and the importance of this Plan. The Steering Committee, representing a wide spectrum of interests, contributed countless hours to the success of the Plan and their advisory role should be continued officially throughout the life of the Plan. Their help in guiding priorities, considering emerging issues, and developing partnerships will be essential over the next 10 years.

The 2005 Plan was a giant step in guiding actions to understand and conserve a plethora of species that were poorly understood or lacked funding for effective conservation. It chartered a greatly expanded area of responsibility and action for MDIFW. Citizen scientists participated in numerous statewide surveys covering everything from butterflies and herons to freshwater mussels. Many of these volunteers are state and national experts and the data are excellent. As a result of this information, specific conservation actions are in place for these species and their habitats. The 2005 Plan also highlighted the Beginning with Habitat (BwH) initiative, which is a voluntary, non-regulatory program. More than 100 towns and NGO's have used BwH data compiled by MDIFW and the Maine Natural Areas Program to prioritize and conserve important habitats containing rare ecosystems and associated SGCN. These efforts are concentrated in southern and central regions and have been highly successful.

The 2015 Plan builds on the achievements of the earlier Plan but is much more comprehensive; the number of SGCN species almost doubles in the current Plan. This is partly due to the excellent survey and monitoring that occurred over the past 10 years providing MDIFW with a greater understanding of the status of many poorly understood species. However, the greatest number of new species occurs in marine or estuarine habitats poorly documented in the 2005

Plan. The Maine Department of Marine Resources has statutory responsibility for all marine and estuarine species, including migratory fish. Their participation in the 2005 Plan was limited; however, they have been an integral part of the team developing the current Plan and have provided a wealth of information and conservation needs on numerous poorly known species.

Based on vulnerability, a total of 58 species are designated of highest priority. Timely conservation measures presented in the Plan can avoid further declines in these and other species. The Plan is easy to follow. To check on a species' status, simply click on it in Table 1-3 and all of the data are available, including qualification criteria, habitat associations, stressors, conservation actions, and range maps. The detail is amazing and represents a quantum leap in our understanding of many species. The Plan emphasizes habitat stressors as well as stressors to individual SGCN. In doing this, groups of species and guilds are incorporated into the conservation actions. Although plants are not dealt with individually, conservation actions dealing with habitats and ecosystems will include many of the state's rare plant species.

Finally, there is the issue of funding the key components of this Plan. Currently, there is no long term, predictable funding at the state or federal level that parallels the Federal Aid Programs for harvested species. The Association of Fish and Wildlife Agencies has formed a Blue Ribbon Committee on Sustaining America's Diverse Fish and Wildlife Resources under their Teaming With Wildlife theme to address this important issue. Their success in this effort will influence greatly the ability of Maine and other states to conserve the vast majority of species under their jurisdiction. All of us will need to support this in the future.

In summary, Maine's 2015 Wildlife Action Plan is a tribute to all of the conservation partners and their extraordinary efforts to gather the vast quantities of data on many rare or poorly known species, and chart a path for their conservation. The Plan is exhaustive, well presented, and easy to follow and will guide the state for years to come.

Congratulations are due to everyone who made this Plan a reality.

Ray "Bucky" Owen
Professor Emeritus, University of Maine, Orono
Commissioner, Maine Dept. of Inland Fisheries and Wildlife, 1993-1997

Introduction

WELCOME TO MAINE

Located at the northeast tip of the United States, Maine is a relatively large and very rural state by eastern standards. It spans 320 miles from north-to-south and 210 miles east-to-west at its full extent. Maine lies halfway between the equator and the North Pole. It is the only state in the continental U.S. more connected to Canada than its border with other states. The total area (33,315 square miles) nearly equals that of the other four New England states combined. The 2013 U.S. census reported a human population of only 1.33 million in Maine, or 43 people per square mile: the lowest population density in the East.



Tumbledown Mountain Maine.
© Phillip deMaynadier

Maine is a land rich in contrasts between the boreal and temperate, freshwater and saltwater, upland and wetland, and alpine and lowlands. The predominant feature across this diverse landscape is 17.5 million acres of forests that cover 89% of Maine's land area. Woodlands are interspersed with rugged mountains; more than 5,600 lakes and ponds; 5,000,000 acres of wetlands; 31,800 miles of rivers and streams; 4,100 miles of coastline; and 4,613 coastal islands and ledges (Brandes 2001, Gawler et al. 1996). Maine is the most heavily forested state in the nation, but also boasts some of the most significant grassland and agricultural lands in New England.

This mosaic of diverse physical settings supports a wide diversity of wildlife. Islands in the Gulf of Maine showcase one of the most unique blends of seabird nesting colonies along the East Coast, including rare species such as Roseate and Arctic Terns, Atlantic Puffin, and Razorbill. Maine's relatively clean, free-flowing rivers sustain some of the best remaining populations of rare freshwater mussels and dragonflies in the East; host globally rare endemics, such as the Tomah Mayfly and Roaring Brook Mayfly; and support a distinct population segment of the federally Endangered Atlantic Salmon. Maine's mountains and forested habitats host a significant portion of the global breeding habitat of neotropical migrant birds such as the Bicknell's Thrush and Black-throated Blue Warbler. The state has some of the best examples of Pitch Pine-Scrub Oak forest remaining in New England, which host a suite of globally rare plants and invertebrates.

Maine is in an ecological transition zone, and its wildlife resources are a convergence of species that are at or approaching the northern or southern limit of their ranges. The species most familiar to us – birds (423 species), non-marine mammals (61 species), reptiles (17 species), amphibians (18 species), inland fish (39 species), and marine species (>280 fishes, mammals, and other chordates) – actually comprise less than two percent of the known wildlife species in the state. Experts have documented over 15,000 species of invertebrates, 2,100 species of plants, 310 species of phytoplankton, 271 species of macrophytes, and 3,500 species of fungi,

but they believe many times these numbers actually exist (McCollough et al. 2003, D. Gilbert pers. comm.). This array of flora and fauna is particularly impressive when one considers that only a handful of species were present just 15,000 years ago when a mile-high sheet of ice covered the state.

Fish and wildlife play an important role in the lives of Maine people as they provide a source of enjoyment, recreation, and employment. Maine's quality of life, its traditional "outdoor" values, and its economy, particularly its rural economy, are strongly shaped by the diversity and abundance of its fish and wildlife. The Maine Department of Inland Fisheries and Wildlife (MDIFW) and the Maine Department of Marine Resources (MDMR) are the state agencies in which the public has entrusted its concern for Maine's fish and wildlife.



Birch Point State Park, Maine. © Mark Stadler

STATE AUTHORITY FOR WILDLIFE AND FISHERIES MANAGEMENT

The Maine Department of Inland Fisheries and Wildlife (MDIFW) is responsible for the stewardship of Maine's inland fisheries and wildlife resources. MDIFW conducts its management programs under the guidance of the legislature's Joint Standing Committee on Inland Fisheries and Wildlife and with the advice and consent of the Fish and Wildlife Advisory Council: a ten-member citizen's advisory group whose members are appointed by the governor and subject to legislative confirmation. MDIFW partners with the U.S. Fish and Wildlife Service (USFWS) for management of 'federal trust species:' notably migratory birds, federally-listed Endangered or Threatened (E/T) species, and species that are candidates for E/T listing.

Maine has had laws protecting its fish and wildlife since 1830. This early enforcement effort was the birth of the MDIFW (then Department of Inland Fisheries and Game). Although MDIFW's mission has always included protection of species not pursued for food or sport, there has been a continual shift in its focus from that of a state agency concerned mostly with the administration of laws dealing with hunting and fishing to one with considerable responsibility for the conservation and enhancement of all the inland fisheries and wildlife resources of the state.

During the 1970s, the Maine Legislature broadened the MDIFW mission. It enacted laws pertaining to E/T species and nongame wildlife, which clearly established that MDIFW had the authority to protect, maintain, and enhance all fish and wildlife species in the state, as well as their habitat. To reflect this, the legislature changed the name of the Department from 'Inland Fisheries and Game' to 'Inland Fisheries and Wildlife.' Beginning in the 1990s, MDIFW mainstreamed nongame responsibilities throughout its Bureau of Resource Management and these are now widely integrated throughout MDIFW's work program.

The Maine Department of Marine Resources (MDMR) functions to conserve and manage marine and estuarine resources; to conduct and sponsor scientific research; to promote and develop Maine's coastal fishing industries; to advise and cooperate with local, state, and federal officials concerning activities in coastal waters; and to implement, administer, and enforce the laws and regulations necessary for these purposes. It is responsible for the management of Maine's marine resources from the high-water mark out to three nautical miles from the outermost islands lying offshore in the Gulf of Maine.



Rockport Harbor, Maine. © Mark Stadler

Management responsibilities follow guidance from the state legislature and the MDMR Advisory Council: 15 representatives from coastal fishing industries who are appointed by the governor and subject to legislative confirmation. The legislature directs development of state policy, and through the Joint Standing Committee on Marine Resources, oversees legislation regarding the conservation and development of marine resources. MDMR partners with the National Marine Fisheries Service for management of 'federal trust' fauna: inter-jurisdictional fish, marine mammals, and other species of concern including federally listed E/T species.

THE STATE WILDLIFE GRANT PROGRAM

As the responsibilities of MDIFW have evolved over time so has the method of funding fish and wildlife conservation and management activities. Like other state fish and wildlife agencies, MDIFW programs rely heavily on federal aid distributed to states as established by the Wildlife Restoration (Pittman - Robertson) Act enacted in 1937 and the Sport Fish Restoration (Dingell - Johnson) Act passed in 1950. These funds are derived from federal excise taxes on firearms, ammunition, fishing equipment and tackle. The USFWS Wildlife and Sport Fisheries Restoration program is critical to state agency partners and the conservation of game fish and wildlife species. A traditional emphasis on habitat management has provided numerous secondary benefits to nongame species as well. Federal funding for E/T species are administered under Section 6 of the Endangered Species Act (ESA): often strategic, but funds are limited.

MDMR has fulfilled its charge to conserve and manage marine and estuarine resources and to conduct and sponsor scientific research with the support of funding sources that have also changed over the years. Since 1984, MDMR has complete projects supported by USFWS Wildlife and Sport Fish Restoration funds (Wallop - Breaux Amendment). With the Federal ESA listing of some marine species, MDMR has conducted work with the aid of National Oceanic and Atmospheric Administration Species Recovery Grants to States (ESA, Section 6). Past programs, like the Species of Concern Grant Program, enabled the MDMR to advance research of non-listed species such as Rainbow Smelt. These opportunities have provided the necessary funds for the agency to complete work on non-commercial species; however, work focusing on many species of conservation need have not been eligible for these programs as they are not federally listed or do not support recreational fisheries.



At the state level, it is clear that stable and secure financial support for nongame and E/T wildlife and fish has not developed for MDIFW or MDMR. The legislature established a voluntary income tax donation 'Chickadee Check-off' in 1984 followed by a conservation registration 'Loon Plate' (1995) and then a 'Sportsman's Plate' (2007) for vehicles as initial sources for program funding. These and other charitable contributions generate >90% of state funds for MDIFW nongame programs and are held in trust as the 'Endangered and Nongame Wildlife Fund'. Profits from a special lottery ticket 'Maine Outdoor Heritage Fund' help support new projects by state resource agencies via a competitive grants program. After 31 years, all state funds reliant on donations have declined, programs for nongame species operate via triage, and the number of E/T species continues to rise.

Recognizing this broad need, Congress created the State Wildlife Grant Program (SWG) in 2002 to help state and tribal resource agencies address conservation for fish and wildlife deemed to be 'Species of Greatest Conservation Need' (SGCN). SWG funds are appropriated annually by Congress and allocated to states by a formula that takes into account each state's size and population.

"Action Plans provide a foundation for the future of wildlife conservation and a stimulus to engage states and federal agencies and other conservation partners to think strategically about their individual and coordinated roles in prioritizing and accomplishing conservation actions."

To be eligible to participate in the SWG program, Congress required all states and territories to develop a statewide Comprehensive Wildlife Conservation Strategy (CWCS), now formally known as a State Wildlife Action Plan (SWAP). Action Plans provide a foundation for the future of wildlife conservation and a stimulus to engage states and federal agencies and other conservation partners to think strategically about their individual and coordinated roles in prioritizing and accomplishing conservation actions. In 2005, states and territories submitted their first round of plans to the U.S. Fish and Wildlife Service (USFWS) for review. Maine's CWCS (http://www.maine.gov/ifw/wildlife/reports/wap.html) was approved as submitted and remains a valuable, comprehensive review.

SWG funds apportioned to Maine totaled $7.6 million during 2001-2014. Projects undertaken with SWG funds (MDIFW 2014) have addressed many SGCN, all geographic areas of the state, and have ranged in scale from ecosystems to subspecies. Projects have varied in length from one to five years. They include baseline surveys and inventories, research, management, and habitat conservation. SWG funds also help support 10 full-time biologist positions. The SWG program has significantly advanced the conservation of Maine's SGCN and continues to play a critical role in minimizing reliance on E/T listings.

THE VALUE OF MAINE'S WILDLIFE ACTION PLAN

Early successes from the first generation of state Action Plans are widely chronicled (Association of Fish and Wildlife Agencies 2011, Cook et al. 2008). A summary of accomplishments from Maine's 2005 plan (MDIFW 2014) reveals the wide array of conservation

benefits for SGCN: population management, habitat management, research, surveys/monitoring, and outreach. Many ongoing efforts and most new initiatives during the past ten years were enhanced or enabled by SWG funding administered by MDIFW as outlined in the 2005 Plan.

This 2015 Action Plan reflects greater expectations for prioritization, performance monitoring, efficiencies, and overall collaboration with conservation partners (Heinz Center 2008, Lauber et al. 2009, Wilkinson et al. 2009). The full document itself is reduced by 70% in length from our 2005 CWCS, but provides a pathway to detailed reports on 378 SGCN, 42 macrogroups, and 38 stressors evaluated in the 2015 Plan. These linked reports are generated by a database. Thus, their content is not static and can be updated periodically during the ten-year horizon of this Plan.

The value of Maine's 2015 Wildlife Action Plan extends far beyond the requirements of the State Wildlife Grant program and beyond the missions of both MDIFW and MDMR. It is an opportunity and challenge for both agencies and their conservation partners to provide effective and visionary leadership in the conservation of all the state's wildlife. Maine's Action Plan is intended to supplement, not duplicate, existing fish and wildlife programs and to target species in greatest need of conservation - species that are indicative of the diversity and health of wildlife in the state - while keeping "common species common."

The Plan addresses the full array of vulnerable wildlife and their habitats in Maine: vertebrates and invertebrates in both terrestrial and aquatic habitats. Maine law defines 'wildlife' as any species of wild, free-ranging fauna including fish and invertebrates that are absent from the jurisdiction for some state agencies. The Plan builds on a long history of public involvement and collaboration among conservation partners. It is meant to be dynamic, responsive, and adaptive. Hence, Maine's Action Plan serves as a solid foundation for the future of wildlife conservation that will help guide the collaborative efforts of state and federal agencies, tribes, conservation partners, and individuals to ensure success.

Maine's conservation partners developed the Wildlife Action Plan through a lengthy participatory process that included the general public. The Plan is non-regulatory. The suite of voluntary species and habitat conservation actions in the Plan complement, but do not compete with, existing work programs and priorities of state agencies and their partners. Indeed, conservation actions will in most cases supplement existing efforts and inspire new initiatives on behalf of Maine' SGCN.

ROADMAP TO THE PLAN'S EIGHT ELEMENTS

Congress identified eight required elements to be addressed in each state's SWAP (Teaming with Wildlife Committee 2003). Congress also directed that strategies identify and focus on "species of greatest conservation need," yet address the "full array of wildlife" and wildlife-related issues, helping to keep common species common. Wildlife Action Plans must address these eight elements:

1. Information on the distribution and abundance of species of wildlife, including low and declining populations as the state fish and wildlife agency deems appropriate, that are indicative of the diversity and health of the state's wildlife;

2. Descriptions of locations and relative condition of key habitats and community types essential to conservation of species identified in (1);

3. Descriptions of problems that may adversely affect species identified in (1) or their habitats, and priority research and survey efforts needed to identify factors that may assist in restoration and improved conservation of these species and habitats;

4. Descriptions of conservation actions proposed to conserve the identified species and habitats and priorities for implementing such actions;

5. Proposed plans for monitoring species identified in (1) and their habitats, for monitoring the effectiveness of the conservation actions proposed in (4), and for adapting these conservation actions to respond appropriately to new information or changing conditions;

6. Descriptions of procedures to review the strategy at intervals not to exceed 10 years;

7. Plans for coordinating the development, implementation, review, and revision of the plan with federal, state, and local agencies and Indian tribes that manage significant land and water areas within the state or administer programs that significantly affect the conservation of identified species and habitats; and

8. Provide an opportunity for public participation in the development of the Wildlife Action Plan.

The founding legislation and subsequent guidance emphasize that broad public participation is an essential element of developing and implementing these plans.

MDIFW led the effort to develop Maine's 2015 Action Plan. The Plan creates a vision for conserving the state's wildlife, and it is much more than an agency plan because of broad participation by dozens of Maine's conservation partners. While each state's strategy will reflect a different set of issues, management needs, and priorities, states are working together to ensure nationwide consistency and a common focus (AFWA 2012, Crisfield et al. 2013).

To facilitate development of Maine's revised Action Plan, MDIFW and partners addressed Elements 1, 2, 3, and 4 in unique chapters. We combined Elements 5 and 6 into a single chapter because of the considerable overlap of monitoring and adaptive management inherent in each. Similarly, we have combined elements 7 and 8 as a single chapter reflecting their mutual emphasis on collaboration and public involvement.

KEY TO ACRONYMS

CWCS	Comprehensive Wildlife Conservation Strategy
ESA	Endangered Species Act
E/T	Endangered and/or Threatened Species
MDIFW	Maine Dept. of Inland Fisheries and Wildlife
MDMR	Maine Dept. of Marine Resources
SGCN	Species of Greatest Conservation Need
SWAP	State Wildlife Action Plan
SWG	State Wildlife Grants (Program)
USFWS	U.S Fish and Wildlife Service

LITERATURE CITED AND REFERENCES

Association of Fish and Wildlife Agencies. 2011. State and tribal wildlife grants program - ten years of success. Washington (DC): Association of Fish and Wildlife Agencies. 72pp. Available online at http://www.fishwildlife.org/files/StateWildlifeGrants_10YearSuccess-Report.pdf

Association of Fish and Wildlife Agencies, Teaming with Wildlife, State Wildlife Action Plan (SWAP) Best Practices Working Group. 2012. Best practices for state wildlife action plans – voluntary guidance to states for revision and implementation. Washington (DC): Association of Fish and Wildlife Agencies. 80pp. Available online at http://teaming.com/sites/default/files/SWAP%20Best%20Practices%20Report%20Nov%202012.pdf

Brandes, K. M. 2001. Moon handbooks: Maine. Avalon Travel Publishing, CA. 651pp.

Crisfield, E. and the Northeast Fish and Wildlife Diversity Technical Committee (NEFWDTC). 2013. The Northeast Lexicon: terminology conventions and data framework for State Wildlife Action Plans in the Northeast region. A report submitted to the Northeast Fish and Wildlife Diversity Technical Committee. Terwilliger Consulting, Inc., Locustville, VA. 94pp. Available online at http://teaming.com/sites/default/files/The%20Northeast%20Lexicon%20Report.pdf

Cook, M. T., D. Chadwick and S. Robertson. 2008. State wildlife action plans: from vision to on-the-ground action. Association of Fish and Wildlife Agencies, Washington DC. 116pp. Available online at http://teaming.com/sites/default/files/SWAP%20From%20Vision%20to%20on%20the%20Ground%20Report.pdf

Gawler, S. C., J. J. Albright, P. D. Vickery, and F. C. Smith. 1996. Biological diversity in Maine – an assessment of status and trends in the terrestrial and freshwater landscape. Maine Natural Areas Program, Department of Conservation, Augusta, ME. 80pp plus appendices.

Heinz Center. 2008. Measuring results of the state wildlife action plans. Washington, DC. 46pp. Available online at http://teaming.com/sites/default/files/Measuring%20the%20Results%20of%20the%20SWAP%20Report%202008.pdf

Lauber, T. B., R. C. Stedman, D. J. Decker, and B. A. Knuth. 2009. Using state wildlife action plans to achieve your conservation goals through collaboration. HDRU Series No. 09-5, Cornell Univ., Ithaca NY. 22pp. Available online at http://teaming.com/sites/default/files/Using%20SWAP%20to%20Achieve%20Collaboration%202009.pdf

Maine Department of Inland Fisheries and Wildlife (MDIFW). 2014. Maine's State Wildlife Grant Program - 10 years of enhanced wildlife conservation. 14pp. Report available online at http://www.maine.gov/ifw/wildlife/reports/MWAP2015_Meetings.html

McCollough, M. A., Todd, B. Swartz, P. deMaynadier, and H. Givens. 2003. Maine's Endangered and Threatened Wildlife. Maine Department of Inland Fisheries and Wildlife, Augusta, ME. 117pp.

Teaming With Wildlife Committee. 2003. State wildlife conservation strategies: eight required elements. Association of Fish and Wildlife Agencies, Washington, DC. 2pp. Available online at http://www.teaming.com/swap-overview

Wilkinson, J. B., J. M. McElfish, R. Kihslinger, R. Bendick, and B. A. McKenney. 2009. The next generation of mitigation: linking current and future mitigation programs with state wildlife action plans and other state and regional plans. Environmental Law Institute and The Nature Conservancy. 66pp. Report available online at http://teaming.com/sites/default/files/Mitigation%20and%20SWAP%20white%20paper%202009.pdf

Executive Summary

INTRODUCTION

Located at the northeast tip of the United States, the State of Maine is approximately 320 miles long and 210 miles wide. It is almost as large (33,315 square miles) as all other New England states combined. Maine is a land rich in contrasts between the boreal and temperate, freshwater and saltwater, upland and wetland, and alpine and lowlands. Maine is a transition area, and its wildlife resources represent a blending of species that are at or approaching the northern or southern limit of their ranges. This mosaic of diverse physical settings supports a wide diversity of wildlife that few other states can equal.

Fish and wildlife play an important role in the lives of Maine people as they provide a source of enjoyment, recreation, and employment -- Maine's quality of life, its traditional "outdoor" values, and its economy, particularly its rural economy, are strongly shaped by the diversity and abundance of its fish and wildlife. The public has entrusted the conservation of Maine's fish and wildlife to the Maine Dept. of Inland Fisheries and Wildlife (MDIFW) and the Maine Dept. of Marine Resources (MDMR).

Road Map to the Eight Required Elements

To facilitate review of Maine's Action Plan, separate chapters address each of the eight required elements.

Elements 1, 2, 3, and 4 each have a unique chapter; we have combined elements 5 and 6 and also 7 and 8 into a single chapter because of their close relationships. Each chapter also addresses differences from Maine's 2005 Comprehensive Wildlife Conservation Strategy.

Maine's 2015 Wildlife Action Plan addresses the full array of wildlife and their habitats in Maine -- vertebrates and invertebrates in terrestrial and aquatic (freshwater, estuarine, and marine) habitats – and wildlife is defined as any species of wild, free-ranging fauna including fish. It builds on a long history of public involvement and collaboration among conservation partners. The Plan is dynamic, responsive, and adaptive. Hence, Maine's Action Plan serves as a solid foundation for the future of wildlife conservation that will help guide the collaborative efforts of state and federal agencies, tribes, conservation partners, and individuals to ensure success.

The Wildlife Action Plan was developed through a lengthy participatory process with state agencies, targeted conservation partners, and the general public. The Plan is non-regulatory. The suite of voluntary species and habitat scale conservation actions in the Plan complement, but do not compete with, existing work programs and priorities by state agencies and partners. Indeed, conservation actions will in most cases not replace current management strategies, but hopefully supplement existing efforts and inspire new initiatives on behalf of Maine' Species of Greatest Conservation Need.

ELEMENT 1: SPECIES OF GREATEST CONSERVATION NEED

A critical dilemma facing conservation biologists and managers worldwide is the need to allocate limited dollars, staff, and programmatic resources toward a growing list of conservation challenges. Foundational to this prioritization process in Maine's State Wildlife Action Plan is the development of a list of Species of Greatest Conservation Need (SGCN). Biologists from Maine Department of Inland Fisheries and Wildlife (MDIFW) and other state agencies, with cooperation from conservation partners and species experts, developed a suite of objective criteria for designating SGCN that is intended to be transparent and science-based, and recognizes that species conservation concerns can be identified at global, regional, and local scales. The primary themes for SGCN prioritization include risk of extirpation, population trend, endemicity, and regional conservation concerns. Secondary themes for SGCN prioritization include climate change vulnerability, survey knowledge, and indigenous cultural significance.

Maine's 2005 list of SGCN totaled 213 species grouped into two priority levels. To help further advance the challenge of species prioritization, Maine's 2015 list of 378 SGCN are assigned to three species priority levels: Priority 1 (Highest; 58 SGCN), Priority 2 (High; 131 SGCN), and Priority 3 (Moderate; 189 SGCN), all of which are eligible for State Wildlife Grant (SWG) assistance from the U.S. Fish and Wildlife Service. The 2015 process for reviewing and identifying Maine SGCN included both species deletions (33) and additions (198) to the 2005 list. The net increase in SGCN is driven primarily from a) additional conservation science designation criteria, b) scrutiny of more invertebrate taxa, c) significantly greater attention to marine fauna in the Gulf of Maine, and d) more explicit recognition of climate change vulnerability. It is our hope that identifying a relatively comprehensive, prioritized suite of SGCN will help MDIFW and conservation partners implement meaningful conservation actions for some of Maine's most vulnerable and valued wildlife resources over the coming decade.

ELEMENT 2: KEY HABITATS AND NATURAL COMMUNITIES

Maine's Wildlife Action Plan employs The Northeast Terrestrial Habitat Classification System (NETHCS), developed by NatureServe and The Nature Conservancy (TNC), to identify the extent of habitats and community types essential to the conservation of Species of Greatest Conservation Need (SGCN). Federal and state agencies in the Northeast have endorsed the NETHCS as a tool for assessing habitat distribution and composition. The specific version of the NETHCS used in Maine includes a number of modifications made by the Maine Dept. of Inland Fisheries and Wildlife (MDIFW) and the Maine Dept. of Marine Resources (MDMR) to reflect Maine's landscape and coastal features. The basic layer within NETHCS is the habitat 'system', which corresponds to the Ecological Systems classification. There are approximately 150 Ecological Systems in Maine. We used the more general 'Macrogroup' level for several of our analyses, and there are 42 habitat macrogroups in Maine.

Maine further consolidated the macrogroups into three broad habitat categories to facilitate development of conservation actions. The broad categories are Coastal and Marine, Terrestrial (including Freshwater Wetlands) and Freshwater Aquatic (Rivers, Lakes, and Ponds). The importance of various habitats to SGCN is not related to their statewide abundance; habitats such as pine barrens, open freshwater wetlands, and rivers and streams are dis-proportionately important compared to many other habitat types. We estimate that there are 3,824,842 acres of conservation land in Maine, accounting for nearly 20% of the State. Much of this conserved

land lies within Focus Areas of Statewide Significance; we identify these focus areas to help prioritize Maine's landscape for SGCN and other habitat values.

ELEMENT 3: PROBLEMS AFFECTING SGCN AND THEIR HABITATS

Maine's State Wildlife Action Plan (SWAP) focuses much attention on the habitats used by Species of Greatest Conservation Need (SGCN). The Plan uses a coarse filter – fine filter approach to conservation to ensure, where possible, that individual conservation initiatives benefit multiple species, while also acknowledging that some species require individualized attention. We assigned stressors to both habitats and to SGCN, in order to clearly identify the issues that should be addressed at each level in the conservation hierarchy. As with most other states in the Northeast, we identified stressors using the International Union for the Conservation of Nature (IUCN) Threat Classification Scheme. While the IUCN system is useful for categorizing stressors to SGCN and their habitats, we found that the system lacks the resolution to clearly identify the specific issues that should be considered for conservation attention. Therefore, when assigning stressors we chose to adopt the primary and secondary IUCN categories, but replaced the tertiary category with a detailed narrative that fully describes the issue and its impact on the species or habitat being considered. In addition, we adapted Table 7 (*Threat characteristics and categorical ratings)* from The Northeast Lexicon to identify characteristics for each stressor assignment.

We assigned stressors to Priority 1 and 2 SGCN, and assigned 'Severity' and 'Actionabilty' characteristics for each Stressor – SGCN interaction. The concepts of 'Likelihood', 'Certainty' and 'Spatial Extent' were considered implicitly, and only those Stressors that were determined to have a moderate or high Impact for each of these characteristics were assigned. In addition, only those stressors with moderate or high Severity were assigned to SGCN. We developed a simple matrix to prioritize SGCN stressors, using the combination of the Impact scores for 'Severity' and 'Actionability.' We identified stressors for terrestrial and freshwater aquatic habitats using Anderson at al. (2013) as our primary source of reference material. Because no single comprehensive source is available that describes that state of marine habitats along Maine's coast, we used a wide variety of scientific publications, as well as expert opinion of agency staff and partners, to compile information on stressors. We assumed that the habitat systems within each terrestrial and marine macrogroup all faced similar conservation problems; therefore we assigned stressors to each macrogroup, but did not identify stressors separately for each habitat system, with the exception of freshwater aquatic habitats (River and Streams, and Lakes and Ponds) were we identified stressors separately for each of systems Unlike our approach for SGCN, we assigned all 7 stressor characteristics for each habitat – stressor combination.

We assigned 38 unique stressors to 190 Priority 1 and 2 SGCN species, for a total of 1,099 SGCN – stressor combinations. We assigned 31 unique stressors to 34 habitats macrogroups, for a total of 326 habitat – stressor combinations. Development, including existing and new Roads and Railroads and Housing and Urban Areas, and Invasive Non-native/Alien Species/Diseases, were assigned to the largest number of habitats.

ELEMENT 4: CONSERVATION ACTIONS

The conservation actions contained in Maine's revised State Wildlife Action Plan (SWAP) consist of complementary coarse- and fine-filter approaches that maximize limited conservation dollars. The Maine Department of Inland Fisheries and Wildlife (MDIFW), the Maine Department of Marine Resources (MDMR), the Maine Coastal Program (MCP), the Maine Natural Areas Program (MNAP), and other conservation partners worked closely to develop a thorough catalog of coarse- and fine-filter conservation actions. We attempted to balance action specificity with flexibility so that actions can be adapted as needed to emerging issues and information. Conservation actions are non-regulatory approaches undertaken voluntarily by agencies and other conservation partners. Actions are not intended to replace current management strategies, but can be used to bolster existing efforts or inspire new ones.

The actions reflect several stages of prioritization. Conservation partners identified a total of 311 actions for Species of Greatest Conservation Need (SGCN). Of these, partners applied 197 actions to individual SGCN, 88 to guilds, and 26 to one or more taxonomic groups. We assigned nine of these actions to all SGCN species. Conservation partners also identified 322 habitat actions, including 165 marine and coastal habitat actions, 54 freshwater aquatic habitat actions, and 103 terrestrial and wetland habitat actions. Given the volume of habitat conservation actions identified, workgroups developed several themes to organize actions into discrete packages of related actions that address common stressors or use similar techniques. Actions within a theme are often complementary, and when undertaken together, may be the most effective and efficient use of conservation resources. Three 'super-themes' emerged across habitat groups: Connectivity, Invasive Species, and Mapping and Outreach. Actions included in these themes will be more effective with coordinated efforts across habitats. Each conservation action is linked to its target SGCN or habitat and the stressor(s) the action is addressing in a relational database, an idea proposed in the 2005 Comprehensive Wildlife Conservation Strategy (CWCS) and successfully developed as part of this Plan. We also identified 11 programmatic actions to help guide implementation and tracking of the 2015 Action Plan; we have broadly grouped these actions as Outreach and Engagement, Funding and Tracking, Action Development, and Regional Partnerships. In this chapter, we also propose criteria partners may wish to consider if evaluating how best to direct resources to conservation actions in the plan. We also discuss differences from Maine's 2005 CWCS.

ELEMENT 5: MONITORING

ELEMENT 6: PERIODIC REVIEW

In this chapter, we outline the methods we will use to monitor SGCN and their habitats, describe how we will monitor the progress made in implementing the Action Plan over the next ten years, and address the procedures we will use to review and update the Action Plan moving forward. We work closely with federal, state, and private conservation partners to develop and participate in cooperative species monitoring programs. Where possible, monitoring programs target multiple species, usually within the same taxonomic group. We also describe the monitoring programs that are in place for SGCN in Maine. We include a table for each of the five taxonomic groups this plan references.

MDIFW and partners identified habitat-scale survey and monitoring needs during development of conservation actions. We present these actions with examples of existing and general survey and monitoring techniques that partners can used to achieve these habitat-monitoring objectives.

MDIFW and partners developed 11 programmatic actions to help guide Action Plan implementation over the next ten years. Three of these actions address monitoring, which this chapter describes in detail.

MDIFW will use the programmatic actions to monitor conservation action progress at least annually. MDIFW will also establish an Implementation Committee in the Fall 2015 comprised of agency staff and conservation partners. This committee will review Action Plan accomplishments and address emerging issues or adaptive management needs. We will undertake a comprehensive plan review beginning in year eight of the 2015 Action Plan.

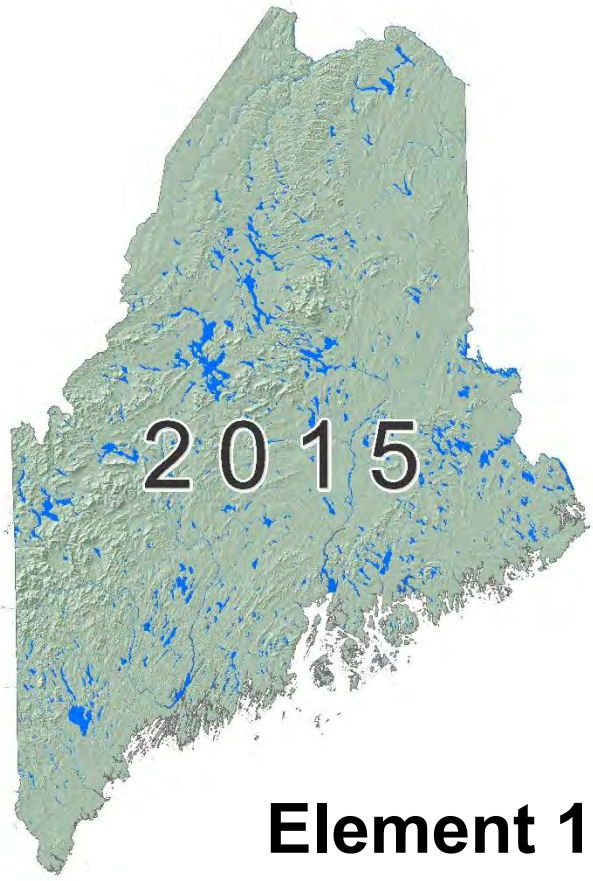
ELEMENT 7: COORDINATION WITH PARTNERS

ELEMENT 8: PUBLIC PARTICIPATION

Maine has a long history of successful collaboration among conservation partners -- conducting comprehensive wildlife planning and public involvement for nearly forty years. MDIFW began assembling a SWAP coordination team in January 2014. This planning team developed the strategies necessary to achieve the eight required elements of the 2015 SWAP. In September 2014, the Coordination Team established a SWAP Steering Committee to guide the overall development of the SWAP. The Steering Committee represented the broader partner group by providing regular and timely input into the activities and proposed strategies of the Coordination Team. The Coordination Team and the Steering Committee began preparing Maine's charter early in the update; the Steering Committee officially adopted the charter in November 2014. The Coordination Team invited 158 conservation partners to participate in the preparation of Maine's 2015 SWAP, representing 102 unique organizations and the public from July 2014 – June 2015. The partners attended five, seven-hour "conservation partner" meetings at which they collaborated in the development of Elements 1-5 of the 2015 SWAP.

MDIFW sought to both inform the public of its intent to revise the Action Plan and to encourage public participation. It established a Public Outreach Subcommittee to guide its public participation efforts. The subcommittee identified effective methods for engaging and soliciting input from the public, and the Coordination Team and Steering Committee scaled these methods to make effective use of agency resources and ensure an appropriate level of public participation.

The success of Maine's 2015 Wildlife Action Plan depends on continued partner and public engagement during plan implementation. To help guide implementation of these actions and to encourage continued public involvement, MDIFW and its partners developed six outreach Programmatic Theme that relate to 1. Outreach and Engagement and 2. Program Funding and Tracking.



MAINE'S WILDLIFE ACTION PLAN

Element 1: Species of Greatest Conservation Need

Prepared by

Maine Department of Inland Fisheries and Wildlife

In collaboration with

Maine's Conservation Partners

September 2015

TABLE OF CONTENTS

Element 1: Species of Greatest Conservation Need

1.0 Abstract....1

1.1 Introduction....2

1.2 Significant Changes from Maine's 2005 Plan....3

1.3 An Overview of Maine's Fauna and SGCN....4
- 1.3.1 Mammals (Non-Marine)....5
- 1.3.2 Birds....7
- 1.3.3 Reptiles and Amphibians....10
- 1.3.4 Freshwater (Non-Diadromous) Fish....11
- 1.3.5 Inland and Freshwater Invertebrates....12
- 1.3.6 Marine Fauna (Except Birds)....16

1.4 Distribution of Maine's SGCN and Associated Habitats....19
- 1.4.1 Methodology for Mapping Element 1 – SGCN Distributions....20
- 1.4.2 Methodology for Mapping Element 2 – Habitats....20
- 1.4.3 Species Conservation Range Maps....21
- 1.4.4 SGCN Distribution Synthesis....22

1.5 Designation Criteria for Maine's SGCN - 2015....26
- 1.5.1 Priority 1 (Highest Priority) SGCN....26
- 1.5.2 Priority 2 (High Priority) SGCN....27
- 1.5.3 Priority 3 (Moderate Priority) SGCN....28

1.6 Maine's 2015 SGCN....31

1.7 Literature Cited and References....60

1.8 Appendices....64

LIST OF TABLES

Table 1-1. Diversity of fauna, E/T listings, and SGCN in Maine by major taxa groups. 5

Table 1-2. Vulnerability concepts and criteria for designating Maine's SGCN. 30

Table 1-3. Maine's 2015 SGCN and scale of conservation concerns 33

LIST OF FIGURES

Figure 1-1. Examples of conservation range maps by USGS sub-watersheds for aquatic SGCNs and by Maine townships for terrestrial SGCNs. Red/yellow shaded areas indicate an SGCN's presence based on observation data; green/blue indicates presence of potential habitats associated with the SGCN. 23

Figure 1-2. Examples of SGCN summaries by taxa class and habitat associations for USGS sub-watersheds and Maine townships. 25

LIST OF APPENDICES

Appendix 1-1. Maine's list of state-designated Endangered / Threatened plants administered by Natural Areas Program - Maine Department of Agriculture, Conservation and Forestry. 64

Appendix 1-2. Maine's list of state-designated Endangered and Threatened inland fish and wildlife administered by the Maine Department of Inland Fisheries and Wildlife (in statute; see Title 12 MRSA, §12803, http://legislature.maine.gov/legis/statutes/12/title12sec12803.html). 69

Appendix 1-3. Maine's list of state-designated Endangered and Threatened marine fish and wildlife administered by the Maine Department of Marine Resources (in statute; see Title 12 MRSA, §6975, http://legislature.maine.gov/legis/statutes/12/title12sec6975.html). 71

Appendix 1-4. Maine's list of federally-designated Endangered and Threatened species administered by the U.S. Fish and Wildlife Service and National Marine Fisheries Service; see http://ecos.fws.gov/ecp/. 72

Appendix 1-5. Maine's 2005 SGCN that are removed from the 2015 Wildlife Action Plan. 73

Appendix 1-6. Maine's plant Species of Greatest Conservation Need (SGCN) administered by Maine Natural Areas Program – Maine Department of Agriculture, Conservation and Forestry and conservation actions associated with habitat groupings. 74

KEY TO ACRONYMS

ASMFC	Atlantic States Marine Fisheries Commission
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
EBTJV	Eastern Brook Trout Joint Venture
ECOS	Environmental Conservation Online System
ESA	U.S. Endangered Species Act
E/T	Endangered and/or Threatened
ETSC	Endangered, Threatened, and Special Concern
GIS	Geographic Information System
IUCN	International Union for the Conservation of Nature
MDACF	Maine Department of Agriculture, Conservation and Forestry
MDIFW	Maine Department of Inland Fisheries and Wildlife
MDMR	Maine Department of Marine Resources
MESA	Maine Endangered Species Act
MRSA	Maine Revised Statutes Annotated
NARSP	North Atlantic Regional Shorebird Plan
NAWCP	North American Waterbird Conservation Plan
NEFWDTC	Northeast Fish and Wildlife Diversity Technical Committee
NEPARC	Northeast Partners in Amphibian and Reptile Conservation
NMFS	National Marine Fisheries Service
RSGCN	Regional Species of Greatest Conservation Need
SC	Special Concern
SGCN	Species of Greatest Conservation Need
SoC	Species of Concern
SWAP	State Wildlife Action Plan
SWG	State Wildlife Grants
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USSCP	U.S. Shorebird Conservation Plan
WNS	White-nose syndrome

The Legislature finds that various species of fish and wildlife have been and are in danger of being rendered extinct within the state of Maine, and that these species are of esthetic, ecological, educational, historical, recreational and scientific value to the people of the State. The Legislature, therefore, declares that it is the policy of the State to conserve, by according such protection as is necessary to maintain and enhance their numbers, all species of fish or wildlife found in the State, as well as the ecosystems upon which they depend.

107th Maine Legislature, 1975: preface to Maine's Endangered Species Act (MESA)

1.0 ABSTRACT

A critical dilemma facing conservation biologists and managers worldwide is the need to allocate limited dollars, staff, and programmatic resources toward a growing list of conservation challenges. Foundational to this prioritization process in Maine's State Wildlife Action Plan is the development of a list of Species of Greatest Conservation Need (SGCN). Biologists from Maine Department of Inland Fisheries and Wildlife (MDIFW) and other state agencies, with cooperation from conservation partners and species experts, developed a suite of objective criteria for designating SGCN that is intended to be transparent and science-based, and recognizes that species conservation concerns can be identified at global, regional, and local scales. The primary themes for SGCN prioritization include risk of extirpation, population trend, endemicity, and regional conservation concerns. Secondary themes for SGCN prioritization include climate change vulnerability, survey knowledge, and indigenous cultural significance.

Maine's 2005 list of SGCN totaled 213 species grouped into two priority levels. To help further advance the challenge of species prioritization, Maine's 2015 list of 378 SGCN are assigned to three species priority levels: Priority 1 (Highest; 58 SGCN), Priority 2 (High; 131 SGCN), and Priority 3 (Moderate; 189 SGCN), all of which are eligible for State Wildlife Grant (SWG) assistance from the U.S. Fish and Wildlife Service. The 2015 process for reviewing and identifying Maine SGCN included both species deletions (33) and additions (198) to the 2005 list. The net increase in SGCN is driven primarily from a) additional conservation science designation criteria, b) scrutiny of more invertebrate taxa, c) significantly greater attention to marine fauna in the Gulf of Maine, and d) more explicit recognition of climate change vulnerability. It is our hope that identifying a relatively comprehensive, prioritized suite of SGCN will help MDIFW and conservation partners implement meaningful conservation actions for some of Maine's most vulnerable and valued wildlife resources over the coming decade.

"A critical dilemma facing conservation biologists and managers worldwide is the need to allocate limited dollars, staff, and programmatic resources toward a growing list of conservation challenges. Foundational to this prioritization process in Maine's State Wildlife Action Plan is the development of a list of SGCN."

1.1 INTRODUCTION

Agencies and conservation partners have long faced the dilemma of allocating limited funds to address the critical needs of species designated as Endangered or Threatened (E/T). The much larger number of vulnerable species at risk of being listed as E/T is even more problematic. The Conservation and Reinvestment Act in the U.S. (2001) and a similar Species at Risk Act in Canada (2002) emphasize that need and established funding for states and provinces to address an array of biodiversity risks within their borders beyond a focus on E/T species. Conservation challenges solved at these local and regional scales are less likely to escalate into national or international crises. Additional benefits of working proactively with locally or regionally vulnerable species include a greater likelihood of success and minimal reliance on regulations.

An approved State Wildlife Action Plan is a requisite for receipt of federal SWG funding. The primary conservation targets of these plans are SGCN populations and habitats. Each state has considerable flexibility for SGCN designations and resulting SWG expenditures, though there is foundational guidance offered in the Wildlife Conservation and Restoration Act that SWG funds are intended "…for the benefit of a diverse array of wildlife and associated habitats, including species that are not hunted or fished, to fulfill unmet needs of wildlife within the States." Maine's 2015 Plan relies on objective criteria to identify and prioritize SGCN. Specifically, MDIFW and Plan partners emphasize the following five general concepts for SGCN eligibility:

1. **Acute Vulnerability**: State, federal or international agencies formally designate the risk of species extirpation. We also acknowledge those species experiencing recent, dramatic population declines and likely to be listed as E/T in the near future.
2. **Regional Conservation Priority**: One or more scientific partners have identified the species as a high regional concern in the Northeast. We include regional endemics and species with disproportionate range occurrences in the Northeast.
3. **Data Deficiency**: Some rare, understudied taxa require further survey and research to accurately determine conservation status.
4. **Climate Change Sensitivity**: Northeastern climate change projections indicate a suite of species will face significant risks in the near future.
5. **Cultural Significance**: Maine tribes identified some SGCN based on special values to tribal heritage in combination with emerging ecological vulnerabilities.

Some states develop Wildlife Action Plans that reflect the scope of the jurisdiction in the wildlife agency that legally administers SWG allocations to states. Maine's 2015 Plan includes other natural resource agencies. MDIFW is the lead agency for any terrestrial or freshwater wildlife species (including all birds). The Maine Department of Marine Resources (MDMR) has primary authority for all fauna (except birds) in coastal waters. The Maine Coastal Program in the state's Department of Agriculture, Conservation and Forestry (MDACF) also considers conservation issues in the Gulf of Maine. The Maine Natural Areas Program in MDACF has sole responsibility for rare plants. While flora are not directly eligible for SWG funds in Maine's 2015 Plan, Maine's Endangered and Threatened Plants (Appendix 1-1) are considered in the Plan's habitat-based conservation strategies. Finally, we acknowledge that participation by Maine's diverse alliance of conservation partners (private, public, and tribal) is essential to effective Plan implementation.

1.2 SIGNIFICANT CHANGES FROM MAINE'S 2005 PLAN

Maine and other states drafted their initial plans as a "Comprehensive Wildlife Conservation Strategy" (CWCS) for submission in 2005. The CWCS documents of that era were retitled (but not reformatted) as State Wildlife Action Plans (SWAP). Maine's 2005 CWCS still serves as a thorough, detailed account of the full scope of wildlife, habitats, threats, conservation actions, and monitoring programs in the State (http://www.maine.gov/ifw/wildlife/reports/wap.html). Key differences in Element 1 of the 2015 Action Plan are:

- Purpose: Maine's resource agencies and conservation partners strove to construct a document that better served as a statewide conservation plan rather than one focused on MDIFW perspectives.

- SGCN emphasis: A focus on SGCN rather than the full array of fish and wildlife resources significantly reduced the length of Element 1 and each subsequent chapter of the 2015 Action Plan.

- SWAP database: Similar to the review of habitats and stressors in subsequent parts of this Plan, Element 1 includes a tabulation of 378 SGCN (Table 1-3) that is hot-linked to database report summaries for each SGCN. This strategy streamlines the Plan itself and provides updateable information (in lieu of static tables) during its 10-year horizon.

- Expanded faunal reviews: Several taxa groups received much greater attention for SGCN eligibility in 2015: marine fauna in the Gulf of Maine and terrestrial/freshwater invertebrates. Plant conservation remains ineligible for SWG funding, but habitat-scale conservation actions from Maine's 2015 Plan will benefit vulnerable flora and important natural communities.

- Refinements to SGCN qualifying criteria: Whenever possible, we employ objective, published reviews of species vulnerability among faunal groups to identify SGCN.

- Coordinated conservation in the Northeast: The Northeastern states and partner collaborations in USFWS Region 5 have focused on the regional scale of vulnerability. The Northeast Regional Conservation Needs program (http://rcngrants.org/) and North Atlantic Landscape Conservation Cooperative (http://northatlanticlcc.org/) are premiere examples.

- Vulnerable species in Canada: This Plan now extends SGCN eligibility for Maine fauna that are listed E/T by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; http://www.cosewic.gc.ca/eng/sct5/index_e.cfm) in the neighboring provinces of New Brunswick, Nova Scotia and Quebec.

- Global vulnerability: Maine's 2015 Plan newly recognizes fish and wildlife species occurring in Maine as SGCN if listed as "Critically Endangered" (CR), "Endangered" (EN), or "Vulnerable" (VU) on the IUCN Red List.

- Climate change vulnerability: Although many climate change projections escalate beyond the 10-year duration of the Plan, the revised SGCN list of 2015 now includes species with high vulnerability and high certainty for this stressor in Maine.

1.3 AN OVERVIEW OF MAINE'S FAUNA AND SGCN

The diversity and health of Maine's natural resources is a priority for both residents and visitors. Maine's varied landscape, rural character, and traditional resource-based economy heighten public familiarity and appreciation for fish and wildlife. Regular exposure to fauna in the every-day lives of many Maine citizens reinforces concern for the state's natural heritage generally, and species-at-risk in particular.

"Maine's varied landscape, rural character, and traditional resource-based economy heighten public familiarity and appreciation for fish and wildlife. Regular exposure to fauna in the every-day lives of many Maine citizens reinforces concern for the state's natural heritage generally, and species-at-risk in particular."

The variety of wildlife is also key to the allure. Maine is a mixing zone of northern species allied with boreal systems prevalent in neighboring Canada that yield to southern species typical of Appalachian habitats that predominate further south in New England and beyond. Examples of northern fauna include Canada Lynx (*Lynx canadensis)*, Arctic Charr (*Salvelinus alpinus*), Mink Frog (*Lithobates septentrionalis*), and Atlantic Puffin (*Fratercula arctica*); all approach southernmost range limits in the state. Southern fauna that are near the northern edge of their range in Maine include New England Cottontail (*Sylvilagus transitionalis*), Roseate Tern (*Sterna dougalli*), Black Racer (*Coluber constrictor*), Loggerhead Sea Turtle (*Caretta caretta*), and Monarch Butterfly (*Danaus plexippus*).

The composition of Maine's animal and plant communities shifts considerably from south-to-north, in both terrestrial and aquatic habitats. Woodlands encompass nearly 85% of Maine's land area, but forests vary from deciduous and mixed forests prevalent in southern, western and central Maine to boreal conifers in northern and eastern regions and at higher elevations. Faunal associations shift accordingly as well. Surface waters cover almost 13% of the State and also offer diverse environments. Predominantly cool / cold lakes, rivers and streams yield to warmer waters in southwestern Maine. Maine's intricate coastline totals almost 3,500 miles, and the Gulf of Maine itself transitions into cooler waters along a west-to-east gradient due to tidal mixing with the North Atlantic's Labrador Current.

Not surprisingly, our knowledge of Maine fauna has limitations. For example, many invertebrate taxa are not yet considered, let alone proportionately represented among Maine's SGCN. Nevertheless, Maine's 2015 Plan identifies 378 SGCN spanning 44 orders of vertebrates and 28 orders of invertebrates. A compilation by major taxa groups (Table 1-1) reveals both the sheer number and diversity of SGCN at present in Maine.

Sixty (16%) SGCN in Maine are state-listed E/T species (Appendices 1-2 and 1-3). Only 18 SGCN (<5%) are federally-listed as E/T (Appendix 1-4). Thus, the vast majority of Maine's SGCN, while

"…the vast majority of Maine's SGCN, while characterized by distinct biological sensitivities, are not on the brink of extirpation or ecological crisis. This provides a strategic opportunity for MDIFW and a coalition of conservation partners to implement meaningful conservation for some of Maine's most vulnerable and valued wildlife populations in advance of the necessity for ESA listings and regulatory implications."

characterized by distinct biological sensitivities, are not on the brink of extirpation or ecological crisis. This provides a strategic opportunity for MDIFW and a coalition of conservation partners to implement meaningful conservation interventions for some of Maine's most vulnerable and valued wildlife populations in advance of the necessity for ESA listings and regulatory implications.

Table 1-1. Diversity of fauna, E/T listings, and SGCN in Maine by major taxa groups.

Taxa Groups lead state agency juridiction	# Species			
	Extant in Maine	Federal E/T (ESA)	State E/T (MESA)	SGCN in 2015 Plan
Invertebrates subtotal[1]	>33,000	0	20	168
freshwater / terrestrial (MDIFW)	>15,000	0	20	132
marine (MDMR)	>18,000	0	0	36
Vertebrates subtotal	840	18	40	210
Amphibians (MDIFW)	18	0	0	4
Birds (MDIFW)	423	3	20	130
Fish	291	3	3	43
freshwater (MDIFW)	39	0	2	15
marine / diadromous (MDMR)	252	3	1	28
Mammals	85	8	10	22
marine (MDMR)	24	6	5	7
terrestrial (MDIFW)	61	2	5	15
Reptiles	23	4	7	11
freshwater / terrestrial (MDIFW)	17	0	4	7
marine (MDMR)	6	4	3	4
MAINE FAUNA TOTALS	>33,840	18	60	378

[1]Total includes only described species; the actual number is much greater.

1.3.1 MAMMALS (NON-MARINE)

General Overview

Maine's 61 species of non-marine mammals may be best characterized as a diverse mixture of boreal and temperate species. Maine encompasses three ecoregional provinces (Warm Continental Mountains, Warm Continental Division, and the Hot Continental Division) and is near the Subarctic Division in Canada. Maine's proximity to the Subarctic Division enables species, such as the Canada Lynx, that are typically found in boreal forests of Canada, to thrive in the mixed coniferous forests of northern Maine. Similarly, the Hot Continental Division's climate helps make it possible for species such as the New England Cottontail to persist at the northern extent of their range in southern Maine. While Maine's proximity to boreal and temperate regions may contribute to the diversity of mammals found in the state, this same proximity also raises a number of challenges for species that live near the edge of their range. Species on the southern edge of their range, like American Marten (*Martes americana*) and Canada Lynx may compete for resources with species more common to the south, such as Fisher (*Martes pennanti*) and Bobcat (*Lynx rufus*). Although we cannot say for certain how

mammals in Maine will be affected by climate change, it will likely be the species at the edge of their range that will experience the greatest change.

Conservation Overview

The species comprising Maine's native mammals have remained fairly constant over the last 100 years, since extinction of the Sea Mink (*Mustela macrodon*) and Eastern Cougar (*Felis concolor*), and state extirpation of Caribou (*Rangifer tarandus*) and Gray Wolf (*Canis lupus*). Today, Maine's mammals receive greater protection through regulatory measures and the conservation efforts carried out by MDIFW and a host of dedicated conservation partners.

Notwithstanding these conservation efforts, Maine mammals face a variety of challenges and threats. A total of 15 species (25%) of Maine's nonmarine mammals are listed as SGCN in this Plan. Although Moose (*Alces alces*) and Muskrat (*Ondatra zibethicus*) are numerous in Maine, they were listed as SGCN because of their cultural significance to native tribes and recent changes in the populations of these species in the Northeast and elsewhere. The factors behind these changes are still under investigation.

Bats, as an order, perhaps face the most unified set of conservation threats. White-nose syndrome (WNS), a deadly fungal disease, has drastically reduced populations of *Myotis* spp. Because of this disease, Little Brown Bats (*Myotis lucifugus*) and Northern Long-eared Bats (*Myotis septentrionalis*) were state-listed as Endangered in 2015, and the Eastern Small-footed Bat (*Myotis leibii*) was newly state-listed as Threatened. These bat populations are not only threatened by WNS in Maine but throughout most of their U.S. range. Although WNS has primarily affected *Myotis* spp., Tri-colored Bats (*Perimyotis subflavus*) and Big Brown Bats (*Eptesicus fuscus*) are also affected. The impact of WNS on Maine's bat populations has heightened concerns over the effects of other mortality factors, such as wind turbines, and the vulnerability of maternity colonies to disturbance. Our lack of knowledge about the habits of bats in Maine also poses a significant threat to the species. It is difficult to undertake effective conservation actions if we do not understand many of the basic habits of bats. In addition to the three bat species that have recently been listed as E/T under MESA, Maine's five other species of bats are all considered species of Special Concern and/or SGCN.



Efforts underway in Maine and five other Northeast states were pivotal to a recent decision not to list the New England Cottontail (*Sylvilagus transitionalis*, SGCN Priority 1) as E/T under the federal ESA. © Tom Barnes

The availability and structure of forest seral stages in Maine is a major factor determining the abundance of Maine's mammals. In southern Maine, the loss of early successional habitat through forest maturation and development has resulted in a 75% to 80% decline of suitable habitat for New England Cottontail. In York County, only 3% of the landscape can be characterized as early successional forest habitat. The lack of shrublands and young forests in southern Maine threatnes not only the New England Cottontail, but also several SGCN birds associated with scrub-shrub habitat.

Conversely, in northern Maine, less than 3% of the landscape remains as ecologically mature forest that is suitable for deer wintering areas. This not only impacts Maine's White-tailed Deer (*Odocoileus virginianus*) but other mammals (e.g., American Marten, *Martes americana*) and birds that are dependent on mature interior forests. Unlike the interior boreal forests of Canada

and Alaska, where natural wildfires play a major role in determining the pace of forest succession, commercial logging operations and market forces are major factors influencing the composition and structure of Maine's northern forests.

1.3.2 BIRDS

General Overview
Birds enrich our lives and reflect the quality and health of our environment. North America provides habitat for over 900 species of birds. The Maine Bird Records Committee considers 423 bird species (nearly half of all North American birds) to be positively documented within the state of Maine. Maine's diverse mosaic of habitats supports 225 species of nesting birds. Nearly 200 others visit Maine as either fall / spring migrants or winter residents.

Maine's landscape is used by at least 29 inland species that reach the northern limits of their breeding distribution in Maine, and 28 species reside here at their southern limits. In addition, many of Maine's island-nesting seabirds reach their southern breeding terminus on Maine's coastal islands. Several other species have expanded their breeding ranges into Maine over the past century. New arrivals include the Sandhill Crane (*Grus canadensis*) and most recently, the Eastern Screech Owl (*Megascops asio*). Two species, the Peregrine Falcon (*Falco peregrinus*) and the Wild Turkey (*Meleagris gallopavo*) have been reintroduced into Maine following prolonged extirpation. Both are now carefully monitored and managed.

Maine is strategically located at a constriction point of the funnel in the Atlantic Flyway, a migratory path along eastern North America that tapers from a wide swath over the eastern Canadian arctic southward along the east coast. The Atlantic Ocean has a channeling effect on these migratory movements as birds fly south in late-summer and fall. In addition, Maine's vast coastline and more than 4,000 coastal islands provide important stopover areas for millions of migrating birds. This flyway includes some of the continent's most productive ecosystems and is home to about a third of the U.S. human population. Conserving birds and their habitats in Maine's portion of this important flyway is a monumental task.

Conservation Overview
All of Maine's bird guilds are represented on Maine's official E/T List or the List of Species of Special Concern (SC). The latter is an administrative list of species that could become E/T without attention. The challenges for future conservation and stewardship are many. At least five bird species are documented as extinct or extirpated from Maine, emphasizing the importance of preventing any more erosion of the state's avian biodiversity. Among 423 birds documented in Maine, 11 are listed as state Endangered, nine are listed as state Threatened, and 130 are listed SC and/or SGCN. Thus, conservation concerns exist for ~31% of the bird species known to inhabit Maine. Most attention is devoted to birds that breed, nest and raise their young in Maine. However two waterfowl, the Barrow's Goldeneye (*Bucephala islandica*) and Harlequin Duck (*Histrionicus histrionicus*), are state-listed as Threatened because they winter in significant numbers in coastal Maine. Since a large percentage of the North Atlantic populations of these waterfowl species winter here, Maine has a high regional management responsibility for them.

Threats to bird populations are many and conservation challenges are equally diverse. Managers are tasked with protecting small numbers of ground-nesting Least Terns (*Calidris minutilla*) and Piping Plovers (*Charadrius melodus*) that struggle to co-habit southern Maine's

sand beaches with tens of thousands of recreational users. Maine forest birds and many species of wetland birds may be faring well recently, but they too are threatened by cumulative impacts of development, habitat fragmentation, intensive forest practices, invasive species and various forest pests and diseases. While these species face numerous threats, vast areas of forest in Maine remain intact, presenting opportunities for large-scale conservation.

Songbirds are well represented in Maine given our diverse landscape. Because the state is so heavily forested, most forest-dwelling Passerines are doing well with only a few "vulnerable" exceptions for specialists such as Bicknell's Thrush (*Catharus bicknelli*). Abundance of some forest birds follows periodic boom and bust insect outbreaks. For example, Tennesee Warbler (*Oreothlypis peregrina*) and Evening Grosbeak (*Coccothraustes vespertinus*) peak during epidemics of Spruce Budworm (*Choristoneura fumiferana*). Overall, the health of Maine's forest songbirds is good, and their consideration as SGCN stems largely from disproportionate rangewide responsibility for them in Maine.

Grassland birds, in contrast, have struggled to maintain populations in Maine. Grasshopper Sparrows (*Ammodramus savannarum*) continue to occupy just a few sites in southern Maine, and Eastern Meadowlark (*Sturnella magna*) populations continue a long-term decline. Leading the declines however, are the aerial insectivores, mostly swallows, which by any measure are in rapid decline. Even populations of the widespread, locally abundant Tree Swallow (*Tachycineta bicolor*) have steadily declined over the last decade. Although causes remain speculative, most of these species are considered SGCN based on steep population declines.

In general, raptor populations have also fared well in Maine since the use of certain harmful pesticides was banned. Following years of intensive management to protect nests, Bald Eagles (*Haliaeetus leucocephalus*) were delisted in 2009, and populations continue to grow statewide. Changes in land use practices, population shifts, and some environmental toxins appear to be foremost influences at present. Habitat losses may result from natural (e.g., succession of grasslands to fwoodlands) or human impacts (including land development, fragmentation, etc.) that lead to both direct and indirect effects. Most raptor populations lack baseline indices or trend indicators. Limiting disturbance from recreation and development provides additional protection during critical nesting periods. Documenting continuing exposure of some persistent toxins such as lead, mercury, polychlorinated biphenyls, and polybrominated diphenyl ethers is a potential priority for some raptors.

Seabirds and salt marsh dependent birds face threats from pollution, over-fishing of important food items, and warming sea temperatures and rising sea levels caused by climate change. Rare seabirds and some colonial waterbird populations remain vulnerable as high percentages of their statewide nesting populations occur on a just a handful of managed sites. The maintenance and enhancement of populations of focal species will require careful monitoring of breeding populations and management that addresses threats that include: predations from gulls, habitat loss, changes in food availability in the Gulf of Maine, oil spills, incidental take during commercial fishing, and human disturbance near nests.



This regional endemic, the Saltmarsh Sparrow (*Ammodramus caudactus*, SGCN Priority 1) is a "vulnerable" species on the IUCN Red List. It lives in one of the most threatened habitats in the Northeast. © Patrick Leary

Maine's numerous wetlands and riparian areas are critical to a large percentage of Maine birds, including shorebirds, wading birds, and waterfowl. Poorly planned development that is too close to wetlands puts ecological functions at risk and leads to general habitat degradation, lower productivity, and eventual loss of birds. While the rate at which wetlands are lost has slowed since the 1980s, some of Maine's marsh birds (e.g., rails and bitterns) have become increasingly rare for unknown reasons. With rarity comes increased vulnerability to all stressors such as flooding associated with severe weather due to climate change; displacement of native vegetation by invasive species, human disturbance through recreation and development; and water regime changes at managed wetlands. Colonial wading birds such as Great Blue Herons (*Ardea herodias*) and Black-crowned Night Herons (*Nycticorax nycticorax*) have declined along the coast for unknown reasons; however disturbance, predators, and changes in food resources are all suspected. Continued surveys and monitoring are needed to shed light on the complex interspecific interactions as well as how species respond to changes in their local environment.

And finally, shorebirds that rely on coastal habitats for feeding and roosting during migration are negatively influenced by declining food resources and human disturbance. Recent data suggest that several Atlantic Flyway shorebird species have experienced declines of between 50% and 90% within the last three decades. Shorebird experts throughout the U.S. and Canada agree that the primary reason for shorebird declines is habitat loss from coastal development and human related disturbances. Thirty-eight shorebird species spend some portion of their annual life cycle in Maine including the federally listed Piping Plover and Red Knot (*Calidris canutus rufa*). Shorebirds are an important group for management consideration because large numbers of these birds concentrate in discrete areas of coastal habitat where they are highly susceptible to disturbance, habitat loss, and environmental contaminants. Conservation requires attention to these cumulative impacts.



Semipalmated Sandpipers (*Calidris pusilla*, SGCN Priority 2) & 13 other SGCN shorebirds stage along the Maine coast in annual, long-distance migrations from the Arctic to South America. © Lindsay Tudor

Maine's diverse and abundant bird resource face many natural challenges including starvation, predation, and severe weather. But the major threat for Maine birds remains habitat loss. Well-designed biological monitoring of Maine's bird resource is required to guide conservation strategies for priority birds. Conserving high value habitats and directing disturbance activities away from the most sensitive habitats will go a long way in ensuring a viable future for Maine birds and the people of Maine who enjoy watching them.

1.3.3 REPTILES AND AMPHIBIANS

General Overview
By eastern U.S. standards, Maine is a large and climatically diverse state. Thus, while North American reptiles and amphibians (herpetofauna) are richest at southern latitudes, Maine's relatively moderate southern and coastal climate permits a large number of species, especially snakes and turtles, to reach their northeastern range limit in the state. Only one species, the Mink Frog (*Rana septentrionalis*), reaches the southern edge of its range in Maine (and northern New Hampshire and Vermont). There are 36 species of herpetofauna known from Maine, including 18 amphibians and 18 reptiles, one of which is considered extirpated (Timber Rattlesnake, *Crotalus horridus*). Two others are introduced: a salamander (Mudpuppy, *Necturus maculosus*) and a turtle (Red-eared Slider, *Trachemys scripta elegans*). While Maine has a lower diversity of reptiles and amphibians than most eastern states, it provides some of the most extensive and intact remaining habitat for the species it hosts. Several are of regional and national conservation concern.

Conservation Overview
Reptiles and amphibians are two of the most imperiled vertebrate taxa worldwide, and this pattern of endangerment is also reflected in the status of Maine's fauna where a relatively large proportion of native reptile and amphibian species (33%) are listed as state Endangered or Threatened (four species), Special Concern (six species), Extirpated (one species), and/or SGCN (one additional species). This is in part due to the biogeography described above, whereby the area of greatest diversity, southern and coastal Maine, is also the most densely human populated with associated high rates of development, habitat loss and fragmentation, road mortality, predation, pollution, and illegal collection. The effect of climate change on the status of Maine's herpetofauna is uncertain, but given the group's limited dispersal capability and sensitivity to temperature and humidity gradients it is safe to expect significant changes in local distribution and abundance.

Reptiles (Snakes and Turtles)
Among Maine's vertebrates, reptiles are arguably the most imperiled, with eight of the state's native 17 species (47%) listed as Endangered, Threatened, Special Concern, Extirpated, and/or SGCN. The rarity of many of the state's snakes and turtles is partially attributed to the fact that nearly all reach or approach the northern edge of their range in Maine, but population viability for several species is further stressed by anthropogenic factors including most notably habitat loss, road kill, nest and hatchling loss to human-subsidized predators, and illegal collection. The globally rare and declining Wood Turtle (*Glyptemys insculpta*) is patchily distributed throughout the state, but the fate of Maine's other imperiled reptiles will likely be determined in just a few southern counties where the challenge is to conserve remaining high quality occurrences in a relatively densely human populated landscape.



Northern Black Racers (*Coluber constrictor*, SGCN Priority 1), Maine's rarest snake, persist only in barren and dry woodland habitats of York County, at their northernmost range limit. © Jonathan Mays



Spring Salamanders (*Gyrinophilus porphyriticus*, SGCN Priority 2), one of Maine's rarest amphibians, are a specialist of headwater streams in central and western regions of the state. © Jonathan Mays

Amphibians (Frogs, Toads and Salamanders)
Four of Maine's 18 amphibian species are listed as Special Concern and/or SGCN. As a group, Maine's amphibians are relatively secure compared to its reptiles, likely because of their greater fecundity, higher densities, lower sensitivity to adult mortality factors, and generally wider range distribution across the state. Two of Maine's salamanders are listed as SGCN largely because of their close breeding association with a specialized aquatic habitat that is vulnerable to loss and degradation – headwater streams (Spring Salamander; *Gyrinophilus porphyriticus*) and vernal pools (Blue-spotted Salamander; *Ambystoma laterale*).

1.3.4 FRESHWATER (NON-DIADROMOUS) FISH

General Overview
Maine's freshwaters host a variety of fishes including 39 native freshwater obligate species (live their entire lives in freshwater habitats) and 12 diadromous species that live part of their lives in freshwaters. A significant proportion of the fish fauna (diadromous or obligate freshwater) that occur in Maine's inland waters is non-native: 19 species (27%). We include two whose exact status needs to be confirmed: Banded Sunfish (*Enneacanthus obesus*) and Emerald Shiner (*Notropis atherinoides*). As with other fauna, Maine sits at a biogeographic transition zone with some native fishes occurring at the northernmost extent of their natural distribution such as Redfin Pickerel (*Esox americanus americanus*), Swamp Darter (*Etheostoma fusiforme*) and American Brook Lamprey (*Lethenteron appendix*). Others are at the southern end of their range, like Brook Stickleback (*Culaea inconstans*), Lake Whitefish (*Coregonus clupeaformis*) and Lake Trout (*Salvelinus namaycush*). In addition, Maine maintains the only remaining U.S. populations of a regional endemic freshwater fish, a landlocked subspecies of Arctic Charr (*Salvelinus alpinus oquassa*).

Conservation Overview
Freshwater and diadromous fishes of North America are among the most threatened taxonomic groups. The American Fisheries Society reports that approximately 39% of all described species are considered imperiled (Jelks et al. 2008). Five Maine species are E/T listed under either state (MESA) or federal law (ESA). Moreover, 51% (26/51) of Maine's native freshwater and diadromous fishes are listed as SGCN. Most fish require clean, clear waters and all are naturally restricted to movements within aquatic habitats. Hence their survival, reproduction, movement and dispersal capabilities are compromised by natural landscape features (ex. waterfalls, watershed divides) as well as anthropogenic infrastructure (e.g., dams, road/stream crossings, developed shorelines). In addition, Maine's native freshwater fishes are adapted to relative depauperate fish community conditions. Hence, many of Maine's native fishes compete poorly with the on-going invasions of non-native species whose presence can have potentially strong effects on local distribution and abundance.

Inland Coldwater Fishes (Salmon, Trout, Charr, Smelt and Whitefishes)
By physiological limitations, Maine's native salmonid fishes are at or near their southerly range extent and all seven native species have some level of conservation concern. Atlantic Salmon (*Salmo salar*) are federally listed as Endangered in Maine. Arctic Charr, Lake Whitefish, and anadromous populations of Brook Trout (*Salvelinus fontinalis*) are designated as Special Concern and all, including Lake Trout, Round Whitefish (*Prosopium cylindraceum*) and anadromous Rainbow Smelt (*Osmerus mordax*) are SGCN. In addition to threats associated with water quality and impediments to dispersal and migration, coldwater fishes are likely to be significantly affected by climate change in Maine.



Brook Trout (*Salvelinus fontinalis*, SGCN Priority 3), are a "Maine Heritage Fish." Although occurring statewide and in a diversity of habitats, their range is retracting due to multiple stressors including interactions with non-native species, land use conversion, fish passage constraints and climate change. © Merry Gallagher

Rare Native Fishes (Minnows and others)
Redfin Pickerel and Swamp Darter are state-listed as Endangered and Threatened respectively. Both species occur at the northern extent of their natural range in Maine where they have highly restricted distributions and are subject to water quality degradation and habitat loss. Most other rare native fishes in Maine are listed as SGCN (10 species) because of a general lack of knowledge regarding their current abundance, population trend and distribution. Their habitat and ecological requirements are diverse. However identifying true threats is difficult at this time without a better understanding of their current status.

1.3.5 INLAND AND FRESHWATER INVERTEBRATES

As is true globally, invertebrates dominate Maine's biota, both in terms of richness and biomass. Based on available data, Gawler et al. (1996) conservatively estimated that Maine hosts a total of 15,000 non-marine invertebrate species, representing nearly 98% of the state's animal species diversity. Like most other states, Maine's legal definition of "wildlife" (any species of the animal kingdom) includes invertebrates, thus challenging MDIFW and cooperators with a tremendous breadth and volume of species to protect and manage (McCollough 1997). One of the ways MDIFW triages its limited staff and program resources toward the conservation and management of invertebrates is to focus on those species and groups that are better-studied and which have well documented declines or imperilment.

The best-studied phyla in Maine, as in most states, are the Mollusca (e.g., snails and mussels: ~200 species) and Arthropoda (e.g., insects, crustaceans, spiders: ~7,950 species). These two groups include all of the non-marine invertebrate species considered in this Plan. Within these phyla, the state of knowledge on distribution, status, and life history is strongest for just three orders: the Unionoida (freshwater mussels), Odonata (damselflies and dragonflies), and Lepidoptera (butterflies and moths), or what some have referred to as the "charismatic microfauna." Accordingly, a large proportion (66%) of the priority invertebrate species determined to be SGCN are represented by members of these same groups (Unionoida – 6 species; Odonata – 36 species; and Lepidoptera – 47 species). Other invertebrate taxa also

considered in the SWAP because of partial, but growing, knowledge include Gastropoda (snails; 8 species), Plecoptera (stoneflies; 3 species), Trichoptera (caddisflies; 4 species), Ephemeroptera (mayflies; 15 species), Hymenoptera (bumble bees; 10 species), Coleoptera (beetles; 4 species), and Decapoda (crayfish; 1 species).

Conservation Overview
Maine was one of the last states in New England to officially include invertebrates among its state-listed E/T species in 1997, but there have since been considerable efforts to improve our knowledge of the targeted groups highlighted above. As such, Maine has now assigned official conservation status to a total of 134 invertebrate species, including 20 species as E/T, 78 species as SC, and 36 additional fauna as SGCN. Still, the list of Maine invertebrates of conservation concern remains very low as a proportion of the state's estimated non-marine species richness (<0.01%). It should be noted this is primarily because of a lack of knowledge, and not because invertebrates as a group are inherently more abundant or secure in Maine, as illustrated by the fact that over half (8 of 15 species) of all documented state wildlife extinctions and extirpations are comprised of invertebrates (Coleoptera and Lepidoptera). Undoubtedly, many more invertebrate losses remain undocumented. The conservation knowledge gap for Maine's invertebrates is significant compared to plants and vertebrates, and thus their representation on Maine's SGCN and other conservation status lists will inevitably grow as further knowledge is obtained on the population status, distribution, and trends of various at-risk taxa.

The following is a brief review of the conservation status and imperilment patterns for select groups of Maine invertebrate taxa that host most of the state's SGCN.

Snails (subclass: Pulmonata and Prosobranchia, class: Gastropoda, phylum: Mollusca)
According to Martin (1999, 2000), there are 76 species of terrestrial snails, and 45 species of freshwater snails, reported from Maine. At least five species are introduced, and the taxonomic status of several others is questionable. While a number of individual investigations of Maine's snails exist *(*Gleich and Gilbert 1976, Hotopp and Smith 1994, Martin 1999, Martin 2000, systematic surveys targeting terrestrial (Nekola 2008) and aquatic (Hotopp 2012) species of potential conservation concern have only recently been initiated. Most Maine SGCN snails fall in the Stagnicola (aquatic) and Vertigo (terrestrial) genera and are thought to be limited by requirements for high water quality and/or extreme habitat specialization.

Freshwater Mussels (order: Unionoida, class: Bivalvia, phylum: Bivalvia)
Freshwater mussels are one of the few invertebrate taxa that have been a focus of intensive statewide survey efforts in Maine. From 1992 to present, MDIFW biologists systematically surveyed over 1,700 sites on the state's rivers, streams, lakes and ponds to document the distribution and status of mussels in Maine. Ten species are documented in Maine, all native, with the greatest diversity in the Kennebec and Penobscot River drainages, where all 10 species are often present in the same stretch of river (Nedeau et al. 2000). To date, the invasive zebra mussel (*Dreissena polymorpha*) has not been reported in Maine, but it occurs in Vermont and Massachusetts. If introduced, this species could have substantial impacts on native mussels and other aquatic biota. While freshwater mussel diversity is relatively low in Maine, their levels of imperilment are high with 6 of 10 species assigned Threatened and/or SGCN status, a trend mirrored nationally where over 3/4 of U.S. species are considered imperiled by various states in their range. The group shares several life history characteristics (long-lived, benthic, sedentary, filter feeding) that increase their exposure to a suite of anthropogenic stressors including water pollution, eutrophication, sedimentation, dams, and the degradation of riparian integrity along forested rivers and streams.

Mayflies (order: Ephemeroptera), Stoneflies (order: Plecoptera), and Caddisflies (order: Trichoptera) = all class: Insecta, phylum: Arthropoda
At least 162 species of mayflies are reported from Maine (Burian and Gibbs 1991, S. Burian, pers. communication). While this group is relatively well studied compared to many other insects, comprehensive surveys have never been conducted in Maine, and information on mayfly diversity and status is incomplete. Maine has two species of regionally endemic mayflies listed as state Threatened and 13 additional species listed as Special Concern and/or SGCN. Most of Maine's mayflies of conservation concern have narrow geographic distributions and occupy riverine habitats, with many of these specialized to small, cold, headwater settings.

At least 94 species of stoneflies, representing all nine North American families, are reported from Maine (Mingo 1983; S. Burian, pers. Communication). Typically inhabiting cold, fast-flowing streams and rivers, stoneflies are likely more diverse than what is currently documented for Maine. Two of Maine's three SGCN stoneflies are globally rare species with only historic occurrence data, emphasizing the need for further survey effort.

The species richness of caddisflies is higher in Maine than in most regions of North America (Huryn and Harris 2000) with recent collections suggesting a total that exceeds 300 species (Huryn and Harris 2000). At least an additional 50 species of the lesser-known "micro caddisflies" in the family Hydroptilidae are also reported from the state (Blickle and Morse 1966, Huryn and Harris 2000). All of Maine's four SGCN species are considered globally rare, with two species having only been described and documented (to date) in Maine.

Bees, Wasps, and Ants (order: Hymenoptera, class: Insecta, phylum: Arthropoda)
At least 52 families and 855 species of bees, wasps, and ants have been reported from Maine (Dearborn et al. 1983; Stubbs et al. 1995). These numbers are most certainly conservative estimates, as surveys specifically designed to assess species diversity for the Hymenoptera have never been conducted (Stubbs et al. 1995). With the help of NatureServe, MDIFW recently acquired sufficient information to begin assessing the conservation status of Maine's bumble bees (*Bombus spp*), one of the state's most valuable pollinators of wild plants and cultivated crops. Of the 17 species of bumble bees documented from Maine, 10 are considered SGCN due to the lack of modern records or range-wide declines. Habitat loss, introduced diseases and parasites, pesticides, and intensive agricultural practices are all believed to have played a role in bumble bee declines in Maine and across North America. A recently launched citizen-science atlasing effort (http://mainebumblebeeatlas.umf.maine.edu/) is designed to increase our knowledge of bumble bee distribution and status in Maine.



Significant declines of the globally rare Rusty-patched Bumble Bee (*Bombus affinis,* SGCN Priority 1) are increasingly evident in many different pollinators. Monitoring programs are critical to better understand distribution, status and conservation strategies. © Rich Hatfield

Beetles (order: Coleoptera, class: Insecta, phylum: Arthropoda)
There are at least 96 families and 2,871 species of beetles reported from Maine (Majka et al. 2011). Generally recognized as the largest order of insects, the Coleoptera have not been

systematically surveyed in Maine and there are likely hundreds of state species records yet to be discovered (D. Dearborn, pers. communication). The best studied group of beetles in Maine, and probably North America, is the tiger beetles (family Carabidae, subfamily Cicindelinae). Three of Maine's four SGCN beetles are Cicindelids, including a newly discovered state species record, the Cobblestone Tiger Beetle (*Cicindela marginipennis*) known from only one riverine population in the western foothills. The federally-endangered American Burying Beetle (*Nicrophorus americanus*) is known historically from southwestern and central Maine, but is now believed to be state extirpated.

Butterflies and Moths (order: Lepidoptera, class: Insecta, phylum: Arthropoda)
Colorful, conspicuous, and ecologically important, butterflies are among the few insect groups that have benefited from considerable attention by early Maine naturalists (collections exist from as far back as 1870) and recent citizen scientist efforts through the Maine Butterfly Survey (http://mbs.umf.maine.edu/). There are 123 documented species of butterflies and skippers representing five families in Maine (Webster and deMaynadier 2005). Of special note is the relatively high proportion (20%) of Maine butterflies that are listed as Extirpated (five species), Endangered or Threatened (eight species), or Special Concern and/or SGCN (12 species): a result consistent with global trends elsewhere for the group (Stein et al. 2000, Thomas et al. 2004). Primary threats to Maine's butterflies include habitat loss and degradation to development, succession, and aerial pesticides. Most of Maine's rarest butterflies are associated with three habitat types: swamps, peatlands, and dry barrens, with the latter especially vulnerable to multiple threats in southern Maine.



Crowberry Blue (*Plebejus idas empetri,* SGCN Priority 2) is one of Maine's few regional endemics. The global range of this butterfly is restricted to a narrow band of coastal crowberry bogs in Maine and Canada's Maritime Provinces. © Bryan Pfeiffer

There are at least 17 families and 1,152 species of moths (macro) reported from Maine (Brower 1974). An additional 41 families and 1,720 species of "micro-moths" are also documented to occur in the state (Brower 1983, 1984, D. Dearborn, pers. communication). Much of this information is based on historic collections and the focused efforts of a few individual researchers. Comprehensive statewide surveys and species assessments have never been done for this taxon with especially pronounced knowledge gaps for the micro Lepidoptera. Much of what we know about the conservation status of moths in Maine comes from NatureServe, which tracks 108 species from the state, of which 18 are ranked as globally rare. Currently Maine lists two species of moth as Threatened and 24 species as SC and/or SGCN, with several more likely to be extirpated (D. Schweitzer, pers. communication). Like the butterflies, several of Maine's rarest moths are associated with pitch pine-scrub oak barrens and peatlands and are especially sensitive to any threats to these habitats.

Dragonflies and Damselflies (order: Odonata, class: Insecta, phylum: Arthropoda)
Like butterflies, dragonflies and damselflies are a popular and conspicuous insect group that have attracted significant attention from both scientists and the general public. Much of what is currently known about Maine's Odonates is the result of an assessment of historic records, MDIFW targeted surveys, and the recently completed Maine Dragonfly and Damselfly Survey (MDDS) (http://mdds.umf.maine.edu/). These efforts have led to a list of 158 species of dragonflies and damselflies known from Maine and considerable knowledge on distribution, habitat relationships, and conservation status of most species (Brunelle and deMaynadier 2005). Three of Maine's Odonata are listed as E/T and 25 species as Special Concern and/or SGCN. A recent assessment of high priority Odonata for conservation action in the Northeast identified 21 species in Maine because of high regional responsibility (narrow geographic ranges centered in the Northeast) and/or moderate to high imperilment due to habitat vulnerabilities and potential population declines (White et al. 2014). Most of Maine's most vulnerable Odonata are associated with northern peatlands, lakes, and moderate to large forested rivers.

1.3.6 MARINE FAUNA (EXCEPT BIRDS)

General Overview
There are approximately 1,800 known marine animal species in the Gulf of Maine, but it is estimated that far more are still undiscovered, especially in the invertebrate and chordate groups (Census of Marine Life 2015). Maine state waters (<3 nautical miles offshore) host a wide array of species including invertebrates, diadromous fishes, groundfish, marine mammals, sea birds, pelagic finfishes, and more. The diversity of habitat within coastal and marine waters, the geographic location between the Artic and Temperate zones, as well as complex coastal circulation patterns all provide Maine with unique and delicately balanced species assemblages.

Maine is the southern extent for some marine fauna. Polar Lebbeid Shrimp (*Lebbeus polaris*), Sea Strawberry (*Gersemia rubiformis*), and Atlantic Great Piddock (*Zirfaea crispata*) are SGCN from 3 different invertebrate classes that are restricted to waters from Maine northward. Conversely, others are at the northernmost range limits in Maine. The Horseshoe Crab (*Limulus polyphemus*) and Leatherback Sea Turtle (*Dermochelys coriacea*) are SGCN with distributions that range southward from the Gulf of Maine.

Some marine fauna have undergone severe population reductions in recent years. Maine waters host some of the last remaining, sizeable populations in the U.S. Notable SGCN examples include Atlantic Salmon and Rainbow Smelt. Several marine SGCN have large oceanic ranges or are highly migratory as adults: Atlantic Bluefin Tuna (*Thunnus thynnus*), Atlantic Salmon, all whales, and all sea turtles. The majority of marine species have highly dispersive juvenile stages. Taken together, these attributes contribute to a unique balance of species assemblages, with each species relying on the suite of others for prey, prey buffering, habitat (e.g., mollusk reefs), and nutrients transfer.

Conservation Overview
Aside from the Sea Mink (Section 1.2.1), only one marine species is known to be extinct in the Gulf of Maine: the Eelgrass Limpet (*Lottia alveus*). The Eelgrass Limpet, a marine gastropod, was estimated to have become extinct in the 1930s due to massive die-offs of eelgrass, which served as its primary habitat (Carlton et al. 1991).

A small number of marine species are protected via federal listing as E/T: three diadromous fish, six whales and four sea turtles. Eleven of these are also state-listed under MESA. The National Marine Fisheries Service (NMFS) designates some fauna as Species of Concern (SoC): three diadromous fishes, three groundfish and two elasmobranchs. However, numerous other species warrant conservation attention. State-listing of marine fauna under MESA is limited by statute to those federally listed as E/T.

While many marine species are subject to commercial and recreational fisheries, or being caught indirectly as bycatch, some of these species warrant conservation measures beyond fisheries management plans. The 2015 Maine Wildlife Action Plan lists 71 SGCN: nine diadromous fish, six groundfish, a pelagic fish (Bluefin Tuna, *Thunnus thynnus*), one ammodyte (American Sand Lance, *Ammodytes americanus*), five sharks, four skates, four sea turtles, six whales, one porpoise, and 34 invertebrates (= eight bivalves, one brachipod, two Cnidaria, 11 echinoderms, seven gastropods, and five arthropods).

The following is a brief review of the conservation status and imperilment patterns for select groups of marine taxa that host significant numbers of the state's SGCN.

Marine Invertebrates

Although a large proportion of the known marine animal species in the Gulf of Maine are invertebrates (~80%), less than half of the marine SGCN are invertebrates (34 species, 48% of SGCN). This is primarily due to a lack of knowledge about the status, distribution, or abundance of these species. Marine invertebrates face many of the same research challenges as terrestrial and freshwater invertebrates, including their small size, and small niches/habitats. Additionally, financial and logistical challenges specific to working in the marine environment compound these issues. Since 24% of the marine SGCN are commercially or recreationally harvested, some may have existing monitoring programs in place. However, there is a need for increased knowledge about population trends and reasons for decline for many of the invertebrate SGCN.



Sea Cucumbers (*Thyonidium drummondii*, SGCN Priority 2) and several other invertebrates are an important foundation of the marine ecosystem that may face additional risks from warming waters and acidification in the Gulf of Maine. © Maggie Hunter

Marine invertebrates vary in life history and are thus subject to a variety of stresses. Most juvenile invertebrates are found in the water column as zooplankton, and some species are sessile during at least part of their life cycle. Sessile organisms can be slow to recolonize an area after an event that reduces their abundance. Many invertebrates can be sensitive to changes in water quality including non-point source pollution and thermal changes. Calcareous invertebrates may be susceptible to changes in water pH resulting from increased dissolved carbon dioxide in the water. SGCN vulnerable to ocean acidification include Softshell Clam (*Mya arenaria*) and Gaper Clam (*Mya truncata*). With recent and sometimes rapid changes in coastal development, increases in sea surface temperature, and decreases in ocean pH, understanding if and

how these species are adapting and how their ranges and habitats are affected is imperative for developing successful conservation strategies.

Finfish: Diadromous, Groundfish, and Ocean Migratory Fish

There are over 50 commonly found finfish species in Maine waters, most of which have experienced population declines in the past 10-50 years. A total of 16 finfish species have been identified as SGCN for Maine, and 11 of those species have experienced recent, significant declines in abundance. Overfishing has been attributed to the decline of many of these species, including Atlantic Cod (*Gadus morhua*) and Haddock (*Melanogrammus aeglefinus*).

Some SGCN declines may be due to environmental changes and habitat alterations: e.g., Atlantic Wolfish (*Anarhichas lupus*) and Spotted Wolffish (*Anarhichas minor*). Fish populations can be slow to rebound after marked declines, even after fishing pressure has been reduced. This may be due to populations having been reduced below a critical threshold, combined with changes in habitat including increasing water temperature, reduction of bottom structure following trawling, and changes in predator-prey abundances. Key to the conservation of these species are efforts to identify spawning locations, migration patterns, habitat use, impacts of changing water chemistry and temperature, as well as how changing species assemblages will affect predator-prey relationships.

Diadromous fishes face a unique set of threats as they migrate between marine and freshwater. Obstructions in rivers and streams, alterations in water flow, and water runoff contamination and high nutrient inputs have all led to the reduction of species' populations. While some of these species respond well to existing management strategies, like improving fish passage and seed-stocking (e.g., Alewives, *Alosa pseudoharengus*), others continue to maintain only small populations despite conservation efforts (e.g., Atlantic Salmon). Continuing to improve fish passage and water quality is necessary to recover these species. Additionally, recent research has shown the importance of interspecific relationships. For example, the timing of spawning and migration patterns may provide prey-buffering for species of reduced numbers – e.g., schools of river herring may reduce predation of Atlantic Salmon smolts.



Alewives (SGCN Priority 2) are among the eight diadromous fish recognized as SGCN in this Plan. Most Maine rivers once supported major spawning runs, but many runs are currently less than half of their estimated potential. © Sharon Fiedler

Whales and Sea Turtles

There are at least 22 species of marine mammals and turtles that are known to frequent the waters of the northern Gulf of Maine. Many are SGCN, including six species of large whales federally-listed as Endangered since 1970: North Atlantic Right (*Eubalaena glacialis*), Humpback (*Megaptera novaeangliae*), Finback (*Balaenoptera physalus*), Sei (*Balaenoptera borealis*), Sperm (*Physeter macrocephalus*), and Blue (*Balaenaoptera musculus*). There are four species of federally-listed sea turtles: Kemp's Ridley (*Lepidochelys kempii*), Leatherback (*Dermochelys coriacea*), Green (*Chelonia mydas*), and the Northwest Atlantic Ocean distinct population segment of Loggerhead Turtles. All range widely in international waters with some presence in state jurisdiction in the Gulf of Maine.

The North Atlantic Right Whale, with a population now estimated over 400 is considered one of the most endangered of the large whales. For decades, since the end of commercial whaling, the Right Whale has shown slow recovery. The lack of Right Whale recovery has been linked to collisions with ships, entanglement in specific fishing gear, habitat degradation, and disturbance from vessels. Additionally, the Maine gillnet and lobster fisheries are documented as causing serious injury and mortality to this SGCN, as well as to other bycatch. Consequently MDMR, in collaboration with Maine's commercial fishing industries, developed a Comprehensive Marine "Wildlife Conservation Strategy for Large Whales and Sea Turtles" to reduce the risk posed by these fisheries to North Atlantic Right Whales and other protected resources. MDMR has a strategic role to balance commercial lobster and gillnet fisheries within State waters and impacts to large whales and sea turtles. The State of Maine is fully committed to the protection of Atlantic large whales and sea turtles, while at the same time protecting the economic and operational realities of the State's fisheries.

1.4 DISTRIBUTION OF MAINE'S SGCN AND ASSOCIATED HABITATS

Best management practices for State Wildlife Action Plan updates (AFWA 2012) recommend compiling information on the distribution of each SGCN and its associated habitats to help prioritize areas within the state for conservation actions. Range, distribution, and observations all describe geographic arrangements of elements (species and habitats) across a landscape. However, these terms have different meanings. Range is the broadest geographic extent across which an element could be found. The distribution of an element is the spatial pattern of its occurrence within its range and may be scattered, random, clustered, or regular depending on the population/community dynamics of the element and the heterogeneity of the landscape. Further, individual observations of an element may or may not be evidence of a viable or persistent population.

The sampling unit used for a spatial analysis should be appropriate to the scale and resolution of the input data and the needs it is intended to meet. We chose Maine's municipal township boundaries (for non-aquatic SGCN) and United States Geological Survey (USGS) HUC12 sub-watersheds (for aquatic SGCN) as the sampling units for this analysis. Both are familiar to the Maine conservation community and the general public and can easily be generalized to broader scales (e.g., counties, watersheds, or ecoregions).

We used our best available information to develop "species conservation range maps" for SGCNs in Maine. These maps are intended to identify within Maine the broadest geographic extent across which conservation actions might benefit each SGCN. These maps are not meant to convey the ecological ranges or distributions of these species. Because we used habitat to qualify these maps, however, for some species the maps may approximate their ecological distribution subject to 1) accuracy and resolution of the habitat mapping, 2) generalization of observation data to the sub-watershed/township scale, and 3) the existence of undocumented areas occupied by the species.

1.4.1 METHODOLOGY FOR MAPPING ELEMENT 1 – SGCN DISTRIBUTIONS

Our primary source of observation data was MDIFW's "Endangered, Threatened, and Special Concern" (ETSC) database, which includes observations on some, but not all of Maine's SGCNs. We supplemented MDIFW's ETSC data with SGCN observations from the following:

- Maine Damselfly and Dragonfly Atlas; (http://www.maine.gov/ifw/wildlife/species/invertebrates/damselfly_dragonfly.html)
- Maine Butterfly Survey; (http://www.maine.gov/ifw/wildlife/species/invertebrates/butterfly_survey.html)
- Maine Mussel Survey; (http://www.maine.gov/ifw/wildlife/species/invertebrates/freshwater_mussels.html)
- Maine Amphibian and Reptile Atlas Project; (http://www.maine.gov/ifw/wildlife/species/reptiles/atlasing_project.html)
- North American Breeding Bird Survey; (https://www.pwrc.usgs.gov/bbs/)
- Essential Wildlife Habitats mapped under Maine's Endangered Species Act
- MDIFW radio-telemetry locations and track surveys for Canada Lynx
- Shorebird Areas mapped under Maine's Natural Resources Protection Act
- MDIFW vernal pool locations with Blue-spotted Salamander observations
- MDIFW fish data sets
- eBird
- Maine Bumble Bee Atlas; (http://mainebumblebeeatlas.umf.maine.edu/)
- Maine Mayfly Database (http://www.maine.gov/ifw/wildlife/species/invertebrates/rare_mayflies.html)

These data sets varied greatly in data format. Some data sets were geospatial (i.e., GIS files), whereas others stored only attributes but included geographic coordinates that we used to generate geospatial representations. Most were point data, but some linked observations to unmapped sites along survey transects and others mapped observations as polygons. Thus, our first step in generating SGCN distributions was to standardize and assimilate these data sets. We then used all of these observations to determine in which Maine townships and sub-watersheds each SGCN occurred. We did not attempt to count observations of an SGCN within a township or sub-watershed or to estimate densities because sampling effort varied geographically and among data sets. Some observations also may have been duplicated across data sets. Although an observation from any of the data sets could indicate presence of the SGCN in a particular township or sub-watershed, we presented the data sets as separate GIS layers so users could compare the data sources or view them collectively for an SGCN.

1.4.2 METHODOLOGY FOR MAPPING ELEMENT 2 – HABITATS

We used a modified version of the Northeast Ecological Systems, 2014 Update (Ferree and Anderson 2013, http://northatlanticlcc.org/data/regional-spatial-data/terrestrial/tnc-terrestrial-habitat/ne-terrestrial-habitat-map) mapped by the North Atlantic Landscape Conservation Cooperative (NALCC), the Northeast Association of Fish and Wildlife Agencies, and The Nature Conservancy to map habitats for each SGCN. We updated their map for habitat classes for which we had and/or required more accurate/higher resolution spatial data including:

- Rivers and streams classified by MDIFW to small, medium, or large river or headwater/creek
- Lakes and ponds classified by MDIFW to oligotrophic, eutrophic, mesotrophic/intermediate, or dystrophic
- Tidal flats classified by substrate type by the National Wetlands Inventory
- Tidal marshes as mapped/classified by the Maine Natural Areas Program
- Lake and river shores classified by the National Wetlands Inventory
- Intertidal and subtidal habitats as mapped/classified by the Maine Department of Marine Resources

Using the resulting habitats, species specialists from MDIFW, with input from conservation partners, associated each SGCN with each ecological system and habitat macrogroup it was believed to use. We then identified the townships and sub-watersheds where these associated habitats occurred for each SGCN. Part of our goal was to identify unoccupied habitats or areas of undocumented SGCN presence. Some habitats, however, extended beyond the range of an SGCN and therefore presented an unrealistic estimate of its potential distribution. As part of our 2005 SWAP conservation actions, Maine divided the state into ecoregions and surveyed them for a variety of species including many SGCN. This work was the source for many of the SGCN observations in MDIFW's ETSC database. The species specialists associated each SGCN with each ecoregion where it was believed to occur and we then used those ecoregional associations to constrain the habitat mapping to more realistic extents.

The Maine GAP Analysis project (Krohn et al. 1998) used a similar process (i.e., combining observation data with habitat maps) to estimate distributions for vertebrate species in Maine. We included the GAP data in our species conservation range maps, calling it "potential habitat." Despite having fewer observations to work with and a much simpler habitat data set, the GAP distributions are quite similar to our updated distributions for many SGCNs.

1.4.3 SPECIES CONSERVATION RANGE MAPS

Our large number of SGCN, observation data sets, and habitat associations precluded mapping by hand. Instead, we used our SWAP database and a series of custom Python programs to automate map production. This approach will allow maps to be updated with relative ease for additional SGCNs as new observation data becomes available, our understanding of habitat relationships improve, or if the habitat map changes. The process generates a series of data tables linking SGCNs to townships and sub-watersheds based on observations of the SGCN and mapping of its associated habitats. Data for each SGCN then is used to update a map template that produces a PDF document in which the various input data sets can be toggled on or off according to user preference.

All of the SGCN species conservation range maps will be served to conservation partners and the public as digital files and/or via a web mapping service. Figure 1-1 illustrates some static images of a few SGCN example maps illustrating some of the variation in distribution patterns such as edge-of-range, rare but scattered, concentrated (e.g., coastal, mountainous), and ubiquitous.

1.4.4 SGCN DISTRIBUTION SYNTHESIS

Summarizing SGCN patterns statewide was a primary goal of mapping species conservation ranges to determine where conservation actions might be best applied to benefit the most species. One summary method is by taxonomic class—for example, all birds. This approach benefits conservation partners interested in working with certain groups of SGCN. Other groups might be interested in SGCN associated with particular habitats (e.g., emergent marshes), especially when a specific conservation action is tied to a habitat type (e.g., improved riparian buffer conservation). As with the species conservation ranges, we based our SGCN summaries on USGS subwatersheds for aquatic SGCN classes and habitats and on Maine townships for non-aquatic SGCN classes and habitats. Our goal is to present these summaries in an interactive map format where users can select which SGCN classes, habitats, and landscape units to use. For purposes of this static document, we have included a few possible examples (Figure 1-2).

Figure 1-1. Examples of conservation range maps by USGS sub-watersheds for aquatic SGCNs and by Maine townships for terrestrial SGCNs. Red/yellow shaded areas indicate an SGCN's presence based on observation data; green/blue indicates presence of potential habitats associated with the SGCN.

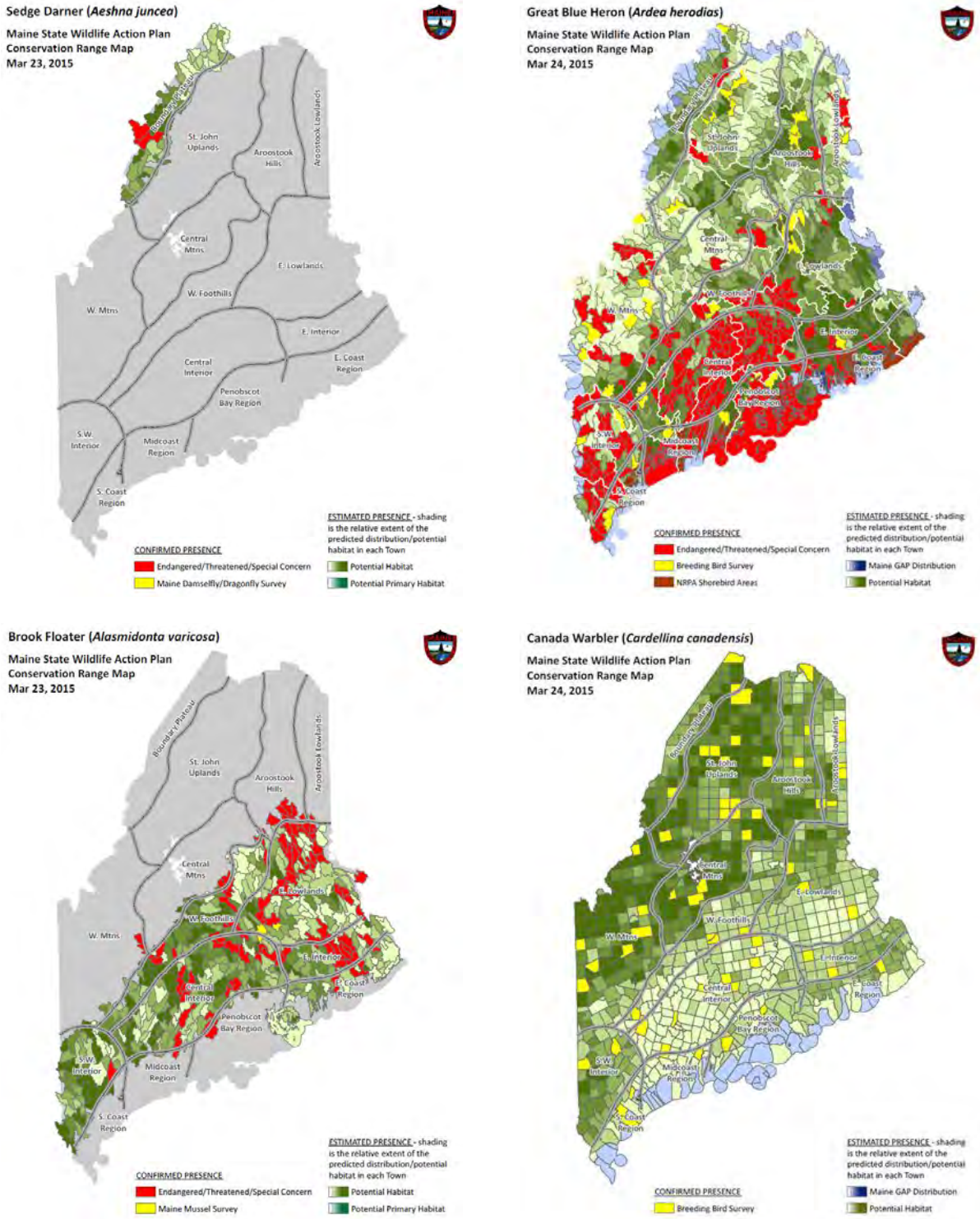
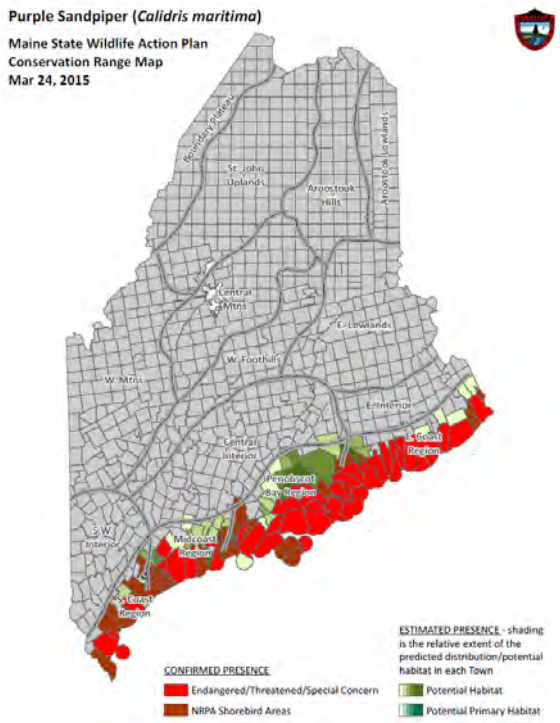
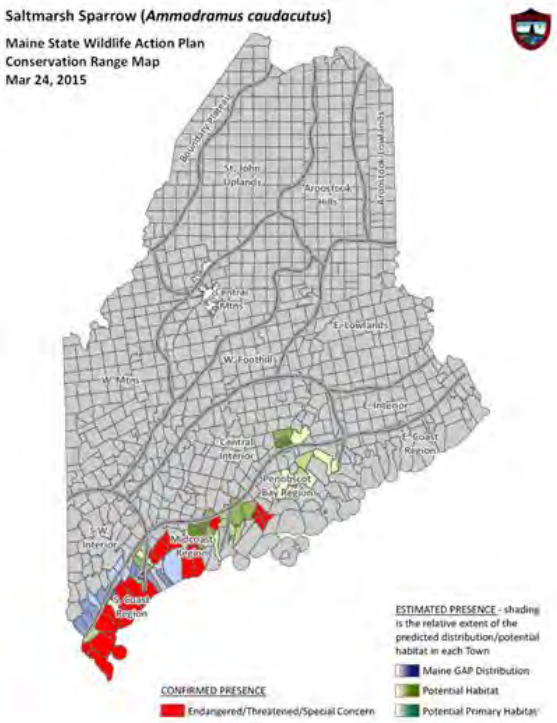


Figure 1-1. *continued: page 2 of 2.*





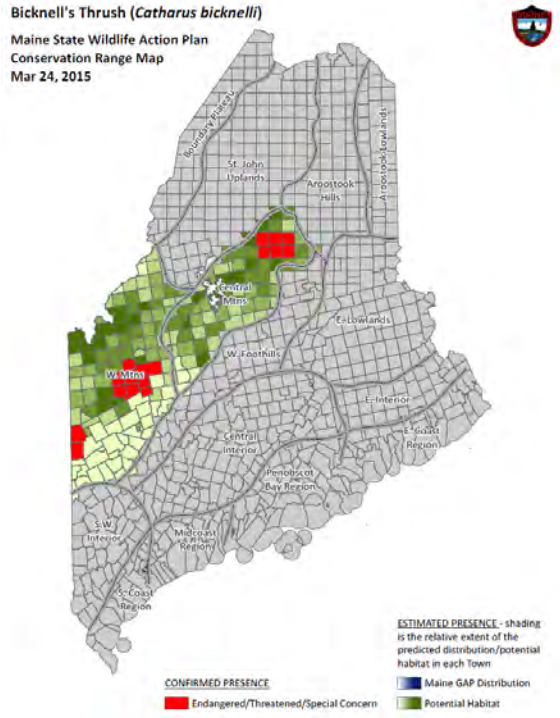
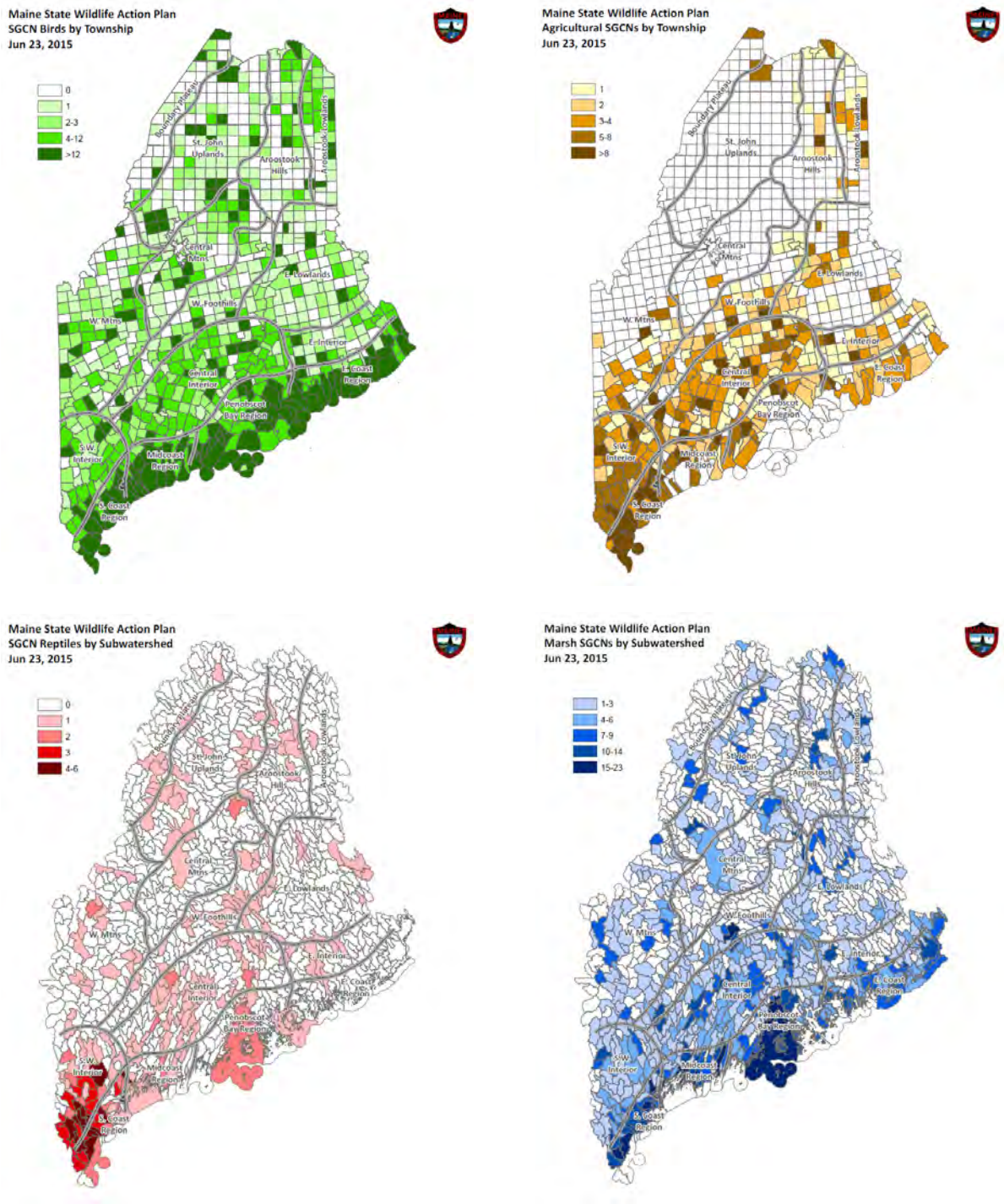




Figure 1-2. Examples of SGCN summaries by taxa class and habitat associations for USGS sub-watersheds and Maine townships.



1.5 DESIGNATION CRITERIA FOR MAINE'S SGCN - 2015

MDIFW biologists, with review and cooperation from conservation partners and species experts, offer the following criteria (and subcriteria) for designating Maine's eligible Species of Greatest Conservation Need (SGCN). The criteria and process for selecting SGCN are intended to be comprehensive, transparent, and based on best available science for prioritizing species of conservation concern at local, regional, and global scales. As proposed, fish and wildlife species (and subspecies) designated as priority 1 or 2 or 3 qualify as SGCN, and are thus eligible for State Wildlife Grant funding. The primary themes for SGCN prioritization include risk of extirpation, population trend, endemicity, and regional conservation responsibility. Secondary themes for SGCN prioritization include climate change vulnerability, survey knowledge, and cultural significance to Maine tribes (Table 1-2). Finally, only Maine extant species were considered for designation as SGCN in 2015.

"The criteria and process for selecting SGCN are intended to be comprehensive, transparent, and based on best available science for prioritizing species of conservation concern at local, regional, and global scales."

1.5.1 PRIORITY 1 (HIGHEST PRIORITY) SGCN

Generally, Priority 1 species include those that meet <u>two or more</u> of the following criteria:

1. **Risk of Extirpation** – Have current (or proposed) state or federal E/T status, or global endangerment status (International Union for the Conservation of Nature [IUCN])

2. **Recent Significant Declines** – A species currently (within 15 years) undergoing steep population decline statewide or regionally, which has already led to, or if unchecked is likely to lead to, local extinction and/or significant range contraction.

3. **Regional Endemic** – A species whose global geographic range is at least 90% contained within the area defined by USFWS Region 5, the Canadian Maritime Provinces, and southeastern Quebec (south of the St. Lawrence River).

4. **High Regional Conservation Priority** -- Identified as a high regional or global species of conservation concern by <u>one</u> of the following species assessment authorities (see Table 1-2 for Priority 1 subcriteria):

    a. Northeast Endangered Species and Wildlife Diversity Technical Committee [NESWDTC] (all vertebrates and freshwater mussels) – Therres 1999
    b. Northeast Regional Synthesis [RSGCN] (all vertebrates, freshwater mussels, and tiger beetles) – Terwilliger 2013
    c. NatureServe (all taxa) – NatureServe 2014
    d. Partners in Flight (land birds). Partners In Flight Science Committee 2012 Species Assessment Database, version 2012.
    e. North American Waterbird Conservation Plan [NAWCP] (all waterbirds) – Kushlan et al. 2002 and 2006 (marsh birds)
    f. North Atlantic Regional Shorebird Plan [NARSP] (shorebirds) – Clark and Niles 2000

g. U.S. Shorebird Conservation Plan [USSCP] (shorebirds) – U.S. Shorebird Conservation Plan 2004
h. Birds of Conservation Concern (all birds) – USFWS 2008
i. Northeast Partners In Amphibian and Reptile Conservation [NEPARC] (herpetofauna) – NEPARC 2010
j. American Fisheries Society (freshwater & diadromous fish) – Jelks et al. 2008
k. Atlantic States Marine Fisheries Commission Stock Assessments [ASMFC] - ASMFSC 2012
l. Eastern Brook Trout Joint Venture [EBTJV] - EBTJV 2011
m. Northeast Odonate Assessment (damselflies & dragonflies) – White et al. 2014

Note: Priority 1 designation is not intended for:

- species that have expanded their range into Maine within the past 50 years, OR
- species with only historic documentation (generally prior to mid-1970s)

1.5.2 PRIORITY 2 (HIGH PRIORITY) SGCN

Generally, Priority 2 species include:

- all other current State (Endangered, Threatened, or Proposed), Federal (Endangered, Threatened, Candidate, or Proposed) or Global (IUCN Critically Endangered or Threatened) risk of extirpation species, OR
- those that meet at least two of the following criteria:

1. **Global Vulnerability** – A species designated as Vulnerable by the International Union for the Conservation of Nature (IUCN).

2. **State Special Concern** – Listed as a current or proposed species of Special Concern in Maine.

3. **Recent Significant Declines** – A species currently (within 30 years) undergoing steep population decline statewide or regionally, which has already led to, or if unchecked is likely to lead to, local extinction and/or significant range contraction.

4. **Regional Endemic** – A species whose global geographic range is at least 90% contained within the area defined by USFWS Region 5, the Canadian Maritime Provinces, and southeastern Quebec (south of the St. Lawrence River).

5. **High Climate Change Vulnerability** – A species identified as highly vulnerable by Whitman et al. 2013 or Galbraith et al. 2014 (or other published source).

6. **Historical** -- Species currently listed as state (SH) or global (GH) Historical (by MDIFW or NatureServe) that have a reasonable probability of population rediscovery with further survey.

7. **High Regional Conservation Priority** -- Identified as a high regional or global species of conservation concern by one of the following authorities (see Table 1-2 for Priority 2 subcriteria):

a. Northeast Endangered Species and Wildlife Diversity Technical Committee [NESWDTC] (all vertebrates and freshwater mussels) – Therres 1999
b. Northeast Regional Synthesis [RSGCN] (all vertebrates, freshwater mussels, and tiger beetles) – Terwilliger 2013
c. NatureServe (all taxa) – NatureServe 2014
d. Partners in Flight (land birds). Partners In Flight Science Committee 2012 Species Assessment Database, version 2012.
e. North American Waterbird Conservation Plan [NAWCP] (all waterbirds) – Kushlan et al. 2002 and 2006 (marsh birds)
f. North Atlantic Regional Shorebird Plan [NARSP] (shorebirds) – Clark and Niles 2000
g. U.S. Shorebird Conservation Plan [USSCP] (shorebirds) – U.S. Shorebird Conservation Plan 2004
h. Birds of Conservation Concern (all birds) – USFWS 2008
i. Northeast Partners In Amphibian and Reptile Conservation [NEPARC] (herpetofauna) – NEPARC 2010
j. American Fisheries Society (freshwater & diadromous fish) – Jelks et al. 2008
k. Atlantic States Marine Fisheries Commission Stock Assessments [ASMFC] - ASMFSC 2012
l. Eastern Brook Trout Joint Venture [EBTJV] - EBTJV 2011
m. Northeast Odonate Assessment (damselflies & dragonflies) – White et al. 2014
n. Committee on the Status of Endangered Wildlife in Canada [COSEWIC] (all taxa) – COSEWIC 2015

Note: Priority 2 designation is not intended for species that have expanded their range into Maine within the past 25 years.

1.5.3 PRIORITY 3 (MODERATE PRIORITY) SGCN

Generally, Priority 3 species include those that meet at least one of the following criteria:

1. **Global Vulnerability** – A species designated as Vulnerable by the International Union for the Conservation of Nature (IUCN).

2. **State Special Concern** – Listed as a current or proposed species of Special Concern in Maine.

3. **Recent Significant Declines** – A species currently (within 30 years) undergoing steep population decline statewide or regionally, which has already led to, or if unchecked is likely to lead to, local extinction and/or significant range contraction.

4. **Regional Endemic** – A species whose global geographic range is at least 90% contained within the area defined by USFWS Region 5, the Canadian Maritime Provinces, and southeastern Quebec (south of the St. Lawrence River).

5. **High Climate Change Vulnerability** – A species identified as highly vulnerable by Whitman et al. 2013 or Galbraith et al. 2014 (or other published source).

6. **Understudied Rare Taxa** -- Recently documented or poorly surveyed rare species for which risk of extirpation is potentially high (e.g. few known occurrences), but insufficient data exist to conclusively assess distribution and status.

7. **Historical** -- Species currently listed as state (SH) or global (GH) Historical (by MDIFW or NatureServe) that have a reasonable probability of population rediscovery with further survey.

8. **Culturally Significant** -- Species identified as both biologically vulnerable and culturally significant by Maine's tribes.

9. **High Regional Conservation Priority** -- Identified as a high regional or global species of conservation concern by one of the following authorities (see Table 1-2 for Priority 2 subcriteria):

    a. Northeast Endangered Species and Wildlife Diversity Technical Committee [NESWDTC] (all vertebrates and freshwater mussels) – Therres 1999
    b. Northeast Regional Synthesis [RSGCN] (all vertebrates, freshwater mussels, and tiger beetles) – Terwilliger 2013
    c. NatureServe (all taxa) – NatureServe 2014
    d. Partners in Flight (land birds). Partners In Flight Science Committee 2012 Species Assessment Database, version 2012.
    e. North American Waterbird Conservation Plan [NAWCP] (all waterbirds) – Kushlan et al. 2002 and 2006 (marsh birds)
    f. North Atlantic Regional Shorebird Plan [NARSP] (shorebirds) – Clark and Niles 2000
    g. U.S. Shorebird Conservation Plan [USSCP] (shorebirds) – U.S. Shorebird Conservation Plan 2004
    h. Birds of Conservation Concern (all birds) – USFWS 2008
    i. Northeast Partners In Amphibian and Reptile Conservation [NEPARC] (herpetofauna) – NEPARC 2010
    j. American Fisheries Society (freshwater & diadromous fish) – Jelks et al. 2008
    k. Atlantic States Marine Fisheries Commission Stock Assessments [ASMFC] - ASMFSC 2012
    l. Eastern Brook Trout Joint Venture [EBTJV] - EBTJV 2011
    m. Northeast Odonate Assessment (damselflies & dragonflies) – White et al. 2014
    n. Committee on the Status of Endangered Wildlife in Canada [COSEWIC] (all taxa) – COSEWIC 2015

Note: Priority 3 designation is not intended for species that have expanded their range into Maine within the past 10 years.

Table 1-2. Vulnerability concepts and criteria for designating Maine's SGCN.

Vulnerability Factor	Authority (Source)	Metric[1]	Potential Priority	Primary Taxa
Extirpation	IUCN	"CR" or "EN"	1-2	all
Extirpation	IUCN	"VU"	1-3	all
Extirpation	ESA (USFWS)	"E" or "T" or "C" or "P"	1-2	all
Extirpation	MESA (MDIFW)	"E" or "T" or "P"	1-2	all
Potential Extirpation	MDIFW	"Special Concern"	2-3	all
Potential Extirpation	NMFS	"Species of Concern"	2-3	marine
Recent Decline	MDIFW (multiple)	Steep declines < 15 yrs.	1	all
Recent Decline	MDIFW (multiple)	Steep declines < 30 yrs.	2-3	all
Regional Endemics	MDIFW (multiple)	>90% of geographic range in the Northeast	1-3	all
Specialist Group Assessment	NEFWDTC (Therres 1999)	> 1: risk, data, area, spec, federal concerns	1-3	vertebrates & mussels
Specialist Group Assessment	RSGCN (Terwilliger & NEFWDTC 2013)	"high responsibility" AND "very high concern"	1	vertebrates
Specialist Group Assessment	RSGCN (Terwilliger & NEFWDTC 2013)	"high responsibility" AND "high concern"	2-3	vertebrates
Specialist Group Assessment	NatureServe (2014)	"G1-G2" (vertebrates) "G1" (invertebrates)	1	all
Specialist Group Assessment	NatureServe (2014)	"G3" (vertebrates) "G2" (invertebrates)	2-3	all
Specialist Group Assessment	COSEWIC (2015)	"E" or "T" in Atlantic Canada	2-3	all
Specialist Group Assessment	Partners in Flight (2012)	"concern, regional concern, or stewardship species" in US & CA	1-3	landbirds
Specialist Group Assessment	NAWCP (Kushlan et al. 2002, 2006)	"high concern"	1-3	waterbirds
Specialist Group Assessment	USSCP & NARSP (USSCP 2004; Clark & Niles 2000)	"highly imperiled" OR species of "high concern"	1-3	shorebirds
Specialist Group Assessment	Birds of Conservation Concern (USFWS 2008)	Listed in BCR 14 or 30	1-3	all birds
Specialist Group Assessment	NEPARC (2010)	"high responsibility" + "high concern" (red list)	1-3	reptiles & amphibians
Specialist Group Assessment	American Fisheries Society (Jelks et al. 2008)	Imperiled	1-3	fish

Table 1-2. *continued: page 2 of 2.*

Vulnerability Factor	Authority (Source)	Metric[1]	Potential Priority	Primary Taxa
Specialist Group Assessment	ASMFC (2012)	"decreasing, unstable/decreasing, or local subpopulation"	1-3	marine fish
Specialist Group Assessment	EBTJV (2011)	"imperiled"	1-3	brook trout
Specialist Group Assessment	Northeast RCN Odonate Assessment (White et al. 2014)	"high vul" OR ["mod vul" + "primary-significant" responsibility]	1-3	damselflies & dragonflies
Climate Change	Manomet (Whitman et al. 2013)	"high vulnerability" + > "low confidence"	2-3	all
Climate Change	(Galbraith et al. 2014)	"high concern, highly imperiled, or critical"	2-3	shorebirds
Climate Change	Multiple	miscellaneous	2-3	marine
Rare & Poorly Surveyed	MDIFW	specialized habitat + <5 EOs and "G4-G5" OR < 10 EOs and "G3"	3	all
Historical	MDIFW & NatureServe (2014)	SH/GH and high rediscovery potential	2-3	all
Culturally Significant	Maine Tribes	culturally significant + biologically vulnerable	3	all

[1]**Metric Notes:** CR = Critically Endangered, EN = Endangered, VU = Vulnerable, E = Endangered, T = Threatened, C = Candidate, P = Proposed, G1-G5 & GH = NatureServe Global rarity ranks (range ranks rounded as follows: G1G2=G1, G1G3=G2), SH = State Historic, BCR = Bird Conservation Region, EO = Element Occurrences

1.6 MAINE'S 2015 SGCN

Vulnerability concepts and criteria (Table 1-2) adopted in this Plan identified 378 SGCN in Maine. This number is significantly greater than the 213 SGCN recognized in the 2005 Plan, however of the 2005 total, 33 species have lost SGCN eligibility in 2015 (Appendix 1-5). The net expansion of the SGCN list between 2005 and 2015 mostly reflects updates and additions in SGCN designation criteria, recent significant declines for some species, more scrutiny of invertebrate taxa not assessed in 2005, and much greater attention to marine fauna now at risk in the Gulf of Maine.

For example, Maine's 2005 CWCS identified only 13 marine SGCN (five finfish, five whales, and three sea turtles), of which 11 were federally-listed as E/T. All 13 retain their SGCN status, but the 2015 Plan identifies 62 additional fauna in the Gulf of Maine as SGCN, a tally that does not consider species (especially marine invertebrates) for which there are no data to evaluate vulnerability. MDMR, the lead state agency for marine fauna (except birds), focused SGCN designations on species with reliable abundance indices and/or significant stressors.

The 2015 compilation of Maine's SGCN (Table 1-3) includes 378 fauna. Each cell for a species is linked to an SGCN Report that summarizes qualification criteria, habitat associations (Element 2), significant stressors to the species or its habitats (Element 3), potential conservation actions (Element 4), and conservation range maps. Click on the cell with the scientific name / common name to view reports of these details for each Maine SGCN, including data (e.g., range) that can be updated during the life of the Plan.

"The net expansion of the SGCN list between 2005 and 2015 mostly reflects changes in SGCN designation criteria, recent significant declines for some species, more scrutiny of invertebrate taxa not assessed in 2005, and much greater attention to marine fauna now at risk in the Gulf of Maine."

Priority tiers of SGCN in this Plan ultimately are based on the degree of vulnerability for each species. Tier 1 SGCN receive utmost concern throughout the various Plan elements. However, higher SGCN priority levels do not necessarily infer they are absolute priority conservation targets. Instead, habitat-based conservation actions, or those that address a guild of several SGCN, may be more significant than a strategy that benefits a single Tier 1 SGCN. Feasibility, outcomes, and cost of conservation actions also influence Plan priorities. Among the 378 SGCN recognized in this Plan, the total number of SGCN by priority level separate as follows:

- Tier 1 (Highest Priority) – 58 SGCN
- Tier 2 (High Priority) – 131 SGCN
- Tier 3 (Moderate Priority) – 189 SGCN

Table 1-3. Maine's SGCN (by taxa class) and qualifying factors, 2015.

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
ACTINOPTERYGII (ray-finned fishes; N = 33)							
Acipenseriformes (sturgeons and paddlefishes; N = 2)							
Acipenser brevirostrum Shortnose sturgeon	1	1	E	yes	E	VU	
Acipenser oxyrinchus Atlantic sturgeon	1	1		yes	T		1
Anguilliformes (true eels; N = 1)							
Anguilla rostrata American Eel	1	2	SC	yes			2
Clupeiformes (herrings; N = 3)							
Alosa aestivalis Blueback Herring	no	1		yes	SoC	VU	2
Alosa pseudoharengus Alewife	no	2		yes	SoC		2
Alosa sapidissima American Shad	2	1		yes			3
Cypriniformes (carps, minnows, loaches and allies; N = 7)							
Catostomus catostomus Longnose Sucker	2	3					1
Erimyzon oblongus Creek Chubsucker	no	3	SC				1
Hybognathus regius Eastern Silvery Minnow	no	3					1
Margariscus margarita Pearl Dace	no	3					1
Notropis bifrenatus Bridle Shiner	no	2	SC	yes			
Notropis heterolepis Blacknose Shiner	no	3					1
Rhinichthys cataractae Longnose Dace	no	3	SC				1
Esociformes (pikes and mudminnows; N = 1)							
Esox americanus americanus Redfin Pickerel	1	2	E				

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.

[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].

[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 2 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
ACTINOPTERYGII (ray-finned fishes; continued)							
Gadiformes (cods, haddocks, grenadiers; N = 4)							
Brosme brosme Cusk	no	2		yes	SoC		1
Gadus morhua Atlantic Cod	no	1		yes		VU	
Lota lota Burbot	2	3					1
Melanogrammus aeglefinus Haddock	no	1		yes		VU	
Gasterosteiformes (sticklebacks; N = 1)							
Culaea inconstans Brook Stickleback	no	3	SC				1
Osmeriformes (smelts and allies; N = 1)							
Osmerus mordax Rainbow Smelt	2	1		yes	SoC		3
Perciformes (perch-like fishes; N = 6)							
Ammodytes americanus American Sand Lance	no	3		yes			
Anarhichas lupus Atlantic Wolffish	no	2			SoC		2
Anarhichas minor Spotted Wolffish	no	3		yes			1
Etheostoma fusiforme Swamp Darter	1	2	T				
Morone saxatilis Striped Bass	no	2		yes			2
Thunnus thynnus Atlantic Bluefin Tuna	no	2		yes	SoC	EN	
Pleuronectiformes (flatfish; N = 1)							
Pseudopleuronectes americanus Winter Flounder	no	2		yes			1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 3 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
ACTINOPTERYGII (ray-finned fishes; continued)							
Salmoniformes (salmon, trout, and whitefish; N = 6)							
Coregonus clupeaformis Lake Whitefish	1	2	SC				2
Prosopium cylindraceum Round Whitefish	2	2		yes			1
Salmo salar Atlantic Salmon	1	1		yes	E		1
Salvelinus alpinus oquassa Arctic Charr	1	1	SC	yes			1
Salvelinus fontinalis Brook Trout	2	3		yes			1
Salvelinus namaycush Lake Trout	1	3					1
AMPHIBIA (amphibians; N = 4)							
Anura (frogs and toads; N = 2)							
Lithobates pipiens Northern Leopard Frog	no	2	SC	yes			
Lithobates septentrionalis Mink Frog	no	3					1
Caudata (salamanders; N = 2)							
Ambystoma laterale Blue-spotted Salamander	2	2	SC	yes			
Gyrinophilus porphyriticus porphyriticus Northern Spring Salamander	no	2	SC	yes			
ANTHOZOA (corals, sea pens, sea fans, sea anemones; N = 2)							
Alcyonacea (soft corals; N = 2)							
Alcyonium digitatum Dead Man's Fingers	no	3					2
Gersemia rubiformis Sea Strawberry	no	2					3

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 4 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
ASTEROIDEA (sea stars; N = 5)							
Forcipulatida (sea stars; N = 3)							
Asterias forbesi Forbes's Starfish	no	2					3
Asterias rubens Common Sea Star	no	2					3
Stephanasterias albula White Sea Star	no	2					3
Valvatida (N = 2)							
Crossaster papposus Common Sun Star	no	2					3
Solaster endeca Purple Sunstar	no	2					3
AVES (birds; N = 130)							
Accipitriformes (hawks, kites, eagles, and allies; N = 3)							
Aquila chrysaetos Golden Eagle	2	2	E	yes			
Buteo platypterus Broad-winged Hawk	no	3		yes			
Circus cyaneus Northern Harrier	no	3	SC				
Anseriformes (waterfowl; N = 5)							
Aythya marila Greater Scaup	2	2	SC				1
Bucephala islandica Barrow's Goldeneye	2	1	T				1
Clangula hyemalis Long-tailed Duck	no	3				VU	
Histrionicus histrionicus Harlequin Duck	2	1	T	yes			1
Somateria mollissima Common Eider	2	3					1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 5 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
AVES (birds; continued)							
Apodiformes (swifts and hummingbirds; N = 1)							
Chaetura pelagica Chimney Swift	2	2	SC	yes			1
Caprimulgiformes (nightjars; N = 2)							
Antrostomus vociferus Eastern Whip-poor-will	2	2	SC	yes			
Chordeiles minor Common Nighthawk	2	3		yes			
Charadriiformes (plovers, sandpipers, and allies; N = 30)							
Alca torda Razorbill	2	2	T				1
Arenaria interpres Ruddy Turnstone	2	2		yes			2
Bartramia longicauda Upland Sandpiper	1	1	T	yes			
Calidris alba Sanderling	2	2		yes			1
Calidris alpina Dunlin	no	3					1
Calidris canutus rufa Red Knot	2	1	SC	yes	T		1
Calidris maritima Purple Sandpiper	2	1		yes			2
Calidris minutilla Least Sandpiper	no	3					1
Calidris pusilla Semipalmated Sandpiper	2	2	SC	yes			2
Charadrius melodus Piping Plover	1	1	E	yes	T		
Chlidonias niger Black Tern	1	2	E				1
Chroicocephalus philadelphia Bonaparte's Gull	2	3	SC				

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 6 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
AVES (birds; continued)							
Charadriiformes (plovers, sandpipers, and allies; continued)							
Fratercula arctica Atlantic Puffin	2	2	T				1
Haematopus palliatus American Oystercatcher	1	3	SC	yes			1
Leucophaeus atricilla Laughing Gull	no	3	SC				
Limnodromus griseus Short-billed Dowitcher	no	3		yes			1
Numenius phaeopus Whimbrel	2	2	SC	yes			1
Phalaropus fulicarius Red Phalarope	no	3					1
Phalaropus lobatus Red-necked Phalarope	2	2	SC				2
Pluvialis squatarola Black-bellied Plover	no	3					1
Scolopax minor American Woodcock	2	3					1
Sterna dougallii Roseate Tern	1	1	E	yes	E		
Sterna hirundo Common Tern	2	2	SC	yes			
Sterna paradisaea Arctic Tern	2	1	T	yes			
Sternula antillarum Least Tern	1	1	E	yes			
Tringa flavipes Lesser Yellowlegs	no	1	SC	yes			1
Tringa melanoleuca Greater Yellowlegs	2	3					1
Tringa semipalmata Willet	2	3					1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 7 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
AVES (birds; continued)							
Charadriiformes (plovers, sandpipers, and allies; continued)							
Tringa solitaria Solitary Sandpiper	no	2		yes			1
Uria aalge Common Murre	2	3	SC				1
Coraciiformes (kingfishers and allies; N = 1)							
Megaceryle alcyon Belted Kingfisher	no	3		yes			
Cuculiformes (cuckoos; N = 2)							
Coccyzus americanus Yellow-billed Cuckoo	no	2	SC	yes			
Coccyzus erythropthalmus Black-billed Cuckoo	2	3		yes			
Falconiformes (caracaras and falcons; N = 2)							
Falco peregrinus Peregrine Falcon	1	1	E	yes			
Falco sparverius American Kestrel	no	3		yes			
Galliformes (grouse, quail, and allies; N = 1)							
Falcipennis canadensis Spruce Grouse	no	3					2
Gaviiformes (loons; N = 2)							
Gavia immer Common Loon	2	3					1
Gavia stellata Red-throated Loon	no	3		yes			
Gruiformes (cranes and rails; N = 4)							
Coturnicops noveboracensis Yellow Rail	2	2	SC	yes			1
Fulica americana American Coot	2	3	SC				
Gallinula galeata Common Gallinule	2	2	T				1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.

[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].

[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 8 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
AVES (birds; continued)							
Gruiformes (cranes and rails; continued)							
Porzana carolina Sora	no	3		yes			
Passeriformes (perching birds; N = 59)							
Ammodramus caudacutus Saltmarsh Sparrow	1	1	SC	yes		VU	1
Ammodramus nelsoni Nelson's Sparrow	2	2	SC	yes			1
Ammodramus savannarum Grasshopper Sparrow	2	1	E	yes			
Anthus rubescens American Pipit	2	2	E				1
Cardellina canadensis Canada Warbler	2	2	SC	yes			
Catharus bicknelli Bicknell's Thrush	1	1	SC	yes		VU	1
Catharus fuscescens Veery	2	2	SC	yes			
Catharus ustulatus Swainson's Thrush	no	3					1
Cistothorus platensis Sedge Wren	1	1	E	yes			
Coccothraustes vespertinus Evening Grosbeak	no	2	SC	yes			1
Contopus cooperi Olive-sided Flycatcher	2	2	SC	yes			
Contopus virens Eastern Wood-Pewee	no	2	SC	yes			
Dolichonyx oryzivorus Bobolink	2	3		yes			
Empidonax flaviventris Yellow-bellied Flycatcher	no	3					1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 9 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
AVES (birds; continued)							
Passeriformes (perching birds; continued)							
Empidonax minimus Least Flycatcher	no	3	SC				
Eremophila alpestris Horned Lark	2	3	SC				
Euphagus carolinus Rusty Blackbird	2	1	SC	yes		VU	
Geothlypis philadelphia Mourning Warbler	no	3					1
Haemorhous purpureus Purple Finch	2	3		yes			
Hirundo rustica Barn Swallow	2	2	SC	yes			1
Hylocichla mustelina Wood Thrush	2	1	SC	yes			1
Icterus galbula Baltimore Oriole	2	3		yes			
Icterus spurius Orchard Oriole	no	3	SC				
Loxia curvirostra Red Crossbill	2	3					1
Loxia leucoptera White-winged Crossbill	no	3					1
Melospiza lincolnii Lincoln's Sparrow	no	3					1
Mniotilta varia Black-and-white Warbler	2	2	SC	yes			
Oreothlypis peregrina Tennessee Warbler	no	2	SC				1
Parkesia motacilla Louisiana Waterthrush	2	3		yes			
Passerella iliaca Fox Sparrow	no	3	SC				

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 10 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
AVES (birds; continued)							
Passeriformes (perching birds; continued)							
Perisoreus canadensis Gray Jay	no	3					1
Petrochelidon pyrrhonota Cliff Swallow	no	3					1
Pheucticus ludovicianus Rose-breasted Grosbeak	2	3		yes			
Pinicola enucleator Pine Grosbeak	no	3					1
Pipilo erythrophthalmus Eastern Towhee	2	2	SC	yes			
Piranga olivacea Scarlet Tanager	2	3		yes			
Poecile hudsonicus Boreal Chickadee	no	2		yes			1
Progne subis Purple Martin	2	2	SC				1
Regulus calendula Ruby-crowned Kinglet	no	2					2
Riparia riparia Bank Swallow	no	1		yes			1
Setophaga americana Northern Parula	2	3					1
Setophaga caerulescens *Black-throated Blue Warbler*	2	3		yes			
Setophaga castanea Bay-breasted Warbler	2	3		yes			
Setophaga discolor Prairie Warbler	2	2	SC	yes			
Setophaga fusca Blackburnian Warbler	2	3		yes			
Setophaga pensylvanica Chestnut-sided Warbler	2	2	SC	yes			

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 11 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
AVES (birds; continued)							
Passeriformes (perching birds; continued)							
Setophaga petechia Yellow Warbler	no	3	SC				
Setophaga ruticilla American Redstart	no	2	SC	yes			
Setophaga striata Blackpoll Warbler	no	3					1
Setophaga tigrina Cape May Warbler	2	3					1
Setophaga virens Black-throated Green Warbler	2	3		yes			
Spizella pusilla Field Sparrow	2	3		yes			
Stelgidopteryx serripennis Northern Rough-winged Swallow	no	3	SC				
Sturnella magna Eastern Meadowlark	2	2	SC	yes			
Tachycineta bicolor Tree Swallow	no	2	SC	yes			
Toxostoma rufum Brown Thrasher	2	2	SC	yes			
Tyrannus tyrannus Eastern Kingbird	2	2	SC	yes			
Vermivora cyanoptera Blue-winged Warbler	1	2	SC	yes			
Zonotrichia albicollis White-throated sparrow	no	3	SC				
Pelecaniformes (pelecans, herons, ibises, and allies; N = 6)							
Ardea herodias Great Blue Heron	2	2	SC				1
Botaurus lentiginosus American Bittern	2	3		yes			

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 12 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
AVES (birds; continued)							
Pelecaniformes (pelecans, herons, ibises, and allies; continued)							
Egretta caerulea Little Blue Heron	2	3		yes			
Egretta thula Snowy Egret	2	3		yes			
Ixobrychus exilis Least Bittern	2	1	E	yes			
Nycticorax nycticorax Black-crowned Night-heron	2	2	E				
Piciformes (woodpeckers; N = 3)							
Colaptes auratus Northern Flicker	2	3		yes			
Picoides arcticus Black-backed Woodpecker	no	3					1
Picoides dorsalis American Three-toed Woodpecker	2	3					1
Podicipediformes (grebes; N = 2)							
Podiceps auritus Horned Grebe	no	3		yes			
Podilymbus podiceps Pied-billed Grebe	2	3		yes			
Procellariiformes (tubenoses; N = 2)							
Oceanodroma leucorhoa Leach's Storm-petrel	no	3	SC				
Puffinus gravis Great Shearwater	2	3		yes			
Strigiformes (owls; N = 4)							
Asio flammeus Short-eared Owl	1	2	T	yes			
Asio otus Long-eared Owl	2	3					1
Megascops asio Eastern Screech-Owl	2	3	SC				1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.

[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].

[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 13 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
AVES (birds; continued)							
Strigiformes (owls; continued)							
Tyto alba Barn Owl	no	3	SC				
Suliformes (frigatebirds, boobies, cormorants, darters, and allies; N = 1)							
Phalacrocorax carbo Great Cormorant	2	1	T	yes			1
BIVALVIA (marine and freshwater molluscs; N = 14)							
Myoida (saltwater clams; N = 3)							
Mya arenaria Softshell Clam	no	3					1
Mya truncata Gaper Clam	no	3					4
Zirfaea crispata Atlantic Great Piddock	no	2					3
Mytiloida (mussels; N = 1)							
Mytilus edulis Blue Mussel	no	3					1
Ostreoida (oysters, scallops, and allies; N = 1)							
Crassostrea virginica Eastern oyster	no	3					2
Pectinoida (N = 2)							
Chlamys islandica Icelandic Scallop	no	3					2
Placopecten magellanicus Atlantic Sea Scallop	no	3					1
Unionoida (freshwater mussels; N = 6)							
Alasmidonta undulata Triangle Floater	no	3		yes			
Alasmidonta varicosa Brook Floater	2	1	T	yes			
Anodonta implicata Alewife Floater	no	3		yes			

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 14 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
BIVALVIA (marine and freshwater molluscs; continued)							
Unionoida (freshwater mussels; continued)							
Lampsilis cariosa Yellow Lampmussel	1	1	T	yes		EN	
Leptodea ochracea Tidewater Mucket	1	1	T	yes			
Margaritifera margaritifera Eastern Pearlshell	no	3				EN	
Veneroida (veneroids; N = 1)							
Mercenaria mercenaria Hard-shelled Clam	no	3					1
CEPHALASPIDOMORPHI (lampreys; N = 1)							
Petromyzontiformes (lampreys; N = 1)							
Lethenteron appendix American Brook Lamprey	no	3		yes			
CHONDRICHTHYES (sharks, rays, and skates; N = 9)							
Carcharhiniformes (ground sharks; N = 2)							
Prionace glauca Blue Shark	no	3					
Sphyrna zygaena Smooth Hammerhead	no	3				VU	
Lamniformes (sharks, skates, and rays ; N = 3)							
Alopias vulpinus Common Thresher Shark	no	3				VU	
Isurus oxyrinchus Shortfin Mako	no	2		yes		VU	
Lamna nasus Porbeagle	no	2		yes	SoC	VU	
Rajiformes (rays; N = 4)							
Amblyraja radiata Thorny Skate	no	2			SoC	VU	
Dipturus laevis Barndoor Skate	no	2		yes		EN	

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 15 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
CHONDRICHTHYES (sharks, rays, and skates; continued)							
Rajiformes (rays; continued)							
Leucoraja ocellata Winter Skate	no	2				EN	
Malacoraja senta Smooth Skate	no	2				EN	
ECHINOIDEA (sea urchins; N = 1)							
Camarodonta (sea urchins; N = 1)							
Strongylocentrotus droebachiensis Green Sea Urchin	no	2					2
GASTROPODA (aquatic and terrestrial snails; N = 15)							
Basommatophora (air-breathing freshwater snails; N = 2)							
Stagnicola mighelsi Bigmouth Pondsnail	2	1	SC	yes			1
Stagnicola oronoensis Obese Pondsnail	no	3					1
Littorinimorpha (N = 2)							
Arrhoges occidentalis American Pelican Foot	no	2					3
Limneria undata Wavy Lamellaria	no	3					2
Neotaenioglossa (mostly sea snails; N = 5)							
Boreotrophon clathratus Clathrate Trophon	no	2					3
Boreotrophon truncatus Murex	no	2					3
Colus pygmaeus Colus Snail	no	2					3
Floridobia winkleyi New England Silt Snail	no	3					2
Ptychatractus ligatus Spindle Shell	no	2					3

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 16 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
GASTROPODA (aquatic and terrestrial snails; continued)							
Stylommatophora (air-breathing snails land snails; N = 5)							
Appalachina sayana Spike-lip Crater	no	3					1
Neohelix dentifera Big-tooth Whitelip	no	3					1
Vertigo malleata Malleated Vertigo	no	3	SC				1
Vertigo morsei Six-whorl Vertigo	2	1	E				2
Vertigo paradoxa Mystery Vertigo	2	2	SC				
Thecosomata (sea butterflies; N = 1)							
Limacina helicina Limancina Snail	no	3					1
HOLOTHUROIDEA (sea cucumbers; N = 4)							
Dendrochirotida (sea cucumbers; N = 4)							
Cucumaria frondosa Orange-footed Sea Cucumber	no	2					2
Psolus fabricii Psolus	no	2					3
Psolus phantapus Psolus	no	2					3
Thyonidium drummondii Sea Cucumber	no	2					3
INSECTA (insects; N = 119)							
Coleoptera (beetles; N = 4)							
Cicindela ancocisconensis White Mountain Tiger Beetle	no	2	SC	yes			1
Cicindela marginata Salt Marsh Tiger Beetle	no	2	SC				1
Cicindela marginipennis Cobblestone Tiger Beetle	no	1	E	yes			1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 17 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
INSECTA (insects; N = 119)							
Coleoptera (beetles; continued)							
Nebria nivalis gaspesiana Gaspe Gazelle Beetle	no	3					1
Ephemeroptera (mayflies; N = 15)							
Ameletus browni A Mayfly	no	3	SC				1
Baetisca berneri A Mayfly	no	3	SC				1
Baetisca carolina A Mayfly	no	3	SC				1
Baetisca lacustris A Mayfly	no	3	SC				1
Baetisca rubescens A Mayfly	2	3	SC				2
Epeorus frisoni Roaring Brook Mayfly	1	1	T	yes			1
Hexagenia rigida A Mayfly	no	3	SC				1
Metretopus borealis A Mayfly	no	3	SC				1
Nixe horrida A Mayfly	2	3	SC	yes			1
Parameletus midas A Mayfly	no	3	SC				1
Rhithrogena undulata A Mayfly	no	3	SC				1
Siphlonisca aerodromia Tomah Mayfly	1	1	T				1
Siphlonurus barbaroides A Mayfly	no	3	SC				1
Siphlonurus barbarus A Mayfly	no	2	SC	yes			1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 18 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
INSECTA (insects; continued)							
Ephemeroptera (mayflies; continued)							
Siphlonurus demaryi A Mayfly	2	2	SC	yes			2
Hymenoptera (ants, bees, wasps and sawflies; N = 10)							
Bombus affinis Rusty-patched Bumble Bee	no	1	SC	yes			1
Bombus ashtoni Ashton's Cuckoo Bumble Bee	no	2	SC				2
Bombus citrinus Lemon Cuckoo Bumble Bee	no	3	SC				1
Bombus fernaldae Fernald's Cuckoo Bumble Bee	no	3	SC				1
Bombus fervidus Yellow Bumble Bee	no	3	SC				1
Bombus griseocollis Brown-belted Bumble Bee	no	3	SC				1
Bombus insularis Indiscriminate Cuckoo Bumble Bee	no	2	SC				2
Bombus pensylvanicus American Bumble Bee	no	2	SC				2
Bombus sandersoni Sanderson's Bumble Bee	no	3	SC				1
Bombus terricola Yellowbanded Bumble Bee	no	3	SC				1
Lepidoptera (butterflies, skippers, and moths; N = 47)							
Atrytonopsis hianna Dusted Skipper	no	3	SC				1
Boloria chariclea grandis Purple Lesser Fritillary	2	2	T				2
Boloria frigga saga Frigga Fritillary	2	1	E				2
Callophrys gryneus Juniper Hairstreak	2	2	E				1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 19 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
INSECTA (insects; continued)							
Lepidoptera (butterflies, skippers, and moths; continued)							
Callophrys hesseli Hessel's Hairstreak	1	1	E				1
Callophrys lanoraieensis Bog Elfin	no	3					1
Catocala similis Similar Underwing	no	3	SC				1
Chaetaglaea cerata A Noctuid Moth	2	2	SC				1
Chaetaglaea tremula Barrens Chaetaglaea	no	3	SC				1
Citheronia sepulcralis Pine Devil	2	2	SC				1
Cucullia speyeri A Moth	2	3					1
Cupido amyntula maritima Western Tailed Blue	no	3					1
Danaus plexippus Monarch	no	3					1
Erora laeta Early Hairstreak	2	2	SC				1
Erynnis brizo Sleepy Duskywing	2	2	T				
Hemaris gracilis Graceful Clearwing	2	3	SC				1
Hemileuca lucina New England Buckmoth	no	3					1
Hemileuca maia maia Eastern Buckmoth	2	2	SC				1
Hesperia leonardus Leonard's Skipper	2	3	SC				
Hesperia metea Cobweb Skipper	2	3	SC				1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 20 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
INSECTA (insects; continued)							
Lepidoptera (butterflies, skippers, and moths; continued)							
Lapara coniferarum Southern Pine Sphinx	no	3	SC				1
Lepipolys perscripta A Moth	no	3	SC				1
Lithophane lepida lepida Pine Pinion	2	2	SC	yes			2
Lycaena dorcas claytoni Clayton's Copper	1	2	T	yes			
Lycia rachelae Twilight Moth	1	2	T				1
Metarranthis apiciaria Barrens Metarranthis Moth	no	2	SC	yes			1
Nepytia pellucidaria A Moth	2	3	SC				1
Oeneis polixenes katahdin Katahdin Arctic	1	1	E	yes			1
Paonias astylus Huckleberry Sphinx	no	3	SC				1
Papilio brevicauda gaspeensis Short-tailed Swallowtail	no	3	SC				1
Papilio troilus Spicebush Swallowtail	2	3	SC				
Plebejus idas Northern Blue	no	2	SC				2
Plebejus idas empetri Crowberry Blue	2	2	SC				1
Polygonia satyrus Satyr Comma	no	3	SC				1
Psectraglaea carnosa Pink Sallow	2	2	SC				2
Satyrium edwardsii Edwards' Hairstreak	2	2	E				1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 21 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
INSECTA (insects; continued)							
Lepidoptera (butterflies, skippers, and moths; continued)							
Satyrium titus Coral Hairstreak	2	3	SC				
Satyrodes appalachia Appalachian Brown	no	3	SC				
Spartiniphaga inops Spartina Borer Moth	no	3					1
Speranza exonerata Barrens Itame	2	2	SC				2
Thorybes bathyllus Southern Cloudywing	no	3	SC				1
Xylena thoracica Acadian Swordgrass Moth	no	3	SC				
Xylotype capax Broad Sallow	no	3	SC				1
Xystopeplus rufago Red-winged Sallow	no	3	SC				1
Zale lunifera Bold-based Zale Moth	2	3	SC				1
Zale obliqua Oblique Zale	no	3	SC				1
Zanclognatha martha Pine Barrens Zanclognatha	2	1	T				2
Odonata (dragonflies and damselflies; N = 36)							
Aeshna juncea Sedge Darner	2	2	SC	yes			2
Aeshna sitchensis Zigzag Darner	no	3	SC	yes			
Anax longipes Comet Darner	no	3	SC				1
Argia translata Dusky Dancer	2	3	SC				1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 22 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
INSECTA (insects; continued)							
Odonata (dragonflies and damselflies; continued)							
Arigomphus furcifer Lilypad Clubtail	no	3	SC				
Celithemis martha Martha's Pennant	no	3		yes			1
Cordulegaster obliqua Arrowhead Spiketail	2	3	SC	yes			
Enallagma carunculatum Tule Bluet	2	3	SC				1
Enallagma durum Big Bluet	2	3	SC				1
Enallagma laterale New England Bluet	no	2		yes			1
Enallagma pictum Scarlet Bluet	2	2	SC	yes			1
Epiaeschna heros Swamp Darner	2	3	SC				1
Erythrodiplax berenice Seaside Dragonlet	no	3		yes			
Gomphus quadricolor Rapids Clubtail	1	2	E				
Gomphus vastus Cobra Clubtail	2	3	SC				1
Ischnura hastata Citrine Forktail	2	3	SC				1
Ischnura ramburii Rambur's Forktail	2	3	SC				1
Lanthus vernalis Southern Pygmy Clubtail	no	2	SC				1
Leucorrhinia patricia Canada Whiteface	2	2	SC	yes			1
Libellula needhami Needhams Skimmer	no	3	SC				1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 23 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
INSECTA (insects; continued)							
Odonata (dragonflies and damselflies; continued)							
Libellula semifasciata Painted Skimmer	no	3	SC				
Nannothemis bella Elfin Skimmer	no	3		yes			
Neurocordulia michaeli Broad-tailed Shadowdragon	no	3		yes			
Ophiogomphus anomalus Extra-striped Snaketail	no	3		yes			
Ophiogomphus colubrinus Boreal Snaketail	2	1	T	yes			
Ophiogomphus howei Pygmy Snaketail	2	2	SC	yes			
Progomphus obscurus Common Sanddragon	no	3	SC				
Rhionaeschna mutata Spatterdock Darner	1	3	SC				1
Somatochlora albicincta Ringed Emerald	no	3	SC				
Somatochlora brevicincta Quebec Emerald	2	2	SC	yes			1
Somatochlora incurvata Incurvate Emerald	no	3	SC	yes			
Somatochlora minor Ocellated Emerald	no	3		yes			
Stylurus spiniceps Arrow Clubtail	2	3	SC				
Tramea carolina Carolina Saddlebags	no	3	SC				1
Tramea lacerata Black Saddlebags	no	3	SC				1
Williamsonia lintneri Ringed Boghaunter	1	1	T	yes		VU	1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 24 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
INSECTA (insects; continued)							
Plecoptera (stoneflies; N = 3)							
Alloperla voinae A Stonefly	no	3					1
Neoperla mainensis A Stonefly	2	3	SC	yes			1
Pteronarcys comstocki Spiny Salmonfly	no	3					1
Trichoptera (caddisflies; N = 4)							
Hydroptila blicklei A Caddisfly	no	3	SC	yes			2
Hydroptila parachelops A Caddisfly	no	3	SC	yes			2
Hydroptila tomah A Caddisfly	2	3	SC	yes			2
Ochrotrichia denningi A Caddisfly	no	3					2
MALACOSTRACA (crustaceans; N = 4)							
Decapoda (decapods; N = 4)							
Lebbeus groenlandicus Spiny Lebbeid Shrimp	no	2					3
Lebbeus polaris Polar Lebbeid Shrimp	no	2					3
Orconectes limosus Spinycheek Crayfish	no	3					1
Pandalus borealis Northern Shrimp	no	1		yes			2
MAMMALIA (mammals; N = 22)							
Artiodactyla (even-toed ungulates; N = 1)							
Alces alces americanus Moose	no	3					1
Carnivora (carnivores; N = 1)							
Lynx canadensis Canada Lynx	2	2	SC		T		1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.

[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].

[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 25 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
MAMMALIA (mammals; continued)							
Cetacea (whales; N = 7)							
Balaenoptera borealis Sei Whale	1	2	E	yes	E	EN	
Balaenoptera musculus Blue Whale	no	2		yes	E	EN	
Balaenoptera physalus Finback Whale	1	2	E	yes	E	EN	
Eubalaena glacialis North Atlantic Right Whale	1	1	E	yes	E	EN	
Megaptera novaeangliae Humpback Whale	1	1	E	yes	E		
Phocoena phocoena Harbor Porpoise	no	2					
Physeter macrocephalus Sperm Whale	1	2	E	yes	E	VU	
Chiroptera (bats; N = 8)							
Eptesicus fuscus Big Brown Bat	no	2	SC				1
Lasionycteris noctivagans Silver-haired Bat	no	2	SC	yes			
Lasiurus borealis Eastern Red Bat	no	3	SC				
Lasiurus cinereus Hoary Bat	no	3	SC				
Myotis leibii Eastern Small-footed Myotis	2	1	T	yes			
Myotis lucifugus Little Brown Bat	no	1	E				1
Myotis septentrionalis Northern Long-eared Myotis	no	1	E	yes	T		1
Perimyotis subflavus Tri-colored Bat	no	2	SC	yes			

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 26 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
MAMMALIA (mammals; continued)							
Lagomorpha (rabbits, hares, and pikas; N = 1)							
Sylvilagus transitionalis New England Cottontail	1	1	E	yes	C	VU	2
Rodentia (rodents; N = 3)							
Microtus pennsylvanicus shattucki Penobscot Meadow Vole	1	2	SC	yes			
Ondatra zibethicus Muskrat	no	3					1
Synaptomys borealis sphagnicola Northern Bog Lemming	2	1	T	yes			
Soricomorpha (shrews and relatives; N = 1)							
Sorex dispar Long-tailed Shrew	no	3		yes			
MAXILLOPODA (crustaceans; N = 1)							
Calanoida (calanoid copepods; N = 1)							
Calanus finmarchicus A Copepod	no	3					1
MEROSTOMATA (horseshoe crabs and sea scorpions; N = 1)							
Xiphosurida (horseshoe crabs; N = 1)							
Limulus polyphemus Horseshoe Crab	no	1		yes			1
OPHIUROIDEA (brittle stars; N = 1)							
Euryalida (basket stars; N = 1)							
Gorgonocephalus arcticus Northern Basket Starfish	no	2					3
REPTILIA (reptiles; N = 11)							
Squamata (lizards and snakes; N = 3)							
Coluber constrictor constrictor Northern Black Racer	2	1	E	yes			
Storeria dekayi dekayi Northern Brownsnake	no	2	SC				1

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

Table 1-3. *continued: page 27 of 27*

CLASS Order *Scientific name*[1] Common name[1]	Maine SGCN Tier		Scale of Conservation Concern[2]				Number of Other Factors[3]
	2005	2015	State	Regional	National	Global	
REPTILIA (reptiles; N = 11)							
Squamata (lizards and snakes; continued)							
Thamnophis sauritus Eastern Ribbon Snake	no	2	SC	yes			
Testudines (turtles and tortoises; N = 8)							
Caretta caretta Loggerhead Seaturtle	no	2	T	yes	T	EN	
Chelonia mydas Green Seaturtle	no	2		yes	E	EN	
Clemmys guttata Spotted Turtle	2	1	T	yes		EN	
Dermochelys coriacea Leatherback Seaturtle	no	1	E	yes	E	VU	
Emydoidea blandingii Blanding's Turtle	1	1	E	yes		EN	
Glyptemys insculpta Wood Turtle	2	1	SC	yes		EN	
Lepidochelys kempii Kemp's Ridley Seaturtle	no	2	E	yes	E	CR	
Terrapene carolina carolina Eastern Box Turtle	1	2	E	yes		VU	
RHYNCHONELLATA (brachiopods; N = 1)							
Terebratulida (articulate brachiopods; N = 1)							
Terebratulina septentrionalis Lamp Shell	no	2					3

[1] Click on a species name to launch a full SGCN report summarizing associated habitats, stressors, and conservation strategies for that species.
[2] State & Federal ESA Codes: Endangered Species [E]; Threatened Species [T]; Candidate Species [C]; Special Concern Species [SC]; Species of Concern [SoC]. IUCN Codes: Critically Endangered [CR]; Endangered [EN]; Vulnerable [VU].
[3] Other potential qualifying factors for 2015 SGCN designation include: climate change, recent significant decline, understudied species, regional endemism, historic taxon with rediscovery potential, and tribal cultural significance.

1.7 LITERATURE CITED AND REFERENCES

Association of Fish and Wildlife Agencies (AFWA) - Teaming With Wildlife Committee, State Wildlife Action Plan (SWAP) Best Practices Working Group. 2012. Best practices for State Wildlife Action Plans - voluntary guidance to states for revision and implementation. Association of Fish and Wildlife Agencies, Washington, DC. 80pp.

Atlantic States Marine Fisheries Commission (ASMFC). 2012. Stock assessments. Available online at http://www.asmfc.org/fisheries-science/stock-assessments#Documents Last accessed: July 19, 2015.

Blickle, R. L. and W. J. Morse. 1966. The caddisflies (Trichoptera) of Maine excepting the Family Hydroptilidae. Maine Agricultural Experiment Station Technical Bull. T-24. University of Maine, Orono. 12pp.

Brower, A. E. 1974. A list of the Lepidoptera of Maine, Part I, The Macrolepidoptera. Maine Agricultural Experiment Station Technical Bull. 66. Univ. of Maine, Orono. 136pp.

_____. 1983. A list of the Lepidoptera of Maine, Part 2, The Microlepidoptera, Section 1, Limacodidae through Cossidae. Maine Forest Service and Maine Agricultural Experiment Station Technical Bull. 109. University of Maine, Orono. 60pp.

_____. 1984. A list of the Lepidoptera of Maine, Part 2, The Microlepidoptera, Section 2, Cosmopterigidae through Hepialidae. Maine Forest Service and Maine Agricultural Experiment Station Technical Bull. 114. University of Maine, Orono. 70pp.

Brunelle, P. M., and P. G. deMaynadier. 2005. The Maine damselfly and dragonfly survey: a final report. Technical report submitted to the Maine Department of Inland Fisheries and Wildlife, Bangor.

Burian, S. K. and K. E. Gibbs. 1991. Mayflies of Maine: an annotated faunal list. Maine Agricultural Experiment Station Technical Bull. 142, University of Maine, Orono. 109pp.

Carlton, J.T., G. J, Vermeij, D. R. Lindberg, D. A. Carlton, and E.C. Dubley. 1991. The first historical extinction of a marine invertebrate in an ocean basin: the demise of the eelgrass limpet *Lottia alveus*. Biological Bulletin 180(1):72-80.

Census of Marine Life. 2015. Gulf of Maine area - Register of marine species. Available at http://www.gulfofmaine-census.org/about-the-gulf/biodiversity-of-the-gulf/lists/gulf-of-maine-register-of-marine-species/

Clark, K. E. and L. J. Niles. 2000. North Atlantic regional shorebird plan. Endangered and Nongame Species Program, Woodbine, NJ. 17pp. plus appendices.

Committee on the Status of Endangered Widlife in Canada (COSEWIC). 2015. Database of species assessed by COSEWIC. Last Update August 24, 2015. Available at http://www.cosewic.gc.ca/eng/sct1/searchform_e.cfm

Dearborn, R. G., R. Bradbury, and G. Russell. 1983. The forest insect survey of Maine: Order Hymenoptera. Maine Forest Service Entomology Division Tech. Rep. 202. Maine Department of Conservation, Augusta. 101pp.

Eastern Brook Trout Joint Venture (EBJTV). 2011. Conserving the eastern brook trout: conservation strategies. EBJTV, Sanbornton, NH. 91pp. Available at http://easternbrooktrout.org/reports/ebtjv-conservation-strategy/view

Ferree, C. and M. G. Anderson. 2013. A map of terrestrial habitats of the northeastern United States: methods and approach. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA. 85pp.

Galbraith H., D.W. DesRochers, S. Brown, and J.M. Reed. 2014. Predicting Vulnerabilities of North American Shorebirds to Climate Change. PLoS ONE 9(9): e108899

Gawler, S. C., J. J. Albright, P. D. Vickery, and F. C. Smith. 1996. Biological diversity in Maine – an assessment of status and trends in the terrestrial and freshwater landscape. Maine Natural Areas Program, Department of Conservation, Augusta, Maine. 80pp plus appendices.

Gleich, J. G. and F. F. Gilbert. 1976. A survey of terrestrial gastropods from central Maine. Canadian Journal of Zoology 54:620-627.

Hotopp, K. C., 2012. Freshwater snail inventory of the Fish River Lakes. Final Report submitted to Maine Outdoor Heritage Fund, Pittston, ME. 55pp.

_____, and D. A. Smith. 1994. Notes on land snails near Big Reed Pond. Unpublished report to the Maine Chapter of The Nature Conservancy, Brunswick, Maine. 4pp.

Huryn, A. D. and S. C. Harris. 2000. High species richness of caddisflies (Trichoptera) from a riparian wetland in Maine. Northeastern Naturalist 7:189-204.

International Union for Conservation of Nature (IUCN). 2015. IUCN Red List [web application]. Version 2015-3. IUCN, Gland, Switzerland. Available at http://www.iucnredlist.org/. Last accessed: September 17, 2015.

Jelks, H. L., S. J. Walsh, N. M. Burkhead, S. Contreras-Balderas, E. Díaz-Pardo, D. A. Hendrickson, J. Lyons, N. E. Mandrak, F. McCormick, J. S. Nelson, S. P. Platania, B. A. Porter, C. B. Renaud, J. J. Schmitter-Soto, E. B. Taylor, and M. L. Warren, Jr. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33:372–407.

Krohn, W. B., R. B. Boone, S. A. Sader, J. A. Hepinstall, S. M. Schaefer, and S. L. Painton. 1998. The Maine GAP analysis project, final report. University of Maine, Orono, ME. 123pp plus appendices.

Kushlan, J. A., M. J. Steinkamp, K. C. Parsons, J. Capp, M. Acosta Cruz, M. Coulter, I. Davidson, L. Dickson, N. Edelson, R. Elliot, R. M. Erwin, S. Hatch, S. Kress, R. Milko, S. Miller, K. Mills, R. Paul, R. Phillips, J. E. Saliva, B. Sydeman, J. Trapp, J. Wheeler, and K. Wohl. 2002. Waterbird conservation for the Americas: the North American waterbird

conservation plan, Version 1. Waterbird conservation for the Americas, Washington, DC. 78pp. Available at http://www.waterbirdconservation.org/pubs/complete.pdf

Kushlan et al. 2006. Conservation status and distribution of solitary-nesting waterbird species, Revision April 17, 2006. Waterbird Conservation for the Americas: The North American waterbird conservation plan. Washington, DC. Summary Table available at http://www.waterbirdconservation.org/pdfs/status_assessment/FinalStatusandDistributionMarshbirdsTable.pdf

Majka, C. D., D. S. Chandler, and C. P. Donahue. 2011. Checklist of the beetles of Maine, USA. Empty Mirrors Press, Halifax, NS, Canada. 328pp.

Martin, S. M. 1999. Freshwater snails (Mollusca: Gastropoda) of Maine. Northeastern Naturalist 6(1):39-88.

_____. 2000. Terrestrial snails and slugs (Mollusca: Gastropoda) of Maine. Northeastern Naturalist 7(1):33-88.

McCollough, M. A. 1997. Conservation of invertebrates in Maine and New England: perspectives and prognoses. Northeastern Naturalist 4(4):261-278.

Mingo, T. M. 1983. An annotated checklist of the stoneflies (Plecoptera) of Maine. Entomology News 94(2):65-72.

NatureServe. 2014. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, VA. Available at http://www.natureserve.org/explorer Last accessed: September 18, 2015.

Nedeau, E. J., M. A. McCollough, and B. I. Swartz. 2000. The freshwater mussels of Maine. Maine Department of Inland Fisheries and Wildlife, State House Station #41, Augusta, ME. 118pp.

Nekola, J. C. 2008. Land Snail Ecology and Biogeography of Eastern Maine. Report to the Maine Department of Inland Fisheries and Wildlife, Augusta, ME. 119pp.

Northeast Partners in Amphibian and Reptile Conservation (NEPARC). 2010. Northeast amphibian and reptile species of regional responsibility and conservation concern. Northeast Partners in Amphibian and Reptile Conservation (NEPARC). Publication 2010-1. 20pp. Availabe at http://www.northeastparc.org/products/pdfs/NEPARC_NEspeciesofresponsibility.pdf

Partners in Flight Science Committee 2012. Species Assessment Database, version 2012. Available at http://rmbo.org/pifassessment. Last accessed: September 18, 2015.

Stein, B. A., L. S. Kutner, and J. S. Adams (Eds.). 2000. Precious heritage: the status of biodiversity in the United States. Oxford University Press, Oxford, UK. 399pp.

Stubbs, C. S., E. A. Osgood, J. D. Dimond, and F. A. Drummond. 1995. Letter to Maine Natural Areas Program, Augusta. 6pp.

Terwilliger Consulting, Inc. and the Northeast Fish and Wildlife Diversity Technical Committee (NEFWDTC). 2013. Taking action together: Northeast regional synthesis for state wildlife action plans. A report submitted to the Northeast Association of Fish and Wildlife Agencies. Locustville, VA. 291pp.

Therres, G. D. 1999. Wildlife species of regional conservation concern in the northeastern United States. Northeast Wildlife 54:93-100.

Thomas, J. A., M. G. Telfer, D. B. Roy, C. D. Preston, J. D. Greenwood, J. Asher, R. Fox, R. T. Clarke, and J. H. Lawton. 2004. Comparative losses of British butterflies, birds, and plants and the global extinction crisis. Science 303:1879-1881.

U.S. Fish and Wildlife Service. 2008. Birds of conservation concern - 2008. U.S. Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, VA. 85pp.

U.S. Shorebird Conservation Plan (USSCP). 2004. High priority shorebirds – 2004. Unpubl. Report, U.S. Fish and Wildlife Service, 4401 N. Fairfax Dr., MBSP 4107, Arlington, VA. 5pp.

Webster, R.P. and P.G. deMaynadier. 2005. A baseline atlas and conservation assessment of the butterflies of Maine. A Technical Report submitted to the Maine Department of Inland Fisheries and Wildlife, Bangor.

White, E. L., P. D. Hunt, M. D. Schlesinger, J. D. Corser, and P. G. deMaynadier. 2014. A conservation status assessment of Odonata for the northeastern United States. New York Natural Heritage Program, Albany. 50pp.

Whitman, A., A. Cutko, P. deMaynadier, S. Walker, B. Vickery, S. Stockwell, and R. Houston. 2013. Climate change and biodiversity in Maine: vulnerability of habitats and priority species. Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Working Group) Report NCI-2013-03. Brunswick, ME. 105pp. Available at https://www.manomet.org/sites/default/files/publications_and_tools/BwHSummary_021914.pdf

1.8 APPENDICES

Appendix 1-1. Maine's list of state-designated Endangered / Threatened plants administered by Natural Areas Program - Maine Department of Agriculture, Conservation and Forestry.

Taxa group (class) *Scientific name*	Common name	State status (updated, 2015)
Class Dicotyledoneae (Dicots)		
Adlumia fungosa	Allegheny Vine	Endangered
Agalinis neoscotica	Nova Scotia False-foxglove	Threatened
Agalinis purpurea	Large-purple False Foxglove	Endangered
Amelanchier nantucketensis	Nantucket Shadbush	Threatened
Amerorchis rotundifolia	Small Round-leaved Orchis	Threatened
Anemone multifida	Cut-leaved Anemone	Threatened
Arctous alpina	Alpine Bearberry	Threatened
Arnica lanceolata	Hairy Arnica	Threatened
Asarum canadense	Wild Ginger	Threatened
Astragalus robbinsii var. *minor*	Robbins' Milk Vetch	Endangered
Bartonia paniculata	Screwstem	Threatened
Benthamidia florida	Flowering Dogwood	Endangered
Betula glandulosa	Tundra Dwarf Birch	Endangered
Betula minor	Dwarf White Birch	Endangered
Bistorta vivipara	Alpine Bistort	Endangered
Boechera laevigata	Smooth Rockcress	Threatened
Boechera missouriensis	Missouri Rockcress	Threatened
Calystegia spithamaea	Upright Bindweed	Threatened
Cardamine bellidifolia	Alpine Bitter-cress	Endangered
Cardamine concatenata	Cut-leaved Toothwort	Endangered
Cardamine longii	Long's Bitter-cress	Threatened
Carya cordiformis	Bitternut Hickory	Endangered
Ceanothus americanus	New Jersey Tea	Threatened
Chenopodium foggii	Fogg's Goosefoot	Threatened
Chimaphila maculata	Spotted Wintergreen	Endangered
Coptidium lapponicum	Lapland Buttercup	Threatened
Cynoglossum virginianum var. *boreale*	Northern Wild Comfrey	Endangered
Dicentra canadensis	Squirrel-corn	Threatened
Draba arabisans	Rock Whitlow-grass	Threatened
Draba cana	Lance-leaved Draba	Endangered
Draba glabella	Smooth Draba	Endangered
Drosera anglica	English Sundew	Endangered
Drosera linearis	Slender-leaved Sundew	Endangered
Epilobium anagallidifolium	Alpine Willow-herb	Endangered
Epilobium hornemannii	Hornemann's Willow-herb	Endangered
Eupatorium pubescens	Hairy Boneset	Endangered
Eupatorium sessidifolium	Upland Boneset	Endangered
Euthamia caroliniana	Narrow-leaved Goldenrod	Threatened
Gentiana rubricaulis	Red-stemmed Gentian	Threatened
Gentianella amarella ssp. *acuta*	Northern Gentian	Endangered

Appendix 1-1. *continued: page 2 of 5.*

Taxa group (class) *Scientific name*	Common name	State status (updated, 2015)
Class Dicotyledoneae (Dicots) - *continued*		
Geum fragarioides	Barren-strawberry	Endangered
Hackelia deflexa ssp. *americana*	Northern Stickseed	Endangered
Harrimanella hypnoides	Moss Bell-heather	Threatened
Hieracium robinsonii	Robinson's Hawkweed	Endangered
Hieracium venosum var. *nudicaule*	Rattlesnake Hawkweed	Endangered
Hottonia inflata	Featherfoil	Threatened
Hypericum ascyron	Great Saint John's-wort	Endangered
Ilex glabra	Ink-berry	Endangered
Iva frutescens ssp. *oraria*	Marsh-elder	Endangered
Kalmia procumbens	Alpine Azalea	Threatened
Krigia virginica	Dwarf Dandelion	Endangered
Lespedeza hirta hirta	Hairy Bush-clover	Endangered
Liatris novae-angliae	Northern Blazing Star	Threatened
Lomatogonium rotatum	Marsh Felwort	Threatened
Lonicera dioica	Mountain Honeysuckle	Endangered
Micranthes foliolosa	Star Saxifrage	Endangered
Minuartia michauxii	Michaud's Stitchwort	Endangered
Minuartia rubella	Arctic Sandwort	Endangered
Nabalus boottii	Boott's Rattlesnake Root	Endangered
Nymphaea leibergii	Pygmy Water-lily	Threatened
Omalotheca supina	Alpine Cudweed	Endangered
Oxytropis campestris var. *johannensis*	Saint John Oxytrope	Threatened
Panax quinquefolius	American Ginseng	Endangered
Paronychia argyrocoma	Silverling	Threatened
Pedicularis furbishiae	Furbish's Lousewort	Endangered
Phyllodoce caerulea	Mountain Heath	Threatened
Pinguicula vulgaris	Common Butterwort	Endangered
Polemonium vanbruntiae	Bog Jacob's-ladder	Endangered
Polygala senega	Seneca Snakeroot	Endangered
Proserpinaca pectinata	Comb-leaved Mermaid-weed	Endangered
Prunus maritima	Beach Plum	Endangered
Quercus bicolor	Swamp White Oak	Threatened
Quercus coccinea	Scarlet Oak	Endangered
Quercus montana	Chestnut Oak	Threatened
Ranunculus fascicularis	Early Crowfoot	Threatened
Rhododendron lapponicum	Lapland Rosebay	Threatened
Rhododendron maximum	Great Rhododendron	Threatened
Rhododendron viscosum	Clammy Azalea	Endangered
Salix arctophila	Arctic Willow	Endangered
Salix candida	Hoary Willow	Endangered
Salix exigua ssp. *interior*	Sandbar Willow	Endangered
Salix herbacea	Dwarf Willow	Threatened
Salix myricoides	Blue-leaf Willow	Threatened
Salix planifolia	Tea-leaved Willow	Threatened

Appendix 1-1. *continued: page 3 of 5.*

Taxa group (class) *Scientific name*	Common name	State status (updated, 2015)
Class Dicotyledoneae (Dicots) - *continued*		
Salix uva-ursi	Bearberry Willow	Threatened
Sanguisorba canadensis	Canada Burnet	Threatened
Saxifraga paniculata ssp. *neogaea*	Livelong Saxifrage	Endangered
Sericocarpus asteroids	White-topped Aster	Endangered
Shepherdia canadensis	Canada Buffaloberry	Endangered
Solidago leiocarpa	Cutler's Goldenrod	Threatened
Solidago speciose	Showy Goldenrod	Threatened
Suaeda calceoliformis	American Sea-blite	Threatened
Symphyotrichum anticostense	Anticosti Aster	Endangered
Symphyotrichum subulatum	Small Salt-marsh Aster	Threatened
Thalictrum thalictroides	Rue-anemone	Endangered
Thalictrum venulosum var. *confine*	Boundary Meadow-rue	Threatened
Triosteum aurantiacum	Wild Coffee	Endangered
Veronica wormskjoldii	Alpine Speedwell	Endangered
Vitis aestivalis var. *bicolor*	Summer Grape	Threatened
Class Filicopsida (Ferns)		
Adiantum aleuticum	Aleutian Maidenhair Fern	Endangered
Asplenium viride	Green Spleenwort	Endangered
Cryptogramma stelleri	Slender Cliffbrake	Threatened
Dryopteris filix-mas ssp. *brittonii*	Male Wood Fern	Endangered
Woodsia alpine	Northern Woodsia	Threatened
Woodsia glabella	Smooth Woodsia	Threatened
Woodsia obtusa	Blunt-lobed Woodsia	Threatened
Class Isoetopsida (Quillworts & Spike-mosses)		
Isoetes prototypus	Prototype Quillwort	Threatened
Selaginella apoda	Creeping Spike-moss	Endangered
Selaginella selaginoides	Low Spike-moss	Threatened
Class Lycopodiopsida (Clubmosses)		
Diphasiastrum sitchense	Alaskan Clubmoss	Threatened
Huperzia selago	Northern Firmoss	Threatened
Lycopodiella alopecuroides	Foxtail Bog-clubmoss	Endangered
Class Monocotyledoneae (Monocots)		
Agrostis mertensii	Boreal Bentgrass	Threatened
Anthoxanthum monticola	Alpine Sweet-grass	Threatened
Bolboschoenus novae-angliae	Marsh Bulrush	Endangered
Bromus kalmia	Wild Chess	Endangered
Calamagrostis pickeringii	Pickering's Reed Bent-grass	Threatened
Calamagrostis stricta ssp. *inexpansa*	Northern Reed Grass	Endangered
Calamagrostis stricta ssp. *stricta*	Neglected Reed-grass	Threatened
Carex adusta	Swarthy Sedge	Endangered
Carex atherodes	Awned Sedge	Threatened
Carex bicknellii	Bicknell's Sedge	Endangered

Appendix 1-1. *continued: page 4 of 5.*

Taxa group (class) *Scientific name*	Common name	State status (updated, 2015)
Class Monocotyledoneae (Monocots) - *continued*		
Carex eburnea	Ebony Sedge	Endangered
Carex granularis	Meadow Sedge	Threatened
Carex laxiculmis	Spreading Sedge	Endangered
Carex media	Intermediate Sedge	Endangered
Carex muehlenbergii	Muhlenberg Sedge	Endangered
Carex oronensis	Orono Sedge	Threatened
Carex polymorpha	Variable Sedge	Endangered
Carex prairea	Prairie Sedge	Threatened
Carex saxatilis	Russett Sedge	Endangered
Carex sparganioides	Bur-reed Sedge	Endangered
Carex typhina	Cattail Sedge	Endangered
Carex vacillans	Brackish Sedge	Endangered
Carex vestita	Clothed Sedge	Endangered
Corallorhiza odontorhiza	Autumn Coral-root	Endangered
Cyperus erythrorhizos	Red-root Flatsedge	Endangered
Cypripedium arietinum	Ram's-head Lady's-slipper	Endangered
Eleocharis rostellata	Beaked Spikerush	Threatened
Eleocharis tuberculosa	Long-tubercled Spikerush	Endangered
Festuca prolifera	Arctic Red Fescue	Endangered
Galearis spectabilis	Showy Orchis	Endangered
Glyceria acutiflora	Sharp-scaled Manna-grass	Endangered
Goodyera oblongifolia	Giant Rattlesnake-plantain	Endangered
Iris prismatica	Slender Blue Flag	Threatened
Isotria medeoloides	Small Whorled Pogonia	Endangered
Juncus secundus	Secund Rush	Threatened
Juncus subtilis	Slender Rush	Endangered
Juncus vaseyi	Vasey's Rush	Endangered
Lipocarpha micrantha	Dwarf Bulrush	Threatened
Luzula confuse	Northern Wood-rush	Endangered
Luzula spicata	Spiked Wood-rush	Threatened
Malaxis monophyllos	White Adder's-mouth	Endangered
Muhlenbergia sobolifera ssp. *brachypoda*	Cliff Muhly	Endangered
Listera auriculata	Auricled Twayblade	Threatened
Phleum alpinum	Mountain Timothy	Threatened
Platanthera leucophaea	Prairie White-fringed Orchid	Endangered
Poa glauca	White Bluegrass	Threatened
Poa laxa fernaldiana	Wavy Bluegrass	Endangered
Potamogeton friesii	Fries' Pondweed	Endangered
Potamogeton pulcher	Spotted Pondweed	Threatened
Potamogeton strictifolius	Straight-leaved Pondweed	Threatened
Rhynchospora capillacea	Horned Beak-rush	Threatened
Rhynchospora macrostachya	Tall Beak-rush	Endangered
Scirpus longii	Long's Bulrush	Threatened

Appendix 1-1. *continued: page 5 of 5.*

Taxa group (class) *Scientific name*	Common name	State status (updated, 2015)
Class Monocotyledoneae (Monocots) - *continued*		
Sorghastrum nutans	Indian Grass	Endangered
Spiranthes lucida	Shining Ladies'-tresses	Threatened
Sporobolus compositus var. *drummondii*	Longleaf Dropseed	Endangered
Triphora trianthophora	Nodding Pogonia	Threatened
Vahlodea atropurpurea	Mountain Hairgrass	Endangered
Xyris smalliana	Yellow-eyed Grass	Endangered
Class Ophioglossopsida (Adder's-tongues and Grapeferns)		
Botrychium lunaria	Moonwort	Endangered
Botrychium oneidense	Blunt-lobed Grapefern	Threatened
Botrychium pallidum	Pale Moonwort	Endangered

Appendix 1-2. Maine's list of state-designated Endangered and Threatened inland fish and wildlife administered by the Maine Department of Inland Fisheries and Wildlife (in statute; see Title 12 MRSA, §12803, http://legislature.maine.gov/legis/statutes/12/title12sec12803.html).

Taxa group (class) *Scientific name*	Common name	State status (year listed)
Class Actinopterygii (Fish)		
Esox americanus americanus	Redfin Pickerel	Endangered (2007)
Etheostoma fusiforme	Swamp Darter	Threatened (1997)
Class Aves (Birds)		
Alca torda	Razorbill	Threatened (1997)
Ammodramus savannarum	Grasshopper Sparrow	Endangered (1987)
Anthus rubescens	American Pipit	Endangered (1997)
Aquila chrysaetos	Golden Eagle	Endangered (1987)
Asio flammeus	Short-eared Owl	Threatened (1987)
Bartramia longicauda	Upland Sandpiper	Threatened (1997)
Bucephala islandica	Barrow's Goldeneye	Threatened (2007)
Charadrius melodus	Piping Plover	Endangered (1987)
Chlidonias niger	Black Tern	Endangered (1997)
Cistothorus platensis	Sedge Wren	Endangered (1987)
Falco peregrinus	Peregrine Falcon	Endangered (1975)
Fratercula arctica	Atlantic Puffin	Threatened (1997)
Gallinula galeata	Common Gallinule	Threatened (2007)
Haliaeetus leucocephalus	Bald Eagle	Recovered (2009) / Threatened (1996) / Endangered (1978)
Histrionicus histrionicus	Harlequin Duck	Threatened (1997)
Ixobrychus exilis	Least Bittern	Endangered (2007)
Nycticorax nycticorax	Black-crowned Night Heron	Endangered (2015) Threatened (2007)
Phalacrocorax carbo	Great Cormorant	Threatened (2007)
Sternula antillarum	Least Tern	Endangered (1984)
Sterna paradisaea	Arctic Tern	Threatened (1997)
Sterna dougallii	Roseate Tern	Endangered (1997) / Threatened (1987)
Class Bivalvia (Molluscs)		
Alasmidonta varicose	Brook Floater	Threatened (2007)
Lampsilis cariosa	Yellow Lampmussel	Threatened (1997)
Leptodea ochracea	Tidewater Mucket	Threatened (1997)
Class Gastropoda (Snails)		
Vertigo morseii	Six-whorled Vertigo	Endangered (2015)

Appendix 1-2. *continued: page 2 of 2.*

Taxa group (class) *Scientific name*	Common name	State status (year listed)
Class Insecta (Insects)		
Boloria chariclea grandis	Purple Lesser Fritillary	Threatened (2007)
Boloria frigga	Frigga Fritillary	Endangered (2015)
Callophrys gryneus	Juniper Hairstreak	Endangered (2007)
Callophrys hesseli	Hessel's Hairstreak	Endangered (1997)
Cicindela marginipennis	Cobblestone Tiger Beetle	Endangered (2015)
Epeorus frisoni	Roaring Brook Mayfly	Threatened (2015) / Endangered (2007)
Erynnis brizo	Sleepy Duskywing	Threatened (2007)
Gomphus quadricolor	Rapids Clubtail	Endangered (2007)
Lycaena dorcas claytoni	Clayton's Copper	Threatened (2015) / Endangered (1997)
Lycia rachelae	Twilight Moth	Threatened (2007)
Oeneis polixenes katahdin	Katahdin Arctic	Endangered (1997)
Ophiogomphus colubrinus	Boreal Snaketail	Threatened (2007)
Satyrium edwardsii	Edwards' Hairstreak	Endangered (1997)
Siphlonisca aerodromia	Tomah Mayfly	Threatened (1997)
Williamsonia lintneri	Ringed Boghaunter	Threatened (2007)
Zanclognatha martha	Pine Barrens Zanclognatha	Threatened (1997)
Class Mammalia (Mammals)		
Myotis leibii	Eastern Small-footed Bat	Threatened (2015)
Myotis lucifugus	Little Brown Bat	Endangered (2015)
Myotis septentrionalis	Northern Long-eared Bat	Endangered (2015)
Sylvilagus transitionalis	New England Cottontail	Threatened (2007)
Synaptomys borealis	Northern Bog Lemming	Endangered (1987)
Class Reptilia (Reptiles)		
Clemmys guttata	Spotted Turtle	Threatened (1987)
Coluber constrictor	Black Racer	Endangered (1987)
Emydoidea blandingii	Blanding's Turtle	Endangered (1997) / Threatened (1987)
Terrapene carolina	Box Turtle	Endangered (1987)

Appendix 1-3. Maine's list of state-designated Endangered and Threatened marine fish and wildlife administered by the Maine Department of Marine Resources (in statute; see Title 12 MRSA, §6975, http://legislature.maine.gov/legis/statutes/12/title12sec6975.html).

Taxa group (class) *Scientific name*	Common name	State status (year listed)
Class Actinopterygii (Fish)		
Acipenser brevirostrum	Short-nosed Sturgeon	Endangered (1975)
Class Mammalia (Mammals)		
Balaenoptera borealis	Sei Whale	Endangered (1975)
Balaenoptera physalus	Finback Whale	Endangered (1975)
Eubalaena glacialis	North Atlantic Right Whale	Endangered (1975)
Megaptera novaeangliae	Humpback Whale	Endangered (1975)
Physeter macrocephalus	Sperm Whale	Endangered (1975)
Class Reptilia (Reptiles)		
Caretta caretta	Loggerhead Sea Turtle	Threatened (1978)
Dermochelys coriacea	Leatherback Sea Turtle	Endangered (1975)
Lepidochelys kempii	Kemp's Ridley Sea Turtle	Endangered (1975)

Appendix 1-4. Maine's list of federally-designated Endangered and Threatened species administered by the U.S. Fish and Wildlife Service and National Marine Fisheries Service; see http://ecos.fws.gov/ecp/.

Taxa group (class) *Scientific name*	Common name	Federal status (year listed)
FAUNA		
Class Actinopterygii (Fish)		
Acipenser brevirostrum	Short-nosed Sturgeon	Endangered (1967)
Acipenser oxyrinchus (Gulf of Maine distinct population segment)	Atlantic Sturgeon	Threatened (2012)
Salmo salar (Gulf of Maine distinct population segment)	Atlantic Salmon	Endangered (2000)
Class Aves (Birds)		
Calidris canutus rufa	Red Knot	Threatened (2015)
Charadrius melodus	Piping Plover	Threatened (1985)
Falco peregrinus anatum	American Peregrine Falcon	Recovered (1999) / Endangered (1970)
Falco peregrinus tundrius	Arctic Peregrine Falcon	Recovered (1994) / Threatened (1984) / Endangered (1970)
Haliaeetus leucocephalus	Bald Eagle	Recovered (2007) / Threatened (1995) / Endangered (1978)
Sterna dougallii	Roseate Tern	Endangered (1987)
Class Mammalia (Mammals)		
Balaenoptera borealis	Sei Whale	Endangered (1970)
Balaenoptera musculus	Blue Whale	Endangered (1970)
Balaenoptera physalus	Finback Whale	Endangered (1970)
Canis lupus	Gray Wolf	Endangered (1967)
Eubalaena glacialis	North Atlantic Right Whale	Endangered (1970)
Lynx canadensis	Canada Lynx	Threatened (2000)
Megaptera novaeangliae	Humpback Whale	Endangered (1970)
Myotis septentrionalis	Northern Long-eared Bat	Threatened (2015)
Physeter macrocephalus	Sperm Whale	Endangered (1970)
Class Reptilia (Reptiles)		
Caretta caretta	Loggerhead Sea Turtle	Threatened (1978)
Chelonia mydas	Green Sea Turtle	Threatened (1978)
Dermochelys coriacea	Leatherback Sea Turtle	Endangered (1970)
Lepidochelys kempii	Kemp's Ridley Sea Turtle	Endangered (1970)
FLORA		
Class Dicotyledonae (Dicots)		
Isotria medeoloides	Small Whorled Pogonia	Threatened (1994) / Endangered (1982)
Pedicularis furbishiae	Furbish's Lousewort	Endangered (1978)
Class Monocotyledonae (Monocots)		
Platanthera leucophaea	Prairie White-fringed Orchid	Threatened (1989)

Appendix 1-5. Maine's 2005 SGCN that are removed from the 2015 Wildlife Action Plan.

Taxa group (class) *Scientific name*	Common name	Factors contributing to loss of SGCN status in Maine (2005 → 2015)
Class Aves (Birds)		
Anas rubripes	American Black Duck	revised regional significance criteria
Ardea alba	Great Egret	recent range expansion & low vulnerability
Bubulcus ibis	Cattle Egret	recent range expansion & low vulnerability
Cistothorus palustris	Marsh Wren	former decline insignificant in 2012 update
Egretta tricolor	Tricolored Heron	recent range expansion & low vulnerability
Empidonax traillii	Willow Flycatcher	former decline insignificant in 2012 update
Grus canadensis	Sandhill Crane	recent, general range expansion
Haliaeetus leucocephalus	Bald Eagle	full species recovery & habitat safeguards
Lanius ludoviciaus	Loggerhead Shrike	long-term extirpation
Myiarchus crinitus	Great Crested Flycatcher	former decline insignificant in 2012 update
Oxyura jamaicensis	Ruddy Duck	revised regional significance criteria
Plegadis falcinellus	Glossy Ibis	recent range expansion & low vulnerability
Pooecetes gramineus	Vesper Sparrow	revised regional significance criteria
Polioptila caerulea	Blue-gray Gnatcatcher	former decline insignificant in 2012 update
Sphyrapicus varius	Yellow-bellied Sapsucker	revised regional significance criteria
Strix varia	Barred Owl	revised regional significance criteria
Vireo flavifrons	Yellow-throated Vireo	former decline insignificant in 2012 update
Class Gastropoda (Snails)		
Amnicola decisus	A Spire Snail	errant record: mistaken identification
Catinella exile	Pleistocene Catinella	uncertain identification & taxonomy
Paravitrea lamellidens	Lamellate Supercoil	errant record: mistaken identification
Physella magnalacustris	Great Lakes Physa	uncertain identification & taxonomy
Vertigo nylanderi	Deep-throat Vertigo	relatively secure status in recent surveys
Class Insecta (Insects)		
Catocala pretiosa pretiosa	Precious Underwing	long-term extirpation
Nicrophorus americanus	American Burying Beetle	long-term extirpation
Nixe rusticalis	A Mayfly	secure status in updated assessment
Plauditus cestus	A Mayfly	uncertain taxonomy
Plebejus saepiolus amica	Greenish Blue	likely non-native & range expansion
Procloeon mendax	A Mayfly	secure status in updated assessment
Procloeon ozburni	A Mayfly	errant record: mistaken identification
Procloeon simplex	A Mayfly	secure status in updated assessment
Siphlonurus securifer	A Mayfly	secure status in updated assessment
Class Mammalia (Mammals)		
Canis lupus	Gray Wolf	long-term extirpation
Class Reptilia (Reptiles)		
Crotalus horridus	Timber Rattlesnake	long-term extirpation

Appendix 1-6. Maine's plant Species of Greatest Conservation Need (SGCN) administered by Maine Natural Areas Program – Maine Department of Agriculture, Conservation and Forestry and conservation actions associated with habitat groupings.

Habitat Grouping **Habitat Macrogroup** *Scientific Name*	**Common Name**	**Priority Level**
Habitat Grouping: Coastal		
Macrogroup - Coastal Grassland & Shrubland		
Agalinis neoscotica	Nova Scotia False Foxglove	1
Artemisia campestris ssp. caudata	Beach Wormwood	3
Botrychium lunaria	Moonwort	1
Botrychium pallidum	Pale Moonwort	1
Ilex glabra	Ink-berry	2
Iva frutescens ssp. oraria	Marsh-elder	2
Lycopodiella alopecuroides	Foxtail Bog-clubmoss	1
Ophioglossum pusillum	Adder's Tongue Fern	2
Prunus maritima	Beach Plum	2
Habitat Grouping: Freshwater Marshes		
Macrogroup - Coastal Plain Pond		
Eleocharis tuberculosa	Long-tuberculed Spikerush	2
Euthamia caroliniana	Narrow-leaved Goldenrod	2
Fimbristylis autumnalis	Fall Fimbry	3
Glyceria acutiflora	Sharp-scaled Manna-grass	2
Lindernia dubia var. anagallidea	Slender False Pimpernel	3
Lipocarpha micrantha	Dwarf Bulrush	2
Proserpinaca pectinata	Comb-leaved Mermaid-weed	2
Macrogroup - Emergent Marsh		
Agalinis purpurea	Large-purple False Foxglove	2*
Bidens eatonii	Eaton's bur-marigold	2*
Bidens hyperborea	Estuary Bur-marigold	3*
Cardamine longii	Long's Bitter-cress	1*
Carex rostrata	Beaked Sedge	2*
Crassula aquatica	Pygmyweed	3*
Cyperus erythrorhizos	Red-root Flatsedge	2*
Eleocharis aestuum	Tidal Spikrush	2*
Eleocharis rostellata	Beaked Spikerush	1*
Eriocaulon parkeri	Parker's Pipewort	2*
Lilaeopsis chinensis	Lilaeopsis	2*
Limosella australis	Mudwort	3*
Nuphar advena	Yellow Pond-lily	2*
Sagittaria montevidensis ssp. spongiosa	Spongy-leaved Arrowhead	3*
Samolus valerandi ssp. parviflorus	Water Pimpernel	3*

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping

Appendix 1-6. continued: page 2 of 13.

Habitat Grouping Habitat Macrogroup *Scientific Name*	**Common Name**	**Priority Level**
Habitat Grouping: Freshwater Marshes (continued)		
Macrogroup - Emergent Marsh		
Wolffia brasiliensis	Pointed Watermeal	3*
Wolffia columbiana	Columbian Watermeal	3*
Zannichellia palustris	Horned Pondweed	3*
Macrogroup - Wet Meadow-Shrub Marsh		
Bartonia paniculata ssp. iodandra	Screwstem	2
Betula pumila	Swamp Birch	3*
Carex atherodes	Awned Sedge	1
Carex bullata	Button Sedge	3
Carex granularis	Meadow Sedge	2*
Carex livida var. radicaulis	Livid sedge	2*
Carex prairea	Prairie Sedge	2*
Carex rostrata	Beaked Sedge	2
Carex sterilis	Dioecious Sedge	3*
Drosera anglica	English Sundew	1
Drosera linearis	Slender-leaved Sundew	1
Eutrochium fistulosum	Hollow Joe-Pye Weed	3*
Galium labradoricum	Bog Bedstraw	3
Gentiana rubricaulis	Red-stemmed Gentian	2
Iris prismatica	Slender Blue Flag	2
Platanthera flava var. herbiola	Pale Green Orchis	3
Platanthera leucophaea	Prairie White-fringed Orchid	1
Polemonium vanbruntiae	Jacob's-ladder	1
Rhynchospora macrostachya	Tall Beak-rush	2
Scirpus georgianus	Georgia Bulrush	3
Scirpus longii	Long's Bulrush	1
Scirpus pendulus	Pendulous Bulrush	3
Selaginella apoda	Creeping Spike-moss	2
Selaginella selaginoides	Low Spike-moss	1*
Xyris smalliana	Yellow-eyed Grass	2
Habitat Grouping: Grassland-shrubland-early Successional		
Macrogroup - Ruderal Shrubland & Grassland		
Aletris farinosa	Unicorn Root	2
Calamagrostis cinnoides	Small Reed Grass	3
Callitriche terrestris	Terrestrial Water-starwort	3
Calystegia spithamea	Upright Bindweed	1

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping

Appendix 1-6. continued: page 3 of 13.

Habitat Grouping Habitat Macrogroup *Scientific Name*	Common Name	Priority Level
Habitat Grouping: Grassland-shrubland-early Successional (continued)		
Macrogroup - Ruderal Shrubland & Grassland		
Carex adusta	Swarthy Sedge	1
Carex bicknellii	Bicknell's Sedge	1
Carex muehlenbergii	Muhlenberg Sedge	2
Carex oronensis	Orono Sedge	1
Carex siccata	Dry land Sedge	3*
Carex vestita	Clothed Sedge	2
Carex waponahkikensis	Dawn-land Sedge	3
Diphasiastrum sitchense	Alaskan Clubmoss	1*
Diphasiastrum sitchense	Alaskan Clubmoss	1*
Eleocharis nitida	Slender Spikerush	2
Eupatorium pubescens	Hairy Boneset	2
Eutrochium fistulosum	Hollow Joe-Pye Weed	3
Geum fragarioides	Barren-strawberry	2
Liatris novae-angliae	Northern Blazing Star	1
Lycopodiella appressa	Southern Bog-clubmoss	2
Piptatherum canadense	Canada Mountain-ricegrass	2*
Polygala senega	Seneca Snakeroot	2
Salix occidentalis	Dwarf Prairie Willow	3
Sericocarpus asteroides	White-topped Aster	2
Sorghastrum nutans	Indian Grass	2*
Habitat Grouping: Floodplain Forest		
Macrogroup - Northeastern Floodplain Forest		
Allium canadense	Wild Garlic	3
Allium tricoccum	Wild Leek	3
Asarum canadense	Wild Ginger	2
Carex hirtifolia	Pubescent Sedge	3
Carex typhina	Cattail Sedge	2
Elymus hystrix	Bottlebrush Grass	3*
Elymus macgregorii	MacGregor's Rye	2
Hypericum ascyron	Great St John's-wort	2
Quercus bicolor	Swamp White Oak	2
Verbena urticifolia	White Vervain	3
Habitat Grouping: Northern Forests and Swamps		
Macrogroup - Boreal Upland Forest		
Adiantum aleuticum	Aleutian Maidenhair Fern	1

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping

Appendix 1-6. continued: page 4 of 13.

Habitat Grouping Habitat Macrogroup *Scientific Name*	**Common Name**	**Priority Level**
Habitat Grouping: Northern Forests and Swamps (continued)		
Macrogroup - Boreal Upland Forest		
Epilobium hornemannii	Hornemann's Willow-herb	1
Pyrola minor	Lesser Wintergreen	3
Macrogroup - Northern Peatland & Fens		
Betula pumila	Swamp Birch	3
Calamagrostis pickeringii	Pickering's Reed Grass	2
Carex bullata	Button Sedge	3*
Carex livida var. radicaulis	Livid sedge	2
Cypripedium reginae	Showy Lady's-slipper	2*
Drosera anglica	English Sundew	1*
Drosera linearis	Slender-leaved Sundew	1*
Geocaulon lividum	Northern Comandra	3
Juncus stygius ssp. americanus	Moor Rush	2
Macrogroup - Northern Swamp		
Amerorchis rotundifolia	Small Round-leaved Orchis	1
Cardamine bulbosa	Bulbous Bitter-cress	3
Carex capillaris	Capillary Sedge	2*
Carex gynocrates	Northern Bog Sedge	2
Carex prairea	Prairie Sedge	2
Carex tenuiflora	Sparse-flowered Sedge	2
Chamaecyparis thyoides	Atlantic White Cedar	3
Clethra alnifolia	Sweet Pepper-bush	3
Coptidium lapponicum	Lapland Buttercup	1
Cypripedium arietinum	Ram's-head Lady's-slipper	1*
Cypripedium reginae	Showy Lady's-slipper	2
Goodyera oblongifolia	Giant Rattlesnake-plantain	1
Huperzia selago	Northern Firmoss	1
Ilex laevigata	Smooth Winterberry Holly	3
Lindera benzoin	Spicebush	3
Lonicera oblongifolia	Swamp Honeysuckle	3
Malaxis monophyllos ssp. brachypoda	White Adder's-mouth	2
Ranunculus gmelinii var. purshii	Small Yellow Water Crowfoot	2
Rhododendron viscosum	Clammy Azalea	2
Salix candida	Hoary Willow	2
Selaginella selaginoides	Low Spike-moss	1
Solidago speciosa	Showy Goldenrod	2

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping

Appendix 1-6. continued: page 5 of 13.

Habitat Grouping Habitat Macrogroup *Scientific Name*	**Common Name**	**Priority Level**
Habitat Grouping: Northern Forests and Swamps (continued)		
Macrogroup - Northern Swamp**		
Valeriana uliginosa	Marsh Valerian	2
Habitat Grouping: Pine Barrens		
Macrogroup - Central Oak-Pine**		
Aureolaria pedicularia	Fern-leaved False Foxglove	3*
Benthamidia florida	Flowering Dogwood	2
Boechera missouriensis	Missouri Rockcress	1
Bromus pubescens	Hairy Wood Brome-grass	3
Carex laxiculmis	Spreading Sedge	2
Carex polymorpha	Variable Sedge	1
Carex siccata	Dry land Sedge	3
Carya cordiformis	Bitternut Hickory	2
Castanea dentata	American Chestnut	3
Chimaphila maculata	Spotted Wintergreen	2
Cyperus houghtonii	Houghton's Flatsedge	2
Elymus hystrix	Bottlebrush Grass	3
Eupatorium sessilifolium	Upland Boneset	2
Hieracium venosum var. nudicaule	Rattlesnake Hawkweed	2
Isotria medeoloides	Small Whorled Pogonia	1
Kalmia latifolia	Mountain-laurel	3
Lespedeza hirta ssp. hirta	Hairy Bush-clover	2
Lonicera dioica	Mountain Honeysuckle	2
Minuartia glabra	Smooth Sandwort	3*
Muhlenbergia sobolifera	Cliff Muhly	2
Piptatherum canadense	Canada Mountain-ricegrass	2
Quercus coccinea	Scarlet Oak	2
Quercus montana	Chestnut Oak	2
Ranunculus fascicularis	Early Crowfoot	2*
Rhododendron maximum	Great Rhododendron	2
Sassafras albidum	Sassafras	3
Vitis aestivalis var. bicolor	Summer Grape	2
Woodsia obtusa	Blunt-lobed Woodsia	2
Habitat Grouping: Rocky Coast		
Macrogroup - Rocky Coast		
Lomatogonium rotatum	Marsh Felwort	1
Montia fontana	Blinks	2

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping

Appendix 1-6. continued: page 6 of 13.

Habitat Grouping Habitat Macrogroup *Scientific Name*	**Common Name**	**Priority Level**
Habitat Grouping: Rocky Coast (continued)		
Macrogroup - Rocky Coast		
Primula laurentiana	Bird's-eye Primrose	2
Habitat Grouping: Rocky Summits-Outcrops-Mountaintops		
Macrogroup - Alpine		
Agrostis mertensii	Boreal Bentgrass	2
Anthoxanthum monticola	Alpine Sweet Grass	1
Arctous alpina	Alpine Bearberry	1
Betula glandulosa	Tundra Dwarf Birch	1
Betula minor	Dwarf White Birch	1
Bistorta vivipara	Alpine Bistort	1
Calamagrostis stricta ssp. inexpansa	Northern Reed Grass	1*
Carex bigelowii	Bigelow's Sedge	2
Carex saxatilis	Russett Sedge	1
Carex scirpoidea	Bulrush Sedge	2*
Diapensia lapponica	Lapland Diapensia	2
Diphasiastrum sitchense	Alaskan Clubmoss	1
Epilobium anagallidifolium	Alpine Willow-herb	1
Euphrasia oakesii	Oakes' Eyebright	1
Festuca prolifera	Arctic Red Fescue	1
Geocaulon lividum	Northern Comandra	3*
Harrimanella hypnoides	Moss Bell-heather	1
Hedysarum alpinum var. americanum	Alpine Sweet-broom	3
Huperzia appressa	Mountain Firmoss	3
Huperzia selago	Northern Firmoss	1*
Kalmia procumbens	Alpine Azalea	1
Luzula confusa	Northern Wood Rush	1
Luzula spicata	Spiked Wood Rush	1
Micranthes foliolosa	Star Saxifrage	1
Minuartia groenlandica	Mountain Sandwort	3
Minuartia rubella	Arctic Sandwort	1
Nabalus boottii	Boott's Rattlesnake-root	1
Omalotheca supina	Alpine Cudweed	1
Phleum alpinum	Mountain Timothy	1*
Phyllodoce caerulea	Mountain Heath	1
Pinguicula vulgaris	Common Butterwort	1
Poa glauca	White Bluegrass	1*

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping

Appendix 1-6. continued: page 7 of 13.

Habitat Grouping Habitat Macrogroup *Scientific Name*	**Common Name**	**Priority Level**
Habitat Grouping: Rocky Summits-Outcrops-Mountaintops (continued)		
Macrogroup - Alpine		
Poa laxa ssp. fernaldiana	Wavy Bluegrass	1
Rhododendron lapponicum	Lapland Rosebay	1
Salix arctophila	Arctic Willow	1
Salix herbacea	Dwarf Willow	1
Salix planifolia	Tea-leaved Willow	1
Salix uva-ursi	Bearberry Willow	1
Solidago leiocarpa	Cutler's Goldenrod	1
Vaccinium boreale	Alpine Blueberry	3
Vahlodea atropurpurea	Mountain Hairgrass	1
Veronica wormskjoldii	Alpine Speedwell	1
Macrogroup - Cliff and Talus		
Adiantum viridimontanum	Green Mountain Maidenhair Fern	1
Asplenium viride	Green Spleenwort	1
Astragalus robbinsii var. minor	Robbins' Milk-vetch	1
Boechera laevigata	Smooth Rockcress	2
Carex atratiformis	Black Sedge	2*
Carex eburnea	Ebony Sedge	2*
Carex media	Intermediate Sedge	1
Ceanothus americanus	New Jersey Tea	2
Clematis occidentalis var. occidentalis	Purple Clematis	3
Cryptogramma stelleri	Slender Cliffbrake	1
Draba arabisans	Rock Whitlow-grass	1
Draba cana	Lance-leaved Draba	1
Draba glabella	Smooth Draba	1
Dryopteris fragrans	Fragrant Wood Fern	3
Hieracium robinsonii	Robinson's Hawkweed	1
Poa glauca	White Bluegrass	1
Saxifraga cespitosa	Tufted Saxifrage	2
Saxifraga paniculata ssp. neogaea	Livelong Saxifrage	1
Shepherdia canadensis	Canada Buffaloberry	2
Woodsia alpina	Northern Woodsia	1
Woodsia glabella	Smooth Woodsia	1
Macrogroup - Outcrop & Summit Scrub		
Asplenium platyneuron	Ebony Spleenwort	3
Aureolaria pedicularia	Fern-leaved False Foxglove	3

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping

Appendix 1-6. continued: page 8 of 13.

Habitat Grouping Habitat Macrogroup *Scientific Name*	**Common Name**	**Priority Level**
Habitat Grouping: Rocky Summits-Outcrops-Mountaintops (continued)		
Macrogroup - Outcrop & Summit Scrub		
Bromus kalmii	Wild Chess	2
Calamagrostis stricta ssp. inexpansa	Northern Reed Grass	1
Chenopodium foggii	Fogg's Goosefoot	1
Cyperus houghtonii	Houghton's Flatsedge	2*
Juncus secundus	Secund Rush	2
Krigia virginica	Dwarf Dandelion	2
Minuartia glabra	Smooth Sandwort	3
Minuartia groenlandica	Mountain Sandwort	3*
Minuartia michauxii	Michaux's Sandwort	2
Paronychia argyrocoma	Silverling	1
Polygonum douglasii	Douglas' Knotweed	3
Ranunculus fascicularis	Early Crowfoot	2
Habitat Grouping: South-Central Forests and Swamp		
Macrogroup - Central Oak-Pine*		
Aureolaria pedicularia	Fern-leaved False Foxglove	3*
Benthamidia florida	Flowering Dogwood	2
Boechera missouriensis	Missouri Rockcress	1
Bromus pubescens	Hairy Wood Brome-grass	3
Carex laxiculmis	Spreading Sedge	2
Carex polymorpha	Variable Sedge	1
Carex siccata	Dry land Sedge	3
Carya cordiformis	Bitternut Hickory	2
Castanea dentata	American Chestnut	3
Chimaphila maculata	Spotted Wintergreen	2
Cyperus houghtonii	Houghton's Flatsedge	2
Elymus hystrix	Bottlebrush Grass	3
Eupatorium sessilifolium	Upland Boneset	2
Hieracium venosum var. nudicaule	Rattlesnake Hawkweed	2
Isotria medeoloides	Small Whorled Pogonia	1
Kalmia latifolia	Mountain-laurel	3
Lespedeza hirta ssp. hirta	Hairy Bush-clover	2
Lonicera dioica	Mountain Honeysuckle	2
Minuartia glabra	Smooth Sandwort	3*
Muhlenbergia sobolifera	Cliff Muhly	2
Piptatherum canadense	Canada Mountain-ricegrass	2

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping

Appendix 1-6. continued: page 9 of 13.

Habitat Grouping Habitat Macrogroup *Scientific Name*	**Common Name**	**Priority Level**
Habitat Grouping: South-Central Forests and Swamp (continued)		
Macrogroup - Central Oak-Pine**		
Quercus coccinea	Scarlet Oak	2
Quercus montana	Chestnut Oak	2
Ranunculus fascicularis	Early Crowfoot	2*
Rhododendron maximum	Great Rhododendron	2
Sassafras albidum	Sassafras	3
Vitis aestivalis var. bicolor	Summer Grape	2
Woodsia obtusa	Blunt-lobed Woodsia	2
Macrogroup - Northern Hardwood & Conifer		
Adlumia fungosa	Allegheny Vine	2
Allium tricoccum	Wild Leek	3*
Botrychium oneidense	Blunt-lobed Grapefern	1
Cardamine concatenata	Cut-leaved Toothwort	2
Cardamine maxima	Large Toothwort	3
Carex hirtifolia	Pubescent Sedge	3*
Carex sparganioides	Bur-reed Sedge	2
Corallorhiza odontorhiza	Autumn Coral-root	2
Cynoglossum virginianum ssp. boreale	Northern Wild Comfrey	1
Cypripedium arietinum	Ram's-head Lady's-slipper	1
Dicentra canadensis	Squirrel-corn	2
Dryopteris filix-mas ssp. brittonii	Male Wood Fern	1
Dryopteris goldiana	Goldie's Wood Fern	3
Galearis spectabilis	Showy Orchis	2
Galium kamtschaticum	Boreal Bedstraw	2
Goodyera oblongifolia	Giant Rattlesnake-plantain	1*
Hackelia deflexa ssp. americana	Northern Stickseed	1
Impatiens pallida	Pale Jewel-weed	3
Panax quinquefolius	American Ginseng	1
Phegopteris hexagonoptera	Broad Beech Fern	3
Thalictrum thalictroides	Rue-anemone	2
Triosteum aurantiacum	Wild Coffee	2
Triphora trianthophora	Nodding Pogonia	2
Macrogroup - Northern Swamp**		
Amerorchis rotundifolia	Small Round-leaved Orchis	1
Cardamine bulbosa	Bulbous Bitter-cress	3
Carex capillaris	Capillary Sedge	2*

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping

Appendix 1-6. continued: page 10 of 13.

Habitat Grouping Habitat Macrogroup *Scientific Name*	**Common Name**	**Priority Level**
Habitat Grouping: South-Central Forests and Swamp (continued)		
Macrogroup - Northern Swamp**		
Carex prairea	Prairie Sedge	2
Carex tenuiflora	Sparse-flowered Sedge	2
Chamaecyparis thyoides	Atlantic White Cedar	3
Clethra alnifolia	Sweet Pepper-bush	3
Coptidium lapponicum	Lapland Buttercup	1
Cypripedium arietinum	Ram's-head Lady's-slipper	1*
Cypripedium reginae	Showy Lady's-slipper	2
Goodyera oblongifolia	Giant Rattlesnake-plantain	1
Huperzia selago	Northern Firmoss	1
Ilex laevigata	Smooth Winterberry Holly	3
Lindera benzoin	Spicebush	3
Lonicera oblongifolia	Swamp Honeysuckle	3
Malaxis monophyllos ssp. brachypoda	White Adder's-mouth	2
Ranunculus gmelinii var. purshii	Small Yellow Water Crowfoot	2
Rhododendron viscosum	Clammy Azalea	2
Salix candida	Hoary Willow	2
Selaginella selaginoides	Low Spike-moss	1
Solidago speciosa	Showy Goldenrod	2
Valeriana uliginosa	Marsh Valerian	2
Habitat Grouping: Streams, Rivers, Lakes, and Ponds		
Macrogroup - Lake & River Shore		
Amelanchier gaspensis	Gaspé Shadbush	2
Amelanchier nantucketensis	Nantucket Shadbush	1
Anemone multifida	Cut-leaved Anemone	1
Arnica lanceolata	Hairy Arnica	1
Astragalus alpinus var. brunetianus	Alpine Milk-vetch	2
Calamagrostis stricta ssp. stricta	Neglected Reed Grass	1
Carex atratiformis	Black Sedge	2
Carex capillaris	Capillary Sedge	2
Carex eburnea	Ebony Sedge	2
Carex garberi	Garber's Sedge	2
Carex granularis	Meadow Sedge	2
Carex saxatilis	Russett Sedge	1*
Carex scirpoidea	Bulrush Sedge	2
Carex sterilis	Dioecious Sedge	3

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping

Appendix 1-6. continued: page 11 of 13.

Habitat Grouping Habitat Macrogroup *Scientific Name*	**Common Name**	**Priority Level**
Habitat Grouping: Streams, Rivers, Lakes, and Ponds		
Macrogroup - Lake & River Shore		
Castilleja septentrionalis	Northern Painted Cup	2
Clematis occidentalis ssp. occidentalis	Purple Clematis	3*
Cyperus squarrosus	Awned Flatsedge	3
Eleocharis quinqueflora ssp. fernaldii	Few-flowered Spikerush	3
Erigeron hyssopifolius	Hyssop-leaved Fleabane	2
Fimbristylis autumnalis	Fall Fimbry	3*
Gentianella amarella ssp. acuta	Northern Gentian	1
Heteranthera dubia	Water Stargrass	3
Hieracium robinsonii	Robinson's Hawkweed	1*
Hottonia inflata	Featherfoil	2
Houstonia longifolia var. longifolia	Long-leaved Bluet	3
Isoetes acadiensis	Acadian Quillwort	2
Isoetes prototypus	Prototype Quillwort	1
Isoetes riparia var. canadensis	Shore Quillwort	2
Juncus alpinoarticulatus ssp. nodulosus Juncus alpinoarticulatus ssp. americanus	Alpine Rush	3
Juncus subtilis	Slender Rush	1
Juncus vaseyi	Vasey's Rush	1
Lipocarpha micrantha	Dwarf Bulrush	2*
Muhlenbergia richarsdonis	Soft-leaf Muhly	3
Nabalus racemosus	Glaucus Rattlesnake-root	3
Neottia auriculata	Auricled Twayblade	1
Nymphaea leibergii	Pygmy Water-lily	1
Oxytropis campestris var. johannensis	St John Oxytrope	1
Paronychia argyrocoma	Silverling	1*
Pedicularis furbishiae	Furbish's Lousewort	1
Phleum alpinum	Mountain Timothy	1
Potamogeton friesii	Fries' Pondweed	2
Potamogeton pulcher	Spotted Pondweed	2
Potamogeton strictifolius	Straight-leaved Pondweed	2
Potamogeton vaseyi	Vasey's Pondweed	3
Primula mistassinica	Mistassini Primrose	3
Rhynchospora capillacea	Horned Beak-rush	1

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping

Appendix 1-6. continued: page 12 of 13.

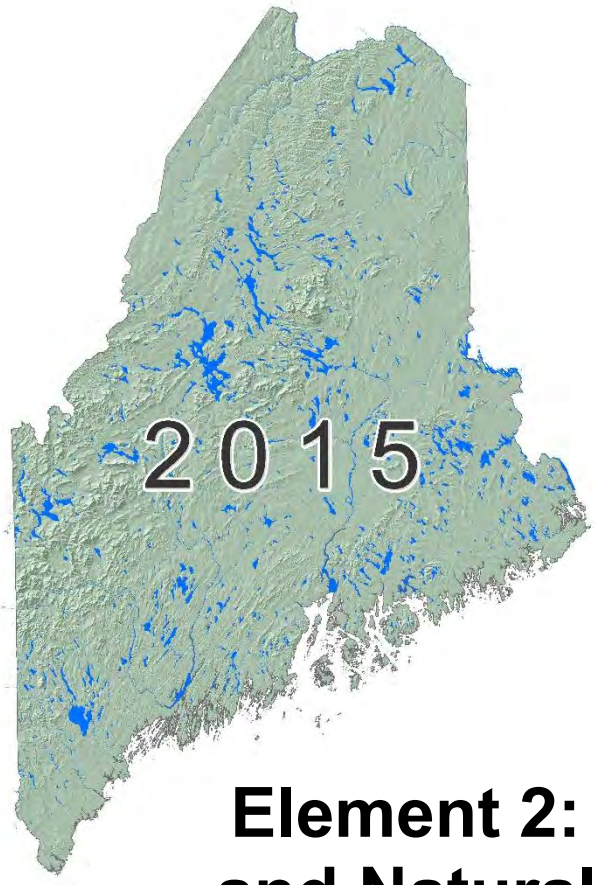
Habitat Grouping Habitat Macrogroup *Scientific Name*	**Common Name**	**Priority Level**
Habitat Grouping: Streams, Rivers, Lakes, and Ponds (continued)		
Macrogroup - Lake & River Shore		
Salix myricoides	Blue-leaf Willow	1
Sanguisorba canadensis	Canada Burnet	2
Sorghastrum nutans	Indian Grass	2
Spiranthes lucida	Shining Ladies'-tresses	2
Sporobolus compositus var. drummondii	Longleaf Dropseed	1
Stuckenia filiformis	Slender pondweed	2
Symphyotrichum anticostense	Anticosti Aster	1
Tanacetum bipinnatum ssp. huronense	Huron tansy	2
Thalictrum venulosum var. confine	Boundary Meadow-rue	1
Trichophorum clintonii	Clinton's Bulrush	2
Viola novae-angliae	New England Violet	2
Wolffia brasiliensis	Pointed Watermeal	3
Wolffia columbiana	Columbian Watermeal	3
Habitat Grouping: Tidal Marsh		
Macrogroup - Intertidal Tidal Marsh (peat-forming)		
Agalinis maritima	Saltmarsh False-foxglove	2
Agalinis purpurea	Large-purple False Foxglove	2
Bidens eatonii	Eaton's bur-marigold	2
Bidens hyperborea	Estuary Bur-marigold	3
Bolboschoenus novae-angliae	Marsh Bulrush	1
Bolboschoenus robustus	Saltmarsh Bulrush	2
Cardamine longii	Long's Bitter-cress	1
Carex vacillans	Brackish Sedge	1
Crassula aquatica	Pygmyweed	3
Cyperus erythrorhizos	Red-root Flatsedge	2
Eleocharis aestuum	Tidal Spikrush	2
Eleocharis rostellata	Beaked Spikerush	1
Eriocaulon parkeri	Parker's Pipewort	2
Lilaeopsis chinensis	Lilaeopsis	2
Limosella australis	Mudwort	3
Nuphar advena	Yellow Pond-lily	2
Sagittaria montevidensis ssp. spongiosa	Spongy-leaved Arrowhead	3
Salicornia bigelovii	Dwarf Glasswort	2
Samolus valerandi ssp. parviflorus	Water Pimpernel	3

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping

Appendix 1-6. continued: page 13 of 13.

Habitat Grouping **Habitat Macrogroup** *Scientific Name*	**Common Name**	**Priority Level**
Habitat Grouping: Tidal Marsh (continued)		
Macrogroup - Intertidal Tidal Marsh (peat-forming)		
Suaeda calceoliformis	American Sea-blite	1
Symphyotrichum subulatum	Small Salt-marsh Aster	2
Triglochin gaspense	Gaspé Arrow-grass	2
Zannichellia palustris	Horned Pondweed	3

*Species is associated with more than one Habitat Macrogroup
**Habitat Macrogroup is associated with more than one Habitat Grouping



MAINE'S WILDLIFE ACTION PLAN

Element 2: Key Habitats and Natural Communities

Prepared by

Maine Department of Inland Fisheries and Wildlife

In collaboration with

Maine's Conservation Partners

September 2015

TABLE OF CONTENTS

Element 2: Key Habitats and Natural Communities

2.0 Abstract....1

2.1 Significant Changes from Maine's 2005 Plan....1

2.2 Landscape Overview of Maine....2
2.2.1 Climate....3
2.2.2 Physiography....3

2.3 Habitat Classifications....4
2.3.1 Northeast Terrestrial Habitat Classification System....4
2.3.2 Coastal and Marine Classification System....7

2.4 Coastal and Marine Ecosystems....9

2.5 Freshwater Aquatic Ecosystems....10

2.6 Terrestrial and Wetland Ecosystems....11

2.7 Conservation Land in Maine....13

2.8 Importance of Habitats to SGCN....15

2.9 Maine Flora AND Exemplary Natural Communities....18

2.10 Focus Areas of Ecological Significance....19

2.11 Literature Cited and References....21

LIST OF TABLES

Table 2-1. Acreages of habitat macrogroups and proportions conserved in Maine. Sources: NatureServe Ecological Systems GIS map (2012) and Maine Conserved Lands Database (2015). Extent of marine habitat macrogroups cannot be determined. 6

Table 2-2. Coastal / marine habitat classification developed for the Maine Wildlife Action Plan. 8

Table 2-3. SGCN associations with NETHCS habitat macrogroups. Click on a macrogroup name to launch a full summary report of associated SGCN and for each habitat macrogroup. 17

LIST OF FIGURES

Figure 2-1. Broad breakdown of habitat types in Maine (Source: NatureServe Ecological Systems GIS layer, 2012). 3

Figure 2-2. River and stream mileage in Maine. 11

Figure 2-3. Generalized map of Maine habitat types, from the Northeastern Habitat Classification System. 12

Figure 2-4. Conserved lands in Maine. Dark green lands are Gap 2 (off limits to extractive uses) and light green lands are considered Gap 3 (fee lands and conservation easements managed for forest products). 14

Figure 2-5. Proportions of habitat types expressed as percentages of all state habitats and as value to SGCN. 16

KEY TO ACRONYMS

GIS	Geographic Information System
MCP	Maine Coastal Program
MDIFW	Maine Dept. of Inland Fisheries and Wildlife
MDMR	Maine Dept. of Marine Resources
MNAP	Maine Natural Areas Program
NALCC	North Atlantic Landscape Conservation Cooperative
NETHCS	Northeast Terrestrial Habitat Classification System
SGCN	Species of Greatest Conservation Need
SWAP	State Wildlife Action Plan
TNC	The Nature Conservancy
USFWS	U.S. Fish and Wildlife Service
WMA	Wildlife Management Area

What is most striking in the Maine wilderness is the continuousness of the forest, with fewer open intervals of glades than you had imagined. Except the few burnt lands, the narrow intervals on the rivers, the bare tops of the high mountains, and the lakes and streams…the forest is uninterrupted.

Henry David Thoreau, 1846: *The Maine Woods*

2.0 ABSTRACT

Element 2 identities the extent and condition of wildlife habitats and community types essential to the conservation of Species of Greatest Conservation Need (SGCN). Maine's Wildlife Action Plan employs The Northeast Terrestrial Habitat Classification System (NETHCS) to identify the extent of habitats and community types essential to the conservation of SGCN. Federal and state agencies in the Northeast have endorsed the NETHCS as a tool for assessing habitat distribution and composition on a regional scale. The specific version of the NETHCS used in Maine includes a number of modifications made by the Maine Department of Marine Resources (MDMR) and the Maine Department of Inland Fisheries and Wildlife (MDIFW) to reflect Maine's landscape and coastal features. The basic layer within NETHCS is the habitat 'system', which corresponds to the national Ecological Systems classification. There are approximately 150 Ecological Systems in Maine. MDIFW and conservation partners used the more general 'Macrogroup' level of this hierarchical system for assigning stressors (Element 3) and some analyses; there are 42 habitat macrogroups in Maine.

Maine further consolidated the macrogroups into three broad habitat categories to facilitate development of conservation actions and ease of Plan use by conservation partners. The broad categories are Coastal and Marine, Terrestrial (including Freshwater Wetlands) and Freshwater Aquatic (Rivers, Lakes, and Ponds). The importance of various habitats to SGCN is not directly correlated to their statewide abundance; habitats such as pine barrens, open freshwater wetlands, and rivers and streams are dis-proportionately important compared to many other habitat types. It is estimated that there are presently 3,824,842 acres of conservation land in Maine, accounting for nearly 20% of the State. Much of this conserved land lies within Focus Areas of Statewide Significance, which have been identified to help prioritize conservation of Maine's landscape for SGCN and other habitat values (Element 4).

2.1 SIGNIFICANT CHANGES FROM MAINE'S 2005 PLAN

Drawing from several sources, Maine's 2005 Plan highlighted 21 habitat types and provided overviews (by ecoregions) across the State (http://www.maine.gov/ifw/wildlife/reports/wap.html). This Plan does not attempt to replicate that detailed narrative. Important changes in Element 2 of the 2015 Wildlife Action Plan include:

- Standard habitat classification: This Plan employs the NETHCS developed by The Nature Conservancy (TNC) in collaboration with fish and wildlife agencies. Habitat associations for SGCN are made with 'systems,' the finest resolution of this hierarchial system. Federal and state programs in the Northeast have endorsed the NETHCS as a standard that is compatible with nationwide classifications (http://www.landfire.gov/).

- Standard habitat mapping: NatureServe and TNC developed seamless GIS coverage to assess habitat distribution and composition terrestrial and freshwater systems in the Northeast. The specific version of the NETHCS used in Maine includes a number of minor alterations and additions made by the University of Massachusetts, as well as minor modifications made by the MDMR and MDIFW to improve resolution on some Maine's landscape and coastal features.

- SGCN - habitat associations: We evaluated SGCN occurrences at two different scales of habitat classification: approximately 150 'systems' grouped within 42 'macrogroups'. The results demonstrate that Maine's current assemblage of 378 SGCN occur disproportionately relative to the extent of habitat types within the State.

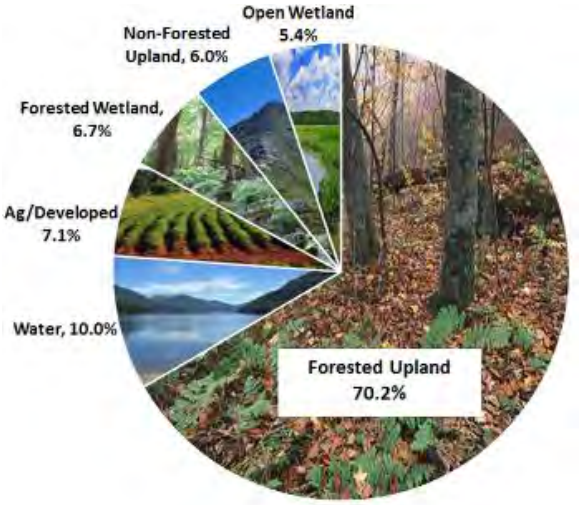
- Broad habitat groupings: We further consolidated the macrogroups into three broad ecosystem categories to facilitate discussion among conservation partners during the consideration of the extent and condition of SGCN habitats and during the development of conservation actions. The broad categories are Marine; Terrestrial, including Freshwater Wetlands; and Freshwater Rivers, Streams, Lakes, and Ponds.

- State Wildlife Action Plan database: As elsewhere in this Plan, the tabular compilation of SGCN associations in each of 42 'macrogroups' (Table 2-3) also functions as a gateway to more detailed reports. Each macrogroup summary reports compiles associated SGCN and major stressors for that system. Such information can be readily updated in the 10-year horizon of the Plan.

2.2 LANDSCAPE OVERVIEW OF MAINE

Maine encompasses approximately 21 million acres of lands and waters, from the dramatic coastline to the heights of Mount Katahdin. Maine is as large as the remaining New England states combined, and more than 31,800 miles of streams and rivers and 5,600 lakes and ponds dot the landscape. Maine's scenic, rock-bound coast is 4,100 miles long and embraces 4,613 islands between Kittery and Eastport. Roughly one quarter of the state consists of freshwater wetlands, including hardwood floodplains, freshwater marshes, and dense assemblages of vernal pools. At nearly 90% forest cover, Maine is the most heavily forested state in the United States, but it also contains some of the most significant grassland and farmlands in the Northeast. Maine's broad habitat types are shown in Figure 2-1.

Figure 2-1. Broad breakdown of habitat types in Maine (Source: NatureServe Ecological Systems GIS layer, 2012).



2.2.1 CLIMATE

Maine's climate plays a major role in determining the plant and animal assemblages within the State. The National Weather Service separates Maine into three distinct climatological divisions – coastal, southern interior, and northern interior (Brandes 2001). The coastal division runs from Kittery to Eastport and about 20 miles inland. Here the ocean moderates the climate, making coastal winters warmer and summers cooler than the interior. The southern interior division, covering the bottom one-third of the state, has the warmest summer weather and the highest numbers of clear days, whereas the northern interior (upper two-thirds of the state) boasts a mixed bag of snowy winters, warm summers, and the state's lowest rainfall.

Potential changes to Maine's climate, and their subsequent impacts on Maine's habitats and wildlife, have been the focus of recent studies by the University of Maine, conservation groups, and state agencies (Whitman et al. 2013, Fernandez et al. 2015). These changes include rising seas, altered natural disturbance processes (e.g., increased fire), changes in hydrology of wetlands and waterways, and transitions in forest composition. Despite uncertainties regarding the magnitude and timing of future changes in Maine's climate, there is a general understanding that high elevation habitats, boreal forests and peatlands, tidal marshes, and cold water fisheries are among Maine's vulnerable habitats (Whitman et al. 2013). Potential climate change impacts on SGCN are discussed in Element 3, and associated conservation actions are addressed in Element 4.

2.2.2 PHYSIOGRAPHY

Maine's western border adjoining New Hampshire and Quebec is characterized by rugged terrain with numerous glacier-scoured peaks, lakes, and valleys. The Appalachian Mountain chain, formed nearly 500 million years ago, extends into Maine from New Hampshire,

terminating at the 5,268-foot Mount Katahdin. South and east of mountain areas lie rolling hills, smaller mountains, and broad river valleys. Maine's coastline consists of long sand beaches interrupted intermittently by rocky promontories in the southwest, and a series of peninsulas, narrow estuaries, bays, and coves north and east of Portland. Tides along Maine's coast are among the highest in the world, running between 12 and 24 feet. More than 4,600 islands dot the coast, some no more than rock ledges; others are vegetated and home to fulltime and seasonal residents.

2.3 HABITAT CLASSIFICATIONS

Fish and Wildlife Agencies in the Northeast have agreed to a regional standard for evaluating habitats within each State (Terwilliger and NEFWDTC 2013). This commitment not only eliminates the >900 classifications used individually by 13 northeastern states in 2005 plans, it aids regional conservation strategies across boundaries. In fact the North Atlantic Landscape Conservation Cooperative (NALCC; Anderson et al. 2015) recently extended this NETHCHS coverage into the Canadian Maritime provinces and southern Quebec. Maine shares a longer border with both New Brunswick and Quebec than it does with the continental U.S. Therefore, many landscape analyses, SGCN assessments, and conservation efforts in Maine benefit from an international perspective with Atlantic Canada.

2.3.1 NORTHEAST TERRESTRIAL HABITAT CLASSIFICATION SYSTEM

The NETHCS, initially developed by NatureServe and TNC, is a hierarchical framework for characterizing ecological systems and mapping habitats in the region (TNC and NatureServe 2011). TNC subsequently refined the classification system with collaboration and funding from the Regional Conservation Needs Grants administered by the Northeast Association of Fish and Wildlife Agencies and U.S. Fish and Wildlife Service (USFWS). NETHCS serves as a standard for assessing habitat distribution and composition across the Northeast. The mapping effort is augmented by profiles of many common habitat systems (Anderson et al. 2013a), extent and condition analyses (Anderson et al. 2013b), and an evaluation of site resiliency (Anderson et al. 2011). Details of the NETHCS methodology are available at a TNC website: https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/habitatmap/Pages/default.aspx.

The specific version of the NETHCS used for Maine's State Wildlife Action Plan (SWAP) includes a number of minor alterations and additions made by the University of Massachusetts (digital 'ESM Plus' layer available from NALCC), with additional minor modifications by the MDMR and MDIFW to reflect Maine's landscape and coastal features. State-based modifications include incorporation of a geographic information system (GIS) layer of impermeable surfaces by MDIFW, and finer-scaled marine classes identified by MDMR that reflect underlying substrate and biotic composition in the intertidal and subtidal areas.

The basic layer within NETHCS is the habitat 'system', which corresponds to the Ecological Systems classification. There are approximately 150 Ecological Systems in Maine, and all have been entered into the SWAP database. These include natural vegetated habitats ('Boreal Laurentian Bog'), freshwater aquatic systems ('Headwaters and Creeks'), marine systems ('Gastropod Reef'), and human-modified habitats ('Powerline Right of Way').

It is important to note that only about 50 of the 150 ecological systems are reflected in the GIS map layer because of scale limitations or difficulty of distinguishing tidal and subtidal habitats.

It should also be noted that although the classification system can accommodate structural modifiers (e.g., early successional forest), the GIS layer upon which our analyses are based does not generally distinguish between successional stages of forest. Therefore, the 'Northern Hardwood and Conifer' macrogroup, for example, includes forest stands of all successional stages. Forest condition and structure (e.g., canopy closure, vertical layering) are important habitat characteristics for many SGCN. However, the NETHCS GIS habitat layer is not an effective source for this spatial information. Other sources of information on forest condition include the U.S. Forest Service's Inventory and Analysis Program and various remote sensing data sources such as the Global Forest Change 2000-2014 project (http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.2.html).

The more general 'Macrogroup' level was used for several of our analyses. There are 42 habitat macrogroups in Maine, though not all of these are mapped (e.g., intertidal mollusc reef). Acreages for terrestrial, wetland, and freshwater macrogroups mapped in Maine are shown in Table 2-1 (shown in descending order of statewide acreage). Spatial mapping of marine habitats is particularly challenging and has not occurred.

Table 2-1. Acreages of habitat macrogroups and proportions conserved in Maine. Sources: NatureServe Ecological Systems GIS map (2012) and Maine Conserved Lands Database (2015). Extent of marine habitat macrogroups cannot be determined.

Habitat Macrogroup	Acres in state	% of State	% Conserved
Northern Hardwood & Conifer	8,787,683	39.87%	17.1%
Boreal Upland Forest	6,560,611	29.77%	26.0%
Open Water	2,206,392	10.01%	1.9%
Northern Swamp	1,435,003	6.51%	18.9%
Agricultural	802,154	3.64%	1.2%
Urban/Suburban Built	765,055	3.47%	4.6%
Emergent Marsh	438,838	1.99%	52.2%
Northern Peatland	362,022	1.64%	27.9%
Wet Meadow / Shrub Marsh	354,013	1.61%	19.4%
Central Oak-Pine	126,500	0.57%	13.3%
Outcrop & Summit Scrub	64,435	0.29%	33.5%
Cliff and Talus	43,774	0.20%	49.4%
Northeastern Floodplain Forest	29,135	0.13%	13.8%
Salt Marsh	26,213	0.12%	30.2%
Ruderal Shrubland & Grassland	22,632	0.10%	7.1%
Alpine	3,624	0.02%	99.1%
Coastal Grassland & Shrubland	4,443	0.02%	11.0%
Central Hardwood Swamp	2,790	0.01%	1.8%
Rocky Coast	3,146	0.01%	18.7%
Coastal Plain Swamp	654	0.00%	18.9%
Glade and Savanna	183	0.00%	16.4%

2.3.2 COASTAL AND MARINE CLASSIFICATION SYSTEM

Since the NETHCS focuses on habitats vegetated with vascular plants, the NETHCS marine and coastal habitat components had poor accuracy and low specificity, especially for intertidal and subtidal habitats. "Rocky coast," "coastal," and "tidal marsh" habitat macrogroups were retained from the NETHCS scheme because they have associated vegetation, but all intertidal and subtidal habitats were reclassified to increase the specificity and accuracy for these ecologically, culturally, and economically important habitats. Staff from MDMR and the Maine Coastal Program (MCP) worked with other SWAP partners to generate a coastal and marine habitat classification scheme for Maine's marine and coastal environment (Table 2-2) that encompasses all areas from the high tide line to the boundary of state waters, which extend three nautical miles offshore.

This habitat scheme was based on several existing classification systems that were either too detailed for our intended purpose or did not encompass the diverse breadth of habitats found in the coastal and marine regions in Maine (Coastal and Marine Ecological Classification Standard 2012; Brown 1993). Although this scheme was adapted to fit the particular needs of the Maine SWAP, it is written in generalized terms, where possible, in order to fit the needs of surrounding New England states. Additionally, it is possible to crosswalk this scheme with the other classification schemes listed above in order to compare existing habitat classification and maps for the limited regions where these data exist. During the development of this habitat scheme, several gaps in knowledge were identified, including the geographic locations and spatial extents of most marine and coastal habitats, the health and resiliency of these habitats, and past and projected ecosystem changes over time. Thus, mapping marine and coastal habitats and monitoring their changes over time have been highlighted as priorities for the conservation of marine SGCN over the next 10 years.

There are five broad coastal and marine habitat *formations* associated with conservation actions (tidal marsh, rocky coast, coastal, intertidal, and subtidal). The tidal marsh formation includes all peat-forming tidal marshes. The rocky coast formation encompasses rocky habitats above the high tide line. The coastal formation encompasses coastal grasslands and shrublands. The intertidal and sub-tidal formations encompass all of the benthic and pelagic (water column) habitats from the littoral zone to the open ocean. These broad habitat groups were subdivided into 15 *macrogroups* based on wave energy and the resulting physical composition of the substrate for benthic habitats (e.g. tidal marsh, mud, sand, rock, etc.); pelagic habitats are classified separately (e.g. water column).

At the more specific habitat *system* level, additional biological and physical drivers that shape the ecosystem were incorporated into the classification scheme (e.g. presence of fauna and flora, relative nutrient concentration, desiccation and temperature stressors, etc.). In Maine, certain kinds of flora and fauna, such as eelgrass, kelp beds, and soft corals, form ecologically important habitats by creating a three-dimensional structure that rises above the substrate and serves as a nursery ground or can be used for protection by fishes and invertebrates. These habitats also tend to be vulnerable to environmental stressors. To highlight the importance and relative vulnerability of these habitats, the classification scheme lists these individually at the habitat system level. The language has been generalized to "submerged aquatic vegetation," "kelp bed," and " erect epifauna" to encompass additional flora and fauna that may exist throughout the northeast region in case other New England states elect to adopt this classification scheme.

Table 2-2. Coastal / marine habitat classification developed for the Maine Wildlife Action Plan.

Formation	Macrogroup	Habitat System
Tidal Marsh	Intertidal Tidal Marsh (peat-forming)	Acadian Coastal Salt Marsh
		Coastal Plain Tidal Marsh
Rocky Coast	Rocky Coast	Acadian-North Atlantic Rocky Coast
		North Atlantic Cobble Shore
Coastal	Coastal Grassland & Shrubland	Northern Atlantic Coastal Plain Dune and Maritime Grassland
		Northern Atlantic Coastal Plain Sandy Beach
Intertidal	Intertidal Mudflat	Non-Vascular Mudflat
		Freshwater Tidal Marsh
		Submerged Aquatic Vegetation
	Intertidal Sandy Shore	Sand Flat
		Submerged Aquatic Vegetation
		Sand Beach
	Intertidal Mollusc Reefs	Oyster Reef
		Gastropod Reef
		Mussel Reef
	Intertidal Bedrock	High Intertidal
		Mid-Intertidal
		Low-Intertidal
	Intertidal Gravel Shore	High Intertidal
		Mid-Intertidal
		Lower Intertidal
	Intertidal Water Column	Confined Channel
		Embayment
		Exposed Shore
Subtidal	Subtidal Mud Bottom	Unvegetated
		Submerged Aquatic Vegetation
	Subtidal Sand Bottom	Unvegetated
		Submerged Aquatic Vegetation
	Subtidal Mollusc Reefs	Oyster Reef
		Gastropod Reef
		Mussel Reef
	Subtidal Bedrock Bottom	Bedrock
		Kelp Bed
		Erect Epifauna
	Subtidal Coarse Gravel Bottom	Coarse Gravel
		Kelp Bed
		Erect Epifauna
	Subtidal Pelagic (Water Column)	Nearshore
		Offshore
		Upwelling Zones
		Confined Channel

2.4 COASTAL AND MARINE ECOSYSTEMS

The Gulf of Maine watershed encompasses 69,115 square miles adjacent to Nova Scotia, New Brunswick, Maine, New Hampshire, Massachusetts, and Quebec. Maine is the only state or provincial jurisdiction located entirely within the watershed. The Gulf of Maine, largely created by glaciers 10,000 to 20,000 years ago, is a semi-enclosed sea bounded to the south and east by Browns Bank and Georges Bank, and includes the Bay of Fundy. Underwater valleys plunge to depths of 1,500 feet.

Tidal Marshes and Estuaries

Gulf of Maine intertidal areas include salt marsh, rocky intertidal, and mudflat. The location and extent of these habitats are influenced by substrate, wave and tidal energy, tidal range, and slope. These habitats support several commercially important species as well as numerous SGCN.

"Tidal marshes are among the most productive ecosystems on earth."

Tidal marshes occur throughout the Gulf of Maine as large estuarine complexes or small fringe marshes. Of more than 5 million acres of wetlands in the state, approximately 157,500 acres are tidal (tidal flats, salt marsh, brackish marsh, aquatic beds, beach bars and reefs), including roughly 22,000 acres of salt marsh (MDEP 1996, MEPC 1998, MNAP 2014). In fact, there are more tidal wetlands in Maine than in any state north of New Jersey (MEPC 1998).

Despite harsh growing conditions and low plant diversity, tidal marshes are among the most productive ecosystems on earth. They provide food, shelter, spawning, and nursery areas for Striped Bass (*Morono saxatilis*), Winter Flounder (*Psudopleuronectes americanus*), and Mummichogs (*Fundulus heteroclitus*). Clams and Ribbed Mussels (*Geukensia granosissima*) inhabit tidal marshes and adjacent tidal flats, and birds rely on the rich food webs of tidal marshes for breeding and during migration.



A tidal marsh estuary in Sagadahoc County, Maine. © Maine Natural Areas Program

Estuaries, places where freshwater rivers meet the ocean, receive high concentrations of nutrients that are exported from watersheds, particularly during late winter and early spring snowmelt. Land-derived nutrients combine with nutrients from tidal marshes, rockweeds, and oceanic sources to stimulate phytoplankton growth throughout the year. Eelgrass and other submerged aquatic vegetation sometimes grow in estuaries and provide a three-dimensional habitat that serve as critically important nurseries for larval and juvenile invertebrates and fish, and feeding and nesting areas for migratory fish and birds. In addition, these areas serve as coastal storm buffers and filter sediments and pollutants before they reach coastal waters. Despite their importance, up to 50% of the region's original estuarine marshes have been lost through various human activities (MEPC 1998), and many eelgrass meadows have receded dramatically over the last few years due to a myriad of known and unknown causes.

Islands, Beaches, and Dunes

Roughly 500 Maine islands support nesting wading birds, seabirds, and Common Eiders. Islands cause upwelling of deep, nutrient-rich water to the sea surface, enriching nearby waters. Currents driven by tidal action swirl around islands and surge through passages, "creating a funnel effect that increases the volume of feed available to filter feeders, as well as those species that prey on the filter feeders" (Conkling 1995).

Nearly all of Maine's larger islands were cleared in the past, primarily for sheep or cattle pasture. Many islands were burned repeatedly to remove trees and increase hay production. Human use of the islands peaked roughly 100 years ago, and since early in this century, gradual abandonment of many islands has resulted in their reforestation. In the last few decades, recreational use and construction of seasonal homes have limited the ecological recovery of some islands.

Beaches, pounded by an average 8,000 waves a day, are high-energy, climatically extreme environments. They vary from long shorelines of fine-grained silt or sand to cobbleshores and boulders. Because of geological differences between western and Downeast Maine, large sand beaches are mostly limited to southern Maine. Sand dunes, often located upslope of sand beaches, are hillocks of wind-blown sand originally brought to the rear of beaches by ocean waves and stabilized by beach grasses. Major dune systems in Maine are located at Scarborough Beach and Popham and Reid State Parks.

2.5 FRESHWATER AQUATIC ECOSYSTEMS

Maine has more than 5,000 rivers and streams, encompassing 31,800 miles of flowing waters that cover nearly half of the watershed for the Gulf of Maine. These waterways and their riparian borders are important for Maine's fisheries and wildlife, and they also serve as an important recreational resource for anglers, canoers, and rafters. More of Maine's rivers and streams are undeveloped and free-flowing than any other state in the northeastern U.S. (Bennett 1988). The state's major rivers include the Penobscot (350 mi), the St. John (211 mi), the Androscoggin (175 mi), the Kennebec (150 mi), the Saco (104 mi), and the St. Croix (75 mi).



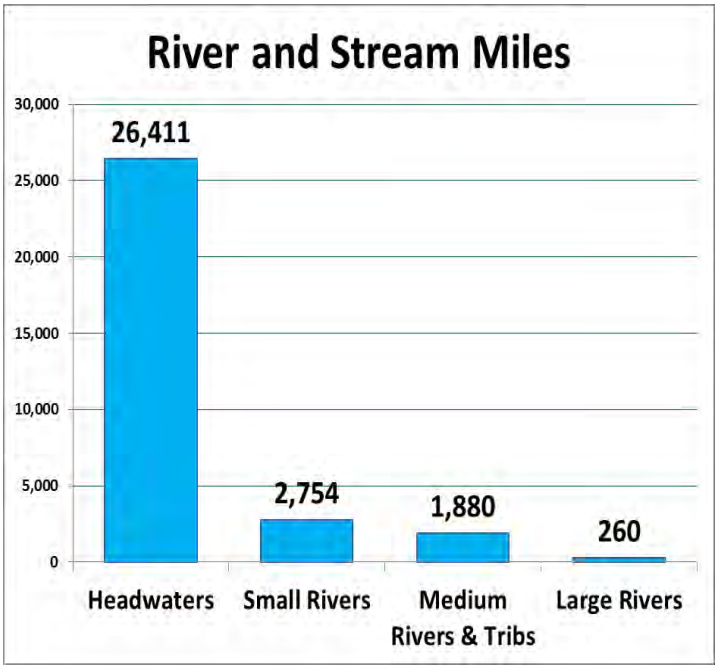
An oligotrophic lake in Somerset County, Maine. © Charlie Todd

However, the overwhelming majority of flowing water mileage in Maine is in headwater streams (Figure 2-2). Cold headwater streams and small rivers are vital habitat for Maine's brook trout, among other species, and Maine has the most extensive distribution and abundance of brook trout (*Salvelinus fontinalis*) throughout their native range in the U.S.

Maine also boasts more than 5,600 lakes and ponds, more than any other state in the Northeast. Moosehead Lake, covering about 117 mi^2, is the state's largest lake, and Sebago Lake is the deepest at 316 ft (40 ft below sea level). The availability of nutrients and oxygen at different lake depths have important implications for fish habitat, and for the purposes of this

Action Plan, Maine's lakes have been classified according to their nutrient and oxygen availability: oligotrophic (low nutrients, high oxygen), mesotrophic (intermediate nutrients and oxygen), eutrophic (nutrient-rich, low oxygen), and dystrophic (low oxygen, acidic/tannic waters). Maine also has a small number of fishless ponds, considered important for a variety of invertebrate and amphibian species.

Figure 2-2. River and stream mileage in Maine.



2.6 TERRESTRIAL AND WETLAND ECOSYSTEMS

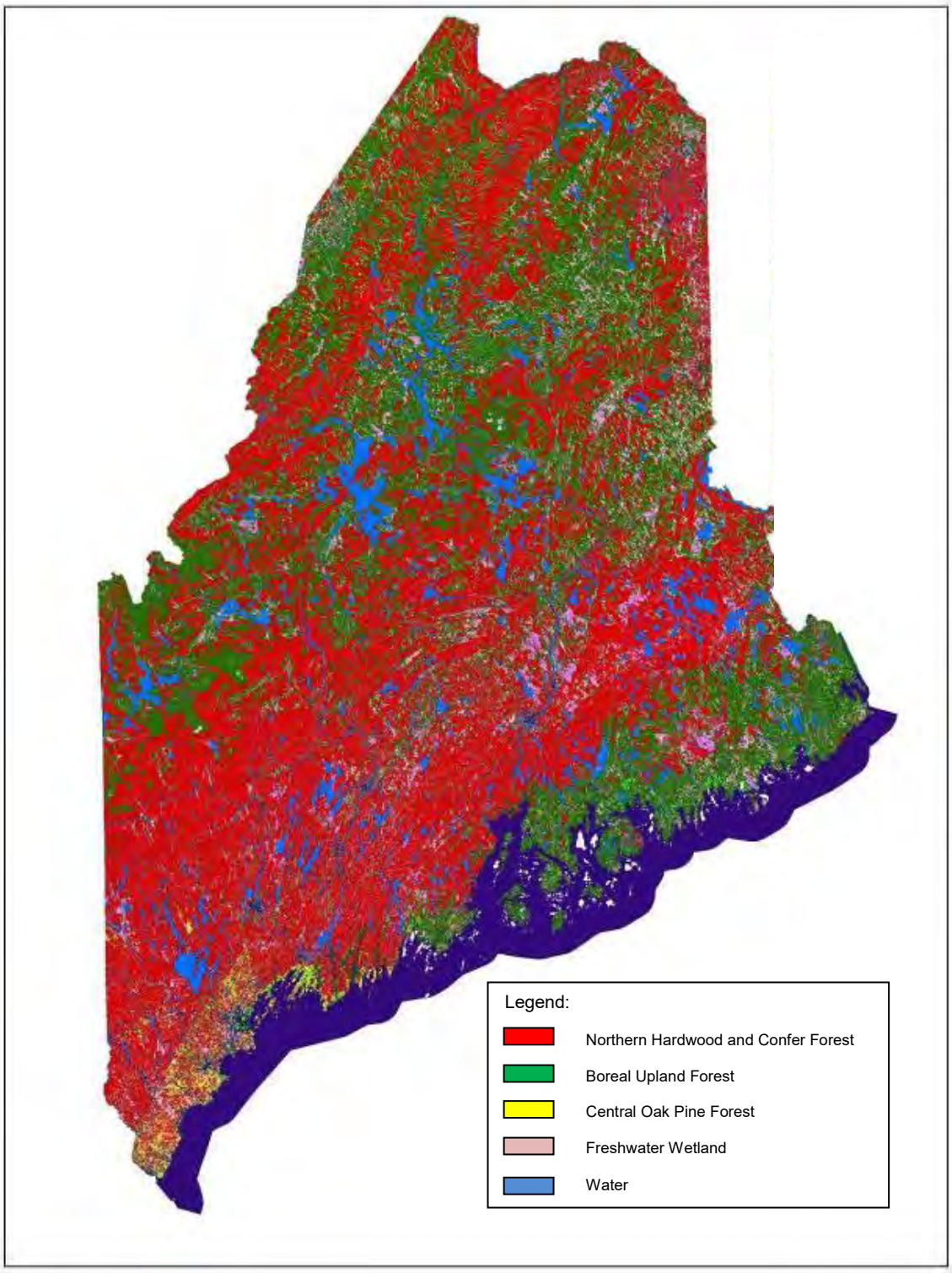
Upland Forests

Maine falls in the transition between the deciduous forest region to the south and the boreal forest region to the north. Maine's forests cover more than 17 million acres, making Maine the most heavily forested state in the nation. Unlike other regions where forest cover has been almost completely lost due to conversion to agriculture or other uses, Maine retains or has regrown much of its forest cover. Sixty-seven woody plant species reach their range limits in south-central Maine, and an additional 44 woody plant species define a coastal-inland transition zone, reaching their western range limits in a southwest-northeast belt bisecting the state (McMahon 1990). *Natural Landscapes of Maine* (Gawler and Cutko, 2010) describes 104 Natural Community types that are linked to the NatureServe's National Vegetation Classification and the Ecological Systems.

"Maine's forests cover more than 17 million acres, making Maine the most heavily forested state in the nation."

At the macrogroup level, Maine's most abundant forest type is Northern Hardwood and Conifer, which accounts for approximately 40% of the state and extends from York to Aroostook County (Figure 2-3). This macrogroup consists of a mosaic of northern hardwood, spruce-fir, and mixed

Figure 2-3. Generalized map of Maine habitat types, from the Northeastern Habitat Classification System.



forest types featuring Sugar Maple, American Beech, Yellow, Red Spruce, Balsam Fir, and Eastern Hemlock. Boreal Forest, which accounts for 30% of the state, is dominated by spruce-fir types and is most common in northern Maine and along the Downeast Coast. The Central Oak Pine macrogroup, characterized by White Pine and Red Oak, occurs in southernmost Maine and accounts for less than 1% of the state.

Forest structure and condition are important attributes for many wildlife species. Both early- (young) and late-successional (old) forests are uncommon in parts of Maine. Statewide, Maine's older forests (stand age of more than 120 years) account for less than 3% of the state (U.S. Forest Service 2014), and true old growth may be as little as 0.1% of the state (Barton et al. 2012). Maine's conserved lands, in particular those classified as Gap 1 and 2, are an important resource for older forest.

Early Successional Habitats

In southern Maine, young forest is also uncommon. In York and Cumberland counties, forest younger than 40 years old accounts for less than 8% of the landscape, compared to more than 28% statewide (U.S. Forest Service 2014). In the Northeast U.S., and especially in Maine, terrestrial openings are most often the result of disturbances, whether by human activity or, historically, by wildfires (Askins et al. 2007). Open habitats increased greatly in the 18th and 19th centuries as settlers converted forests for agriculture (Todd 1940). By 1880, approximately 34% of Maine was cleared for farming (Day 1954), but that pattern reversed dramatically via reforestation during the 1900s (Powell and Dickson 1984). By 1997, only 6% of the state's land area was in agricultural use (National Agricultural Statistics 2009). That proportion has changed little during the past 30 years, but remaining farms are often row-crop agriculture. Pastures decline by 97% in the past 135 years as former pastures have re-grown. Wildfire suppression and reversion of fallow fields to forests have further reduced grasslands and shrublands.

Freshwater Wetland Ecosystems

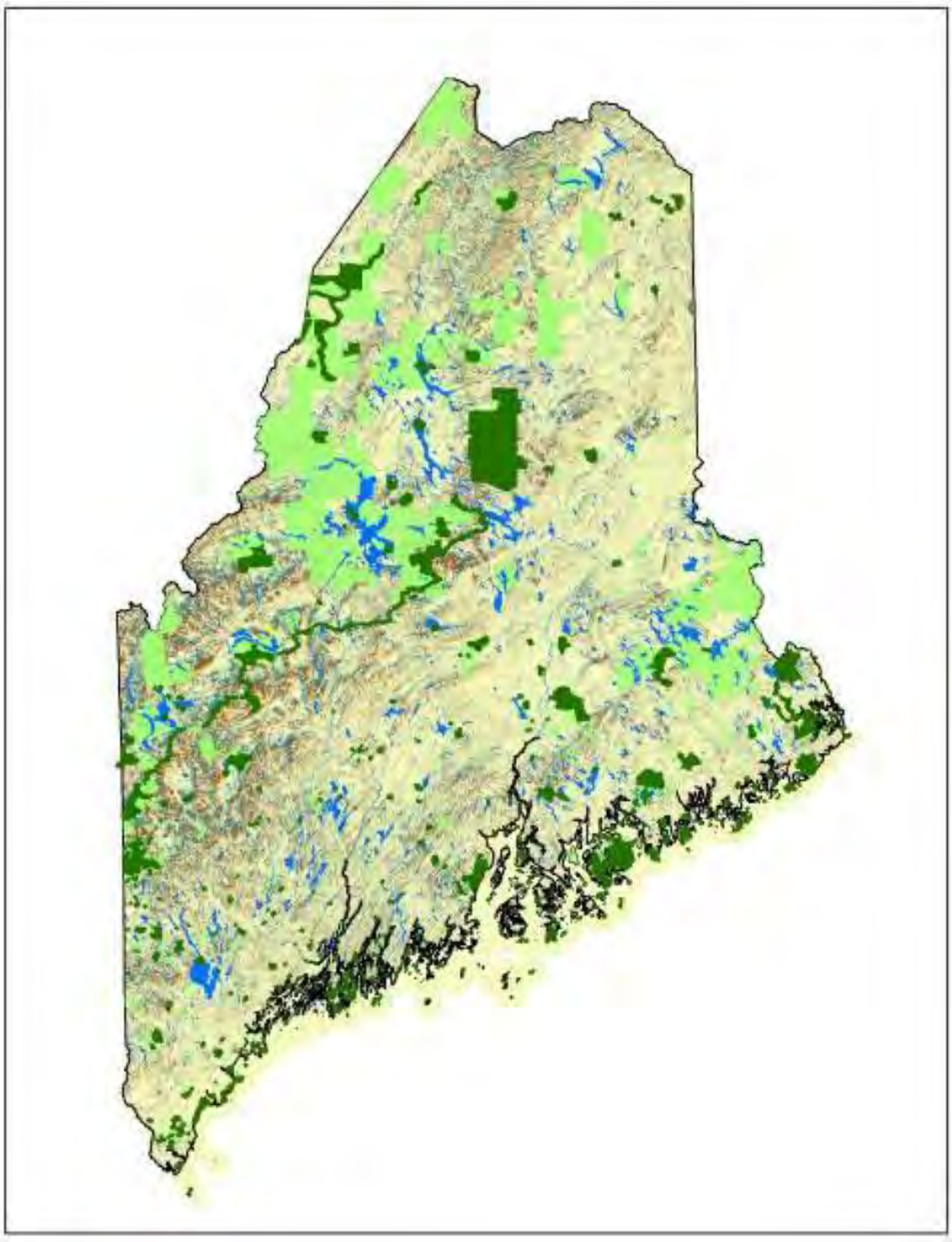
"Freshwater wetlands account for roughly one quarter of the surface of Maine, four times the wetland area of the other New England sates combined."

Freshwater wetlands account for roughly one quarter of the surface area of Maine (Calhoun 2001), four times the wetland area of the other New England States combined. Forested wetlands include red maple swamps, spruce flats, and cedar swamps, while non-forested wetlands range from large peatlands to emergent meadows created by beavers. In particular, Maine's diversity of peatland types is unequaled in the United States (Davis et al. 1983). The state's latitudinal, altitudinal, and coastal-inland gradients are all reflected in the varying peatland morphologies and vegetation composition. Some Maine peatland types are rare in the state (maritime slope bogs, coastal plateau bogs, circumneutral fens, patterned fens, and eccentric bogs), while others are more common (unpatterned fens, level bogs, kettlehole bogs and ponds, and some streamshore ecosystems).

2.7 CONSERVATION LAND IN MAINE

According to the best available data, there are 3,824,842 acres of conservation land statewide, accounting for nearly 20% of Maine (Schlawin and Cutko 2014; Figure 2-4). This conservation land includes parcels with a variety of restrictions, including "working forest" conservation

Figure 2-4. Conserved lands in Maine. Dark green lands are Gap 2 (off limits to extractive uses) and light green lands are considered Gap 3 (fee lands and conservation easements managed for forest products).



easements, public lands managed for multiple uses, private conservation lands, state Ecological Reserves, and others. There are 757,450 acres of land that are considered 'Gap 1 or Gap 2' according to the USFWS classification of conserved lands. These Gap 1 and Gap 2 lands are managed for non-extractive uses (i.e., off limits to timber harvesting, gravel extraction, etc.) and account for just under 4% of Maine's conservation land.

"There are 3,824,842 acres of conservation land in Maine, accounting for nearly 20% of the state."

MDIFW holds title to approximately 106,000 acres on more than 50 Wildlife Management Areas (WMAs). Most of these lands were purchased with federal Pittman-Robertson funds, other federal matching funds, Maine citizen approved bond monies, gifts, Maine State Lottery Outdoor Heritage funds, and North Atlantic Wetland Conservation Act grants. Holdings include forested uplands, grasslands, freshwater and tidal wetlands, and seabird nesting islands. Wetlands account for more than 37% of WMAs, and several wetland types (emergent marsh, northern peatland, northern swamp, wet meadow/shrub marsh) are more than twice as well represented in WMAs than in the landscape as a whole.

For each WMA, MDIFW develops a management plan that describes the natural resources occurring on the property, history of past uses, wildlife management objectives, and future plans for additional acquisitions, habitat maintenance, and development activities. Management plans are updated every five years to reflect new land acquisitions and any changes in management objectives. WMA information and map are available at http://www.maine.gov/ifw/wildlife/land/index.html.

2.8 IMPORTANCE OF HABITATS TO SGCN

Maine identified 378 SGCN in this Plan. MDIFW and MDMR staff, in consultation with species experts and stakeholders, identified the primary and secondary habitats important to the lifecycle of each of Maine's SGCN when known. However, habitat requirements for some SGCN, especially invertebrates, are not well understood; in those cases, staff used professional knowledge to identify habitat. All Priority 1 and Priority 2 SGCN were associated with the finest scale 'habitat systems' in the hierarchical classification. Habitat assignments for Priority 3 SGCN were at the mid-scale 'habitat macrogroup' since many of the fauna in that category are poorly studied and/or handicapped by scant information.

The importance of each habitat type to SGCN varies and is not proportional to their statewide acreage. Figure 2-5 indicates that while the vast majority of the state is forested uplands, those habitats provide habitat to fewer than 35% of the state's SGCN. Conversely, open freshwater wetlands account for only 5% of Maine's area but support more than 21% of the state's SGCN.

Figure 2-5. Proportions of habitat types expressed as percentages of all state habitats and as value to SGCN.

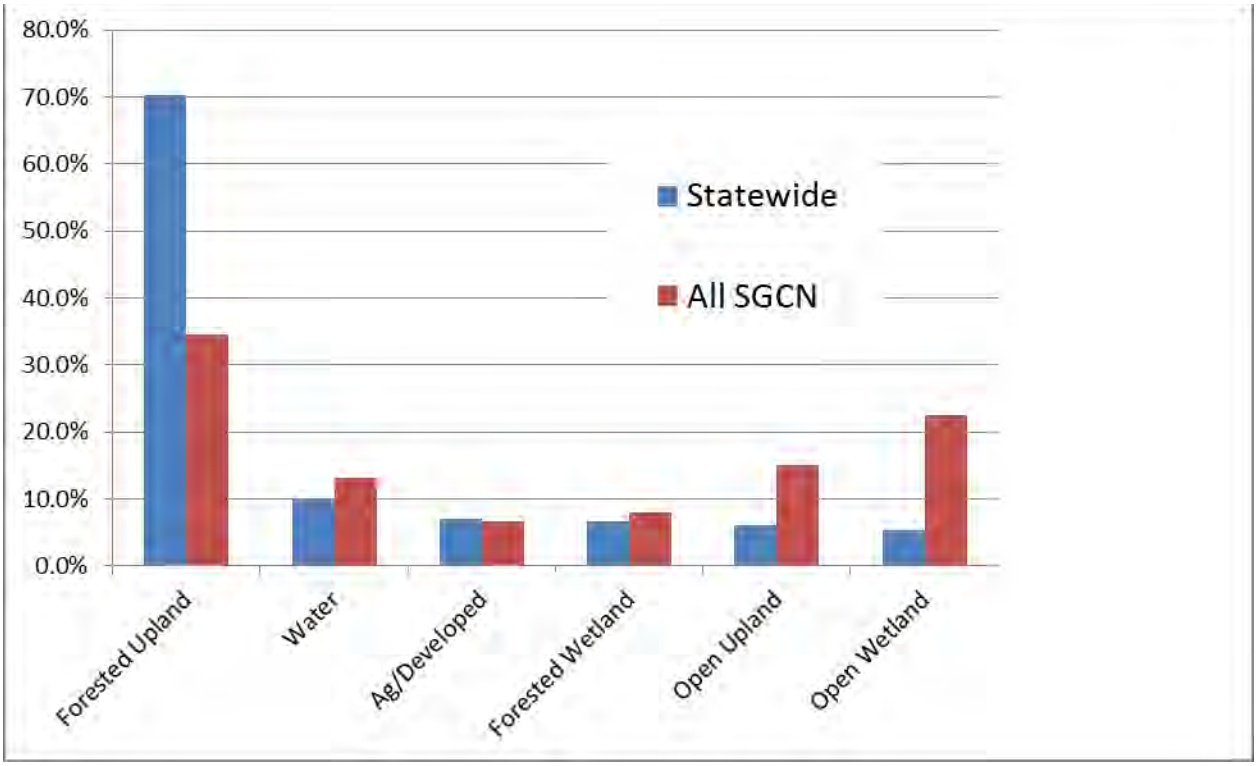


Table 2-3 summarizes the importance of various habitat macrogroups to SGCN. Northern Hardwood and Conifer Forests support 153 SGCN: more than any other type. This is not surprising, given that this habitat types is the most abundant in the state, covering nearly 40% of Maine. However, Central Oak Pine Forests provide habitat for 127 SGCN but covers *less than 1% of the state.* The importance of the Central Oak Pine Type is largely driven by the value of the Northeastern Interior Pine Barrens ecological system, which itself is home to 42 SGCN and covers less than 9,000 acres statewide, only 0.04% of Maine.

"Central Oak-Pine Forest provides habitat for 127 Species of Greatest Conservation Need but covers less than 1% of the state."

All 14 of the Marine and Coastal Macrogroups support multiple SGCN, with the sub-tidal pelagic group is home to the most Priority 1 SGCN as well as total SGCN. Many marine fauna have complex life histories with varying habitat affinities at different stages of development.

Notably, habitats that are moderately to significantly altered by humans provide habitat for numerous SGCN. In particular, agricultural areas support 40 SGCN, and significant numbers of SGCN are also supported by Ruderal Grasslands and Shrublands, Urban/Suburban – Built, and Modified – Managed Marshes. Reforestation of former agricultural lands and the near demise of some types (e.g., old fields and pastures) has become a critical limitation for many SGCN.

Table 2-3. SGCN associations with NETHCS habitat macrogroups. Click on a macrogroup name to launch a full summary report of associated SGCN and for each habitat macrogroup.

Macrogroup Name	Priority 1 SGCN	Priority 2 SGCN	Priority 3 SGCN	Total # SGCN
Coastal/Marine				
Intertidal Bedrock	3	10	6	19
Intertidal Gravel Shore	1	19	15	35
Intertidal Mollusc Reefs	3	1	5	9
Intertidal Mudflat	7	13	16	36
Intertidal Sandy Shore	8	10	9	27
Intertidal Tidal Marsh (peat-forming)	6	14	16	36
Intertidal Water Column	11	5	10	26
Rocky Coast	6	11	13	30
Subtidal Bedrock Bottom	3	13	2	18
Subtidal Coarse Gravel Bottom	7	31	9	47
Subtidal Mollusc Reefs	2	3	3	8
Subtidal Mud Bottom	6	20	9	35
Subtidal Pelagic (Water Column)	22	46	28	96
Subtidal Sand Bottom	9	21	4	34
Freshwater/Aquatic				
Coastal Plain Pond	4	9	9	22
Lake & River Shore	2	3	4	9
Lakes and Ponds	12	24	43	79
Rivers and Streams	25	21	54	100
Terrestrial				
Agricultural	10	16	14	40
Alpine	3	4	13	20
Boreal Upland Forest	11	28	82	121
Central Oak-Pine	9	47	71	127
Cliff and Talus	4	4	2	10
Coastal Grassland & Shrubland	1	7	10	18
Exotic Upland Forest	4	5	3	12
Extractive	7	4	3	14
Glade, Barren and Savanna		7	1	8
Maintained Grasses and Mixed Cover	4	5	10	19
Northern Hardwood & Conifer	12	42	99	153
Outcrop & Summit Scrub	6	6	6	18
Plantation and Ruderal Forest	4	18	12	34
Ruderal Shrubland & Grassland	11	27	34	72
Urban-Suburban Built	3	14	15	32

Table 2-3. *continued: page 2 of 2.* Click on a macrogroup name to launch a full summary report of associated SGCN and for each habitat macrogroup.

Macrogroup Name	Priority 1 SGCN	Priority 2 SGCN	Priority 3 SGCN	Total # SGCN
Wetlands				
Boreal Forested Peatland	1	8	20	29
Central Hardwood Swamp	3	4	1	8
Coastal Plain Peat Swamp	1	2		3
Emergent Marsh	7	18	26	51
Modified-Managed Marsh	6	12	12	30
Northeastern Floodplain Forest	5	8	21	34
Northern Peatland & Fens	7	18	33	58
Northern Swamp	6	22	26	54
Wet Meadow-Shrub Marsh	11	22	27	60

2.9 MAINE FLORA AND EXEMPLARY NATURAL COMMUNITIES

Rare Plant Data

There are approximately 1,443 native and 653 introduced species of vascular plants in Maine (Gawler et al. 1996). The state's vascular plants include species at the northern edge of their range and boreal representatives at their southern limit. The Official List of Endangered and Threatened Plants in Maine is a list of native vascular plant species whose populations within the state are highly vulnerable to loss. Species on the list are typically known from a very small number of sites within the state, and many require unique habitat for survival. Roughly one third are considered vulnerable to climate change. The list is used to assist scientific research, environmental assessment, permit review, land management, and for educational purposes. Nearly one quarter of Maine's native flora (340 species) is considered possibly extirpated, rare, Threatened, or Endangered in the State, and 15 species, or fewer than two percent, of the plants native to Maine are rare throughout their worldwide range (e.g., ranked G1 or G2). The list is managed by the Maine Natural Areas Program (MNAP) and is under the jurisdiction of the Commissioner of the Department of Agriculture, Conservation and Forestry. Section 6 funding under the U.S. Endangered Species Act supports conservation of federally listed plants in Maine.



Small Round-leafed Orchis (*Amerorchis rotundifolia*): an orchid state-listed as a Threatened Species. © Maine Natural Areas Program

No plant species are included as Maine SGCN taxa because SWG funds are restricted to fauna only. There is presently no statutory protection for native plants in Maine, though natural community and landscape level conservation of SGCN and their habitats will provide secondary benefits to many rare and vulnerable plants. Informational summaries of SGCN in habitat macrogroups (Table 2-3) include E/T flora of Maine.

MNAP Rare or Exemplary Natural Communities are two broad classes of natural communities recognized as important for conservation: those that are rare and those that are common but in exemplary condition. A natural community is a system of interacting plants and their common environment, recurring across the landscape, where the effects of human intervention are minimal. There are currently 104 natural communities known in Maine, examples of which include Pitch Pine/Scrub Oak barrens, Atlantic White cedar bog, and *Spartina* tidal marsh. Examples of common community types include oak/pine forest, Red Maple swamp, and cattail marsh. Most upland natural communities have been impacted by land use practices, and it is unusual to find relatively large, undisturbed examples of them. Size, disturbance, and condition are all considered when assessing the quality of common natural communities.



A Pitch Pine/Scrub Oak barrens in York County, Maine. © Maine Natural Areas Program

MNAP Rare Plant Locations designate specific points where populations of Rare, Threatened, and Endangered plants have been documented and, for some species, MNAP has identified habitat for the respective plants. Rare plants have no formal protection in Maine (rare plant legislation is for informational purposes only), thus the habitat in which these plants occur is important for their survival. Rare Plant Locations may occur outside of, or within documented MNAP Rare and Exemplary Natural Communities. Rare plants are often components of documented natural communities and can be conserved in the context of these larger systems. Populations of rare plants outside of documented natural communities will require separate conservation actions.

2.10 FOCUS AREAS OF ECOLOGICAL SIGNIFICANCE

Background

Over the last decade, MDIFW partnered with MNAP, MDMR, USFWS and TNC to identify concentrations of rare species, including many SGCN, and high quality habitats across Maine. Using confirmed survey data, rarity indicators, and landscape condition (size and integrity), this effort resulted in a mapped suite of more than 100 species-at-risk Focus Areas across the state. These areas include assemblages of some of the best examples of rare wildlife and plant populations and high quality natural habitats in Maine. For each species-at-risk Focus Area, there is a basic conservation plan that includes descriptions of significant features, voluntary recommendations for how best to conserve those resources and a map that delimits the area.

Maps and descriptions of Focus Areas that occur in Maine's organized towns are available at http://www.maine.gov/dacf/mnap/focusarea/.

Criteria, Delineation, and Application
Criteria used to delineate Focus Areas include multiple locations of rare plants, animals, and natural communities; locations of the best examples of common natural communities; locations of significant wildlife habitats; and, locations where these features overlapped with larger undeveloped blocks. Focus Area boundaries are based on sub-watersheds and major fragmenting features such as roads. The boundaries are strictly non-regulatory and are neither firm nor always field-delineated; rather, they are meant to indicate the general location of high value areas where voluntary land conservation and outreach measures are likely to have disproportionate benefit to Maine's vulnerable species and habitats.

Focus Areas have become integrated into a number of land conservation programs such as the Maine Natural Resources Conservation Program and the Forest Legacy Program. Focus Areas have been recognized by the land trust community and others as important indictors of ecological significance.

What do Focus Areas Represent?
In 2014, an assessment of Maine's Focus Areas was initiated to determine their effectiveness at conserving the variety of SGCN and habitats across the state, including considerations for a changing climate. While this assessment is ongoing, a few key findings include:

- Nearly all Focus Areas meet multiple criteria; that is, most Focus Areas support a combination of rare species and important wildlife habitats.

- Most habitat macrogroups are well represented in Focus Areas, and several macrogroups (e.g. alpine) are more than four times as abundant in Focus Areas relative to their overall statewide coverage.

- The network of Focus Areas generally indicates a high resilience to climate change, reflecting both high habitat connectivity and representing nearly the full variety of Maine's geophysical settings.

2.11 LITERATURE CITED AND REFERENCES

Anderson, M. G., M. Clark, and A. Olivero Sheldon. 2011. Resilient sites for species conservation in the Northeast and mid-Atlantic region. The Nature Conservancy, Eastern Conservation Science. Boston, MA. 122pp. Available online at *http://static.rcngrants.org/sites/default/files/final_reports/Resilient-Sites-for-Species-Conservation%281%29.pdf*

Anderson, M. G., M. Clark, C. E. Ferree, A. Jospe, A. Olivero Sheldon and K. J. Weaver. 2013a. Northeast habitat guides: a companion to the terrestrial and aquatic habitat maps. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA. 394pp. Available online at http://rcngrants.org/sites/default/files/news_files/Northeast%20Aquatic%20and%20Terrestrial%20Habitat%20Guide.pdf.

Anderson, M. G., M. Clark, C.E. Ferree, A. Jospe, and A. Olivero Sheldon. 2013b. Condition of the Northeast terrestrial and aquatic habitats: a geospatial analysis and tool set. The Nature Conservancy, Eastern Conservation Science. Boston, MA. 171pp. Available online at *http://easterndivision.s3.amazonaws.com/Geospatial/ConditionoftheNortheastTerrestrialandAquaticHabitats.pdf*

Anderson, M. G., C. Ferree, and K. McGargial. 2015. Extending the Northeast terrestrial habitat map to Atlantic Canada. Report to North Atlantic Landscape Conservation Cooperative, Hadley,MA. 23pp. Available online at http://northatlanticlcc.org/projects/habitat-map-to-atlantic-canada/canada-map-final-report/index_html

Askins, R. A., F. Chavez-Ramirez, B. C. Dale, C. A Haas, J. R. Herkert, F. L. Knopf, and P. D. Vickery. 2007. Conservation of grassland birds in North America: understanding ecological processes in different regions. Ornithological Monographs No. 64. 46pp.

Barton, A.M, White, A.S., and C.V Cogobill. 2012. The Changing Nature of the Maine Woods. University of New England Press. 304pp.

Bennett, D. B. 1988. Maine's natural heritage. For the Maine Critical Areas Program, State Planning Office, Augusta, ME. 285pp.

Brandes, K. M. 2001. Moon handbooks: Maine. Avalon Travel Publishing, CA. 651pp.

Brown, B. 1993. A classification system of marine and estuarine habitats in Maine: An ecosystem approach to habitats. Maine Natural Areas Program, Department of Economic and Community Development.

Calhoun, A. 2001. Vernal pool assessment. Maine Department of Inland Fisheries and Wildlife, 284 State Street, State House Station 41, Augusta, Maine, 04333-0041. 70pp.

Coastal and Marine Ecological Classification Standard (CMECS). 2012. Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee.

Conkling, P. W. (ed.). 1995. From Cape Cod to the Bay of Fundy: An environmental atlas of the Gulf of Maine. The MIT Press, Cambridge, MA.

Davis, R. B., G. L. Jacobson, Jr., L. S. Widoff, and A. Zlotsky. 1983. Evaluation of Maine peatlands for their unique and exemplary qualities. Maine Department of Conservation, Augusta, ME.

Day, C. A. 1954. A history of Maine agriculture, 1604-1860. University Press, Orono, ME. 318pp.

Fernandez, I.J., C.V. Schmitt, S.D. Birkel, E. Stancioff, A.J. Pershing, J.T. Kelley, G.L. Jacobson, and P.A. Mayewvski. 2015. Maine's Climate Future: 2015 Update. Orono, ME. University of Maine. 24pp.

Gawler, S. C., J. J. Albright, P. D. Vickery, and F. C. Smith. 1996. Biological diversity in Maine – an assessment of status and trends in the terrestrial and freshwater landscape. Maine Natural Areas Program, Department of Conservation, Augusta, Maine. 80pp plus appendices.

Gawler, S., and A. Cutko. 2010. Natural Landscapes of Maine: A Guide to Natural Communities and Ecosystems. Maine Natural Areas Program, Augusta.

Maine Department of Environmental Protection (MDEP). 1996. Issue profile Maine's wetlands: their functions and values. DEP, Augusta, ME.

Maine Environmental Priorities Council (MEPC). 1998. An assessment of the quality of Maine's environment 1998. Augusta, ME. 28pp.

Maine Natural Areas Program (MNAP). 2014. Analysis of tidal marsh acreage in Maine, based on digitized air imagery and National Wetlands Inventory maps. Unpublished data from Don Cameron.

McMahon, J. S. 1990. The biophysical regions of Maine: patterns in the landscape and vegetation. M.S. Thesis, Univ. of Maine, Orono. 120pp.

National Agricultural Statistics Service. 2009. The 2007 census of agriculture: table of 2007 statistics and earlier census years. Volume I, Chapter 1: Maine state level data. Available online at http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/Maine/st23_1_001_001.pdf

Powell, D. S. and D. R. Dickson. 1984. Forest statistics for Maine, 1971 and 1982. U. S. Department of Agriculture, Forest Service Bulletin. NE-81, Broomall, PA. 194pp.

Schlawin, J., and A. Cutko. 2014. A Conservation Vision for Maine Using Ecological Systems. Maine Natural Areas Program, Augusta ME.

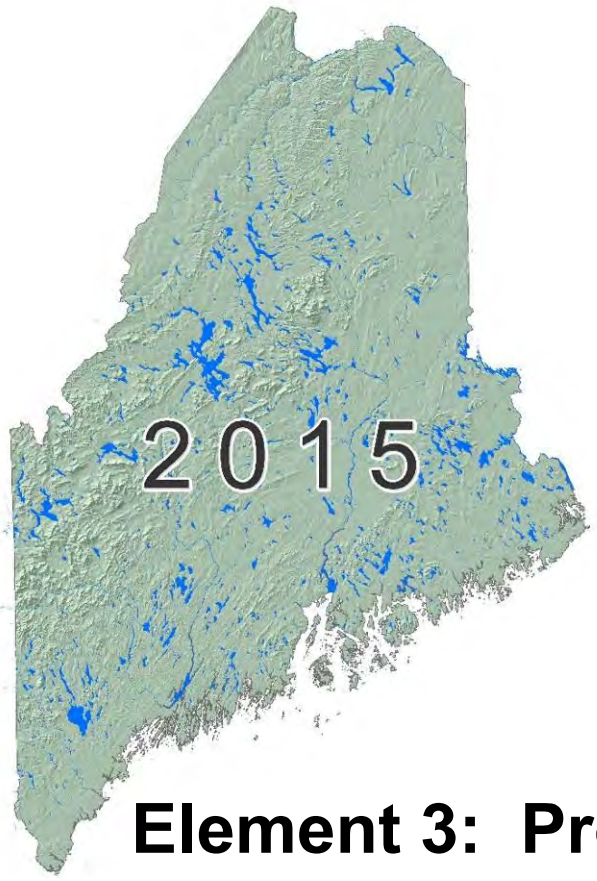
Terwilliger Consulting, Inc. and the Northeast Fish and Wildlife Diversity Technical Committee (NEFWDTC). 2013. Taking action together: Northeast regional synthesis for state wildlife action plans. A report submitted to the Northeast Association of Fish and Wildlife Agencies. Locustville, VA. 291pp.

The Nature Conservancy and NatureServe. 2011. Northeast Terrestrial Habitat Classification System. Available online at https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/habitatmap.

Todd, W. E. C. 1940. Birds of western Pennsylvania. University of Pittsburgh Press, Pittsburgh, PA. 710pp.

U.S. Forest Service (2014). Inventory and Analysis Project, e-validator on-line data tool. Available online at http://apps.fs.fed.us/Evalidator/evalidator.jsp. Last accessed - November 5, 2014.

Whitman, A., A. Cutko, P. deMaynadier, S. Walker, B. Vickery, S. Stockwell, and R. Houston. 2013. Climate change and biodiversity in Maine: vulnerability of habitats and priority species. Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Working Group) Report NCI-2013-03. Brunswick, ME. 105pp. Available online at https://www.manomet.org/sites/default/files/publications_and_tools/BwHSummary_021914.pdf



MAINE'S WILDLIFE ACTION PLAN

Element 3: Problems Affecting SGCN and Their Habitats

Prepared by

Maine Department of Inland Fisheries and Wildlife

In collaboration with

Maine's Conservation Partners

September 2015

TABLE OF CONTENTS

Element 3 – Problems Affecting SGCN and Their Habitats

3.0 Abstract 1

3.1 Introduction 2
3.1.1 Significant Differences from Maine's 2005 Plan 2
3.1.2 Assigning Stressors – General Considerations 3
3.1.3 Stressor Classification and Characteristics 3
3.1.4 Assigning and Prioritizing Stressors for SGCN 10
3.1.5 Assigning Stressors for Habitats 10

3.2 Stressors to SGCN 11

3.3 Stressorts to Habitats 17

3.4 Literature Cited and References 19

LIST OF TABLES

Table 3-1. Nomenclature, Descriptions, and Examples of Positive Impacts on Wildlife for IUCN Threat Categories assigned to SGCN and Habitats in Maine. 5

Table 3-2. Characteristics and rankings used to summarize stressors assigned to SGCN and Habitats. Adapted from Crisfield et al. 2013. 9

Table 3-3. IUCN Threat Category and the Number of Priority 1 SGCN, Priority 1 SGCN, and Habitat Macrogroups associated with each category. Complete stressor reports can be downloaded by clicking on the hyperlinks within the table. 12

Table 3-4. Secondary IUCN Threat Categories and the number of Priority 1 and Priority 2 SGCN assigned to each category where the stressor was ranked as either high or medium-high priority for action. Complete stressor reports can be downloaded by clicking on the hyperlinks within the table. 15

LIST OF FIGURES

Figure 3-1. SGCN Stressor Priority Level based on Severity and Reversibility. 10

Figure 3-2. Number of SGCN stressor assignments categorized as low, medium, medium-high, and high priority. 14

KEY TO ACRONYMS

IUCN	International Union for the Conservation of Nature
MDIFW	Maine Department of Inland Fisheries and Wildlife
SGCN	Species of Greatest Conservation Need

3.0 ABSTRACT

Maine's State Wildlife Action Plan (SWAP) focuses much attention on the habitats used by Species of Greatest Conservation Need (SGCN). The Plan uses a coarse filter – fine filter approach to conservation to ensure that, where possible, individual conservation initiatives benefit multiple species, while also acknowledging that some species require individualized attention. We assigned stressors to both habitats and to SGCN, in order to clearly identify the issues that should be addressed at each level in the conservation hierarchy. As with most other states in the Northeast, we identified stressors using the International Union for the Conservation of Nature (IUCN) Threat Classification Scheme. While the IUCN system is useful for categorizing stressors to SGCN and their habitats, we found that the system lacks the resolution to clearly identify the specific issues that should be considered for conservation attention. Therefore, when assigning stressors we chose to adopt the primary and secondary IUCN categories, but replaced the tertiary category with a detailed narrative that fully describes the issue and its impact on the species or habitat being considered. In addition, we adapted Table 7 (*Threat characteristics and categorical ratings)* from The Northeast Lexicon to identify characteristics for each stressor assignment.

We assigned stressors to Priority 1 and 2 SGCN, and assigned 'Severity' and 'Actionabilty' characteristics for each Stressor – SGCN interaction. We implicitly considered the concepts of 'Likelihood', 'Certainty' and 'Spatial Extent', and assigned only those stressors that were determined to have a moderate or high Impact for each of these characteristics. In addition, only those stressors with moderate or high Severity were assigned to SGCN. We developed a simple matrix to prioritize SGCN stressors, using the combination of the Impact scores for 'Severity' and 'Actionability.' We identified stressors for terrestrial and freshwater aquatic habitats using Anderson et al. (2013) as our primary reference. Because no single comprehensive source is available that describes that state of marine habitats along Maine's coast, we used a wide variety of scientific publications, as well as expert opinion of agency staff and partners, to compile information on stressors. We assumed that the habitat systems within each terrestrial and marine macrogroup all faced similar conservation problems; therefore we assigned stressors to each macrogroup, but did not identify stressors separately for each habitat system, with the exception of freshwater aquatic habitats (River and Streams, and Lakes and Ponds) were we identified stressors separately for each of systems Unlike our approach for SGCN, we assigned all seven stressor characteristics for each habitat – stressor combination.

We assigned 38 unique stressors to 190 Priority 1 and 2 SGCN species, for a total of 1,099 SGCN – stressor combinations, and 31 unique stressors to 34 habitats macrogroups, for a total of 326 habitat – stressor combinations. Development, including existing and new Roads and Railroads and Housing and Urban Areas, and Invasive Non-native/Alien Species/Diseases, impacted largest number of habitats.

3.1 INTRODUCTION

In previous elements, we summarized what we know about the abundance and distribution of Maine's fauna, described how we selected SGCN, and described how we identified and characterized Maine's key habitats. In this element, we outline how we integrated this information with information on problems facing SGCN and their habitats.

The problems that impact SGCN are often multi-faceted, with a variety of ultimate and proximate causes that lead to negative impacts on a species' habitat, behavior, or health. In some cases, issues that have negative impacts for some species, such as a particular type of agriculture, may be highly beneficial to other species. Therefore, the factors that impact SGCN must be considered thoughtfully, with recognition that measures designed to resolve problems faced by one species may have negative implications for others. This is especially important in Maine, where much of the state is privately owned and managed for the production of forestry or agricultural products; invariably these activities are less impactful on SGCN than alternate land uses, such as commercial development. Nonetheless, identifying problems for SGCN and their habitats is a fundamental step towards developing meaningful Conservation Actions that will have the greatest benefit for the full suite of SGCN that are present in Maine.

> *"The factors that impact SGCN must be considered with the understanding that measures designed to resolve problems faced by one species may have negative implications for others"*

3.1.1 SIGNIFICANT DIFFERENCES FROM MAINE'S 2005 PLAN

In 2005, the Maine Department of Inland Fisheries and Wildlife used a variety of international, national, regional, and state plans and initiatives to compile information on the problems impacting SGCN and their habitats. Efforts focused on Priority 1 and Priority 2 species, with some attention given to Priority 3 species in certain taxonomic groups. The plan identified the major known stressors to each SGCN, with recognition that additional stressors existed that were poorly understood or were of relatively low priority. The information was descriptive, and did not follow a standardized approach for stressor categorization or nomenclature.

In this plan, we made several revisions to our approach for identifying problems for SGCN and their habitats, including:

- Replaced the term 'threat' with 'stressor' to acknowledge that factors that are a problem for some SGCN may be beneficial for others. We continue to use the term 'threat' only when referring to the IUCN classification scheme (see below).
- In addition to identifying stressors for habitats, we identified stressors for Priority 1 and Priority 2 SGCN, but not Priority 3 species.
- Utilized the IUCN Threat Classification Scheme to categorize stressors.
- Used an adapted version of Table 7 (*Threat characteristics and categorical ratings)* from The Northeast Lexicon to identify characteristics for each stressor assignment.
- Categorized SGCN stressors as either Low, Medium, Medium-High, or High priority for Action.

3.1.2 ASSIGNING STRESSORS – GENERAL CONSIDERATIONS

Although Maine's Wildlife Action Plan is ultimately intended to benefit SGCN, our plan focuses much attention on the habitats used by these species. This coarse filter – fine filter approach to conservation ensures that, where possible, individual conservation initiatives benefit multiple species, while also acknowledging that some species require individualized attention. In keeping with this approach, we assigned stressors to both habitats and to SGCN, in order to clearly identify the issues that should be addressed at each level in the conservation hierarchy. We assumed that the stressors identified for habitats would apply to the SGCN that used those habitats, reducing or eliminating the need to assign these same stressors to individual SGCN. To advance our goal of developing a highly prioritized, streamlined Action Plan, we used a strategic approach to identify stressors to SGCN that included assignment of only those stressors that are currently having, or in the near future are likely to have, a significant impact on high priority SGCN (see section 3.1.4 for further detail).

"A coarse filter – fine filter approach to conservation ensures that where possible, individual conservation initiatives benefit multiple species, while also acknowledging that some species require individualized attention"

To identify stressors specific to SGCN and their habitats, we consulted international, national, regional, and state plans and initiatives, including Maine's 2005 Comprehensive Wildlife Conservation Strategy (MDIFW 2005). We also consulted recent scientific literature and state surveys, particularly for marine species, which were not fully included in Maine's 2005 Plan. Our knowledge base of stressors was also supplemented from our comprehensive species planning process (Chapters 6, 7, MDIFW 2005). As part of the planning process, we developed species assessments for individual species or groups of species, which required the author (species expert) to identify known stressors to the species and their habitats. Other species experts reviewed these assessments and provided additional input, and following this review, a public working group further identified threats to the species and its habitats as they developed species management goals and objectives. We also relied on species experts within MDIFW and the Maine Dept. of Marine Resources, who through years of experience and accumulated knowledge have become very familiar with the stressors facing the species with which they work. Finally, we provided Conservation Partners the opportunity to critique these tables and provide further input. For more detailed information on sources we consulted, please refer to the *Literature Cited and References* section of this document.

Although we sought to identify the major, known stressors to each SGCN and habitat, we know that there may be stressors that we did not list. Also, our knowledge of some species is very limited, and consequently we may not clearly understand the stressors they face.

3.1.3 STRESSOR CLASSIFICATION AND CHARACTERISTICS

As did most other states in the Northeast, we identified stressors using the IUCN Threat Classification Scheme (http://www.iucnredlist.org/technical-documents/classification-schemes/threats-classification-scheme). The IUCN developed this classification scheme to provide conservationists with a universal menu of terminology to describe the "proximate human

activities or processes that have impacted, are impacting, or may impact the status of the taxon being assessed" (IUCN 2015). The IUCN classification scheme is hierarchical, and includes 11 primary (Level 1) threat categories, 44 secondary (Level 2) categories, and 76 tertiary (Level 3) categories. The categories are customizable, and may be expanded at each level in the hierarchy if necessary to adequately describe the impact being assessed. Although some categories are not applicable to Maine (e.g. earthquakes, volcanoes), our assessment of the IUCN hierarchy determined that the classification system included most factors that negatively impact SGCN in our state. Most stressors are recognized as having potentially negative and positive impacts on different wildlife species. Table 3-1 contains a list of the IUCN Level 2 threat categories that were determined to negatively impact SGCN and their habitats in Maine, a brief description of those stressors, and where applicable, examples of positive impacts that the stressor may have for other wildlife.



Improperly installed culverts can impede movement and restrict habitat connectivity for many aquatic ecosystems. In this case, a fish ladder may allow some species to traverse the barrier. © Department of Marine Resources

While the IUCN system is useful for categorizing stressors to SGCN and their habitats, and will ultimately allow multi-state summaries of these factors across the Northeast region, we found that the system lacks the resolution to clearly identify the specific issues that should be considered for conservation attention. Therefore, when assigning stressors we chose to adopt the primary and secondary IUCN categories (e.g. the first and second levels of the hierarchy), but replaced the tertiary category with a detailed narrative that describes the issue and its impact on the species or habitat being considered. This approach provided more detailed information on the stressor than the IUCN system allows, which we ultimately found important when considering whether stressors should be addressed with conservation actions. In addition, it should be noted that for some stressor categories, particularly those associated with natural resource use (such as aquaculture, wood harvesting, and fishing), it is not the presence of the activity itself that necessarily causes stress, but rather the way in which it is practiced. Although we use the standard IUCN terminology to describe these stressors, the narrative for each SGCN or habitat stressor contains more detail on the actual practice being considered.



Roads can fragment habitat and contribute to mortality for many turtles and other SGCN. © Department of Inland Fisheries and Wildlife

In addition to identifying stressors using a modified version of the IUCN system, we adapted Table 7 (*Threat characteristics and categorical ratings)* from The Northeast Lexicon to identify characteristics for each stressor assignment (Crisfield et al. 2013). This table presents six Threat Characteristics that biologists used to describe the specific nature of a particular stressor: 'Severity', 'Reversibility', 'Immediacy', 'Spatial Extent', 'Certainty', and 'Likelihood'. Each characteristic can be identified as having a low, moderate, or high level of impact (Table 3-2).

Table 3-1. Nomenclature, Descriptions, and Examples of Positive Impacts on Wildlife for IUCN Threat Categories assigned to SGCN and Habitats in Maine.

IUCN Threat Category	Description	Example of Positive Impact on Wildlife
Residential and Commercial Development		
Housing and Urban Areas	Human cities, towns, and settlements including non-housing development typically integrated with housing	Some species are adept at utilizing human-food sources and habitats provided in residential areas
Commercial and Industrial Areas	Factories and other commercial centers	Large commercial buildings may provide nesting habitat for some species (e.g. Peregrine Falcons)
Tourism and Recreational Areas	Tourism and recreation sites with a substantial footprint	These areas often enhance the public's perceptions of wildlife and the outdoors, which is important to building support for conservation
Agriculture and Aquaculture		
Annual and Perennial Non-timber crops	Crops planted for food, fodder, fiber, fuel, or other uses	Provides forage for a wide variety of wildlife species
Livestock Farming and Ranching	Domestic terrestrial animals raised in one location on farmed or non-local resources (farming); also domestic or semi-domesticated animals allowed to roam in the wild and supported by natural habitats (ranching)	Maintains grassland habitat required by many wildlife species
Marine and Freshwater Aquaculture	Aquatic animals raised in one location on farmed or non-local resources; also hatchery fish allowed to roam in the wild	Reduces reliance on wild-caught fish for human consumption
Energy Production and Mining		
Oil and Gas Drilling	Exploring for, developing, and producing petroleum and other liquid hydrocarbons	
Mining and Quarrying	Exploring for, developing, and producing minerals and rocks	
Renewable Energy	Exploring, developing, and producing renewable energy	Reduces reliance on non-renewable energy sources
Transportation and Service Corridors		
Roads and Railroads	Surface transport on roadways and dedicated tracks	

Table 3-1. *continued: page 2 of 4.*

IUCN Threat Category	Description	Example of Positive Impact on Wildlife
Transportation and Service Corridors - *continued*		
Utility and Service Lines	Transport of energy & resources	Provides early successional habitat important for some wildlife (e.g. New England Cottontail)
Shipping Lanes	Transport on and in freshwater and ocean waterways	
Biological Resource Use		
Hunting and Collecting Terrestrial Animals	Killing or trapping terrestrial wild animals or animal products for commercial, recreation, subsistence, research or cultural purposes, or for control/persecution reasons; includes accidental mortality/bycatch	Important wildlife management tool to help prevent overabundant wildlife populations
Gathering Terrestrial Plants	Harvesting plants, fungi, and other non-timber/non-animal products for commercial, recreation, subsistence, research or cultural purposes, or for control reasons	Can increase society's connection with wildlife, often leading to increased support for conservation
Logging and Wood Harvesting	Harvesting trees and other woody vegetation for timber, fiber, or fuel	Provides wildlife habitat for many species by altering forest structure and composition
Fishing and Harvesting of Aquatic Resources	Harvesting aquatic wild animals or plants for commercial, recreation, subsistence, research, or cultural purposes, or for control/persecution reasons; includes accidental mortality/bycatch	Can increase society's connection with wildlife, often leading to increased support for conservation
Human Intrusions and Disturbance		
Recreational Activities	People spending time in nature or traveling in vehicles outside of established transport corridors, usually for recreational reasons	Improves society's connection with wildlife, often leading to increased support for conservation
War, Civil Unrest and Military Exercises	Actions by formal or paramilitary forces without a permanent footprint	
Work and Other Activities	People spending time in or traveling in natural environments for reasons other than recreation or military activities	

Table 3-1. *continued: page 3 of4.*

IUCN Threat Category	Description	Example of Positive Impact on Wildlife
Natural Systems Modifications		
Fire and Fire Suppression	Suppression or increase in fire frequency and/or intensity outside of its natural range of variation	Fire (both natural and prescribed) can enhance some wildlife habitats and is required for regeneration in some forest types
Dams and Water Management/Use	Changing water flow patterns from their natural range of variation either deliberately or as a result of other activities	Can be used to enhance habitat for fish and wildlife species (e.g. waterfowl) and to provide a renewable energy source.
Other Ecosystem Modifications	Other actions that convert or degrade habitat in service of "managing" natural systems to improve human welfare	
Invasive and Other Problematic Species, Genes and Diseases		
Invasive Non-native/Alien Species/Diseases	Harmful plants, animals, pathogens and other microbes not originally found within the ecosystem(s) in question and directly or indirectly introduced and spread into it by human activities	
Problematic Native Species/Diseases	Harmful plants, animals, or pathogens and other microbes that are originally found within the ecosystem(s) in question, but have become "out-of-balance" or "released" directly or indirectly due to human activities	
Problematic Species/Diseases of Unknown Origin	Harmful plants, animals, or pathogens and other microbes of unknown origin.	
Viral/Prion-induced Diseases	Viruses are small infectious agents that replicate only inside the living cells of an organism. Prions are infectious agents composed of protein in a misfolded form.	
Pollution		
Domestic and Urban Waste Water	Water-borne sewage and non-point runoff from housing and urban areas that include nutrients, toxic chemicals and/or sediments	

Table 3-1. *continued: page 4 of 4.*

IUCN Threat Category	Description	Example of Positive Impact on Wildlife
Pollution - *continued*		
Industrial and Military Effluents	Water-borne pollutants from industrial and military sources including mining, energy production, and other resource extraction industries that include nutrients, toxic chemicals and/or sediments	
Agricultural and Forestry Effluents	Water-borne pollutants from agricultural, silivicultural, and aquaculture systems that include nutrients, toxic chemicals and/or sediments including the effects of these pollutants on the site where they are applied	
Garbage and Solid Waste	Rubbish and other solid materials including those that entangle wildlife	
Air-Bourne Pollutants	Atmospheric pollutants from point and nonpoint sources	
Excess Energy	Inputs of heat, sound, or light that disturb wildlife or ecosystems	
Climate Change and Severe Weather		
Habitat Shifting or Alteration	Major changes in habitat composition and location	Changing habitat composition will benefit species that utilize the new habitat type
Droughts	Periods in which rainfall falls below the normal range of variation	
Temperature Extremes	Periods in which temperatures exceed or go below the normal range of variation	
Storms and Flooding	Extreme precipitation and/or wind events	Wind events can result in the creation of early successional habitats, benefiting some wildlife species

Table 3-2. Characteristics and rankings used to summarize stressors assigned to SGCN and Habitats. Adapted from Crisfield et al. 2013.

Stressor Characteristic	Low Impact	Moderate Impact	High Impact
Severity	**Slight Severity**: Degree of ecological change is minor	**Moderate Severity:** Degree of ecological change is substantial	**Severe:** Degree of ecological change is major
Actionability (Consider the likelihood of implementing conservation actions to begin reducing the impact of the Stressor within the next 10 years)	**Actionable with Difficulty:** Impacts of a Stressor can only be minimally reversed, prevented, or mitigated, and cost or logistics make solutions difficult to implement	**Moderately Actionable:** Impacts of a Stressor can be reversed, prevented, or mitigated, however solutions are only partially effective or may be difficult to implement	**Highly Actionable:** Impacts of the Stressor can be reversed, prevented, or mitigated with proven strategies, at relatively low costs and with few logistical difficulties
Reversibility (Consider the likelihood of reversing the impacts within 10 years)	**Reversible:** Effects of the threat can be reversed by proven actions	**Reversible with difficulty:** effects of the threat may be reversed but costs or logistics make action impractical	**Irreversible:** Effects of the threat are irreversible
Immediacy (This characteristic assesses the time scale over which impacts of the threat will be observable)	**Long-term:** Effects of the threat are expected in 10-100 years given known ecosystem interactions or compounding threats	**Near-term:** Effects of the threat are expected within the next 1-10 years	**Immediate:** Effects of the threat are immediately observable (current or existing)
Spatial Extent (Consider the impact of threat within 10 years)	**Localized:** (<10%) A small portion of the habitat or population is negatively impacted by the threat.	**Dispersed or Patchy:** (10-50%)	**Pervasive:** (>50%) A large portion of the habitat or population is negatively impacted by the threat.
Certainty (This characteristic is used to assess the certainty surrounding the threat and its impacts)	**Low Certainty:** threat is poorly understood, data are insufficient, or the response to threat is poorly understood	**Moderate Certainty:** some information describing the threat and ecological responses to it is available, but many questions remain	**High Certainty:** Sufficient information about the threat and ecological responses to it is available
Likelihood (Consider impact of the threat within 10 years.)	**Unlikely:** Effects of the threat are unlikely to occur (less than 30% chance)	**Likely:** effects of threat are likely to occur (30-99% chance)	**Occurring:** effects of the threat are already observable (100% chance)

We added an additional characteristic – 'Actionability' – in order to more explicitly indicate the relative ease with which the impact of the stressor could be addressed through prevention, restoration, or mitigation. We determined that a stressor is 'Actionable' if either the stressor itself, or the impact of the stressor, can be reversed, prevented, or mitigated in some way. Conceptually, 'Actionability' is similar to, but distinct from the concept of 'Reversibility'. While 'Reversibility' considers only whether the impact of the stressor can be reversed once it occurs, 'Actionability' incorporates the idea that preventing or mitigating the impact of a stressor can be just as effective, and in some cases more desirable, than reversing the impact once it has

already occurred. For example, expected shifts or changes in habitats due to sea level rise may not be reversible, but the impacts of seas level rise on a salt marsh may be partially mitigated if space for the marsh to migrate inland is available. Similarly, the loss of habitat from existing housing and urban development is not reversible, but some impacts of development, such as run-off, may be actionable.

3.1.4 ASSIGNING AND PRIORITIZING STRESSORS FOR SGCN

We assigned stressors to Priority 1 and Priority 2 SGCN and assigned 'Severity' and 'Actionabilty' characteristics for each stressor – SGCN interaction (Table 3-2). We considered the concepts of 'Likelihood', 'Certainty' and 'Spatial Extent' implicitly, and only assigned those Stressors that we believed had a moderate or high impact for each of these characteristics. In addition, we only assigned those stressors with moderate or high severity to SGCN. Using this approach, we excluded those stressors with low importance for a particular species from further consideration, in recognition that these low-priority issues were not likely to be considered for conservation action if they only impacted a single SGCN or were not impacting a habitat.

In addition, we developed a simple matrix to prioritize SGCN stressors, using the combination of the Impact scores for 'Severity' and 'Actionability' (Figure 3-1). We considered these priority levels during the assignment of Conservation Actions (see Element 4).

Figure 3-1. SGCN Stressor Priority Level based on Severity and Reversibility.

		Severity	
		Moderate	**Severe**
Actionability	**Highly Actionable**	Medium - High	High
	Moderately Actionable	Medium	Medium - High
	Actionable with Difficulty	Low	Low

3.1.5 ASSIGNING STRESSORS FOR HABITATS

We identified stressors for terrestrial and freshwater aquatic habitats using Anderson et al. (2013) as our primary of reference. Because no single comprehensive source is available that describes the state of marine habitats along Maine's coast, we used a wide variety of scientific publications, which are listed in the Literature Cited, to compile information on stressors. We assumed that the habitat systems within each terrestrial and marine macrogroup all faced similar conservation problems; therefore we assigned stressors to each macrogroup, but did not identify stressors separately for each habitat system. However, because we determined that the macrogroups for freshwater aquatic habitats (River and Streams, and Lakes and Ponds) were too coarse for assigning stressors in a meaningful way, we identified stressors separately for each of these systems. Unlike our approach for SGCN, we assigned all 7 stressor characteristics (Table 3-2) for each habitat – stressor combination.

Although we acknowledge that there may be stressors that we did not list, we attempted to assign all known stressors for each habitat, regardless of severity or impact level for other characteristics. Our stressor assignments for habitats were intended to be comprehensive, in recognition that over the long term, relatively minor problems within a habitat could have important implications for large numbers of SGCN. In addition, this approach increased the likelihood that a problem would be identified for potential conservation attention if it impacted a species' habitat, even if it was not assigned for an SGCN because it was of slight severity.



Utility and service corridors, such as this powerline, may have positive benefits for SGCN by providing a source of early successional habitat that is lacking in much of southern Maine. © Department Inland Fisheries and Wildlife

In contrast to our approach for SGCN, we did not use a formal ranking system to prioritize stressors to habitats. Instead, we convened a group of experts to review the stressor information for each habitat and determine which stressors required attention (see Element 4). We considered stressor characteristics during this qualitative process, but did not use them to determine which stressors required attention.

3.2 STRESSORS TO SGCN

We assigned 38 unique stressors to 190 Priority 1 and Priority 2 SGCN species, for a total of 1,099 SGCN – stressor combinations. Because of the complexity of species-specific stressors and the sheer volume of information, we did not attempt to summarize and discuss all stressors, but instead refer the reader to reports for individual species. However, for ease of reference, we developed Table 3-3, which is includes a list of the Secondary (Level 2) IUCN threat categories and the number of Priority 1 and 2 SGCN, as well as the number of Habitat Macrogroups, that are associated with each category. Complete stressor reports can be downloaded by clicking on the hyperlinks embedded within the table.

We identified 'Habitat Shifting or Alteration' (mostly due to expected climate changes or sea level rise), 'Lack of Knowledge', and 'Fishing and Harvesting of Aquatic Resources' as stressors for the largest number of SGCN, affecting 108, 109, and 69 species, respectively (Table 3-3). Each of these stressors impacted more than one-third of all Priority 1 and Priority 2 SGCN, indicating that they are wide-spread issues that occur across taxonomic groups. However, a simple evaluation of the numbers of species impacted by each stressor does not necessarily translate into priority for conservation attention. In fact, our assessment indicated that a relatively small number of SGCN stressors were both highly severe and highly actionable, resulting in a high priority ranking (Figure 3-2). We classified only 30% of SGCN stressors as either high or medium-high priority for action, indicating that they were both severe enough to warrant immediate attention, and that solutions are available to mitigate, reverse, or prevent the impact of the stressor. In fact, of the 38 unique stressors assigned to SGCN, we determined that only 28 were of medium-high or high priority for one or more species.

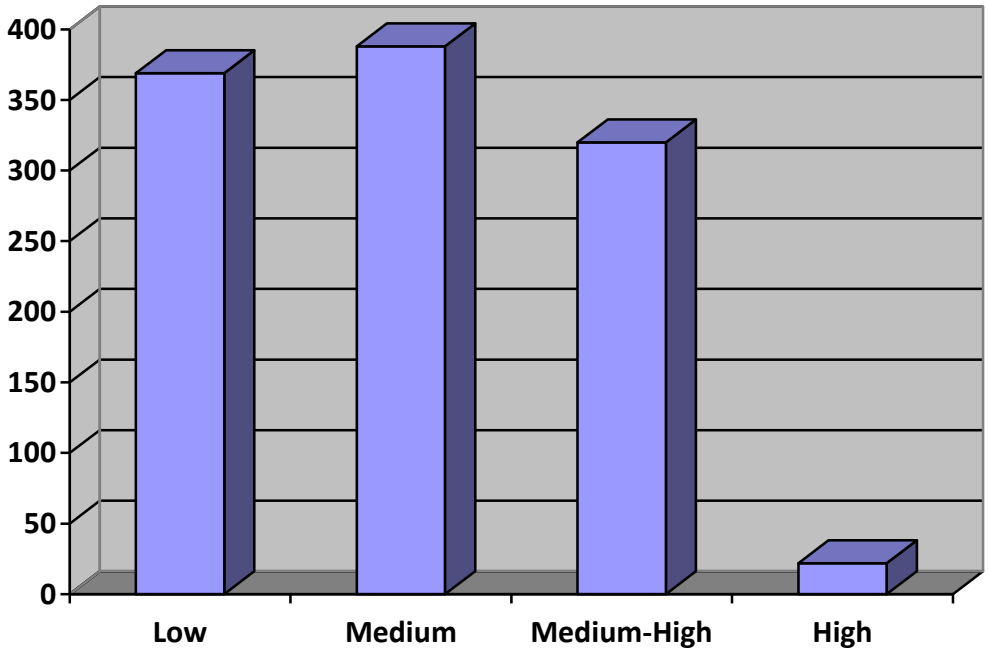
Table 3-3. IUCN Threat Category and the Number of Priority 1 SGCN, Priority 1 SGCN, and Habitat Macrogroups associated with each category. Complete stressor reports can be downloaded by clicking on the hyperlinks within the table.

IUCN Threat Category	Priority 1 SGCN	Priority 2 SGCN	Total SGCN	Habitat Macrogroups
Residential and Commercial Development				
Housing and Urban Areas	27	34	61	19
Commercial and Industrial Areas	20	17	37	18
Tourism and Recreational Areas	6	0	6	6
Agriculture and Aquaculture				
Annual and Perennial Non-timber crops	9	18	27	7
Livestock Farming and Ranching	3	3	6	6
Marine and Freshwater Aquaculture	1	0	1	5
Energy Production and Mining				
Oil and Gas Drilling	9	12	21	0
Mining and Quarrying	8	10	18	7
Renewable Energy	13	16	29	10
Transportation and Service Corridors				
Roads and Railroads	16	24	40	19
Utility and Service Lines	5	3	8	15
Shipping Lanes	4	4	8	11
Biological Resource Use				
Hunting and Collecting Terrestrial Animals	4	4	8	0
Gathering Terrestrial Plants	0	0	0	1
Logging and Wood Harvesting	12	16	28	9
Fishing and Harvesting of Aquatic Resources	21	48	69	11
Human Intrusions and Disturbance				
Recreational Activities	22	28	50	18
War, Civil Unrest and Military Exercises	2	4	6	0
Work and Other Activities	1	1	2	0
Natural Systems Modifications				
Fire and Fire Suppression	3	16	19	5
Dams and Water Management-Use	19	15	34	8
Other Ecosystem Modifications	5	5	10	0

Table 3-3. *continued: page 2 of 2.*

IUCN Threat Category	Priority 1 SGCN	Priority 2 SGCN	Total SGCN	Habitat Macrogroups
Invasive and Other Problematic Species, Genes and Diseases				
Invasive Non-native-Alien Species-Diseases	25	39	64	27
Problematic Native Species-Diseases	8	15	23	8
Problematic Species-Diseases of Unknown Origin	1	2	3	1
Viral-Prion-induced Diseases	0	2	2	2
Diseases of Unknown Cause	0	1	1	0
Pollution				
Domestic and Urban Waste Water	12	24	36	19
Industrial and Military Effluents	23	40	63	18
Agricultural and Forestry Effluents	14	53	67	17
Garbage and Solid Waste	5	7	12	7
Air-Bourne Pollutants	4	2	6	3
Excess Energy	3	7	10	0
Climate Change and Severe Weather				
Habitat Shifting or Alteration	33	75	108	20
Droughts	6	2	8	2
Temperature Extremes	20	45	65	9
Storms and Flooding	15	13	28	9
Other Options				
Other Threat	0	6	6	0
Lack of knowledge	31	78	109	1

Figure 3-2. Number of SGCN stressor assignments categorized as low, medium, medium-high, and high priority.



We identified 'Lack of Knowledge', 'Agricultural and Forestry Effluents', and 'Fishing and Harvesting of Aquatic Resources' as medium-high or high priority stressors for the largest number of SGCN (Table 3-4). Interestingly, 'Habitat Shifting or Alteration', which we found to impact a large number of SGCN, was identified as a priority stressor for only five SGCN. In most cases, impacts from 'Habitat Shifting or Alteration' were related to changes in habitat that will occur as a result of predicted levels of climate change. Common examples include the direct impacts of increasing seawater temperatures on coastal species, effects of shifts in forest composition on terrestrial species, and loss of saltmarsh habitat due to sea level rise. Although these effects are diverse and statewide in scope, most are not highly actionable at the level of individual SGCN within the scope of an individual state's Wildlife Action Plan, or are not predicted to have severe impacts on those species. However, we fully recognize the long-term implications of climate change for SGCN in Maine, and address these issues more fully at the coarse-filter (habitat) scale. We also refer readers to Whitman et al. (2013) for more information on the potential impacts of climate change on SGCN and their habitats in Maine.

Unlike 'Climate Change', 'Lack of Knowledge' is often highly actionable at the level of individual SGCN, and in many cases is one of the most severe stressors impacting species in Maine. In particular, Maine's invertebrate and marine fauna are generally poorly studied, and little information exists to describe distribution, trends in abundance, or limiting factors. Gathering basic ecological information on these species will be fundamental to advancing their conservation over the next 10 years.

Table 3-4. Secondary IUCN Threat Categories and the number of Priority 1 and Priority 2 SGCN assigned to each category where the stressor was ranked as either high or medium-high priority for action. Complete stressor reports can be downloaded by clicking on the hyperlinks within the table.

IUCN Threat Category	Number of SGCN Assignments
Residential and Commercial Development	
Housing and Urban Areas	25
Commercial and Industrial Areas	4
Tourism and Recreational Areas	1
Agriculture and Aquaculture	
Livestock Farming and Ranching	1
Marine and Freshwater Aquaculture	1
Energy Production and Mining	
Mining and Quarrying	2
Renewable Energy	12
Transportation and Service Corridors	
Roads and Railroads	12
Utility and Service Lines	1
Biological Resource Use	
Hunting and Collecting Terrestrial Animals	1
Logging and Wood Harvesting	8
Fishing and Harvesting of Aquatic Resources	39
Human Intrusions and Disturbance	
Recreational Activities	21
Work and Other Activities	1
Natural Systems Modifications	
Fire and Fire Suppression	13
Dams and Water Management-Use	12
Other Ecosystem Modifications	4
Invasive and Other Problematic Species, Genes and Diseases	
Invasive Non-native-Alien Species-Diseases	4
Problematic Native Species-Diseases	8
Viral-Prion-induced Diseases	1
Diseases of Unknown Cause	1

Table 3-4. *continued: page 2 of 2.*

IUCN Threat Category	Number of SGCN Assignments
Pollution	
Domestic and Urban Waste Water	19
Industrial and Military Effluents	18
Agricultural and Forestry Effluents	46
Air-Bourne Pollutants	1
Climate Change and Severe Weather	
Habitat Shifting or Alteration	5
Storms and Flooding	6
Other Options	
Other Threat	1
Lack of knowledge	74

The types of 'Agricultural and Forestry Effluents' that impact SGCN in Maine are diverse, and include pesticides, excessive nutrients, sedimentation, and the release of heavy metals. Many insect SGCN can be negatively impacted by the application of agricultural pesticides intended to control other species. Although these effects can be severe, they are often actionable through slight modifications to pesticide application methods, changes in the types of pesticides used, or in some cases, use of alternate pest control methods. Freshwater Aquatic and Marine habitats, and their associated SGCN, are often sensitive to declines in water quality, which can be caused by both point-source and non-point-sources. Excessive nutrients and sedimentation from agricultural activities (both crop and livestock operations) and finfish aquaculture facilities can cause elevated algae growth and lead to reduced levels of dissolved oxygen. Slight changes to farming practices are often sufficient to reduce nutrient and sediment migration to aquatic habitats and many programs currently exist to assist agricultural producers with these efforts. Established industry standards addressing feeding rates and stocking densities have successfully mitigated most effects from finfish aquaculture, drastically reducing algal growth and improving water quality.

We identified 'Fishing and Harvesting of Aquatic Resources' as a medium-high or high priority stressor for 39 SGCN. In most cases, these impacts are related to overfishing of commercial species or accidental by-catch of non-target species. Because there is no commercial harvest of terrestrial or freshwater SGCN, these impacts are limited to marine species. Often, these are historic issues that have largely been addressed through changes in regulations or fishing practices, however stocks of some species are slow to recover. Commercial fishing for marine species is a staple industry in Maine, and addressing past and current impacts will ensure that this important industry can continue to operate sustainably.

3.3 STRESSORS TO HABITATS

We assigned 31 unique stressors to 34 habitat macrogroups, for a total of 326 habitat – stressor combinations. Similar to SGCN, we do not attempt to summarize and discuss all stressors, but instead refer the reader to reports for individual habitats, and to Table 3-3 which includes links to summary reports for each stressor.



Poorly planned residential development proximate to a high value vernal pool, which has degraded terrestrial habitat for amphibians and is leaching excessive nutrients into the pool depression. © Department Inland Fisheries and Wildlife

We assigned 'Invasive Non-native/Alien Species/Diseases' and development (comprised of 'Roads and Railroads', and 'Housing and Urban Areas') to the largest number of habitats. Although all of these issues occur statewide and have the potential to impact virtually every habitat in Maine, their impacts on SGCN differ markedly depending on geography and the sensitivity of the individual speces.

Impacts from 'Invasive Non-native/Alien Species/Diseases' are most commonly related to invasive plant and animal species that degrade habitats or directly displace native species through competition or predation. These issues tend to be more prevalent in southern Maine,

where higher human populations and a moderate climate facilitate expansion of non-native species. In the marine environment, green crabs are a prevalent invasive species with deleterious impacts on a variety of habitats and SGCN. In some cases, non-native diseases, such as white-nosed syndrome in bats, have also had devastating impacts on SGCN. Impacts from 'Invasive Non-native/Alien Species/Diseases' can be severe, and in many cases it is extremely difficult to reverse the spread of invasive species or diseases; prevention is often the only feasible solution.

In contrast, 'Roads and Railroads' tend to impact habitats through fragmentation, especially for aquatic species, and by altering hydrology. Improperly installed or sized culverts can prevent or reduce passage by many SGCN, reducing connectivity between habitat patches. Both roads and railroads can also impede water flowage in seepage forests, tidal marshes, mudflats, and floodplains, reducing the function of these habitats. Construction of new roads and railroads is not prevalent in most of Maine, so addressing impacts from this stressor typically involves partial reconstruction of existing infrastructure through installation of improved culverts and bridges, and for the sake of terrestrial species such as turtles, installing signage to alert motorists to slow down.

"Development of Housing and Urban Areas is most prevalent in southern Maine, where most of Maine's human population lives, and where populations are expected to increase over the next two decades"

Development of 'Housing and Urban Areas' is most prevalent in southern Maine, where most of Maine's human population lives, and where human populations are expected to increase over the next two decades (Maine Office of Policy and Management 2015). Conversion of forest or agricultural land to residential areas causes a net loss of habitat for most species, although some SGCN are capable of adapting to development. In many cases, secondary impacts from development, such as increases in run-off, pollution, off-leash pets, traffic volumes, and even foot traffic, can have greater impacts on SGCN than the development itself. Outside of southern Maine, human populations are predicted to stabilize or decline over the next 20 years, so future impacts from new housing development are likely to be localized and should have relatively minor impacts on SGCN.



Hemlock tree in York County infected with hemlock wooly adelgid, a non-native pest. © Phillip DeMaynadier

3.4 LITERATURE CITED AND REFERENCES

Allen, R. B. 2000. Common Eider assessment. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine. 50pp.

Allen, R. B. 2004. Maine Colonial Waterbird Inventory. Page 54 *In:* Wildlife Division Research & Management Report 2004. Maine Department of Inland Fisheries and Wildlife, Augusta Mane. 78pp.

Anderson, M. G., M. Clark, C. E. Ferree, A. Jospe, A. Olivero Sheldon and K. J. Weaver. 2013. Northeast Habitat Guides: A companion to the terrestrial and aquatic habitat maps. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, Massachussetts. http://nature.ly/HabitatGuide.

Anderson, P.J. 2000. Pandalid shrimp as indicators of ecosystem regime shift. Journal of Northwest Atlantic Fisheries Science 27:1-10.

Appelhans, Y. S., J. Thomsen, C. Pinch, F. Melzner, and M. Wahl. 2012. Sour times: seawater acidification effects on growth, feeding behaviour and acid-base status of *Asterias rubens* and *Carcinus maenas*. Marine Ecology Progress Series 459:85-97.

Armstrong, C, and J Falk-Peterson. 2008. Habitat–fisheries interactions: a missing link? – ICES Journal of Marine Science 65:817–821.

Association of Fish and Wildlife Agencies, Teaming With Wildlife Committee, State Wildlife Action Plan (SWAP) Best Practices Working Group. 2012. Best Practices for State Wildlife Action Plans—Voluntary Guidance to States for Revision and Implementation. Washington (DC): Association of Fish and Wildlife Agencies. 80pp.

Atlantic Leatherback Turtle Recovery Team. 2006. Recovery strategy for leatherback turtle (*Dermochelys corriacea*) in Atlantic Canada. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. 45pp.

Auster, P. J., R. J. Malatesta, R. W. Langton, L. Watting, P. C. Valentine, C. L. S. Donaldson, E. W. Langton, A. N. Shepard and W. G. Babb. 1996. The impacts of mobile fishing gear on seafloor habitats in the gulf of Maine (Northwest Atlantic): Implications for conservation of fish populations. Reviews in Fisheries Science 4(2):185-202.

Bailey, H., K. L. Bookes, and P.M. Thompson. 2014. Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. Aquatic Biosystems 10:8.

Barsiene, J., V. Dedonyte, A. Rybakovas, L. Andreikenaite, and O. K. Andersen. 2006. Investigation of micronuclei and other nuclear abnormalities in peripheral blood and kidney of marine fish treated with crude oil. Aquatic Toxicology 78(Supplement 1): S99-S104.

Bates, A. E., B. J. Hilton, and C. D. Harley. 2009. Effects of temperature, season and locality on wasting disease in the keystone predatory sea star *Pisaster ochraceus*. Diseases of Aquatic Organisms 86:245-251.

Baum, J. K., Myers, R. A., Kehler, D. G., Worm, B., Harley, S. J., and P. A. Doherty. 2003. Collapse and conservation of shark populations in the Northwest Atlantic. Science 17 299:389-392.

Birchenough, S. N. R., H. Reiss, S. Degraer, N. Mieszkowska, Á. Borja, I. Buhl-Mortensen, U. Braeckman, J. Craeymeersch, I. De Mesel, F. Kerckhof, I. Kröncke, S. Parra, M. Rabaut, A. Schröder, C. Van Colen, G. Van Hoey, M. Vincx and K. Wätjen. 2015. Climate change and marine benthos: a review of existing research and future directions in the North Atlantic. WIREs Clim Change, 6:203–223.

Black, D.E., D. K. Phelps, and R.L. Lapan. 1988. The effect of inherited contamination on egg and larval winter flounder, *Pseudopleuronectes americanus*. Marine Environmental Research 25:45-62.

Blinn, B. M., A. W. Diamond, and D. J. Hamilton. 2008. Factors affecting selection of brood-rearing habitat by Common Eiders (*Somateria mollissima*) in the Bay of Fundy, New Brunswick, Canada. Waterbirds: The International Journal of Waterbird Biology 31(4):520-529.

Brooks, D. A., M. W. Baca, and Y.-T. Lo. 1999. Tidal circulation and residence time in a macrotidal estuary: Cobscook Bay, Maine. Estuarine, Coastal and Shelf Science 49:647-665.

Brousseau, D. J. and R. Goldberg. 2007. Effect or predation by the invasive crab *Hemigrapsus sanguineus* on recruiting barnacles *Semibalanus balanoides* in western Long Island Sound, USA. Marine Ecology Progress Series 339:221–228.

Brown, B .E., J. A. Brennan, M. D. Grosslein, E. G. Heyerdahl, and R. C. Hennemuth. 1976. The effect of fishing on the marine finfish biomass in the Northwest Atlantic from the Gulf of Maine to Cape Hatteras. International Commission for the Northwest Atlantic Fisheries Research Bulletin 12:49-68.

Burridge L, J. S. Weis, F. Cabello, J. Pizarro, and K. Bostick. 2010. Chemical use in salmon aquaculture: a review of current practices and possible environmental effects. Aquaculture 306:7–23.

Carey, F. G., J. V. Scharold, and Ad. J. Kalmign. 1990. Movements of blue sharks (*Prionace glauca*) in depth and course. Marine Biology 106:329-342.

Carrington, E., J. Herbert Waite, G. Sar`a, and K. P. Sebens. 2015. Mussels as a model system for integrative ecomechanics. Annual review of Marine Science 7:9.1 – 19.27.

Caswell, H., S. Brault, A. J. Read, and T. D. Smith. 1998. Harbor porpoise and fisheries: An uncertainty analysis of incidental mortality. Ecological Applications 8:1226-1238.

Chase, M. E., S. H. Jones, P. Hennigar, J. Sowles, G. C. H. Harding, K. Freeman, P. G. Wells, C. Krahforst, K. Coombs, R. Crawford, J. Pederson, and D. Taylor. 2001. Gulfwatch: Monitoring spatial and temporal patterns of trace metal and organic contaminants in the Gulf of Maine (1991-1997) with the blue mussel, *Mytilus edulis L*. Marine Pollution Bulletin 42:490-504.

Chen, Y., and M. Hunter. 2003. Assessing the green sea urchin (*Strongylocentrotus drobachiensis*) stock in Maine, USA. Fisheries Research 60:527-537.

Cheung, W.W.L., V. W. Y. Lam, J. L. Sarmiento, K. Kearney, R. Watson, and D. Pauly. 2009. Projecting global marine biodiversity impacts under climate change scenarios. Fish and Fisheries 10:235-251.

Clapham, P. J., S. B. Young, and R. L. Brownell, Jr. 2002. Baleen whales: conservation issues and the status of the most endangered populations. Mammal Review 29:37-62.

Clark, K. E. and L. J. Niles. 2001. Northern Atlantic Regional Shorebird Plan, ver. 1. Endangered and Nongame Species Program, New Jersey Division of Fish and Wildlife, Woodbine, NJ.

Clark, S. H., S. X. Cadrin, D. F. Schick, P. J. Diodati, M. P. Armstrong, and D. McCarron. 2000. The Gulf of Maine northern shrimp (*Pandalus borealis*) fishery: A review of the record. Journal of Northwest Atlantic Fishery Science 27:193-226.

Clements, J. C., and H. L. Hunt. 2014. Influence of sediment acidification and water flow on sediment acceptance and dispersal of juvenile soft-shell clams (*Mya arenaria L.*). Journal of Experimental Marine Biology 453:62-69.

Collie, J. S., S. J. Hall, M. J. Kaiser, and I. R. Poiners. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. Journal of Animal Ecology 69:785–798.

Colwell, Mark A. 2010. Shorebird ecology, conservation, and management. University of California Press, Berkeley, California.

Comeau, S., G. Gorsky, R. Jeffree, J. L. Teyssie, and J.P. Gattuso. 2009. Impact of ocean acidification on a key Arctic pelagic mollusc (*Limacina helicina*). Biogeosciences 6: 1877-1882.

COSEWIC. 2012. Assessment and status report on the Spotted Wolfish Anarhichas minor in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 44pp. Available at http://www.registrelep-sararegistry.gc.ca/virtual_sara/files/cosewic/sr_loupe_tachete_spotted_wolffish_1113_e.pdf.

Couillard, C. M., K. Lee, B. Légaré, and T. L. King. 2005. Effect of dispersant on the composition of the water-accommodated fraction of crude oil and its toxicity to larval marine fish. Environmental Toxicology and Chemistry 24:1496–1504.

Crain C. M., K. Kroeker, and B. S. Halpern. 2008. Interactive and cumulative effects of multiplehuman stressors in marine systems. Ecology Letters 11:1304–1315.

Crisfield, E. and the Northeast Fish and Wildlife Diversity Technical Committee (NFWDTC). 2013. The Northeast Lexicon: Terminology Conventions and Data Framework for State Wildlife Action Plans in the Northeast Region. A report submitted to the Northeast Fish and Wildlife Diversity Technical Committee. Terwilliger Consulting, Inc., Locustville, VA.

Dettmers, R. 2005. *Blueprint for the Design and Delivery of Bird Conservation in the Atlantic Northern Forest* , http://www.acjv.org/pdf_files/BCR%2014%20Blueprint.pdf.

DFO. 2012. Assessment of winter flounder (*Pseudopleuronectes americanus*) in the southern Gulf of St. Lawrence (NAFO Div. 4T). DFO Canadian Science Advisory Secretariat Science Advisory Report 2012/016.

Dimitriadis C., and D. Koutsoubas. 2011. Functional diversity and species turnover of benthic invertebrates along a local environmental gradient induced by an aquaculture unit: the contribution of species dispersal ability and rarity. Hydrobiologia 670:307–31.

Dixon, D. L., A. R. Jennings, and J. Atema. 2014. Odor tracking in sharks is reduced under future ocean acidification conditions. Global Change Biology 21:1454-1462.

Duffy J. E. (2003). Biodiversity loss, trophic skew and ecosystem functioning. Ecology Letters 6:680–687.

Dulvy N. K., Y. Sadovy, and J. D. Reynolds. 2003. Extinction vulnerability in marine populations. Fish and Fisheries 4:25-64.

Dupont, S., O. Ortega-Martinínez, and M. Thorndyke. 2010. Impact of near-future ocean acidification on echinoderms. Ecotoxicology 19:449-462.

Edgar G. J., C. K. Macleod, R. B. Mawbey, and D. Shield. 2005. Broad-scale effects of marine salmonid aquaculture on macrobenthos and the sediment environment in southeastern Tasmania. Journal of Experimental Marine Biology and Ecology 327:70–90.

Edgar G.J. and C. R. Samson. 2004. Catastrophic decline in mollusc diversity in eastern Tasmania and its concurrence with shellfish fisheries. Conservation Biology 18:1579–1588.

Erwin, R. M. 1989. Responses to human intruders by birds nesting in colonies: experimental results and management guidelines. Colonial Waterbirds 12(1):104-108.

Famous, N. C. 1987. The conservation and ecology of migratory shorebird roosting sites in eastern Maine. Unpub rep. 7pp.

Findlay, R.H., L. Watling, and L.M. Mayer. 1995. Environmental impact of salmon net-pen culture on marine benthic communities in Maine: A case study. Estuaries 18:145-179.

Floyd T., and J. Williams. 2004. Impact of green crab (*Carcinus maenas* L.) predation on a population of soft-shell clams (*Mya arenaria* L.) in the southern Gulf of St. Lawrence. Journal of Shellfish Research 23:457–462.

Fogarty, M., L. Incze, K. Hayhoe, D. Mountain, and J. Manning. 2007. Potential climate change impacts on Atlantic cod (Gadus morhua) off the northeastern USA. Mitigation and Adaptation Strategies for Global Change 13: 453-466.

Fogarty M., K. D. Friedland, L. Col, R. Gamble, J. Hare, K. Hyde, J. S. Link, S. Lucey, H. Liu, J. Nye, W. J. Overholtltz, D. Richardson, B. Roundtree and M. Taylor. 2012. Status of the Northeast US continental shelf Large Marine Ecosystem: an indicator-based approach. American Fisheries Society Symposium 79:1 – 28.

Fromentin, J. M. and J. E. Powers. 2005. Atlantic bluefin tuna: Population dynamics, ecology, fisheries and management. Fish and Fisheries 6:281-306.

Galbraith H., D. W. DesRochers, S. Brown, and J. M. Reed. 2014. Predicting Vulnerabilities of North American Shorebirds to Climate Change. PLoS ONE 9(9):e108899.

Gallagher, A.J., E. S. Orbesen, N. Hammerschlag, and J. E. Serafy. 2014. Vulnerability of oceanic sharks as pelagic longline bycatch. Global Ecology and Conservation 1:50-59.

Gaskin D. E., and G. J. D. Smith. 1979. Observations on marine mammals, birds and environmental conditions in the Head Harbor region of the Bay of Fundy. In: Scarratt DJ (ed) Evaluation of the recent data relevant to potential oil spills in the Passamaquoddy area. Fishery Marine Service Technical Report 901:69–86.

Gehrels, W.R., D. F. Belknap, S. Black, and R. M. Newnham. 2002. Rapid sea-level rise in the Gulf of Maine, USA, since AD 1800. The Holocene 12:383-389.

Gerrodette T., P. K. Dayton, S. Macinko, and M. J. Fogarty. 2002. Precautionary management of marine fisheries: moving beyond burden of proof. Bulletin of Marine Science 70:657–668.

Gilbert, M. A. 1977. The Gaper Clam (*Mya truncata*) in Maine and its relavance to the Critical Area Program of the State Planning Office. Maine Critical Areas Program of the State Planning Office. Maine Critical Areas Program Report 29:1-16.

Gill, A. B., Y. Huang, I. Gloyne-Phillips, J. Metcalfe, V. Quayle, J. Spencer, and V. Wearmouth. 2009. COWRIE 2.0 Electromagenetic Fields (EMF) Phase 2: EMF-sensitive fish response to EM emissions from sub-sea electricity cables of the type used by the offshore renewable energy industry. Commissioned by COWRIE Ltd (project reference COWRIE-EMF-1-06). http://www.thecrownestate.co.uk/media/5924/km-ex-pc-emf-032009-cowrie-20-electromagnetic-fields-emf-phase-2.pdf.

Glude, J. B. 1955. The effects of temperature and predators on the abundance of the soft-shell clam, *Mya arenaria*, in New England. Transactions of the American Fisheries Society 84:13-26.

Goldburg, R. J., M. S. Elliott, and R. L. Naylor. Marine aquaculture in the United States: Environmental Impacts and Policy Options. Prepared for the Pew Oceans Commission. http://www.iatp.org/files/Marine_Aquaculture_in_the_United_States_Enviro.htm.

Greene, K .E., J. L. Zimmerman, R. W. Laney, and J. C. Thomas-Blate. 2009. Atlantic coast diadromous fish habitat: A review of utilization, threats, recommendations for conservation, and research needs. Atlantic States Marine Fisheries Commission Habitat Management Series No. 9, Washington, D.C.

Hall, C., A. Jordaan, M. Frisk. 2012. Centuries of Anadromous Forage Fish Loss: Consequences for Ecosystem Connectivity and Productivity. BioScience 62(8):723-731.

Hall, C. J., Jordaan, A., and M. G. Frisk. 2011. The historic influence of dams on diadromous fish habitat with a focus on river herring and hydrologic longitudinal connectivity. Landscape Ecology 26:95-107.

Hamilton, D. J. 2001. Feeding behavior of common eider ducklings in relation to availability of rockweed habitat and duckling age. Waterbirds: The International Journal of Waterbird Biology 24(2): 233-241.

Hamilton, D. J. and T. D. Nudds. 2003. Effects of predation by common eiders (*Somateria mollissima*) in an intertidal rockweed bed relative to an adjacent mussel bed. Marine Biology 142:1-12.

Hansen, L. P., and M. L. Windsor. 2006. Interactions between aquaculture and wild stocks of Atlantic salmon and other diadromous fish species: Science and management, challenges and solutions. ICES Journal of Marine Sciences 63:1159-1161.

Harvell, C. D., K. Kim, J. M. Burkholder, R. R. Colwell, P. R. Epstein, D. J. Grimes, E. E. Hofmann, E. K. Lipp, A. D. M. E. Osterhaus, R. M. Overstreet, J. W. Porter, G. W. Smith, and G. R. Vasta. 1999. Emerging marine diseases – Climate links and anthropogenic factors. Science 285:1505-1510.

Heilmayer, O., T. Brey, and H. O. Pörtner. 2004. Growth efficiency and temperature in scallops: a comparative analysis of species adapted to different temperatures. Functional Ecology, 18(5):641-647.

Holtmann, W. C., M. Stumpp, M. A. Gutowska., S. Syre, N. Himmerkus, F. Melzner, and M. Bleich. 2013. Maintenance of coelomic fluid pH in sea urchins exposed to elevated CO2: the role of body cavity epithelia and stereom dissolution. Marine Biology 160: 2631-2645. http://www.iucnredlist.org/technical-documents/classification-schemes/threats-classification-scheme. Accessed May 29, 2015.

Hudon, C. 1990. Distribution of shrimp and fish by-catch assemblages in the Canadian eastern Arctic in relation to water circulation. Canadian Journal of Fisheries and Aquatic Sciences, 47(9):1710-1723.

Hvingel, C., and M. C.S . Kinsgley. 2006. A framework to model shrimp (Pandalus borealis) stock dynamics and to quantify the risk associated with alternative management options, using Bayesian methods. ICES Journal of Marine Science 63:68-82.

International Union for Conservation of Nature (IUCN). 2015. Threat Classification Scheme (version 3.2). Available at http://www.iucnredlist.org/technical-documents/classification-schemes/threats-classification-scheme. Last accessed: May 29, 2015.

Jackson, J. B. 2001. What was natural in the coastal oceans? Proceedings of the National Academy of Science USA 98:5411–5418.

Jackson, J. B. C., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. W. Botsford, B. J. Bourque, R. H. Bradbury, R. Cooke, J. Erlandson, J. A. Estes, T. P. Hughes, S. Kidwell, C. B. Lange, H. S. Lenihan, J. M. Pandolfi, C. H. Peterson, R. S. Teneck, M. J. Tegner, and R. R. Warner. Historical overfishing and the recent collapse of coastal ecosystems. Science 293:629-637.

Jelks, H. L., S. J. Walsh, N. M. Burkhead, S. Contreras-Balderas, E. Diaz-Pardo, D. A. Hendrickson, J. Lyons, N. E. Mandrak, F. McCormick, J. S. Nelson, S. P. Platania, B. A.

Porter, C. B. Renaud, J. J. Shmitter-Soto, E. B. Taylor, and M. L. Warren Jr. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33:372-407.

Jenkins S. R., B. D. Beukers-Stewart and A. R. Brand. 2001. Impact of scallop dredging on benthic megafauna: a comparison of damage levels in captured and non-captured organisms. Marine Ecology Progress Series 215:297–301.

Jennings S., J. K. Pinnegar, N. V. Polunin, and K. J. Warr. 2001. Impacts of trawling disturbance on the trophic structure of benthic invertebrate communities. Marine Ecology Progress Series 213:127–142.

Jentoft, S. 1989. Fisheries co-management: Delegating government responsibility to fishermen's organizations. Marine Policy 13(2):137-154.

Johnson A. F., G. Gorelli, S. R. Jenkins, J. G. Hiddink, and H. Hinz. 2015. Effects of bottom trawling on fish foraging and feeding. Proceedins of the Royal Society B 282:2014-2336.

Kappel, C. V. 2005. Losing pieces of the puzzle: Threats to marine, estuarine, and diadromous species. Frontiers in Ecology and the Environment 3:275-282.

Kaiser M. J., K. Ramsay, C. A. Richardson, F. E. Spence, and A. R. Brand. 2000. Chronic fishing disturbance has changed shelf sea benthic community structure. Journal of Animal Ecology 69:494-503.

Keppel, E. A., R. A. Scrosati, and S. C. Courtenay. 2014. Interactive effects of ocean acidification and warming on subtidal mussels and sea stars from Atlantic Canada. Marine Biology Research 11(4):337-348.

Kingsley, M. C. S., P. Kanneworff, and D. M. Carlsson. 1999. By-catches of fish in the West Greenland shrimp survey: an initial analysis. NAFO SCR Document 111.

Kulka, D. W., M. R. Simpson, and the Department of Fisheries and Oceans. 2004. Determination of allowable harm for spotted (*Anarhichas minor*) and northern (*Anarhichas denticulatus*) wolffish. Canadian Science Advisory Secretariat.

Kushlan, J. A., M. J. Steinkamp, K. C. Parsons, J. Capp, M. Acosta Cruz, M. Coulter, I. Davidson, L. Dickson, N. Edelson, R. Elliot, R. M. Erwin, S. Hatch, S. Kress, R. Milko, S. Miller, K. Mills, R. Paul, R. Phillips, J. E. Saliva, B. Sydeman, J. Trapp, J. Wheeler, and K. Wohl. 2002. Waterbird Conservation for the Americas: The North American Waterbird Conservation Plan, Version 1. Waterbird Conservation for the Americas, Washington, DC, U.S.A. 78pp. http://www.waterbirdconservation.org/pubs/complete.pdf

Laist, D. W. 1997. Chapter 8: Impacts of marine debris: Entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records." In Marine Debris: Sources, Impacts, and Solutions. Edited by Coe, J.M., and D.B. Rogers. 1997. Springer-Verlag New York, Inc., Ann Arbor, MI. Pp. 99-413.

Larsen, P. F., K. A. Wilson, and D. Morse. 2013. Observations on the expansion of a relict population of Eastern Oysters (*Crassostrea virginica*) in a Maine Estuary: Implications for climate change and restoration. Northeastern Naturalist 20(4):28-32.

Lebel, L., J. M. Anderies, B. Campbell, C. Folke, S. Hatfield-Dodds, T. P. Hughes, and J. Wilson. 2006. Governance and the Capacity to Manage Resilience in Regional Social-Ecological Systems. Marine Sciences Faculty Scholarship. Paper 52.

Limburg, K. E., and J. R. Waldman. 2009. Dramatic declines in North Atlantic diadromous fishes. BioScience 59:955-965.

Lotze, H. K., and I. Milewski. 2004. Two centuries of multiple human impacts and successive changes in a North Atlantic food web. Ecological Applications 14:1428-1447.

Lyons, K., and C. G. Lowe. 2013. Mechanisms of maternal transfer of organochlorine contaminants and mercury in the common thresher shark (*Alopias vulpinus*). Canadian Journal of Fisheries and Aquatic Sciences 70:1667-1672.

Maine Department of Inland Fisheries and Wildlife. 2005. Maine's comprehensive wildlife conservation strategy. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine.

Maine Department of Marine Resources. Historical Maine Fisheries Landings Data. http://www.maine.gov/dmr/commercialfishing/documents/shrimp.graph.pdf

Maine Office of Policy and Management. 2015. Maine State and County Population Projections 2032. http://maine.gov/economist/projections/index.shtml. Accessed May 29, 2015.

Mayor, D. J., C. Matthews, K. Cook, A. F. Zuur, and S. Hay. 2007. CO2-induced acidification affects hatching success in *Calanus finmarchicus*. Marine Ecology Progress Series 350:91-97.

McCauley, D.J., M. L. Pinsky, S. R. Palumbi, J. A. Estes, F. H. Joyce, and R.R. Warner. 2015. Marine defaunation: Animal loss in the global ocean. Science 347:1255641.

McDonald P. S., G. C. Jensen, and D. A. Armstrong. 2001. The competitive and predatory impacts of the nonindigenous crab *Carcinus maenas* (L.) on early benthic phase Dungeness crab *Cancer magister* Dana. Journal of Experimental Marine Biology and Ecology 258:39–54.

Melzner, F., P. Strange, K. Trubenbach, J. Thomsen, I. Casties, U. Panknin, S. N. Gorb, and M. A. Gutowska. 2011. Food supply and seawater pCO_2 impact calcification and internal shell dissolution in the blue mussel *Mytilus edulis*. PloSONE 6: e24223.

Menge, B. A. 1979. Coexistence between the seastars Asterias vulgaris and A. forbesi in a heterogeneous environment: A non-equilibrium explanation. Oecologia 41:245-272.

Merkel, F. R., A. Mosbech and F. Riget. 2009. Common Eider (Somateria mollissima) Feeding Activity and the Influence of Human Disturbances. Ardea 97(1):99-107.

Moul, I. E. 1990. Environmental contaminants and breeding failure at a Great Blue Heron colony on Vancouver Island. M.Sc. thesis. Univ. B.C., Vancouver, B.C.

Musick, J. A., G. Burgess, G. Cailiet, M. Camhi, and S. Fordham. 2000. Management of sharks and their relatives (Elasmobranchii). Fisheries 25:9-13.

Occhipinti-Ambrogi, A. and D. Savini. 2003. Biological invasions as a component of globalchange in stressed marine ecosystems. Marine Pollution Bulletin 46:542–551.

O'Donnell, M. J., M. N. George, and E. Carrington. 2013. Mussel byssus attachment weakened by ocean acidification. Nature Climate Change 3:587-590.

Orr, J. C., V. J. Fabry, O. Aumont, L. Bopp, S. C. Doney, R. A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R. M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R. G. Majjar, G.-K. Plattner, K. B. Rodgers, C. L. Savine, J. L. Sarmiento, R. Schlitzer, R. D. Slater, I. J. Totterdell, M.-F. Weirig, Y. Yamanaka and A. Yool. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437:681-686.

Payne, J. F., J. Kicenuik, L. L. Fancey, U. Williams, G. L. Fletcher, A. Rahimtula, and B. Fowler. 1988. What is a safe level of polycyclic aromatic hydrocarbons for fish: Subchronic toxicity study of winter flounder (*Pseudopleuronectes americanus*). Canadian Journal of Fisheries and Aquatic Sciences 45:1983-1993.

Payne, L. X., and E. P. Pierce. 2002. Purple Sandpiper (*Calidris maritima*). In The Birds of North America, no. 706. Edited by A. Poole and F. Gill. The Birds of North America, Inc., Philadelphia, PA.

Peck, L. S., M. S. Clark, D. Power, J. Reis, F. Batista, and E. M. Harper. 2015. Acidification effects on biofouling communities: winners and losers. Global Change Biology 21(5):1907-1913.

Pederson J., N. Mieszkowska, J. T. Carlton, S. Gollasch, A. Jelmert, D. Minchin, A. Occhipinti-Ambrogi, and I. Wallentinus. 2011. Climate change and non-native species in the North Atlantic. Pages 174-256 In ICES Status Report on Climate Change in the North Atlantic. Edited by P. C. Reid and L. Valdés. ICES Cooperative Research Report No 310. 257pp.

Perry, A. L., P. J. Low, J. R. Ellis, and J. D. Reynolds. 2005. Climate change and distribution shifts in marine fishes. Science 308:1912-1915.

Pohle G., B. Frost, R. Findlay. 2001. Assessment of regional benthic impact of salmonmariculture within the Letang Inlet, Bay of Fundy. ICES Journal of Marine Science 58:417–426.

Roberts, D. A., S. N. Birchenough, C. Lewis, M. B. Sanders, T. Bolam, and D. Sheahan. 2013. Ocean acidification increases the toxicity of contaminated sediments. Global Change Biology, 19(2):340-351.

Robertson, G. J. and R. I. Goudie. 1999. Harlequin Duck (Histrionicus histrionicus). In The Birds of North America, no. 706. Edited by A. Poole and F. Gill. The Birds of North America, Inc., Philadelphia, PA.

Robinson S, A. MacIntyre, and S. Bernier. 1994. The impact of scallop drags on sea urchingrounds. In Workshop on the management and biology of the Green Sea Urchin (*Strongylocentrotus droebachiensis*). Edited by J. Harris and H. A. Car. Maine Department of Marine Resources, Boothbay Harbor, Maine, pp 102–123.

Rodgers, J. A., Jr. and H. T. Smith. 1995. Set-back distances to protect nesting bird colonies from human disturbance in Florida. Conservation Biology 9(1):89-99.

Roman, J. 2006. Diluting the founder effect: Cryptic invasions expand a marine invader's range. Proceedings of the Royal Society B 273:2453-2459.

Ruiz G. M., P. W. Fofonoff, J. T. Carlton, M. J. Wonham, and A. H. Hines. 2000. Invasion of coastal marine communities in North America: apparent patterns, processes, and biases. Annual Review of Ecology, Evolution, and Systematics 31:481–531.

Salafsky, N., D. Salzer, J. Ervin, T. Boucher, and W. Ostlie. 2003. Conventions for defining, naming, measuring, combining, and mapping threats in conservation: an initial proposal for a standard system. Conservation Measures Partnership, Washington, D.C.

Salafsky, N. D., A. J. Salzer, A. J. Stattersfield, C. Hilton-Taylor, R. Neugaren, B. H. Buchart, B. Collen, N. Cox, L. L. Master, S. O'Connor, and D. Wilkie. 2008. A Standard Lexicon for Biodiversity Conservation: Unified Classifications of Threats and Actions. Conservation Biology 22 (4):897–911.

Schiel, D. R., J. R. Steinbeck and M. S. Foster. 2004. Ten years of induced ocean warming causes comprehensive changes in marine benthic communities. Ecology 85(7):1833-1839.

Smith, R. M., and C. F. Cole. 1970. Chlorinated hydrocarbon insecticide residues in winter flounder, *Pseudopleuronectes americanus*, from the Weweantic River Estuary, Massachusetts. Journal of the Fisheries Research Board of Canada 27:2374-2380.

Southward, A. J., S. J. Hawkins and M. T. Burrows. 1995. Seventy years' observations of changes in distribution and abundance of zooplankton and intertidal organisms in the western English Channel in relation to rising sea temperature. Journal of Thermal Biology 20(1):127-155.

Stachowicz J. J., J. R. Terwin, R. B. Whitlatch, and R. W. Osman. 2002. Linking climate change and biological invasions: ocean warming facilitates nonindigenous species invasions. Proceedings of the National Academy of Sciences 99:15497–15500.

Steneck, R. S. 1997. Fisheries-induced biological changes to the structure and function of theGulf of Maine ecosystem. In Proceedings of the Gulf of Maine ecosystem dynamics scientific symposium and workshop. Edited by G. T. Wallace and E. F. Braasch. Regional Association for Research on the Gulf of Maine, Hanover, New Hampshire. Pp 151–165.

Steneck, R.S., A. Leland, D. C. McHaught, and J. Vavrinec. 2013. Ecosystem flips, locks, and feedbacks: the lasting effects of fisheries on Maine's kelp forest ecosystem. Bulletin of Marine Science 89:31-55.

Stevens, J.D., T. I. Walker, S. F. Cook, and S.V. Fordham. 2005. "Chapter 5: Threats faced by Chondrichthyan fish." In Sharks, Rays and Chimaeras: The Status of the Chondrichthyan Fishes. Status Survey. Edited by S.L. Fowler, R.D. Cavanagh, M. Camhi, G.H. Burgess, G.M. Cailliet, S.V. Fordham, C.A. Simpfendorfer, and J.A. Musick. IUCN, Gland, Switzerland and Cambridge, UK. Pp. 48-57.

Stortini, C.H., N. L. Shackell, P. Tyedmers, and K. Beazley. 2015. Assessming marine species vulnerability to projected warming on the Scotian Shelf, Canada. ICES Journal of Marine Science 72:1731-1743.

Talmage, S. C., and C. J. Gobler. 2009. The effects of elevated carbon dioxide concentrations on the metamorphosis, size, and survival of larval hard clams (Mercenaria mercenaria), bay scallops (Argopecten irradians), and Eastern oysters (Crassostrea virginica). Limnology and Oceanography 54(6):2072-2080.

Talmage, S. C., and C. J. Gobler. 2010. Effects of past, present, and future ocean carbon dioxide concentrations on the growth and survival of larval shellfish. Proceedings of the National Academy of Sciencies of the United States of America 107:17246-17251.

Thrush S. F. and P.K. Dayton. 2002. Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. Annual Review of Ecology, Evolution, and Systematics 33 449–473.

Todd, C., B. Swartz, P. deMaynadier, and H. Givens. 2003. Maine's Endangered and Threatened wildlife. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine. 117pp.

Trott, T. J. 2004a. Late 20-th century qualitative intertidal faunal changes in Cobscook Bay, Maine. Northeastern Naturalist 11(Spec Issue 2):325-354.

Trott, T. J. 2004b. Cobscook Bay inventory: A historical checklist of marine invertebrates spanning 162 years. Northeastern Naturalist 11(Spec Issue 2):261-324.

Trott, T. J. (in review). Century-scale species incidence, rareness and turnover in a high diversity Northwest Atlantic coastal embayment. Marine Biodiversity.

Tudor, L. 2002. Coastal migratory shorebird management system and data base. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine. 50pp.

Tudor, L. 2005. Island-nesting terns assessment. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine. 38pp.

U.S. Fish and Wildlife Service. 2008. Birds of Conservation Concern 2008. United States Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, Virginia. 85pp. [Online version available at http://www.fws.gov/migratorybirds/]

U.S. Fish and Wildlife Service. 2002. Birds of conservation concern 2002. Division of Migratory Bird Management, Arlington, Virginia. 99pp.

U.S. Fish and Wildlife Service. 1996. Pipnig Plover (Charadrius melodus), Atlantic Coast Population, Revised Recovery Plan. Hadley, Massachussetts. 258pp.

U.S. Fish and Wildlife Service. 2009. Pipng Plover (Charadrius melodus), 5-Year Review: Summary and Evaluation. Northeast Region, Hadley, Massachussetts and Midwest Region's East Lansing Field Office, MI.

Valentine P. C., M. R. Carman, D. S. Blackwood, and E. J. Heffron. 2007. Ecological observations on the colonial ascidian Didemnum sp. in a New England tide pool habitat. Journal of Experimental Marine Biology and Ecology 342:109–121.

Vandendriessche, S., K. Hostens, W. Courtens, and E. W. M. Stienen. 2011. Monitoring the effects of offshore wind farms: evaluating changes in fishing effort using Vessel Monitoring System data: targeted monitoring results. Offshore Wind Farms in the Belgian part of the North Sea: Selected Findings from the Baseline and Targeted Monitoring. RBINS-MUMM, Brussels, pp 83-92.

Vanderlaan, A. S. M., C. T. Taggart, A. R. Serdynska, R. D. Kenney, and M.W. Brown. 2008. Reducing the risk of lethal encounters: Vessels and right whales in the Bay of Fundy and on the Scotian Shelf. Endangered Species Research 4:283-297.

Vennesland, R. G. 2000. The effects of disturbance from humans and predators on the breeding decisions and productivity of the Great Blue Heron in south-coastal British Columbia. M.Sc. thesis. Simon Fraser Univ., Burnaby, B.C.

Vos, D.K., P. A. Ryder, and W. D. Graul. 1985. Response of breeding great blue herons to human disturbance in Northcentral Colorado. Colonial Waterbirds 8:13–22.

Waldbusser, G. G. and J. E. Salisbury. 2014. Ocean acidification in the coastal zone from an organism's perspective: Multiple system parameters, frequency domains, and habitats. Annual Review of Marine Science 6:221-247.

Watling L. and E. A. Norse. 1998. Disturbance of the seabed by mobile fishing gear: a comparison to forest clearcutting. Conservation Biology 12:1180–1197.

Watling, L., R. H. Findlay, L. M. Mayer, and D. F. Schick. 2001. Impact of a scallop drag on the sediment chemistry, microbiota, and faunal assemblages of a shallow subtidal marine benthic community. Journal of Sea Research, 46(3):309-324.

Watts, B.D. and D.S. Bradshaw. 1994. The influence of human disturbance on the location of great blue heron colonies in the lower Chesapeake Bay. Colonial Waterbirds 17(2):184-186.

Weinberg, J. R. 2002. Influence of rising sea surface temperature on commercial bivalve species of the U.S. Atlantic coast. Fisheries in a Changing Climate 32:131-140.

Weinstein, J. E. 1996. Anthropogenic impacts on salt marshes – A review. In Sustainable Development in the Southeastern Coastal Zone. Edited by F. J. Vernberg, W. B.

Vernberg, and T. Siewicki. University of South Carolina Press, Columbia, SC. 1996. pp. 135-170.

White, M. M., D. C. McCorkle, L. S. Mullineaux, and A.L. Cohen. 2013. Early exposure of bay scallops (*Argopecten irradians*) to high CO_2 causes a decrease in larval shell growth. PLoS ONE 8:e61065.

White, M. M., L. S. Mullineaux, D. C. McCorkle, and A. L. Cohen. 2014. Elevated pCO_2 exposure during fertilization of the bay scallop *Argopecten irradians* reduces larval survival but not subsequent shell size. Marine Ecology Progress Series 498:173-186.

Whitman, A., A. Cutko, P. deMaynadier, S. Walker, B. Vickery, S. Stockwell, and R. Houston. 2013. Climate Change and Biodiversity in Maine: Vulnerability of Habitats and Priority Species. Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Working Group) Report SEI-2013-03. 96pp.

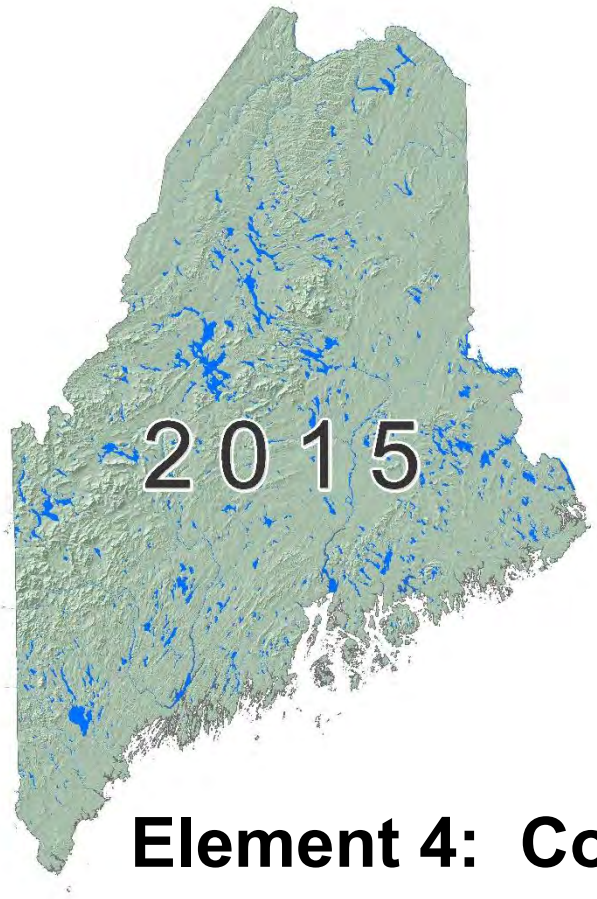
Wildish D. J. and G. W. Pohle. 2005. Benthic macrofaunal changes resulting from finfishmariculture. In Environmental effects of marine finfish aquaculture. Handbook of Environmental Chemistry. Edited by E. Hargrave E and T. Barry. Springer Berlin, Heidelberg, pp 275–304.

Wilhelmsson D., T. Malm, amd M. C. Ohman. 2006. The influence of offshore wind power on demersal fish. ICES Journal of Marine Science 63:775-784.

Winn, B, et al. 2013. The Atlantic Flyway Shorebird Business Strategy. http://manometcenter.pairserver.com/sites/default/files/publications_and_tools/AtlanticFlywayShorebirdBusinessStrategy.pdf.

Worm B., E. B. Barbier, N. Beaumont, J. E. Duffy, C. Folke, B. S. Halpern, J. B. C. Jackson, H. K. Lotze, F. Micheli, S. R. Palumbi, E. Sala, K. A. Selkoe, J. J. Stachowicz, and R.Watson. 2006. Impacts of biodiversity loss on ocean ecosystem services. Science 314:787-790.

Wyatt, L. H., A. L. Baker, and D. L. Berlinsky. 2010. Effects of sedimentation and periphyton communities on embryonic Rainbow Smelt, Osmerus mordax. Aquatic Sciences 72(3):361-369.



MAINE'S WILDLIFE ACTION PLAN

Element 4: Conservation Actions

Prepared by

Maine Department of Inland Fisheries and Wildlife

In collaboration with

Maine's Conservation Partners

September 2015

TABLE OF CONTENTS

Element 4: Conservation Actions

4.0 Abstract....1

4.1 Introduction....2
4.1.1 Significant Differences from Maine's 2005 Plan....2
4.1.2 General Considerations for Development of Conservation Actions....3

4.2 SGCN Conservation Actions....6
4.2.1 SGCN Action Background....6
4.2.2 Development of SGCN Conservation Actions....6
4.2.3 Summary of SGCN Conservation Actions....7

4.3 Habitat Conservation Actions....36
4.3.1 Habitat Action Background....36
4.3.2 Development of Habitat Conservation Actions....36
4.3.3 Summary of Habitat Conservation Actions....41
4.3.4 Development of Habitat Themes....84

4.4 Programmatic Conservation Actions....90

4.5 An Approach to Prioritizing Conservation Efforts....93
4.5.1 Uses for Prioritization Considerations....93
4.5.2 Potential Criteria for Prioritizing Conservation Actions....93

4.6 Literature Cited....95

LIST OF TABLES

Table 4-1. Conservation Actions assigned to Taxonomic Groups....8

Table 4-2. Conservation Actions assigned to Bird Guilds. 10

Table 4-3. Conservation Actions assigned to Reptile, Amphibian, and Invertebrate Guilds. 12

Table 4-6. Conservation Actions assigned to Marine Guilds....16

Table 4-7. Conservation Actions assigned to Bird SGCN. 19

Table 4-8. Conservation Actions assigned to Reptile, Amphibian, and Invertebrate SGCN. 25

Table 4-9. Conservation Actions assigned to Inland Fish SGCN. 30

Table 4-10. Conservation Actions assigned to Mammal SGCN. 31

Table 4-11. Conservation Actions assigned to Marine SGCN. 32

Table 4-12. SGCN conservation sctions by Action Category. 35

Table 4-13. SGCN conservation actions by Type. 35

Table 4-14. SGCN conservation actions by Biological Priority. 35

Table 4-15. Habitat groupings addressed by conservation action workgroups. 37

Table 4-16. 2015 Maine Wildlife Action Plan Habitat Conservation Actions. Actions are sorted by Habitat Workgroup (FW=freshwater habitats, M=marine and coastal habitats, TW=terrestrial and freshwater wetland habitats), Habitat Grouping (see Table 4-15), Action Category, then by Biological Priority (C=critical, H=high, M=moderate). Themes are described in Table 4-20. The Action ID # will allow users to search the relational database (once it becomes publically available) for a specific action. 42

Table 4-17. Habitat conservation actions by Action Category. 83

Table 4-18. Habitat conservation actions by Type. 83

Table 4-19. Habitat conservation actions by Biological Priority. 83

Table 4-20. Habitat conservation action themes. 85

Table 4-21. 2015 Maine Wildlife Action Plan Programmatic Actions. 92

LIST OF FIGURES

Figure 4-1. Overall process for developing SGCN, habitat, and programmatic conservation actions. Agencies and partners involved at each stage are noted in italics.....4

Figure 4-2. Example Open Standards conceptual model diagram for the central oak pine barren habitat. Text boxes are as follows: yellow boxes (conservation actions); orange boxes (contributing factors); peach boxes (key stressors); blue boxes (specific issues caused by stressors; green box (target habitat) and yellow ovals (specific conservation targets). Arrows indicate relationships among elements in the model. 40

Figure 4-3. Cost-benefit matrix of conservation proposals.....94

KEY TO ACRONYMS

CMP	Conservation Measures Partnership
COA	Conservation Opportunity Areas
CWCS	Comprehensive Wildlife Conservation Strategy
MDMR	Maine Dept. of Marine Resources
MCP	Maine Coastal Program
MDIFW	Maine Dept. of Inland Fisheries and Wildlife
MNAP	Maine Natural Areas Program
MTA2C	Mount Agamenticus to the Sea Conservation Initiative
RCN	Regional Conservation Needs
SGCN	Species of Greatest Conservation Need
SMART	Specific, Measurable, Achievable, Results-oriented, and Time-bound
SWAP	State Wildlife Action Plan
SWG	State Wildlife Grants
TNC	The Nature Conservancy

4.0 ABSTRACT

The conservation actions contained in Maine's revised State Wildlife Action Plan (SWAP) consist of complementary coarse- and fine-filter approaches that maximize limited conservation dollars. The Maine Department of Inland Fisheries and Wildlife (MDIFW), the Maine Department of Marine Resources (MDMR), the Maine Coastal Program (MCP), the Maine Natural Areas Program (MNAP), and other conservation partners worked closely to develop a thorough catalog of coarse- and fine-filter conservation actions. We attempted to balance action specificity with flexibility so that actions can be adapted as needed to emerging issues and information. Conservation actions are non-regulatory approaches undertaken voluntarily by agencies and other conservation partners. Actions are not intended to replace current management strategies, but can be used to bolster existing efforts or inspire new ones.

The actions reflect several stages of prioritization. Conservation partners identified a total of 311 actions for Species of Greatest Conservation Need (SGCN). Of these, partners applied 197 actions to individual SGCN, 88 to guilds, and 26 to one or more taxonomic groups. We assigned nine of these actions to all SGCN species. Conservation partners also identified 322 habitat actions, including 165 marine and coastal habitat actions, 54 freshwater aquatic habitat actions, and 103 terrestrial and wetland habitat actions. Given the volume of habitat conservation actions identified, workgroups developed several themes to organize actions into discrete packages of related actions that address common stressors or use similar techniques. Actions within a theme are often complementary, and when undertaken together, may be the most effective and efficient use of conservation resources. Three 'super-themes' emerged across habitat groups: Connectivity, Invasive Species, and Mapping and Outreach. Actions included in these themes will be more effective with coordinated efforts across habitats. Each conservation action is linked to its target SGCN or habitat and the stressor(s) the action is addressing in a relational database, an idea proposed in the 2005 Comprehensive Wildlife Conservation Strategy (CWCS) and successfully developed as part of this Plan. We also identified 11 programmatic actions to help guide implementation and tracking of the 2015 Action Plan; we have broadly grouped these actions as Outreach and Engagement, Funding and Tracking, Action Development, and Regional Partnerships. In this chapter, we also propose criteria partners may wish to consider if evaluating how best to direct resources to conservation actions in the plan. We also discuss differences from Maine's 2005 CWCS.

4.1 INTRODUCTION

In the previous chapter, we identified the primary issues affecting Maine's Species of Greatest Conservation Need (SGCN) and their habitats. In this chapter, we discuss strategies ('conservation actions') to address the negative effects of stressors on SGCN and habitats. **Conservation actions are non-regulatory approaches undertaken voluntarily by agencies and other conservation partners. They are not intended to replace current management strategies, but can be used to bolster existing efforts or inspire new ones.** In this chapter, we describe our approach to developing conservation actions at the SGCN, habitat, and programmatic scales and introduce a strategy for prioritizing conservation projects over the next ten years.

Maine's 2015 Wildlife Action Plan consists of complementary coarse- and fine-filter conservation actions that maximize limited conservation dollars. Coarse-filter conservation actions are those applied broadly at large spatial scales (e.g., habitats) or groupings (e.g., communities) and benefit most species associated with that habitat or group. Coarse-filter actions focus largely on conserving plant and animal communities and the interactions among them. However, certain SGCN require 'fine-filter' actions designed to alleviate stressors not adequately addressed through coarse-filter actions.

"Conservation actions are non-regulatory approaches undertaken voluntarily by agencies and other conservation partners."

Conservation partners worked closely to develop a thorough catalog of coarse- and fine-filter conservation actions. We attempted to balance action specificity with flexibility so that actions can be adapted to emerging issues and information. These actions are extensive and comprehensive, and thus, their implementation will require a truly statewide collaborative effort among partners. Maine's conservation actions present a diverse set of opportunities from which conservation partners can select actions that reflect their interests and abilities. For example, some actions are suitable for private citizens while others are best accomplished by large regional inter-agency partnerships. We hope partners will see a role for themselves in the 2015 Wildlife Action Plan and identify new opportunities for collaboration.

4.1.1 SIGNIFICANT DIFFERENCES FROM MAINE'S 2005 PLAN

Both Maine's 2005 CWCS (MDIFW 2005) and the 2015 Wildlife Action Plan incorporate fine- and coarse-filter approaches to SGCN conservation. For SGCN in 2005, MDIFW relied heavily on the comprehensive species planning process to identify SGCN and habitat-scale actions. Our coarse-filter conservation efforts in the 2005 CWCS relied heavily on providing SGCN information to municipalities and land trusts for land-use planning and voluntary conservation. In the 2015 Wildlife Action Plan, however, MDIFW and MDMR species experts identified both broad and species-specific SGCN actions. We also worked with partners to expand our coarse-filter habitat conservation approaches to include a variety of education, outreach, management, and research actions aimed at multiple habitat scales.

In this Plan, we also:

1. Identified and developed actions (especially for habitats) collaboratively among agencies and other conservation partners; MDIFW also provided all conservation partners an opportunity to review and comment on conservation actions before posting the Wildlife Action Plan for the 30-day public comment period.

2. Developed habitat actions that directly address habitat stressors and not just stressors to SGCN.

3. Developed habitat action themes to help organize habitat actions into discrete packages that address a common set of stressors or use similar approaches to do so.

4. Added the action type 'new' or 'on-going' to distinguish between existing programs and those that need to be initiated.

5. Developed programmatic actions to guide Wildlife Action Plan implementation, reporting, and partner involvement.

6. Prioritized actions based on biological priority for SGCN and habitats.



Conservation partners coordinated on all aspects of Plan development. © George Matula

7. Developed a prioritization approach to evaluate SWG-funded project proposals.

8. Linked conservation actions to SGCN, habitats, and stressors in a relational database.

4.1.2 GENERAL CONSIDERATIONS FOR DEVELOPMENT OF CONSERVATION ACTIONS

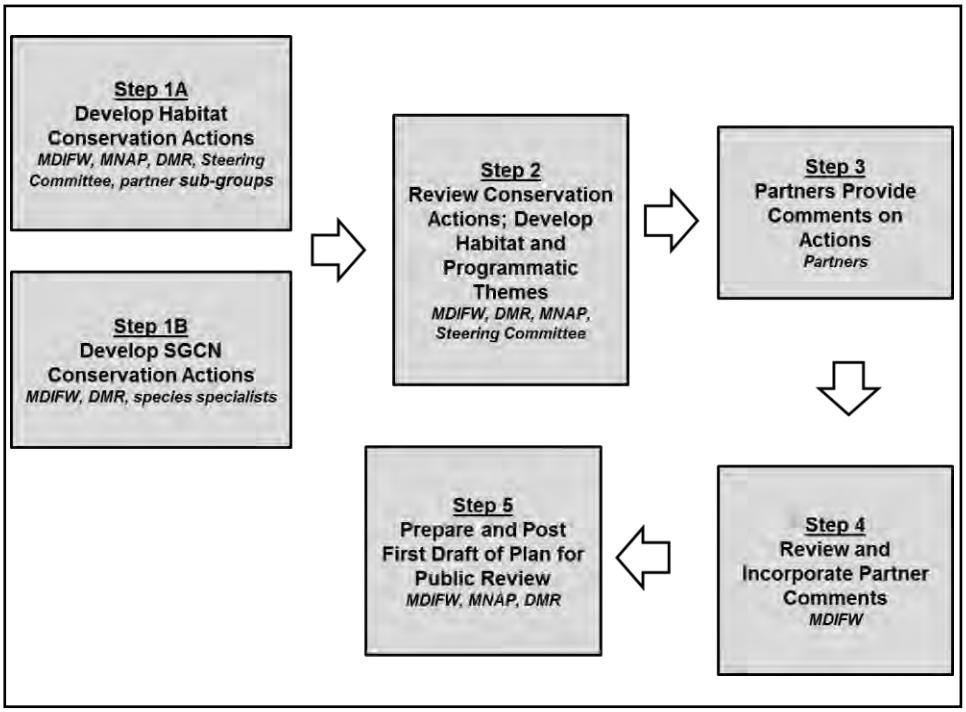
MDIFW collaborated closely with partners, species specialists, and habitat experts over a five-month period (February-July 2015) to develop SGCN and habitat conservation actions. While MDIFW used slightly different but parallel approaches to develop SGCN and habitat actions (Figure 4-1), conservation actions at both scales address specific stressor(s) to SGCN and habitats. We wrote conservation action descriptions broadly enough to allow for adaptive management over the next ten years, but with enough specificity to help assess performance (AFWA 2012). We also developed 11 programmatic actions that will guide SWAP implementation of the over the next ten years.

We identified comprehensive lists of 311 SGCN and 322 habitat conservation actions. These lists reflect several stages of consolidation and prioritization. First, we developed SGCN-

specific actions only for Priority 1 and Priority 2 species and addressed Priority 3 species at the guild level. Second, we only developed conservation actions for priority habitat and SGCN stressors, which we defined as stressors that were at least moderately actionable and moderately severe (Figure 4-1).

"MDIFW collaborated closely with partners, species specialists, and habitat experts over a five-month period (February-July 2015) to develop SGCN and habitat conservation actions."

Figure 4-1. Overall process for developing SGCN, habitat, and programmatic conservation actions. Agencies and partners involved at each stage are noted in italics.



Finally, we further prioritized our comprehensive list of actions based on biological priority (see below for further explanation).

We used the following categories to help organize and prioritize SGCN and habitat conservation actions:

1. **Action Category:** MDIFW assigned conservation actions to one of the following six broad categories to help organize related actions. While some actions fit into multiple categories, we assigned the best-fitting category for each action.

    a. **Habitat management:** Addresses stressors to SGCN habitats through habitat conservation, management, or stewardship.

    b. **Policy:** Addresses existing policies or the need for new policies that encourage conservation of SGCN and habitats; all actions in this category are strictly non-regulatory.

c. **Public outreach:** Addresses the need to raise the public's awareness of the stressors to SGCN and their habitats.

d. **Research:** Addresses gaps in our understanding of life history, productivity, mortality, habitat requirements, limiting factors, interactions with other species, and conservation needs of SGCN.

e. **Species Management:** Addresses management needs at the species or population level.

f. **Surveys and Monitoring:** Addresses data gaps and informational needs on the distribution, abundance, and status of SGCN.

2. **Biological Priority:** MDIFW assigned actions a biological priority based on how essential that action will be toward conserving a species or habitat over the next ten years. Biological priority does not take into account the economic or practical feasibility of actions. Because MDIFW developed actions only for priority stressors, there is no 'low' level of biological priority.

   a. **Critical**: Actions that are necessary for sustaining species or habitats in order to prevent the loss of populations or significant portions of habitats or habitat integrity in the next ten years.

   b. **High**: Actions that are important for conserving habitats or preventing the loss of SGCN populations but would not result in dire losses if not enacted over the next ten years.

   c. **Moderate:** Actions that would benefit habitats or SGCN but alone may not be crucial for their continued existence over the next ten years.

"Each conservation action is linked to its target SGCN or habitat and the stressor(s) the action is addressing in a relational database, an idea proposed in the 2005 CWCS and successfully developed as part of the 2015 Action Plan."

3. **Action Type:** This category indicates whether an action is already underway ('**on-going**') or if a new effort is needed ('**new**'). We included on-going actions in the 2015 Plan to acknowledge and provide continued support for on-going conservation efforts.

Each conservation action is linked to its target SGCN or habitat, the stressor(s) the action is addressing, and the above categories in a relational database, an idea proposed in the 2005 CWCS and successfully developed as part of the 2015 Wildlife Action Plan. This database allows users to quickly search by 1) habitat, SGCN, or stressor and 2) group actions by categories or programs of interest. MDIFW hopes to add additional information to habitat and SGCN conservation actions in the database (e.g., contact information for partners or agencies coordinating projects and information on project progress). Programmatic actions may eventually be added to the database, but are currently housed in this chapter.

4.2 SGCN CONSERVATION ACTIONS

4.2.1 SGCN ACTION BACKGROUND

Conservation actions for Maine's SGCN represent the Wildlife Action Plan's fine-filter approach to species conservation. Although we anticipate that coarse-filter, habitat-based actions will ultimately address most of the important problems facing SGCN, there are some species that require individual attention. In some cases, stressors impacting SGCN are not directly related to that species' habitat (e.g., white-nosed syndrome in bats), or individual SGCN have specific habitat requirements that cannot be reasonably addressed by generic conservation actions for habitats. Additionally, some SGCN have pre-existing conservation plans (e.g., Atlantic Salmon) where mangers have already determined actions to monitor and conserve the species. In these cases, MDIFW adopted actions from these established plans. In assigning conservation actions to SGCN, we hope to ensure that no SGCN 'falls through the cracks' over the next 10 years. At the same time, we attempted to limit the application of species-specific conservation actions to those SGCN with pressing conservation needs.

4.2.2 DEVELOPMENT OF SGCN CONSERVATION ACTIONS

We developed conservation actions as follows:

1. Species specialists within MDIFW and MDMR developed 23 species 'guilds' in order to streamline the assignment of conservation actions. These guilds consisted of groups of species facing similar conservation problems, and for which conservation actions could be developed concurrently. Guilds included Priority 1, Priority 2, and Priority 3 SGCN.

2. Using professional knowledge, species specialists assigned conservation actions to address stressors of medium-high or high priority (see Element 3) that had been assigned to Priority 1 or Priority 2 SGCN. Conservation actions that species specialists assigned to guilds applied to all species within the guild, regardless of the species priority level. For each conservation action, specialists assigned a rank for biological priority, action type, and action category using the criteria described in this chapter's introduction.

3. Once specialists completed initial assignments, a small group of MDIFW and marine species experts reviewed the draft list of conservation actions and identified several similar actions that had been applied to many species within a single taxonomic group, and in some cases, to multiple species across taxonomic groups. They refined these actions and applied them either to all SGCN species or to all SGCN within a taxonomic group, as appropriate.

4. A small group of staff reviewed and edited the full list of SGCN conservation actions to improve editorial consistency and ensure accuracy.

5. MDIFW presented the draft list of SGCN conservation actions to conservation partners at a meeting on June 16, 2015 and distributed them by email for review and feedback. MDIFW modified SGCN conservation actions as appropriate.

6. On July 13, 2015, MDIFW posted the entire draft Wildlife Action Plan online for a 30-day public comment period (see Elements 7/8 for more information). MDIFW, agency partners, and the Steering Committee reviewed the comments received addressing SGCN conservation actions. MDIFW and the Steering Committee modified conservation actions as appropriate.

4.2.3 SUMMARY OF SGCN CONSERVATION ACTIONS

MDIFW and partners identified a total of 311 conservation actions for SGCN. Of these, we applied 26 actions to one or more taxonomic groups (Table 4-1), 88 to guilds of species (Tables 4-2 to 4-6), and 197 to individual SGCN (Tables 4-7 to 4-11). We assigned nine actions to all SGCN species and applied three to multiple taxonomic groups (Table 4-1). Of the remaining 299 actions, MDIFW and partners applied 127 to birds, 65 to reptiles, amphibians, or invertebrates, 16 to inland fish, 20 to mammals, and 78 to marine species (Table 4-12). We classified most actions as research or survey and monitoring, reflecting the pervasive need to gather more information on SGCN in order to facilitate their conservation. Nearly half of the SGCN conservation actions are already on-going in some form (although they may require enhancement). MDIFW and partners viewed approximately 20% of actions as critical to habitat conservation over the next ten years (Tables 4-13 and 4-14).

Table 4-1. Conservation Actions assigned to Taxonomic Groups.

Taxonomic Groups	Category	Biological Priority	Type	Description
All Terrestrial and Freshwater SGCN (Birds; Reptiles, Amphibians, and Invertebrates; Inland Fish; Mammals)	Habitat Management	High	On-going	Map and distribute information on species distribution, habitat requirements, and conservation actions with a goal of increased voluntary conservation by landowners, towns, and land trusts.
All SGCN (Birds; Reptiles, Amphibians, and Invertebrates; Inland Fish; Mammals; Marine)	Policy	High	New	Develop conservation actions for all medium-ranked stressors assigned to Priority 1 and Priority 2 SGCN
				Collaborate with partners to develop habitat management recommendations for all Priority 1 and Priority 2 SGCN and Guilds that are sensitive to certain intensive forest management practices.
				Review and update SGCN distribution maps on a regular basis throughout the Wildlife Action Plan implementation period.
				Ensure ETSC database tracking is in place and accurate for all Priority 1 SGCN, and develop a system for prioritizing ETSC database tracking for a higher proportion of Priority 2 SGCN than are currently tracked.
				Integrate SGCN habitat needs and Conservation Actions more explicitly into MDIFW Wildlife Management Area Plan reviews and updates, while maintaining the original management goals for each property.
			On-going	Conduct a comprehensive review of S-ranks and share with NatureServe
				Continue and improve quality of mapping and tracking of documented populations using MDIFW's ETSC database.
	Public Outreach	High	New	Provide increased partner and public access to SGCN species reports, maps, and conservation actions through MEGIS, or other venues.
			On-going	Increase public awareness of the economic and ecological value of SGCN and their conservation needs.
All Marine SGCN	Habitat Management	High	On-going	Assess new aquaculture sites for potential positive, benign, or negative species interactions. Continue to review the presence of and impacts to ecologically sensitive species and areas during the review process.
	Public Outreach	High	On-going	Increase capacity for collaborative data collection and management that fosters partnerships among harvesters, citizens, scientists, and managers.
				Increased leadership and education regarding climate change mitigation and adaptation

Table 4-1. *continued: page 2 of 2.*

Taxonomic Groups	Category	Biological Priority	Type	Description
All Marine SGCN (continued)	Research	Critical	On-going	Create species distribution maps to facilitate reduced response time to potential oil spills by creating 'hot' zones.
		High	New	Conduct laboratory and in situ research to understand the direct and indirect impacts of climate change (e.g. warming ocean temperatures, decreased salinity, increased eutrophication) and ocean acidification on individual species, food webs, and ecosystems.
				Conduct research to better understand impacts on marine SGCN and recovery from mechanical disturbances at various scales (e.g. dredging, dredge disposal, offshore infrastructure construction, mineral mining, etc.).
			On-going	Improve understanding of non-harvested species through targeted data collection, habitat surveys, and other efforts
				Map species distributions and abundances to track changes over time, identify ecologically important areas for multiple SGCN, and examine ecosystem interactions and predator-prey relationships.
				Conduct research to evaluate the impacts (including sublethal/lethal effects) of nutrients, chemicals, and other pollutants on marine SGCN to better understand risks to exposure, and monitor natural environments to understand where these stressors may be occurring.
				Investigate biological effects (both lethal and sublethal) of oil spills and related treatments and response techniques including oil dispersants, burning, etc., as well as the short and long term effect of oil spills.
				Determine accuracy of harvester and dealer reported landings for target species and bycatch.
		Moderate	On-going	Research the impacts of diversifying Maine's marine fisheries on both non-commercial and commercially important SGCN.
	Species Management	High	On-going	Improve evaluation of commercially-harvested intertidal and subtidal SGCN through designation of conserved areas and rotational management (e.g., scallops).
	Survey and Monitoring	High	On-going	Conduct surveys to monitor and better understand distribution and abundance.
		Moderate	On-going	Create an incentive-based reporting tool for non-commercial bycatch.
All Bird SGCN	Survey and Monitoring	High	New	Improve documentation of breeding status and distribution through an update to the Maine Breeding Bird Atlas.
All Reptile, Amphibian, and Invertebrate SGCN	Survey and Monitoring	High	On-going	Implement targeted professional surveys to better understand species distribution and status and to help direct conservation actions to newly documented populations.

Table 4-2. Conservation Actions assigned to Bird Guilds.

Guild	Species	Category	Biological Priority	Type	Description
Grassland birds	Northern Harrier, Upland Sandpiper, American Kestrel, Horned Lark, Grasshopper Sparrow, Field Sparrow, Bobolink, Eastern Meadowlark, Short-eared Owl, Barn Owl	Public Outreach	High	New	Develop a program to inform small landowners of the best methods for keeping fields open for grassland wildlife.
		Species Management	High	New	Collaborate with partners to develop a BMP guide for farmers to minimize negative effects of cutting hay/silage during the grassland bird nesting season. NRCS recommendations should be viewed as a start with increased emphasis on timing, field size, and bird behavioral cues.
Island Nesting Seabirds	Razorbill, Atlantic Puffin, Laughing Gull, Roseate Tern, Common Tern, Arctic Tern, Leach's Storm-petrel, Great Cormorant	Research	High	New	Determine the association with commercial fisheries and climate-induced changes to food availability.
				On-going	Determine which factors influence breeding success and productivity.
		Survey and Monitoring	High	On-going	Continue seabird restoration activities at historic nesting sites using social attraction, vegetation management, and predator control.
Marsh birds	Black Tern, Yellow Rail, American Coot, Common Gallinule, Sora, Sedge Wren, American Bittern, Least Bittern, Pied-billed Grebe	Habitat Management	High	New	Work with landowners to maximize hemi-marsh conditions and maintain stable water levels.
		Species Management	Moderate	New	Work with landowners to develop and post signs or other strategies for discouraging recreational users from disturbing nesting birds.
		Survey and Monitoring	High	New	Implement targeted surveys to better understand the distribution and status of this species and to help direct conservation actions to newly documented populations.

Table 4-2. *continued: page 2 of 2.*

Guild	Species	Category	Biological Priority	Type	Description
Shorebirds	Black-bellied Plover, American Oystercatcher, Ruddy Turnstone, Sanderling, Dunlin, Red Knot, Purple Sandpiper, Least Sandpiper, Semipalmated Sandpiper, Short-billed Dowitcher, Whimbrel, Red Phalarope, Lesser Yellowlegs, Greater Yellowlegs	Habitat Management	Moderate	New	Use voluntary agreements, conservation easements, conservation tax abatements and incentives to protect important habitats.
		Public Outreach	High	On-going	Provide outreach to pet owners, beachgoers, kayakers, beach managers, and landowners to raise public awareness on shorebirds and on the impacts of disturbance from recreational activities in coastal areas.
		Research	High	On-going	Work with the Maine Department of Marine Resources to conduct research to determine the impact of macroalgae harvest on wintering waterfowl.
					Identify prey resources in significant staging areas to determine potential limiting factors and optimal management techniques to promote these resources.
					Determine length of stay at stopover areas, site fidelity, local movements and premigration condition to determine if coastal habitats are meeting shorebird requirements for successful migration.
					Gain a better understanding of the extent and impacts of algae harvesting on staging and wintering shorebirds. Conduct long-term monitoring of ecosystem-wide impacts of cutting algae to determine potential impacts to shorebird habitats and invertebrate prey.
			Moderate	New	Determine limiting factors for SGCN shorebird species on breeding, migratory, or wintering areas.
		Species Management	High	New	Place symbolic stake and twine fencing around important beach roosting areas with signage to identify roosting areas.
		Survey and Monitoring	High	On-going	Identify and map priority feeding and roosting areas including offshore habitats, and implement protection initiatives. Enter data in IFW ETSC database.
					To determine population status, continue monitoring program for SGCN shorebird species at high priority migration sites coastwide. Continue to coordinate with ISS, PRISM, Atlantic Flyway ESMP programs.

Table 4-3. Conservation Actions assigned to Reptile, Amphibian, and Invertebrate Guilds.

Guild	Species	Category	Biological Priority	Type	Description
Bumble Bees	Rusty-patched Bumble Bee, Ashton's Cuckoo Bumble Bee, Lemon Cuckoo Bumble Bee, Fernald's Cuckoo Bumble Bee, Yellow Bumble Bee, Brownbelted Bumble Bee, Indiscriminate Cuckoo Bumble Bee, American Bumble Bee, Sanderson's Bumble Bee, Yellowbanded Bumble Bee	Public Outreach	Moderate	New	Develop and implement outreach materials to raise public awareness of native pollinator ecology, threats and conservation needs, and to encourage use of Integrated Pest Management practices.
		Research	High	New	Produce a statewide atlas and conservation assessment.
		Survey and Monitoring	High	On-going	Conduct statewide surveys to document species diversity, distribution and relative abundance.
Dry Barrens Lepidoptera	Dusted Skipper, Sleepy Duskywing, Leonard's Skipper, Cobweb Skipper, Southern Cloudywing, Edwards' Hairstreak, Coral Hairstreak, Similar Underwing, Oblique Zale, Barrens Itame, Twilight Moth, Barrens Metarranthis Moth, Nepytia pellucidaria, Chaetaglaea ce	Habitat Management	Critical	New	Conduct a statewide review of potential high quality barrens habitat that is threatened by succession and identify strategic habitat restoration actions for implementation by key conservation partners.
		Species Management	Critical	New	Prepare occurrence maps and pesticide spray consultation guidelines for rare Lepidoptera and distribute to strategic partners including Maine Bureau of Pesticides Control.

Table 4-3. *continued: page 2 of 3.*

Guild	Species	Category	Biological Priority	Type	Description
Forested Wetlands Lepidoptera	Hessel's Hairstreak, Satyr Comma, Appalachian Brown, Spicebush Swallowtail	Research	High	New	Prepare a statewide atlas and conservation assessment.
Lacustrine Odonates	Comet Darner, Dusky Dancer, Tule Bluet, Big Bluet, New England Bluet, Scarlet Bluet, Citrine Forktail, Rambur's Forktail, Ringed Emerald, Lilypad Clubtail, Common Sanddragon, Needhams Skimmer, Carolina Saddlebags, Black Saddlebags, Martha's Pennant	Research	High	New	Prepare a statewide atlas and conservation assessment.
Palustrine Odonates	Sedge Darner, Swamp Darner, Spatterdock Darner, Quebec Emerald, Ringed Boghaunter, Canada Whiteface, Painted Skimmer, Zigzag Darner, Incurvate Emerald, Elfin Skimmer	Research	High	New	Prepare a statewide atlas and conservation assessment.

Table 4-3. *continued: page 3 of 3.*

Guild	Species	Category	Biological Priority	Type	Description
Peatland Lepidoptera	Bog Elfin, Clayton's Copper, Crowberry Blue, Frigga Fritillary, New England Buckmoth	Species Management	Critical	New	Prepare occurrence maps and pesticide spray consultation guidelines for rare Lepidoptera and distribute to strategic partners including Maine Bureau of Pesticides Control.
Riverine Odonates	Arrowhead Spiketail, Broadtailed Shadowdragon, Rapids Clubtail, Cobra Clubtail, Southern Pygmy Clubtail, Extra-striped Snaketail, Boreal Snaketail, Pygmy Snaketail, Arrow Clubtail, Ocellated Emerald	Research	High	New	Prepare a statewide atlas and conservation assessment.

Table 4-4. Conservation Actions assigned to Inland Fish Guilds.

Guild	Species	Category	Biological Priority	Type	Description
Rare Minnows	Creek Chubsucker, Eastern Silvery Minnow, Pearl Dace, Bridle Shiner, Blacknose Shiner, Longnose Dace	Research	Critical	New	Determine population abundance, habitat use, size and age structure and interaction with other fish species in representative waters.
					Develop a robust, reliable method to assess population trends, habitat associations, and geographic distribution.
					Determine susceptibility and risks associated with certain disease scenarios.
Whitefishes	Lake Whitefish, Round Whitefish	Research	Critical	On-going	Determine population abundance, habitat use, size and age structure and interaction with other fish species in representative waters.
		Research	High	On-going	Identify factors that have contributed to declining populations of lake whitefish.
		Species Management	Critical	On-going	Develop and implement rehabilitation programs for fisheries that have declined.

Table 4-5. Conservation Actions assigned to Mammal Guilds.

Guild	Species	Category	Biological Priority	Type	Description
Cave bats	Big Brown Bat, Eastern Smallfooted Myotis, Little Brown Bat, Northern Long-eared Myotis, Tricolored Bat	Public Outreach	Moderate	New	Investigate the feasibility of gating known hibernaculum.
		Research	High	On-going	Conduct research and monitoring to address knowledge gaps, with a focus on developing baseline presence/absence data, monitoring and identifying new hibernacula, and furthering our understanding of habitat selection by cave bat species, including the use of cavity trees.

Table 4-6. Conservation Actions assigned to Marine Guilds.

Guild	Category	Biological Priority	Type	Description
Bivalves	Policy	Critical	On-going	Through education and collaboration, reduce the use of antifouling agents and biocides that negatively affect SGCN, and investigate alternative biofouling agents.
Brachiopod	Policy	Critical	New	Reduce the collection and possession of live specimens.
				Through education and collaboration, reduce the use of antifouling agents and biocides that negatively affect SGCN, and investigate alternative biofouling agents.
	Public Outreach	High	On-going	Encourage the use of more targeted fishing gear in order to reduce bycatch and habitat disturbance.
	Research	High	New	Develop molecular tools to identify where specimens are collected.
Cnidaria	Policy	Critical	New	Reduce the collection and possession of live specimens.
				Through education and collaboration, reduce the use of antifouling agents and biocides that negatively affect SGCN, and investigate alternative biofouling agents.
	Public Outreach	High	On-going	Encourage the use of more targeted fishing gear in order to reduce bycatch and habitat disturbance.
	Research	High	New	Develop molecular tools to identify where specimens are collected.
Diadromous Fish	Policy	High	On-going	Encourage improved municipal planning for siting for new or retrofitting development, taking into account future environmental change, to improve connectivity for diadromous fish passage.
	Public Outreach	High	On-going	Conduct education to increase awareness of the importance of these species to maintaining productive ecosystem functioning.
				Encourage the use of more targeted fishing gear in order to reduce bycatch and habitat disturbance.
		Moderate	On-going	Continue to work with the fishing industry to develop gear modifications that reduce bycatch of diadromous fishes.
	Research	Critical	On-going	Determine the location and timing of critical habitat use (for endangered species) and important habitat use for diadromous fishes at different life history stages.
		High	New	Investigate methods to reduce incidental bycatch in commercial and recreational fisheries.
				Improve understanding of the relative roles of natural predation, fishing mortality, and climate change in stock dynamics.
			On-going	Improve understanding of species distribution especially in regards to ecosystem interactions, predator-prey relationships, and prey buffering concepts. Gather information to support management, including stock assessments, population genetics, population monitoring, etc.
	Survey and Monitoring	Critical	On-going	Monitor population stock status through surveys and sampling programs.

Table 4-6. *continued: page 2 of 3.*

Guild	Category	Biological Priority	Type	Description
Echinoderms	Policy	Critical	On-going	Through education and collaboration, reduce the use of antifouling agents and biocides that negatively affect SGCN, and investigate alternative biofouling agents.
	Public Outreach	High	On-going	Encourage the use of more targeted fishing gear in order to reduce bycatch and habitat disturbance.
	Research	High	New	Investigate the effect of various harvesting practices on the integrity of habitats and trophic and ecological systems.
				Research to understand how effects such as habitat modifications, population changes, and pollution can influence SGCN.
				Identify species that are resilient to ocean acidification (OA) and rises in sea surface temperature (SST).
			On-going	Expand existing education and research among researchers and managers to improve understanding and management ability.
				Conduct research to support management, including but not limited to stock assessments, population genetics, population monitoring, etc.
	Survey and Monitoring	High	New	Ground-truth mapped habitat and compare to historical maps to monitor change over time, may require updating mapping plans to map more frequently.
Gastropods	Policy	Critical	New	Reduce the collection and possession of live specimens.
				Reduce the use of tributyltin compounds as a biocide and antifouling prophylactic.
	Public Outreach	High	On-going	Encourage the use of more targeted fishing gear in order to reduce bycatch and habitat disturbance.
	Research	High	New	Develop molecular tools to identify where specimens are collected.
	Survey and Monitoring	High	New	Ground-truth mapped habitat and compare to historical maps to monitor change over time, may require updating mapping plans to map more frequently.
Seaturtles	Habitat Management	Moderate	On-going	Reduce the amount of ghost gear that could increase the risk of entanglement for sea turtles.
	Public Outreach	High	New	Conduct outreach with fishermen to increase reporting for entangled turtles.

Table 4-6. *continued: page 3 of 3.*

Guild	Category	Biological Priority	Type	Description
Seaturtles (continued)	Public Outreach (continued)	Moderate	New	Conduct outreach and trainings to improve the detection of and response time to entangled turtles in Maine waters.
			On-going	Continue to work with the fishing industry to develop gear modifications that reduce the risk of entanglement and conduct outreach on gear best practices to use.
	Survey and Monitoring	Critical	On-going	Conduct baseline surveys to determine the seasonal density and distribution of fixed fishing gear.
		High	On-going	Gather baseline data on the configurations of fixed fishing gear used as a function of seasonality and distance from shore.
		Moderate	New	Conduct surveys (aerial, boat based) to determine the distribution of sea turtles in the coastal waters of Maine.
Shrimp	Policy	Critical	New	Through education and collaboration, reduce the use of antifouling agents and biocides that negatively affect SGCN, and investigate alternative biofouling agents.
	Research	High	New	Develop molecular tools to identify where specimens are collected.
			On-going	Expand existing education and research among researchers and managers to improve understanding and close data gaps in order to inform management.
	Survey and Monitoring	High	New	Ground-truth mapped habitat and compare to historical maps to monitor change over time, may require updating mapping plans to map more frequently.
Whales	Habitat Management	Moderate	On-going	Reduce the amount of ghost gear that could increase the risk of entanglement for large whales.
	Public Outreach	High	On-going	Continue to work with the fishing industry to develop gear modifications that reduce the risk of entanglement and conduct outreach on gear best practices to use.
		Moderate	On-going	Conduct outreach and trainings to improve the detection of and response time to entangled whales in Maine waters.
	Survey and Monitoring	Critical	New	Conduct surveys (aerial, boat based and/or passive acoustic) to determine the distribution of large whales in the coastal waters of Maine.
			On-going	Conduct baseline surveys to determine the seasonal density and distribution of fixed fishing gear.
		High	On-going	Gather baseline data on the configurations of fixed fishing gear used as a function of seasonality and distance from shore.
				Determine the high overlap areas between whales, high risk behaviors or persistent habitat use and fixed fishing gear.

Table 4-7. Conservation Actions assigned to Bird SGCN.

Scientific Name	Common Name	Category	Biological Priority	Type	Description
Aythya marila	Greater Scaup	Public Outreach	High	On-going	Install signage at boat ramps
		Survey and Monitoring	High	On-going	Continue monitoring through the mid-winter waterfowl survey
Histrionicus histrionicus	Harlequin Duck	Habitat Management	Critical	New	Continue to work with the Maine Department of Marine Resources to coordinate macroalgae harvest in important wintering sites and determine the level of impact on wintering birds
Bartramia longicauda	Upland Sandpiper	Survey and Monitoring	Critical	New	Support state and regional efforts to survey/inventory populations of Upland Sandpiper leading to an estimate of population trend
Calidris canutus rufa	Red Knot	Species Management	High	New	Partner with municipalities and BP&L to develop beach management agreements to minimize impacts to feeding and roosting red knots using beach habitats.
Calidris maritima	Purple Sandpiper	Habitat Management	Critical	On-going	Continue to work with the Maine Department of Marine Resources to coordinate macroalgae harvest in important wintering sites and determine the level of impact on wintering birds
		Survey and Monitoring	Critical	On-going	Continue annual long term monitoring plan to determine if the Purple Sandpiper population is in severe decline. Combine annual survey with a coastwide survey to be conducted every 5 years.
Charadrius melodus	Piping Plover	Habitat Management	High	On-going	Collaborate with partners to develop long-term, non-regulatory habitat protection via management agreements or conservation easements.
		Public Outreach	High	On-going	Continue efforts to educate beach recreationalists, landowners and municipal officials regarding ecology and life history requirements.
		Species Management	Critical	On-going	Continue current management activities including: stake and twine symbolic fencing around nesting areas, exclosures around nests, posting signage to identify nesting areas, and locating and monitoring nesting pairs.
					Conduct intensive predator management including lethal and nonlethal removal of native and nonnative predators from nesting and brood rearing areas.
		Survey and Monitoring	High	On-going	Continue efforts to annually monitor abundance, distribution, and productivity.
			Moderate	On-going	Continue efforts to recruit and provide training sessions for volunteer beach monitors.

Table 4-7. *continued: page 2 of 6.*

Scientific Name	Common Name	Category	Biological Priority	Type	Description
Numenius phaeopus	Whimbrel	Research	High	New	Determine population status, pre migration body condition, and importance of commercial blueberry barrens to staging whimbrels.
					Determine potential impacts from hazing and disturbance occurring on commercial blueberry barrens
Sterna dougallii	Roseate Tern	Species Management	High	On-going	Increase breeding population distribution and productivity
Sternula antillarum	Least Tern	Habitat Management	High	On-going	Develop long-term, non-regulatory habitat protection via management agreements or conservation easements.
		Public Outreach	High	On-going	Continue efforts to educate beach recreationalists, landowners and municipal officials regarding ecology and life history requirements.
		Species Management	Critical	On-going	Continue current management activities including: stake and twine symbolic fencing around nesting areas, exclosures around colonies, posting signage to identify nesting areas, and locating and monitoring nesting pairs.
					Continue targeted management of native and nonnative predators at nesting and brood rearing areas, including lethal and nonlethal methods
		Survey and Monitoring	High	On-going	Continue efforts to annually monitor abundance, distribution, and productivity.
		Survey and Monitoring	Moderate	On-going	Continue efforts to recruit and provide training sessions for volunteer beach monitors.
Tringa flavipes	Lesser Yellowlegs	Research	High	New	To determine if recent population declines are due to impacts occurring in Maine, conduct research to: identify food quality and quantity at lesser yellowleg staging areas; assess premigration body condition; length of stay; other potential limiting
		Survey and Monitoring	High	New	Survey inland wetlands to identify and map important inland staging areas.
Tringa solitaria	Solitary Sandpiper	Survey and Monitoring	High	New	Survey inland wetlands to identify and map important inland staging areas.
Falco peregrinus	Peregrine Falcon	Public Outreach	Moderate	New	Develop an information pamphlet and website content focused on the importance of hikers and rock climbers limiting disturbance to nesting peregrines.
		Species Management	High	On-going	Work with landowners to reduce seasonal disturbances within 1/4 mile of occupied nests
					Encourage voluntary trail closures until five weeks after the last bird has fledged

Table 4-7. *continued: page 3 of 6.*

Scientific Name	Common Name	Category	Biological Priority	Type	Description
Ammodramus caudacutus	Saltmarsh Sparrow	Habitat Management	High	On-going	Support current Phragmites control efforts in southern Maine and expand to other regions as needed. Monitor effectiveness by conducting point counts to determine bird response.
		Research	High	New	Determine the relative impacts of point source (river-born) vs non-point source (atmospheric) contamination by Mercury.
					Investigate what role, if any, non-native invasive species have in habitat loss or reduction in habitat quality. Determine mitigation measures appropriate for Maine saltmarshes.
			Moderate	New	Determine whether the restoration of tidal action would improve resiliency to sea level rise and whether restricted areas would serve as High marsh refugia, at least temporarily
		Species Management	Moderate	New	Determine whether gene flow from Nelson's sparrow will lead to loss of Saltmarsh Sparrow genotype from Maine, and whether certain marshes may be more resistant to hybridization?
		Survey and Monitoring	Critical	New	Develop a long-term monitoring program which allows for evaluation of effects of human perturbations, natural changes to habitat and management actions to reverse/mitigate such actions.
Ammodramus nelson	Nelson's Sparrow	Research	High	New	Investigate what role, if any, non-native invasive species have in habitat loss or reduction in habitat quality. Determine mitigation measures appropriate for Maine saltmarshes.
			Moderate	New	Assess whether Mercury is a problem at marshes across Maine and whether certain marshes pose a Higher risk
			Moderate	New	Determine the relative impacts of point source (landfills) vs non-point source (atmospheric) contamination by Mercury on post-fledgling survival
		Survey and Monitoring	High	New	Develop a long-term monitoring program which allows for evaluation of effects of human perturbations, natural changes to habitat and management actions to reverse/mitigate such actions.
Ammodramus savannarum	Grasshopper Sparrow	Habitat Management	Critical	New	Conduct landscape analysis to determine potential for other sites for this species, what management would be necessary, and current ownership
			High	On-going	Maintain known nesting areas in native grasses, little bluestem, or low-growing shrubs like lowbush blueberry and prevent conversion to other land uses
			Moderate	New	Restore old, unused gravel pits and agricultural fields to grasslands and low shrubs

Table 4-7. *continued: page 4 of 6.*

Scientific Name	Common Name	Category	Biological Priority	Type	Description
Ammodramus savannarum (continued)	Grasshopper Sparrow (continued)	Public Outreach	Critical	New	Contact landowners at formerly occupied (Wells, Sanford) and potential sites (near Poland) to examine opportunities for habitat enhancement and management of species.
		Research	Critical	New	Conduct research on population status, productivity levels, and limiting factors at individual sites, and use this information to update a Population Viability Analysis
			High	New	Assess effects of past and present management practices at the Kennebunk Plains by comparing with long-term population data by management unit over time
		Survey and Monitoring	Critical	On-going	Continue to monitor populations at Kennebunk Plains and the former Naval Air Station in Brunswick
			High	New	Expand monitoring effort to other potential or previously occupied sites (Sanford Airport, Wells Barrens, Poland Spring fields)
		Habitat Management	High	New	Encourage landowners to manage the amount and timing of pre-commercial thinning in areas occupied by this species, and to leave residual patches in areas that are thinned
					Encourage land managers to rotate harvests and create a mixed distribution of stand ages, which might undergo pre-commercial thinning and cutting at different times, thus temporally balancing the amount of habitat available at a given time.
		Policy	High	New	For suitable/occupied habitat on public lands (BPL) incorporate stand management BMPs into public land management policy.
Catharus bicknelli	Bicknell's Thrush	Research	High	New	Determine how this species responds to specific forestry practices on the landscape.
					Assess the effects of climate change on habitat loss, occupancy, and predicted range shift.
		Species Management	Critical	New	Work to ensure that developments at high elevation that entail land clearing, specifically permanent conversion of forest to non-forest (road, gravel, grass) avoid areas occupied by Bicknell's Thrush
			High	On-going	Participate in work of International Bicknell's Thrush Conservation Group (IBTCG) to track progress on conservation and research actions, discuss funding needs and revise the wildlife action plan as appropriate to ensure that emerging information is used to inform
		Survey and Monitoring	High	On-going	Support Mountain Birdwatch 2.0, an international, volunteer-based program to track Bicknell's Thrush populations across their breeding range.

Table 4-7. *continued: page 5 of 6.*

Scientific Name	Common Name	Category	Biological Priority	Type	Description
Euphagus carolinus	Rusty Blackbird	Research	High	New	Examine the food web of boreal forest wetlands and determine the role of aquatic invertebrates (Tricoptera, Odonata) in maintaining Rusty Blackbird abundance and productivity.
					Investigate postfledging habitat use relative to timber harvest practices
					Evaluate the effects of precommercial thinning on nesting habitat quality and determine whether nesting success is more sensitive to pre-commercial thinning in some landscapes than in others
				On-going	Support cross-agency data sharing to better understand breeding range-wide survival and fecundity.
		Species Management	High	New	Work with partners on wintering grounds to develop a full life cycle model of demography
Progne subis	Purple Martin	Habitat Management	High	New	Support further development, and increase awareness of, existing BMPs for purple martin colony management in concert with Purple Martin Conservation Association
		Public Outreach	High	On-going	Increase public awareness of the Purple Martin Conservation Association and its activities
		Research	High	On-going	Support Scout Arrival Study, monitoring of arrival times, through Purple Martin Conservation Association
					Support Purple Martin Nest Cavity Research Project which uses mini martin cams to monitor nestling development and engage volunteers; consider a live web cam
		Species Management	High	New	Provide support or otherwise increase awareness of the mentor program for Purple Martin colony landlords consistent with efforts of the Purple Martin Conservation Association
		Survey and Monitoring	Critical	New	Conduct an inventory of breeding colonies, possibly using eBird.
			High	On-going	Promote the registration of existing colonies through Purple Martin Conservation Association
				On-going	Support Project Martinwatch, a weekly nest monitoring program, through Purple Martin Conservation Association
Riparia riparia	Bank Swallow	Public Outreach	High	New	Collaborate with gravel pit operators to develop Best Management Practices for reclamation of abandoned pits
		Research	Critical	New	Gather more information on the influence of Neonicotinoid (systemic) pesticides on populations of aerial insectivores.

Table 4-7. *continued: page 6 of 6.*

Scientific Name	Common Name	Category	Biological Priority	Type	Description
Sturnella magna	Eastern Meadowlark	Habitat Management	Critical	New	Improve habitat quality and abundance.
Nycticorax nycticorax	Black-crowned Night-heron	Research	High	New	Determine whether prefledging success and productivity rates are contributing to declining numbers
			Moderate	New	Investigate effect of aerial predators (gulls, crows, eagles) on nesting success.
		Species Management	Moderate	New	Develop outreach program to educate landowners and recreational users about black-crowned night herons' breeding habitat requirements and sensitivity to disturbance.
					In cooperation with landowners and partners, develop and post signs at colonies encouraging users to keep a wide berth during nesting.
		Survey and Monitoring	High	New	Implement targeted surveys to better understand the distribution and status of this species and to help direct conservation actions to Newly documented populations

Table 4-8. Conservation Actions assigned to Reptile, Amphibian, and Invertebrate SGCN.

CLASS Scientific Name	Common Name	Category	Biological Priority	Type	Description
AMPHIBIA (Amphibians)					
Ambystoma laterale	Blue-spotted Salamander	Policy	Moderate	On-going	Cooperate with University of Maine and the Maine Department of Environmental Protection to research and implement a voluntary Special Area Management Program (SAMP) by towns.
		Research	High	On-going	Develop an improved understanding of habitat and movement ecology with the goal of informing Best Management Practices and other targeted species conservation actions
		Survey and Monitoring	High	On-going	Pure diploid (and non-hybrid) populations of Ambystoma laterale are believed to be rare in Maine and throughout their range. Systematic tissue sampling is needed to document the extent and distribution of all genotypes within the species complex, with a focus on identifying cryptic diploid populations requiring potential targeted conservation attention.
REPTILIA (Reptiles)					
Coluber constrictor constrictor	Northern Black Racer	Habitat Management	Critical	On-going	Manage black racer habitat to improve and expand upon habitat that is available where populations occur.
		Survey and Monitoring	Moderate	New	Identify potential road crossing hotspots using GIS and monitor mortality at those locations with road surveys to prioritize the most problematic road segments for mitigation measures such as cautionary signage, exclusionary fencing, and under-road passages.
Storeria dekayi dekayi	Northern Brownsnake	Survey and Monitoring	Moderate	New	Implement targeted professional surveys to better understand the distribution and status of this species and to help direct conservation actions to Newly documented populations
Thamnophis sauritus	Eastern Ribbon Snake	Policy	Moderate	On-going	Cooperate with University of Maine and the Maine Department of Environmental Protection to research and implement a voluntary Special Area Management Program (SAMP) by towns.
		Research	High	New	Develop an improved understanding of habitat and movement ecology to help develop Best Management Practices and other targeted species conservation actions

Table 4-8. *continued: page 2 of 5.*

CLASS Scientific Name	Common Name	Category	Biological Priority	Type	Description
REPTILIA (Reptiles) *continued*					
Clemmys guttata	Spotted Turtle	Habitat Management	High	New	Research and coordinate the development of a publically available Potential Vernal Pool map product that covers the entire State, or at least all organized townships
		Policy	Moderate	On-going	Cooperate with University of Maine and the Maine Department of Environmental Protection to research and implement a voluntary Special Area Management Program (SAMP) by towns.
		Public Outreach	High	On-going	Continue to build public awareness of risks posed by roadways with seasonally appropriate press release that also warns motorists to be on the lookout for turtles during spring/early summer.
		Species Management	Critical	New	Identify potential road crossing hotspots using GIS and monitor mortality at those locations with road surveys to prioritize the most problematic road segments for mitigation measures such as cautionary signage and exclusionary fencing.
					Install road crossing structures consisting of under-road passageways and guidance fencing where High-mortality road segments bisect habitat that hosts High priority populations
			High	On-going	Continue the cautionary road crossing signage program, and expand the number of locations with signs as additional road crossing hotspots are identified.
					Deter casual collection by educating the public on the importance of leaving turtles where they find them
Emydoidea blandingii	Blanding's Turtle	Habitat Management	High	New	Manage and where necessary create nesting habitat to improve viability of High-priority Blanding's turtle populations
			High	New	Research and coordinate the development of a publicly available Potential Vernal Pool map product that covers the entire State, or at least all organized townships
		Policy	Moderate	On-going	Cooperate with University of Maine and the Maine Department of Environmental Protection to research and implement a voluntary Special Area Management Program (SAMP) by towns.
		Public Outreach	High	On-going	Continue to build public awareness of risks posed by roadways with seasonally appropriate press release that also warns motorists to be on the lookout for turtles during spring/early summer.

Table 4-8. *continued: page 3 of 5.*

CLASS Scientific Name	Common Name	Category	Biological Priority	Type	Description
REPTILIA (Reptiles) *continued*					
Emydoidea blandingii (continued)	Blanding's Turtle (continued)	Research	Critical	On-going	Identify potential road crossing hotspots using GIS and monitor mortality at those locations with road surveys to prioritize the most problematic road segments for mitigation measures such as cautionary signage, exclusionary fencing, and under-road passages.
		Species Management	Critical	New	Install road crossing structures consisting of under-road passageways and guidance fencing where high-mortality road segments bisect habitat that hosts high priority populations.
			High	On-going	Continue the cautionary road crossing signage program, and expand the number of locations with signs as additional road crossing hotspots are identified.
Glyptemys insculpta	Wood Turtle	Policy	High	On-going	Deter casual collection by educating the public on the importance of leaving turtles where they find them
		Public Outreach	Moderate	On-going	Continue to build public awareness of risks to wood turtles posed by roadways with seasonally appropriate press release that also warns motorists to be on the lookout for turtles during spring/early summer.
		Species Management	High	New	Install road crossing structures consisting of under-road passageways and guidance fencing where High-mortality road segments bisect habitat that hosts High priority populations
			High	On-going	Identify potential road crossing hotspots using GIS and monitor mortality at those locations with road surveys to prioritize the most problematic road segments for mitigation measures such as cautionary signage and exclusionary fencing.
			Moderate	On-going	Expand cautionary road crossing signage program to include wood turtle as important road crossing hotspots are identified for this species.
BIVALVIA (Bivalves)					
Alasmidonta varicosa	Brook Floater	Survey and Monitoring	Critical	On-going	Develop and implement a systematic protocol for monitoring population size, demographics, and trends.
Lampsilis cariosa	Yellow Lampmussel	Survey and Monitoring	Critical	New	Develop and implement a systematic protocol for monitoring population size, demographics, and trends.
Leptodea ochracea	Tidewater Mucket	Survey and Monitoring	Critical	New	Develop and implement a systematic protocol for monitoring population size, demographics, and trends.

Table 4-8. *continued: page 4 of 5.*

CLASS Scientific Name	Common Name	Category	Biological Priority	Type	Description
GASTRPODA (Gastropods)					
Stagnicola mighelsi	Bigmouth Pondsnail	Research	High	New	Examine effects of dams as well as water quality changes from residential and agricultural pollutant and nutrient runoff on bigmouth pondsnail populations
				On-going	Develop an improved understanding of habitat and movement ecology with the goal of informing Best Management Practices and other targeted species conservation actions
Cicindela marginipennis	Cobblestone Tiger Beetle	Research	High	New	Develop an improved understanding of habitat and movement ecology with the goal of informing Best Management Practices and other targeted species conservation actions
INSECTA (Insects)					
Epeorus frisoni	Roaring Brook Mayfly	Survey and Monitoring	High	On-going	Develop and implement a systematic protocol for monitoring population size, demographics, and trends.
Siphlonisca aerodromia	Tomah Mayfly	Survey and Monitoring	High	On-going	Develop and implement a systematic protocol for monitoring population size, demographics, and trends.
Boloria chariclea grandis	Purple Lesser Fritillary	Research	High	New	Prepare a statewide atlas and conservation assessment.
		Species Management	Critical	New	Prepare occurrence maps and pesticide spray consultation guidelines for rare Lepidoptera and distribute to strategic partners including Maine Bureau of Pesticides Control.
			Moderate	New	Collaborate with the Maine Forest Service and other partners to develop Forestry Species Management Guidelines for distribution to cooperative landowners and the forest management community.
Callophrys gryneus	Juniper Hairstreak	Habitat Management	Critical	New	Research host tree regeneration ecology and develop site restoration management strategies for distribution to cooperative landowners.
		Research	High	New	Prepare a statewide atlas and conservation assessment.
Callophrys hesseli	Hessel's Hairstreak	Habitat Management	Moderate	New	Conduct a comprehensive review of silvicultural effects on Atlantic White Cedar habitat (e.g., regeneration, composition, structure)
		Species Management	Moderate	New	Collaborate with the Maine Forest Service and other partners to develop Forestry Species Management Guidelines for distribution to cooperative landowners and the forest management community.
Erora laeta	Early Hairstreak	Research	High	New	Prepare a statewide atlas and conservation assessment.

Table 4-8. *continued: page 5 of 5.*

CLASS Scientific Name	Common Name	Category	Biological Priority	Type	Description
INSECTA (Insects) *continued*					
Erynnis brizo	Sleepy Duskywing	Research	High	New	Prepare a statewide atlas and conservation assessment.
Lycaena dorcas claytoni	Clayton's Copper	Habitat Management	Critical	New	Conduct selective thinning at sites where forest canopy is encroaching and shading out host plant stands.
		Research	High	New	Prepare a statewide atlas and conservation assessment.
		Survey and Monitoring	Critical	On-going	Develop and implement a systematic protocol for monitoring population size, demographics, and trends.
Lycia rachelae	Twilight Moth	Research	High	New	Identify host plant(s) and document extent of habitat use outside Pitch Pine - Scrub Oak barrens
		Survey and Monitoring	High	New	Develop and implement a systematic protocol for monitoring population size, demographics, and trends.
Oeneis polixenes katahdin	Katahdin Arctic	Habitat Management	High	New	Work with BSP and MNAP to develop tundra habitat monitoring procedures for assessing potential impacts from off-trail recreation.
		Research	High	New	Prepare a statewide atlas and conservation assessment.
		Survey and Monitoring	High	New	Work with Baxter State Park to develop species monitoring protocols that are robust enough to detect potential trends in population size.
Plebejus idas	Northern Blue	Research	High	New	Prepare a statewide atlas and conservation assessment.
		Species Management	Critical	New	Prepare occurrence maps and pesticide spray consultation guidelines for rare Lepidoptera and distribute to strategic partners including Maine Bureau of Pesticides Control.
Plebejus idas empetri	Crowberry Blue	Research	High	New	Prepare a statewide atlas and conservation assessment.
Satyrium edwardsii	Edwards' Hairstreak	Research	High	New	Prepare a statewide atlas and conservation assessment.
Zanclognatha martha	Pine Barrens Zanclognatha	Survey and Monitoring	High	New	Develop and implement a systematic protocol for monitoring population size, demographics, and trends.
Gomphus quadricolor	Rapids Clubtail	Survey and Monitoring	Critical	New	Conduct surveys to determine the status of the historic population(s) on the Saco River. This species may no longer be extant in Maine.
Williamsonia lintneri	Ringed Boghaunter	Research	High	New	Develop an improved understanding of habitat and movement ecology with the goal of informing Best Management Practices and other targeted species conservation actions

Table 4-9. Conservation Actions assigned to Inland Fish SGCN.

Scientific Name	Common Name	Category	Biological Priority	Type	Description
Esox americanus americanus	Redfin Pickerel	Habitat Management	Critical	On-going	Work with landowners to enhance and restore riparian buffers on redfin pickerel occupied streams within agricultural lands.
					Enhance and improve fish passage to proximal habitats so redfin pickerel can migrate to and colonize new habitats as necessary.
			High	On-going	Work with agricultural landowners to restrict or eliminate livestock access to streams occupied by redfin pickerel.
Etheostoma fusiforme	Swamp Darter	Research	High	New	Conduct research to develop an improved understanding of seasonal habitat requirements for all size and age classes
					Conduct research to develop an improved understanding of spawning ecology
					Conduct research to develop an improved understanding of trophic ecology
		Survey and Monitoring	High	On-going	Implement targeted professional surveys to better understand the distribution and status of this species and to help direct conservation actions to newly documented populations
Salvelinus alpinus oquassa	Arctic Charr	Habitat Management	High	On-going	Identify key aquatic habitats such as spawning sites and coordinate protection with federal, state, or NGOs and willing private landowners
					Identify key terrestrial habitats connected or adjacent to aquatic habitats that are essential to maintaining viability of populations
		Research	High	On-going	Investigate and describe all life history and life cycle requirements of each population to provide for maximum protection of each population
		Species Management	Critical	On-going	Assess population status at each location where the species is present
			High	On-going	Assess the utilization of charr by recreational anglers, including harvest rates and the attitudes of participating anglers

Table 4-10. Conservation Actions assigned to Mammal SGCN.

Scientific Name	Common Name	Category	Biological Priority	Type	Description
Sylvilagus transitionalis	New England Cottontail	Habitat Management	Critical	On-going	Restore early successional habitat in southern Maine following guidance in the New England Cottontail Conservation Strategy.
		Public Outreach	High	On-going	Improve public perception of the value of early successional habitat following guidance in the New England Cottontail Conservation Strategy.
		Species Management	High	On-going	Conduct a captive breeding program following guidance in the New England Cottontail Conservation Strategy.
		Survey and Monitoring	High	New	Conduct active restoration of early-successional brushy habitat on both private and public lands in southern Maine, and monitor the success of habitat restoration using methodologies identified in the Rangewide Conservation Strategy.
					Monitor released individuals from the captive breeding program using radio telemetry to determine survival and use of landscape. Alternatively, populations may be monitored using mark-recapture techniques that rely on genotype.
Synaptomys borealis sphagnicola	Northern Bog Lemming	Policy	Moderate	On-going	Develop a policy where the Maine Forest Service or LURC would notify IFW of forest management plans where cutting was planned on High elevation sites (above 2,700 feet).
		Research	Moderate	New	Develop a technique to identify northern bog lemmings using e-DNA found in small water bodies associated with alpine sites.

Table 4-11. Conservation Actions assigned to Marine SGCN.

CLASS Scientific Name	Common Name	Category	Biological Priority	Type	Description
ACTINOPTERYGII (Ray-finned fishes)					
Pseudopleuronectes americanus	Winter Flounder	Research	Moderate	New	Identify areas where winter flounder spawn
				On-going	Conduct research regarding winter flounder habitat needs for various life stages and determine the importance of unique habitat systems such as eelgrass on survivability
		Survey and Monitoring	High	On-going	Monitor water quality at winter flounder habitats to determine effect of changing water quality on winter flounder biology and survivability (e.g. temperature and sex ratio relationships).
CHONDRICHTHYES (Sharks and skates)					
Isurus oxyrinchus	Shortfin Mako	Research	High	New	Determine the location and timing of important habitat use at different life history stages
					Identify methods to reduce incidental bycatch by recreational anglers
					Develop an improved understanding of discard mortality rates
Lamna nasus	Porbeagle	Research	Critical	New	Determine the location and timing of important habitat use at different life history stages
					Identify methods to reduce incidental bycatch by recreational anglers
					Develop an improved understanding of discard mortality rates
Amblyraja radiata	Thorny Skate	Research	Critical	New	Develop an improved understanding of discard mortality rates
					Determine the location and timing of important habitat use at different life history stages
					Update life history data across species range
Dipturus laevis	Barndoor Skate	Research	High	New	Develop an improved understanding of discard mortality rates
					Update life history data across species range
			Moderate	New	Determine the location and timing of important habitat use at different life history stages
Leucoraja ocellata	Winter Skate	Research	High	New	Update life history data across species range
Malacoraja senta	Smooth Skate	Research	Critical	New	Develop an improved understanding of discard mortality rates
					Determine the location and timing of important habitat use at different life history stages

Table 4-11. *continued: page 2 of 3.*

CLASS Scientific Name	Common Name	Category	Biological Priority	Type	Description
ECHINOIDEA (Echinoderms)					
Strongylocentrotus droebachiensis	Green Sea Urchin	Public Outreach	High	On-going	Design and encourage the use of more size-selective fishing gear
		Research	High	New	Determine the relative roles of natural predation, fishing mortality, and climate change in stock dynamics
					Assess the feasibility and advantages of local or area species management approaches
				On-going	Conduct research to support stock assessment and population dynamics modeling
			Moderate	New	Determine the feasibility of reseeding programs
		Species Management	High	On-going	Support community engagement in developing a fisheries management plan
		Survey and Monitoring	Critical	On-going	Monitor stock status through surveys and sampling programs
HOLOTHUROIDEA (Sea cucumbers)					
Cucumaria frondosa	Orange-footed Sea Cucumber	Public Outreach	High	On-going	Design and encourage the use of more size-selective fishing gear
		Research	High	New	Conduct research to support management, including stock assessments, reproduction, growth and aging data, and habitat mapping
			Moderate	New	Assess the feasibility and advantages of local or area species management approaches
		Species Management	Moderate	New	Support community engagement in developing a fisheries management plan
		Survey and Monitoring	High	New	Monitor stock status through surveys and sampling programs

Table 4-11. *continued: page 3 of 3.*

CLASS Scientific Name	Common Name	Category	Biological Priority	Type	Description
MALACOSTRACA (Crabs, lobsters, and shrimp)					
Pandalus borealis	Northern Shrimp	Public Outreach	High	On-going	Design and encourage the use of more size-selective fishing gear
		Research	High	New	Conduct research to support stock assessment and population dynamics modeling
				On-going	Determine the relative roles of natural predation, fishing mortality, and climate change in stock dynamics
		Survey and Monitoring	Critical	On-going	Monitor stock status through surveys and sampling programs
MAMMALIA (Mammals)					
Phocoena phocoena	Harbor Porpoise	Public Outreach	Moderate	On-going	Continue to work with the fishing industry to develop gear modifications that reduce the risk of entanglement and conduct outreach on gear best practices to use
MEROSTOMATA (Horseshoe crabs)					
Limulus polyphemus	Horseshoe Crab	Habitat Management	High	On-going	Collaborate with partners to conserve undeveloped shoreline and adjacent areas that is known or potential habitat for horseshoe crab
		Public Outreach	High	On-going	Encourage use of selective fishing gear that minimizes bycatch and impacts to habitat.
		Research	High	On-going	Promote research to fill data gaps and inform managers
			Moderate	On-going	Identify areas where degraded water quality may adversely impact horseshoe crabs
		Survey and Monitoring	High	New	Conduct surveys to monitor and better understand distribution and abundance

Table 4-12. SGCN conservation actions by Action Category.

Taxonomic Group	Habitat Management	Policy	Public Outreach	Research	Species Management	Survey and Monitoring	Total
Birds	24	9	12	34	21	25	**125**
Inland Fish	5	0	0	6	2	3	**16**
Mammals	3	4	1	4	3	5	**20**
Marine	1	0	8	44	12	13	**78**
Reptiles, Amphibians, and Invertebrates	9	5	3	17	13	13	**60**
Total	**42**	**18**	**24**	**105**	**51**	**59**	**299**

Table 4-13. SGCN conservation actions by Type.

Taxonomic Group	New	On-going	Total
Birds	65	60	**125**
Inland Fish	3	13	**16**
Mammals	10	10	**20**
Marine	35	43	**78**
Reptiles, Amphibians, and Invertebrates	38	22	**60**
Total	**151**	**148**	**299**

Table 4-14. SGCN conservation actions by Biological Priority.

Taxonomic Group	Critical	High	Moderate	Total
Birds	19	73	33	**125**
Inland Fish	4	12	0	**16**
Mammals	3	14	3	**20**
Marine	15	42	21	**78**
Reptiles, Amphibians, and Invertebrates	14	35	11	**60**
Total	**55**	**176**	**68**	**299**

4.3 HABITAT CONSERVATION ACTIONS

4.3.1 HABITAT ACTION BACKGROUND

Maine's 2015 Wildlife Action Plan takes a holistic approach to SGCN conservation by focusing on both species and habitats. Habitat-scale conservation uses a coarse-filter approach whereby strategies applied to habitats likely benefit many of the species that occur there. Because habitat-scale actions simultaneously benefit multiple species, they often are an efficient way to stretch limited conservation dollars and often complement species-specific approaches. While this Plan identifies over 300 SGCN actions, many of the most common stressors to Maine's SGCN are associated with habitats (see Element 3).

Maine's landscape is diverse, from subtidal gravel beds to alpine tundra, and the issues facing these habitats are complex, from localized land-use conversion to regional impacts of climate change. In order to systematically address these complexities, MDIFW, the Steering Committee, and conservation partner representatives worked in small groups (10-15 people) to draft habitat-scale conservation actions based on The Open Standards for the Practice of Conservation (hereafter referred to as 'Open Standards'; Conservation Measures Partnership [CMP] 2013). While widespread conservation partner involvement was crucial at all stages of Wildlife Action Plan development, the Steering Committee and MDIFW chose this small workgroup approach out of respect for partners' limited time. We felt the most efficient approach was to first create draft actions to which the full partner group could modify as needed.

"Maine's landscape is diverse, from subtidal gravel beds to alpine tundra, and the issues facing these habitats are equally complex..."

4.3.2 DEVELOPMENT OF HABITAT CONSERVATION ACTIONS

Maine developed its habitat conservation actions as follows:

1. MDIFW, the Steering Committee, and several conservation partners attended an Open Standards introductory training led by a local CMP Conservation Coach in mid-February 2015.

2. MDIFW, MNAP, MCP, MDMR, and members of the Steering Committee assigned all habitat macrogroups to one of 14 'habitat groupings' (Table 4-15), based on similar ecology, spatial distribution, and/or stressors. Certain macrogroups (e.g., vernal pools, northeastern floodplain forests, central oak pine barrens) did not fit cleanly into habitat groupings due to their ecological uniqueness or nuances of stressors facing them; we pulled these macrogroups out separately into their own habitat grouping. We then assigned habitat groupings to one of three workgroups for discussion: 1) terrestrial/wetland habitats; 2) marine/coastal habitats; or 3) freshwater aquatic habitats.

Table 4-15. Habitat groupings addressed by conservation action workgroups.

Workgroup	Habitat Grouping	Habitats (Macrogroups)
Terrestrial/Freshwater Wetlands	Northern Forests and Swamps	boreal forested peatland; boreal upland forest; northern swamp, plantation and ruderal forest, northern hardwood and conifer; northern peatland and fens
	Rocky Summits-Outcrops-Mountaintops	alpine; cliff and talus; outcrop and summit scrub
	Floodplain Forests	northeastern floodplain forest
	Freshwater Marshes	wet meadow-shrub marsh; emergent marsh; modified-managed marsh; coastal plain pond
	Vernal Pools	vernal pools
	Grassland-shrubland-early Successional	agricultural; maintained grasses and mixed cover; ruderal shrubland and grassland
	South-Central Forests and Swamps	central hardwood swamp; glade, barren and savanna; northern hardwood and conifer; northern swamp; coastal plain peat swamp
	Pine Barrens	central oak pine
Marine/Coastal	Tidal Marsh	intertidal tidal marsh (peat forming)
	Intertidal	bedrock; gravel shore; mollusc reefs; mudflat; sandy shore; water column
	Subtidal	bedrock bottom; coarse gravel bottom; mollusc reefs; mud bottom; sand bottom; pelagic (water column)
	Rocky Coast	rocky coast/islands
	Coastal	coastal grasslands and shrublands
Freshwater Aquatics	Streams, Rivers, Lakes, and Ponds	dystrophic lakes and ponds; eutrophic lakes and ponds; mesotrophic or intermediate lakes and ponds; oligotrophic lakes and ponds; lakeshore beach; large, medium, and small rivers, headwaters and creeks

3. In late February 2015, MDIFW, MNAP, MCP, MDMR, the Steering Committee, and partners nominated by the Steering Committee participated in two full-day Open Standards work sessions to begin developing conservation actions for each habitat grouping. Each work session was led by a CMP Conservation Coach who also was a member of the Steering Committee or a conservation partner. As a group, we created a conceptual model for each habitat grouping, linking key stressors to actions using the following approach:

   a. **Conservation Targets:** For each habitat grouping, the workgroup identified conservation targets, such as maintaining the current distribution of the habitat or its ecological integrity.

   b. **Key Stressors:** We then identified the key stressors to the habitat grouping. We began this discussion by first looking at stressors assigned to habitat macrogroups within the grouping that were at least moderately actionable and moderately severe. If the workgroup felt this list of stressors sufficiently captured the major challenges facing the habitat grouping as a whole, we moved onto the next step. If not, we used our best professional judgement to decide whether we should address additional stressors with conservation actions.

      We recognize that certain activities identified as 'stressors' to certain habitats or SGCN can also have positive effects or no effects at all. For example, aquaculture activities like shellfish seeding and macroalgae can help improve water quality and help form substrate for important habitats like eelgrass. For this exercise, however, we limited our scope of conservation actions to address only the negative effects of stressors.

   c. **Contributing Factors:** For each stressor, the workgroup identified the contributing factors that exacerbated the stressor for a particular habitat grouping. For example, we identified Fire Suppression as a key stressor to central oak pine barrens. This stressor is exacerbated by the public's perception of fire and its lack of understanding of the role of fire in maintaining this habitat. These are key factors inhibiting the use of fire as a management tool, especially near developed areas.



Conservation partners used an Open Standards approach to develop habitat conservation actions. © Mark Stadler

   d. **Conservation Actions:** For each stressor, we developed conservation actions designed to alleviate or mitigate that stressor and its contributing factors. For each conservation action, we strived to create a clear link between the action, stressor, and the action's intended benefit to the habitat grouping. We diagrammed these

relationships based on Open Standards models. Figure 4-2 depicts a draft conceptual diagram linking stressors and actions for central oak pine barrens.

e. **Categorization:** For each conservation action, we assigned a rank for Biological Priority, Action Type, and Action Category using the criteria described in section 4.1.2.

f. **Review:** Each workgroup reviewed and provided feedback on the conceptual diagrams for each habitat grouping in mid-March 2015.

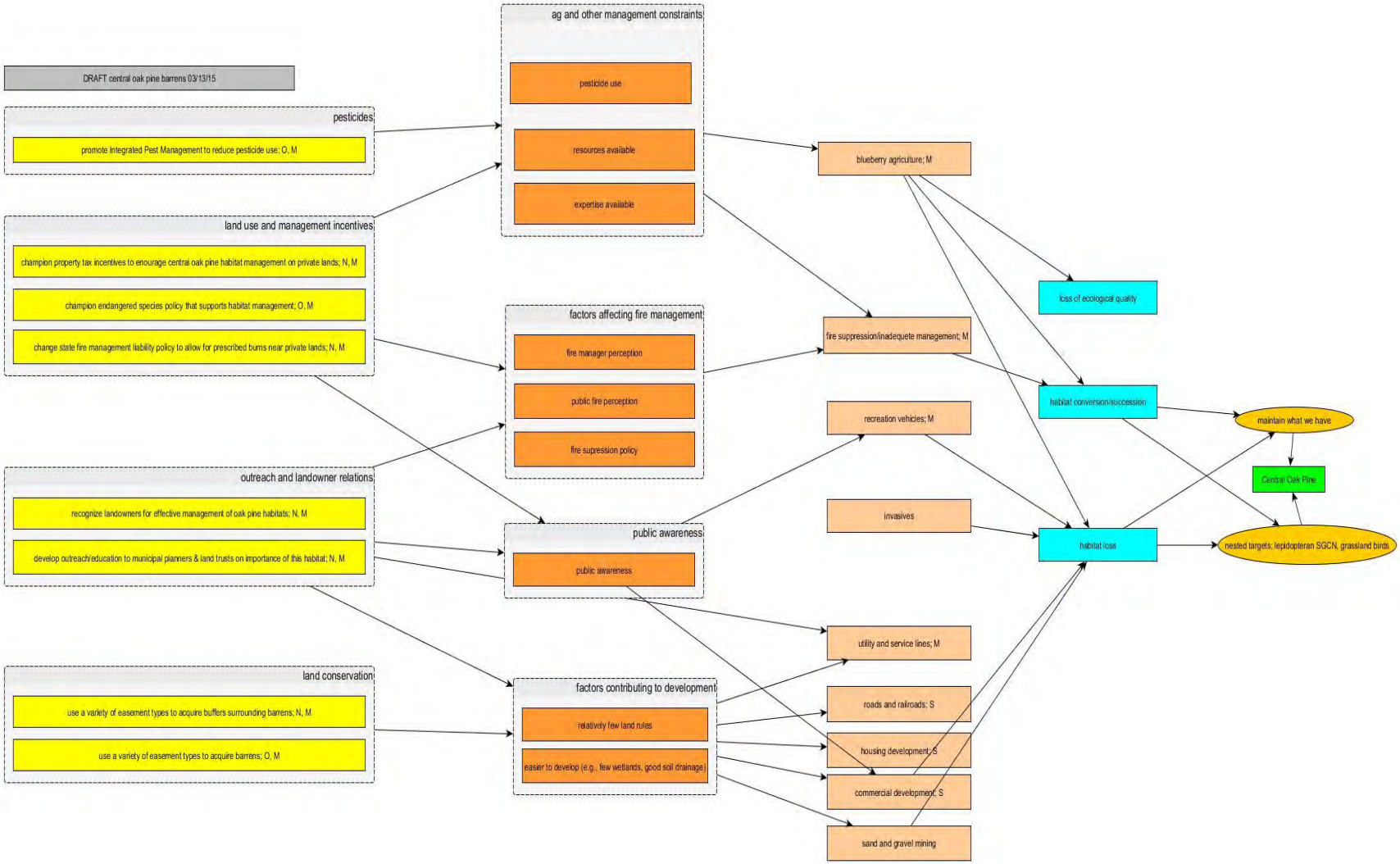
4. We presented the draft list of habitat conservation actions to conservation partners at a meeting on June 16, 2015; we also distributed actions by email for review and feedback. We modified habitat conservation actions as appropriate, based upon partner review comments.

5. We posted the draft Wildlife Action Plan online on July 13, 2015 for a 30-day public comment period (see Elements 7/8 for more information). MDIFW and agency partners reviewed habitat action comments and modified conservation actions as appropriate, again, based on review comments.



Restoring habitat connectivity at road crossings is an important conservation action for many SGCN and often involves coordination among state and local transportation agencies, biologists, landowners, and other partners. © John Perry

Figure 4-2. Example Open Standards conceptual model diagram for the central oak pine barren habitat. Text boxes are as follows: yellow boxes (conservation actions); orange boxes (contributing factors); peach boxes (key stressors); blue boxes (specific issues caused by stressors; green box (target habitat) and yellow ovals (specific conservation targets). Arrows indicate relationships among elements in the model.



4.3.3 SUMMARY OF HABITAT CONSERVATION ACTIONS

We identified 322 habitat actions that address stressors in all habitat groupings, including 54 freshwater aquatic habitat actions, 165 marine and coastal habitat actions, and 103 terrestrial and freshwater wetland habitat actions (Table 4-16). In general, we classified most actions as habitat management, policy, or public outreach (Table 4-17), and more than half are already on-going (Table 4-18). While all actions included on our list are important, we viewed approximately 25% as critical to habitat conservation over the next ten years (Table 4-19).



Creation and management of early successional habitat is important for many SGCN. This restored New England Cottontail (*Sylvilagus transitionalis*, SGCN Priority 1) habitat at Camp Ketcha in Scarborough, Maine, was made possible by partnerships among landowners, agencies, and biologists. © U.S. Fish and Wildlife Service

Table 4-16. 2015 Maine Wildlife Action Plan Habitat Conservation Actions. Actions are sorted by Habitat Workgroup (FW=freshwater habitats, M=marine and coastal habitats, TW=terrestrial and freshwater wetland habitats), Habitat Grouping (see Table 4-15), Action Category, then by Biological Priority (C=critical, H=high, M=moderate). Themes are described in Table 4-20. The Action ID # will allow users to search the relational database (once it becomes publically available) for a specific action.

*Stressor names are from Level 2 of the IUCN Threat Classification Scheme; these are broad categories that may not capture all the nuances of stressor-SGCN-habitat interactions, including beneficial effects. Readers are urged to refer to species and habitat reports for more details on interactions among stressors, habitats, and SGCN.

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
FW	82	Headwaters and Creeks	Public Outreach	H	new	Encourage improved road maintenance to reduce road gravel input and other pollutants into streams	F5			Roads and Railroads, Logging & Wood Harvesting
FW	83	Headwaters and Creeks	Public Outreach	H	new	Collaborate with partners to develop best management practices and provide technical assistance to landowners for riparian management in forest and agricultural lands	F4			Logging & Wood Harvesting, Agricultural and Forestry Effluents
FW	84	Headwaters and Creeks	Public Outreach	H	on-going	Provide outreach and education to forest landowners on the value of maintaining >60% tree cover in watersheds with high value SGCN habitats	F4	F1		Logging & Wood Harvesting
FW	85	Headwaters and Creeks	Public Outreach	H	on-going	Encourage wood addition as a management objective for riparian areas	F4			Logging & Wood Harvesting
FW	87	Headwaters and Creeks	Survey and Monitoring	M	new	Identify high value native Coldwater SGCN fish and other SGCN species habitats that may be vulnerable to watershed scale hydrology effects due to tree loss	F4	F1		Logging and Wood Harvesting
FW	121	Streams, Rivers, Lakes, and Ponds	Habitat Mgmt.	H	new	Identify and conserve coldwater resilient areas and waterbodies that are not amenable to the spread of invasive species	F3	F1		Invasive Non-native/Alien Species/Diseases

Table 4-16. *continued: page 2 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
FW	130	Streams, Rivers, Lakes, and Ponds	Habitat Mgmt.	H	on-going	Encourage implementation of the Standards for Placing Wood Into Stream Channels to Enhance Cold Water Fisheries Habitat, also known as the Chop and Drop Rule, to replace lost natural habitat structure in streams and lakes	F4			Logging & Wood Harvesting
FW	131	Streams, Rivers, Lakes, and Ponds	Habitat Mgmt.	H	on-going	Construct crossings to pass storm flows and ensure enduring aquatic SGCN organism passage	F2			Roads & Railroads
FW	104	Streams, Rivers, Lakes, and Ponds	Habitat Mgmt.	M	new	Encourage installation of constructed wetlands to buffer waterways from wastewater contamination	F5			Domestic and Urban Waste Water, Industrial and Military Effluents, Agricultural and Forestry Effluents
FW	122	Streams, Rivers, Lakes, and Ponds	Habitat Mgmt.	M	new	Use habitat modifications to reduce the vulnerability of habitats to species invasions, such as returning impoundments to free-flowing river conditions	F3	F2		Invasive Non-native/Alien Species/Diseases
FW	105	Streams, Rivers, Lakes, and Ponds	Policy	C	new	Provide incentives for landowners to maintain riparian buffers	F4			Domestic & Urban Waste Water, Agricultural and Forestry Effluents
FW	118	Streams, Rivers, Lakes, and Ponds	Policy	C	new	Encourage septic inspections when a house sells to ensure that it is functioning properly	F5			Domestic & Urban Waste Water
FW	124	Streams, Rivers, Lakes, and Ponds	Policy	C	on-going	Improve enforcement of existing laws related to the transport of invasive species by boats, anglers, and through the pet trade	F3			Invasive Non-native/Alien Species/Diseases
FW	125	Streams, Rivers, Lakes, and Ponds	Policy	C	on-going	Expand targeted inspections of boats and the pet trade in order to reduce the spread of invasives and raise awareness	F3			Invasive Non-native/Alien Species/Diseases

Table 4-16. *continued: page 3 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
FW	135	Streams, Rivers, Lakes, and Ponds	Policy	C	on-going	Provide support for municipalities implementing road stream crossing improvements	F2			Roads & Railroads
FW	89	Streams, Rivers, Lakes, and Ponds	Policy	H	new	Continue efforts to identify barriers to aquatic organism passage	F6	F1		Dams & Water Management/Use
FW	91	Streams, Rivers, Lakes, and Ponds	Policy	H	new	Identify funding to construct passage structures at dams	F6			Dams & Water Management/Use
FW	92	Streams, Rivers, Lakes, and Ponds	Policy	H	new	Provide outreach to practitioners on technologies that are effective at passing fish	F6			Dams & Water Management/Use
FW	93	Streams, Rivers, Lakes, and Ponds	Policy	H	new	Collaborate with partners to develop monitoring standards for SGCN fish passage efficiency	F6			Dams & Water Management/Use
FW	97	Streams, Rivers, Lakes, and Ponds	Policy	H	new	Apply state Streamflow standards to dams	F6			Dams & Water Management/Use
FW	106	Streams, Rivers, Lakes, and Ponds	Policy	H	new	Collaborate with partners to develop incentives to encourage homeowners near lake/river shores to replace their old septic systems	F5			Domestic & Urban Waste Water
FW	132	Streams, Rivers, Lakes, and Ponds	Policy	H	new	Collaborate with partners to develop standards for new/replacement road stream crossings	F2			Roads & Railroads

Table 4-16. *continued: page 4 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
FW	133	Streams, Rivers, Lakes, and Ponds	Policy	H	new	Collaborate with partners to develop a state road stream crossing restoration program with dedicated staff	F2			Roads & Railroads
FW	136	Streams, Rivers, Lakes, and Ponds	Policy	H	on-going	Conduct statewide/watershed scale connectivity planning	F2			Roads & Railroads
FW	137	Streams, Rivers, Lakes, and Ponds	Policy	H	on-going	Enhance coordination of agencies and NGOs to facilitate road stream crossing improvements	F2			Roads & Railroads
FW	109	Streams, Rivers, Lakes, and Ponds	Policy	M	new	Encourage municipalities to increase the capacity of their treatment facilities	F5			Domestic and Urban Waste Water
FW	139	Streams, Rivers, Lakes, and Ponds	Public Outreach	C	on-going	Continue Stream Smart general and technical training	F2			Roads & Railroads
FW	46	Streams, Rivers, Lakes, and Ponds	Public Outreach	H	new	Provide outreach and education to horticulturalists and landscape architects on the importance of maintaining riparian vegetation during the course of their work	F4	F1		Domestic & Urban Waste Water
FW	47	Streams, Rivers, Lakes, and Ponds	Public Outreach	H	new	Provide outreach and education to town planning boards on the importance of maintaining riparian vegetation to prevent declines in water quality	F4	F1		Domestic & Urban Waste Water, Industrial and Military Effluents, Agricultural and Forestry Effluents
FW	95	Streams, Rivers, Lakes, and Ponds	Public Outreach	H	new	Provide outreach and education to dam operators on ways to facilitate SGCN fish passage at dams	F6			Dams & Water Management/Use

Table 4-16. *continued: page 5 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
FW	112	Streams, Rivers, Lakes, and Ponds	Public Outreach	H	new	Provide outreach and education to residents living on lake or river shores on the importance of maintaining riparian buffers, including options that allow water views (i.e. unmowed grass, shrubs)	F4	F1		Domestic & Urban Waste Water
FW	113	Streams, Rivers, Lakes, and Ponds	Public Outreach	H	new	Provide outreach and education to code enforcement officers and town planners on wastewater discharge	F5	F1		Domestic & Urban Waste Water
FW	114	Streams, Rivers, Lakes, and Ponds	Public Outreach	H	new	Work with municipalities to increase treatment capacity of wastewater facilities to reduce wastewater impacts to aquatic habitats	F5			Domestic & Urban Waste Water
FW	138	Streams, Rivers, Lakes, and Ponds	Public Outreach	H	new	Provide online tools to prioritize road crossing upgrades	F2	F1		Roads & Railroads
FW	140	Streams, Rivers, Lakes, and Ponds	Public Outreach	H	on-going	Encourage the use of temporary and permanent bridges rather than culverts	F2			Roads & Railroads
FW	141	Streams, Rivers, Lakes, and Ponds	Public Outreach	H	on-going	Encourage information exchange forums such as Fisheries Improvement Network (FIN) and Small Woodlot Owners Association of Maine (SWOAM)	F2			Roads & Railroads
FW	142	Streams, Rivers, Lakes, and Ponds	Public Outreach	H	on-going	Encourage alternative road routes that do not interfere with streams or riparian areas	F2	F1		Roads & Railroads
FW	143	Streams, Rivers, Lakes, and Ponds	Public Outreach	H	on-going	Continue advanced aquatic SGCN organism passage training	F2			Roads & Railroads

Table 4-16. *continued: page 6 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
FW	96	Streams, Rivers, Lakes, and Ponds	Public Outreach	M	on-going	Train new and existing engineers on proper ways to design fish passage structures through universities and training programs	F6			Dams and Water Management/Use
FW	115	Streams, Rivers, Lakes, and Ponds	Public Outreach	M	new	Collaborate with partners to develop best management practices for development near waterways	F4	F5		Domestic and Urban Waste Water
FW	116	Streams, Rivers, Lakes, and Ponds	Public Outreach	M	new	Find ways to support communities addressing sewer overflow (e.g., treat storm water differently than sewage where appropriate)	F5			Domestic and Urban Waste Water
FW	99	Streams, Rivers, Lakes, and Ponds	Research	H	on-going	Investigate alternative technologies to promote passage of aquatic organisms	F6	F2		Dams & Water Management/Use
FW	100	Streams, Rivers, Lakes, and Ponds	Research	H	on-going	Research fish behavior and movement to identify ways to improve the design of fish passage structures	F6			Dams & Water Management/Use
FW	120	Streams, Rivers, Lakes, and Ponds	Research	H	new	Solicit help from experts in septic system design to determine solutions to septic seepage into waterways	F5			Domestic & Urban Waste Water
FW	127	Streams, Rivers, Lakes, and Ponds	Research	H	on-going	Conduct research on the economic impact of invasive species, mitigation strategies, and containment strategies in aquatic ecosystems	F3			Invasive Non-native/Alien Species/Diseases
FW	144	Streams, Rivers, Lakes, and Ponds	Research	M	on-going	Increase understanding of climate change/infrastructure threats to freshwater aquatic ecosystems	F2			Roads and Railroads, Habitat Shifting and Alteration, Dams and Water Management/Use

Table 4-16. *continued: page 7 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
FW	128	Streams, Rivers, Lakes, and Ponds	Species Mgmt.	H	on-going	Expand efforts to suppress and control invasive species, including through reclamation of water bodies	F3			Invasive Non-native/Alien Species/Diseases
FW	129	Streams, Rivers, Lakes, and Ponds	Species Mgmt.	M	on-going	Promote native species abundance in aquatic SGCN habitats in order to foster competition that may reduce or slow the spread of invasives	F3			Invasive Non-native/Alien Species/Diseases
FW	102	Streams, Rivers, Lakes, and Ponds	Survey and Monitoring	H	new	Identify priority locations for ecological flow management in aquatic habitats	F6	F1		Dams & Water Management/Use
FW	145	Streams, Rivers, Lakes, and Ponds	Survey and Monitoring	H	on-going	Increase habitat surveys and models for road stream crossings	F2	F1		Roads & Railroads
FW	146	Streams, Rivers, Lakes, and Ponds	Survey and Monitoring	H	on-going	Complete a statewide inventory of the status and condition of road and railroad crossings, including on headwater streams	F2	F1		Roads & Railroads
FW	103	Streams, Rivers, Lakes, and Ponds	Survey and Monitoring	M	new	Develop better methods to map potential barriers in priority watersheds	F2	F6	F1	Dams and Water Management/Use, Roads and Railroads
FW	147	Streams, Rivers, Lakes, and Ponds	Survey and Monitoring	M	on-going	Track completed road stream crossing projects	F2			Roads and Railroads
M	170	Coastal	Habitat Mgmt.	C	on-going	Develop and implement best management practices or beach management agreements with municipalities and beach managers	M10	M5		Commercial & Industrial Areas , Housing & Urban Areas, Other Ecosystem Modifications, Roads & Railroads, Tourism & Recreational Areas

Table 4-16. *continued: page 8 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	171	Coastal	Habitat Mgmt.	C	on-going	Implement predator control programs near SGCN nesting areas in coastal and rocky coast habitats	M8			Commercial & Industrial Areas , Housing & Urban Areas, Other Ecosystem Modifications, Roads & Railroads, Tourism & Recreational Areas
M	168	Coastal	Habitat Mgmt.	H	on-going	Use voluntary agreements and incentives to conserve important coastal and rocky coast SGCN habitats	M10			Commercial & Industrial Areas , Housing & Urban Areas, Other Ecosystem Modifications, Roads & Railroads, Tourism & Recreational Areas
M	174	Coastal	Habitat Mgmt.	M	on-going	Assist municipalities in identifying areas that will allow coastal habitats to migrate inland as sea level rise occurs	M5	M3M4		Habitat Shifting or Alteration, Storms and Flooding, Temperature Extremes
M	173	Coastal	Public Outreach	C	on-going	Provide outreach to recreationalists regarding effects of human disturbance on beach nesting birds and roosting/feeding shorebirds	M8	M10		Recreational Activities
M	175	Coastal	Research	M	new	Research and identify management actions that may minimize impacts to coastal SGCN habitats from climate change	M3M4			Storms and Flooding, Temperature Extremes, Habitat Shifting or Alteration
M	167	Coastal	Survey and Monitoring	H	on-going	Work with municipalities to identify important SGCN nesting and migratory areas in rocky coast and coastal habitats during comprehensive planning	M1			Commercial & Industrial Areas , Housing & Urban Areas, Other Ecosystem Modifications, Roads & Railroads, Tourism & Recreational Areas
M	221	Intertidal	Habitat Mgmt.	C	on-going	Encourage partnership projects among transportation agencies, utility companies, etc. to facilitate fish passage and maintain connectivity in or near subtidal, intertidal, and tidal marsh habitats especially in cases where structures have different purposes for different users	M5			Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines
M	257	Intertidal	Habitat Mgmt.	C	on-going	Decommission remnant or unused roads and dams in or near tidal marsh, intertidal, and subtidal habitats	M5			Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines

Table 4-16. *continued: page 9 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	262	Intertidal	Habitat Mgmt.	C	new	Use transportation bonds to provide funding for culvert replacement in or near intertidal, subtidal, and tidal marsh habitats using best management practices	M5			Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines
M	209	Intertidal	Habitat Mgmt.	H	on-going	Promote voluntary baywide (or scale of ecological relevance) coordination of shared resources and education addressing the impacts of fishing and harvesting aquatic resources on SGCN intertidal and subtidal habitats	M9			Fishing & Harvesting of Aquatic Resources
M	225	Intertidal	Habitat Mgmt.	H	on-going	Restore and improve conservation management at state and municipal levels to reduce impacts of effluents and wastewater on intertidal and subtidal SGCN habitats	M3M4			Agricultural & Forestry Effluents, Domestic & Urban Waste Water, Industrial & Military Effluents
M	369	Intertidal	Habitat Mgmt.	H	on-going	Assess new aquaculture sites for potential positive, benign, or negative species interactions with the surrounding habitat and ecological systems	M1	M10		Marine & Freshwater Aquaculture
M	370	Intertidal	Habitat Mgmt.	H	on-going	Increase riparian and coastal buffer zones by limiting development in these areas to minimize damage to these properties due to flooding/waves and to maintain pervious surfaces for improved water management	M3M4			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	249	Intertidal	Habitat Mgmt.	H	on-going	Mitigate coastal acidification of intertidal and subtidal habitats using strategies similar to those for reducing effects of effluents/wastewater	M2			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	261	Intertidal	Habitat Mgmt.	H	on-going	Use technology to reduce discharge of wastewater and effluents into intertidal and subtidal SGCN habitats	M2			Agricultural & Forestry Effluents, Domestic & Urban Waste Water, Industrial & Military Effluents
M	365	Intertidal	Habitat Mgmt.	H	on-going	Investigate the effects of commercial trawling within the intertidal zone	M2	M9	M10	Fishing & Harvesting of Aquatic Resources

Table 4-16. *continued: page 10 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	371	Intertidal	Habitat Mgmt.	M	new	Alter shipping lanes and dredging plans in intertidal and subtidal habitats to minimize biological and ecological impacts to SGCN	M1	M10		Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents
M	219	Intertidal	Habitat Mgmt.	M	on-going	Conduct law enforcement training and workshops to support knowledge of SGCN and how existing regulations affect SGCN and their habitats	M6			Recreational Activities, Fishing and Harvesting
M	236	Intertidal	Habitat Mgmt.	M	on-going	Improve response plans for industrial spills (e.g., oil spills) in intertidal and subtidal habitats and support research on oil dispersants and short and long term effect of oil spills	M2			Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents
M	242	Intertidal	Habitat Mgmt.	M	new	Increase pH of mudflats (e.g., using harvested shell waste) to restore more favorable habitat conditions for intertidal and subtidal SGCN	M2			Fishing and Harvesting of Aquatic Resources
M	372	Intertidal	Policy	H	on-going	Increase capacity for enforcement of current laws and regulations regarding proper infrastructure (e.g., roads, dams, utility lines, shipping lanes) construction, maintenance, water quality, and fish passage in tidal marsh, intertidal, and subtidal SGCN habitats	M5	M6		Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines
M	245	Intertidal	Policy	H	on-going	Increase enforcement for dumping/litter/gear abandonment in intertidal and subtidal habitats	M6			Garbage & Solid Waste
M	252	Intertidal	Policy	H	new	Provide incentives for building Stream Smart structures and road crossings in or near intertidal, subtidal, and tidal marsh habitats that allow for changing environmental conditions such as sea level rise and increased flooding	M5			Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines
M	259	Intertidal	Policy	H	on-going	Increase awareness about invasive species and problems following the introduction of invasive species in the shipping, transportation, and other industries to prevent introductions and spread of invasive species in intertidal and subtidal habitats	M6	M7		Invasive Non-native/Alien Species/Diseases, Problematic Native Species/Diseases, Viral/Prion-induced Diseases

Table 4-16. *continued: page 11 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	223	Intertidal	Policy	M	on-going	Expand existing education and incentive programs for lawn care companies, homeowners, and municipalities to reduce wastewater and effluent inputs and effects on intertidal and subtidal SGCN habitats	M2			Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents
M	224	Intertidal	Policy	M	new	Explore value of utilizing conservation leases to limit uses/stresses in intertidal and subtidal habitats	M9			Fishing and Harvesting of Aquatic Resources
M	234	Intertidal	Policy	M	on-going	Increase capacity for municipal planning for siting of new or retrofit developments (i.e., Smart Growth)to reduce wastewater and effluent effects on intertidal and subtidal SGCN habitats while also accounting for future environmental change	M3M4			Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents
M	239	Intertidal	Policy	M	on-going	Provide incentives for and education on using green infrastructure for preventing erosion and loss/damage of property near intertidal habitats	M2			Commercial and Industrial Areas , Housing and Urban Areas, Livestock Farming and Ranching
M	373	Intertidal	Policy	M	new	Update permit requirements for new and retrofitted developments in, near, or adjacent to intertidal habitats with up-to-date data/models of climate predictions	M3M4			Commercial and Industrial Areas , Housing and Urban Areas, Livestock Farming and Ranching
M	256	Intertidal	Policy	M	on-going	Retrofit existing effluent and wastewater treatment infrastructure and plan for sea level rise by providing economic incentives and education	M3M4			Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents
M	258	Intertidal	Policy	M	on-going	Provide stewardship/conservation incentives to harvesters working in intertidal and subtidal SGCN habitats	M9			Fishing and Harvesting of Aquatic Resources
M	211	Intertidal	Public Outreach	H	on-going	Continue/expand litter reduction programs/public education in intertidal and subtidal habitats	M2			Garbage & Solid Waste

Table 4-16. *continued: page 12 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	212	Intertidal	Public Outreach	H	on-going	Continue/expand marine debris recovery programs in intertidal and subtidal habitats and education to fishermen	M2			Garbage & Solid Waste
M	218	Intertidal	Public Outreach	H	on-going	Provide education and outreach through local meetings and trainings (e.g., Stream Smart) on techniques, problems and ecological effects of dams, roads, shipping lanes, and utility corridors on intertidal, subtidal, and tidal marsh habitats and publicize completed projects	M5	M3M4		Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines
M	231	Intertidal	Public Outreach	H	new	Improve knowledge of effects of renewable energy on intertidal and subtidal SGCN habitats and convey this information to the public	M2			Renewable Energy
M	240	Intertidal	Public Outreach	H	on-going	Increase outreach and education on preventing the spread of invasive/problematic species and diseases in intertidal, subtidal, and tidal marsh habitats	M7			Invasive Non-native/Alien Species/Diseases, Problematic Native Species/Diseases, Viral/Prion-induced Diseases
M	244	Intertidal	Public Outreach	H	on-going	Increase capacity for local engagement in data collection, surveys, and management of intertidal and subtidal SGCN and their habitats that fosters partnerships among harvesters, citizens, scientists, and managers	M9			Fishing & Harvesting of Aquatic Resources
M	246	Intertidal	Public Outreach	H	on-going	Increase leadership opportunities and education regarding climate change mitigation and adaptation in intertidal and subtidal habitats	M3M4			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	208	Intertidal	Public Outreach	M	on-going	At popular sites, increase education and outreach on the effects of recreation on sensitive intertidal ecosystems, spread of invasive species, etc.	M1	M7		Recreational Activities
M	215	Intertidal	Public Outreach	M	new	Develop best management practices for maintaining energy facilities in intertidal and subtidal habitats	M2			Renewable Energy

Table 4-16. *continued: page 13 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	222	Intertidal	Public Outreach	M	new	Expand existing education and research at the management level to improve understanding and management ability to reduce wastewater and effluent inputs and effects into intertidal and subtidal SGCN habitats	M2			Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents
M	251	Intertidal	Public Outreach	M	on-going	Post signs describing specific usage constraints (e.g. avoid certain areas during breeding seasons, pick up dog waste, don't disturb flora and fauna) to minimize impacts of recreational activities on intertidal SGCN habitats	M8			Recreational Activities
M	260	Intertidal	Public Outreach	M	on-going	Promote use of more targeted fishing techniques in intertidal and subtidal habitats (e.g., bycatch reduction and not disturbing habitat) by encouraging discussions between harvesters, ecologists, and managers	M9			Fishing and Harvesting of Aquatic Resources
M	210	Intertidal	Research	C	new	Create a coastal acidification budget to determine which factors (i.e. point, non-point source pollution, atmospheric CO2, etc.) are most important in driving acidification nearshore in intertidal and subtidal habitats	M2			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	226	Intertidal	Research	C	new	Identify local intertidal and subtidal ocean acidification and sea surface temperature refuges and resilient species	M3M4			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	214	Intertidal	Research	H	on-going	Develop better understanding of climate change effects on intertidal and subtidal SGCN and ecosystem interactions	M3M4			Lack of knowledge
M	220	Intertidal	Research	H	new	Encourage installation of lower cost SGCN-friendly infrastructure in and near subtidal, intertidal, and tidal marsh habitats through technology development and transfer of technology	M2			Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines
M	228	Intertidal	Research	H	on-going	Improve understanding of distribution, biology, and ecology of non-commercially harvested intertidal and subtidal SGCN	M1			Lack of knowledge

Table 4-16. *continued: page 14 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	230	Intertidal	Research	H	on-going	Improve knowledge of intertidal and subtidal SGCN habitat use and migration patterns to better inform renewable energy project siting	M1	M10		Renewable Energy
M	233	Intertidal	Research	H	on-going	Improve modeling (at local and Gulf of Maine scales) of sea level rise effects on intertidal and subtidal SGCN habitats and incorporate into planning	M3M4			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	235	Intertidal	Research	H	on-going	Improve mapping of intertidal and subtidal habitats and include information on SGCN movements	M1	M10		Renewable Energy
M	255	Intertidal	Research	H	on-going	Research the feasibility of diversifying Maine's marine fisheries of SGCN in response to changing environmental variables	M3M4			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	366	Intertidal	Research	H	on-going	Monitor coastal streams, rivers, and sediments for excessive nutrients and chemical therapeutants	M2			Agricultural & Forestry Effluents, Domestic & Urban Waste Water, Industrial & Military Effluents, Storms & Flooding
M	213	Intertidal	Research	M	on-going	Determine accuracy of commercial harvester- and dealer-reported landings and recreational fishing reports and surveys for target intertidal and subtidal SGCN and bycatch	M9			Fishing and Harvesting of Aquatic Resources
M	227	Intertidal	Research	M	on-going	Improve understanding of effects of energy development on bird and other SGCN use of migration corridors in intertidal and subtidal habitats	M1	M2		Renewable Energy
M	229	Intertidal	Research	M	on-going	Improve understanding of intertidal and subtidal SGCN distributions especially in regards to ecosystem interactions and predator prey relationships	M1			Lack of knowledge

Table 4-16. *continued: page 15 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	238	Intertidal	Research	M	on-going	Continue to work with industry to minimize escape of aquaculture-raised individuals	M7			Marine and Freshwater Aquaculture
M	247	Intertidal	Research	M	on-going	Investigate the effects of various harvesting practices on intertidal and subtidal SGCN habitats and on trophic and ecological processes	M9			Fishing and Harvesting of Aquatic Resources
M	217	Intertidal	Survey and Monitoring	H	on-going	Develop monitoring systems and rapid response plans to prevent the colonization of invasive/problematic species and diseases in intertidal, subtidal, and tidal marsh habitats	M7			Invasive Non-native/Alien Species/Diseases, Problematic Native Species/Diseases, Viral/Prion-induced Diseases
M	107	Intertidal	Survey and Monitoring	H	new	Develop coastal focus areas encompassing marine habitats with high concentrations of SGCN using improved species occurrence maps	M1			Lack of knowledge
M	367	Intertidal	Survey and Monitoring	H	on-going	Continue underwater surveillance of potential and active aquaculture lease sites with a focus on SGCN and important habitats	M2			Fishing & Harvesting of Aquatic Resources
M	248	Intertidal	Survey and Monitoring	M	on-going	More frequently update intertidal and subtidal SGCN habitat maps and compare to historical maps to monitor changes in distribution over time	M1			Fishing and Harvesting of Aquatic Resources
M	161	Rocky Coast	Habitat Mgmt.	C	on-going	Implement predator control programs near SGCN nesting areas in coastal and rocky coast habitats	M8			Commercial & Industrial Areas , Housing & Urban Areas
M	152	Rocky Coast	Habitat Mgmt.	H	on-going	Minimize disturbances around rocky coast SGCN nesting and roosting habitat through voluntary agreements	M10	M8		Fishing & Harvesting of Aquatic Resources, Recreational Activities

Table 4-16. *continued: page 16 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	153	Rocky Coast	Habitat Mgmt.	H	on-going	Limit disturbance of shorebird roosting areas and seabird nesting islands through signage, closure to foot traffic, and other effective means	M8			Fishing & Harvesting of Aquatic Resources, Recreational Activities
M	163	Rocky Coast	Habitat Mgmt.	M	on-going	Implement invasive species eradication programs where appropriate (e.g., not in areas where invasive plants provide cover for SGCN and reestablishment of native plants is unlikely), and encourage growth of native species	M7			Invasive Non-native/Alien Species/Diseases
M	164	Rocky Coast	Habitat Mgmt.	M	on-going	Identify conservation and restoration opportunities that allow for rocky coast habitat migration to higher elevations	M3M4	M1		Habitat Shifting or Alteration, Storms and Flooding
M	165	Rocky Coast	Habitat Mgmt.	M	on-going	Identify conservation and restoration opportunities at historic but currently unused nesting sites in rocky coast habitats	M1	M8		Habitat Shifting or Alteration, Storms and Flooding
M	166	Rocky Coast	Habitat Mgmt.	M	on-going	Deploy armoring structures on state-owned lands at high value nesting areas along the rocky coast where migration of nesting habitat is not possible	M3M4			Habitat Shifting or Alteration, Storms and Flooding
M	150	Rocky Coast	Policy	H	on-going	Seasonally close rocky coast SGCN nesting and roosting areas to foot traffic on state-owned lands	M8			Recreational Activities
M	154	Rocky Coast	Policy	H	on-going	Encourage safe operational procedures and spill clean-up and rehabilitation of oiled birds	M1	M6	M10	Industrial & Military Effluents, Shipping Lanes
M	156	Rocky Coast	Policy	H	on-going	Enhance oil spill contingency planning and response efforts in rocky coast habitats including purchasing survey and hazing equipment	M10			Industrial & Military Effluents, Shipping Lanes

Table 4-16. *continued: page 17 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	159	Rocky Coast	Policy	H	on-going	Use voluntary agreements, conservation easements, and tax abatements and incentives to conserve important coastal and rocky coast SGCN habitats	M3M4	M10	M8	Commercial & Industrial Areas , Housing & Urban Areas
M	149	Rocky Coast	Public Outreach	H	on-going	Erect signage at important nesting and roosting areas in rocky coast habitats to discourage destructive effects of human recreation	M8			Recreational Activities
M	148	Rocky Coast	Public Outreach	M	on-going	Provide outreach to recreationalists regarding effects of human disturbance on nesting colonies and roosting shorebirds	M8			Recreational Activities
M	157	Rocky Coast	Survey and Monitoring	H	on-going	Identify and prioritize significant nesting, migratory, and wintering areas in rocky coast habitats for contingency planning	M10			Industrial & Military Effluents, Shipping Lanes
M	158	Rocky Coast	Survey and Monitoring	H	on-going	Work with municipalities to identify important SGCN nesting and migratory areas in rocky coast and coastal habitats during comprehensive planning	M10	M1		Commercial & Industrial Areas , Housing & Urban Areas
M	162	Rocky Coast	Survey and Monitoring	M	on-going	Identify invasive plant hot spots in rocky coast habitats	M7			Invasive Non-native/Alien Species/Diseases
M	279	Subtidal	Habitat Mgmt.	C	on-going	Encourage partnership projects among transportation agencies, utility companies, etc. to facilitate fish passage and maintain connectivity in or near subtidal, intertidal, and tidal marsh habitats especially in cases where structures have different purposes for different users	M5			Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines
M	314	Subtidal	Habitat Mgmt.	C	on-going	Decommission remnant or unused roads and dams in or near tidal marsh, intertidal, and subtidal habitats	M5			Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines

Table 4-16. *continued: page 18 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	321	Subtidal	Habitat Mgmt.	C	new	Find ways to support culvert replacement in or near intertidal, subtidal, and tidal marsh habitats using best management practices	M5			Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines
M	264	Subtidal	Habitat Mgmt.	H	on-going	Promote voluntary baywide (or scale of ecological relevance) coordination of shared resources and education addressing the impacts of fishing and harvesting aquatic resources on SGCN intertidal and subtidal habitats	M9			Fishing & Harvesting of Aquatic Resources
M	285	Subtidal	Habitat Mgmt.	H	on-going	Restore and improve conservation management at state and municipal levels to reduce impacts of effluents and wastewater on intertidal and subtidal SGCN habitats	M3M4			Agricultural & Forestry Effluents, Domestic & Urban Waste Water, Industrial & Military Effluents
M	374	Subtidal	Habitat Mgmt.	H	on-going	Assess new aquaculture sites for potential positive, benign, or negative species interactions with the surrounding habitat and ecological systems	M1	M10		Marine & Freshwater Aquaculture
M	308	Subtidal	Habitat Mgmt.	H	on-going	Mitigate coastal acidification of intertidal and subtidal habitats using strategies similar to those for reducing effects of effluents/wastewater	M2			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	309	Subtidal	Habitat Mgmt.	H	on-going	Model effects of sea level rise and other climate change factors on subtidal SGCN patterns including physiology, migration patterns, and trophic changes	M3M4			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	320	Subtidal	Habitat Mgmt.	H	on-going	Use technology to reduce discharge of wastewater and effluents into intertidal and subtidal SGCN habitats	M2			Agricultural & Forestry Effluents, Domestic & Urban Waste Water, Industrial & Military Effluents
M	375	Subtidal	Habitat Mgmt.	M	new	Alter shipping lanes and dredging plans in intertidal and subtidal habitats to minimize biological and ecological impacts to SGCN	M1	M10		Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents

Table 4-16. *continued: page 19 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	277	Subtidal	Habitat Mgmt.	M	on-going	Conduct law enforcement training and workshops to support knowledge of SGCN and how existing regulations affect SGCN and their habitats	M6			Recreational Activities, Fishing and Harvesting
M	296	Subtidal	Habitat Mgmt.	M	on-going	Improve response plans for industrial spills (e.g., oil spills) in intertidal and subtidal habitats and support research on oil dispersants and short and long term effect of oil spills	M2			Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents
M	376	Subtidal	Policy	H	on-going	Increase capacity for enforcement of current laws and regulations regarding proper infrastructure (e.g., roads, dams, utility lines, shipping lanes) construction, maintenance, water quality, and fish passage in tidal marsh, intertidal, and subtidal SGCN habitats	M5	M6		Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines
M	310	Subtidal	Policy	H	new	Provide incentives for building Stream Smart structures and road crossings in or near intertidal, subtidal, and tidal marsh habitats that allow for changing environmental conditions such as sea level rise and increased flooding	M5			Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines
M	317	Subtidal	Policy	H	on-going	Increase awareness about invasive species regulations and problems following the introduction of invasive species in the shipping, transportation, and other industries to prevent introductions and spread of invasive species in intertidal and subtidal habitats	M6	M7		Invasive Non-native/Alien Species/Diseases, Problematic Native Species/Diseases, Viral/Prion-induced Diseases
M	377	Subtidal	Policy	H	on-going	Time dredging projects in subtidal and tidal marsh habitats to minimize harm to SGCN based on migration and spawning cycles	M1	M10		Mining & Quarrying, Shipping Lanes
M	282	Subtidal	Policy	M	on-going	Expand existing education and incentive programs for lawn care companies, homeowners, and municipalities to reduce wastewater and effluent inputs and effects on intertidal and subtidal SGCN habitats	M2			Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents
M	284	Subtidal	Policy	M	new	Explore value of utilizing conservation leases to limit uses/stresses in intertidal and subtidal habitats	M9			Fishing and Harvesting of Aquatic Resources

Table 4-16. *continued: page 20 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	294	Subtidal	Policy	M	on-going	Increase capacity for municipal planning for siting of new or retrofit developments (i.e., Smart Growth)to reduce wastewater and effluent effects on intertidal and subtidal SGCN habitats while also accounting for future environmental change	M3M4			Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents
M	302	Subtidal	Policy	M	on-going	Increase enforcement for dumping/litter/gear abandonment in intertidal and subtidal habitats	M6			Garbage and Solid Waste
M	313	Subtidal	Policy	M	on-going	Retrofit existing effluent and wastewater treatment infrastructure and plan for sea level rise by providing economic incentives and education	M3M4			Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents
M	378	Subtidal	Policy	M	on-going	Site shipping lanes and dredging projects to minimize negative impacts to intertidal and subtidal SGCN and their habitats	M1	M10		Mining and Quarrying, Shipping Lanes
M	316	Subtidal	Policy	M	on-going	Provide stewardship/conservation incentives to harvesters working in intertidal and subtidal SGCN habitats	M9			Fishing and Harvesting of Aquatic Resources
M	267	Subtidal	Public Outreach	C	on-going	Continue/expand litter reduction programs/public education in intertidal and subtidal habitats	M2			Garbage & Solid Waste
M	268	Subtidal	Public Outreach	H	on-going	Continue/expand marine debris recovery programs in intertidal and subtidal habitats and education to fishermen	M2			Garbage & Solid Waste
M	275	Subtidal	Public Outreach	H	on-going	Provide education and outreach through local meetings and trainings (e.g., Stream Smart) on techniques, problems and ecological effects of dams, roads, shipping lanes, and utility corridors on intertidal, subtidal, and tidal marsh habitats and publicize completed projects	M5	M3M4		Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines

Table 4-16. *continued: page 21 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	291	Subtidal	Public Outreach	H	new	Improve knowledge of effects of renewable energy on intertidal and subtidal SGCN habitats and convey this information to the public	M2			Renewable Energy
M	299	Subtidal	Public Outreach	H	on-going	Increase outreach and education on preventing the spread of invasive/problematic species and diseases in intertidal, subtidal, and tidal marsh habitats	M7			Invasive Non-native/Alien Species/Diseases, Problematic Native Species/Diseases, Viral/Prion-induced Diseases
M	303	Subtidal	Public Outreach	H	on-going	Increase leadership opportunities and education regarding climate change mitigation and adaptation in intertidal and subtidal habitats	M3M4			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	304	Subtidal	Public Outreach	H	on-going	Increase capacity for local engagement in data collection, surveys, and management of intertidal and subtidal SGCN and their habitats that fosters partnerships among harvesters, citizens, scientists, and managers	M9			Fishing & Harvesting of Aquatic Resources
M	271	Subtidal	Public Outreach	M	new	Develop best management practices for maintaining energy facilities in intertidal and subtidal habitats	M2			Renewable Energy
M	274	Subtidal	Public Outreach	M	on-going	Continue partnerships between anglers, guides, scientists, and managers to collect biological information and catch data to use in population assessments and identifying species habitat use and behavior	M9			Recreational Activities
M	276	Subtidal	Public Outreach	M	on-going	Provide outreach and education to recreational marine harvesters on proper catch and release methods to minimize trauma (including barotrauma)	M9			Recreational Activities
M	280	Subtidal	Public Outreach	M	on-going	Continue to work with recreational marine charter captains to collect accurate data that can be used to assess SGCN populations	M9			Recreational Activities

Table 4-16. *continued: page 22 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	281	Subtidal	Public Outreach	M	new	Expand existing education and research at the management level to improve understanding and management ability to reduce wastewater and effluent inputs and effects into intertidal and subtidal SGCN habitats	M2			Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents
M	319	Subtidal	Public Outreach	M	on-going	Promote use of more targeted fishing techniques in intertidal and subtidal habitats (e.g., bycatch reduction and not disturbing habitat) by encouraging discussions between harvesters, ecologists, and managers	M9			Fishing and Harvesting of Aquatic Resources
M	265	Subtidal	Research	C	new	Create a coastal acidification budget to determine which factors (i.e. point, non-point source pollution, atmospheric CO2, etc.) are most important in driving acidification nearshore in intertidal and subtidal habitats	M2			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	286	Subtidal	Research	C	new	Identify local intertidal and subtidal ocean acidification and sea surface temperature refuges and resilient species	M3M4			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	295	Subtidal	Research	C	on-going	Improve mapping of intertidal and subtidal habitats and include information on SGCN movements and mortality due to turbines	M1	M10		Renewable Energy
M	305	Subtidal	Research	C	new	Investigate offshore changes in circulation patterns, plankton distribution and abundance, and other bio-chemical and physical processes	M2			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	270	Subtidal	Research	H	on-going	Develop better understanding of climate change effects on intertidal and subtidal SGCN and ecosystem interactions	M3M4			Lack of knowledge
M	278	Subtidal	Research	H	new	Encourage installation of lower cost SGCN-friendly infrastructure in and near subtidal, intertidal, and tidal marsh habitats through technology development and transfer of technology	M2			Dams & Water Management/Use, Roads & Railroads, Shipping Lanes, Utility & Service Lines

Table 4-16. *continued: page 23 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	289	Subtidal	Research	H	on-going	Improve understanding of distribution, biology, and ecology of non-commercially harvested intertidal and subtidal SGCN	M1			Lack of knowledge
M	290	Subtidal	Research	H	on-going	Improve knowledge of intertidal and subtidal SGCN habitat use and migration patterns to better inform renewable energy project siting	M3M4			Renewable Energy
M	293	Subtidal	Research	H	on-going	Improve modeling (at local and Gulf of Maine scales) of sea level rise effects on intertidal and subtidal SGCN habitats and incorporate into planning	M3M4			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	312	Subtidal	Research	H	on-going	Research the feasibility of diversifying Maine's marine fisheries of SGCN in response to changing environmental variables	M3M4			Habitat Shifting or Alteration, Storms & Flooding, Temperature Extremes
M	269	Subtidal	Research	M	on-going	Determine accuracy of commercial harvester- and dealer-reported landings and recreational fishing reports and surveys for target intertidal and subtidal SGCN and bycatch	M9			Fishing and Harvesting of Aquatic Resources
M	287	Subtidal	Research	M	on-going	Improve understanding of intertidal and subtidal SGCN distributions especially in regards to ecosystem interactions and predator prey relationships	M1			Lack of knowledge
M	288	Subtidal	Research	M	on-going	Improve understanding of effects of energy development on bird and other SGCN use of migration corridors in intertidal and subtidal habitats	M1	M2		Renewable Energy
M	298	Subtidal	Research	M	on-going	Continue to work with industry to minimize escape of aquaculture-raised individuals	M7			Marine and Freshwater Aquaculture

Table 4-16. *continued: page 24 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	301	Subtidal	Research	M	new	Expand research and pilot studies to test the efficacy of increasing pH of mudflats (e.g., using harvested shell waste) to restore more favorable habitat conditions for intertidal and subtidal SGCN	M2			Fishing and Harvesting of Aquatic Resources
M	306	Subtidal	Research	M	on-going	Investigate the effects of various harvesting practices on intertidal and subtidal SGCN habitats and on trophic and ecological processes	M9			Fishing and Harvesting of Aquatic Resources
M	272	Subtidal	Survey and Monitoring	M	on-going	Develop coastal focus areas encompassing marine habitats with high concentrations of SGCN using improved species occurrence maps	M1			Lack of knowledge
M	273	Subtidal	Survey and Monitoring	H	on-going	Develop monitoring systems and rapid response plans to prevent the colonization of invasive/problematic species and diseases in intertidal, subtidal, and tidal marsh habitats	M7			Invasive Non-native/Alien Species/Diseases, Problematic Native Species/Diseases, Viral/Prion-induced Diseases
M	368	Subtidal	Survey and Monitoring	H	on-going	Continue underwater surveillance of potential and active aquaculture lease sites with a focus on SGCN and important habitats	M2			Fishing & Harvesting of Aquatic Resources
M	266	Subtidal	Survey and Monitoring	M	on-going	Continue to improve rapid response for oil and gas spills in intertidal and subtidal habitats, including state agencies efforts to have most up-to-date species maps, rapid response protocols in place, and regular scenario training	M1	M10		Mining and Quarrying, Shipping Lanes
M	283	Subtidal	Survey and Monitoring	M	on-going	Expand surveys of recreational fishing efforts to include SGCN that are not targeted in current survey efforts	M9			Recreational Activities
M	307	Subtidal	Survey and Monitoring	M	on-going	More frequently update intertidal and subtidal SGCN habitat maps and compare to historical maps to monitor changes in distribution over time	M1			Fishing and Harvesting of Aquatic Resources

Table 4-16. *continued: page 25 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	180	Tidal Marsh	Habitat Mgmt.	C	on-going	Work with land conservation organizations and private landowners to conserve tidal marshes, adjacent uplands, and marsh migration corridors	M3M4			Annual & Perennial Non-timber crops, Commercial & Industrial Areas , Housing & Urban Areas, Livestock Farming & Ranching, Utility & Service Lines
M	183	Tidal Marsh	Habitat Mgmt.	C	on-going	Conserve lands that are upland and inland of marshes to allow for marsh migration and maintain habitat connectivity	M3M4			Habitat Shifting or Alteration
M	194	Tidal Marsh	Habitat Mgmt.	C	new	Use transportation bonds to provide funding for culvert replacement in or near intertidal, subtidal, and tidal marsh habitats using best management practices	M5			Dams & Water Management/Use, Roads & Railroads
M	196	Tidal Marsh	Habitat Mgmt.	C	on-going	Decommission remnant or unused roads and dams in or near tidal marsh, intertidal, and subtidal habitats	M5			Dams & Water Management/Use, Roads & Railroads
M	198	Tidal Marsh	Habitat Mgmt.	H	on-going	Encourage installation of lower cost SGCN-friendly infrastructure in and near subtidal, intertidal, and tidal marsh habitats through technology development and transfer of technology	M2			Dams & Water Management/Use, Roads & Railroads
M	379	Tidal Marsh	Habitat Mgmt.	H	on-going	Time dredging projects in subtidal and tidal marsh habitats to minimize harm to SGCN based on migration and spawning cycles	M10	M1		Shipping Lanes
M	179	Tidal Marsh	Habitat Mgmt.	M	on-going	Maintain or create corridors between tidal marshes and other habitats used by tidal marsh SGCN	M3M4			Annual and Perennial Non-timber crops, Commercial and Industrial Areas , Housing and Urban Areas, Livestock Farming and Ranching, Utility and Service Lines
M	182	Tidal Marsh	Habitat Mgmt.	M	new	Employ technology to reduce nutrient discharge adjacent to tidal marshes, e.g. storm water remediation measures including SmartSponge, infiltration chambers, and storm water settling areas	M2	M10		Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents, Storms and Flooding

Table 4-16. *continued: page 26 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	192	Tidal Marsh	Habitat Mgmt.	M	on-going	Re-route existing trails and/or boardwalks around tidal marshes to minimize foot traffic and disturbance to SGCN habitats	M10			Recreational Activities
M	195	Tidal Marsh	Policy	C	new	Provide incentives for building Stream Smart structures and road crossings in or near intertidal, subtidal, and tidal marsh habitats that allow for changing environmental conditions such as sea level rise and increased flooding	M5			Dams & Water Management/Use, Roads & Railroads
M	197	Tidal Marsh	Policy	H	new	Implement through voluntary or regulatory means best standards for road/stream crossings in or near tidal marshes	M5			Dams & Water Management/Use, Roads & Railroads
M	380	Tidal Marsh	Policy	H	on-going	Increase capacity for enforcement of current laws and regulations regarding proper infrastructure (e.g., roads, dams, utility lines, shipping lanes) construction, maintenance, water quality, and fish passage in tidal marsh, intertidal, and subtidal SGCN habitats	M5	M6		Dams & Water Management/Use, Roads & Railroads
M	381	Tidal Marsh	Policy	H	new	Site shipping lanes and dredging projects to minimize negative impacts to intertidal and subtidal SGCN and their habitats	M1	M10		Shipping Lanes
M	204	Tidal Marsh	Policy	H	on-going	Continue to improve rapid response for oil and gas spills in intertidal and subtidal habitats, including state agencies efforts to have most up-to-date species maps, rapid response protocols in place, and regular scenario training	M1	M10		Shipping Lanes
M	188	Tidal Marsh	Policy	M	on-going	Increase awareness about invasive species regulations and problems following the introduction of invasive species in the shipping, transportation, and other industries to prevent introductions and spread of invasive species in intertidal and subtidal habitats	M6	M7		Invasive Non-native/Alien Species/Diseases, Problematic Native Species/Diseases
M	201	Tidal Marsh	Policy	M	on-going	Develop and provide model best practice maintenance and operating procedures (e.g., maintenance frequency, replacement schedules) for municipal, state, and private managers of infrastructure in tidal marshes	M5	M3M4		Dams and Water Management/Use, Roads and Railroads

Table 4-16. *continued: page 27 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	181	Tidal Marsh	Public Outreach	H	on-going	Encourage partnership projects among transportation agencies, utility companies, etc. to facilitate fish passage and maintain connectivity in or near subtidal, intertidal, and tidal marsh habitats especially in cases where structures have different purposes for different users	M5			Dams & Water Management/Use, Roads & Railroads
M	200	Tidal Marsh	Public Outreach	H	on-going	Provide education and outreach through local meetings and trainings (e.g., Stream Smart) on techniques, problems and ecological effects of dams, roads, shipping lanes, and utility corridors on intertidal, subtidal, and tidal marsh habitats and publicize completed projects	M5	M3M4		Dams & Water Management/Use, Roads & Railroads
M	176	Tidal Marsh	Public Outreach	M	on-going	Provide outreach and education to homeowners and businesses to reduce their wastewater and storm water inputs into and effects on tidal marshes, including increased buffers and minimal fertilizer use	M1	M10		Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents, Storms and Flooding
M	178	Tidal Marsh	Public Outreach	M	new	Research the efficacy of tidal marsh conversion	M3M4			Annual and Perennial Non-timber crops, Commercial and Industrial Areas , Housing and Urban Areas, Livestock Farming and Ranching, Utility and Service Lines
M	186	Tidal Marsh	Public Outreach	M	new	Provide outreach and education to planners, developers, and homeowners about best management practices for site design, property maintenance, and landscaping adjacent to tidal marshes and their buffers	M1	M10		Annual and Perennial Non-timber crops, Commercial and Industrial Areas , Housing and Urban Areas, Livestock Farming and Ranching, Utility and Service Lines
M	187	Tidal Marsh	Public Outreach	M	on-going	Provide outreach and education to homeowners and municipalities regarding proper installation, maintenance, and removal of septic systems	M10	M1		Agricultural and Forestry Effluents, Domestic and Urban Waste Water, Industrial and Military Effluents, Storms and Flooding
M	189	Tidal Marsh	Public Outreach	M	on-going	Increase outreach and education on preventing the spread of invasive/problematic species and diseases in intertidal, subtidal, and tidal marsh habitats	M7			Invasive Non-native/Alien Species/Diseases, Problematic Native Species/Diseases
M	190	Tidal Marsh	Public Outreach	M	new	Provide incentives for converting land into tidal marsh or protecting existing tidal marsh	M7			Annual and Perennial Non-timber crops, Commercial and Industrial Areas , Housing and Urban Areas, Livestock Farming and Ranching, Utility and Service Lines

Table 4-16. *continued: page 28 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
M	193	Tidal Marsh	Public Outreach	M	on-going	Deploy signage to notify recreationalists to the sensitivity of tidal marsh habitat	M10			Recreational Activities
M	184	Tidal Marsh	Research	M	on-going	Research and model marsh migration scenarios resulting from sea level rise	M10			Habitat Shifting or Alteration
M	177	Tidal Marsh	Survey and Monitoring	H	on-going	Build upon and coordinate with existing monitoring efforts to establish a long term tidal marsh monitoring program, with emphasis on assessing sediment dynamics in the context of sea level rise	M3M4			Annual & Perennial Non-timber crops, Commercial & Industrial Areas , Housing & Urban Areas, Livestock Farming & Ranching, Utility & Service Lines
M	191	Tidal Marsh	Survey and Monitoring	H	on-going	Develop monitoring systems and rapid response plans to prevent the colonization of invasive/problematic species and diseases in intertidal, subtidal, and tidal marsh habitats	M5	M3M4		Invasive Non-native/Alien Species/Diseases, Problematic Native Species/Diseases
M	185	Tidal Marsh	Survey and Monitoring	M	on-going	Continue and expand monitoring programs that track tidal marsh changes over time	M3M4			Habitat Shifting or Alteration
TW	322	Floodplain Forests	Habitat Mgmt.	H	new	Encourage conservation owners to address floodplain forests in management plans	TW9			Dams & Water Management/Use, Invasive Non-native/Alien Species/Diseases, Logging & Wood Harvesting
TW	327	Floodplain Forests	Habitat Mgmt.	H	on-going	Conserve at-risk high value floodplain forests using a variety of voluntary approaches	TW8			Annual & Perennial Non-timber crops, Commercial & Industrial Areas , Housing & Urban Areas, Logging & Wood Harvesting, Roads & Railroads, Utility & Service Lines
TW	323	Floodplain Forests	Habitat Mgmt.	M	New	Work collaboratively with the Maine Forest Service and other partners to review current Maine Forestry Best Management Practices to determine if floodplain forest SGCN are adequately considered and revise, if needed	TW10			Logging and Wood Harvesting

Table 4-16. *continued: page 29 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	324	Floodplain Forests	Habitat Mgmt.	M	New	Work collaboratively with the Maine Forest Service and other partners to develop logging and wood harvesting Habitat Management Guidelines for sensitive floodplain forest SGCN, if needed	TW10			Logging and Wood Harvesting
TW	325	Floodplain Forests	Habitat Mgmt.	M	new	Work with forest landowners to implement revised Habitat Management Guidelines in floodplain forests	TW10	TW1		Logging and Wood Harvesting
TW	328	Floodplain Forests	Habitat Mgmt.	M	new	Support floodplain forest management in forest certification program	TW10			Logging and Wood Harvesting
TW	339	Floodplain Forests	Habitat Mgmt.	M	new	Support efforts to restore hydrologic connections to floodplain forests isolated by roads	TW8	TW2	TW5	Roads and Railroads
TW	341	Floodplain Forests	Habitat Mgmt.	M	new	Support statewide invasive species monitoring and education programs in floodplain forests	TW6			Invasive Non-native/Alien Species/Diseases
TW	333	Floodplain Forests	Policy	H	on-going	Support incentives that discourage conversion of floodplain forests to other uses	TW2			Annual & Perennial Non-timber crops, Logging & Wood Harvesting
TW	334	Floodplain Forests	Policy	H	on-going	Improve non-federal match ratio for floodplain forest conservation projects	TW2			Annual & Perennial Non-timber crops, Commercial & Industrial Areas , Housing & Urban Areas, Logging & Wood Harvesting
TW	335	Floodplain Forests	Policy	H	on-going	Support habitat incentive programs by providing additional technical assistance for SGCN habitat management in floodplain forests	TW2			Annual & Perennial Non-timber crops, Logging & Wood Harvesting

Table 4-16. *continued: page 30 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	337	Floodplain Forests	Policy	H	on-going	Collaborate with partners to develop state landowner incentive programs for floodplain forests	TW2			Annual & Perennial Non-timber crops, Housing & Urban Areas, Logging & Wood Harvesting
TW	338	Floodplain Forests	Policy	M	new	Consider buffers to floodplain forests in prioritizing conservation opportunities	TW8	TW2		Agricultural and Forestry Effluents, Annual and Perennial Non-timber crops
TW	340	Floodplain Forests	Policy	M	new	Find sources of non-federal match for federal programs offering riparian easements (e.g., USDA-Conservation Reserve Enhancement Program) especially for floodplain forests	TW2	TW8		Agricultural and Forestry Effluents, Annual and Perennial Non-timber crops, Logging and Wood Harvesting
TW	343	Floodplain Forests	Policy	M	new	Account for deer impacts to SGCN habitats in southern Maine floodplains during deer management planning process	TW7			Problematic Native Species/Diseases
TW	331	Floodplain Forests	Public Outreach	H	new	Provide high value floodplain location information to municipalities and land trusts	TW1			Annual & Perennial Non-timber crops, Commercial & Industrial Areas , Domestic & Urban Waste Water, Housing & Urban Areas, Industrial & Military Effluents, Logging & Wood Harvesting, Roads & Railroads, Utility & Service Lines
TW	329	Floodplain Forests	Public Outreach	M	new	Consider mapping SGCN habitats within floodplains	TW1			Annual and Perennial Non-timber crops, Commercial and Industrial Areas , Housing and Urban Areas, Logging and Wood Harvesting, Roads and Railroads, Utility and Service Lines
TW	332	Floodplain Forests	Public Outreach	M	new	Develop outreach materials focused on community benefits derived from floodplain forests	TW1			Commercial and Industrial Areas, Housing and Urban Areas

Table 4-16. *continued: page 31 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	342	Floodplain Forests	Survey and Monitoring	M	new	Identify aggressive invasives in floodplain forests and pre-treat to prevent spread	TW6			Invasive Non-native/Alien Species/Diseases
TW	62	Freshwater Marshes	Habitat Mgmt.	H	on-going	Conserve freshwater marsh buffers using a variety of voluntary approaches	TW8	TW5		Agricultural & Forestry Effluents, Commercial & Industrial Areas , Domestic & Urban Waste Water, Housing & Urban Areas, Roads & Railroads, Utility & Service Lines
TW	59	Freshwater Marshes	Habitat Mgmt.	M	new	Target invasive species control at high value wetlands	TW6			Invasive Non-native/Alien Species/Diseases
TW	64	Freshwater Marshes	Habitat Mgmt.	M	on-going	Encourage conservation of freshwater marshes and other high value SGCN wetland habitats using a variety of approaches	TW8			Commercial and Industrial Areas , Housing and Urban Areas, Roads and Railroads, Utility and Service Lines
TW	66	Freshwater Marshes	Habitat Mgmt.	M	new	Work collaboratively with partners to develop water control level standards for freshwater marshes in wildlife management areas	TW9	TW10		Annual and Perennial Non-timber crops, Habitat Shifting or Alteration, Livestock Farming and Ranching
TW	68	Freshwater Marshes	Policy	M	on-going	Support incentives for agricultural practices that benefit freshwater marshes	TW2			Annual and Perennial Non-timber crops, Livestock Farming and Ranching
TW	61	Freshwater Marshes	Public Outreach	H	on-going	Provide information to municipalities and land trusts on high priority freshwater wetlands near or bisected by roads	TW1	TW5		Agricultural & Forestry Effluents, Commercial & Industrial Areas , Domestic & Urban Waste Water, Livestock Farming & Ranching, Roads & Railroads, Utility & Service Lines
TW	60	Freshwater Marshes	Survey and Monitoring	C	new	Identify high priority road segments/culverts for organism passage among freshwater wetlands	TW1	TW5		Roads & Railroads

Table 4-16. *continued: page 32 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	345	Grassland-shrubland-early Successional	Habitat Mgmt.	C	on-going	Promote management of grasslands, shrublands, and early successional SGCN habitats on conservation lands, wildlife management areas, etc.	TW9	TW3	TW4	Annual & Perennial Non-timber crops, Other Ecosystem Modifications
TW	346	Grassland-shrubland-early Successional	Habitat Mgmt.	H	new	Focus conservation of grassland, shrub, and early successional SGCN habitat in areas not in conflict with landowner economics and are compatible with existing management practices	TW3	TW2	TW4	Annual & Perennial Non-timber crops, Commercial & Industrial Areas , Housing & Urban Areas
TW	351	Grassland-shrubland-early Successional	Habitat Mgmt.	H	on-going	Encourage conservation of grass/shrub habitats using a variety of voluntary approaches	TW8	TW3	TW2	Annual & Perennial Non-timber crops, Commercial & Industrial Areas , Housing & Urban Areas, Utility & Service Lines
TW	344	Grassland-shrubland-early Successional	Habitat Mgmt.	M	on-going	Promote Integrated Pest Management to reduce pesticide use in blueberry barrens	TW7	TW6	TW3	Annual and Perennial Non-timber crops
TW	349	Grassland-shrubland-early Successional	Habitat Mgmt.	M	on-going	Work collaboratively with partners to develop best management practices for retaining a shrub component around agricultural fields	TW3	TW10		Annual and Perennial Non-timber crops
TW	350	Grassland-shrubland-early Successional	Policy	H	new	Research the practicality and feasibility of term easements for grassland, shrub, and early-successional SGCN habitats	TW8	TW3	TW2	Annual & Perennial Non-timber crops, Housing & Urban Areas, Utility & Service Lines
TW	352	Grassland-shrubland-early Successional	Policy	H	new	Establish formal assurance agreements for landowners managing for SGCN (e.g., Safe Harbor Agreements) in grassland, shrub, and early successional habitats	TW2	TW3	TW4	Annual & Perennial Non-timber crops, Housing & Urban Areas, Utility & Service Lines
TW	353	Grassland-shrubland-early Successional	Policy	H	on-going	Support habitat incentive programs by providing additional technical assistance for SGCN habitat management in grasslands, shrublands, and early-successional habitats	TW2	TW3	TW4	Annual & Perennial Non-timber crops, Housing & Urban Areas, Utility & Service Lines

Table 4-16. *continued: page 33 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	354	Grassland-shrubland-early Successional	Policy	M	on-going	Provide better forgone income incentives (e.g., deferred harvest of hay, deferred grazing of portions of pasture, harvest trees earlier than usual) to encourage grassland, shrub, and early successional habitat management practices beneficial to SGCN	TW2	TW3	TW4	Annual and Perennial Non-timber crops
TW	361	Grassland-shrubland-early Successional	Policy	M	new	Work with municipalities/towns to reduce conflicts that impede needed habitat management in grasslands, shrublands, and early successional SGCN habitat	TW3	TW2	TW4	Annual and Perennial Non-timber crops, Commercial and Industrial Areas , Housing and Urban Areas, Utility and Service Lines
TW	357	Grassland-shrubland-early Successional	Public Outreach	M	on-going	Promote community and land trust stewardship of grassland, shrub, and early-successional SGCN habitats through outreach programs	TW1	TW3	TW9	Commercial and Industrial Areas , Housing and Urban Areas
TW	358	Grassland-shrubland-early Successional	Public Outreach	M	on-going	Target outreach to Soil Water Conservation Districts, Maine Farmland Trust, landowners, and others on the importance of grasslands, shrublands, and early successional SGCN habitats	TW3	TW1	TW10	Annual and Perennial Non-timber crops, Housing and Urban Areas
TW	359	Grassland-shrubland-early Successional	Public Outreach	M	on-going	Incorporate more public outreach information on multiple species (e.g., not just New England Cottontail) that are declining due to lack of suitable grassland, shrub, or early successional habitat	TW3	TW1	TW10	Annual and Perennial Non-timber crops, Commercial and Industrial Areas , Housing and Urban Areas, Roads and Railroads, Utility and Service Lines
TW	360	Grassland-shrubland-early Successional	Public Outreach	M	new	Reinforce and acknowledge good management practices by utility companies along utility corridors that contain grasslands, shrublands, and early successional SGCN habitats	TW3	TW4		Utility and Service Lines
TW	362	Grassland-shrubland-early Successional	Public Outreach	M	on-going	Deploy improved signage promoting conservation of grassland, shrub, early successional habitats, and their associated SGCN	TW3	TW1		Annual and Perennial Non-timber crops, Housing and Urban Areas
TW	363	Grassland-shrubland-early Successional	Public Outreach	M	on-going	Promote better communication tools and training on grassland/shrub habitat conservation	TW3			Annual and Perennial Non-timber crops, Commercial and Industrial Areas , Housing and Urban Areas, Roads and Railroads, Utility and Service Lines

Table 4-16. *continued: page 34 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	364	Grassland-shrubland-early Successional	Public Outreach	M	new	Establish and promote demonstration areas highlighting habitat management for grassland, shrub, and early successional SGCN	TW3			Annual and Perennial Non-timber crops, Commercial and Industrial Areas , Housing and Urban Areas, Utility and Service Lines
TW	347	Grassland-shrubland-early Successional	Survey and Monitoring	C	new	Research and identify explicit areas and amounts of grassland, shrub, and early successional habitats needed to conserve target SGCN	TW1	TW3	TW4	Housing & Urban Areas, Utility & Service Lines, Annual & Perennial Non-timber crops, Commercial & Industrial Areas
TW	348	Grassland-shrubland-early Successional	Survey and Monitoring	H	on-going	Assist municipal efforts to identify key grassland, shrub, and early successional SGCN habitats	TW1	TW3	TW4	Annual & Perennial Non-timber crops, Commercial & Industrial Areas , Housing & Urban Areas, Utility & Service Lines
TW	355	Grassland-shrubland-early Successional	Survey and Monitoring	H	new	Map and distribute information on existing ruderal habitats likely to be high value for SGCN	TW1	TW3	TW4	Annual & Perennial Non-timber crops, Commercial & Industrial Areas , Housing & Urban Areas, Roads & Railroads, Utility & Service Lines
TW	356	Grassland-shrubland-early Successional	Survey and Monitoring	H	new	Map potential ruderal habitats likely to be high value for SGCN	TW1	TW3	TW4	Annual & Perennial Non-timber crops, Commercial & Industrial Areas , Housing & Urban Areas, Roads & Railroads, Utility & Service Lines
TW	35	Northern Forests and Swamps	Habitat Mgmt.	C	on-going	Encourage conservation of northern forest and swamp habitats, including late successional forests, using a variety of approaches such as easements and leases	TW8			Commercial & Industrial Areas , Housing & Urban Areas, Logging & Wood Harvesting, Roads & Railroads, Tourism & Recreational Areas, Utility & Service Lines
TW	36	Northern Forests and Swamps	Habitat Mgmt.	C	new	Provide support for landowner incentives for SGCN habitat management in northern forests and swamps and south-central forests and swamps	TW2			Commercial & Industrial Areas , Logging & Wood Harvesting, Roads & Railroads, Tourism & Recreational Areas, Utility & Service Lines
TW	42	Northern Forests and Swamps	Habitat Mgmt.	C	on-going	Offer collaboration and technical expertise to forest certification systems for a subset of applicable SGCN and their forest habitats	TW10	TW2		Logging & Wood Harvesting

Table 4-16. *continued: page 35 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	43	Northern Forests and Swamps	Habitat Mgmt.	C	new	Collaborate with forest landowners and managers to discuss options for voluntary integration of SGCN habitat conservation actions into outcome-based forestry practices	TW10	TW2		Logging & Wood Harvesting
TW	33	Northern Forests and Swamps	Habitat Mgmt.	H	on-going	Consider alternate chemicals or techniques to control invasive species and diseases in northern forests and swamps (especially spruce budworm) and south-central forests and swamps	TW7	TW6		Problematic Native Species/Diseases, Invasive Non-native/Alien Species/Diseases
TW	40	Northern Forests and Swamps	Policy	C	new	Provide support for existing tree growth tax law to discourage conversion of northern forest and swamp SGCN habitats to other non-forested land types	TW2	TW5		Commercial & Industrial Areas , Housing & Urban Areas, Logging & Wood Harvesting, Roads & Railroads, Utility & Service Lines
TW	26	Northern Forests and Swamps	Public Outreach	C	new	Provide outreach to landowners and the public on the effects of roads on northern forest and swamp SGCN habitats	TW1			Roads & Railroads
TW	44	Northern Forests and Swamps	Public Outreach	C	on-going	Provide outreach and education to the general public on the importance of societal consumption of forest products for providing SGCN habitat through forest habitat management	TW1			Logging & Wood Harvesting
TW	21	Northern Forests and Swamps	Public Outreach	M	on-going	Increase outreach and education to the public and landowners on the role of fire in maintaining northern forest and swamp SGCN habitats	TW4	TW1		Fire and Fire Suppression, Habitat Shifting or Alteration
TW	45	Northern Forests and Swamps	Public Outreach	M	on-going	Provide outreach and education to recreationalists on reducing impacts to northern forest and swamp SGCN habitats	TW1			Recreational Activities, Tourism and Recreational Areas
TW	20	Northern Forests and Swamps	Research	C	new	Continue research to better understand and mitigate impacts of climate change on northern forest and swamp SGCN habitats	TW11	TW5		Habitat Shifting or Alteration

Table 4-16. *continued: page 36 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	31	Northern Forests and Swamps	Survey and Monitoring	C	new	Assess conserved lands, especially northern forests and swamps and rocky summits/outcrops/mountaintops, for climate change resiliency and use this information to guide future conservation efforts	TW5			Habitat Shifting or Alteration
TW	32	Northern Forests and Swamps	Survey and Monitoring	C	new	Identify and conserve through a variety of voluntary approaches boreal forest refugia associated with SGCN	TW5			Habitat Shifting or Alteration
TW	30	Northern Forests and Swamps	Survey and Monitoring	H	on-going	Continue stewardship/habitat monitoring on conserved northern forest and swamp lands	TW9	TW11		Recreational Activities
TW	34	Northern Forests and Swamps	Survey and Monitoring	H	on-going	Continue monitoring for invasive and problematic species and diseases, especially forest insect pests, in northern forest and swamps and south-central forests and swamps	TW6	TW7		Invasive Non-native/Alien Species/Diseases, Problematic Native Species/Diseases
TW	38	Northern Forests and Swamps	Survey and Monitoring	H	on-going	Continue long-term monitoring of SGCN habitat condition and forest structure in northern forests and swamps through programs such as the annual Forest Inventory and Analysis	TW11	TW4		Commercial & Industrial Areas , Housing & Urban Areas, Logging & Wood Harvesting, Roads & Railroads, Utility & Service Lines
TW	48	Pine Barrens	Habitat Mgmt.	H	on-going	Encourage conservation of pine barrens through a variety of voluntary approaches	TW8	TW5		Annual & Perennial Non-timber crops, Recreational Activities
TW	49	Pine Barrens	Habitat Mgmt.	M	new	Provide support for property tax incentives to encourage pine barren habitat management on private land	TW2	TW5		Annual and Perennial Non-timber crops, Recreational Activities
TW	56	Pine Barrens	Habitat Mgmt.	M	new	Recognize pine barren landowners for effective habitat management	TW2	TW5	TW1	Fire and Fire Suppression, Invasive Non-native/Alien Species/Diseases, Recreational Activities

Table 4-16. *continued: page 37 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	58	Pine Barrens	Habitat Mgmt.	M	new	Use a variety of incentives to conserve or buffers surrounding pine barrens	TW8	TW5		Commercial and Industrial Areas , Housing and Urban Areas, Mining and Quarrying, Roads and Railroads, Utility and Service Lines
TW	52	Pine Barrens	Policy	C	new	Secure stable funding for fire management in pine barrens	TW2			Fire & Fire Suppression
TW	53	Pine Barrens	Policy	C	new	Provide cost-share for mechanical treatments where fire management is not practical in pine barrens	TW9	TW2		Fire & Fire Suppression
TW	54	Pine Barrens	Policy	C	new	Use agreements (e.g., MOU's) and partnerships to increase fire management capacity in pine barrens	TW9	TW2		Fire & Fire Suppression
TW	55	Pine Barrens	Policy	C	new	Promote inter-agency prescribed fire training and assistance in pine barrens	TW9	TW2		Fire & Fire Suppression
TW	57	Pine Barrens	Public Outreach	M	new	Develop outreach/education to municipal planners and land trusts on the importance of pine barrens and the positive effects of fire and mechanical management on biodiversity	TW1	TW5		Fire and Fire Suppression, Invasive Non-native/Alien Species/Diseases, Recreational Activities, Utility and Service Lines
TW	17	Rocky Summits-Outcrops-Mountaintops	Public Outreach	H	on-going	Provide outreach and education to recreationalists on reducing impacts to rocky summits, outcrops, and mountaintop SGCN habitats	TW1	TW8		Recreational Activities
TW	16	Rocky Summits-Outcrops-Mountaintops	Research	C	new	Continue research to better understand and mitigate impacts of climate change on rocky summits, outcrops, and mountaintop SGCN habitats	TW11	TW5		Habitat Shifting or Alteration

Table 4-16. *continued: page 38 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	15	Rocky Summits-Outcrops-Mountaintops	Survey and Monitoring	C	new	Assess conserved lands, especially northern forests and swamps and rocky summits/outcrops/mountaintops, for climate change resiliency and use this information to guide future conservation efforts	TW5			Habitat Shifting or Alteration
TW	18	Rocky Summits-Outcrops-Mountaintops	Survey and Monitoring	H	on-going	Continue habitat/recreational monitoring stewardship on conserved rocky summit, outcrop, and mountaintop SGCN habitats	TW11			Recreational Activities
TW	65	South-Central Forests and Swamps	Habitat Mgmt.	C	new	Provide landowner incentives for SGCN habitat management in northern forests and swamps and south-central forests and swamps	TW2			Commercial & Industrial Areas , Housing & Urban Areas, Roads & Railroads, Utility & Service Lines
TW	67	South-Central Forests and Swamps	Habitat Mgmt.	H	on-going	Identify, map, and provide information to the public on SGCN habitats in south-central forests and swamps	TW1			Commercial & Industrial Areas , Housing & Urban Areas, Roads & Railroads, Utility & Service Lines
TW	69	South-Central Forests and Swamps	Habitat Mgmt.	H	new	Work collaboratively with partners to develop and distribute habitat management guidelines for south-central forests and swamp SGCN habitats	TW1	TW10		Commercial & Industrial Areas , Housing & Urban Areas, Logging & Wood Harvesting, Roads & Railroads, Utility & Service Lines
TW	63	South-Central Forests and Swamps	Habitat Mgmt.	M	on-going	Encourage conservation of south-central forest and swamp habitats using a variety of approaches such as easements and leases	TW8			Commercial and Industrial Areas , Housing and Urban Areas, Recreational Activities, Roads and Railroads, Utility and Service Lines
TW	80	South-Central Forests and Swamps	Habitat Mgmt.	M	on-going	Collaborate with on-going invasive species eradication/early identification efforts in south central forest and swamp SGCN habitats	TW6			Invasive Non-native/Alien Species/Diseases
TW	70	South-Central Forests and Swamps	Public Outreach	C	on-going	Increase outreach and education to landowners, municipal staff, town council/selectman, and other members of the public on the effects of development (e.g., housing, roads, utility lines) on south-central forest and swamp SGCN habitats	TW1			Commercial & Industrial Areas , Housing & Urban Areas, Roads & Railroads, Utility & Service Lines

Table 4-16. *continued: page 39 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	72	South-Central Forests and Swamps	Public Outreach	H	on-going	Develop outreach and location information on SGCN habitats in south-central forests and swamps for land trusts, municipalities, and landowners	TW1			Commercial & Industrial Areas , Housing & Urban Areas, Roads & Railroads, Utility & Service Lines
TW	77	South-Central Forests and Swamps	Public Outreach	H	on-going	Increase outreach and education to the public, landowners, and hunters and trappers on the effects of over-abundant native species (e.g., deer, beaver) on south-central forest and swamp SGCN habitats	TW7	TW1		Problematic Native Species/Diseases of Unknown Origin
TW	76	South-Central Forests and Swamps	Public Outreach	M	new	Provide spatial information on invasive species to landowners, towns, land trusts, etc., especially for south-central forest and swamp SGCN habitats	TW6	TW1		Invasive Non-native/Alien Species/Diseases
TW	73	South-Central Forests and Swamps	Research	H	on-going	Consider alternate chemicals or techniques to control invasive species and diseases in northern forests and swamps (especially for spruce budworm) and south-central forests and swamps	TW6			Invasive Non-native/Alien Species/Diseases
TW	78	South-Central Forests and Swamps	Species Mgmt.	C	on-going	Increase deer hunting/beaver trapping opportunity to reduce impacts of these species on south-central forest and swamp SGCN habitats	TW7			Problematic Native Species/Diseases
TW	79	South-Central Forests and Swamps	Species Mgmt.	H	on-going	Account for deer/beaver impacts to SGCN habitats in south-central forests and swamps during species management planning process	TW7			Problematic Native Species/Diseases
TW	71	South-Central Forests and Swamps	Survey and Monitoring	H	on-going	Undertake long-term monitoring of SGCN and their habitats in south-central forests and swamps	TW11			Commercial & Industrial Areas , Housing & Urban Areas, Roads & Railroads, Utility & Service Lines
TW	74	South-Central Forests and Swamps	Survey and Monitoring	H	on-going	Continue monitoring for invasive and problematic species and diseases, especially forest insect pests, in northern forests and swamps and south-central forests and swamps	TW6	TW7	TW11	Invasive Non-native/Alien Species/Diseases, Problematic Native Species

Table 4-16. *continued: page 40 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	75	South-Central Forests and Swamps	Survey and Monitoring	M	new	Partner with state and local agencies to identify invasive plant "hotspots" along roads and bridges, especially in south-central forests and swamps	TW6			Invasive Non-native/Alien Species/Diseases
TW	9	Vernal Pools	Habitat Mgmt.	C	on-going	Encourage conservation of high value vernal pool complexes using a variety of voluntary approaches	TW8	TW5		Commercial & Industrial Areas , Habitat Shifting or Alteration, Housing & Urban Areas, Logging & Wood Harvesting, Roads & Railroads, Utility & Service Lines
TW	2	Vernal Pools	Habitat Mgmt.	M	new	Identify on-going opportunities/partnerships for invasive plant species management in vernal pools	TW6			Invasive Non-native/Alien Species/Diseases
TW	14	Vernal Pools	Habitat Mgmt.	M	on-going	Continue work with forestry community on vernal pool Habitat Management Guidelines	TW1	TW10		Logging and Wood Harvesting
TW	4	Vernal Pools	Policy	H	new	Develop vernal pool organism passage recommendations for new and existing road crossing structures	TW5	TW8		Roads & Railroads
TW	7	Vernal Pools	Public Outreach	M	on-going	Update statewide roads and riparian connectivity layer and include models specific to SGCN	TW1			Commercial and Industrial Areas , Habitat Shifting or Alteration, Housing and Urban Areas, Roads and Railroads, Utility and Service Lines
TW	12	Vernal Pools	Public Outreach	M	on-going	Use event-specific (e.g., big night, turtle nesting) outreach to draw greater public attention to vernal pools	TW1			Housing and Urban Areas, Roads and Railroads
TW	13	Vernal Pools	Public Outreach	M	new	Integrate the positive impacts of vernal pools (e.g., economic benefits and relation to game species) into vernal pool outreach messaging	TW1			Commercial and Industrial Areas , Housing and Urban Areas, Roads and Railroads, Utility and Service Lines

Table 4-16. *continued: page 41 of 41.*

Habitat Workgroup	Action ID#	Habitat Group	Action Category	Biol. Priority	Action Type	Description	Theme 1	Theme 2	Theme 3	Stressors Addressed*
TW	6	Vernal Pools	Research	C	new	Identify connectivity hotspots among developable high value vernal pools, pool complexes, and non-breeding habitat	TW1			Commercial & Industrial Areas , Habitat Shifting or Alteration, Logging & Wood Harvesting, Roads & Railroads
TW	8	Vernal Pools	Research	H	new	Research vernal pool remote sensing techniques and field verify on public lands	TW1			Commercial & Industrial Areas , Habitat Shifting or Alteration, Housing & Urban Areas, Logging & Wood Harvesting, Roads & Railroads, Utility & Service Lines
TW	10	Vernal Pools	Research	H	on-going	Identify and implement research opportunities exploring ecosystem requirements of specialized vernal pool taxa	TW11			Commercial & Industrial Areas , Droughts, Habitat Shifting or Alteration, Housing & Urban Areas, Roads & Railroads, Storms & Flooding, Temperature Extremes, Utility & Service Lines
TW	1	Vernal Pools	Research	M	new	Research and identify likely climate change impacts to high value vernal pools	TW5	TW8	TW10	Droughts, Habitat Shifting or Alteration, Storms and Flooding, Temperature Extremes
TW	3	Vernal Pools	Research	M	new	Identify and implement research opportunities investigating effects of invasive species on vernal pool organisms and hydrology	TW6	TW11		Invasive Non-native/Alien Species/Diseases, Roads and Railroads

Table 4-17. Habitat conservation actions by Action Category.

Habitat Category	Habitat Management	Policy	Public Outreach	Research	Species Management	Survey and Monitoring	Total
Freshwater	5	16	19	5	2	7	**54**
Marine / Coastal	47	33	37	32	0	16	**165**
Terrestrial / Freshwater Wetlands	34	19	24	8	2	16	**103**
Total	**86**	**68**	**80**	**45**	**4**	**39**	**322**

Table 4-18. Habitat conservation actions by Type.

Habitat Category	New	On-going	Total
Freshwater	30	24	**54**
Marine / Coastal	33	132	**165**
Terrestrial / Freshwater Wetlands	54	49	**103**
Total	**117**	**205**	**322**

Table 4-19. Habitat conservation actions by Biological Priority.

Habitat Category	Critical	High	Moderate	Total
Freshwater	6	37	11	**54**
Marine / Coastal	22	73	70	**165**
Terrestrial / Freshwater Wetlands	24	35	44	**103**
Total	**52**	**145**	**125**	**322**

4.3.4 DEVELOPMENT OF HABITAT THEMES

Given the volume of habitat conservation actions identified in the 2015 Wildlife Action Plan, habitat workgroups developed several themes to organize these actions into discrete packages of related actions that address common stressors or use similar techniques (Table 4-20). Actions within a theme are often complementary, and thus, simultaneously undertaking multiple actions within a theme may be the most effective and efficient use of limited conservation dollars. We assigned each habitat action to as many as three themes within its respective habitat workgroup (i.e., marine/coastal, terrestrial/freshwater wetlands, or freshwater aquatic habitats) with up to 36 actions per theme.

In order to better illustrate the connection between habitat actions and SGCN, we quantified the minimum number of SGCN likely to benefit from a given theme (Table 4-20). We use the term 'minimum' because we assume that habitat actions benefit most, if not all, SGCN associated with a given habitat; however, some species may derive greater benefit than others. We used the approach below to determine the minimum number of SGCN likely to benefit from each theme:

"Given the volume of habitat conservation actions identified in the 2015 Action Plan, habitat workgroups developed several themes to organize these actions into discrete packages of related actions that address common stressors or use similar techniques."

1. We identified all habitat macrogroups associated with a theme.

2. We identified the SGCN (by priority level) associated with each macrogroup. We counted SGCN associated with multiple macrogroups only once.

3. For Priority 1 and 2 SGCN, we identified species with stressors common to those addressed by the habitat theme.

    a. If we ranked the common stressor as moderate or high severity for the SGCN, we assumed the species would likely benefit from a habitat action addressing that stressor. We tallied these species in columns 'P1' and 'P2' of Table 4-20.

        i. For example, we identified Housing and Urban Areas as a severe stressor for Spotted Turtles (Priority 1 SGCN). A theme that includes actions addressing Housing and Urban Areas at the habitat scale would also benefit Spotted Turtles.

    b. If we ranked the common stressor as low severity for the SGCN, we assumed the species may benefit from a habitat theme addressing that stressor, but the link may not be as direct. We tallied these species in the column 'Total SGCN' of Table 4-20. In many cases, we did not assign low severity stressors to SGCN because they are unlikely to be priorities in the next ten years.

    c. We did not assign stressors to Priority 3 SGCN, but these species would likely benefit from habitat actions undertaken in their habitats. We tallied these species in the column 'Total SGCN' of Table 4-20.

Table 4-20. Habitat conservation action themes.

Code	Theme Description (Total No. Conservation Actions per Theme)	Habitat Groups Directly Addressed by Theme	Min. No. of SGCN Likely to Benefit from a Theme		
			P1[1]	P2[1]	Total SGCN[2]
Freshwater Aquatic Themes					
F1 Mapping and Outreach[3]	Map the distribution of SGCN, their habitats, and their stressors, and provide this information to landowners, land trusts, municipal governments, and conservation partners to aid in spatial planning (14)	Streams; Rivers; Lakes; Ponds	20	27	72
F2 Connectivity[3]	Maintain and improve (where practicable) connectivity for SGCN and their habitats through mapping, outreach, and town/municipal collaboration while considering impacts of climate change and invasive species (19)	Streams; Rivers; Lakes; Ponds	20	27	72
F3 Invasive Species[3]	Monitor, contain, and control the spread of invasive species that negatively impact SGCN or their habitats through surveys, research, public outreach, habitat management, and reclamation (7)	Streams; Rivers; Lakes; Ponds	0	0	72
F4	Maintain and restore (where practicable) riparian habitats used by SGCN by providing technical assistance and education to municipalities and natural resource professionals, providing technical assistance and incentives to landowners, and collaborating with interested parties to develop BMPs, in order to mitigate climate change and land-use effects (10)	Streams; Rivers; Lakes; Ponds	20	27	72
F5	Reduce pollution and degradation of important SGCN habitats by working with landowners and municipalities to improve wastewater treatment and reduce impacts from development near lake and river shores (10)	Streams; Rivers; Lakes; Ponds	20	27	72
F6	Improve passage of fish SGCN at dams by providing outreach and technical assistance to dam owners and operators, researching fish behavior and alternative technologies, and conducting a statewide inventory of dams (11)	Streams; Rivers; Lakes; Ponds	20	27	72
Marine Themes					
M1 Mapping and Outreach[3]	Map and provide outreach/technical assistance for SGCN occurrence and habitat location information for marine spatial planning and other uses (32)	Intertidal; Subtidal; Tidal marsh; Rocky coast; Coastal	25	62	108
M2	Research, implement, and provide outreach/technical assistance for new and underutilized technologies designed to reduce impacts to SGCN habitats including, but not limited to, litter reduction, ghost gear removal, bycatch reduction, pollution mitigation, climate change and ocean acidification, alternative energies, and aquaculture (34)	Intertidal; Subtidal; Tidal marsh	25	62	104
M3M4	Research the effects of climate change on SGCN and their habitats and incorporate this information and other climate change concepts (e.g., buffering for marsh migration and extreme storms) into coastal development and infrastructure planning, spatial modeling, fishable stock management, habitat restoration, and other efforts to reduce impacts of climate change to SGCN, SGCN habitats, and coastal communities (36)	Intertidal; Subtidal; Tidal marsh; Rocky coast; Coastal	25	62	108

Table 4-20. *continued: page 2 of 4.*

Code	Theme Description (Total No. Conservation Actions per Theme)	Habitat Groups Directly Addressed by Theme	Min. No. of SGCN Likely to Benefit from a Theme		
			P1[1]	P2[1]	Total SGCN[2]
Marine Themes (continued)					
M5 Connectivity[3]	Maintain and improve habitat connectivity while also considering impacts of climate change for SGCN aquatic organisms through mapping, outreach, town/municipal collaboration, and voluntary habitat conservation (23)	Intertidal; Subtidal; Tidal marsh; Coastal	18	48	107
M6	Conduct law enforcement training and workshops to support knowledge of SGCN and their habitats (11)	Intertidal; Subtidal; Tidal marsh; Rocky coast	23	54	105
M7 Invasive Species[3]	Monitor, contain, and control the spread of invasive species that are negatively affecting SGCN habitats through research, management, public outreach, and enforcement of existing policies and regulations (14)	Intertidal; Subtidal; Tidal marsh; Rocky coast	25	62	105
M8	Minimize impacts to SGCN waterbird feeding, roosting and nesting habitats from activities including but not limited to fishing and recreation (11)	Intertidal; Rocky coast; Coastal	14	26	66
M9	Evaluate and implement new and existing methods to monitor and manage commercial and recreational harvest of SGCN to ensure ecological sustainability (including ecosystem or bay scale management) (19)	Intertidal; Subtidal	23	54	93
M10	Minimize loss of marine SGCN habitats due to development (e.g., structures, dwellings, docks, piers, aquaculture facilities, and marinas) and mitigate for associated impacts such as contaminants (e.g., oil, gas, and chemical spills) and disturbance associated with human activity (30)	Intertidal; Subtidal; Tidal marsh; Coastal; Rocky coast	25	62	108
Terrestrial/Freshwater Wetland Themes					
TW1 Mapping and Outreach[3]	Identify, map, distribute information, and provide technical assistance and outreach to landowners, towns, land trusts, etc. on the location and management of selected high-value, at-risk habitats important to the conservation of SGCN (33)	Vernal pools; South-central forests and swamps; Grassland, shrubland, early successional; Pine barrens; Freshwater marshes; Floodplain forest	23	64	139
TW2	Identify potential additions or improvements to existing financial and non-financial incentives to encourage landowner participation in the restoration, retention, and management of habitats important to SGCN, analyze these ideas for effectiveness, and encourage implementation of those with the greatest potential for use and benefit (26)	Northern forests and swamps; South-central forests and swamps; Grassland, shrubland, early successional; Pine barrens; Freshwater marshes; Floodplain forest	22	60	147
TW3	Identify opportunities for expansion of ruderal habitat in southern Maine, which includes determining the amount needed for SGCN conservation, identifying where habitat expansion could most practically occur, and collaborating with conservation partners to develop habitat management guidelines (21)	Grassland, shrubland, early successional	11	25	57

Table 4-20. *continued: page 3 of 4.*

Code	Theme Description (Total No. Conservation Actions per Theme)	Habitat Groups Directly Addressed by Theme	Min. No. of SGCN Likely to Benefit from a Theme		
			P1[1]	P2[1]	Total SGCN[2]
Terrestrial/Freshwater Wetland Themes (continued)					
TW4	Identify opportunities for expansion of early successional forest habitats in southern Maine and ecologically mature forests in northern Maine needed by SGCN dependent on those habitats, which includes determining the amount needed, and collaborating with conservation partners to develop habitat management guidelines (13)	Northern forests and swamps; Grassland, shrubland, early successional	19	51	108
TW5 Connectivity[3]	Facilitate the persistence and range expansion of SGCN in Maine in the face of a changing climate by ensuring landscape connectivity (both terrestrial and aquatic) through reducing habitat fragmentation and promoting the voluntary conservation of diverse and resilient landscapes and watersheds (18)	Northern forests and swamps; Pine barrens; Freshwater marshes; Rocky summits, outcrops; Vernal pools	22	64	130
TW6 Invasive Species[3]	Monitor, prevent, contain, and control invasive species (plant and animal) and diseases with potential for significant detrimental impact on SGCN and their primary habitats (13)	Vernal pools; Northern forests and swamps; South-central forests and swamps; Freshwater marshes; Floodplain forests; Grasslands, shrublands, early successional	3	3	143
TW7	Monitor and manage the impact of problematic native species and diseases on SGCN and their habitats (8)	Northern forests and swamps; South-central forests and swamps; Floodplain forest; Grasslands, shrublands, early successional	0	0	130
TW8	Minimize habitat loss and fragmentation by guiding detrimental land-use activities away from the most sensitive and limited SGCN habitats and by conserving lands and buffers surrounding sensitive SGCN habitats (16)	Freshwater marshes; Grasslands, shrublands, early successional; Northern forests and swamps; Pine barrens, South-central forests and swamps; Vernal pools; Floodplain forests	25	68	147
TW9	Promote voluntary SGCN habitat management on both private and public lands, especially habitats that are limited and hard to manage economically, such as ruderal habitats, grasslands, pine barrens, floodplains, early and late successional forest habitats (8)	Pine barrens; Rocky summits, outcrops; Grasslands, shrublands, early successional; Northern forests and swamps; Freshwater marshes; Floodplain forest	11	29	144
TW10	Collaborate with conservation partners to develop habitat management guidelines for SGCN and encourage their voluntary incorporation into forest certification systems and outcome-based forestry (13)	Vernal pools; Northern forests and swamps; Floodplain forest; South-central forests and swamps	14	40	76

Table 4-20. *continued: page 4 of 4.*

Code	Theme Description (Total No. Conservation Actions per Theme)	Habitat Groups Directly Addressed by Theme	Min. No. of SGCN Likely to Benefit from a Theme		
			P1[1]	P2[1]	Total SGCN[2]
Terrestrial/Freshwater Wetland Themes (continued)					
TW11	Conduct biological monitoring as required to guide the conservation of SGCN and their habitats especially for habitats requiring active management (e.g., grasslands, shrublands, early successional habitats) or are vulnerable to adjacent activities (9)	Grasslands, shrublands, early successional; vernal pools, Northern forests and swamps; South-central forests and swamps; Rocky summits, outcrops	22	60	134

[1]SGCN included in this tally are most likely to benefit from a theme because actions within that theme address habitat stressors that also were identified as 'moderate' or 'severe' stressors at the species scale; SGCN for which a stressor was determined to be of 'slight' severity are not included in this tally.
[2]This is the total number of SGCN that occur in habitats addressed by a theme.
[3]Cell shading indicates a cross-cutting theme common among the three habitat categories; these cross-cutting themes are abbreviated as: 1) Mapping and Outreach, 2) Connectivity, and 3) Invasive Species

While the number of SGCN likely to benefit from themes can help readers assess the relative breadth of themes, these tallies should not be used to evaluate the relative merits of themes. For example, Terrestrial/Wetland Theme 8 (TW8) is broad (minimizing habitat loss and fragmentation by guiding detrimental land-use activities away from the most sensitive and limited SGCN habitats) and encompasses 16 actions, seven habitat groupings, and likely benefits a minimum of 25, 68, and 147 Priority 1, Priority 2, and total SGCN, respectively. In contrast, Terrestrial/Wetland Theme 7 (TW7) has a narrower scope (monitoring and managing impacts of problematic native species) in four terrestrial/wetland habitats. This theme likely benefits at least 160 SGCN associated with these habitats, but using our approach outlined above, does not link directly with any Priority 1 or Priority 2 SGCN. In this case, we identified Problematic Native Species as a moderate stressor in some habitats but ranked it as a low severity stressor (or not ranked at all) for SGCN associated with these habitats.

Three 'super-themes' emerged across habitat groups; actions included in these themes will likely benefit from coordinated efforts across habitats. The themes are:

1. **Connectivity:** This super-theme addresses habitat connectivity with a focus on facilitating the persistence and range expansion of SGCN and their habitats in the face of climate change. While Habitat Shifting and Alteration related to climate change was not a priority stressor for most SGCN, it is the second most common stressor assigned to habitat macrogroups. This super-theme also addresses other common causes of habitat fragmentation.

2. **Invasive Species:** Actions in this super-theme consist of monitoring, containment, and control of invasive species. We assigned the Invasive Non-native/Alien Species/Diseases stressor to the largest number of habitat macrogroups and it has the potential to affect nearly every habitat in Maine. This stressor also affects many SGCN.



Monitoring, containment, and control of invasive species, such as the Asiatic bittersweet (*Celastrus orbiculata*) pictured here, were identified as important conservation actions across SGCN habitats. © Maine Natural Areas Program.

3. **Mapping and Outreach:** Actions in this super-theme address mapping and outreach needs for SGCN and habitats. We identified Lack of Knowledge as a priority stressor for SGCN. For example, many marine SGCN distributions and habitats are largely unknown and therefore unmapped. Many negative effects of stressors can be minimized or avoided by simply knowing where SGCN and habitats are located and conveying this information to local decision makers, landowners, and conservation stewards.

4.4 PROGRAMMATIC CONSERVATION ACTIONS

MDIFW and the Steering Committee identified 11 programmatic actions to guide implementation and tracking of the 2015 Wildlife Action Plan (Table 4-21). Target start dates for each programmatic action (short-term: within the first few years of Plan implementation; mid-term: within the first half of Plan implementation; long-term: within the second half of Plan implementation) are given. We categorized programmatic actions as follows:

1. **Outreach and Engagement (Programmatic Actions 1-3):** Actions to inform and engage the public and partners on Action Plan accomplishments and opportunities for involvement. We describe these actions in Elements 7-8.

2. **Funding and Tracking (Programmatic Actions 4-8):** Actions to bolster funding, capacity, and tracking of SGCN-related projects. We discuss Programs 4 and 6 briefly below, Program 5 in Elements 7-8, and Programs 7 and 8 in Elements 5-6.

   a. **Program 4:** This action supports efforts to establish stable state and federal funding sources for SGCN and habitat conservation. At the state level, MDIFW and partners will continue to investigate stable funding sources for SGCN conservation.
   b. At the federal level, groups of conservation partners, such as Maine's Teaming with Wildlife Coalition (http://www.teaming.com/state-tribal-wildlife-grants-swg-program), may continue to seek sources of federal funding for SGCN conservation.
   c. **Program 6:** This action focuses on increasing long-term agency support for Wildlife Action Plan implementation. While many staff in MDIFW work on projects related to SGCN conservation, there currently are no dedicated SWAP staff or programs to coordinate Plan administration, tracking, or outreach.

> *"MDIFW and the Steering Committee identified 11 programmatic actions to help guide implementation and tracking of the 2015 Wildlife Action Plan."*

3. **Action Development (Programmatic Action 9):** This action relates to creating SMART (Specific, Measurable, Achievable, Results-oriented, and Time-bound) objectives for high priority SGCN and habitat conservation actions. We discuss this action in Elements 5-6.

4. **Regional Partnerships (Programmatic Actions 10-11):** These actions address continued MDIFW and partner involvement in existing conservation efforts.

   a. **Program 10:** This action supports efforts to identify new and update existing SGCN Conservation Opportunity Areas (COAs). One such effort is already underway. MDIFW, MNAP, MCP, MDMR and other partners are reviewing and revising Maine's Focus Areas of Statewide Ecological Significance. Focus Areas are 140 natural areas of statewide ecological significance that contain unusually rich concentrations of at-risk species and habitats (http://beginningwithhabitat.org/about_bwh/focusareas.html). These areas support rare plants, animals, and natural communities, high-quality common natural communities, significant wildlife habitats, and their intersections with large blocks of undeveloped habitat. We delineate Focus Area boundaries based on the species

and natural communities that occur within them and the supporting landscape conditions that contribute to the long-term viability of the species, habitats, and community types. MDIFW and partners are revising existing Focus Areas with 2015 SGCN distribution and habitat information and are exploring ways to incorporate resilient landscapes and connectivity among Focus Areas. We expect this revision to be completed within the first few years of this Plan's implementation. We also expect to create a framework that will guide and standardize periodic updates to Focus Areas.

MDIFW and conservation partners also are engaged in several on-going efforts to adapt broad-scale climate change resiliency information to local and regional scales. For example, MDIFW, MNAP, The Nature Conservancy (TNC), and the 10 partners of Mount Agamenticus to the Sea Conservation Initiative (MTA2C) are assessing the resilience of the MTA2C Focus Area using climate change resilience data and revised SGCN distribution information (http://www.osiny.org/site/DocServer/Catalyst_GranteesToDate_All.pdf?docID=14401). They will use the results of this project to inform local landscape planning and to serve as a model for other communities wishing to incorporate climate change information into their planning efforts. A similar effort also is underway in several Downeast Maine communities.

b. **Program 11:** This action supports MDIFW and partner participation in the Northeast Regional Conservation Needs (RCN) Grant Program. The RCN Grant Program addresses critical landscape-scale wildlife conservation needs by combining multi-state resources, leveraging funds, and regionally prioritizing SWAP conservation actions; http://rcngrants.org/content/northeast-regional-conservation-needs-grant-program). RCN grants funded several products (e.g., the Northeast Terrestrial Habitat Classification System [Anderson et al. 2013]) used in Maine's 2015 Wildlife Action Plan. MDIFW will work with the Implementation Committee to evaluate, at least annually, continued participation in and endorsement of the RCN program.

Table 4-21. 2015 Maine Wildlife Action Plan Programmatic Actions.

Program Type	Program Code	Program Description	Target Start Timeframe		
			Short Term	Mid Term	Long Term
Outreach and Engagement	Program 1	Establish a Wildlife Action Plan Implementation Committee comprised of conservation partners and agency staff to help guide implementation of the Plan	X		
	Program 2	Devise and implement outreach strategies, including periodic meetings, to inform and engage conservation partners and the general public on 2015 Wildlife Action Plan information, accomplishments, and opportunities for involvement		X	
	Program 3	Develop a public survey of SWAP and non-game species awareness, concerns, and priorities	X		X
Funding and Tracking	Program 4	Secure stable and additional sources of federal and state funding for SGCN and habitat conservation		X	
	Program 5	Consider establishing a competitive small grants program to make a portion of SWG funds available to partners implementing priority actions identified in the 2015 Wildlife Action Plan		X	
	Program 6	Support MDIFW and DMR nongame fish and wildlife staff to help with SGCN conservation action implementation			X
	Program 7	Annually compile agency and partner expenditures and seek additional match opportunities to maximize efficiency and impact of 2015 Wildlife Action Plan implementation	X		
	Program 8	Track SWAP conservation action implementation accomplishments by agencies and partners	X		
Action Development	Program 9	Develop SMART (Specific, Measurable, Achievable, Results-oriented, and Time-bound) style objectives for high priority habitat-scale and SGCN conservation actions		X	
Regional Partnerships	Program 10	Identify new and review/update existing SGCN Conservation Opportunity Areas, including Focus Areas of Statewide Significance, using SGCN distribution data, resilient landscapes analyses, and landscape planning concepts	X		
	Program 11	Participate in the Northeast Regional Conservation Needs (RCN) Grant Program following annual endorsements from Maine's Wildlife Action Plan implementation committee (*tentative*)		X	

4.5 AN APPROACH TO PRIORITIZING CONSERVATION EFFORTS

4.5.1 USES FOR PRIORITIZATION CONSIDERATIONS

Maine's 2015 Wildlife Action Plan needs to be a tightly prioritized plan because State Wildlife Grant (SWG) funds are limited and the number of SGCN is large. As discussed in 4.1.2, we have already prioritized in a number of important ways:

1. We assigned SGCN to three priority levels.

2. We ranked stressors and did not comprehensively develop conservation proposals for any stressors that we ranked less than high or medium-high.

3. We also ranked conservation actions on behalf of SGCN and habitats by biological priority (e.g., Critical, High, Moderate).

With regard to the approximately 30 habitat conservation themes (Section 4.3.4), rather than prioritizing among these per se, we have provided information for each on the number and priority level of the SGCN and habitats they are designed to address. We hope this will help partners evaluate the nature and scope of these themes.

In the sections below, we propose a suite of criteria for conservation partners to use in focusing their conservation resources toward selected conservation actions during implementation of the Wildlife Action Plan. These criteria could also form the basis for MDIFW to select proposals for SWG funding, although for proposals competing for SWG funding, there are likely to be additional criteria and considerations, such as whether the proposal has clear and measurable objectives and the amount of non-federal, non-MDIFW funds offered.

4.5.2 POTENTIAL CRITERIA FOR PRIORITIZING CONSERVATION ACTIONS

1. **Biological Impact Considerations**
   The overarching concept is that, all other things being equal, actions that benefit Priority 1 SGCN (i.e., those at most immediate risk of extirpation from Maine) should be higher priority than those for Priority 2 and Priority 3. Actions that benefit multiple SGCN should have priority over those that benefit only a single species. Actions that impact a larger geographic scale should have priority over those that impact only a small area.

   a. **Degree of Impact:** Will the proposed action or suite of actions significantly affect the conservation status of the SGCN(s) and/or its habitat (e.g., improved distribution, abundance, or viability essential to avoiding extirpation)?

   b. **Scope of Impact:** Will the proposed action or suite of actions significantly affect the conservation status of multiple SGCN or multiple habitats or facilitate multiple actions for multiple SGCN and their habitats at a state-wide level?

c. **Endurance of Impact:** Will the proposed actions likely have lasting impact (e.g., even in the face of significant sea level rise or other impacts of a changing climate)?

d. **Regional/National Collaboration:** Are the proposed actions recommended through an established regional or national conservation initiative, such that the certainty of impact is greater through increased peer review of approach, experience in implementation or evidence of success, as well as amplification of impact through regional networking?

2. **Feasibility Considerations**

a. **Partnership:** Does the proposal enhance opportunities for conservation partner collaboration, and are partners willing and able to participate?

b. **Public Support:** Does the proposal conserve SGCN of high economic, social, or cultural value such that it is likely to have strong support from relevant sectors and/or the general public?

c. **Capacity:** Does MDIFW and/or conservation partners have the necessary expertise, staff capacity and resources to successfully complete the proposal?

d. **Value (Cost-Benefit Ratio)**: How do the proposal's likely costs compare to its likely impact? (Figure 4-3).

Figure 4-3. Cost-benefit matrix of conservation proposals.

COST	BENEFIT		
	HIGH – long lasting, very high improvement in viability for multiple highly ranked SGCN	**MEDIUM**	**LOW**
Low	Worth the effort	Likely worth the effort	Proposal needs revision, or consider other actions
Medium	Likely worth the effort	Find ways to increase benefit and reduce cost	Proposal needs revision, or consider other actions
High	Find funds to do it	Proposal needs revision, or consider other actions	Likely not worth the effort

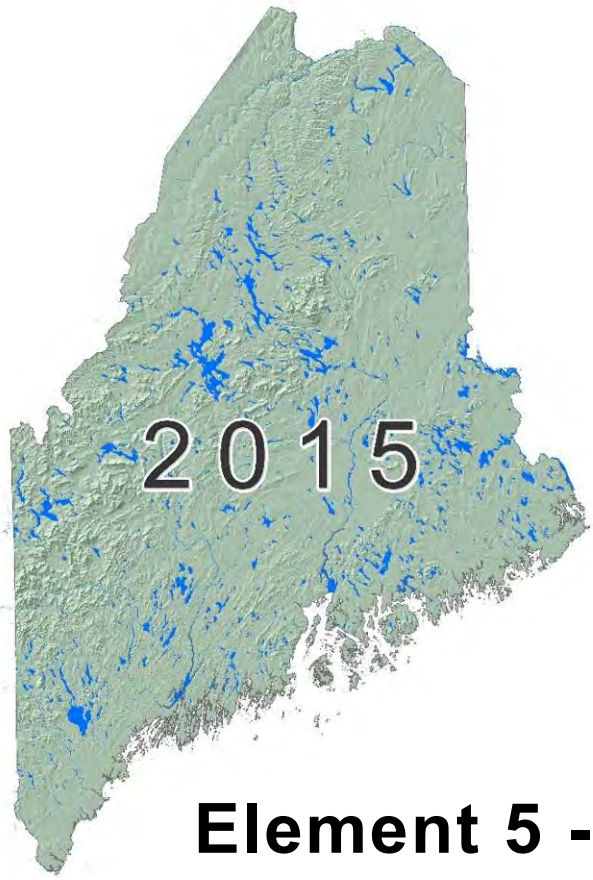
4.6 LITERATURE CITED

Association of Fish and Wildlife Agencies (A FWA). 2012. Best Practices Working Group 2012. Best Practices for State Wildlife Action Plans – Voluntary Guidance to States for Revision and Implementation. Washington (DC): Association of Fish and Wildlife Agencies. 80pp. Association of Fish and Wildlife Agencies, Teaming With Wildlife, State Wildlife Action Plan (SWAP).

Anderson, M.G. M. Clark, C.E. Ferree, A. Jospe, A. Olivero Sheldon and K.J. Weaver. 2013. Northeast Habitat Guides: A companion to the terrestrial and aquatic habitat maps. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA. http://nature.ly/HabitatGuide.

Conservation Measures Partnership (CMP). 2013. Open Standards for the Practice of Conservation. Conservation Measures Partnership.

Maine Dept. of Inland Fisheries and Wildlife (MDIFW). 2005. Maine's comprehensive wildlife conservation strategy. Maine Dept. of Inland Fisheries and Wildlife, Augusta, Maine.



MAINE'S WILDLIFE ACTION PLAN

Element 5 - Monitoring & Element 6 - Periodic Review

Prepared by

Maine Department of Inland Fisheries and Wildlife

In collaboration with

Maine's Conservation Partners

September 2015

TABLE OF CONTENTS

Element 5: Monitoring
Element 6: Periodic Review

5/6.0 Abstract 1

5/6.1 Introduction 1
5/6.1.1 Significant Differences from Maine's 2005 Plan 1

5/6.2 Monitoring SGCN 2
5/6.2.1 Birds 3
5/6.2.2 Reptile, Amphibians, and Invertebrates 16
5/6.2.3 Inland Fish 17
5/6.2.4 Mammals 17
5/6.2.5 Marine Fauna 30

5/6.3 Monitoring SGCN Habitats 41
5/6.3.1 Statewide Habitat and Conservation Action Monitoring 46

5/6.4 Progammatic Monitoring 48

5/6.5 Plans for Revision 50

5/6.6 Literature Cited and References 51

LIST OF TABLES

Table 5/6-1. Status of Population Monitoring for Maine's Bird Species of Greatest Conservation Need. 4

Table 5/6-2. Status of Population Monitoring for Maine's Amphibian and Reptile Species of Greatest Conservation Need. 18

Table 5/6-3. Status of Population Monitoring for Maine's Non Marine Invertebrate Species of Greatest Conservation Need. 19

Table 5/6-4. Status of Population Monitoring for Maine's Inland Fish Species of Greatest Conservation Need. 27

Table 5/6-5. Status of Population Monitoring for Maine's Mammal Species of Greatest Conservation Need. 29

Table 5/6-6. Status of Population Monitoring for Maine's Marine Species of Greatest Conservation Need. 31

Table 5/6-7. Proposed habitat monitoring approaches. 42

KEY TO ACRONYMS

BwH	Beginning with Habitat
GIS	Geographic Information System
HMG	Habitat Management Guidelines
NMFS	National Marine Fisheries Service
MAMP	Maine Amphibian Monitoring Program
MARAP	Maine Amphibian and Reptile Atlasing Project
MBS	Maine Butterfly Survey
MBBA	Maine Bumble Bee Atlas
MDDS	Maine Damselfly and Dragonfly Survey
MDIFW	Maine Dept. of Inland Fisheries and Wildlife
MDMR	Maine Dept. of Marine Resources
NOAA-Fisheries	National Oceanic and Atmospheric Administration - Fisheries
PRISM	Program for Regional and International Shorebird Monitoring
SGCN	Species of Greatest Conservation Need
SMART	Specific, Measurable, Achievable, Results-oriented, and Time-bound
SWAP	State Wildlife Action Plan
SWG	State Wildlife Grants
TRACS	Tracking and Reporting Actions for the Conservation of Species
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

5/6.0 ABSTRACT

In these elements, we outline the methods we will use to monitor Species of Greatest Conservation Need (SGCN) and their habitats, describe how we will monitor the progress made in implementing the Action Plan over the next ten years, and address the procedures we will use to review and update the Action Plan. To accomplish these goals, we work closely with federal, state, and private conservation partners to develop and participate in cooperative species monitoring programs. Where possible, monitoring programs target multiple species, usually within the same taxonomic group. In the pages that follow, we describe the monitoring programs that are in place or proposed for SGCN in Maine. We include a table for each of the five taxonomic groups that are referenced throughout this plan.

The Maine Dept. of Inland Fisheries and Wildlife (MDIFW) and partners also identified habitat-scale survey and monitoring needs during the development of conservation actions. We present these actions with examples of existing and general survey and monitoring techniques that could be used to achieve these habitat monitoring objectives.

Finally, MDIFW and partners developed 11 programmatic actions to help guide Action Plan implementation over the next ten years. Three of these actions address monitoring and are described in greater detail.

MDIFW will use the programmatic actions to monitor conservation action progress at least annually. MDIFW will also establish an Implementation Committee in the Fall of 2015, comprised of agency staff and conservation partners. This committee will review Action Plan accomplishments and address emerging issues or adaptive management needs. We will undertake a comprehensive plan review beginning in year eight of the 2015 Action Plan.

5/6.1 INTRODUCTION

In the previous chapter, we discussed Maine's strategies for conserving SGCN and their habitats across the state. Maine's approach is built on a foundation of habitat conservation, which is designed to ensure that adequate habitat remains available in perpetuity to support not only Maine's SGCN, but the full array of wildlife occurring in Maine. Those efforts are supplemented with species-specific conservation actions focused on priority stressors for Priority 1 and Priority 2 SGCN.

In this chapter, we outline the methods we will use to monitor SGCN and their habitats. We also describe how we will monitor the progress made in implementing the Action Plan over the next 10 years. Finally, we address the procedures we will use to review and update the Action Plan.

5/6.1.1 SIGNIFICANT DIFFERENCES FROM MAINE'S 2005 PLAN

In 2005, MDIFW identified the species-specific monitoring programs that were in place for SGCN, and provided extensive detail on the Department's approach to species planning (Chapters 6, 7, MDIFW 2005). MDIFW's species plans provide a framework for monitoring both

individual species and their habitats, and the 2005 Action Plan referenced this process as the primary mechanism by which we would conduct this work. For some species that had not been ushered through the formal species planning process, the 2005 Action Plan identified additional programs by which we would assess progress in achieving conservation outcomes. The 2005 Plan also described an approach for monitoring statewide changes in habitat, which focused on the use of satellite imagery to measure changes in land cover.

While this plan follows a similar framework as used in 2005 for monitoring SGCN and their habitats, we made several substantive revisions, including:

- Removed references to MDIFW's species planning process, which has evolved since 2005 and has been replaced by the State Wildlife Action Plan (SWAP) as the primary planning tool for SGCN conservation.
- Streamlined the descriptions of SGCN monitoring programs, and provided most of this information in tabular format rather than in the body of the text.
- Added a description of how we will monitor the success of implementing conservation actions.
- Describe the process we will use to review and update the Plan as required by Congress.

5/6.2 MONITORING SGCN

SGCN species run the gamut, from species for which we have little information to those that are intensively monitored through formal, multi-state initiatives. We work closely with federal, state, and private conservation partners to develop and participate in cooperative species monitoring programs. Where possible, monitoring programs target multiple species, usually within the same taxonomic group. In the pages that follow, we describe the monitoring programs that are in place for SGCN in Maine. We include a table for each of the following taxonomic groups (Tables 5/6-1 to 5/6-6):

"We work closely with federal, state, and private conservation partners to develop and participate in cooperative species monitoring programs."

- Birds
- Amphibians and Reptiles
- Inland and Freshwater Invertebrates
- Inland Fish
- Mammals
- Marine species

Within each table, we use an 'O' for 'ongoing' to indicate that the species is currently being monitored with the referenced approach, and an 'N' for 'new' to indicate that the species is not currently monitored with the referenced approach, but it could be monitored using this methodology if resources become available. An 'I' entry indicates that the technique provides interim, preliminary data but the existing methodology is not an optimal strategy to monitor populations.

5/6.2.1 BIRDS

Currently, 14 distinct programs are used to monitor 101 of the 130 bird SGCN in Maine (Table 5/6-1). In addition, MDIFW monitors 16 SGCN birds using individual, species-specific protocols. Only 12 SGCN birds are not currently subject to some type of formal monitoring program, although monitoring protocols for 7 of these species (American Oystercatcher, Red Phalarope, Red-necked Phalarope, Solitary Sandpiper, Yellow Rail, Saltmarsh Sparrow, and Sedge Wren) may be implemented in the near future.

Many of these protocols are statewide in scope. Others, such as the Christmas Bird Count, and the Breeding Bird Survey, occur nationwide. The following describes some of these programs.

MDIFW staff collaborate with U.S. Fish and Wildlife Service (USFWS) to implement the Coastal Waterbird Survey, which provides information on the distribution and abundance of several waterbird SGCN nesting on coastal islands. This program consists of a series of both ground nest counts and aerial surveys of coastal waterbirds along the entire coast of Maine. Ideally, these surveys are designed to cover the entire coast once every five years.

The Maine Owl Survey uses a series of established survey routes to document the distribution and relative abundance of owls within the state. Trained observers make brief roadside stops along survey routes play short recordings of owl calls for 15 minutes at each survey point and note the owls responding.

A Canadian / U.S. Shorebird Working Group and the U.S. Shorebird Council (Bart et al. 2002) implement the Program for Regional and International Shorebird Monitoring (PRISM), based on Canadian and U.S. shorebird conservation plans (Brown et al. 2001, Donaldson et al. 2000). MDIFW is a participant in this monitoring program (Tudor 2002).

Annually, MDIFW conducts Maine Waterfowl Brood Counts and uses the results to develop a long-term index of the size of the breeding waterfowl population found in 36 wetlands (Corr 1988).

MDIFW conducts the Mid-winter Waterfowl Survey, an aerial inventory, annually during the first week of January. It is an index to the total number of waterfowl present in Maine each winter (Corr 1988).

The Vermont Institute of Natural Science (VINS) launched Mountain Birdwatch in the spring of 2000 to establish a monitoring program for Bicknell's Thrush and other montane forest birds. VINS uses these data to measure population trends, monitor changes in bird distribution, model potential breeding habitat, identify conservation opportunities, evaluate proposed development, and predict effects of climate change on mountain songbirds.

The annual island-nesting tern survey is a collaborative effort by the USFWS, the National Audubon Society, MDIFW, and others. The Gulf of Maine Tern Working Group has developed standardized census methods that surveyors use to estimate the total number of individual terns and species composition of terns using each island. Surveyors conduct the assessments annually in June.

Table 5/6-1. Status of Population Monitoring for Maine's Bird Species of Greatest Conservation Need.

Order Scientific Name	Common Name	Priority	Species-Specific Monitoring	Maine River Bird Survey	Breeding Bird Survey	Christmas Bird count	Mountain Birdwatch	Kennebunk Plains / TNC Annual Survey	Secretive Marsh Bird Surveys	Island Nesting Tern Survey	Maine Owl Survey	Wading Bird Colony Surveys and Monitoring	Migratory Shorebird Survey (PRISM/ISS)	Waterfowl Brood Counts	Mid-winter Waterfowl Survey	IFW regional shorebird surveys for SWH designation and mapping	Grassland Bird Surveys
Accipitriformes (hawks, eagles, and vultures)																	
Aquila chrysaetos	Golden Eagle	2															
Buteo platypterus	Broad-winged Hawk	3															
Circus cyaneus	Northern Harrier	3							I								O
Anseriformes (waterfowl)																	
Aythya marila	Greater Scaup	2		O													
Bucephala islandica	Barrow's Goldeneye	1	O	I		I											
Clangula hyemalis	Long-tailed Duck	3		O		I											
Histrionicus histrionicus	Harlequin Duck	1	O														
Somateria mollissima	Common Eider	3	O												O		
Apodiformes (swifts and hummingbirds)																	
Chaetura pelagica	Chimney Swift	2		O	O												
Caprimulgiformes (nighthawks and nightjars)																	
Antrostomus vociferus	Eastern Whip-poor-will	2	O														
Chordeiles minor	Common Nighthawk	3		I													I

Table 5/6-1. *continued: page 2 of 12.*

Order Scientific Name	Common Name	Priority	Species-Specific Monitoring	Maine River Bird Survey	Breeding Bird Survey	Christmas Bird count	Mountain Birdwatch	Kennebunk Plains / TNC Annual Survey	Secretive Marsh Bird Surveys	Island Nesting Tern Survey	Maine Owl Survey	Wading Bird Colony Surveys and Monitoring	Migratory Shorebird Survey (PRISM/ISS)	Waterfowl Brood Counts	Mid-winter Waterfowl Survey	IFW regional shorebird surveys for SWH designation and mapping	Grassland Bird Surveys
Charadriiformes (waders, gulls, and auks)																	
Alca torda	Razorbill	2								O							
Arenaria interpres	Ruddy Turnstone	2		O									O			N	
Bartramia longicauda	Upland Sandpiper	1	O		O			O									O
Calidris alba	Sanderling	2	O										O			N	
Calidris alpina	Dunlin	3											O			N	
Calidris canutus rufa	Red Knot	1	N										O			N	
Calidris maritima	Purple Sandpiper	1	O														
Calidris minutilla	Least Sandpiper	3											O			N	
Calidris pusilla	Semipalmated Sandpiper	2											O			N	
Charadrius melodus	Piping Plover	1	O														
Chlidonias niger	Black Tern	2	O						I								
Chroicocephalus philadelphia	Bonaparte's Gull	3		I													
Fratercula arctica	Atlantic Puffin	2								O							
Haematopus palliatus	American Oystercatcher	3	N														

Table 5/6-1. *continued: page 3 of 12.*

Order Scientific Name	Common Name	Priority	Species-Specific Monitoring	Maine River Bird Survey	Breeding Bird Survey	Christmas Bird count	Mountain Birdwatch	Kennebunk Plains / TNC Annual Survey	Secretive Marsh Bird Surveys	Island Nesting Tern Survey	Maine Owl Survey	Wading Bird Colony Surveys and Monitoring	Migratory Shorebird Survey (PRISM/ISS)	Waterfowl Brood Counts	Mid-winter Waterfowl Survey	IFW regional shorebird surveys for SWH designation and mapping	Grassland Bird Surveys
Charadriiformes (waders, gulls, and auks) *continued*																	
Leucophaeus atricilla	Laughing Gull	3								O							
Limnodromus griseus	Short-billed Dowitcher	3											O			N	
Numenius phaeopus	Whimbrel	2	N										O			N	
Phalaropus fulicarius	Red Phalarope	3	N														
Phalaropus lobatus	Red-necked Phalarope	2	N														
Pluvialis squatarola	Black-bellied Plover	3		O									O			N	
Scolopax minor	American Woodcock	3	O														
Sterna dougallii	Roseate Tern	1								O							
Sterna hirundo	Common Tern	2								O							
Sterna paradisaea	Arctic Tern	1								O							
Sternula antillarum	Least Tern	1	O														
Tringa flavipes	Lesser Yellowlegs	1	N										O			N	
Tringa melanoleuca	Greater Yellowlegs	3											O			N	

Table 5/6-1. *continued: page 4 of 12.*

Order Scientific Name	Common Name	Priority	Species-Specific Monitoring	Maine River Bird Survey	Breeding Bird Survey	Christmas Bird count	Mountain Birdwatch	Kennebunk Plains / TNC Annual Survey	Secretive Marsh Bird Surveys	Island Nesting Tern Survey	Maine Owl Survey	Wading Bird Colony Surveys and Monitoring	Migratory Shorebird Survey (PRISM/ISS)	Waterfowl Brood Counts	Mid-winter Waterfowl Survey	IFW regional shorebird surveys for SWH designation and mapping	Grassland Bird Surveys
Charadriiformes (waders, gulls, and auks) *continued*																	
Tringa semipalmata	Willet	3	N						N				O			N	
Tringa solitaria	Solitary Sandpiper	2	N														
Uria aalge	Common Murre	3															
Coraciiformes (kingfishers, bee-eaters, rollers, motmots, and todies)																	
Megaceryle alcyon	Belted Kingfisher	3		O	O												
Coccyzus americanus	Yellow-billed Cuckoo	2			O												
Coccyzus erythropthalmus	Black-billed Cuckoo	3			O												
Falconiformes (falcons and kestrels)																	
Falco peregrinus	Peregrine Falcon	1	O														
Falco sparverius	American Kestrel	3															I
Galliformes (game birds)																	
Falcipennis canadensis	Spruce Grouse	3				I											

Table 5/6-1. *continued: page 5 of 12.*

Order Scientific Name	Common Name	Priority	Species-Specific Monitoring	Maine River Bird Survey	Breeding Bird Survey	Christmas Bird count	Mountain Birdwatch	Kennebunk Plains / TNC Annual Survey	Secretive Marsh Bird Surveys	Island Nesting Tern Survey	Maine Owl Survey	Wading Bird Colony Surveys and Monitoring	Migratory Shorebird Survey (PRISM/ISS)	Waterfowl Brood Counts	Mid-winter Waterfowl Survey	IFW regional shorebird surveys for SWH designation and mapping	Grassland Bird Surveys
Gaviiformes (loons)																	
Gavia immer	Common Loon	3	O	O													
Gavia stellata	Red-throated Loon	3		O		O											
Gruiformes (cranes and rails)																	
Coturnicops noveboracensis	Yellow Rail	2							N								
Fulica americana	American Coot	3		I					N								
Gallinula galeata	Common Gallinule	2		I					N								
Porzana carolina	Sora	3		I					N								
Passeriformes (passerines)																	
Ammodramus caudacutus	Saltmarsh Sparrow	1							N								
Ammodramus nelsoni	Nelson's Sparrow	2	O						N								
Ammodramus savannarum	Grasshopper Sparrow	1						O									O
Anthus rubescens	American Pipit	2	N				O										
Cardellina canadensis	Canada Warbler	2			O												

Table 5/6-1. *continued: page 6 of 12.*

Order Scientific Name	Common Name	Priority	Species-Specific Monitoring	Maine River Bird Survey	Breeding Bird Survey	Christmas Bird count	Mountain Birdwatch	Kennebunk Plains / TNC Annual Survey	Secretive Marsh Bird Surveys	Island Nesting Tern Survey	Maine Owl Survey	Wading Bird Colony Surveys and Monitoring	Migratory Shorebird Survey (PRISM/ISS)	Waterfowl Brood Counts	Mid-winter Waterfowl Survey	IFW regional shorebird surveys for SWH designation and mapping	Grassland Bird Surveys
Passeriformes (passerines) *continued*																	
Catharus bicknelli	Bicknell's Thrush	1					O										
Catharus fuscescens	Veery	2			O												
Catharus ustulatus	Swainson's Thrush	3			O		O										
Cistothorus platensis	Sedge Wren	1							N								
Coccothraustes vespertinus	Evening Grosbeak	2			O	O											
Contopus cooperi	Olive-sided Flycatcher	2			O		O										
Contopus virens	Eastern Wood-Pewee	2			O												
Dolichonyx oryzivorus	Bobolink	3			O			O									O
Empidonax flaviventris	Yellow-bellied Flycatcher	3		I	O		O										
Empidonax minimus	Least Flycatcher	3		I	O												
Eremophila alpestris	Horned Lark	3			O	O		O									O

Table 5/6-1. *continued: page 7 of 12.*

Order Scientific Name	Common Name	Priority	Species-Specific Monitoring	Maine River Bird Survey	Breeding Bird Survey	Christmas Bird count	Mountain Birdwatch	Kennebunk Plains / TNC Annual Survey	Secretive Marsh Bird Surveys	Island Nesting Tern Survey	Maine Owl Survey	Wading Bird Colony Surveys and Monitoring	Migratory Shorebird Survey (PRISM/ISS)	Waterfowl Brood Counts	Mid-winter Waterfowl Survey	IFW regional shorebird surveys for SWH designation and mapping	Grassland Bird Surveys
Passeriformes (passerines) *continued*																	
Euphagus carolinus	Rusty Blackbird	1	O														
Geothlypis philadelphia	Mourning Warbler	3			O												
Haemorhous purpureus	Purple Finch	3			O	O	O										
Hirundo rustica	Barn Swallow	2		O	O												I
Hylocichla mustelina	Wood Thrush	1			O												
Icterus galbula	Baltimore Oriole	3			O												
Icterus spurius	Orchard Oriole	3			O												
Loxia curvirostra	Red Crossbill	3			O	O	O										
Loxia leucoptera	White-winged Crossbill	3			O	O	O										
Melospiza lincolnii	Lincoln's Sparrow	3			O												
Mniotilta varia	Black-and-white Warbler	2			O		O										
Oreothlypis peregrina	Tennessee Warbler	2			O												

Table 5/6-1. *continued: page 8 of 12.*

Order Scientific Name	Common Name	Priority	Species-Specific Monitoring	Maine River Bird Survey	Breeding Bird Survey	Christmas Bird count	Mountain Birdwatch	Kennebunk Plains / TNC Annual Survey	Secretive Marsh Bird Surveys	Island Nesting Tern Survey	Maine Owl Survey	Wading Bird Colony Surveys and Monitoring	Migratory Shorebird Survey (PRISM/ISS)	Waterfowl Brood Counts	Mid-winter Waterfowl Survey	IFW regional shorebird surveys for SWH designation and mapping	Grassland Bird Surveys
Passeriformes (passerines) *continued*																	
Parkesia motacilla	Louisiana Waterthrush	3			O												
Passerella iliaca	Fox Sparrow	3			O												
Perisoreus canadensis	Gray Jay	3			O	O											
Petrochelidon pyrrhonota	Cliff Swallow	3		O	O												
Pheucticus ludovicianus	Rose-breasted Grosbeak	3			O												
Pinicola enucleator	Pine Grosbeak	3			O	O											
Pipilo erythrophthalmus	Eastern Towhee	2			O			O									I
Piranga olivacea	Scarlet Tanager	3		I	O		O										
Poecile hudsonicus	Boreal Chickadee	2			O	O											
Progne subis	Purple Martin	2	N	I	O												
Regulus calendula	Ruby-crowned Kinglet	2			O		O										

Table 5/6-1. *continued: page 9 of 12.*

Order Scientific Name	Common Name	Priority	Species-Specific Monitoring	Maine River Bird Survey	Breeding Bird Survey	Christmas Bird count	Mountain Birdwatch	Kennebunk Plains / TNC Annual Survey	Secretive Marsh Bird Surveys	Island Nesting Tern Survey	Maine Owl Survey	Wading Bird Colony Surveys and Monitoring	Migratory Shorebird Survey (PRISM/ISS)	Waterfowl Brood Counts	Mid-winter Waterfowl Survey	IFW regional shorebird surveys for SWH designation and mapping	Grassland Bird Surveys
Passeriformes (passerines) *continued*																	
Riparia riparia	Bank Swallow	1		O	O												I
Setophaga americana	Northern Parula	3			O												
Setophaga caerulescens	Black-throated Blue Warbler	3			O												
Setophaga castanea	Bay-breasted Warbler	3			O		O										
Setophaga discolor	Prairie Warbler	2			O												
Setophaga fusca	Blackburnian Warbler	3			O												
Setophaga pensylvanica	Chestnut-sided Warbler	2			O												
Setophaga petechia	Yellow Warbler	3			O												
Setophaga ruticilla	American Redstart	2			O												
Setophaga striata	Blackpoll Warbler	3			O		O										
Setophaga tigrina	Cape May Warbler	3			O		O										

Table 5/6-1. *continued: page 10 of 12.*

Order Scientific Name	Common Name	Priority	Species-Specific Monitoring	Maine River Bird Survey	Breeding Bird Survey	Christmas Bird count	Mountain Birdwatch	Kennebunk Plains / TNC Annual Survey	Secretive Marsh Bird Surveys	Island Nesting Tern Survey	Maine Owl Survey	Wading Bird Colony Surveys and Monitoring	Migratory Shorebird Survey (PRISM/ISS)	Waterfowl Brood Counts	Mid-winter Waterfowl Survey	IFW regional shorebird surveys for SWH designation and mapping	Grassland Bird Surveys
Passeriformes (passerines) *continued*																	
Setophaga virens	Black-throated Green Warbler	3			O		O										
Spizella pusilla	Field Sparrow	3			O												O
Stelgidopteryx serripennis	Northern Rough-winged Swallow	3		O	O												I
Sturnella magna	Eastern Meadowlark	2			O			O									O
Tachycineta bicolor	Tree Swallow	2		O	O												I
Toxostoma rufum	Brown Thrasher	2			O			O									
Tyrannus tyrannus	Eastern Kingbird	2		O	O												I
Vermivora cyanoptera	Blue-winged Warbler	2	N		O			O									
Zonotrichia albicollis	White-throated sparrow	3			O		O										

Table 5/6-1. *continued: page 11 of 12.*

Order Scientific Name	Common Name	Priority	Species-Specific Monitoring	Maine River Bird Survey	Breeding Bird Survey	Christmas Bird count	Mountain Birdwatch	Kennebunk Plains / TNC Annual Survey	Secretive Marsh Bird Surveys	Island Nesting Tern Survey	Maine Owl Survey	Wading Bird Colony Surveys and Monitoring	Migratory Shorebird Survey (PRISM/ISS)	Waterfowl Brood Counts	Mid-winter Waterfowl Survey	IFW regional shorebird surveys for SWH designation and mapping	Grassland Bird Surveys
Pelecaniformes (Pelicans, tropicbirds, and relatives)																	
Ardea herodias	Great Blue Heron	2		I								O					
Botaurus lentiginosus	American Bittern	3		I					N								I
Egretta caerulea	Little Blue Heron	3		I								N					
Egretta thula	Snowy Egret	3		I								N					
Ixobrychus exilis	Least Bittern	1		I					O								
Nycticorax nycticorax	Black-crowned Night-heron	2		I								O					
Piciformes (woodpeckers)																	
Colaptes auratus	Northern Flicker	3			O	O											
Picoides arcticus	Black-backed Woodpecker	3			O	O	O										
Picoides dorsalis	American Three-toed Woodpecker	3			O	O	O										
Podicipediformes (grebes)																	
Podiceps auritus	Horned Grebe	3				I											
Podilymbus podiceps	Pied-billed Grebe	3		I					N								

Table 5/6-1. *continued: page 12 of 12.*

Order Scientific Name	Common Name	Priority	Species-Specific Monitoring	Maine River Bird Survey	Breeding Bird Survey	Christmas Bird count	Mountain Birdwatch	Kennebunk Plains / TNC Annual Survey	Secretive Marsh Bird Surveys	Island Nesting Tern Survey	Maine Owl Survey	Wading Bird Colony Surveys and Monitoring	Migratory Shorebird Survey (PRISM/ISS)	Waterfowl Brood Counts	Mid-winter Waterfowl Survey	IFW regional shorebird surveys for SWH designation and mapping	Grassland Bird Surveys
Podicipediformes (grebes) *continued*																	
Oceanodroma leucorhoa	Leach's Storm-petrel	3															
Puffinus gravis	Great Shearwater	3															
Strigiformes (owls)																	
Asio flammeus	Short-eared Owl	2									I						O
Asio otus	Long-eared Owl	3									O						
Megascops asio	Eastern Screech-Owl	3									O						
Tyto alba	Barn Owl	3									O						
Suliformes (darters, frigatebirds, cormorants, shags, gannets, and boobies)																	
Phalacrocorax carbo	Great Cormorant	1	O														

5/6.2.2 REPTILES, AMPHIBIANS, AND INVERTEBRATES

Currently, biologists use 9 distinct programs to monitor 87 of the 148 (60%) reptile, amphibian, and invertebrate SGCN in Maine (Tables 5-2 and 5-3). In addition, biologists monitor 56 SGCN in these taxonomic groups using individual, species-specific protocols. Forty-six of the SGCN are not currently subject to some type of formal monitoring program, although species-specific monitoring protocols for four of these species (Big-tooth Whitelip, Gaspe Gazelle Beetle, Graceful Clearwing, and Spike-lip Crater) may be implemented in the near future.



Wood Turtles are one of Maine's priority SGCN species that is monitored using standardized regional protocols developed by a Northeast Wood Turtle Working Group. © Philip DeMaynadier

The Maine Amphibian Monitoring Program (MAMP) is a volunteer program that gathers information on the distribution and abundance of calling amphibians, including two SGCN, the Mink Frog and Northern Leopard Frog (Maine Audubon Society 2015). The MAMP is a component of the North American Amphibian Monitoring Program (NAAMP), and is ongoing in Maine since 1997. Currently, volunteers survey approximately 60 road-side routes across the state. Biologists recently analyzed data from the NAAMP and they detected several significant species-specific results in Maine (Weir et al. 2014), including negative population trends for Wood Frog, Spring Peeper, Bullfrog, Northern Leopard Frog, and American Toad.

The Maine Amphibian and Reptile Atlasing Project (MARAP) is one of the longest standing wildlife atlasing projects in Maine. Initiated in 1984, MARAP is currently a cooperative venture between MDIFW and the University of Maine. The MARAP database contains over 10,000 records for 35 terrestrial and freshwater species (33 native, 2 exotic), as well as marine turtles and the extirpated Timber Rattlesnake. As with many wildlife atlas datasets that are primarily designed to document distribution, biologists can use the MARAP database to indirectly infer population trends and range shifts by revisiting previously documented sites over time.

Monitoring of invertebrate SGCN lags behind that of reptiles, amphibians, and other vertebrate taxa. This is due to the high diversity of SGCN invertebrates, a lower level of knowledge about their distribution and habitat relationships, and limited MDIFW staff and resources to work with the group. Nevertheless, MDIFW and partners have increased their knowledge of SGCN invertebrates considerably since 2005, with special emphasis on Unionoida (freshwater mussels), Gastropoda (aquatic and terrestrial snails), Ephemeroptera (mayflies), Odonata (damselflies and dragonflies), Lepidoptera (butterflies and moths), Coleoptera (tiger beetles), and most recently Hymenoptera (bumble bees). A series of volunteer wildlife atlasing programs now provide distribution baselines for many of Maine's invertebrate

"Monitoring of invertebrate SGCN lags behind that of reptiles, amphibians, and other vertebrate taxa. This is due to the high diversity of SGCN invertebrates, and a lower level of knowledge about their distribution and habitat relationships…"

SGCN. Biologists have designed the Maine Butterfly Survey (MBS), Maine Damselfly and Dragonfly Survey (MDDS), Maine Mussel Baseline Atlas, and Maine Bumble Bee Atlas (MBBA) to collect sighting information from trained volunteer citizen scientists, to help map the distribution and relative abundance of these species groups across the state. In many cases, these programs are among the first of their kind in the country, and have helped to gather critical information on these understudied and poorly understood taxa. In the future MDIFW hopes to collaborate with partners to develop the Maine Tiger Beetle Atlas, which would gather similar data on three additional SGCN: Cobblestone Tiger Beetle, Saltmarsh Tiger Beetle, and the White Mountain Tiger Beetle.

5/6.2.3 INLAND FISH

MDIFW monitors the 17 inland fish SGCN through the application of 17 distinct methodologies (Table 5/6-4). In most cases, MDIFW monitors individual species using multiple methods. Many of the monitoring approaches that apply to inland fish SGCN are components of MDIFW's larger fisheries management program implemented by regional biologists, and are not targeted towards specific species. However, species-specific monitoring protocols are in place for six species in this group. In addition, two new monitoring protocols (eDNA and Trawling) may be applicable to several SGCN in the future. In particular, eDNA, which relies on the detection of DNA in water samples to determine the presence or absence of species within the water body, could prove to be an extremely powerful approach for monitoring rare aquatic taxa as well as the presence of invasive fish species.

5/6.2.4 MAMMALS



Monitoring New England Cottontails with radiotelemetry. © Department of Inland Fisheries and Wildlife

Mammals often occur at relatively low densities and occupy large landscapes, making the application of comprehensive, multi-species monitoring protocols challenging. Of Maine's 15 mammal SGCN, four currently are subject to a species-specific monitoring protocol or a multi-species monitoring program (Table 5/6-5). In addition, MDIFW ultimately will use a new initiative, the North American Bat Survey, to monitor all eight bat SGCN. MDIFW has yet to develop monitoring protocols for three mammal SGCN (the Penobscot Meadow Vole, the Long-tailed Shrew, and the Northern Bog Lemming).

Table 5/6-2. Status of Population Monitoring for Maine's Amphibian and Reptile Species of Greatest Conservation Need.

CLASS Order Scientific Name	Common Name	Priority	Species-specific Monitoring	Maine Amphibian Monitoring Project (MAMP)	NE Regional Blanding's and Wood Turtle Survey & Monitoring	Maine Amphibian & Reptile Atlasing Project (MARAP)	Maine Road Herp Hotspot Monitoring Project
AMPHIBIA (amphibians)							
Anura (frogs and toads)							
Lithobates pipiens	Northern Leopard Frog	2		O		O	N
Lithobates septentrionalis	Mink Frog	3		O		O	N
Caudata (salamanders)							
Ambystoma laterale	Blue-spotted Salamander	2	O			O	N
Gyrinophilus porphyriticus porphyriticus	Northern Spring Salamander	2	O			O	N
REPTILIA (reptiles)							
Squamata (lizards and snakes)							
Coluber constrictor constrictor	Northern Black Racer	1	O			O	N
Storeria dekayi dekayi	Northern Brownsnake	2				O	N
Thamnophis sauritus	Eastern Ribbon Snake	2	O			O	N
Testudines (turtles and tortoises)							
Clemmys guttata	Spotted Turtle	1	O			O	N
Emydoidea blandingii	Blanding's Turtle	1	O		O	O	N
Glyptemys insculpta	Wood Turtle	1	O		O	O	N
Terrapene carolina carolina	Eastern Box Turtle	2	O			O	N
Alasmidonta undulata	Triangle Floater	3	O				
Anodonta implicata	Alewife Floater	3	O				
Margaritifera margaritifera	Eastern Pearlshell	3	O				
Clemmys guttata	Spotted Turtle	1	O			O	N

Table 5/6-3. Status of Population Monitoring for Maine's Non Marine Invertebrate Species of Greatest Conservation Need.

CLASS Order Scientific Name	Common Name	Priority	Species-specific Monitoring	Maine Butterfly Survey (MBS)	Maine Damselfly & Dragonfly Survey (MDDS)	Maine Mussel Baseline Atlas & Surveys	Maine Bumble Bee Atlas (MBBA)	Maine Tiger Beetle Atlas
BIVALVIA (mussels and clams)								
Unionoida (freshwater mussels)								
Alasmidonta undulata	Triangle Floater	3	O			O		
Alasmidonta varicosa	Brook Floater	1	O			O		
Anodonta implicata	Alewife Floater	3	O			O		
Lampsilis cariosa	Yellow Lampmussel	1	O			O		
Leptodea ochracea	Tidewater Mucket	1	O			O		
Margaritifera margaritifera	Eastern Pearlshell	3	O			O		
GASTROPODA (aquatic and terrestrial snails)								
Basommatophora (air-breathing freshwater snails)								
Stagnicola mighelsi	Bigmouth Pondsnail	1	O					
Stagnicola oronoensis	Obese Pondsnail	3	O					
Neotaenioglossa (mostly sea snails)								
Floridobia winkleyi	New England Silt Snail	3	O					
Stylommatophora (air-breathing land snails)								
Appalachina sayana	Spike-lip Crater	3	N					
Neohelix dentifera	Big-tooth Whitelip	3	N					
Vertigo malleata	Malleated Vertigo	3	O					
Vertigo morsei	Six-whorl Vertigo	1	O					
Vertigo paradoxa	Mystery Vertigo	2	O					
INSECTA (insects)								
Coleoptera (beetles)								
Cicindela ancocisconensis	White Mountain Tiger Beetle	2	O					N
Cicindela marginata	Salt Marsh Tiger Beetle	2	O					N

Table 5/6-3. *continued: page 2 of 8.*

CLASS Order Scientific Name	Common Name	Priority	Species-specific Monitoring	Maine Butterfly Survey (MBS)	Maine Damselfly & Dragonfly Survey (MDDS)	Maine Mussel Baseline Atlas & Surveys	Maine Bumble Bee Atlas (MBBA)	Maine Tiger Beetle Atlas
Coleoptera (beetles) *continued*								
Cicindela marginipennis	Cobblestone Tiger Beetle	1	O					N
Nebria nivalis gaspesiana	Gaspe Gazelle Beetle	3	N					
Ephemeroptera (mayflies)								
Ameletus browni	A Mayfly	3						
Baetisca berneri	A Mayfly	3						
Baetisca carolina	A Mayfly	3						
Baetisca lacustris	A Mayfly	3						
Baetisca rubescens	A Mayfly	3						
Epeorus frisoni	Roaring Brook Mayfly	1	O					
Hexagenia rigida	A Mayfly	3						
Metretopus borealis	A Mayfly	3						
Nixe horrida	A Mayfly	3						
Parameletus midas	A Mayfly	3						
Rhithrogena undulata	A Mayfly	3						
Siphlonisca aerodromia	Tomah Mayfly	1	O					
Siphlonurus barbaroides	A Mayfly	3						
Siphlonurus barbarus	A Mayfly	2						
Siphlonurus demaryi	A Mayfly	2						
Hymenoptera (ants, bees, wasps, and sawflies)								
Bombus affinis	Rusty-patched Bumble Bee	1					O	
Bombus ashtoni	Ashton's Cuckoo Bumble Bee	2					O	
Bombus citrinus	Lemon Cuckoo Bumble Bee	3					O	

Table 5/6-3. *continued: page 3 of 8.*

CLASS Order Scientific Name	Common Name	Priority	Species-specific Monitoring	Maine Butterfly Survey (MBS)	Maine Damselfly & Dragonfly Survey (MDDS)	Maine Mussel Baseline Atlas & Surveys	Maine Bumble Bee Atlas (MBBA)	Maine Tiger Beetle Atlas
Hymenoptera (ants, bees, wasps, and sawflies) *continued*								
Bombus fernaldae	Fernald's Cuckoo Bumble Bee	3					O	
Bombus fervidus	Yellow Bumble Bee	3					O	
Bombus griseocollis	Brown-belted Bumble Bee	3					O	
Bombus insularis	Indiscriminate Cuckoo Bumble Bee	2					O	
Bombus pensylvanicus	American Bumble Bee	2					O	
Bombus sandersoni	Sanderson's Bumble Bee	3					O	
Bombus terricola	Yellowbanded Bumble Bee	3					O	
Lepidoptera (butterflies, skippers, and moths)								
Atrytonopsis hianna	Dusted Skipper	3	O	O				
Boloria chariclea grandis	Purple Lesser Fritillary	2	O	O				
Boloria frigga saga	Frigga Fritillary	1	O	O				
Callophrys gryneus	Juniper Hairstreak	2	O	O				
Callophrys hesseli	Hessel's Hairstreak	1	O	O				
Callophrys lanoraieensis	Bog Elfin	3	O	O				
Catocala similis	Similar Underwing	3						
Chaetaglaea cerata	A Noctuid Moth	2						
Chaetaglaea tremula	Barrens Chaetaglaea	3						
Citheronia sepulcralis	Pine Devil	2						
Cucullia speyeri	A Moth	3						

Table 5/6-3. *continued: page 4 of 8.*

CLASS Order Scientific Name	Common Name	Priority	Species-specific Monitoring	Maine Butterfly Survey (MBS)	Maine Damselfly & Dragonfly Survey (MDDS)	Maine Mussel Baseline Atlas & Surveys	Maine Bumble Bee Atlas (MBBA)	Maine Tiger Beetle Atlas
Lepidoptera (butterflies, skippers, and moths) *continued*								
Cupido amyntula maritima	Western Tailed Blue	3		O				
Danaus plexippus	Monarch	3		O				
Erora laeta	Early Hairstreak	2	O	O				
Erynnis brizo	Sleepy Duskywing	2	O	O				
Hemaris gracilis	Graceful Clearwing	3						
Hemileuca lucina	New England Buckmoth	3	N					
Hemileuca maia maia	Eastern Buckmoth	2						
Hesperia leonardus	Leonard's Skipper	3		O				
Hesperia metea	Cobweb Skipper	3	O	O				
Lapara coniferarum	Southern Pine Sphinx	3						
Lepipolys perscripta	A Moth	3						
Lithophane lepida lepida	Pine Pinion	2						
Lycaena dorcas claytoni	Clayton's Copper	2	O	O				
Lycia rachelae	Twilight Moth	2						
Metarranthis apiciaria	Barrens Metarranthis Moth	2						
Nepytia pellucidaria	A Moth	3						
Oeneis polixenes katahdin	Katahdin Arctic	1	O	O				
Paonias astylus	Huckleberry Sphinx	3						

Table 5/6-3. *continued: page 5 of 8.*

CLASS Order Scientific Name	Common Name	Priority	Species-specific Monitoring	Maine Butterfly Survey (MBS)	Maine Damselfly & Dragonfly Survey (MDDS)	Maine Mussel Baseline Atlas & Surveys	Maine Bumble Bee Atlas (MBBA)	Maine Tiger Beetle Atlas
Lepidoptera (butterflies, skippers, and moths) *continued*								
Papilio brevicauda gaspeensis	Short-tailed Swallowtail	3	O	O				
Oeneis polixenes katahdin	Katahdin Arctic	1	O	O				
Paonias astylus	Huckleberry Sphinx	3						
Papilio brevicauda gaspeensis	Short-tailed Swallowtail	3	O	O				
Papilio troilus	Spicebush Swallowtail	3	O	O				
Plebejus idas	Northern Blue	2		O				
Plebejus idas empetri	Crowberry Blue	2	O	O				
Polygonia satyrus	Satyr Comma	3		O				
Psectraglaea carnosa	Pink Sallow	2						
Satyrium edwardsii	Edwards' Hairstreak	2	O	O				
Satyrium titus	Coral Hairstreak	3	O	O				
Satyrodes appalachia	Appalachian Brown	3		O				
Spartiniphaga inops	Spartina Borer Moth	3						
Speranza exonerata	Barrens Itame	2						
Thorybes bathyllus	Southern Cloudywing	3		O				
Xylena thoracica	Acadian Swordgrass Moth	3						
Xylotype capax	Broad Sallow	3						
Xystopeplus rufago	Red-winged Sallow	3						
Zale lunifera	Bold-based Zale Moth	3						

Table 5/6-3. *continued: page 6 of 8.*

CLASS Order Scientific Name	Common Name	Priority	Species-specific Monitoring	Maine Butterfly Survey (MBS)	Maine Damselfly & Dragonfly Survey (MDDS)	Maine Mussel Baseline Atlas & Surveys	Maine Bumble Bee Atlas (MBBA)	Maine Tiger Beetle Atlas
Lepidoptera (butterflies, skippers, and moths) *continued*								
Zale obliqua	Oblique Zale	3						
Zanclognatha martha	Pine Barrens Zanclognatha	1						
Odonata (dragonflies and damselflies)								
Aeshna juncea	Sedge Darner	2			O			
Aeshna sitchensis	Zigzag Darner	3			O			
Anax longipes	Comet Darner	3	O		O			
Argia translata	Dusky Dancer	3			O			
Arigomphus furcifer	Lilypad Clubtail	3			O			
Celithemis martha	Martha's Pennant	3			O			
Cordulegaster obliqua	Arrowhead Spiketail	3	O		O			
Enallagma carunculatum	Tule Bluet	3			O			
Enallagma durum	Big Bluet	3			O			
Enallagma laterale	New England Bluet	2	O		O			
Enallagma pictum	Scarlet Bluet	2	O		O			
Epiaeschna heros	Swamp Darner	3	N		O			
Erythrodiplax berenice	Seaside Dragonlet	3			O			
Gomphus quadricolor	Rapids Clubtail	2	O		O			
Gomphus vastus	Cobra Clubtail	3			O			
Ischnura hastata	Citrine Forktail	3			O			
Ischnura ramburii	Rambur's Forktail	3			O			
Lanthus vernalis	Southern Pygmy Clubtail	2			O			
Leucorrhinia patricia	Canada Whiteface	2	O		O			

Table 5/6-3. *continued: page 7 of 8.*

CLASS Order Scientific Name	Common Name	Priority	Species-specific Monitoring	Maine Butterfly Survey (MBS)	Maine Damselfly & Dragonfly Survey (MDDS)	Maine Mussel Baseline Atlas & Surveys	Maine Bumble Bee Atlas (MBBA)	Maine Tiger Beetle Atlas
Odonata (dragonflies and damselflies) *continued*								
Libellula needhami	Needhams Skimmer	3			O			
Libellula semifasciata	Painted Skimmer	3			O			
Nannothemis bella	Elfin Skimmer	3			O			
Neurocordulia michaeli	Broad-tailed Shadowdragon	3			O			
Ophiogomphus anomalus	Extra-striped Snaketail	3			O			
Ophiogomphus colubrinus	Boreal Snaketail	1	O		O			
Ophiogomphus howei	Pygmy Snaketail	2	O		O			
Progomphus obscurus	Common Sanddragon	3			O			
Rhionaeschna mutata	Spatterdock Darner	3	O		O			
Somatochlora albicincta	Ringed Emerald	3			O			
Somatochlora brevicincta	Quebec Emerald	2	O		O			
Somatochlora incurvata	Incurvate Emerald	3			O			
Somatochlora minor	Ocellated Emerald	3			O			
Stylurus spiniceps	Arrow Clubtail	3			O			
Tramea carolina	Carolina Saddlebags	3			O			
Tramea lacerata	Black Saddlebags	3			O			
Williamsonia lintneri	Ringed Boghaunter	1	O		O			

Table 5/6-3. *continued: page 8 of 8.*

CLASS Order Scientific Name	Common Name	Priority	Species-specific Monitoring	Maine Butterfly Survey (MBS)	Maine Damselfly & Dragonfly Survey (MDDS)	Maine Mussel Baseline Atlas & Surveys	Maine Bumble Bee Atlas (MBBA)	Maine Tiger Beetle Atlas
Plecoptera (stoneflies)								
Alloperla voinae	A Stonefly	3						
Neoperla mainensis	A Stonefly	3						
Pteronarcys comstocki	Spiny Salmonfly	3						
Trichoptera (caddisflies)								
Hydroptila blicklei	A Caddisfly	3						
Hydroptila parachelops	A Caddisfly	3						
Hydroptila tomah	A Caddisfly	3						
Ochrotrichia denningi	A Caddisfly	3						
MALACOSTRACA (crabs, krill, pill bugs, shrimp, and relatives)								
Decapoda (decapods)								
Orconectes limosus	Spinycreek Crayfish	3	N					

Table 5/6-4. Status of Population Monitoring for Maine's Inland Fish Species of Greatest Conservation Need.

Scientific Name	Common Name	Priority	Species-specific Monitoring	Clerk Creel Census	Voluntary Creel Census	Baitfish Dealer Inspections	Stream Electro Fishing	Lake Electro Fishing	Gill Netting	Trap Netting	Telemetry/Marking	eDNA	Beach Seines	Minnow Traps/Pots	Fishway Traps	Trawling	SCUBA / Snorkeling	Experimental Angling	Monitoring Salmon Traps & Lifts	Spawning Stock Surveys
Catostomus catostomus	Longnose Sucker	3	N			O	N	O	O	O					O					
Coregonus clupeaformis	Lake Whitefish	2	O	O	O		N	N	O	O					N	N	N	O		O
Culaea inconstans	Brook Stickleback	3	N				O				N	N	N	O	N					
Erimyzon oblongus	Creek Chubsucker	3	N			O	O	N	N	O	N	N	O	O	N					
Esox americanus americanus	Redfin Pickerel	2	O	O			O	N		N			N							
Etheostoma fusiforme	Swamp Darter	2	N				O						O				N			
Hybognathus regius	Eastern Silvery Minnow	3	N			O	O	O					O	O	N					
Lethenteron appendix	American Brook Lamprey	3	N				O				N	N								
Lota lota	Burbot	3	N	O	O		O	N	N	N	N	N			N			N		
Margariscus margarita	Pearl Dace	3	N			O	O	O					O	O	N					
Notropis bifrenatus	Bridle Shiner	2	N			O	O	O			N	N	O	O	N					

Table 5/6-4. *continued: page 2 of 2.*

Scientific Name	Common Name	Priority	Species-specific Monitoring	Clerk Creel Census	Voluntary Creel Census	Baitfish Dealer Inspections	Stream Electro Fishing	Lake Electro Fishing	Gill Netting	Trap Netting	Telemetry/Marking	eDNA	Beach Seines	Minnow Traps/Pots	Fishway Traps	Trawling	SCUBA / Snorkeling	Experimental Angling	Monitoring Salmon Traps & Lifts	Spawning Stock Surveys
Notropis heterolepis	Blacknose Shiner	3	N			O	O	O			N	N	O	O	N					
Prosopium cylindraceum	Round Whitefish	2	O	O	O		N	N	O	O					N	N	N	N		N
Rhinichthys cataractae	Longnose Dace	3	N			O	O	O					O	O	N					
Salvelinus alpinus oquassa	Arctic Charr	1	O	O	O				O	O	O	N					O	O		O
Salvelinus fontinalis	Brook Trout	3	O	O	O		O	O	O	O	O	N			O		O	O	O	O
Salvelinus namaycush	Lake Trout	3	O	O	O			O	O	O						N	O	O		O

Table 5/6-5. Status of Population Monitoring for Maine's Mammal Species of Greatest Conservation Need.

Scientific Name	Common Name	Priority	Species-specific Monitoring	North American Bat Survey	N England Cottontail Range-Wide Conservation Strategy Monitoring
Alces alces americanus	Moose	3	O		
Eptesicus fuscus	Big Brown Bat	2		N	
Lasionycteris noctivagans	Silver-haired Bat	2		N	
Lasiurus borealis	Eastern Red Bat	3		N	
Lasiurus cinereus	Hoary Bat	3		N	
Lynx canadensis	Canada Lynx	2	O		
Microtus pennsylvanicus shattucki	Penobscot Meadow Vole	2			
Myotis leibii	Eastern Small-footed Myotis	1		N	
Myotis lucifugus	Little Brown Bat	1		N	
Myotis septentrionalis	Northern Long-eared Myotis	1		N	
Ondatra zibethicus	Muskrat	3	O		
Perimyotis subflavus	Tri-colored Bat	2		N	
Sorex dispar	Long-tailed Shrew	3			
Sylvilagus transitionalis	New England Cottontail	1	O		O
Synaptomys borealis sphagnicola	Northern Bog Lemming	1			

5/6.2.5 MARINE FAUNA

Monitoring of marine SGCN occurs through a wide variety of programs, and includes the involvement of numerous conservation partners. In the pages that follow we summarize these monitoring programs according to broad taxonomic groupings of species that are monitored using similar methods. In addition, Table 5/6-6 provides a detailed list of the monitoring approaches that are used for each species.

Marine Mammals and Sea Turtles
Programs that monitor marine mammals and sea turtles occur largely through reports from entanglements and gear modification studies. The Maine Department of Marine Resources (MDMR) Marine Mammal Strandings and Sightings Program was a component of the conservation and monitoring work until the fall of 2011. The program did not receive the necessary federal funding through the Prescott Grant Program and without funds to support the program MDMR discontinued it. In collaboration with Maine's commercial fishing industries, MDMR developed a Comprehensive Marine Wildlife Conservation Strategy for Large Whales and Sea Turtles in the State of Maine to reduce the risk posed by these fisheries to Right Whales and other protected resources. The Bureau of Marine Patrol and the advanced trained lobsterman use special disentanglement tools, based on those created for the Large Whale Disentanglement Network. Recent efforts have focused on understanding baseline amounts of gear utilized seasonally, specifically vertical lines, in Maine's lobster fishery. These efforts have enabled both state and federal regulators the ability to focus potential regulations to areas where they make the most positive impact for reducing co-occurrence between whales and fishing gear.

MDMR and collaborators at the University of Maine also investigate whale habitat through a monitoring program that samples habitat characteristics in Midcoast and Downeast Maine using plankton and water column sampling. The project will help determine the inshore/offshore and seasonal distributions of Right Whale prey species. Additionally, MDMR completed a Dtag project in Maine coastal fishing habitats that successfully tagged two Humpback Whales near Mount Desert Island. Dive profiles show the whales diving to the bottom during foraging events in addition to using the upper 20 meters of the water column.

Finfish: Diadromous, Groundfish, and Ocean Migratory Fish
MDMR regularly performs both species-specific monitoring programs, as well as surveys that target multiple species, in Maine waters. The Inshore Trawl Survey is a fisheries-independent assessment of living resources inside the coastal waters of Maine. Until this survey began in 2000, Maine and New Hampshire were the only states on the east coast that did not conducti a near-shore assessment. While the U.S. Congress provided this funding for economic relief to the groundfish industry, the assessment is more than a groundfish survey. Marine biologists also assess lobsters, recreational finfish, and non-commercial species of ecological interest. This multispecies survey benefits decision makers confronted with a diverse array of fisheries management issues.

Monitoring programs also include port sampling and reporting from commercial and recreational fishers. During MDMR's commercial and recreational sampling efforts, it collects biological data including length, weight, and maturity from groundfish, river herring, scallops, urchins, shrimp, and other fished species. MDMR also collects scales and otoliths from fish for ageing.

Table 5/6-6. Status of Population Monitoring for Maine's Marine Species of Greatest Conservation Need.

CLASS Scientific Name	Common Name	Priority	Species-specific Monitoring	Clerk Creel Census	Voluntary Creel Census	Mandatory Reporting	Stream Electro Fishing	Lake Electro Fishing	Gill Netting	Trap Netting	Beach Seines	Fishway Traps	DMR trawl survey	SCUBA / Snorkeling	Experimental Angling	Voluntary Sightings network	Monitoring Salmon Traps & Lifts	Spawning Stock Surveys	Habitat Mapping	Species Interaction Studies	Environmental/Habitat Change Effect Studies
ACTINOPTERYGII (ray-finned fishes)																					
Acipenser brevirostrum	Shortnose sturgeon	1	O						O		O							O	O		
Acipenser oxyrinchus	Atlantic Sturgeon	1	O						O		O		O					O	O		
Anguilla rostrata	American Eel	2	O			O	O			O	O	O	O					O	O		N
Alosa aestivalis	Blueback Herring	1	O			O	O			O	O	O	O					O	O	N	
Alosa pseudoharengus	Alewife	2	O			O	O			O	O	O	O					O	O	N	N
Alosa sapidissima	American Shad	1	O	O	O		O		O	O	O	O	O					O	O		
Alcyonium digitatum	Dead Man's Fingers	3	N																N	N	N
Gadus morhua	Atlantic Cod	1	O	O	O	O							O					O			
Melanogrammus aeglefinus	Haddock	1		O	O	O							O					O	N		
Osmerus mordax	Rainbow Smelt	1	O	O	O	O				O	O		O					O	O	N	N
Ammodytes americanus	American Sand Lance	3											O								
Anarhichas lupus	Atlantic Wolffish	2											O					O	N		

Table 5/6-6. *continued: page 2 of 7.*

CLASS Scientific Name	Common Name	Priority	Species-specific Monitoring	Clerk Creel Census	Voluntary Creel Census	Mandatory Reporting	Stream Electro Fishing	Lake Electro Fishing	Gill Netting	Trap Netting	Beach Seines	Fishway Traps	DMR trawl survey	SCUBA / Snorkeling	Experimental Angling	Voluntary Sightings network	Monitoring Salmon Traps & Lifts	Spawning Stock Surveys	Habitat Mapping	Species Interaction Studies	Environmental/Habitat Change Effect Studies
ACTINOPTERYGII (ray-finned fishes) *continued*																					
Anarhichas minor	Spotted Wolffish	3	N																		
Morone saxatilis	Striped Bass	2	O	O	O						O		O					O	O		
Thunnus thynnus	Atlantic Bluefin Tuna	2		O	O	O												O			
Pseudopleuronectes americanus	Winter Flounder	2	O			O							O					O	O		O
Salmo salar	Atlantic Salmon	1	O				O					O		O			O	O	O	N	O
ANTHOZOA (anthozoans)																					
Crassostrea virginica	Eastern oyster	3	O			O													O	N	N
Gersemia rubiformis	Sea Strawberry	2	O											O					N		N
ASTEROIDEA (sea stars)																					
Asterias forbesi	Forbes's Starfish	2	O											O					N		N
Asterias rubens	Common Sea Star	2	O										O	O					N		N
Stephanasterias albula	White Sea Star	2	O											O					N		N

Table 5/6-6. *continued: page 3 of 7.*

CLASS Scientific Name	Common Name	Priority	Species-specific Monitoring	Clerk Creel Census	Voluntary Creel Census	Mandatory Reporting	Stream Electro Fishing	Lake Electro Fishing	Gill Netting	Trap Netting	Beach Seines	Fishway Traps	DMR trawl survey	SCUBA / Snorkeling	Experimental Angling	Voluntary Sightings network	Monitoring Salmon Traps & Lifts	Spawning Stock Surveys	Habitat Mapping	Species Interaction Studies	Environmental/Habitat Change Effect Studies
ASTEROIDEA (sea stars) *continued*																					
Crossaster papposus	Common Sun Star	2	O										O	O					N		N
Solaster endeca	Purple Sunstar	2	O										O	O					N		N
BIVALVIA (mussels and clams)																					
Mya arenaria	Softshell Clam	3	O			O													O	N	N
Mya truncata	Gaper Clam	3	O											O					N	N	N
Zirfaea crispata	Atlantic Great Piddock	2	O											O					N		N
Mytilus edulis	Blue Mussel	3	O			O							O						O	N	N
Margaritifera margaritifera	Eastern Pearlshell	3	O											O					N		N
Chlamys islandica	Icelandic Scallop	3	O										O	O					N	N	N
Placopecten magellanicus	Atlantic Sea Scallop	3	O			O							O	O					O	N	N
Mercenaria mercenaria	Hard-shelled Clam	3	O			O							O						O	N	N
CHONDRICHTHYES (cartilaginous fishes)																					
Prionace glauca	Blue Shark	3	O	O																	

Table 5/6-6. *continued: page 4 of 7.*

CLASS Scientific Name	Common Name	Priority	Species-specific Monitoring	Clerk Creel Census	Voluntary Creel Census	Mandatory Reporting	Stream Electro Fishing	Lake Electro Fishing	Gill Netting	Trap Netting	Beach Seines	Fishway Traps	DMR trawl survey	SCUBA / Snorkeling	Experimental Angling	Voluntary Sightings network	Monitoring Salmon Traps & Lifts	Spawning Stock Surveys	Habitat Mapping	Species Interaction Studies	Environmental/Habitat Change Effect Studies
CHONDRICHTHYES (cartilaginous fishes) *continued*																					
Sphyrna zygaena	Smooth Hammerhead	3	O	O																	
Alopias vulpinus	Common Thresher Shark	3	O	O																	
Isurus oxyrinchus	Shortfin Mako	2	O	O																	
Lamna nasus	Porbeagle	2	O	O																	
Amblyraja radiata	Thorny Skate	2	O										O								
Dipturus laevis	Barndoor Skate	2	O										O								
Leucoraja ocellata	Winter Skate	2	O										O								
Malacoraja senta	Smooth Skate	2	O										O								
ECHINOIDEA (Sea urchins)																					
Strongylocentrotus droebachiensis	Green Sea Urchin	2	O			O							O	O					O	N	N
GASTROPODA (gastropods)																					
Arrhoges occidentalis	American Pelican Foot	2	O											O					N		N
Limneria undata	Wavy Lamellaria	3	O											O					N		N

Table 5/6-6. *continued: page 5 of 7.*

CLASS Scientific Name	Common Name	Priority	Species-specific Monitoring	Clerk Creel Census	Voluntary Creel Census	Mandatory Reporting	Stream Electro Fishing	Lake Electro Fishing	Gill Netting	Trap Netting	Beach Seines	Fishway Traps	DMR trawl survey	SCUBA / Snorkeling	Experimental Angling	Voluntary Sightings network	Monitoring Salmon Traps & Lifts	Spawning Stock Surveys	Habitat Mapping	Species Interaction Studies	Environmental/Habitat Change Effect Studies
GASTROPODA (gastropods) *continued*																					
Boreotrophon clathratus	Clathrate Trophon	2	O											O					N		N
Boreotrophon truncatus	Murex	2	O											O					N		N
Colus pygmaeus	Colus Snail	2	O											O					N		N
Ptychatractus ligatus	Spindle Shell	2	O											O					N		N
Limacina helicina	Limancina Snail	3	O											O					N		N
HOLOTHUROIDEA (sea cucumbers)																					
Cucumaria frondosa	Orange-footed Sea Cucumber	2	O			O							O								
Psolus fabricii	Psolus	2	O											O					N		N
Psolus phantapus	Psolus	2	O											O					N		N
Thyonidium drummondii	Sea Cucumber	2	O										O								
MALACOSTRACA (crabs, krill, pill bugs, shrimp, and relatives)																					
Lebbeus groenlandicus	Spiny Lebbeid Shrimp	2	O										O	O					N		N

Table 5/6-6. *continued: page 6 of 7.*

CLASS Scientific Name	Common Name	Priority	Species-specific Monitoring	Clerk Creel Census	Voluntary Creel Census	Mandatory Reporting	Stream Electro Fishing	Lake Electro Fishing	Gill Netting	Trap Netting	Beach Seines	Fishway Traps	DMR trawl survey	SCUBA / Snorkeling	Experimental Angling	Voluntary Sightings network	Monitoring Salmon Traps & Lifts	Spawning Stock Surveys	Habitat Mapping	Species Interaction Studies	Environmental/Habitat Change Effect Studies
MALACOSTRACA (crabs, krill, pill bugs, shrimp, and relatives)																					
Lebbeus polaris	Polar Lebbeid Shrimp	2	O										O	O					N		N
Pandalus borealis	Northern Shrimp	1	O			O							O						O		O
Balaenoptera borealis	Sei Whale	2	O													O			O		
MAMMALIA (mammals)																					
Balaenoptera musculus	Blue Whale	2														O					
Balaenoptera physalus	Finback Whale	2	O													O					
Eubalaena glacialis	North Atlantic Right Whale	1	O													O			O		
Megaptera novaeangliae	Humpback Whale	1	O													O			O		
Phocoena phocoena	Harbor Porpoise	2	O													O			O		
Physeter macrocephalus	Sperm Whale	2	O													O					

Table 5/6-6. *continued: page 7 of 7.*

CLASS Scientific Name	Common Name	Priority	Species-specific Monitoring	Clerk Creel Census	Voluntary Creel Census	Mandatory Reporting	Stream Electro Fishing	Lake Electro Fishing	Gill Netting	Trap Netting	Beach Seines	Fishway Traps	DMR trawl survey	SCUBA / Snorkeling	Experimental Angling	Voluntary Sightings network	Monitoring Salmon Traps & Lifts	Spawning Stock Surveys	Habitat Mapping	Species Interaction Studies	Environmental/Habitat Change Effect Studies
MAXILLIPODA (barnacles and copepods)																					
Calanus finmarchicus	A Copepod	3	N																	N	N
MEROSTOMATA (horseshoe crabs)																					
Limulus polyphemus	Horseshoe Crab	1	O																O		N
OPHIUROIDEA (brittle stars)																					
Gorgonocephalus arcticus	Northern Basket Starfish	2	O										O	O					N		N
REPTILIA (reptiles)																					
Caretta caretta	Loggerhead Seaturtle	2														O					
Chelonia mydas	Green Seaturtle	2														O					
Dermochelys coriacea	Leatherback Seaturtle	1														O					
Lepidochelys kempii	Kemp's Ridley Seaturtle	2														O					
RHYNCHONELLATA																					
Terebratulina septentrionalis	Lamp Shell	2	O											O					N		N

Annually, from May through October, MDMR interviews anglers to estimate the total number of fish caught, released, and harvested; the weight of the harvest; total number of angler trips; and number of people participating in marine recreational fishing in Maine. This effort is part of a National Marine Fisheries Service (NMFS) program (Marine Recreational Information Program) to estimate the impact of recreational fishing on marine resources. Sampling in Washington County continues with the assistance of Maine Sea Grant's Marine Extension Agent and students from the University of Maine at Machias. MDMR staff also monitor the winter Rainbow Smelt recreational fishery throughout the state through creel surveys and a catch card program.

MDMR's recreational fishing staff conduct the NMFS Large Pelagic Survey from July through October, annually, to monitor the catch and the effort expended by fishers to take tunas and sharks. This survey consists of dockside vessel interviews and telephone calls to Atlantic Tuna permit holders. Additionally, Volunteer Logbook Programs for Striped Bass and Rainbow Smelt monitor avid recreational fishers to collect additional information. In this program, anglers record information about fish harvested or released during each trip, time spent fishing, area fished, number of anglers, and target species.

Annually, from mid-May through August, MDMR conducts bi-weekly beach seine surveys in the estuary formed by the Kennebec and Androscoggin Rivers. MDMR uses these surveys to monitor the abundance of juvenile shad, alewives, and Blueback Herring, as well as Striped Bass, Rainbow Smelt, and other resident species. MDMR conducts the surveys at 14 permanent sampling sites in the tidal freshwater portion of the estuary and at six additional sites in the lower, salinity-stratified portion of the river. MDMR has conducted this survey since 1979 and it used the data to monitor species assemblages, population trends, and habitat use.

MDMR monitors diadromous fish passage efficiency through collaborative efforts between agencies, universities, and hydropower companies. For example, the U.S. Geological Survey (USGS) Conte Anadromous Fish Research Lab completed three years (2002-2004) of field work on a collaborative project with MDMR, the Penobscot Indian Nation, National Oceanic and Atmospheric Administration – Fisheries (NOAA-Fisheries), and the University of Maine, documenting the upstream migration of adult Atlantic Salmon in the Penobscot River. The research used Passive Integrated Transponder tag technology to gather data on movements of individual adult salmon, Fishery managers use this information to evaluate upstream movements and distribution of salmon within the drainage, the probability that fish are able to access spawning habitat, broodstock management, and the effectiveness of current juvenile stocking practices. Current projects (2014-2015) include monitoring American Shad passage at the Benton Falls Dam on the Sebasticook River and measuring the passage efficiency of fishways in Phippsburg and Bristol for alewife passage.



Monitoring diadromous fish in coastal Maine.
© Department of Marine Resources

MDMR conducts routine monitoring of the abundance and status of juvenile and adult diadromous fishes in most of Maine's large watersheds. MDMR operates traps to monitor adult returns on the Penobscot, Narraguagus, and Sebasticook rivers. Brookfield Renewable Energy Group operates traps in the upper Penobscot, Union, Kennebec, Androscoggin, and Saco rivers that provide counts of adult fish, and to a lesser extent, information on juveniles. The St. Croix Waterway Commission operates a trap on the St. Croix River and Algonquin Power operates a trap on the Aroostook River.

MDMR directs its Atlantic Salmon monitoring at determining the causes of the precipitous decline in Atlantic Salmon returning to Maine waters. The focus of ongoing projects is to determine survival among freshwater life stages and understanding the biological and environmental factors affecting survival. These include parr density and relative abundance, estimates of smolt emigration, smolt physiology, effects of marine and estuarine smolt trawling, and smolt tracking through estuaries. Redd counts are used to track spawning escapement in the Gulf of Maine Distinct Population Segment rivers without adult traps.

MDMR assess the population status of Shortnose and Atlantic Sturgeon on the Saco, Kennebec, Androscoggin, and Penobscot Rivers. They encompass determining sturgeon abundance, age structure and recruitment, sampling areas of historic sturgeon occurrence, documentation of seasonal distribution and essential habitat, development of criteria to identify critical habitat, designating identifiable habitat for sturgeon populations, ensuring fish passages, and examining the relationship between dam discharge levels and spawning success.

Annually, MDMR assesses spawning smelt runs to determine population status. The survey produces a fishery-independent index of abundance by collecting biological data from spawning runs, including information on size and age composition, catch-per-unit-effort, and mortality. As part of this project, fishery managers sample fyke-net stations at specific coastal rivers in Maine, New Hampshire, and Massachusetts. The project has collected standardized data since 2008.

MDMR monitors American Eel populations using two fishery-independent surveys; a young-of-year survey and yellow eel count. Each spring, for a period of six weeks, MDMR scientists enumerate all young-of-year (glass) eels that migrate upstream into West Harbor Pond and collect biological information (length, weight, pigmentation) on subsamples. From June to September each year, MDMR concuts the Yellow Eel survey in the Kennebec River watershed, at two hydropower facilities on the Sebasticook River and one facility on the Kennebec River. This survey provides an annual index of recruitment (multiple year classes) to the Kennebec River watershed.

Marine Invertebrates

State, federal, university, and non-governmental organizations collaboratively monitor marine invertebrates. In addition to the Nearshore Trawl Survey and Port Sampling programs described above, MDMR collects information about commercial species through fishery-independent surveys.

Marine scientists monitor the northern shrimp population using multiple surveys. Scientists from NMFS, Maine, New Hampshire, and Massachusetts collaborate to conduct a series of tows for northern shrimp in the Gulf of Maine each summer. The survey provides fishery-independent data that are an important component of the assessment of the Gulf of Maine shrimp stock. In the winter of 2014-2015, in an effort to collect information about winter populations of northern

shrimp during the fishery closure, MDMR worked with local fishermen in Maine to collect trawl and trap samples to document the species' maturity schedules and size distribution.

MDMR uses dive surveys to monitor Green Sea Urchins and assess the status of urchin larvae. MDMR and industry divers count and measure urchins at fixed and random sites each spring from Kittery to Eastport. This survey provides fishery-independent data that MDMR uses in stock assessments to describe the status of the resource and provide a scientific basis for the development of management measures. To monitor larval settlement, MDMR divers deploy settlement plates at Pemaquid Point each spring, collect them during the summer, and examine the plates in the laboratory to enumerate the number of new young-of-the-year sea urchins. This continues a time series begun at that site in the mid-1990s by the University of Maine, which tracks annual sea urchin larval settlement.

With the drastic depletion of the Horseshoe Crab in the Mid-Atlantic States and the resultant increased harvest in Maine, anecdotal information suggested that Maine's population had also experienced a decline. Since 2001, MDMR, several coastal watershed volunteer monitoring groups, and a private contractor have conducted annual surveys of Horseshoe Crab spawning populations and breeding sites. Biologists make a visual count of spawning Horseshoe Crabs at three sites along the coast annually during May and June spring tides. This survey relies on volunteers who walk a standard-survey transect at high tide counting crabs observed within a one meter band. Since 2005, MDMR has reduced the number of sites from 14 to three, and in recent years, relied entirely on volunteer monitoring. These surveys are intended to update the last assessment of Maine Horseshoe Crabs and breeding locations, which fishery managers conducted in 1977 for the Maine State Planning Office.

MDMR and industry partners survey the Maine scallop resource annually, rotating among coastal sites from southern Maine to Quoddy Head. Sampling occurs in October and November prior to the start of the scallop season in December. The surveys provide fishery-independent data that fishery managers use for stock assessments to describe the status of the resource and provide a scientific basis for the development of management measures. The surveys also provide information on the effectiveness of the areas closed to fishing in growing scallop populations and to guide re-opening strategies.

The National Park Service monitors rocky shores in Maine as part of their Northeast Temperature Monitoring Network that extends to the Boston Harbor Islands in Massachusetts. In Maine, field work is centered on Acadia National Park, specifically Ship Harbor, Bass Harbor, Otter Point, Schoodic Point, and Little Moose Island. Samplings also occurs at Metinic and Petit Manan islands. This is a long-term, annual program focuses on detecting changes in rocky-shore fauna and flora, monitoring tide pools, barnacle recruitment, vertical distributions of macroalgae and macroinverterates, and counting target species. It monitors alterations in oceanographic patterns and climate change on decadal time scales.

The New England Aquatic Nuisance Species Panel was established in 2001 to monitor nuisance species, create public outreach programs, suggest policy, and facilitate coordination of these activities among the New England states. While most efforts have targeted freshwater invasive species, scientists also monitor marine non-native macroalgae and macroinvertebrates as part of the Rapid Assessment Survey, conducted from New York City to Eastport, Maine (Pederson et al. 2005, Wells et al. 2014). Data from these surveys are available from the Massachusetts Invader Tracking and Information System (MITIS; http://mit.sea-grant.net/mitis/mitis_map). Citizen monitoring programs supply the scientific survey efforts that

increase the spatial and temporal coverage of the Rapid Assessment Survey from Rhode Island to Wells, Maine for an abridged list of invasive species. The data collected from 2008 to present are available at the Massachusetts Ocean Resource Information System http://maps.massgis.state.ma.us/map_ol/moris.php.

The incipient network of field station sites called the Field Station and Marine Lab network in the Northeast includes a number of nonprofit and university affiliated coastal stations that monitor rocky and unconsolidated shores in Maine. Some of these projects involve citizen-science programs with significant outreach and education. Current stations include the R.S. Friedman Field Station in Cobscook Bay, Hurricane Island in Penobscot Bay, Coastal Studies Center in Casco Bay, and several others.

5/6.3 MONITORING SGCN HABITATS

Many of the SGCN monitoring efforts above involve some component of habitat monitoring. For SGCN habitats, factors affecting habitat distribution and integrity often occur at regional or state-wide scales. For example, the health of a headwater stream and its resident SGCN are influenced, in part, by barriers downstream and the integrity of the watershed as a whole. Likewise, the future distribution of tidal marshes in response to sea level rise and marsh migration is driven by factors at multiple scales, from individual culverts restricting tidal flow in streams to dynamics of large-scale sediment accretion. For other types of habitats, especially marine systems, we simply do not have a clear understanding of current or historic distributions and therefore have limited baseline information to assess changes over time. To address these knowledge gaps, MDIFW and partners identified habitat-scale survey and monitoring needs during development of conservation actions. We present these actions in Table 5/6-7 with examples of existing programs (e.g., Stream Smart) and general survey and monitoring techniques (e.g., remote sensing) that could be used to achieve habitat monitoring objectives. This is not an exhaustive list of approaches, but rather a starting place to identify next steps and potential partnerships.



The Maine Bumble Bee Atlas, launched in 2015 with citizen scientists, will establish a baseline assessment for future monitoring of a potentially declining group of significant pollinators. © Kalyn Bickerman

Table 5/6-7. Proposed habitat monitoring approaches.

Habitat Group	Conservation Action Description (Action ID #)	Examples of Potential Monitoring and Survey Programs and Collaborations[1]
Freshwater Aquatic Habitats		
Headwaters and Creeks	• Identify high value native coldwater SGCN fish and other SGCN species habitats that may be vulnerable to watershed scale hydrology effects due to tree loss (#87)	SGCN and habitat surveys, GIS models, remote sensing, Maine Department of Environmental Protection (MaineDEP) water quality and bioindicator monitoring
Streams, Rivers, Lakes, and Ponds	• Complete a statewide inventory of the status and condition of road and railroad crossings, including on headwater streams (#146) • Conduct a statewide inventory of dams, including on headwater streams (#101) • Identify priority locations for ecological flow management in aquatic habitats (#102) • Increase habitat surveys & models for road stream crossings (#145) • Develop better methods to map potential barriers in priority watersheds (#103) • Track completed road stream crossing projects (#147)	Stream Smart, National Lakes Condition Assessment, stream barrier assessments, GIS models, remote sensing. MaineDEP water quality and bioindicator monitoring
Marine Habitats		
Coastal	• Work with municipalities to identify important SGCN nesting and migratory areas in rocky coast and coastal habitats during comprehensive planning with assistance from programs such as Beginning with Habitat (#167)	SGCN and habitat surveys, Beginning with Habitat
Intertidal	• Develop monitoring systems and rapid response plans to prevent the colonization of invasive/problematic species and diseases in intertidal, subtidal, and tidal marsh habitats (#217) • More frequently update intertidal and subtidal SGCN habitat maps and compare to historical maps to monitor changes in distribution over time (#248) • Continued underwater surveillance of potential and active aquaculture lease sites with a focus on SGCN and important habitats (new)	Maine Invasive Species Network, iMapinvasives, Beginning with Habitat, eel grass surveys, remote sensing, SGCN and habitat surveys

Table 5/6-7. *continued: page 2 of 4.*

Habitat Group	Conservation Action Description (Action ID #)	Examples of Potential Monitoring and Survey Programs and Collaborations[1]
Rocky Coast	• Identify and prioritize significant nesting, migratory, and wintering areas in rocky coast habitats for contingency planning (#157) • Work with municipalities to identify important SGCN nesting and migratory areas in rocky coast and coastal habitats during comprehensive planning with assistance from programs such as Beginning with Habitat (#158) • Identify invasive plant hot spots in rocky coast habitats (#162)	SGCN and habitat surveys, Beginning with Habitat, Maine Invasive Species Network, iMapinvasives
Subtidal	• Develop monitoring systems and rapid response plans to prevent the colonization of invasive/problematic species and diseases in intertidal, subtidal, and tidal marsh habitats (#273) • Continue to improve rapid response for oil and gas spills in intertidal and subtidal habitats, including state agencies efforts to have most up-to-date species maps, rapid response protocols in place, and regular scenario training (#266) • Expand surveys of recreational fishing efforts to include SGCN that are not targeted in current survey efforts (#283) • More frequently update intertidal and subtidal SGCN habitat maps and compare to historical maps to monitor changes in distribution over time (#307) • Continued underwater surveillance of potential and active aquaculture lease sites with a focus on SGCN and important habitats (new)	Maine Invasive Species Network, iMapinvasives, citizen scientist or volunteer monitoring programs, remote sensing, eel grass monitoring
Tidal Marsh	• Build upon and coordinate with existing monitoring efforts to establish a long term tidal marsh monitoring program, with emphasis on assessing sediment dynamics in the context of sea level rise (#177) • Develop monitoring systems and rapid response plans to prevent the colonization of invasive/problematic species and diseases in intertidal, subtidal, and tidal marsh habitats (#191) • Continue and expand monitoring programs that track tidal marsh changes over time (#185)	GIS models, remote sensing, sediment accretion monitoring (Rod Surface Elevation Tables), Saltmarsh Habitat and Avian Research Program, Maine Invasive Species Network, iMapinvasives, Global Programme of Action Coalition (GPAC), National Wetland Condition Assessment, baseline and long-term ecological marsh monitoring, LiDAR models

Table 5/6-7. *continued: page 3 of 4.*

Habitat Group	Conservation Action Description (Action ID #)	Examples of Potential Monitoring and Survey Programs and Collaborations[1]
Terrestrial and Freshwater Wetland Habitats		
Floodplain Forests	• Identify aggressive invasives in floodplain forests and pre-treat to prevent spread (#342)	Maine Invasive Species Network, iMapinvasives, citizen scientist or volunteer monitoring programs, National Wetland Condition Assessment, Ecological Reserve Monitoring, development of reference wetland dataset
Freshwater Marshes	• Identify high priority road segments/culverts for organism passage among freshwater wetlands (#60)	Road Watch, Beginning with Habitat, SGCN and habitat surveys, GIS models, remote sensing, National Wetland Condition Assessment, Ecological Reserve Monitoring, development of reference wetland dataset
Grassland-shrubland-early Successional	• Research and identify explicit areas and amounts of grassland, shrubland, and early successional habitats needed to conserve target SGCN (#347) • Assist municipal planning, through programs such as Beginning with Habitat, to identify key grassland, shrubland, and early successional SGCN habitats (#348) • Map and distribute information on existing ruderal habitats (#355) • Map potential ruderal habitats (#356)	GIS models, remote sensing, SGCN and habitat surveys, Beginning with Habitat

Table 5/6-7. *continued: page 4 of 4.*

Habitat Group	Conservation Action Description (Action ID #)	Examples of Potential Monitoring and Survey Programs and Collaborations[1]
Northern Forests and Swamps	• Assess conserved lands, especially northern forests and swamps and rocky summits/outcrops/mountaintops, for climate change resiliency and use this information to guide future conservation efforts (#31) • Identify and conserve boreal forest refugia associated with SGCN (#32) • Continue long-term monitoring of SGCN and SGCN habitats associated with northern forests and swamps (#38) • Continue monitoring for invasive and problematic species and diseases, especially forest insect pests, in northern forest and swamps and south-central forests and swamps (#34) • Continue stewardship/habitat monitoring on conserved northern forest and swamp lands (#30)	GIS models, remote sensing, SGCN and habitat surveys, Maine Invasive Species Network, iMapinvasives, Forest Inventory and Assessment, Ecological Reserve monitoring, National Wetland Condition Assessment
Rocky Summits-Outcrops-Mountaintops	• Assess conserved lands, especially northern forests and swamps and rocky summits/outcrops/mountaintops, for climate change resiliency and use this information to guide future conservation efforts (#15) • Continue habitat/recreational monitoring stewardship on conserved rocky summit, outcrop, and mountaintop SGCN habitats (#18)	GIS models, remote sensing, SGCN and habitat surveys, citizen science or volunteer monitoring programs
South-Central Forests and Swamps	• Continue monitoring for invasive and problematic species and diseases, especially forest insect pests, in northern forests and swamps and south-central forests and swamps (#74) • Undertake long-term monitoring of SGCN and their habitats in south-central forests and swamps (#71) • Partner with Maine Department of Transportation to identify invasive plant "hotspots" along roads and bridges, especially in south-central forests and swamps (#75)	Maine Invasive Species Network, iMapinvasives, citizen science or volunteer monitoring programs, Forest Inventory and Assessment, Ecological Reserve monitoring, National Wetland Condition Assessment

[1]This column contains examples of existing programs (e.g., Stream Smart) and general survey and monitoring techniques (e.g., remote sensing) that could be used to achieve habitat monitoring objectives. This is not an exhaustive list of approaches, but rather a starting place to identify next steps and potential partnerships.

5/6.3.1 STATEWIDE HABITAT AND CONSERVATION ACTION MONITORING

In addition to SGCN and habitat monitoring, we will track habitat trends and the effectiveness of broad conservation programs at the statewide scale. Several of these approaches are described below. We expect to add approaches as new assessment, mapping, landscape modeling, and remote sensing techniques emerge over the next decade.

1. **Beginning with Habitat (BwH)**
   a. **Description:** BwH is a non-regulatory, habitat-based model that provides wildlife and habitat information to local decision-makers, conservation organizations, and landowners interested in their local wildlife and habitats. BwH provides these individuals with the necessary habitat information to voluntarily balance growth with conservation of natural spaces needed for wildlife, recreation, agriculture, forestry, and other resources. In the first decade of the program, BwH worked closely with towns to fulfill this goal. Over the next ten years, BwH will continue to work with towns while also providing enhanced/updated online mapping resources, searchable information on SGCN and conservation actions, and increased technical assistance for landowners and others implementing voluntary SGCN conservation measures. Under the direction of the Action Plan Implementation Committee, the BwH Steering Committee will revise BwH's strategic plan over the next two years to include measurable objectives and performance measures to monitor delivery, utilization, and effectiveness of BwH in supporting local voluntary efforts to conserve Maine's wildlife resources.
   b. **Periodically Assessed Metrics**
      i. Number of towns and regions mapped.
      ii. Number of towns, land trusts, and landowners receiving BwH information and technical assistance.
      iii. Ease of access to up-to-date habitat data for all user groups (government agencies, towns, conservation groups, and landowners).
      iv. Number of users accessing online mapping tools.
      v. Development of improved outreach modules for different user groups, especially landowners.
      vi. Number of conserved acres (including easements) in BwH Focus Areas.
      vii. Number of acres in BwH Focus Areas in "Tree Growth" or "Farm and Open Space" current use tax programs.
      viii. Successful creation of new incentives for towns and landowners to conserve priority SGCN habitats.

2. **Spatial Data Updates**
   a. **Description:** Since Maine's 2005 Plan, multiple partners have updated or created numerous habitat-related spatial datasets. The Maine Office of Geographic Information System data catalog (http://www.maine.gov/megis/catalog/) provides many of these datasets to the public, and others are available directly from partners. MDIFW and BwH host and maintain several datasets, which are listed here. These datasets are updated regularly and can be queried to monitor statewide SGCN, land use, and habitat patterns over time.

b. Periodically Assessed Metrics

i. Impervious/Developed Areas: Areas of impervious surfaces including buildings and roads.
ii. Rare, Threatened, and Endangered Wildlife Data (includes some SGCN): Includes known rare, Endangered, and Threatened species occurrences and/or the associated habitats based on species sightings.
iii. Undeveloped Habitat Blocks: Blocks of undeveloped land, including those greater than 100 acres.
iv. Habitat Connections: Modeled habitat areas needed to maintain or restore functional wildlife travel corridors between undeveloped habitat blocks greater than 100-acres and between higher value wetlands.
v. Riparian Connectors: Modeled crossing locations for wetland dependent species moving between waterways and wetlands divided by roads.
vi. Conserved Lands: The State of Maine's conserved lands database includes lands in federal, state, and non-profit ownership.

3. Habitat Management Guidelines

a. Description: MDIFW and partners will develop voluntary, non-regulatory habitat management guidelines for priority habitats and species and make these available to landowners, land managers, towns, land trusts, and others. Several habitat conservation actions (see Element 4) address the need for habitat management guidelines (HMG). We include this topic here in order to monitor develop of HMGs statewide.

b. Periodically Assessed Metrics

i. The number of SGCN for which HMGs are developed and published.
ii. The number of landowners, land managers, towns, land trusts, and others that receive HMGs.
iii. The number of landowners, etc., that implement habitat management according to the guidelines.

4. Land Conservation, Stewardship, and Management

a. Description: Cooperation with state and federal agencies, non-profit organizations, landowners, land trusts, municipalities, and other partners to conserve habitat for priority species using fee acquisition, conservation easements, purchase of development rights, cooperative management agreements, management plans, improved comprehensive planning, habitat restoration and enhancements, and other conservation tools. Several habitat conservation actions and themes (see Element 4) address habitat conservation and supporting/expanding landowner incentives. This is an extremely important aspect of Maine's efforts to conserve habitats for SGCN, and we have included this topic here in order to track efforts at a statewide scale.

b. **Periodically Assessed Metrics:** To monitor the success of these efforts collectively, we will develop a way to periodically monitor the number of acres under habitat conservation through:

i. Fee acquisition
ii. Conservation easement
iii. Purchase of development rights
iv. Cooperative management agreements and management plans

5/6.4 PROGRAMMATIC MONITORING

MDIFW and conservation partners developed 11 programmatic actions to help guide Action Plan implementation over the next ten years (see Element 4, Table 4-21). Each is summarized below.

In addition, 3 of these -- Programs 7, 8, and 9 -- address monitoring. Programs 7 and 9 are described in detail.

Outreach and Engagement (Programmatic Actions 1-3): Actions to inform and engage the public and partners on Action Plan accomplishments and opportunities for involvement.

> **Program 1**: Establish an Action Plan implementation committee comprised of conservation partners and agency staff to help guide implementation of the 2015 Action Plan (short-term). (Elements 7/8)
>
> **Program 2**: Devise and implement outreach strategies, including periodic meetings, to inform and engage conservation partners and the general public on 2015 Action Plan information, accomplishments, and opportunities for involvement (mid-term). (Elements 7/8)
>
> **Program 3**: Develop a public survey of SWAP and non-game species awareness, concerns, and priorities (initial survey: short-term; second survey: long-term [tentative]). (Elements 7/8)

Funding and Tracking (Programmatic Actions 4-8): Actions to bolster funding, capacity, and tracking of SGCN-related projects.

> **Program 4:** This action supports efforts to establish stable state and federal funding sources for SGCN and habitat conservation. (Element 4)
>
> **Program 5**: Consider establishing a competitive small grants program to make a portion of State Wildlife Grant (SWG) funds available to partners implementing priority actions identified in the 2015 Action Plan (mid-term). (Elements 7/8)
>
> **Program 6:** This action focuses on increasing long-term agency staffing and capacity needs for Action Plan implementation. (Element 4)
>
> **Program 7:** Annually compile agency and partner expenditures and seek additional match opportunities to maximize efficiency and impact of 2015 Action Plan implementation (short-term). (Elements 5/6)
>
> **Program 8:** Track SWAP conservation action implementation accomplishments by agencies and partners (short-term). (Elements 5/6)

"Within the first few years of Plan implementation, MDIFW will work closely with partners to develop tracking systems for conservation expenditures and expenses. MDIFW will develop feedback mechanisms to track partner efforts and accomplishments and use this information to periodically assess the effectiveness of the 2015 Action Plan."

With over 500 SGCN and habitat-related conservation actions, successful implementation of Maine's 2015 Action Plan will require collaborative efforts beween MDIFW and its many conservation partners. Furthermore, State Wildlife Grant funds are limited and, as a state, we need to ensure these dollars are being spent efficiently to achieve desired conservation outcomes. Within the first few years of Plan implementation, MDIFW will work closely with partners to develop tracking systems for conservation expenditures and expenses. MDIFW will develop feedback mechanisms to track partner efforts and accomplishments and use this information to periodically assess the effectiveness of the 2015 Action Plan. MDIFW is currently developing a Tracking and Reporting Actions for the Conservation of Species (TRACS) compliant tracking system for agency projects and may develop a similar mechanism for partners. MDIFW also will highlight Action Plan progress and successes at periodic meetings with partners and through media as part of Programmatic Theme 2. To further leverage limited funds, MDIFW also will work with partners to maximize existing match opportunities and identify new ones, especially for volunteer time that MDIFW has not previously tracked.

Action Development (Programmatic Action 9): This action relates to creating SMART (Specific, Measurable, Achievable, Results-oriented, and Time-bound) objectives for high priority SGCN and habitat conservation actions. (Elements 5/6)

MDIFW and partners developed a comprehensive menu of conservation actions to address Maine's most pressing SGCN and habitat needs. The list is long, despite taking several measures to include only the most important actions (e.g., only developing actions for medium or high level stressors). This is due to several reasons. First, Maine has a wide range of habitats, from subtidal mollusk reefs to high altitude alpine meadows. The stressors affecting these habitats and their SGCN are extremely nuanced and often habitat-specific. Furthermore, we are fortunate to have a broad partner base with diverse interests and missions, from habitat conservation and research to advocacy. Rather than present a restricted list applicable to only a subset of partners, we opted to present the full suite of actions so that partners across the state can find a nexus to some aspect of the plan.

We recognize that we cannot implement every action in the plan, even with broad partner support. In order to focus our efforts, we will use the prioritization approach presented in Element 4 to evaluate proposed conservation actions that are not already underway. We may first focus on the 20% of actions ranked as 'critical' for Biological Priority, but we also will consider lower-ranked partner-driven efforts. For actions determined to have sufficient biological impact and feasibility, we will establish SMART objectives to monitor action accomplishments over the next ten years and include this information in tracking programs developed under Programs 7 and 8 above.

Regional Partnerships (Programmatic Actions 10-11): These actions address continued MDIFW and partner involvement in existing conservation efforts.

Program 10: This action supports efforts to identify new and update existing SGCN Conservation Opportunity Areas (COAs). (Element 4)

Program 11: This action supports MDIFW and partner participation.

5/6.5 PLANS FOR REVISION

States are required to review and revise, as appropriate, State Wildlife Action Plans (SWAP) at least every ten years. In addition to a major plan revision every 10 years, MDIFW is committed to assessing regularly the progress made in implementing the Action Plan. MDIFW will use the programmatic actions described above to monitor conservation action progress at least annually, and will summarize this information in annual reports to USFWS as required by the State Wildlife Grant Program. As described in Elements 7/8, MDIFW will also establish an Implementation Committee in the Fall of 2015 comprised of agency staff and conservation partners. This committee will meet at least annually to review Action Plan accomplishments and to address any emerging issues or adaptive management needs. We will undertake a comprehensive plan review beginning in year eight of the 2015 Action Plan that will include reviewing the criteria and literature used for designating SGCN. We will revisit the stressor levels assigned to SGCN and habitats and determine if our actions sufficiently prevented additional declines or actually improved stressor rankings. MDIFW and its conservation partners will develop a revised Action Plan by October 1, 2025 for submission to USFWS.

5/6.6 LITERATURE CITED AND REFERENCES

Bart, J., B. Andres, S. Brown, G. Donaldson, B. Harrington, H. Johnson, V. Johnston, S. Jones, R. I. G. Morrison, M. Sallaberry, S. K. Skagen, and N. Warnock. 2002. Program for Regional and International Shorebird Monitoring (PRISM): version 0.7. Manomet Center for Conservation Sciences, Manomet, MA. 30pp. http://www.fws.gov/shorebirdplan/USShorebird/downloads/PRISMOverview1_02.doc

Brown, S., C. Hickey, B. Harrington, and R. Gill. 2001. U.S. Shorebird Conservation Plan, 2nd ed. Manomet Center for Conservation Sciences, Manomet, MA. 60pp.

Corr, P. O. 1988. Waterfowl management system and data base. Maine Department of Inland Fisheries and Wildlife, 284 State Street, State House Station 41, Augusta, Maine, 04333-0041. 60pp plus appendices.

Donaldson, G., C. Hyslop, R. I. G. Morrison, H. L. Dickson, and I. Davidson. 2000. Canadian shorebird conservation plan. Special Publication, Canadian Wildlife Service, Ottawa. 34pp.

Maine Audubon Society. 2015. http://maineaudubon.org/wildlife-habitat/amphibian-monitoring. Accessed May 29, 2015.

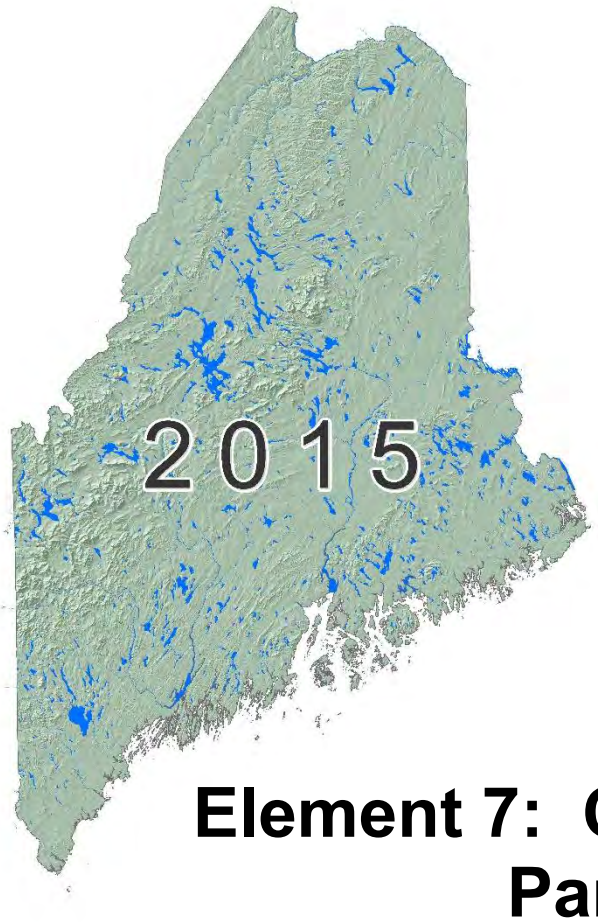
Maine Dept. of Inland Fisheries and Wildlife (MDIFW). 2005. Maine's comprehensive wildlife conservation strategy. Maine Dept. of Inland Fisheries and Wildlife, Augusta, Maine.

Pederson J., R. Bullock, J. T. Carlton, J. Dijkstra, N. Dobroski, P. Dyrynda, R. Fishers, L. Harris, N. Hobbs, G. Lambert, E. Lazo-Wasem, A. Mathieson, M. Miglietta, J. Smith, J. Smith III, M. Tyrrell. 2005. Marine invaders in the northeast: Rapid assessment survey of non-native and native marine species of floating dock communities, report of the August 3-9, 2003, survey. Publication No. 05-03. Cambridge: Massachusetts Institute of Technology, Sea Grant College Program. 40pp.

Tudor, L. 2002. Coastal migratory shorebird management system and data base. Maine Department of Inland Fisheries and Wildlife, 284 State Street, State House Station 41, Augusta, Maine, 04333-0041. 50pp.

Weir, L. A., J. A. Royle, K. D. Gazenski, and O. Villena. 2014. Northeast regional and state trends in anuran occupancy from calling survey data (2001-2011) from the North American Amphibian Monitoring Program. Herpetological Conservation and Biology 9(2): 223-245.

Wells, C. D., A. L. Pappal, Y. Cao, J. T. Carlton, Z. Currimjee, J. A. Dijkstra, S. K. Edquist, and A. Gittenberger. 2014. Report on the 2013 Rapid Assessment Survey (RAS) of Marine Species at New England Bays and Harbors. Massachussetts Office of Coastal Management (CZM), Boston, MA, United States. 32pp.



MAINE'S WILDLIFE ACTION PLAN

Element 7: Coordination with Partners &

Element 8: Public Participation

Prepared by

Maine Department of Inland Fisheries and Wildlife

In collaboration with

Maine's Conservation Partners

September 2015

TABLE OF CONTENTS

Element 7: Coordination with Partners
Element 8: Public Participation

7/8.0 Abstract....1

7/8.1 Introduction....1
7/8.1.1 Significant Differences from Maine's 2005 Plan....2

7/8.2 Action Plan Coordination Team / Action Plan Steering committee....3
7/8.2.1 Action Plan Coordination Team....3
7/8.2.2 Action Plan Steering Committee....4
7/8.2.3 SWAP Review and Update Charter....5

7/8.3 Coordination with Conservation Partners....5
7/8.3.1 Coordination with Federal Partners....9
7/8.3.2 Coordination with State Partners....9
7/8.3.3 Coordination with Tribal Partners....9
7/8.3.4 Coordination with Public and Local Partners, Including Non-governmental Organizations....9

7/8.4 Public Engagement....27
7/8.4.1 Public Presentations....27
7/8.4.2 Brochure....27
7/8.4.3 Peer Review....27
7/8.4.4 Maine Action Plan Webpage....28
7/8.4.5 Email Correspondence....28
7/8.4.6 30-Day Comment Period....28

7/8.5 Public and Partner Engagement During Plan Implementations....37

7/8.6 Literature Cited and References....40

7/8.7 Appendices....41

LIST OF TABLES

Table 7/8-1. Comparison of Conservation Partner Engagement 2005 and 2015. 3

Table 7/8-2. Conservation Partners invited to participate in the preparation of Maine's 2015 SWAP. 6

Table 7/8-3. Extent of coordination with Federal Partners. 10

Table 7/8-4. Extent of coordination with State Partners. 13

Table 7/8-5. Extent of coordination with Tribal Partners. 16

Table 7/8-6. Extent of coordination with Public and Local Partners. 18

Table 7/8-7. Press Releases, Articles, and Social Media. 27

Table 7/8-8. Summary of all comments and inquiries received. 29

LIST OF APPENDICES

Appendix 7/8-1. Operational Charter. 41

Appendix 7/8-2. Agendas – Conservation Partner Meetings. 46

Appendix 7/8-3. Frequently Asked Questions about Maine's 2015 Wildlife Action Plan. 58

KEY TO ACRONYMS

BMP	Best Management Practices
CMP	Conservation Measures Partnership
GIS	Geographic Information System
IUCN	International Union for the Conservation of Nature
MDIFW	Maine Dept. of Inland Fisheries and Wildlife
MDMR	Maine Dept. of Marine Resources
MFS	Maine Forest Service
MNAP	Maine Natural Areas Program
RFP	Request for Proposals
SGCN	Species of Greatest Conservation Need
SWAP	State Wildlife Action Plan
SWG	State Wildlife Grants
SWOAM	Small Woodland Owners Association of Maine
USFWS	U.S. Fish and Wildlife Service

7/8.0 ABSTRACT

Maine has a long history of successful collaboration among conservation partners, conducting comprehensive wildlife planning and public involvement for 50 years. The Maine Department of Inland Fisheries and Wildlife (MDIFW) began assembling an Action Plan Coordination Team in January 2014. This planning team developed the strategies necessary to achieve the eight required elements of the 2015 State Wildlife Action Plan (SWAP). In September 2014, the Coordination Team established an Action Plan Steering Committee to guide the overall development of the SWAP. The Steering Committee represented the broader conservation partner group by providing regular review and advice concerning the activities and proposed strategies of the Coordination Team. The Coordination Team and the Steering Committee began preparing an Operational Charter early in the update to guide the development of the Action Plan; the Steering Committee officially adopted the charter in November 2014. The Coordination Team invited 158 conservation partners to participate in the preparation of Maine's 2015 Action Plan, representing 102 unique organizations and key members of the conservation public. From July 2014 – June 2015 the partners attended five, day-long 'conservation partner' meetings at which they collaboratively developed Elements 1-5 of the 2015 Action Plan.

MDIFW both informed the public of its intent to revise the Action Plan and encouraged public participation. It established a Public Outreach Subcommittee to guide its public participation efforts. The Subcommittee identified methods to engage the public and to solicit its comment. The Coordination Team and Steering Committee implemented these methods in a manner that made effective use of agency resources and ensured an appropriate level of public participation.

The success of Maine's 2015 Wildlife Action Plan depends on continued partner and public engagement during plan implementation. To guide implementation of the Action Plan and to encourage continued public involvement, MDIFW and the Steering Committee identified 11 Programmatic Conservation Actions.

7/8.1 INTRODUCTION

Element 7 (Coordination with Partners) requires MDIFW to coordinate, to the extent feasible, with federal, state, and local agencies and Indian tribes that manage significant areas of land or water within the state, or administer programs that significantly affect the conservation of Species of Greatest Conservation Need (SGCN) during development, implementation, review, and revision of Maine's Action Plan. Element 8 (Public Participation) requires MDIFW to provide an opportunity for public participation in the development of the Plan (AFWA 2012).



September 2015 Conservation Partner meeting. © Mark Stadler

Developing the partnerships identified in Elements 7 and 8 early in the Plan revision fostered partner ownership and support, maintained positive and collaborative relationships, and ensured that the Action Plan is a plan for all of Maine, not merely MDIFW.

MDIFW prepared the Plan in close cooperation with other natural resource agencies and organizations and built public and political support for the Action Plan. Maine's Action Plan reflects the input and values of Maine's diverse suite of conservation partners (federal, state, and local agencies, Indian tribes, academia, private conservation organizations, and the public). MDIFW achieved support for the Plan by ensuring that its update was transparent and open to public input. Successfully implementing many of the Plan's recommended conservation actions will require that the Action Plan is accomplished through coordinated actions undertaken in partnership. Complementary roles and actions with partners elevate conservation actions to broader levels, leverage scarce dollars, and avoid duplication of effort. To guide the implementation of the Plan and to encourage continued public involvement, MDIFW and the Steering Committee identified 11 Programmatic Actions (Section 7/8.5).

7/8.1.1 SIGNIFICANT DIFFERENCES FROM MAINE'S 2005 PLAN

MDIFW has conducted comprehensive wildlife planning and public involvement for 50 years, and has a long history of successful collaboration among conservation partners and the public. Most notable is MDIFW's species planning process (Chapters 6, 7, MDIFW 2005). MDIFW invoked this same historical practice in developing Maine's 2005 Action Plan (MDIFW 2005), and amplified upon this collaborative spirit as it prepared Maine's 2015 Plan. MDIFW invited 158 conservation partners to participate, more than double the 64 partners involved in 2005 (Table 7/8-1). In 2015, conservation partners represented 102 unique agencies and organizations, again doubling the 51 entities that prepared the 2005 Plan (Tables 7/8-1 and 7/8-2). During 2005, conservation partners participated in three day-long meetings to address the eight required elements of the Action Plan. In 2015, conservation partners attended fully five day-long meetings (Table 7/8-1).

"MDIFW has conducted comprehensive wildlife planning and public involvement for 50 years, and has a long history of successful collaboration among conservation partners and the public."

MDIFW established an Action Plan Steering Committee to guide the overall development of the 2015 Plan (Section 7/8.2.2). The Steering Committee represented the broader conservation partner group and provided regular and timely review and advice concerning MDIFW's proposed strategies for accomplishing the 2015 revision; it also monitored Maine's progress in successfully accomplishing the larger, overall aspects of the Plan (AFWA 2012).

The Best Practices for State Wildlife Actions Plans (AFWA 2012) recommends that each state prepare a charter to formalize how conservation partners and fish and wildlife agencies will collaboratively develop their Action Plan. MDIFW and the Steering Committee prepared and adopted Maine's Action Plan Operational Charter (Section 7/8.2.3 and Appendix 7/8-1) in November 2014.

In addition to comparable public outreach activities undertaken in 2005, MDIFW provided a 30-day period during which the public had an opportunity to review the Plan and to provide comments and suggestions (Section 7/8.4). MDIFW broadly announced this opportunity and received several hundred comments, which it consolidated into approximately 50 distinct categories (Table 7/8-8). In addition, MDIFW met twice with forest and agricultural interests: once at the start of the Plan update and again during the public-comment period. Their comments and suggestions are reflected throughout Maine's conservation actions.

As Maine prepared its 2015 Action Plan, it adopted a team approach to authoring the several chapters of the Plan. We addressed Elements 1-4 as individual, stand-alone chapters; we combined Elements 5/6 into a single chapter to better address their close relationship. Similarly, and for the same reason, we combined Elements 7/8. These five sequential chapters constitute the Road Map to the Eight Required Elements.

Table 7/8-1. Comparison of Conservation Partner Engagement 2005 and 2015.

Partnership Metric	2005	2015
Number of Steering Committee members	0	12 (not including MDIFW staff)
Approximate number of conservation partners (individuals)	64	158
Approximate number of unique organizations	51	102
Number of partner meetings	3	5 (and steering committee and subcommittee meetings, workshops, and others described below)

7/8.2 ACTION PLAN COORDINATION TEAM / ACTION PLAN STEERING COMMITTEE

7/8.2.1 ACTION PLAN COORDINATION TEAM

MDIFW began assembling an Action Plan Coordination Team in January 2014. This planning team met bi-weekly and developed the strategies necessary to achieve the eight required elements of the 2015 Plan. As the planning responsibilities of the team broadened, it reached out to include additional individuals. Maine's Coordination Team included the following individuals:

Judy Camuso, Wildlife Division Director, MDIFW
Andrew Cutko, Ecologist, Maine Natural Areas Program
Phillip deMaynadier, Reptile, Amphibian, and Invertebrate Group Leader, MDIFW
Claire Enterline, Diadromous Fisheries Scientist, Maine Department of Marine Resources
Amanda Shearin, Wildlife Planner and Biologist, MDIFW
Mark Stadler, Wildlife Action Plan Coordinator, MDIFW (retired)
Charlie Todd, Endangered and Threatened Species Coordinator, MDIFW
Nathan Webb, Special Projects Biologist, MDIFW

One of the team's initial actions was to identify conservation partners who would participate in developing the Plan (Table 7/8-2).

7/8.2.2 ACTION PLAN STEERING COMMITTEE

In September 2014, the Coordination Team established an Action Plan Steering Committee to guide the Plan's overall development. The Steering Committee represented the broader conservation partner group by providing regular review and advice concerning the activities and proposed strategies of the Coordination Team. The Committee assisted the Coordination Team with planning conservation partner meetings (five, day-long meetings occurring from July 2014 – June 2015), reviewed strategies for developing the Action Plan prior to implementation with partners, and provided suggestions on partner meeting agendas, meeting format, and the presentation of information to partners. Because the Coordination Team was concerned largely with the week-to-week aspects of Plan preparation, the team asked the Steering Committee to monitor MDIFW's success in accomplishing the larger, overall aspects of the Action Plan (AFWA 2012). The Committee served as ambassadors for the larger group of conservation partners and provided quality-control as development of the Plan progressed. The Steering Committee met monthly, generally for four to five hours. MDIFW recorded the minutes of each meeting and made these available to the public on the Action Plan website (http://www.maine.gov/ifw/wildlife/reports/MWAP2015.html).



Conservation Partner break-out session.
© Mark Stadler

The Nature Conservancy, a member of the Committee, provided Open Standards (CMP 2013) training for MDIFW, members of the Steering Committee, and several conservation partners prior to developing SGCN habitat conservation actions. Following the training, MDIFW, MDMR, MNAP, and several conservation partners met for two, day-long sessions to develop preliminary SGCN habitat conservation actions for (1) Terrestrial / Wetland and (2) Coastal / Marine / Freshwater habitats.

The Steering Committee consisted of representatives from:

Brunswick-Topsham Land Trust - Angela Twitchell
Maine Audubon Society - Sally Stockwell
Maine Coastal Program - Emily Norton
Maine Dept. of Marine Resources - Claire Enterline
U.S. Fish and Wildlife Service - Jed Wright and Mitchka Hartley
Maine Coast Heritage Trust - Tim Glidden
Maine Forest Products Council - Barry Burgason
Maine Natural Areas Program - Molly Docherty
Natural Resources Conservation Service, U.S. Dept. of Agriculture - Jeff Norment
Small Woodland Owners Association of Maine - Tom Doak
The Nature Conservancy - Barbara Vickery
Maine Dept. of Inland Fisheries and Wildlife - Judy Camuso, Amanda Shearin, Nate Webb, Charlie Todd, Phillip deMaynadier, Mark Stadler

7/8.2.3 SWAP REVIEW AND UPDATE CHARTER

The Best Practices for State Wildlife Actions Plans (AFWA 2012) recommends that each state prepare a charter to formalize how conservation partners and fish and wildlife agencies will collaboratively develop their Action Plan. The Coordination Team and the Steering Committee began preparing Maine's Operational Charter early in the update; the Steering Committee adopted the charter in November 2014 (Appendix 7/8-2). The Operational Charter outlines the organizational structure that MDIFW and partners established to accomplish the Action Plan update, the process they would use, and the schedule for completing specific tasks. The charter explicitly defines and delineates key roles, responsibilities, and contributions for MDIFW and partners. Maine's Operational Charter addresses the following:

1. Introduction
2. Statement of Purpose: Maine's Wildlife Action Plan
3. Guiding Principles
4. Operational Guidance for Conservation Partners, Including the Steering Committee and Subcommittees

5.0 Process Structure
- 5.1. Conservation partners
- 5.2. Steering Committee
- 5.3. Subcommittees

6.0 Evaluation

7/8.3 COORDINATION WITH CONSERVATION PARTNERS

The Coordination Team invited 158 conservation partners to participate in the preparation of Maine's 2015 SWAP, representing 102 unique organizations and key members of the conservation public (Table 7/8-2).

Federal partners	14
State partners	14
Tribal partners	5
Public and Local partners	68 (includes non-governmental conservation organizations)

From July 2014 – June 2015 the partners attended five, day-long conservation partner meetings at which they collaboratively developed Elements 1-5 of the 2015 Action Plan (Tables 7/8-3 - 7/8-6, Appendix 7/8-2).

Table 7/8-2. Conservation Partners invited to participate in the preparation of Maine's 2015 SWAP.

Federal
Acadia National Park
Maine Army National Guard
National Marine Fisheries Service [Maine Field Station]
Natural Resource Conservation Service
National Oceanic and Atmospheric Administration
U.S. Fish and Wildlife Service, Ecological Services
USFWS Gulf of Maine Coastal Program
USFWS Maine Fishery Resource Office
USFWS North Atlantic Landscape Conservation Cooperative
USFWS Maine Wildlife Action Plan Contact
USFWS Aroostook, National Wildlife Refuge System
USFWS Maine Coastal Islands NWR
USFWS Moosehorn NWR
USFWS Rachel Carson NWR
State
Baxter State Park
DACF[(1)] Bureau of Agriculture, Resource Development Division
DACF Bureau of Agriculture, Food and Rural Resources
DACF Land Use Planning Commission
DACF Lands for Maine's Future Program
DACF Maine Coastal Program
DACF Maine Forest Service
DACF Maine Natural Areas Program
DACF Municipal Planning Assistance Program
DAFC Bureau of Parks and Lands
Dept. of Environmental Protection
Dept. of Marine Resources
Dept. of Inland Fisheries and Wildlife
Dept. of Transportation, Environmental Office
[(1)]Dept. of Agriculture, Conservation, and Forestry
Tribes
Aroostook Band of MicMac Indians
Houlton Band of Maliseet Indians
Passamaquoddy Tribe Indian Township Reservation
Passamaquoddy Tribe Pleasant Point Reservation
Penobscot Nation

Table 7/8-2. *continued: page 2 of 3.*

Public and Local
Appalachian Conservation Biology
Atlantic Salmon Federation
Biodiversity Research Institute
Brunswick Topsham Land Trust
Casco Bay Estuary Partnership
Coastal Mountains Land Trust
Conservation Law Foundation - Maine Advocacy Center
Cornell University
Defenders of Wildlife
Downeast Lakes Land Trust
Downeast Salmon Federation
Ducks Unlimited
Endangered Species Coalition
Forest Society of Maine
GrowSmart Maine
Gulf of Maine Research Institute
Island Institute
Lakes Environmental Association
Maine Aquaculture Association
Maine Association of Wetland Scientists
Maine Association of Conservation Commissions
Maine Association of Planners
Maine Audubon Society
Maine Birding Trail
Maine Bowhunters Association
Maine Chamber of Commerce
Maine Chapter of the Sierra Club
Maine Chapter of the Wildlife Society
Maine Coast Heritage Trust
Maine Cooperative Fish & Wildlife Research Unit
Maine Discovery Museum
Maine Farm Bureau
Maine Farmland Trust
Maine Forest Products Council
Maine Lakes Society
Maine Maritime Academy
Maine Professional Guides Association
Maine Rivers
Maine SeaGrant
Maine Tourism Association
Maine Trappers Association
Maine's Teaming With Wildlife / SWG Coalition
Manomet Center for Conservation Science
MDIFW Advisory Council
Mt. Agamenticus to the Sea Conservation Initiative

Table 7/8-2. *continued: page 3 of 3.*

Public and Local (continued)
National Wild Turkey Federation
Natural Resources Council of Maine
North Maine Woods
Northern Maine Partner
Orono Land Trust
Project Share
Restore: The North Woods
Royal River Conservation Trust
Ruffed Grouse Society
Senator George Mitchell Center / Sustainability Solutions Initiative
Small Woodland Owners Association of Maine
Sportsmen's Alliance of Maine
Suffolk University
The Nature Conservancy
Trout Unlimited
University of Maine at Machias, School of Marine Sciences
University of Maine, Orono, Department of Wildlife Ecology
University of Maine, Orono, School of Forest Resources
University of Maine, Orono, School of Biological Sciences
University of New England
University of Southern Maine
Wells Reserve
Wildlife Alliance of Maine

7/8.3.1 COORDINATION WITH FEDERAL PARTNERS

The Coordination Team invited 14 federal conservation partners to participate in the preparation of the 2015 Action Plan (Table 7/8-2). Federal partners served on the Steering Committee, attended the five conservation partner meetings, and participated in several workshops and training sessions (Table 7/8-3). Federal partners from Region 5, USFWS, provided an essential link with the tribal partners.

7/8.3.2 COORDINATION WITH STATE PARTNERS

Fourteen state agency partners participated in the preparation of the 2015 Action Plan (Table 7/8-2). State partners served on the Steering Committee, attended the five conservation partner meetings, and participated in several workshops and training sessions (Table 7/8-4).

7/8.3.3 COORDINATION WITH TRIBAL PARTNERS

The Coordination Team and Steering Committee invited representatives from five Maine tribes to participate (Table 7/8-2). Tribal partners attended one of the five conservation partner meetings (Table 7/8-5). In March 2015, Maine tribes met with staff from the USFWS and members of the Steering Committee. The day-long meeting addressed opportunities for collaboration between federal, state, and tribal partners in the development and funding of conservation programs for SGCN. The tribes requested that species of tribal cultural significance be included on Maine's list of SGCN species. Maine revised its SGCN list to include those species (Element 1).

7/8.3.4 COORDINATION WITH PUBLIC AND LOCAL PARTNERS, INCLUDING NON-GOVERNMENTAL ORGANIZATIONS

Sixty-six public conservation partners, including non-governmental conservation organizations and academia, assisted with the preparation of 2015 Plan, participating in all aspects of Plan development (Tables 7/8-2 and 7/8-6).

Table 7/8-3. Extent of coordination with Federal Partners.

Month / Year	Event	Federal Agencies	Acadia National Park	Maine Army National Guard	National Marine Fisheries Service (Maine Field Station)	Natural Resource Conservation Service	National Oceanic and Atmospheric Administration	U.S. Fish and Wildlife Service, Ecological Services	USFWS Gulf of Maine Coastal Program	USFWS Maine Fishery Resource Office	USFWS North Atlantic Landscape Conservation Cooperative	USFWS, Region 5	USFWS Aroostook National Wildlife Refuge	USFWS Maine Coastal Islands NWR	USFWS Moosehorn NWR	USFWS Rachel Carson NWR	U.S. Geological Survey, Maine Cooperative Fish and Wildlife Research Unit
May 2014	Invited to participate in 2015 action plan update		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
July 2014	Conservation Partners Meeting #1		X					X	X			X		X		X	X
	Maine Department of Marine Resources Information Session																
August 2014	Public Outreach Subcommittee Meeting																
September 2014	Landowners Meeting																
	Keeping Maine's Forests Implementation Committee																
	Steering Committee Meeting					X				X		X					
	MDIFW Advisory Council Meeting																
	Conservation Partners Meeting #2		X			X		X	X				X	X	X	X	
October 2014	Stanton Bird Club Annual Meeting																
	Society of American Foresters Fall Meeting																
	Steering Committee Meeting					X				X							
November 2014	Tribal Engagement Conference Call with USFWS																
	SFI-Fisheries Improvement Network																
	Conservation Partners Meeting #3							X	X				X				
	Steering Committee Meeting					X				X							
	Human Dimensions Meeting																

Table 7/8-3. *continued: page 2 of 3.*

Month / Year	Event	**Federal Agencies**	Acadia National Park	Maine Army National Guard	National Marine Fisheries Service (Maine Field Station)	Natural Resource Conservation Service	National Oceanic and Atmospheric Administration	U.S. Fish and Wildlife Service, Ecological Services	USFWS Gulf of Maine Coastal Program	USFWS Maine Fishery Resource Office	USFWS North Atlantic Landscape Conservation Cooperative	USFWS, Region 5	USFWS Aroostook National Wildlife Refuge	USFWS Maine Coastal Islands NWR	USFWS Moosehorn NWR	USFWS Rachel Carson NWR	U.S. Geological Survey, Maine Cooperative Fish and Wildlife Research Unit
December 2014	Unity College Herpetology Class																
	Tribal Engagement Conference Call with USFWS																
	Steering Committee Meeting					X				X							
	Tribal Engagement Conference Call																
January 2015	Conservation Partner Meeting #4		X					X							X		
	Steering Committee Meeting					X											
February 2015	Steering Committee Meeting									X							
	Open Standards Training					X				X							
	Marine/Coastal/Aquatic Conservation Proposal Brainstorming		X							X							
	Terrestrial/Wetland Conservation Proposal Brainstorming					X											
March 2015	NE Cottontail Working Group Annual Meeting																
	Eastern Maine Sportsman Show																
	Steering Committee Meeting									X							
	Presque Isle Sportsman Show																
	Maine Association of Wetland Scientists Annual Meeting																
	Maine Tribal Engagement Meeting																
	State of Maine Sportsman Show																
	Maine Dept. of Transportation Meeting on Invasive Species Actions																
	Brunswick Conservation Commission Presentation																

Table 7/8-3. *continued: page 3 of 3.*

Month / Year	Event	**Federal Agencies**	Acadia National Park	Maine Army National Guard	National Marine Fisheries Service (Maine Field Station)	Natural Resource Conservation Service	National Oceanic and Atmospheric Administration	U.S. Fish and Wildlife Service, Ecological Services	USFWS Gulf of Maine Coastal Program	USFWS Maine Fishery Resource Office	USFWS North Atlantic Landscape Conservation Cooperative	USFWS, Region 5	USFWS Aroostook National Wildlife Refuge	USFWS Maine Coastal Islands NWR	USFWS Moosehorn NWR	USFWS Rachel Carson NWR	U.S. Geological Survey, Maine Cooperative Fish and Wildlife Research Unit
April 2015	Steering Committee Meeting					X											
	Marine/Coastal Conservation Action Theme Development Meeting		X														
	Terrestrial/Wetland Conservation Action Theme Development Meeting																
	Steering Committee Review of Habitat Conservation Actions																
	Maine Land Trust Network Conference Workshop																
May 2015	York County Community College Environmental Science Class																
	Maine Association of Conservation Commissions Annual Meeting																
	Steering Committee Meeting					X				X							
June 2015	Steering Committee Meeting					X			X					X		X	
	Maine Forest Products Council Presentation																
	Landowner Meeting																
	Conservation Partners Meeting #5													X			
July 2015	30-day Public Comment Period on Draft Action Plan											X		X			

Table 7/8-4. Extent of coordination with State Partners.

Month / Year	Event	State Agencies	Baxter State Park Authority	DACF(1) Bureau of Agriculture, Resource Development Division	DACF Bureau of Agriculture, Food, and Rural Resources	DACF Land Use Planning Commission	DACF Lands for Maine's Future Program	DACF Maine Coastal Program	DACF Maine Forest Service	DACF Maine Natural Areas Program	DACF Municipal Planning Assistance Program	DACF Bureau of Parks and Lands	Dept. of Environmental Protection	Dept. of Marine Resources	Maine Dept. of Inland Fisheries and Wildlife, Advisory Council	Dept. of Transportation, Environmental Office	Maine Army National Guard
May 2014	Invited to participate in 2015 action plan update		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
July 2014	Conservation Partners Meeting #1					X		X	X	X	X			X	X	X	X
	Maine Department of Marine Resources Information Session																
August 2014	Public Outreach Subcommittee Meeting											X					
September 2014	Landowners Meeting																
	Keeping Maine's Forests Implementation Committee																
	Steering Committee Meeting									X							
	MDIFW Advisory Council Meeting														X		
	Conservation Partners Meeting #2					X		X	X	X	X	X		X		X	X
October 2014	Stanton Bird Club Annual Meeting																
	Society of American Foresters Fall Meeting																
	Steering Committee Meeting									X							
November 2014	Tribal Engagement Conference Call with USFWS																
	SFI-Fisheries Improvement Network																
	Conservation Partners Meeting #3				X			X		X				X			
	Steering Committee Meeting									X							
	Human Dimensions Meeting																

Table 7/8-4. *continued: page 2 of 3.*

Month / Year	Event	**State Agencies**	Baxter State Park Authority	DACF(1) Bureau of Agriculture, Resource Development Division	DACF Bureau of Agriculture, Food, and Rural Resources	DACF Land Use Planning Commission	DACF Lands for Maine's Future Program	DACF Maine Coastal Program	DACF Maine Forest Service	DACF Maine Natural Areas Program	DACF Municipal Planning Assistance Program	DACF Bureau of Parks and Lands	Dept. of Environmental Protection	Dept. of Marine Resources	Maine Dept. of Inland Fisheries and Wildlife, Advisory Council	Dept. of Transportation, Environmental Office	Maine Army National Guard
December 2014	Unity College Herpetology Class																
	Tribal Engagement Conference Call with USFWS																
	Steering Committee Meeting									X							
	Tribal Engagement Conference Call																
January 2015	Conservation Partner Meeting #4				X			X	X	X				X			
	Steering Committee Meeting									X							
February 2015	Steering Committee Meeting							X		X							
	Open Standards Training							X		X							
	Marine/Coastal/Aquatic Conservation Proposal Brainstorming							X		X				X			
	Terrestrial/Wetland Conservation Proposal Brainstorming									X							
March 2015	NE Cottontail Working Group Annual Meeting																
	Eastern Maine Sportsman Show																
	Steering Committee Meeting													X			
	Presque Isle Sportsman Show																
	Maine Association of Wetland Scientists Annual Meeting																
	Maine Tribal Engagement Meeting																
	State of Maine Sportsman Show																
	Maine Dept. of Transportation Meeting on Invasive Species Actions															X	
	Brunswick Conservation Commission Presentation																
April 2015	Steering Committee Meeting							X		X				X			
	Marine/Coastal Conservation Action Theme Development Meeting							X						X			

Table 7/8-4. *continued: page 3 of 3.*

Month / Year	Event	**State Agencies**	Baxter State Park Authority	DACF(1) Bureau of Agriculture, Resource Development Division	DACF Bureau of Agriculture, Food, and Rural Resources	DACF Land Use Planning Commission	DACF Lands for Maine's Future Program	DACF Maine Coastal Program	DACF Maine Forest Service	DACF Maine Natural Areas Program	DACF Municipal Planning Assistance Program	DACF Bureau of Parks and Lands	Dept. of Environmental Protection	Dept. of Marine Resources	Maine Dept. of Inland Fisheries and Wildlife, Advisory Council	Dept. of Transportation, Environmental Office	Maine Army National Guard
April 2015 (continued)	Terrestrial/Wetland Conservation Action Theme Development Meeting									X							
	Steering Committee Review of Habitat Conservation Actions							X		X				X			
	Maine Land Trust Network Conference Workshop																
May 2015	York County Community College Environmental Science Class																
	Maine Association of Conservation Commissions Annual Meeting																
	Steering Committee Meeting							X		X							
June 2015	Steering Committee Meeting																
	Maine Forest Products Council Presentation																
	Landowner Meeting																
	Conservation Partners Meeting #5					X	X	X		X	X					X	
July 2015	30-day Public Comment Period on Draft Action Plan								X								
(1) Dept. of Agriculture, Conservation, and Forestry																	

Table 7/8-5. Extent of coordination with Tribal Partners.

Month / Year	Event	**Tribal Partners**	Aroostook Band or MicMac Indians	Houlton Band of Maliseet Indians	Passamaquoddy Tribe, Indian Township Reservation	Passamaquoddy Tribe, Pleasant Point Reservation	Penobscot Nation
May 2014	Invited to participate in 2015 action plan update		**X**	**X**	**X**	**X**	**X**
July 2014	Conservation Partners Meeting #1						**X**
	Maine Department of Marine Resources Information Session						
August 2014	Public Outreach Subcommittee Meeting						
September 2014	Landowners Meeting						
	Keeping Maine's Forests Implementation Committee						
	Steering Committee Meeting						
	MDIFW Advisory Council Meeting						
	Conservation Partners Meeting #2						
October 2014	Stanton Bird Club Annual Meeting						
	Society of American Foresters Fall Meeting						
	Steering Committee Meeting						
November 2014	Tribal Engagement Conference Call with USFWS						
	SFI-Fisheries Improvement Network						
	Conservation Partners Meeting #3						
	Steering Committee Meeting						
	Human Dimensions Meeting						
December 2014	Unity College Herpetology Class						
	Tribal Engagement Conference Call with USFWS						
	Steering Committee Meeting						
	Tribal Engagement Conference Call						
January 2015	Conservation Partner Meeting #4						
	Steering Committee Meeting						
February 2015	Steering Committee Meeting						
	Open Standards Training						
	Marine/Coastal/Aquatic Conservation Proposal Brainstorming						
	Terrestrial/Wetland Conservation Proposal Brainstorming						

Table 7/8-5. *continued: page 2 of 2.*

Month / Year	Event	**Tribal Partners**	Aroostook Band or MicMac Indians	Houlton Band of Maliseet Indians	Passamaquoddy Tribe, Indian Township Reservation	Passamaquoddy Tribe, Pleasant Point Reservation	Penobscot Nation
March2015	NE Cottontail Working Group Annual Meeting						
	Eastern Maine Sportsman Show						
	Steering Committee Meeting						
	Presque Isle Sportsman Show						
	Maine Association of Wetland Scientists Annual Meeting						
	Maine Tribal Engagement Meeting		X	X	X	X	X
	State of Maine Sportsman Show						
	Maine Dept. of Transportation Meeting on Invasive Species Actions						
	Brunswick Conservation Commission Presentation						
April 2015	Steering Committee Meeting						
	Marine/Coastal Conservation Action Theme Development Meeting						
	Terrestrial/Wetland Conservation Action Theme Development Meeting						
	Steering Committee Review of Habitat Conservation Actions						
	Maine Land Trust Network Conference Workshop						
May 2015	York County Community College Environmental Science Class						
	Maine Association of Conservation Commissions Annual Meeting						
	Steering Committee Meeting						
June 2015	Steering Committee Meeting						
	Maine Forest Products Council Presentation						
	Landowner Meeting						
	Conservation Partners Meeting #5						
July 2015	30-day Public Comment Period on Draft Action Plan			X			

Table 7/8-6. Extent of coordination with Public and Local Partners.

Month / Year	Event	Members of the General Public	Public and Local Partners	Appalachian Conservation Biology	Atlantic Salmon Federation	Biodiversity Research Institute	Brunswick-Topsham Land Trust	Casco Bay Estuary Project	Coastal Mountains Land Trust	Conservation Law Foundation, Maine Advocacy Center	Cornell University	Defenders of Wildlife	Downeast Lakes Land Trust	Downeast Salmon Federation	Ducks Unlimited	Endangered Species Coalition	Forest Society of Maine	GrowSmart Maine	Gulf or Maine Research Institute	Island Institute	Lakes Environmental Association	Maine Aquaculture Association	Maine Association of Wetland Scientists	Maine Audubon Society	Maine Birding Trail	Maine Bowhunters Association
May 2014	Invited to participate in 2015 action plan update			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
July 2014	Conservation Partners Meeting #1					X	X										X						X	X		X
	Maine Department of Marine Resources Information Session																									
August 2014	Public Outreach Subcommittee Meeting																							X		
September 2014	Landowners Meeting						X										X									
	Keeping Maine's Forests Implementation Committee	X																								
	Steering Committee Meeting						X																	X		
	MDIFW Advisory Council Meeting																									
	Conservation Partners Meeting #2			X			X	X					X			X	X						X	X		X
October 2014	Stanton Bird Club Annual Meeting	X																								
	Society of American Foresters Fall Meeting	X																								
	Steering Committee Meeting						X																	X		
November 2014	Tribal Engagement Conference Call with USFWS																									
	SFI-Fisheries Improvement Network	X																								
	Conservation Partners Meeting #3							X					X										X	X		X
	Steering Committee Meeting						X																	X		
	Human Dimensions Meeting																									
December 2014	Unity College Herpetology Class	X																								
	Tribal Engagement Conference Call with USFWS																									
	Steering Committee Meeting						X																	X		
	Tribal Engagement Conference Call																									
January 2015	Conservation Partner Meeting #4						X	X															X			
	Steering Committee Meeting																							X		

Table 7/8-6. *continued: page 2 of 9.*

Month / Year	Event	Members of the General Public	Public and Local Partners	Appalachian Conservation Biology	Atlantic Salmon Federation	Biodiversity Research Institute	Brunswick-Topsham Land Trust	Casco Bay Estuary Project	Coastal Mountains Land Trust	Conservation Law Foundation, Maine Advocacy Center	Cornell University	Defenders of Wildlife	Downeast Lakes Land Trust	Downeast Salmon Federation	Ducks Unlimited	Endangered Species Coalition	Forest Society of Maine	GrowSmart Maine	Gulf or Maine Research Institute	Island Institute	Lakes Environmental Association	Maine Aquaculture Association	Maine Association of Wetland Scientists	Maine Audubon Society	Maine Birding Trail	Maine Bowhunters Association
February 2015	Steering Committee Meeting						X																	X		
	Open Standards Training						X																	X		
	Marine/Coastal/Aquatic Conservation Proposal Brainstorming							X						X									X			
	Terrestrial/Wetland Conservation Proposal Brainstorming																X							X		
March 2015	NE Cottontail Working Group Annual Meeting	X																								
	Eastern Maine Sportsman Show	X																								
	Steering Committee Meeting						X																	X		
	Presque Isle Sportsman Show	X																								
	Maine Association of Wetland Scientists Annual Meeting																						X			
	Maine Tribal Engagement Meeting																									
	State of Maine Sportsman Show	X																								
	Maine Dept. of Transportation Meeting on Invasive Species Actions																									
	Brunswick Conservation Commission Presentation	X																								
April 2015	Steering Committee Meeting																								X	
	Marine/Coastal Conservation Action Theme Development Meeting													X												
	Terrestrial/Wetland Conservation Action Theme Development Meeting																									
	Steering Committee Review of Habitat Conservation Actions																									
	Maine Land Trust Network Conference Workshop	X																								

Table 7/8-6. *continued: page 3 of 9.*

Month / Year	Event	Members of the General Public	Public and Local Partners	Appalachian Conservation Biology	Atlantic Salmon Federation	Biodiversity Research Institute	Brunswick-Topsham Land Trust	Casco Bay Estuary Project	Coastal Mountains Land Trust	Conservation Law Foundation, Maine Advocacy Center	Cornell University	Defenders of Wildlife	Downeast Lakes Land Trust	Downeast Salmon Federation	Ducks Unlimited	Endangered Species Coalition	Forest Society of Maine	GrowSmart Maine	Gulf or Maine Research Institute	Island Institute	Lakes Environmental Association	Maine Aquaculture Association	Maine Association of Wetland Scientists	Maine Audubon Society	Maine Birding Trail	Maine Bowhunters Association
May 2015	York County Community College Environmental Science Class	X																								
	Maine Association of Conservation Commissions Annual Meeting	X																								
	Steering Committee Meeting																							X		
June 2015	Steering Committee Meeting																									
	Maine Forest Products Council Presentation																									
	Landowner Meeting																									
	Conservation Partners Meeting #5	X														X						X	X	X		
July 2015	30-day Public Comment Period on Draft Action Plan	X																				X				

Table 7/8-6. *continued: page 4 of 9.*

Month / Year	Event	Public and Local Partners	Maine Chamber of Commerce	Maine Chapter of the Sierra Club	Maine Chapter or the Wildlife Society	Maine Coast Heritage Trust	Maine Discovery Museum	Maine Farm Bureau	Maine Farmland Trust	Maine Forest Products Council	Maine Lakes Society	Maine Maritime Academy	Maine Professional Guides Association	Maine Rivers	Maine SeaGrant	Maine Tourism Association	Maine Trappers Association	Maine Teaming with Wildlife – State Wildlife Grant Coalition	Manomet Center for Conservation Science	Mt. Agamenticus to the Sea	National Wild Turkey Federation	Natural Resources Council of Maine	North Maine Woods	Northern Maine Partner	Orono Land Trust	Project Share	Restore: The North Woods
May 2014	Invited to participate in 2015 action plan update		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
July 2014	Conservation Partners Meeting #1				X	X		X						X	X	X	X	X	X	X					X		
	Maine Department of Marine Resources Information Session																										
August 2014	Public Outreach Subcommittee Meeting									X																	
September 2014	Landowners Meeting							X		X																	
	Keeping Maine's Forests Implementation Committee																										
	Steering Committee Meeting																										
	MDIFW Advisory Council Meeting																										
	Conservation Partners Meeting #2				X	X		X		X			X			X	X	X	X						X		X
October 2014	Stanton Bird Club Annual Meeting																										
	Society of American Foresters Fall Meeting																										
	Steering Committee Meeting									X																	
November 2014	Tribal Engagement Conference Call with USFWS																										
	SFI-Fisheries Improvement Network																										
	Conservation Partners Meeting #3				X			X		X					X		X	X							X	X	
	Steering Committee Meeting					X				X																	
	Human Dimensions Meeting																										
December 2014	Unity College Herpetology Class																										
	Tribal Engagement Conference Call with USFWS																										
	Steering Committee Meeting					X				X																	
	Tribal Engagement Conference Call																										
January 2015	Conservation Partner Meeting #4												X		X		X	X	X						X		X
	Steering Committee Meeting																										

Table 7/8-6. *continued: page 5 of 9.*

Month / Year	Event	Public and Local Partners	Maine Chamber of Commerce	Maine Chapter of the Sierra Club	Maine Chapter or the Wildlife Society	Maine Coast Heritage Trust	Maine Discovery Museum	Maine Farm Bureau	Maine Farmland Trust	Maine Forest Products Council	Maine Lakes Society	Maine Maritime Academy	Maine Professional Guides Association	Maine Rivers	Maine SeaGrant	Maine Tourism Association	Maine Trappers Association	Maine Teaming with Wildlife – State Wildlife Grant Coalition	Manomet Center for Conservation Science	Mt. Agamenticus to the Sea	National Wild Turkey Federation	Natural Resources Council of Maine	North Maine Woods	Northern Maine Partner	Orono Land Trust	Project Share	Restore: The North Woods
February 2015	Steering Committee Meeting					X				X																	
	Open Standards Training					X																					
	Marine/Coastal/Aquatic Conservation Proposal Brainstorming					X								X													
	Terrestrial/Wetland Conservation Proposal Brainstorming									X								X	X						X		
March2015	NE Cottontail Working Group Annual Meeting																										
	Eastern Maine Sportsman Show																										
	Steering Committee Meeting					X				X																	
	Presque Isle Sportsman Show																										
	Maine Ass'n of Wetland Scientists Annual Meeting																										
	Maine Tribal Engagement Meeting																										
	State of Maine Sportsman Show																										
	Maine Dept. of Transportation Meeting on Invasive Species Actions																										
	Brunswick Conservation Commission Presentation																										
April 2015	Steering Committee Meeting									X																	
	Marine/Coastal Conservation Action Theme Development Meeting																										
	Terrestrial/Wetland Conservation Action Theme Development Meeting																										
	Steering Committee Review of Habitat Conservation Actions																										
	Maine Land Trust Network Conference Workshop																										

Table 7/8-6. *continued: page 6 of 9.*

Month / Year	Event	Public and Local Partners	Maine Chamber of Commerce	Maine Chapter of the Sierra Club	Maine Chapter or the Wildlife Society	Maine Coast Heritage Trust	Maine Discovery Museum	Maine Farm Bureau	Maine Farmland Trust	Maine Forest Products Council	Maine Lakes Society	Maine Maritime Academy	Maine Professional Guides Association	Maine Rivers	Maine SeaGrant	Maine Tourism Association	Maine Trappers Association	Maine Teaming with Wildlife – State Wildlife Grant Coalition	Manomet Center for Conservation Science	Mt. Agamenticus to the Sea	National Wild Turkey Federation	Natural Resources Council of Maine	North Maine Woods	Northern Maine Partner	Orono Land Trust	Project Share	Restore: The North Woods
May 2015	York County Community College Environmental Science Class																									
	Maine Ass'n of Conservation Commissions Annual Meeting																									
	Steering Committee Meeting									X																
June 2015	Steering Committee Meeting																									
	Maine Forest Products Council Presentation																									
	Landowner Meeting																									
	Conservation Partners Meeting #5				X	X							X		X		X									X
July 2015	30-day Public Comment Period on Draft Action Plan							X							X				X			X				

Table 7/8-6. *continued: page 7 of 9.*

Month / Year	Event	Public and Local Partners	Royal River Conservation Trust	Ruffed Grouse Society	Senator George Mitchell Center / Sustainability Solutions Initiative	Small Woodland Owners Association of Maine	Sportsmen's Alliance of Maine	Suffolk University	The Nature Conservancy	Trout Unlimited	University of Maine, Machias School of Marine Sciences	University of Maine, Orono School of Forest Resources and Dept. of Wildlife Ecology	University of Maine, Orono School of Biological Sciences	University of New England	University of Southern Maine	Wells Estuarine Reserve	Wildlife Alliance of Maine	Maine Association of Conservation Commissions	Maine Association of Planners
May 2014	Invited to participate in 2015 action plan update		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
July 2014	Conservation Partners Meeting #1					X			X			X		X		X	X		X
	Maine Department of Marine Resources Information Session																		
August 2014	Public Outreach Subcommittee Meeting											X							
September 2014	Landowners Meeting					X			X										
	Keeping Maine's Forests Implementation Committee																		
	Steering Committee Meeting					X			X										
	MDIFW Advisory Council Meeting																		
	Conservation Partners Meeting #2						X		X	X		X				X			
October 2014	Stanton Bird Club Annual Meeting																		
	Society of American Foresters Fall Meeting																		
	Steering Committee Meeting					X			X										
November 2014	Tribal Engagement Conference Call with USFWS																		
	SFI-Fisheries Improvement Network																		
	Conservation Partners Meeting #3						X		X	X		X							
	Steering Committee Meeting								X										
	Human Dimensions Meeting											X							
December 2014	Unity College Herpetology Class																		
	Tribal Engagement Conference Call with USFWS																		
	Steering Committee Meeting					X			X										
	Tribal Engagement Conference Call																		
January 2015	Conservation Partner Meeting #4						X		X										
	Steering Committee Meeting					X			X										

Table 7/8-6. *continued: page 8 of 9.*

Month / Year	Event	Public and Local Partners	Royal River Conservation Trust	Ruffed Grouse Society	Senator George Mitchell Center / Sustainability Solutions Initiative	Small Woodland Owners Association of Maine	Sportsmen's Alliance of Maine	Suffolk University	The Nature Conservancy	Trout Unlimited	University of Maine, Machias School of Marine Sciences	University of Maine, Orono School of Forest Resources and Dept. of Wildlife Ecology	University of Maine, Orono School of Biological Sciences	University of New England	University of Southern Maine	Wells Estuarine Reserve	Wildlife Alliance of Maine	Maine Association of Conservation Commissions	Maine Association of Planners
February 2015	Steering Committee Meeting								X										
	Open Standards Training								X										
	Marine/Coastal/Aquatic Conservation Proposal Brainstorming								X	X			X		X				
	Terrestrial/Wetland Conservation Proposal Brainstorming					X			X										
March 2015	NE Cottontail Working Group Annual Meeting																		
	Eastern Maine Sportsman Show																		
	Steering Committee Meeting								X										
	Presque Isle Sportsman Show																		
	Maine Association of Wetland Scientists Annual Meeting																	X	
	Maine Tribal Engagement Meeting																		
	State of Maine Sportsman Show																		
	Maine Dept. of Transportation Meeting on Invasive Species Actions																		
	Brunswick Conservation Commission Presentation																		
April 2015	Steering Committee Meeting					X			X										
	Marine/Coastal Conservation Action Theme Development Meeting											X							
	Terrestrial/Wetland Conservation Action Theme Development Meeting								X										
	Steering Committee Review of Habitat Conservation Actions					X			X										
	Maine Land Trust Network Conference Workshop																		

Table 7/8-6. *continued: page 9 of 9.*

Month / Year	Event	Public and Local Partners	Royal River Conservation Trust	Ruffed Grouse Society	Senator George Mitchell Center / Sustainability Solutions Initiative	Small Woodland Owners Association of Maine	Sportsmen's Alliance of Maine	Suffolk University	The Nature Conservancy	Trout Unlimited	University of Maine, Machias School of Marine Sciences	University of Maine, Orono School of Forest Resources and Dept. of Wildlife Ecology	University of Maine, Orono School of Biological Sciences	University of New England	University of Southern Maine	Wells Estuarine Reserve	Wildlife Alliance of Maine	Maine Association of Conservation Commissions	Maine Association of Planners
May 2015	York County Community College Environmental Science Class																		
	Maine Association of Conservation Commissions Annual Meeting																		
	Steering Committee Meeting								X										
June 2015	Steering Committee Meeting																		
	Maine Forest Products Council Presentation																		
	Landowner Meeting																		
	Conservation Partners Meeting #5					X		X	X										
July 2015	30-day Public Comment Period on Draft Action Plan					X			X										

7/8.4 PUBLIC ENGAGEMENT

MDIFW established a Public Outreach Subcommittee comprised of conservation partners to guide its public participation efforts. The Subcommittee identified several methods to engage the public, encourage participation, and solicit comment. The Coordination Team and Steering Committee implemented these methods, making effective use of agency resources to ensure an appropriate level of public participation. Table 7/8-7 presents a summary of these efforts.

Table 7/8-7. Press Releases, Articles, and Social Media.

MDIFW Press Release	November 19, 2014
MDIFW Facebook post (181 likes, 26 shares)	November 19, 2014
MDIFW Twitter	November 24, 2014
SeaCoast Online Article	November 30, 2014
Maine Association of Wetland Scientists Newsletter	February 2015
MDIFW prepared a stock newsletter article available to all partners	February 2015
Action Plan update brochure	March 2015
Press release when the Action Plan was posted for public review	July 2015
Social media posts when the Action Plan was posted for public review	July 2015

7/8.4.1 PUBLIC PRESENTATIONS

During each Action Plan presentation or workshop, MDIFW asked the audience its thoughts on the best ways to present Plan information to partners and what would partners find most useful for incorporating the Plan into their own work. MDIFW also asked what types of 'services' (e.g., web portals, technical assistance) partners would find most helpful. MDIFW recorded all suggestions for consideration during Plan implementation.

7/8.4.2 BROCHURE

MDIFW developed an Action Plan brochure (March 2015) and made it available to agency staff for distribution at non-Action Plan related meetings or presentations. MDIFW also provided the brochure to partners for distribution within their respective organizations.

7/8.4.3 PEER REVIEW

MDIFW and conservation partners invited 47 external biologists and taxa specialists to peer review the criteria used to identify SGCN and the draft SGCN list (June 2014). MDIFW received

several hundred species-specific comments from peer reviewers. In addition, specialists reviewed SGCN habitats and SGCN habitat stressors (January 2015) and provided comments.

7/8.4.4 MAINE ACTION PLAN WEBPAGE

MDIFW established an Action Plan webpage, within the agency website, dedicated to the 2015 Plan revision (June 2014): http://www.maine.gov/ifw/wildlife/reports/MWAP2015.html
The page allows the public and partners to view Action Plan documents, meeting schedules, Steering Committee and subcommittee meeting minutes, and contact information, as well as the 2005 Wildlife Action Plan. MDIFW updates the page regularly.

7/8.4.5 EMAIL CORRESPONDENCE

MDIFW created a dedicated Google email account (July 2014) to receive public inquiries and comments and posted the address on the Action Plan webpage, in press releases, and correspondence with partners. In addition, MDIFW has engaged in numerous email exchanges with partners and the public via staff's individual maine.gov email accounts.

7/8.4.6 30-DAY COMMENT PERIOD

MDIFW provided a 30-day comment period, extending from July 13 – August 12, 2015, to allow the public an opportunity to review the Action Plan and to provide written comments and suggestions. Conservation partners also had an opportunity to provide additional comments during the period. We received approximately 50 unique comments. MDIFW discussed all comments with the Steering Committee (Table 7/8-8). Substantive comments are considered below.



Conservation Partner break-out session.
© Mark Stadler

Public Comments
MDIFW received 196 form emails requesting that the Gray Wolf be added to Maine's list of SGCN. The wolf was an SGCN in Maine's 2005 Plan, but MDIFW did not designate the wolf as an SGCN in 2015. The Steering Committee suggested that MDIFW reconsider the wolf as a potential SGCN. MDIFW concluded that there is no current evidence of a population of wolves in Maine and that the establishment of a viable wolf population is unlikely. As such, the species does not meet Maine's SGCN listing criteria which specifies that only Maine extant species be considered for designation as SGCN.

Table 7/8-8. Summary of all comments and inquiries received.

Affiliation	Comment	Relevant Element
Northeast Wolf Coalition	Add Gray Wolf to SGCN list	1
Maine Wolf Coalition	Add Gray Wolf to SGCN list	1
Public	Add Gray Wolf to SGCN list; more public involvement needed; wolves were on 2005 SGCN list	1
	MDIFW received 196 form emails requesting the addition of the wolf as an SGCN	
Public	Concern over moose declines	1
Public	Clarify the criteria "cultural significance" used to designate SGCN	1
Public	Concern about loon conservation. Why aren't loons on the SGCN list?	1
Freeport Wild Bird Supply	Noted inconsistencies and lacking information in species reports for birds (e.g., no stressors listed for loon; no actions listed for P3 SGCN that are lacking information); concern for use of citizen science and other monitoring methods; provided a species-specific list of comments	1
Public	Concern with noise and chemical effects of fireworks on loons	1
Public	Commented on the lack of several raptors on SGCN list; suggested use of the survey methodology employed by the Maine River Bird Survey	
Public	Recommended use of Natural Resource Conservation Service habitat evaluation procedure	2
Public	Commented that the Plan needs further review and noted that the Northeast Terrestrial Habitat Classification System no longer mandates 75% canopy cover to be assessed as wildlife habitat	2, 4
Natural Resources Council of Maine	Plan lacks consideration of the condition of the Maine forest	2, 4
Suffolk University	Commented that "stressor" is the appropriate term; rockweed is not the only marine resource that is a habitat and in a permanent location	2, 3
Public	Structural modifiers needed; lack of successional stages and forest structure in habitat classification; forests not appropriately classified based on canopy cover; lack of northern White Cedar in plan by name; forestry is a greater stressor than identified; not enough specificity on forest condition; 2005 plan did a better job of identifying canopy closure types	2, 4
Public	More details needed on why climate change impacts are so prevalent in Plan given uncertainty	3

Table 7/8-8. *continued: page 2 of 4.*

Affiliation	Comment	Relevant Element
The Nature Conservancy	Plan needs adjustments to characterization of several coastal habitat stressors and actions (e.g., tidal restrictions need to be added to tidal marshes; culvert replacement timeframes; add living ecosystem alternatives to hardened shorelines, etc.)	3, 4
Maine Aquaculture Association	Plan implementation needs to engage marine resource users; lack of citations; disease actions should be drafted and implemented with USDA APHIS	3, 4
Maine Forest Service	Concern regarding the characterization of forestry as a stressor when other stressors are more prominent; questioned the inclusion of MDIFW in outcome-based forestry and certification programs and in on-going efforts e.g., chop-and-drop, etc.; is MDIFW looking to modify outcome based-forestry, certification? Actions require further prioritization	3, 4
Public	Plan needs additional citations for stressors and actions; need support for landowner incentives such as term easements and technical assistance biologists; need to review actions for specificity and any regulatory language; produce audience specific guides to the Plan; concern about grouping forestry and agricultural stressors together; need more action prioritization and how to define success; expand SGCN management actions on MDIFW lands to all public lands; establish an ongoing landowners committee similar to the steering committee; include more information in the Plan on where nongame funding comes from	3, 4
Public	Plan needs additional citations for stressors and actions; actions require additional specificity; need to review actions for any regulatory language; need stronger language throughout that this is not MDMR's work plan and that MDMR is a partner; make sure all references and disclaimers are included in reports	3, 4
Aquaculture Industry	Recommended line item clarifications to stressors, tables, species, and actions	1, 3, 4
Public	Local funding is necessary for implementation of actions; prioritize and promote habitat connectivity	4
Sea Grant	Reduce marine guilds to only relevant SGCN; amend actions so as not to conflict with aquaculture activities; general rewording of actions	4
Appalachian Mountain Club	Plan needs to address conservation of sub-alpine forest	4
Suffolk University	Why are there conservation actions for harvested (and therefore, regulated) marine species; concern for conflicts between guild-level actions and aquaculture	

Table 7/8-8. *continued: page 3 of 4.*

Affiliation	Comment	Relevant Element
Maliseets	Recommended that the Plan include actions related to installing instream habitat structures in streams, rivers, lakes, and ponds	4
Maine Farm Bureau	Promote landowner incentives; concern that the Plan may become regulatory	4
Manomet	Suggest interagency coordination on Action Plan outreach (e.g., Maine DOT on culverts, MFS on forests); MNAP should be listed as a co-lead on several actions	4
The Nature Conservancy	Provided line item comments on habitat actions, program action themes, and habitat action themes	4
Public	Construct wildlife crossings; stop slaughter of coyotes and cormorants; stop bear baiting; restrict pesticides; protect turtle crossings; need for general public outreach on wildlife issues	4, 8
Public	Remove competing fish species from Atlantic Salmon streams	4
Public	Biodiversity is more important than just game management; manage for old growth not just deer yards	4
Manomet	Provided line item comments on habitat actions and themes; concern that climate change plays too prominent a role relative to other stressors; need to partner with other relevant groups such as developers, builders, and agriculture	3, 4, 7, 8
The Nature Conservancy	Provided comprehensive comments on elements 1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6

Table 7/8-8. *continued: page 4 of 4.*

	General Comments & Inquiries	
U.S. Fish & Wildlife Service	Unable to sort conservation actions in the Excel file	
Small Woodland Owners Association of Maine	Inquiry from SWOAM member concerned that the Plan may become regulatory	
Public	Somewhat difficult to navigate through the Plan; need a summary version	
Public	Need for moose surveys in southern Maine	
Public	Concern about the length of the Plan	
Public	Suggested native partridge restoration in southern Maine	
Public	Increase any-deer permits to take more does	
Public	Increase doe permits	
Public	Plan must remember that people need to live here too	
Public	Reduce hunting and promote tourism	
Public	Where is the list of endangered species?	
Public	Landowner concern about public access to private property	
Public	Is this also a fisheries Action Plan?	
Public	Make the State Wildlife Action Plan happen; thanks for the hard work	

The importance of habitat connectivity was commented upon. MDIFW recognizes the importance of this concept, and several of the habitat conservation actions specifically address connectivity (TW Theme 5, Table 4-20, Element 4).

Some comments concerned the length of the Plan, expressing concern that there is too much content for readers to absorb (Programmatic Action 2, Section 7/8.5). MDIFW shares this concern; notably, the 2015 Action Plan is approximately 20-25% of the page length of the 2005 Action Plan submission.

Conservation Partner Comments

Manomet Center for Conservation Science commented that climate change is an important issue that needs to be addressed in the long-term, but there are a host of other threats that may be more problematic in the short-term, reducing the importance of climate change as a priority. The Steering Committee noted that climate change, in many cases, is listed as an 'other factor' within the threat assessment and this tended to over-emphasize climate change. MDIFW revised Table 1-3 to address this (Element 1).

Manomet suggested partnering with other relevant groups, especially agriculture, developers and builders, urban forestry interests, and the Maine Municipal Association (See Programmatic Action 2, Section 7/8.5). In regards to agricultural interests, Manomet commented that there are increasing pressures to supply food from sources that address biodiversity and anticipates increasing Action Plan opportunities with potato growers, blueberry growers, dairy, and nursery.

Manomet also provided comments addressing specific conservation actions. The Action Plan Implementation Committee will consider these as the Plan is implemented (Programmatic Action 1, Section 7/8.5).

The Maine Chapter of The Nature Conservancy commented that the Plan's habitat actions are numerous and could be combined to reduce their sheer volume and that some actions are not as specific as they could be (Programmatic Action 1, Section 7/8.5; Programmatic Action 9, Elements 5/6; and Section 4.5.2, Element 4). TNC provided comments addressing specific conservation actions. The Action Plan Implementation Committee will consider these as the Plan is implemented (Programmatic Action 1, Section 7/8.5).

The Appalachian Mountain Club commented that the Plan should focus more attention on the acquisition of sub-alpine habitat. The Steering Committee recognized that the Action Plan does identify acquisition as a strategy for the conservation of pine barrens and floodplain forests and could do so for sub-alpine forest as well. It concluded that the Action Plan addressed AMC's concern, the conservation of sub-alpine habitat, by focusing several conservation actions on SGCN associated with sub-alpine forest (e.g., Bicknell's Thrush, Table 4-7, Element 4).

MDIFW received comments from a conservation partner in Northern Maine expressing concern that the Plan does not adequately consider the threats of forest management to the condition and structure of key forest habitats. He offered that the Plan could address this by including measures of relative condition, such as the forest canopy cover and forest development stage, within the Plan's habitat information. The partner also commented that the Plan does not recognize the importance of Northern White Cedar stands as a valuable forest habitat.

MDIFW recognizes that forest condition and structure (e.g., canopy closure, vertical layering) are important habitat characteristics for many SGCN; however, the GIS habitat layer provided with the Northeast Terrestrial Habitat Classification System (The Nature Conservancy and

NatureServe 2011) is not an effective source for this spatial information. MDIFW and the Steering Committee concluded that many of the partner's concerns are addressed adequately in the Plan (TW Theme 4, Table 4-20, Element 4). Also, there is a specific conservation action to "Develop habitat management recommendations for all Priority 1 and Priority 2 SGCN and guilds that are sensitive to certain intensive forest management practices," (Table 4.1, Element 4), that provides an opportunity for outreach to forest managers and landowners that addresses concerns about forest condition applicable to specific, sensitive SGCN.

The Maine Farm Bureau, expressed concern about the possible regulatory implications of the Plan. MDIFW clarified that the Plan was non-regulatory in a written response.

MDMR received comments from marine industries noting a general lack of citations supporting the impacts of various threats to marine SGCN and their habitats. They suggested the addition of applicable citations to bolster the documentation of the stressors, and to make clear that some stressors are perceived and additional investigation is warranted. MDMR provided the requested additional citations.

Landowner Comments
Huber Resources Corporation, SWOAM, and Maine Forest Products Council provided comments during a landowner meeting with MDIFW on August 11, 2015. The group offered these comments:

1. The Action Plan could be improved with greater citation regarding the impacts of stressors. MDIFW responded that citations exist in the species reports, and because this information exists in a database, MDIFW can continuously update citations following plan submission. In addition, MDIFW noted the significance of professional knowledge, based on unpublished field experience, as well as the consensus of conservation partners, and using this collective knowledge in the formulation of Maine's Plan.



Open Standards break-out session. © Mark Stadler

2. Forestry and agricultural effluents should not be included together as a single stressor. The group questioned whether forestry effluents are a stressor, and stated that effluents have become less of an issue in forest management due to increased application of Best Management Practices (BMPs). MDIFW agreed that there is a loss of specificity by grouping forestry and agriculture, but explained that this grouping is the result of using the International Union for the Conservation of Nature (IUCN) threat lexicon, which all the Northeast states are using as a common scheme to categorize stressors.

3. Forest certification should not involve MDIFW in the one-on-one audits between landowners and the certification system. MDIFW indicated that this was not intended and clarified the conservation action to read -- Action 42: MDIFW offer collaboration and technical expertise to forest certifications systems for a subset of applicable SGCN and their forest habitats (Table 4-16, Element 4).

4. The comprehensive nature of the threat assessment in the draft Action Plan could be misused. MDIFW recognized this possibility and addressed it by focusing the Plan's conservation actions only on those issues that address higher priority stressors.

5. Some conservation actions have a regulatory quality. MDIFW revised these to reflect a non-regulatory, collaborative approach to the implementation of conservation actions; MDIFW deleted several actions.

6. Additional prioritization is necessary among the conservation actions (Programmatic Action 1, Section 7/8.5 and Programmatic Action 9, Elements 5/6).

7. The Action Plan should be applicable to all state lands, not just MDIFW's, e.g., the Bureau of Parks and Lands is preparing an integrated resource plan and there is an opportunity to integrate the Action Plan. MDIFW expanded the appropriate conservation actions to include all public lands.

8. MDIFW should establish a post-Plan landowners' committee and charge it with preparing a streamlined Action-Plan-implementation document for landowners similar to BMP manuals. The manual would explain how landowners can engage with the Action Plan, especially smaller landowners in southern Maine. There is also a need for a similar stream-lined Action Plan document for the general public. **(**Programmatic Actions 1 and 2, Section 7/8.5).

9. The post-Plan landowners' committee should explore the use of short-term easements to achieve habitat conservation for SGCN (Programmatic Action 1, Section 7/8.5 and TW Theme 2, Table 4-20, Element 4).

10. The Plan should contain more discussion of nongame funding and its necessity to further implement the Plan (Programmatic Action 1, Section 7/8.5 and Programmatic Actions 4 and 6, Element 4). Maine TNC said that it would be interested in pursuing additional Action Plan related positions at MDIFW (Programmatic Action 6, Element 4). The group also suggested seeking legislative support to acquire funding for landowners to implement conservation actions identified in the Action Plan, as well as funding to implement several projects identified in the Plan (Programmatic Action 5, Section 7/8.5).

11. SWOAM volunteered to assist with Action Plan outreach to landowners by facilitating training and technical outreach to landowners (Programmatic Actions 1 and 2, Section 7/8.5). Landowners suggested that MDIFW provide Action Plan outreach and technical assistance to Maine Forest Service (MFS) and consulting foresters. They felt there would be public support to fund additional state agency staff to provide this outreach; they expressed interest in pursuing additional Plan-related positions at MDIFW (Programmatic Action 6, Element 4).

12. MDIFW Regional Biologists should begin providing Action Plan advice to targeted landowners. MDIFW will implement this through Beginning with Habitat or related outreach programs (Programmatic Actions 1 and 2, Section 7/8.5).

MDIFW received comments from the Director of the Maine Forest Service (MFS). MFS recommended that the stressor category "Logging and Wood Harvesting" be replaced with "Forest Conversion." MFS offered that the key indicators of forest productivity continue to increase or have stabilized at acceptable levels and that the bigger threat to SGCN and their

habitat comes from turning forest into non-forest, particularly when the transformation is permanent. MDIFW concurs that permanent habitat loss poses greater risks to SGCN and their habitat than forest management does; however, the stressor category 'Logging and Wood Harvesting' is a term-of-art employed in the threat lexicon developed by the International Union for the Conservation of Nature (IUCN). The 13 Northeastern states, including Maine, have agreed to use the IUCN lexicon in their Wildlife Action Plans as a standardized means to present a common stressor assessment for the Northeast. Maine's Action Plan will retain the threat category 'Logging and Wood Harvesting,' while recognizing that forest conversion is a greater stressor for most SGCN.

MFS commented that it did not support draft Action 42: Promote greater MDIFW involvement with forest certification to help support conservation/management of SGCN habitats in northern forests and swamps. It predicted that landowner concerns about government agencies inserting themselves into the certification process would deter landowner participation. MDIFW did not desire to insert itself into the private, voluntary interactions between a landowner and a certification system. Rather, the action sought the collaborative integration of SGCN conservation practices into the broad process of forest certification. MDIFW clarified draft Action 42: MDIFW offer collaboration and technical expertise to forest certifications systems for a subset of applicable SGCN and their forest habitats (Table 4-16, Element 4).

MFS did not support draft Action 43: Provide opportunities for MDIFW participation in outcome-based forestry. It stated that private landowners voluntarily participate in Maine's outcome based forestry measure, the effort is guided by a technical panel appointed by the Governor, and a Certified Wildlife Biologist is a member of the panel. MFS commented that draft Action 43 would require a modification to state statute. MDIFW revised draft Action 43: MDIFW collaborate with forest landowners and managers to discuss options for voluntary integration of SGCN habitat conservation actions into outcome-based forestry practices (Table 4-16, Element 4).

MFS stated that draft Action 41: Provide opportunities for MDIFW's participation in Maine Forest Practices Act discussions and encourage outcome-based forestry for landscape scale habitat management, was unnecessary. Given the modifications to Actions 42 and 43, MDIFW deleted draft Action 41.

MFS commented that it, MDIFW, and MDMR collaboratively developed Standards for Placing Wood Into Stream Channels to Enhance Cold Water Fisheries, also known as the Chop and Drop rule and asked why the Action Plan included draft Action 130: Encourage the addition of woody material and other natural instream habitat structures to streams and lakes that replace lost natural habitat complexity. MDIFW clarified Action 130: Encourage the implementation of the Standards for Placing Wood Into Stream Channels to Enhance Cold Water Fisheries, also known as the Chop and Drop rule, to replace lost natural habitat structure in streams and lakes (Table 4-16, Element 4).

MFS noted that several draft conservation actions only addressed "Logging and Wood Harvesting" or "Roads and Railroads" as stressors to water quality and the integrity of riparian areas. MFS offered that the forestry community has made great strides in protecting water quality during all phases of forest management. Forest managers widely use the water-quality BMPs and the BMPs are highly effective. Forest managers also have made great strides in protecting the integrity of riparian areas. MFS concluded that non-forest uses pose a greater threat to water bodies and riparian forests. MDIFW reviewed draft conservation actions 81-83 and 131-147. MDIFW revised each draft conservation action, as necessary, to address all

applicable IUCN threat categories (Table 4-16, Element 4). MDIFW also revised draft Action 86: Assess the overall efficacy of the existing mechanisms (e.g., regulations, standards, BMPs) employed in riparian areas associated with headwaters and creeks at maintaining or enhancing water quality (Table 4-16, Element 4).

MFS noted that more needs to be done to reduce the set of conservation actions to a manageable number. The resources do not exist to carry out the number of actions proposed. The list of conservation actions and the entire Action Plan could be significantly narrowed in size and scope to make it a useful document and tool (Programmatic Action 1, Section 7/8.5; Programmatic Action 9, Elements 5/6; and Section 4.5.2, Element 4).

MDIFW Response to Comments Received
All individuals and organizations who submitted comments received a general acknowledgement from MDIFW that it had received their comments, thanking them for their interest and input. MDIFW is preparing detailed written responses to select partners and individuals that submitted more substantive comments.

7/8.5 PUBLIC AND PARTNER ENGAGEMENT DURING PLAN IMPLEMENTATIONS

The success of Maine's 2015 Wildlife Action Plan depends on continued partner and public engagement during plan implementation. MDIFW and the Steering Committee identified 11 Programmatic Actions to help guide implementation and tracking of the 2015 Wildlife Action Plan (Table 4-21, Element 4). Programmatic actions are categorized as follows:



Conservation Partner break-out session.
© Mark Stadler

Outreach and Engagement (Programmatic Actions 1-3): Actions to inform and engage the public and partners on Action Plan accomplishments and opportunities for involvement.

Program 1: Establish an Action Plan implementation committee comprised of conservation partners and agency staff to help guide implementation of the 2015 Action Plan (short-term).

As described in the beginning of this chapter, MDIFW coordinated closely with the SWAP Steering Committee during plan development. During the winter of 2015/2016, MDIFW will begin to transition this committee into an Action Plan Implementation Committee composed of interested Steering Committee members and other key partners. They will work with agency staff to help implement the 2015 Plan and address emerging issues. The Implementation Committee will meet at least annually with additional updates provided through email and phone conferences. Within the first year of Plan implementation, MDIFW will work with the Implementation Committee to develop a charter and to set goals and objectives for the group. MDIFW also will work with the Implementation Committee to establish several subcommittees (composed of agency staff, Implementation Committee

members, and other interested partners) to address specific implementation measures and technical needs, such as Programmatic Actions 2 and 5.

Program 2: Devise and implement outreach strategies, including periodic meetings, to inform and engage conservation partners and the general public on 2015 Action Plan information, accomplishments, and opportunities for involvement (mid-term).

MDIFW will work with the Implementation Committee and the Outreach Subcommittee (to be established) to develop and implement strategies that: 1) make the 2015 SWAP available to all users in accessible formats, and 2) foster partner and public engagement in the Plan. First, the committees will explore multiple approaches (suggested by partners during plan development) for accessing plan information including online links to SGCN ecology and conservation information, SGCN habitat management recommendations, SGCN distribution data, and information modules targeted to different user groups (e.g., private landowners, land trusts, municipalities) and regions (e.g., individual ecoregions or watersheds). MDIFW also is exploring options for making the 2015 Action Plan database accessible to the public. This relational database contains linked and searchable information for individual SGCN, including their SGCN qualification criteria, habitat and distribution information, threats, threats to associated habitats, conservation actions at both species-specific and habitat scales, and species-specific notes to aid in conservation efforts. MDIFW will work with the Implementation Committee and Outreach Subcommittee to guide development of these online and database tools as well as other formats for accessing plan information. In addition, MDIFW will continue to update the 2015 Wildlife Action Plan website and provide contact information.

To address the second task, MDIFW will work with the Implementation Committee and Outreach Subcommittee to generate materials (e.g., newsletters, blog posts, social media posts) and coordinate periodic events (e.g., annual meetings, trainings) to update partners on plan accomplishments and opportunities for involvement. MDIFW also plans to host periodic workshops with partners addressing their access to Plan information. Furthermore, MDIFW may establish a small grants program for partners implementing conservation actions (Programmatic Action 5). If implemented, this program likely will generate ongoing partner interest in the Action Plan through periodic requests for proposals (RFP) and award announcements.

Program 3: Develop a public survey of SWAP and non-game species awareness, concerns, and priorities (initial survey: short-term; second survey: long-term [tentative]).

In a recent survey, 95% of Mainers valued protection of wildlife for the enjoyment of people, but were largely unaware of how MDIFW is funded to accomplish this task (MDIFW 2010). Additional surveys also highlight the importance of Maine's wildlife resources to land-use decisions (Butler et al. 2014) and to the state's economy (Southwick Associates 2013). However, there is little information on Maine citizens' awareness of Action Plan and non-game species conservation. Public opinion surveys conducted in other states (e.g., Pennsylvania [Responsive Management 2014]) have shown increasing public concern for and awareness of non-game species. Soon, MDIFW will undertake a large-scale public survey to determine attitudes toward game and non-game conservation, management, and funding. Survey results will help guide MDIFW priorities and outreach approaches. This survey also provides a timely opportunity to highlight Maine's 2015 Action Plan and discuss options for establishing stable funding for wildlife conservation. MDIFW may also conduct a

second survey toward the end of Plan implementation to gauge the effectiveness of public outreach and education efforts developed as part of Programmatic Action 2.

Funding and Tracking (Programmatic Actions 4-8): Actions to bolster funding, capacity, and tracking of SGCN-related projects.

Program 4: This action supports efforts to establish stable state and federal funding sources for SGCN and habitat conservation. (Element 4)

Program 5: Consider establishing a competitive small grants program to make a portion of State Wildlife Grant (SWG) funds available to partners implementing priority actions identified in the 2015 Action Plan (mid-term).

MDIFW may establish a competitive grants program to make a small portion of SWG funds available to partners. This program has two major benefits: 1) awarded funds will help leverage partners' existing or new SGCN conservation efforts; and, 2) it encourages ongoing partner involvement in the Action Plan and communication with MDIFW through periodic RFPs and reporting requirements. A small grants program also addresses conservation partner requests for greater access to SWG funds.

To establish a small grants program, MDIFW must first address several logistical and grant administration needs. Because SWG funds are limited, MDIFW will work with partners to identify the minimum award amount necessary to leverage matching funds or seed money for SGCN conservation projects. If this amount is feasible and does not compromise ongoing SWG-funded projects and personnel, MDIFW will work with the Implementation Committee to develop a transparent grant advertising, selection, and reporting process.

Program 6: This action focuses on increasing long-term agency staffing and capacity needs for Action Plan implementation. (Element 4)

Program 7: Annually compile agency and partner expenditures and seek additional match opportunities to maximize efficiency and impact of 2015 Action Plan implementation (short-term). (Elements 5-6)

Program 8: Track SWAP conservation action implementation accomplishments by agencies and partners (short-term). (Elements 5-6)

Action Development (Programmatic Action 9): This action relates to creating SMART (Specific, Measurable, Achievable, Results-oriented, and Time-bound) objectives for high priority SGCN and habitat conservation actions. (Element 4)

Regional Partnerships (Programmatic Actions 10-11): These actions address continued MDIFW and partner involvement in existing conservation efforts.

Program 10: This action supports efforts to identify new and update existing SGCN Conservation Opportunity Areas (COAs). (Element 4)

Program 11: This action supports MDIFW and partner participation in the Northeast Regional Conservation Needs (RCN) Grant Program. (Element 4)

7/8.6 LITERATURE CITED AND REFERENCES

Association of Fish and Wildlife Agencies (AFWA). 2012. Best Practices Working Group. Best Practices for State Wildlife Action Plans – Voluntary Guidance to States for Revision and Implementation. Washington (DC): Association of Fish and Wildlife Agencies. 80pp. Association of Fish and Wildlife Agencies, Teaming With Wildlife, State Wildlife Action Plan (SWAP).

Butler, B. J., J. H. Hewes, B.J. Dickinson, K. Andrejczyk, M. Markowski-Lindsay, S.M. Butler. 2014. USDA Forest Service, National Woodland Owner Survey 2011-2013: National, Regional, and State Statistics for Family Forest and Woodland Ownerships (10+ acres). Res. Bull. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. (DRAFT).

Conservation Measures Partnership (CMP). 2013. Open Standards for the Practice of Conservation. Conservation Measures Partnership.

Maine Dept. of Inland Fisheries and Wildlife (MDIFW). 2005. Maine's comprehensive wildlife conservation strategy. Maine Dept. of Inland Fisheries and Wildlife, Augusta, Maine.

Maine Dept. of Inland Fisheries and Wildlife (MDIFW). 2010. LD 225 Resolve, Chapter 107 to Provide for the Long-term Funding of Programs of the Department of Inland Fisheries and Wildlife. February 11, 2010. 18pp.

Responsive Management. 2014. "Pennsylvania Residents' Opinions on and Attitudes Toward Nongame Wildlife." A report to the Pennsylvania Game Commission, Harrisburg, PA. 125pp.

Southwick Associates. 2013. Hunting in Maine in 2013: A statewide and regional analysis of participation and economic contributions. Prepared for the Maine Office of Tourism and Maine Dept. of Inland Fisheries and Wildlife. Fernandia Beach, FL. 48pp.

The Nature Conservancy and NatureServe. 2011. Northeast Terrestrial Habitat Classification System. https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/habitatmap.

7/8.7 APPENDICES

Appendix 7/8-1. Operational Charter.

2015 Maine Wildlife Action Plan
Conservation Partners / Steering Committee / Subcommittees
Operational Charter
October 2015

1. Introduction

Congress instituted the State Wildlife Grant (SWG]) program in 2001, which provides wildlife conservation funds to the 50 states. States use these to develop and implement management programs that benefit wildlife and their habitat, including species that are not hunted or fished. Since inception of the SWG program, Maine has received close to $8 million in SWG funding and accomplished over 50 research, management, and conservation projects. To receive SWG funding, Maine must have a comprehensive wildlife conservation strategy, now commonly known as a state wildlife action plan (the plan). The U.S. Fish and Wildlife Service ([USFWS) approved Maine's first plan in 2005. The plan identified species and habitats in greatest conservation need, significant threats to wildlife and habitat, and the conservation actions required to prevent endangered species listing and to spur the recovery of endangered species. http://www.maine.gov/ifw/wildlife/reports/wap.html

The SWG program requires that Maine update its plan by October 2015 and forward it to the USFWS for review and approval. The plan must be developed by the Maine Department of Inland Fisheries and Wildlife (MDIFW) in collaboration with Maine citizens and wildlife conservation partners. Partners are private landowners, federal and state agencies, Native American tribes, non-governmental organizations, and academicians that have a role in the conservation of Maine's wildlife and habitat. MDIFW invited 73 partners to participate. Over the next 12 months, partners will collaboratively develop Maine's 2015 plan. MDIFW and partners will also solicit and consider advice and recommendations from the public. Following plan approval by the USFWS, MDIFW and partners together will implement the plan.

2. Statement of Purpose: Maine's Wildlife Action Plan

Maine's plan embodies the shared vision of MDIFW, its conservation partners, and the public. It is Maine's blueprint for achieving our common goal of conserving healthy wildlife populations. The plan

- articulates clear conservation goals and defines the actions required to best conserve species at risk, manage habitats, prevent the listing of rare and imperiled species, and keep common species common,
- outlines strategies to perpetuate regional and state biodiversity,
- provides opportunities for partners to lead in its implementation,
- adapts to changing environmental conditions affecting fish, wildlife, and habitat, and
- establishes efficient and effective stewardship of Maine's natural heritage that is responsive to the public trust and to private landowner rights.

3. Guiding Principles

   As it develops the 2015 plan, the partners will ensure that the plan

   - is built on a foundation of sound scientific principles and is feasible,
   - recognizes that the public has a genuine stake in the plan -- wildlife belongs to the public and is held in the public trust,
   - is developed in an open, transparent, and inclusive process that encourages and facilitates the involvement of all partners,
   - respects property rights and recognizes that landowner participation is critical for the successful development and implementation of the plan,
   - provides opportunities for conservation actions by multiple partners and partnerships across the state,
   - develops and implements conservation actions that are voluntary, based on incentives rather than constraints,
   - does not rely solely on land acquisition, but also incorporates conservation actions on private land,
   - identifies opportunities for conservation and management of landscapes, watersheds, and habitats that address the needs of multiple species, wherever possible, especially in light of climate change, and
   - prioritizes actions for implementation by species and habitat.

4. Operational Guidance for Conservation Partners, Including the Steering Committee (5.2) and Subcommittees (5.3)

   Meetings: MDIFW recognizes that travel expenses impinge upon the budgets of state, federal, tribal, and non-governmental organizations. It will keep the number of meetings to the minimum required to develop an approvable plan.

   Partners will be notified of meeting dates at least 30 days in advance.

   MDIFW will post all documents distributed at partner meetings or by email or as follow-up to partner meetings on the action plan website.
   http://www.maine.gov/ifw/wildlife/reports/MWAP2015.html

   Timelines: Partners have the responsibility to move the process forward. MDIFW and partners will establish timelines to ensure completion of the plan on time. Each will adhere to established timelines for submittal of requested materials and information and for the completion of assigned tasks.

   Mutual Respect and Trust: the strength of the partners is their diverse knowledge and experience. Partners will base their work upon collective contributions and expect others to abide by the following

   - encourage participation by all partners,
   - avoid hidden agendas and to be open about potential conflicts of interests,
   - ensure all partners are respected and treated fairly, respect all contributions and ideas, and direct critiques at the idea not the person,
   - avoid speaking while others are speaking, avoid side-bar conversations, wait until there is an appropriate time to provide your comment,

- keep to the topic,
- avoid creating distractions, and
- place cell phones on silent mode, if receiving a call, minimize disruption to the group.

Decision-making: Unanimous consensus is the goal, but not a requirement. Partners represent the diverse interests of their agencies and organizations. It may be possible that all do not fully agree on specific aspects of the update. MDIFW and partners will strive to be open-minded and creative. As differences arise, partners will listen to other views and rationale. Partners will make decisions based on the general "modified consensus" of those present (i.e., if a partner disagrees with the rest of the group, he can nevertheless "live with" the decision and will not oppose the decision or stand in the way of moving it forward.)

MDIFW will resolve all decisions that do not receive this minimal level of support and will provide a written explanation for its decision to the partners. MDIFW will post the explanation on the action plan website; the explanation will note the degree of consensus reached by partners before the decision was handed to MDIFW for resolution.

Decisions reached by conservation partners are advisory and represent recommendations to MDIFW. If MDIFW decides not to accept a recommendation from the conservation partners, it will provide a written explanation for its decision and post the explanation on the action plan website.

Concurrence: Partners agree to participate as specified in this charter.

Travel Expenses: Partners are responsible for their travel expenses.

Partner funding: Participation will not provide an advantage in securing SWG funds.

Copyrighted or Restricted Material: All such material must be acknowledged and properly referenced.

Acknowledgement: The 2015 plan will acknowledge and recognize the contributions of participating partners and their organizations.

5. Process Structure

5.1 Conservation partners

Conservation partners will develop the 2015 action plan in collaboration with MDIFW and Maine citizens.

MDIFW invited 73 partners to participate in the development of the 2015 action plan. Partners are private landowners, federal and state agencies, Native American tribes, non-governmental organizations, and academicians that have a role in the conservation of Maine's wildlife and habitat.

5.2. Steering Committee

The steering committee (committee) will guide the development of the action plan.

MDIFW assembled a steering committee from the ranks of the conservation partners. Membership was by invitation. Committee members are broadly representative of key conservation partners. The committee may recommend additional members, but their participation must be approved by MDIFW. The committee is limited to no more than fifteen members.

MDIFW recognize that members have obligations to their agency or organization. MDIFW will strive to minimize members' time commitment; however, it is expected that those who agree to participate will endeavor to attend meetings. The committee may meet either in person or by conference call.

5.2.1. Steering Committee Function

The steering committee

- serves as the initial sounding board for MDIFW on both overall process and initial plan components and drafts,
- provides feedback to MDIFW between partner meetings on time-sensitive issues involving the plan update,
- establishes the timeline for the plan update and ensures that the timeline is met, and
- ensures that the process follows the charter's statement of purpose (2.) and guiding principles (3.).

Members present during committee meetings or conference calls are encouraged to participate fully. Not all members may be able to attend and participate in all discussions. As decisions are made or conclusions reached, those not present agree to move forward as a team and not to retrace discussions or decisions.

Members will strive to attend conservation partner meetings.

The committee may designate and establish subcommittees.

The committee may ask partners or its members to develop new materials, provide existing resources, gather information, or complete tasks necessary to the update. The committee will schedule dates when tasks are to be completed by consent of the members present. Members will share tasks and responsibilities by

- volunteering for tasks, especially those for which they have special expertise or interests,
- providing information that can fill data gaps and advance ideas, and
- keeping current with the update, even if unable to attend all discussions.

5.3. Subcommittees

The committee may designate and establish subcommittees.

Prior to the formation of the steering committee, MDIFW established a Public Communications and Outreach Committee and MDIFW / Maine Natural Areas

Program established a Focus Area Review Committee. Both are now considered subcommittees functioning under the guidance of the steering committee.

The committee will designate individuals to chair each subcommittee.
Subcommittees must be chaired by a partner or MDIFW, but subcommittee members may be from outside the participating partners.

Subcommittee chairs report to the committee. Chairs will ensure that steering committee members receive information about the activities of their subcommittee, such as minutes and copies of pertinent correspondence.

Subcommittee chairs are responsible for coordinating their meetings and conference calls.
Subcommittees dissolve when they have accomplished their designated purpose.

6. Evaluation

To be successful, the steering committee and partners must complete the plan update, accomplishing the requirements and objectives specified by the USFWS, prior to October 2015. It is important that committee members and partners are committed to success. The committee must ensure that the plan update remains on schedule and meets deadlines.

Previous sections of the charter guide the deliberations of partners and the committee, and therefore, provide a basis to gauge success. The committee will evaluate periodically the progress of the action plan update and adherence to the requirements of the charter. The committee will conduct the evaluation by a method that it deems appropriate. The committee will use the following attributes to evaluate success.

Participation: MDIFW staff, partners, and committee members are engaged in the plan update; they volunteer to assist with tasks, especially those for which they have special expertise or interest; they are proactive in providing information that fills data gaps and advances ideas; and they keep current with the planning process, even if they are unable to participate in all discussions.

Schedules: MDIFW staff, partners, and committee members develop new materials, provide existing resources, gather information, or complete other necessary tasks as requested and scheduled.

Outreach: Partners and committee members engage the members of their organizations in the plan update, using their outreach mechanisms to inform their members and to solicit comment.
MDIFW provides regular updates to the steering committee and partners and provides opportunities for broad participation by other organizations and citizens.

Subcommittees: Subcommittee chairs conduct meetings and accomplish assigned tasks as scheduled, report to the committee, and ensure that the committee is fully informed of its activities.

Appendix 7/8-2. Agendas – Conservation Partner Meetings.



2015 Maine Wildlife Action Plan

Update Committee - Meeting #1

July 8, 2014

Location: Pineland Farms, New Gloucester

Meeting Purpose

- Provide background on State Wildlife Grant (SWG) program
- Provide overview of SWG accomplishments since 2005
- Review and discuss the process used to develop Maine's Species of Greatest Conservation Need (SGCN) list
- Introduce Habitat and Threat classification systems
- Discuss Public Communication plan

Meeting Agenda

9:00 Welcome and logistics

9:30 Background
- State Wildlife Grants
- State Wildlife Action Plans
- 2005 Maine Wildlife Action Plan
  - Maine's State Wildlife Grant accomplishments

10:15 Elements of Wildlife Action Plans

10:45 Break

11:00 Role of Conservation Partners in Wildlife Action Plans

11:15 Process used to develop Maine's *Species of Greatest Conservation Need* list
- Process and criteria
- Overview
  - Birds
  - Fish
  - Invertebrates
  - Mammals
  - Reptiles and amphibians

12:00 Lunch - provided

1:00 Break-out group review of SGCN list and discussion
- Birds
- Fish
- Invertebrates
- Mammals
- Reptiles and amphibians

1:45 Reconvene for break-out group reports
- Birds
- Fish
- Invertebrates
- Mammals
- Reptiles and amphibians

3:00 Break

3:15 Introduction of Element 2: Habitats

3:45 Introduction of Element 3: Threats

4:15 Public Communication Plan

4:45 Group Discussion

5:00 Adjourn



2015 Maine Wildlife Action Plan

Update Committee - Meeting #2

September 30, 2014

Location: Maple Hill Farm, Hallowell

Meeting Objectives

- Update partners on action plan activity since July 8th meeting
- Finalize Maine's list of Species of Greatest Conservation Need [SGCN] Incorporating marine fauna into the action plan
- Review the process to develop SGCN habitat associations
- Introduce proposed approach for assessing "stressors" affecting SGCN and their habitats

Meeting Agenda

8:30 Gathering / coffee available

9:00 Welcome
- Introductions
- Volunteer time
- Review of day's agenda
  - Meeting objectives

9:15 Brief re-introduction to state wildlife action plans and state wildlife grants.
- SWG and SWAP: why we are here
- Active stakeholder and working groups
  - Conservation partners
  - Steering committee
  - Public outreach committee
  - Focus Areas update committee
- Meeting with landowners

9:45 Finalizing Maine's list of species of greatest conservation need
- Peer review process – comments offered by taxa "specialists" and conservation partners
- Finalizing the criteria used to identify SGCN and the SGCN list
- Questions, discussios

10:15 Marine fauna and habitat, Dept. of Marine Resources

10:45 Break

11:00 Wildlife action plan habitats
- The role of SGCN habitat associations in the action plan update
- System / process / criteria used to classify Maine's wildlife habitats
- System / process / criteria used to identify SGCN habitats associations
- Overview: results, summary analysis
  - Habitat types
  - Habitats used by SGCN
  - Preliminary conservation land "gaps" analysis
  - Habitat distribution and location of SGCN habitats
- Questions, discussion

12:00 Lunch

1:00 Break-out group review of habitat classification and SGCN habitat associations
- Ecosystem groups
  - Wetlands
  - Coastal/marine
  - Freshwater aquatic
  - Terrestrial
- Tasks
  - Review Northeast habitat classification system by ecosystem group
  - Review SGCN habitat associations
  - Identify habitat associations not captured by classification system
  - Discuss aggregation / presentation of SGCN and habitat analysis: geopolitical, biophysical ecoregions, HUC watersheds, other
  - Discuss approaches to identify highest priority habitats for conservation actions
  - Discuss need to develop "user friendly" habitat lexicon

3:00 Break

3:15 Reconvene for break-out group reports
- Wetlands coastal /
- Marine freshwater
- Aquatic terrestrial

3:45 Proposed approach for assessing "stressors" affecting SGCN and their habitats
- October 30, 2014 conservation partner meeting

4:00 Closing discussion

4:15 Adjourn



2015 Maine Wildlife Action Plan

Update Committee - Meeting #3

November 18, 2014

Location: Spectacular Event Center, Bangor

Meeting Objectives

- Update partners on action plan activity since September 30 meeting
- Final consideration and wrap-up of SGCN habitat associations, element 2
- Introduction to criteria used to assess SGCN and habitat stressors, element 3
- Review, discuss criteria for stressor assessment: priority 1 SGCN and habitats
- Introduce ideas for prioritizing 1) habitats and 2) habitat-stressors for conservation action.

Meeting Agenda

8:30 Gathering / coffee available

9:00 Welcome / Judy
- Activity since 09/30 partner meeting / Mark
- Steering committee / October 16 meeting
  - Additions to steering committee
  - Flora and Maine action plan
  - Operational charter
- Planning for November 18 partner meeting
- Focus area review subcommittee

9:15 Public outreach and communications, element 8 / Amanda

9:35 Marine fauna and habitat, Dept. of Marine Resources / Claire
- Marine SGCN list
- Marine habitat classification
- Marine SGCN habitat associations

10:15 Final consideration and wrap-up of SGCN habitat associations, element 2 / Andy
- Brief review of SGCN-habitat associations
  - System / process / criteria used to classify Maine's wildlife habitats
  - System / process / criteria used to identify SGCN habitats associations
- Discuss approaches to SGCN distributions
- Questions, discussion

10:45 Break

11:00 Introduction to the assessment of stressors affecting SGCN and their habitats, element 3 / Nate
- IUCN classification system
- Process and criteria used to identify priority 1 SGCN stressors
- Process and criteria used to identify habitat stressors
- Questions, discussion

12:00 Lunch

1:00 Break-out group logistics and expectations / Amanda

1:05 Break-out group discussion: SGCN priority 1 stressor assessment criteria with focus on stresses that are not related to habitat. The marine group will also discuss the marine SGCN list and habitat associations.
- Taxa groups
  - Birds
  - Fish
  - Invertebrates
  - Mammals and Reptiles
  - Marine
- Tasks
  - Review and discuss SGCN priority 1 stressor assessment
  - Identify errors of inclusion or exclusion
  - Discuss approaches for assigning stressors to SGCN priority 2 and 3

2:00 Move to next break-out group

2:05 Break-out group discussion: habitat stressor assessment
- Ecosystem groups
  - Wetlands
  - Coastal/marine
  - Freshwater aquatic
  - Terrestrial
- Tasks
  - Review and discuss the process and criteria used to assess habitat stressors
  - Identify errors of inclusion or exclusion

3:00 Break

3:15 Reconvene for break-out group reports / Mark
- SGCN priority 1
  - Birds
  - Fish
  - Invertebrates
  - Mammals and Reptiles
  - Marine
- Habitats
  - Wetlands
  - Coastal / marine
  - Freshwater aquatic

- Terrestrial

3:45 Next meeting: January 8, 2015

Options that the partners may use to identify and prioritize habitats and habitat-stressors for conservation action / Phillip, Andy, Nate, Charlie

4:15 Wrap-up / Mark

4:30 Adjourn



2015 Maine Wildlife Action Plan

Update Committee - Meeting #4

January 20, 2015

Location: Maple Hill Farm, Hallowell

Meeting Objectives

- Overview of public outreach and communication, element 8
- Update on the process for identifying distribution of SGCN, element 1
- Overview of the threat assessment process and results,element 3
- Prioritization of SGCN habitats, element 2
- Habitat prioritization: partner review and feedback
  - Introduction to conservation actions, element 4

Meeting Agenda

Morning sessions will provide time for floor discussion.

8:30 Check-in, coffee and tea available

9:00 Welcome

9:15 Overview of public outreach and communication, element 8
- Stakeholders, targeted surveys, focus groups, and analysis.

10:15 Update on the process for identifying distribution of SGCN, element 1

10:45 Break

11:00 Overview of the threat assessment process and results, element 3

12:00 Lunch

12:45 Prioritization of SGCN habitats, element 2 [results of habitat prioritization options]

1:15 Break-out groups
- Habitat prioritization: partner review and feedback
  - Coastal / marine
  - Wetlands
  - Freshwater / aquatics
  - Terrestrial
  - SGCN distribution [tentative]

2:30 Break

2:45 Break-out group reports

3:15 Introduction to conservation actions, element 4
- Options for organizing sub-committees to develop conservation actions
- Process that sub-committees will use to develop conservation actions

3:45 Wrap-up thoughts, suggestions Where are we in the process Closing comments from the floor
- Select date of next partner meeting – tentatively week of 02/09/2015

4:00 Adjourn



2015 Maine Wildlife Action Plan

Update Committee - Meeting #5

June 16, 2015

Location: Maple Hill Farm, Hallowell

Meeting Objectives

- Partner review of 2015 conservation actions:
  - Habitat conservation actions
  - SGCN conservation actions
  - Programmatic conservation actions
- Partner tasks:
  - Review and revise suite of proposed conservation actions
  - Identify partnerships that will bolster action implementation and success
  - Identify preferences for access to plan information and its format
  - Provide input regarding overall satisfaction with identified conservation actions
  - Partner discussion topics:
  - Programmatic conservation actions
- A process outlining considerations to be used when prioritizing conservation actions for Maine's 2015 WAP
- Continuing partner involvement

Meeting Agenda

8:30 Gathering / coffee available

9:00 Welcome / Judy

9:15 Accomplishments since January 20th partner meeting / Mark

9:30 Habitat conservation actions / Amanda

10:00 Break-out group logistics and expectations / Amanda

10:15 Break

10:30 Break-out group discussion: review habitat conservation actions
- Ecosystem groups
  - Terrestrial / wetland
  - Coastal / marine
  - Freshwater / aquatic
- Task
  - Review and revise suite of proposed conservation actions

- Identify partnerships that will bolster action implementation and success
- Identify preferences for access to plan information and its format
- Provide input regarding overall satisfaction with identified conservation actions

11:30 Reconvene for break-out group reports / Amanda
- Habitats
  - Terrestrial / wetland
  - Coastal / marine
  - Freshwater / aquatic

12:00 Lunch

12:30 SGCN conservation actions / Nate

1:00 Break-out group logistics and expectations / Nate

1:15 Break-out group discussion: review SGCN conservation actions
- Taxa groups
  - Bird
  - Inland Fish and Mammals
  - Reptiles, Amphibians, and Invertebrates
  - Marine
- Tasks
  - Review and revise suite of proposed conservation actions
  - Identify partnerships that will bolster action implementation and success
  - Identify preferences for access to plan information and its format
  - Provide input regarding overall satisfaction with identified conservation actions

2:15 Reconvene for beark-out group reports / Nate
- Taxa groups
  - Bird
  - Inland Fish and Mammals
  - Reptiles, Amphibians, and Invertebrates
  - Marine

2:45 Break: partner appreciation / Andy, Amanda, Nate

3:00 Programmatic conservation actions / Amanda, Nate

3:45 Discussion: a process outlining considerations to be used when prioritizing conservation actions for Maine's 2015 WAP / Phillip, Barbara Vickery

4:15 Next steps in the development of the 2015 action plan / Mark
- 1st draft
- Public comment period
- Respond to public comments
- Final draft
- Submit Maine's plan to USFWS for review

4:30 Continue partner involvement / Charlie
- Maine Wildlife Coalition / Teaming with Wildlife

4:45 Adjourn

Appendix 7/8-3. Frequently Asked Questions about Maine's 2015 Wildlife Action Plan.

1. What is the plan for?
2. Who wrote the plan?
3. Are you proposing new regulations?
4. Why is the plan so long?
5. How was the Species of Greatest Conservation Need (SGCN) list developed?
6. How are SGCN different from Threatened and Endangered (T/E) Species?
7. Where can I find the list of SGCN?
8. Don't some of these species already have management plans?
9. Where can I find information on what is affecting SGCN and their habitats ('stressors')?
10. Where do the stressor names come from?
11. Don't certain activities classified as 'stressors' sometimes benefit wildlife and habitats?
12. Where can I find information on the actions being proposed to prevent future species and habitat declines?
13. Who can I contact for more information on the draft plan?
14. When will the final plan be completed?
15. How can I get involved?

1. What is the plan for?

   Maine's 2015 Wildlife Action Plan is a shared vision for our state that identifies the voluntary steps needed to conserve priority wildlife species and habitats through public awareness and partnerships. The plan identifies Maine's Species of Greatest Conservation Need (SGCN), the habitats where SGCN are found, and the recommended 'conservation actions' to help prevent further declines in species and habitats over the next ten years. The 2015 plan also qualifies Maine to receive funds for wildlife conservation projects from the U.S. Fish and Wildlife Service (USFWS) under the State Wildlife Grant (SWG) program:
   http://wsfrprograms.fws.gov/Subpages/GrantPrograms/SWG/SWG.htm

2. Who wrote the plan?

   The Maine Department of Inland Fisheries and Wildlife (MDIFW), Maine Department of Marine Resources (DMR), and Maine Natural Areas Program (MNAP) wrote the plan with input from over 100 'conservation partner' groups representing many interests including private landowners, conservation organizations, sporting groups, scientists, and governmental agencies. The list of invited conservation partners begins on page 15 here:
   http://www.maine.gov/ifw/wildlife/reports/pdfs/2015MaineSWAP_Elements7and8_DRAFT.pdf

3. Are you proposing new regulations?

   No! Maine's 2015 Wildlife Action Plan is strictly non-regulatory. All conservation actions included in the plan are based on voluntary efforts.

4. Why is the plan so long?

   In order to be approved by USFWS, Wildlife Action Plans must address eight elements, described here beginning on page 4:
   http://www.maine.gov/ifw/wildlife/reports/pdfs/2015MaineSWAP_Introduction_DRAFT.pdf

   The 2015 plan provides a comprehensive proposal for how Maine will address each of these elements. We are required to post the entire plan for public review so that everyone has access to all the available plan information. Once the final plan is completed in Fall 2015, MDIFW and conservation partners will develop additional user-friendly ways to search and access plan information. Maine's 2015 plan is much shorter than the original 2005 plan, which was over 2000 pages long. For the 2015 plan, Maine eliminated many pages of text and condensed much of the SGCN, habitat, stressor, and conservation action information into tables.

5. How was the Species of Greatest Conservation Need (SGCN) list developed?

   MDIFW biologists, with review and cooperation from conservation partners and species experts, developed conservation criteria for designating Maine's eligible SGCN. For each species in Maine, MDIFW and partners reviewed the best available science to determine if the SGCN criteria were met. If so, the species was added to the list of SGCN at one of three priority levels (1=critical; 2=high; 3=moderate) depending on which and how many criteria were met. The primary themes for SGCN prioritization include risk of extirpation, population trend, endemicity, and regional conservation concerns. Secondary themes for SGCN prioritization include climate change vulnerability, survey knowledge, and indigenous cultural significance. Information on the SGCN criteria can be found here beginning on page 25:
   http://www.maine.gov/ifw/wildlife/reports/pdfs/2015MaineSWAP_Element1_DRAFT.pdf

6. How are SGCN different from Threatened and Endangered (T/E) Species?

   SGCN are different from T/E species in several ways. First, T/E species are eligible for regulation under the Maine and/or Federal Endangered Species Acts (ESA). Some activities that affect these species or habitats also are potentially regulated. In contrast, SGCN species are not regulated. Many state and federal T/E species also qualify for SGCN status; but, this designation does not add any additional regulations. There are many more SGCN than there are listed T/E species. For example, there are 51 T/E species listed under Maine's ESA, but there are 376 SGCN in Maine's 2015 Action Plan. By designating a species as SGCN now, we can take preventative steps to avoid the need for listing the species in the future under the State or Federal ESA.

7. Where can I find the list of SGCN?

   The list of SGCN begins on page 31 here:
   http://www.maine.gov/ifw/wildlife/reports/pdfs/2015MaineSWAP_Element1_DRAFT.pdf

   SGCN are organized by groups (e.g., birds, mammals, amphibians, etc.); click on each species to view a report that details how the species qualified as SGCN, associated habitats, distribution range in Maine, stressors affecting the species and its habitats, and conservation actions proposed to prevent future declines over the next ten years.

8. Don't some of these species already have management plans?

   Yes. The 2015 Wildlife Action Plan is not intended to replace existing management plans, but rather to provide additional resources for ongoing and new SGCN conservation efforts.

9. Where can I find information on what is affecting SGCN and their habitats ('stressors')?
   Information on SGCN and habitat stressors can be found here:
   http://www.maine.gov/ifw/wildlife/reports/pdfs/2015MaineSWAP_Element3_DRAFT.pdf

10. Where do the stressor names come from?

    As with most other states in the Northeast, we identified stressors using the International Union for the Conservation of Nature (IUCN) Threat Classification Scheme. This system provides standard terms that allow states to 'speak the same language' when describing common stressors. More information can be found here, beginning on page 4:
    http://www.maine.gov/ifw/wildlife/reports/pdfs/2015MaineSWAP_Element3_DRAFT.pdf

11. Don't certain activities classified as 'stressors' sometimes benefit wildlife and habitats?

    Yes, some 'stressors' may also have positive effects on wildlife and habitats. For example, aquaculture activities like shellfish seeding can help improve water quality and help form substrate for important habitats like eelgrass. Wood harvesting and agricultural activities can benefit certain SGCN by creating or maintaining wildlife habitat. We summarized some of these beneficial effects beginning on page 6 in Element 3:
    http://www.maine.gov/ifw/wildlife/reports/pdfs/2015MaineSWAP_Element3_DRAFT.pdf

12. Where can I find information on the actions being proposed to prevent future species and habitat declines?

    Information on conservation actions can be found here:
    http://www.maine.gov/ifw/wildlife/reports/pdfs/2015MaineSWAP_Element4_DRAFT.pdf

    This chapter also contains information on how MDIFW and conservation partners will prioritize and implement these actions over the next ten years.

13. Who can I contact for more information on the draft plan?

    For more information or to submit comments, please contact:

    Becky Orff at: becky.orff@maine.gov

    OR

    SWAP
    Wildlife Division
    Maine Dept. of Inland Fisheries and Wildlife
    284 State St. #41
    Augusta, ME 04333

Public comments will be accepted through August 12, 2015.

14. When will the final plan be completed?

    We must submit the plan to USFWS by October 1, 2015.

15. How can I get involved?

    Completing the 2015 plan is just the first step in the next ten years of wildlife conservation. The success of Maine's 2015 Action Plan relies on your participation and partnership. The plan presents actions ranging from local, SGCN-specific efforts to those with a more regional focus. We hope you will see a role for yourself or your organization in these actions.

    If you belong to one of the conservation partner organizations that participated in writing the 2015 plan (see page 15, http://www.maine.gov/ifw/wildlife/reports/pdfs/2015MaineSWAP_Elements7and8_DRAFT.pdf), you may wish to contact your local chapter or media representative for more information. You also may contact members of the MDIFW 2015 Action Plan Coordination Team at mainewildlifeactionplan@gmail.com.

    As the plan is implemented, we hope to provide ongoing workshops and informational sessions on accessing and using plan information. Please contact us (mainewildlifeactionplan@gmail.com) if your group is interested in having one of these sessions.

DIVERSITY, CONTINUITY AND RESILIENCE – THE ECOLOGICAL VALUES OF THE WESTERN MAINE MOUNTAINS

By Janet McMahon, M.S.



Occasional Paper No. 1

Maine Mountain Collaborative
P.O. Box A
Phillips, ME 04966

© 2016 Janet McMahon

Permission to publish and distribute has been granted by the author to the Maine Mountain Collaborative.

This paper is published by the Maine Mountain Collaborative as part of an ongoing series of informational papers. The information and views expressed in this paper are those of the author and do not necessarily reflect the views of the Maine Mountain Collaborative or its members.

Cover photo: Caribou Mountain by Paul VanDerWerf

https://www.flickr.com/photos/12357841@N02/9785036371/

https://creativecommons.org/licenses/by/2.0/

DIVERSITY, CONTINUITY AND RESILIENCE – THE ECOLOGICAL VALUES OF THE WESTERN MAINE MOUNTAINS



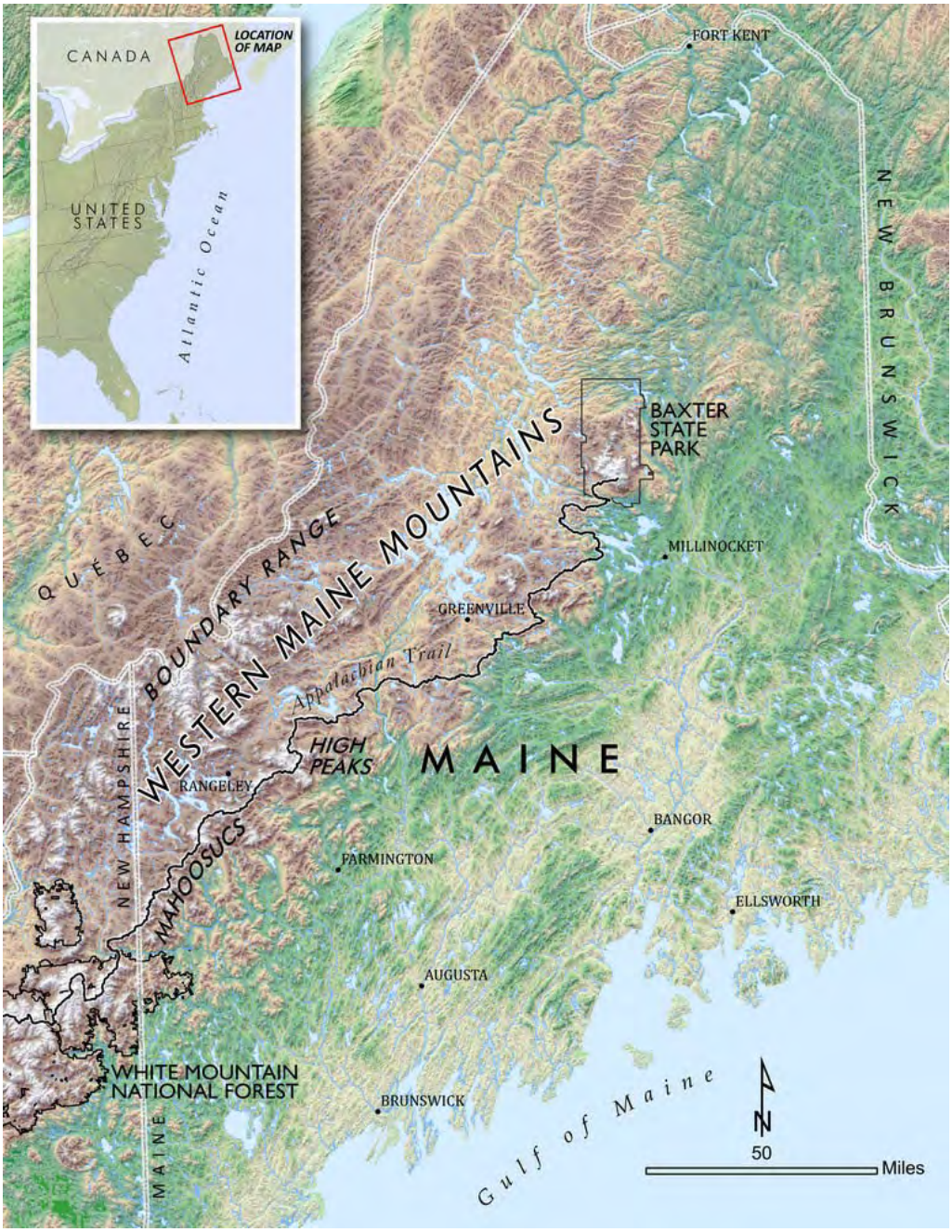
Dawn over Crocker and Redington Mountains *Photo courtesy of The Trust for Public Land, Jerry Monkman, EcoPhotography.com*

Abstract

The five million acre Western Maine Mountains region is a landscape of superlatives. It includes all of Maine's high peaks and contains a rich diversity of ecosystems, from alpine tundra and boreal forests to ribbed fens and floodplain hardwood forests. It is home to more than 139 rare plants and animals, including 21 globally rare species and many others that are found only in the northern Appalachians. It includes more than half of the United States' largest globally important bird area, which provides crucial habitat for 34 northern woodland songbird species. It provides core habitat for marten, lynx, loon, moose and a host of other iconic Maine animals. Its cold headwater streams and lakes comprise the last stronghold for wild brook trout in the eastern United States. Its unfragmented forests and complex topography make it a highly resilient landscape in the face of climate change. It lies at the heart of the Northern Appalachian/ Acadian Forest, which is the largest and most intact area of temperate forest in North America, and perhaps the world. Most importantly, the Western Maine Mountains region is the critical ecological link between the forests of the Adironcaks, Vermont and New Hampshire and northern Maine, New Brunswick and the Gaspé.

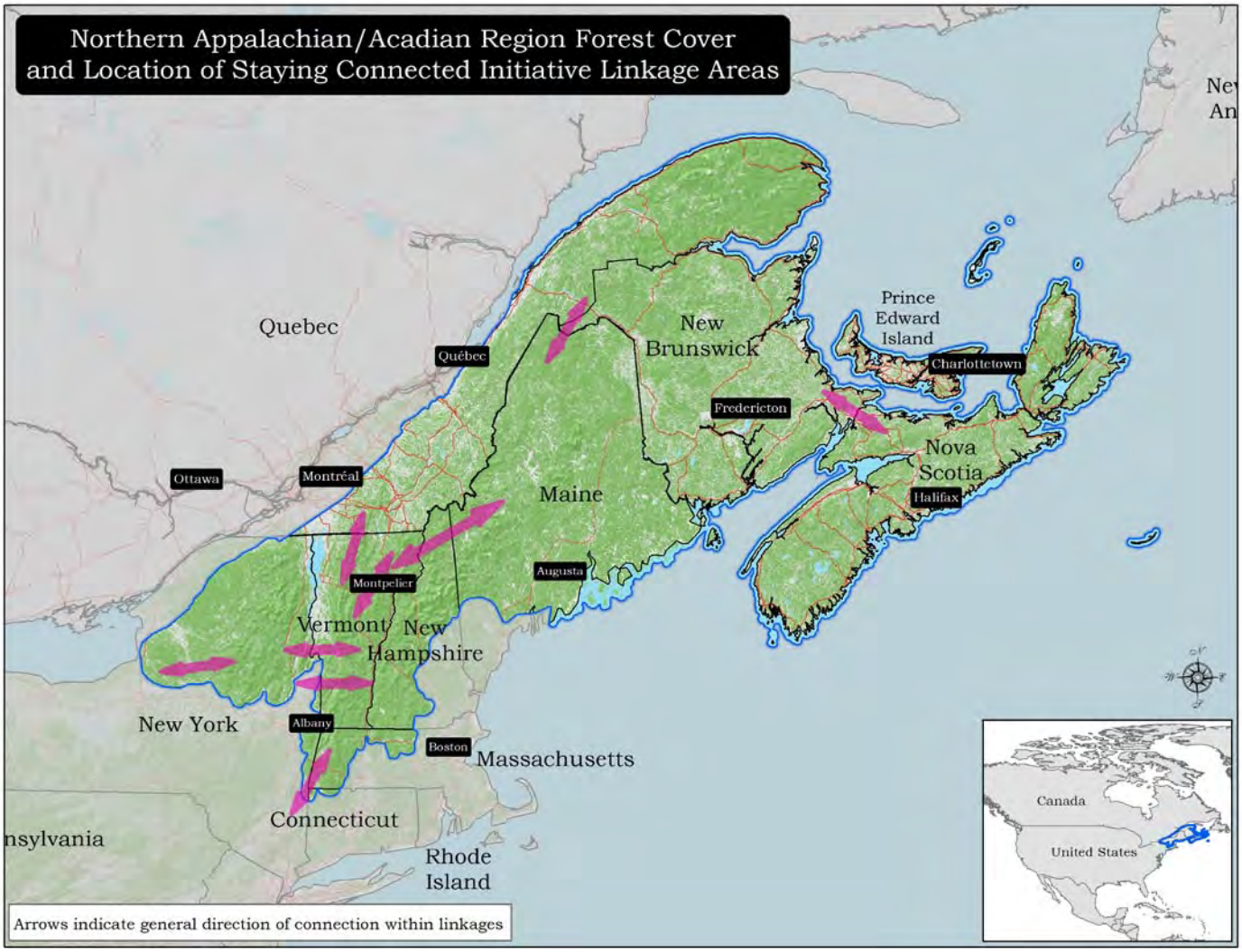
Introduction

In 1884, when Thoreau ascended Ktaadn, the Penobscot Nation's sacred "highest land," he was struck by the *"continuousness of the forest"* with *"no clearing, no house,"* uninterrupted except for *"the narrow intervals on the rivers, the bare tops of the high mountains, and the lakes and streams"* (Thoreau 1984). More than a century later, the view south and west from Mount Katahdin is much the same and, remarkably, with the exception of the wolf, cougar, and caribou which have been driven north and west, all of the animals Thoreau might have encountered more than a century ago still thrive in the Western Maine Mountains.



The Western Maine Mountains stretch in a broad band from the summits of the Katahdin group, southwesterly one hundred and sixty miles to Boundary Bald Mountain and the Mahoosuc Range on Maine's western border. In all, the region encompasses over five million acres. It is a landscape of superlatives. It includes all of Maine's high peaks. It contains a rich diversity of ecosystems, from alpine tundra and boreal forests to ribbed fens and floodplain hardwood forests. It is home to more than 139 rare plants and animals, including 21 globally rare species and many others that are found only in the northern Appalachians.

It includes more than half of the United States' largest globally significant bird area, which provides crucial habitat for 34 northern woodland songbird species. It provides core habitat for marten, lynx, loon, moose and a host of other iconic Maine animals. The region's abundant snowfall and cool summer rains feed hundreds of miles of cold clear headwater streams that are essential habitat for wild brook trout and other cold water species. Its unfragmented forests and complex topography make it a highly resilient landscape in



Credit: The Nature Conservancy

The Staying Connected Initiative, http://stayingconnectedinitiative.org, has identified critical linkages to maintain connectivity in the Northern Appalachian/Acadian Forest Ecoregion.

the face of climate change.[1] It lies at the heart of the Northern Appalachian/Acadian Forest Ecoregion,[2] which is the largest and most intact area of temperate forest in North America, and perhaps the world.[3] Within this vast forest, the Western Maine Mountains region is the critical ecological link between undeveloped lands to the north, south, east and west.

Northern Maine is the only place in the eastern United States where such a large area of contiguous land has remained continuously forested since pre-

The Western Maine Mountains region is a critical linkage in the Northern Appalachian/Acadian Forest Ecoregion, which is the largest and most intact area of temperate forest in North America, and perhaps the world.

1 Resilience is the capacity of an ecosystem to maintain or return to its essential composition, structure, and ecosystem function after disturbance (Holling 1973).

2 Ecoregions are large units of land with similar environmental conditions, especially landforms, geology and soils, which share a distinct assemblage of natural communities and species. The Northern Appalachian-Acadian Forest Ecoregion includes the mountainous regions and boreal hills and lowlands in Northern New England and Maritime Canada. The ecoregion includes the Adirondack Mountains, Tug Hill, the northern Green Mountains, the White Mountains, the Aroostook Hills, New Brunswick Hills, the Fundy coastal section, the Gaspé peninsula and all of New Brunswick, Nova Scotia and Prince Edward Island (Anderson et al. 2006).

3 Based on Riitters et al. (2000) and the author's analysis of Google Earth imagery. Other northern temperate forests at the same latitude have lower species diversity (Scandinavia) and are more fragmented (Europe, eastern Asia) than the forests of the Northern Appalachian/Acadian Forest Ecoregion.

settlement times (Barton et al. 2012). This is in large part because of the timber value and resilience of its vast forests, most of which have been in private ownership and actively managed for more than two centuries. Many of the ecological values of the Western Maine Mountains region remain because of this fact.

The following pages summarize the region's key ecological values, which include:

- High landscape diversity
- A high diversity of northern species and ecosystems
- More than five million acres of contiguous forest that lie at the heart of the largest intact temperate forest in the United States
- Some of the country's least disturbed forests
- A globally important bird area
- A U.S. stronghold for wild populations of brook trout
- Vital habitat for focal carnivore species such as lynx and marten
- An exceptionally resilient landscape today and predicted high resilience in the face of climate change
- A critical ecological link between the boreal and temperate forest biomes
- An important role in buffering and regulating global, regional and local climates

The region's latitudinal position, mountain topography, forest contiguity, and Atlantic influence are unique at a continental scale.

The Western Maine Mountains lie near the northern terminus of the Appalachian Mountains and include some of the chain's most rugged terrain. The western part of the region includes the Boundary Mountains to the north and the Longfellow Mountains to the south. These two mountain ranges are separated by a series of large lakes, including Umbagog, Upper and Lower Richardson, Rangeley and Flagstaff. To the north and east are the mountains and foothills of the Katahdin group as well as the highlands surrounding Moosehead and Chesuncook Lakes. The region has the greatest topographic relief in the state. Its eastern boundary roughly follows the 1,000 foot contour, but elevations range from 600 to 5,270 feet. The region includes Maine's fourteen peaks taller than 4,000 feet as well as all of the state's high elevation habitat.[4]

The region's climate is influenced by its latitude and weather systems that originate in both the Atlantic and the Arctic. It is characterized by cool summers, harsh winters, a short growing season and the highest snowfalls in Maine, which average 120 inches in a typical winter. Annual precipitation is about 40 inches, although some of the higher mountains produce a rain shadow effect, with precipitation as high as 50 inches on windward slopes and less than 35 inches to leeward (McMahon 1990; Lautzenheiser 1978). Thoreau called the land above tree line a *"cloud-factory–these were the cloud works, and the wind turned them off done from the cool, bare rocks"* (Thoreau 1884). The mountainous landscape is dissected by hundreds of cold, fast-flowing streams, which form the headwaters of four of Maine's major rivers, the Penobscot, Kennebec, Androscoggin and Allagash.

Because of their latitude, mountainous topography, continuous forest and Atlantic influence, Maine's Western Mountains are unique at a continental scale and are home to a diversity of rare species and ecosystems.

The region's latitudinal position, mountain topography, forest contiguity, and Atlantic influence are unique at a continental scale (McKinley 2007). And because species diversity is highly correlated with geophysical diversity in the eastern United States (Anderson and Ferree 2010), the Western Maine Mountains are home to a surprising diversity of both widespread and rare species and ecosystems.

4 The high elevation threshold in Maine is 2,700 feet. Subalpine and alpine habitats are typical above this point. About three percent or 139,222 acres of the region is classified as high elevation (Publicover and Kimball 2012).

The ecological diversity of the Western Maine Mountains is significant at multiple scales, ranging from state to continental.

On a summer day, the view from any mountain in the region is of seemingly endless forest, darker greens of spruce and fir on upper and northerly slopes, lighter greens of northern hardwoods on lower and southerly slopes. A closer look reveals a much more complicated picture. In fact, the Western Maine Mountains harbor the largest concentrations of high value ecosystems and natural features in the state (McKinley 2007; McCollough et al. 2003). The region's rich animal diversity ranges from large mammals, such as lynx and moose, to the rare Bicknell's thrush to bog lemmings and endemic[5] mayflies. This diversity is due to a combination of the region's location within the transition zone between the boreal forest biome to the north and the eastern deciduous forest biome to the south (Delcourt and Delcourt 2000), its complex topography, the continuity of the landscape, and the inherent diversity of forests, with their complex vertical structure, which provides habitat for a multitude of plants and animals. For example, of the 55 mammal species documented in Maine, at least 51 occur in the Western Maine Mountains (DeGraaf and Yamasaki 2001). Only the New England cottontail, the woodland vole, the Virginia opossum, a relative newcomer to Maine, and possibly the southern flying squirrel are absent. The region also retains all of the tree species that were here during presettlement times, including the thirty commercial species that are harvested today, as well as at least 41 of the 48 forest community types that occur in Maine.[6]

The rich ecological diversity of the Western Maine Mountains ranges from large mammals, such as lynx and moose, to the rare Bicknell's thrush to bog lemmings and endemic mayflies. This diversity is due to the region's location within the transition zone between the boreal forest biome to the north and the eastern deciduous forest biome to the south, its complex topography, the continuity of the landscape, and the inherent diversity of forests, with their complex vertical structure, which provides habitat for a multitude of plants and animals.

The most distinctive suite of species in the Western Maine Mountains occurs at high elevations—above tree line and in the subalpine fir forests just below. The globally rare boreal and tundra communities that occur here are among the most pristine areas in the Northern Appalachian-Acadian Forest and are classified as rare in all four northeastern states (Publicover and Kimball 2012). They cover about three percent of the Western Maine Mountains region, but contain a disproportionate number of rare species. Maine's alpine communities are remnant biogeographic islands from the last glacial period (Seidel et al. 2009), and as a result contain many local and regional endemics. The species names tell the story: Aleutian maidenhair fern, tundra dwarf birch, alpine azalea, Alaskan clubmoss, Arctic red fescue, Lapland rosebay, northern bog lemming, White Mountain tiger beetle, Katahdin Arctic butterfly. Maine's mountains include some of the lowest elevation alpine areas at similar or more northern latitudes anywhere in the world (Seidel et al. 2009). Mount Katahdin alone has nineteen rare alpine plant species that are found nowhere else in Maine (Maine Beginning with Habitat Program).

The globally rare boreal and tundra communities that occur here are among the most pristine areas in the Northern Appalachian-Acadian Forest.

Between tree line and an elevation of about 2,700 feet are extensive subalpine fir forests. This rare forest type provides nesting habitat for high elevation and coniferous forest specialist birds, such as spruce grouse, dark-eyed junco, bay-breasted warbler, blackbacked woodpecker, white-throated sparrow, blackpoll warbler, and the elusive Bicknell's thrush, a state endangered species that breeds only in subalpine forests and krummholz in the northern Appalachians (Maine Beginning with Habitat Program). In all, more than 52 upland rare plant species and 9 rare animals species have been documented on Maine's mountain tops.[7]

5 Endemic species are those that are found only in a defined geographic area, such as the Katahdin Arctic butterfly, which is found only on Mount Katahdin.

6 Determined from distribution maps in Gawler and Cutko (2010).

7 Estimated from descriptions and maps of the Ecological Focus Areas that occur in the Maine Mountain Collaborative study area.

The natural diversity of the Western Maine Mountains goes far beyond the species and communities found at higher elevations. The Maine Natural Areas Program and Department of Inland Fisheries and Wildlife have identified 20 landscape-scale focus areas of statewide ecological significance in the region. These focus areas encompass nearly 762,000 acres or about 13% of the region's land area. The relatively intact unfragmented landscapes of these focus areas have a high concentration of rare species and high quality natural communities, ecosystems, and wildlife habitats. These are the 'biodiversity hot spots' of the region. A small sample of some of the biological gems in these focus areas showcases the rich diversity of the Western Maine Mountains.

- Between the Moose River and Attean Pond is No. 5 Bog, a 1400+ acre peatland that is one of the largest, most diverse, and least disturbed peatlands in the eastern United States. It contains the southernmost example of a ribbed fen in North America and is considered nationally significant.
- Wild brook trout populations, which have never been genetically modified by stocking, thrive in the cold high elevation streams and lakes of the Western Maine Mountains, where entire watersheds are unimpeded by dams and culverts. Cold Stream in West Forks Plantation, Orbeton Stream in Redington Township, and Wassataquoik Stream, which flows out of Baxter State Park are just a few of the many pristine examples in the region.
- An outstanding 3,000+ acre Appalachian–Acadian Rivershore ecosystem along the lower Wassataquoik and the East Branch of the Penobscot River contains one of the least disturbed and most extensive hardwood floodplains in the state.
- The Klondike, located in the basin just west of the Tablelands on Mount Katahdin, is Maine's largest and most intact example of a black spruce bog.
- The highest concentration of pristine, remote ponds in New England occurs in the Nahmakanta area. Among its dozens of lakes and ponds, Third Debsconeag Lake, Rainbow Lake and Nahmakanta Lake are the largest and most well-known.
- The beech-birch-maple forest southwest of Speckled Mountain is one of the largest and best examples known in the White Mountains, with trees over 150 years old.
- Millinocket Lake Wetlands and West Branch Flowage chain of lakes and wetlands provide habitat for wild brook trout, the state's northernmost populations of the globally rare tidewater mucket and yellow lampmussel, and breeding habitat for the rusty blackbird, a special concern species that breeds in northernmost New England, Canada, and Alaska.
- The calcium-rich soils of the Twin Peaks area support enriched hardwood cove forests and some of Maine's rarest plant species, including Goldies fern, male fern silvery spleenwort, squirrel corn, and a host of others.
- The region's many cold, clear streams and ponds provide some of the state's best habitat for spring salamanders, wood turtles, freshwater mussels, and dozens of rare aquatic insect species, including at least three globally rare boreal species—the Katahdin Arctic butterfly, the Roaring Brook mayfly and the White Mountains tiger beetle.
- Big and Little Moose Mountains boast two exemplary spruce-fir-northern hardwoods ecosystems, one surrounding Big and Little Moose Ponds, and the other on the northern peak of Big Moose Mountain. Both examples are intact, mature forests that include a variety of hardwood and softwood community types.

- Six of Maine's twelve arctic charr populations occur in the Western Maine Mountains. This species thrives in Bald Mountain Pond and other cold clear ponds in the region. Maine and Alaska are the only states in the country with native populations of this species.
- The Lake Umbagog Wetlands focus area supports breeding pairs of peregrine falcons and bald eagles, and historically provided habitat for nesting golden eagles. Peregrines and golden eagles prefer to nest on rugged cliff faces. The majority of documented peregrine nest sites in Maine are in the Western Mountains, and this is the only region in the eastern United States with year round activity by golden eagles, Maine's rarest breeding bird (Morneau et al. 2015; Charlie Todd, personal communication).

The region lies within the largest and most contiguous forested landscape in the eastern United States.

On satellite images taken of North America at night, northern Maine stands out because of its darkness. The Western Maine Mountains lie at the heart of the 26 million acre Northern Appalachian/Acadian Forest, which spans four states and five Canadian provinces. This ecoregion contains the broadest extent of nearly contiguous natural forest east of the Rockies (Anderson et al. 2012; Anderson 2006) and is the only extensive region of interior temperate forest at middle latitudes worldwide (Riitters et al. 2000). Western and northern Maine are the least developed portions of the ecoregion—with few settlements, no large areas of cleared lands, few paved roads, and some of the region's largest unfragmented forested blocks. Less than two percent (~100,000 acres) of the Western Maine Mountains has been converted to date, compared to 28% of the Northeast as a whole (Publicover, personal communication 2016; Anderson and Sheldon 2011). Baldwin, et al. (2007) described Maine's forests as the ecological core of the Northern Appalachian-Acadian forest, important because of their extent, relatively light human footprint, and because they link the forests of the Northeast to those of the Canadian Maritimes. Within the Northern Appalachian-Acadian Forest, the Western Maine Mountains region provides the key link between the unfragmented forests to the west in northern New Hampshire and Vermont and the vast north woods of Maine.

> The Western Maine Mountains lie at the heart of the Northern Appalachian/Acadian Forest, which is the only extensive region of interior temperate forest at middle latitudes worldwide.

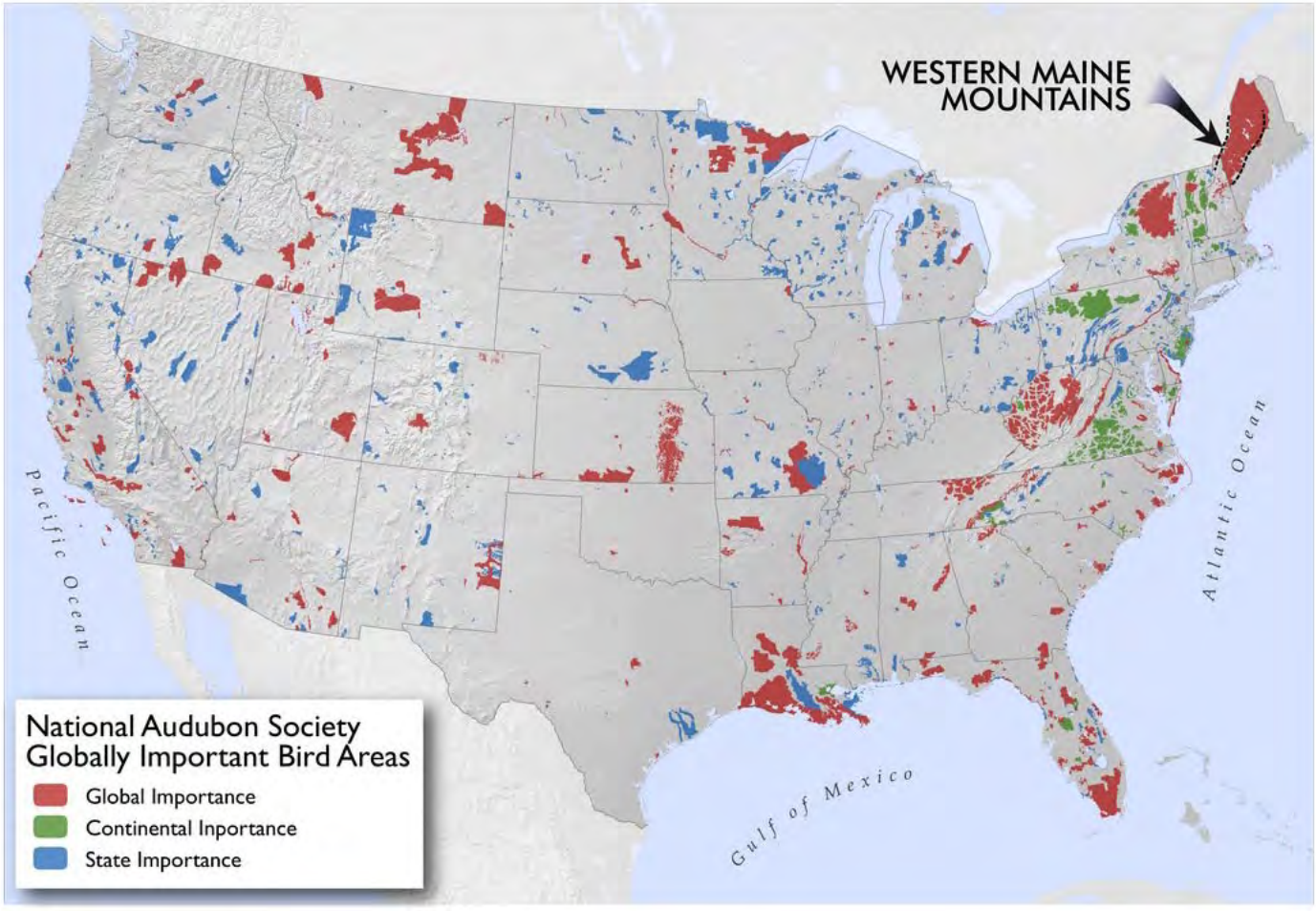
The Western Maine Mountains region includes some of the least disturbed forest landscapes east of the Mississippi.

As noted above, the Northern Appalachian-Acadian Forest is the most intact unfragmented ecoregion east of the Mississippi. In addition, the forests, wetlands and riverine ecosystems of the Western Maine Mountains have experienced less human disturbance than lands to the south, northwest and east. Although the region has a long harvest history, because of its mountainous terrain and short growing season, settlements are few, most of the land was never cleared, plowed or drained for farming, and there are many large blocks of land that have not been fragmented by roads or development. Unlike most of New England, soils here have never been plowed and, as a result, are more likely to have an intact organic soil horizon with native fauna and flora, including native rather than introduced earthworms. Earthworms can have a dramatic effect on nutrient cycling, particularly in northern hardwood forests, where the species composition and richness of the herbaceous layer change markedly after nonnative earthworm invasions (Hopfensperger et al. 2011; Frelich et al. 2006; Burtelow et al. 1998). Invasive plants, which thrive on disturbed soils, have not gained a foothold in the region. In the U.S. Forest Service's 2008 inventory of Maine's forests, the Western Maine Mountains,

upper Saint John Valley and Washington County were the only places where invasive plant populations were not documented (McCaskell et al. 2008). In addition, the region's forests have not experienced overbrowsing by white-tailed deer, which are beginning to impact the ecology of forests to the south (Russell et al. 2001). Finally, compared to New Brunswick, there has been less stand conversion from one forest type to another and plantation forestry is rare (McCaskell et al. 2008). While forest practices have led to a forest that is more homogeneous and has a simpler structure than in presettlement times, all of the region's tree taxa still remain (Thompson et al. 2013). In short, the forests of the region demonstrate a huge natural capacity for renewal.

The Western Maine Mountains region includes more than half of the country's largest Globally Important Bird Area.

Intact forests are critical to the future of most forest birds (National Audubon Society 2015). Maine includes the largest forest blocks in the entire Eastern Atlantic Flyway, which is the major migratory route for hundreds of neotropical bird species, including most of the songbirds familiar to New Englanders. In 2012, National Audubon set out to identify a network of forest blocks that collectively include the best 10 to 25% of forest in the flyway. The "northern Maine forest block" was identified as a Globally Important Bird Area by National Audubon Society and Birdlife International (National Audubon Society 2012). The Western Maine Mountains region makes up more than half of this block and bridges the two avifaunal biomes of the flyway—the Eastern Deciduous Forest Biome and the Northern Forest Biome. The global designation was given because of the area's high bird richness and abundance as well as the extent and intactness of its forest, and is grounded in research that shows that breeding birds are more successful on larger blocks



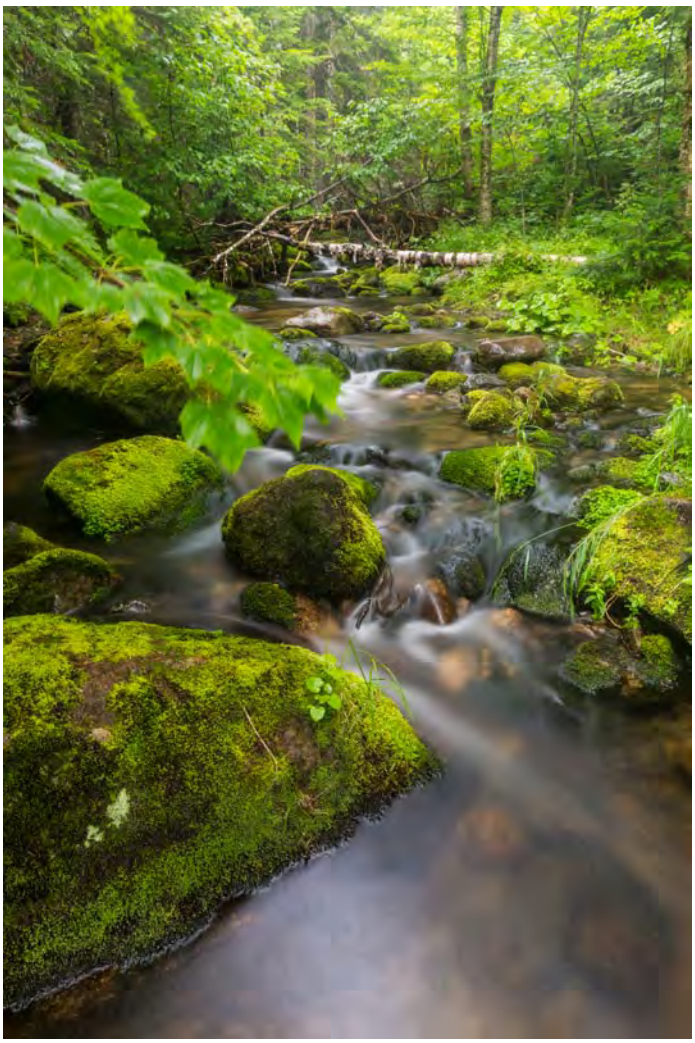
Maine includes the largest Globally Important Bird Area in the US, because if its large intact forests within in the Eastern Atlantic Flyway, the major migratory route for hundreds of neotropical bird species.

(John Guarnaccia, personal communication 2016; Nieme et al. 1998). It is the largest globally important bird area in the United States and is considered vital habitat for 34 priority songbird species whose global breeding distribution is restricted to the northern forest biome[8] (National Audubon Society 2012). The Western Maine Mountains region is a key part of what Maine Audubon biologist Sally Stockwell calls a *"baby bird factory."* Stockwell considers conservation of the forests of the region essential to the future of many of our most cherished bird species.

Northern Maine is the last stronghold for wild brook trout in the eastern United States. Nearly three quarters of the state's wild brook trout waters occur in the Western Maine Mountains.

Northwestern Maine is the last stronghold for wild brook trout[9] in the eastern United States (Whitman et al. 2013a; DeGraaf 2014), supporting 97% of its intact lake and pond wild trout populations. The highest concentration (about 73%) of wild brook trout lakes occurs in the Western Maine Mountains and many more lakes are dependent on the region's snowpack, which provides the clean, cool, well-oxygenated water and the narrow range of water temperatures trout and other cold water species need to survive (Bonney 2009; The Nature Conservancy 2008). In addition, the region's high elevation streams have more intact riparian habitat and are less fragmented by dams and other barriers than elsewhere in New England (Whitman et al. 2013; Anderson and Sheldon 2011). Five of these: the Magalloway, Kennebago, Moose, and East and West Branches of the Penobscot have been identified as particularly important for conservation by The Nature Conservancy because they are long connected stream networks with unaltered water flow and intact forested riparian areas (Anderson and Sheldon 2011).

The region's mountainous landscape is critically important to cold water stream and lake ecosystems, playing a particularly important role in maintaining the flow and high water quality required by brook trout, lake trout, whitefish, spring salamanders, and a variety of aquatic insects.



Perham Stream

Photo courtesy of The Trust for Public Land, Jerry Monkman, EcoPhotography.com

8 Biome-restricted species are those with at least 80% of their population concentrated within one avifaunal biome (US IBA Committee).

9 This number includes heritage brook trout ponds which have never been stocked and wild brook trout ponds, which were historically stocked but are now self-sustaining.

Mountainous landscapes play a particularly important role in maintaining the flow regimes and high water quality required by brook trout, lake trout, whitefish, spring salamanders, and a variety of aquatic insects. On average, the mountains of western and central Maine receive twice the annual snowfall of southern and midcoastal regions (Fernandez et al. 2015; Lautzenheiser, R.E. 1978). These mountains capture, store, purify and gradually release water stored in ice, snow, soils and vegetation into the headwater streams of the Penobscot, Kennebec, Androscoggin, and Allagash Rivers and into groundwater aquifers downstream. Three of the state's prized fish species—lake trout, brook trout, and whitefish—and many other cold water fish and invertebrates depend on this influx of cold water to survive. As the climate warms, snowfall in the mountains is expected to decline at a much lower rate than along the coast (less than 20% versus more than 40% along the coast) and will be all the more important in regulating river flow and maintaining water temperature and supplies in the state (Fernandez et al. 2015). Maine's mountains are and will continue to be critically important to cold water stream and lake ecosystems.

The Western Mountains Region and lands to the north provide the greatest remaining opportunity in eastern North America for maintaining lynx and marten populations, and reestablishing viable populations of the eastern gray wolf.

Nearly one quarter of all designated critical habitat for lynx, a federally threatened species in the United States (Simmons-Legaard et al. 2013) occurs in Maine. The Western Maine Mountains include more than half of this core habitat as well as core habitat for marten. Both lynx and marten are wide-ranging species that reach their southern range limits in the region (Laliberte and Ripple 2004) and, along with the eastern gray wolf, are considered important focal species for biodiversity conservation in the greater Northern Appalachians (Reining et al. 2006). Focal species play a critical ecological role that is of greater importance than we would predict from their abundance. They are wide ranging, so conserving their habitat would provide a protection umbrella for other species with similar requirements; they are sensitive to habitat quality, such as changes in climate; and they are charismatic (Trombulak et al. 2008). In short, if enough habitat is maintained to



Canada lynx

Maintaining habitat requirements for lynx and marten will also maintain the requirements of more than 85% of 110 other vertebrate species.

support viable populations of these species, many other species will also be conserved (Trombulak et al. 2008). Hepinstall and Harrison (in preparation) found that the habitat requirements for lynx and marten encompass the requirements of more than 85% of the 111 forest generalist, deciduous forest specialist, and coniferous forest specialist vertebrate species that occur in northern Maine.



Marten

Lynx and marten are also important because their populations represent "peninsular extensions" of their boreal ranges (Carroll 2005). As a result, they are likely to be particularly sensitive to climate change—especially to changes in snowfall—and they represent unique ecotypes at the southern limit of their range (Carroll 2005; Reining et al. 2006). Models developed by Carroll (2007) and others indicate that the Western Maine Mountains region is likely to be of critical importance to the future of northeastern lynx and marten populations, since their ranges are expected to contract to the north and to higher elevations as the climate warms. The Western Maine Mountains region already serves as a north-south and east-west link between peripheral populations in the White Mountains and those in northeastern Maine and the Gaspé (Carroll 2007). Both species have used this link to recolonize New Hampshire (Daniel Harrison, personal communication). While the forests of the region currently support lynx and marten, recent research suggests that harvest practices on two thirds of Maine's commercial forestland are creating habitat that no longer serves the needs of these umbrella species, and many others, which may lead to population declines in the future (Simmons-Legaard et al. 2013; Fuller and Harrison 2005; Homyack et al. 2010). Lynx thrive in the young dense spruce-fir forests that regenerate after clearcutting, which provide ideal habitat for snowshoe hare, the lynx's principle prey. Over the past several decades, there has been a broad-scale decline of early-successional habitat and in the spruce-fir forest type overall (Simons-Legard et al. 2016).

Although breeding populations of a third focal species—the grey wolf—have not yet been documented in Maine, there are many reports of wolves along the region's western border. The Western Maine Mountains, along with much of northern and central Maine, is considered potential habitat for this wide-ranging carnivore (Laliberte and Ripple 2004). A number of organizations in Maine and elsewhere are working on recovery efforts for this federally endangered species.

The Western Maine Mountains region is poised to serve as a critical ecological linkage between the temperate and boreal forest biomes.

According to Whitman and others (2013b), the composition of nearly every plant community and wildlife habitat in Maine is likely to be affected by climate change (Jacobson et al. 2009). Although there is uncertainty about how individual species' ranges will respond to various climate change scenarios, most species will likely shift north and/or upwards in elevation. Maintaining a connected landscape is the most widely cited strategy

in the scientific literature for building resilience in the face of climate change (Anderson et al. 2012; Heller and Zavaleta 2009). The Western Maine Mountains region is the critical ecological link between the forests of northern Maine, New Brunswick and the Gaspé and the forests of New Hampshire, Vermont and the Adirondacks, as well as smaller forested areas to the south.

Within the northeastern United States, the Western Maine Mountains region is already considered a priority linkage for species such as lynx, marten and moose, because it contains a "highly concentrated east-west regional flow pattern" which connects resilient landscapes to the west and south to those in northern Maine (Anderson et al. 2012). This large-scale directional flow occurs here because the Western Maine Mountains region is sandwiched between the agricultural lands of the St. Lawrence Valley and developed lands in Vermont, New Hampshire and southern and coastal Maine.

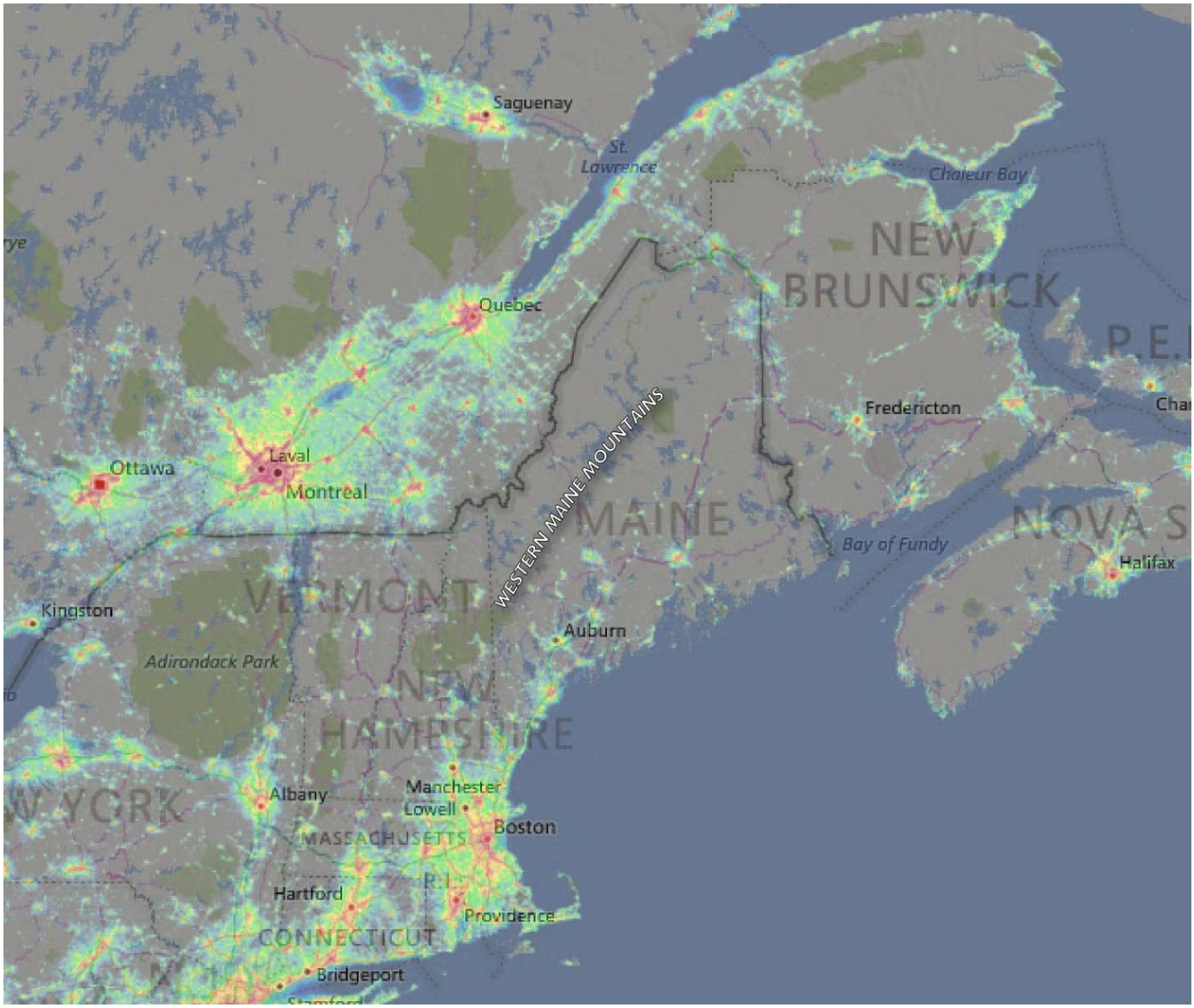


Image from Jurij Stare, www.lightpollutionmap.info, based on original data sourced from Earth Observation Group, NOAA National Geophysical Data Center. Western Maine Mountain text added.

This satellite image of the night sky illustrates the critical position of the Western Maine Mountains region as a link connecting the unfragmented forests in the Adirondacks, Vermont and New Hampshire to Maine's north woods and the forests of Canada, a connection critical to the entire Northern Appalachian-Acadian Forest Ecoregion.

The Wildlands Project has identified four 'megalinkages' that, if implemented, would tie North American ecosystems together to conserve and benefit native species in their current and projected natural patterns of range and abundance (Reining et al. 2006). The Western Mountains Region is a key part of the Atlantic Megalinkage, which extends from Florida to New Brunswick, mostly along the Appalachians. The megalink includes two core areas in Maine, both of which occur in the region—one centered around the Baxter region, the other around the Boundary Mountains and upper Androscoggin watershed. The Wildlands network highlights the great importance of northern Maine and the Gaspé Peninsula for long-term conservation in the Northern Appalachian region, not only for focal species like lynx, marten and (potentially) wolf, but also as the remaining places where large new wildlands could be established (Reining et al 2006).

The region's value as an ecological link would be greatly enhanced by connecting it to the boreal forest north of the St. Lawrence River through the remaining intact forest blocks in adjacent Quebec. Creating a more permeable and connected landscape would be an extremely ambitious project that would require regeneration of existing farmland to forestland and identifying potential corridors across major highways. Many studies have identified the Western Maine Mountains region as a key part of such a linkage (One Country Two Forests, National Audubon Society, Wildlands Project, The Nature Conservancy, Adirondack to Acadia, Boreal Songbird Initiative, Staying Connected). Over time, such a link could potentially enhance some of the other key ecological values of the Western Maine Mountains, for example, by connecting and expanding potential habitat for wide-ranging carnivores and breeding songbirds.

Maine's most extensive older forests are found in the Western Maine Mountains.

Next to conversion of forest to some other land use, the loss of older forest age classes is a major threat to forest biodiversity worldwide (Hagan and Whitman 2004). Older forests of the temperate and boreal zones contain exceptional forest structure including large trees, large snags, large logs, large volumes of dead wood, and vertical structural diversity not found in younger forests (Whitman and Hagan 2007)[10]. In the United States, late-successional stands (those older than 100 years) now constitute less than 4% of forested areas (Ryan et al. 2010). In Maine, late successional forests cover somewhere between 3 and 6% of the state, and their extent continues to decline (Maine Department of Inland Fisheries and Wildlife 2015; Hagan and Whitman 2004). In Finland, where old forests comprise less than 0.5% of all forested areas, extinction-vulnerable old forest species now number more than 1,000 (Hanski 2000), and an estimated 5% of Finland's forest species are predicted to go extinct in the next 50 years (Hagan and Whitman 2004). Much of Maine's older forest is in the Western Maine Mountains at high elevations, in the Baxter area, in the White Mountains and in other ecological focus areas in the region. These areas are important for species such as marten, many woodland raptors and songbirds, mosses, lichens and other species that depend on mature interior forest, large cavity trees, downed wood, and the large number of forest niches present. Hagan and Whitman (2004) suggest that we may be accruing 'extinction debt' in Maine's forests. They describe the process as follows:

> *"Once old forest elements such as large trees or logs are lost from a stand (e.g., as a result of a clearcut, or even a selection cut), it can take centuries for the species to return to that location. A species first has to wait for these structural features to redevelop, and then the species has to find them. Scientists are beginning to understand that forest continuity is key to many forest species. Continuity refers to the persistence of big trees and big logs in a forest stand over a very long period of time (centuries), even though the stand might be subjected to many different disturbances, such as fire, wind, disease, or even selection logging. Species that move or disperse slowly through the landscape, and prefer large old trees or logs, are the species most at risk to the loss older forests."*[11]

10 Most forests in Maine are under 75 years in age. Pathological maturity—the age at which trees begin to suffer serious decay—is 150 years or older, depending on the species (Thompson et al. 2013).

11 These tend to be small and uncharismatic, such as insects, lichens, fungi, and mosses.

Although forest cover has remained relatively stable in Maine, the loss of older forest age classes from the vast Northern Appalachian-Acadian forest could be leading us down a biodiversity path that has already begun to unfold in Scandinavia (Hagan and Whitman 2004). The late successional forests that remain in the Western Maine Mountains are critically important, especially those that are large enough to protect source populations of plants and animals that may disperse to surrounding forests as they mature (Baldwin et al 2007).

Much of Maine's older forest is in the Western Maine Mountains at high elevations. These areas are important for species such as marten, many woodland raptors and songbirds, mosses, lichens and other species that depend on mature interior forest, large cavity trees, downed wood, and the large number of forest niches present in older forests.

The Western Maine Mountains region is expected to be a highly resilient landscape in the face of climate change.

Ecologist Aldo Leopold captured the concept of ecological resilience in two elegant statements (Anderson et al. 2012): "*Health is the capacity of the land for self-renewal. Conservation is our effort to understand and preserve this capacity*" (Leopold 1949). Climate change is expected to alter the distribution of Maine's flora and fauna. The process is well underway—we are already experiencing the northward migration of northern cardinals, Virginia opossums, deer ticks, northern shrimp, and a host of other species. Conservationists are urgently working on strategies that will conserve the maximum amount of biological diversity as species ranges shift.

The Nature Conservancy is at the forefront of developing the science to guide these efforts. Their approach is based on three observations. First, that species diversity is highly correlated with landscape diversity in the Northeast and Mid-Atlantic; second, that species take advantage of microclimates and microhabitats available in complex landscapes, and finally, that species can move to adjust to climatic changes if these landscapes are permeable[12] and connected (Anderson et al. 2012; Anderson et al. 2013). Anderson and others hypothesized that sites with a large variety of landforms and long elevation gradients will retain more species even as the climate changes by offering ample microclimates and thus more options for rearrangement. They then mapped key geophysical settings and land use patterns to identify the most resilient places in the landscape—the places most likely to be natural strongholds for species and nature into the future.

The Western Maine Mountains region is expected to be an important natural stronghold for biodiversity because of its elevation range and varied landforms (e.g., cool ravines, warm southern slopes, cold streams, wind-swept summits) as well as its high landscape connectivity. The region is considered very permeable—its relatively unfragmented landscapes allow the continuous flow of natural processes, including not only the dispersal and recruitment of plants and animals, but the rearrangement of existing communities. (Anderson et al. 2012). These characteristics should help buffer climate change effects and allow for directional range shifts, north-south and east-west migrations, and upslope dispersal (Anderson et al. 2012; Anderson et al. 2015).

The Western Maine Mountains region is expected to be an important natural stronghold for biodiversity because of its elevation range and varied landforms (e.g., cool ravines, warm southern slopes, cold streams, wind-swept summits) as well as its high landscape connectivity.

Mountain tops may be particularly important to the region's biodiversity, at least in the short term. Research suggests that, although the areal extent of high elevation habitat is expected to decline as temperatures rise (Whitman et al. 2013a; Beckage et al. 2008), subalpine and alpine community composition may be relatively stable because their distribution is thought to be more closely tied to icing and the low cloud ceiling typical of higher elevations rather than temperature (Spear 1989; Kimball et al. 2014; Randin et al. 2008). Mid and high

12 Landscape permeability indicates the number of barriers and degree of fragmentation within a landscape. A permeable landscape allows for range shifts and reorganization of communities.

elevation micorefugia[13] are likely to be critical for the survival of many species in the future, especially alpine flora and fauna and species that thrive where snowfall is high, such as lynx, marten, snowshoe hair and moose (Carroll 2005).

The Western Maine Mountains play an important role in regulating local, regional, and global climate.

A walk through the woods on a mid-summer day gives a sense of how forests at our latitude influence local and regional climate. Forests are likely to be much cooler and more humid than more open habitat types. This is in part because precipitation often exceeds evapotranspiration rates in forests. In addition, tree canopies are rougher than cleared or developed land, which decreases wind speed and water loss from evaporation. As a result, temperate forests are typically sources of surface water (Sun and Liu 2013). For example, it is estimated that over 60% of our water supply comes from forest lands in the United States (Brown et al. 2008). Forest soils are regarded as 'sponges' because their deep extensive root systems and layer of leaf litter on the forest floor soak up water. For this reason, soil erosion is rare in forests—they provide the best water quality among all land uses. Forests also affect microclimate by altering solar radiation and how rain and snow fall through large forest canopies (Lee 1981) and by keeping streams cool in summer.

The Western Maine Mountains region also plays a role in moderating climate at the global level. The mountain snowpack that accumulates in winter helps regulate the earth's climate by reflecting solar radiation that would otherwise be absorbed by a darker surface and reradiated as heat into the atmosphere. This phenomenon is known as the albedo effect. More importantly, because trees are tall and long-lived, they sequester a great deal of carbon. In most forests, 95% of the biomass is in woody tissue—boles, limbs and roots (Hunter 1990; Packham and Harding 1982). Soils also sequester carbon and, because decomposition is slow in the cool damp forests of northern and western Maine, these areas serve as a carbon sink. It is estimated that the world's forests store 45% of terrestrial carbon and that they have the potential to absorb almost half of global annual carbon dioxide emissions (Pan et al. 2011). In addition, research suggests that older forests sequester more carbon than younger ones (Kauppi et al. 2015; Stevenson et al. 2014; Birdsey 1992), making the older forests that exist at high elevations, in the Baxter area and in other ecological focus areas of the Western Maine Mountain region that much more important. A shift to sustainable forest management for long-lived wood products that can be used in place of energy intensive construction materials such as cement and steel has great potential to further reduce fossil fuel emissions (Oliver et al. 2014).

Conclusions

The Western Maine Mountains region is a spectacular and rugged landscape defined by forest, rock, snow, clouds, and distance. From its windswept summits to the deep clear lakes and wet meadows of its valleys, it is a region of exceptional diversity and beauty. Study after study highlights the region's significance—with its globally significant alpine and montane forest ecosystems embedded within the largest area of contiguous forest in the eastern United States; as part of the largest remaining block of unfragmented forest in the Atlantic Flyway; as the last stronghold for brook trout in the United States; as the link between marten and lynx populations in the United States and Canada. The combination of boreal and temperate species, steep elevation gradients, and continuous forest make it a resilient landscape in a changing climate—one that is expected to retain the rich diversity and coherency of its natural communities farther into the future than the surrounding lowlands, and one that will provide both refuge and an essential ecological linkage for species such as woodland songbirds, brook trout, moose, marten and lynx that are likely to shift their ranges north and east in response to a warming climate.

Study after study highlights the region's significance—with its globally significant alpine and montane forest ecosystems embedded within the largest area of contiguous forest in the eastern United States; as part of the largest remaining block of unfragmented forest in the Atlantic Flyway; as the last stronghold for brook trout in the United States; as the link between marten and lynx populations in the United States and Canada. The combination of boreal and temperate species, steep elevation gradients, and continuous forest make it a resilient landscape in a changing climate—one that is expected to retain the rich diversity and coherency of its natural communities farther into the future than the surrounding lowlands, and one that will provide both refuge and an essential ecological linkage for species such as woodland songbirds, brook trout, moose, marten and lynx that are likely to shift their ranges north and east in response to a warming climate.

13 Microrefugia are defined as areas with locally favorable environmental conditions in which small populations can survive outside their main distribution area (Rull 2009).

its globally significant alpine and montane forest ecosystems embedded within the largest area of contiguous forest in the eastern United States; as part of the largest remaining block of unfragmented forest in the Atlantic Flyway; as the last stronghold for brook trout in the United States; as the link between marten and lynx populations in the United States and Canada. The combination of boreal and temperate species, steep elevation gradients, and continuous forest make it a resilient landscape in a changing climate—one that is expected to retain the rich diversity and coherency of its natural communities farther into the future than the surrounding lowlands, and one that will provide both refuge and an essential ecological linkage for species such as woodland songbirds, brook trout, moose, marten and lynx that are likely to shift their ranges north and east in response to a warming climate.

Apart from its many ecological values, the Western Maine Mountains region serves as a source of inspiration and spiritual renewal. It is impossible not to be impressed by the countless mountain streams singing over stone, mica sparkling in granite, the densely woven forests of dwarf balsam, the scree-covered ridges, the alpenglow of dusk and the 'fox fire' of northern lights in winter. Thousands are drawn to the region's heights, which are linked by the wildest one hundred miles of the 2,190 mile long Appalachian Trail. And thousands more are drawn to its forests, streams and lakes—to walk, watch, fish, hunt or simply escape the buzz of civilization.

In his book, *The Forest Unseen*, David Haskell describes the value of a small patch of old forest in the southern Appalachians, which applies equally well to the Western Maine Mountains. It is "a *relatively unfragmented, uninvaded forest where the old ecological rulebook has yet to be entirely torn up and blown away. These ants, these flowers, these trees contain the genetic history and diversity from which the future will be written. The more wind-tattered pages we can hold on to, the more materials evolution's scribe will have to draw upon as it reworks the saga."* The Western Maine Mountains region is one of the most intact forested landscapes in North America, one that retains nearly all of the plants and animals that were here before us. It serves as a reservoir, a refuge, and a resilient critical linkage. We are fortunate to be starting with pages that have yet to become "wind-tattered". By working to ensure that the mountains and forests of the region remain diverse, resilient and connected to forested landscapes to the north, south, east and west, we have an unparalleled opportunity to influence how the future will be written.

Literature Cited

Anderson, M.G., C. Ferree, and K. McGargial. 2015. Extending the Northeast Terrestrial Habitat Map to Atlantic Canada. Report to North Atlantic Landscape Conservation Cooperative, Hadley, Massachusetts. 23 pp.

Anderson, M.G., M. Clark, C.E. Ferree, A. Jospe, and A. Olivero Sheldon. 2013. Condition of the Northeast Terrestrial and Aquatic Habitats: A Geospatial Analysis and Tool Set. The Nature Conservancy, Eastern Conservation Science. Boston, MA. 171 pp.

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2012. Resilient Sites for Terrestrial Conservation in the Northeast and Mid-Atlantic Region. The Nature Conservancy, Eastern Conservation Science. 122 pp.

Anderson, M.G. and A. Olivero Sheldon. 2011. Conservation Status of Fish, Wildlife, and Natural Habitats in the Northeast Landscape: Implementation of the Northeast Monitoring Framework. The Nature Conservancy, Eastern Conservation Science. 289 pp.

Anderson M.G. and C. Ferree. 2010. Conserving the Stage: Climate Change and the Geophysical Underpinnings of Species Diversity. PLoS ONE. 5(7):E11554.doi:10.1371/journal. pone.0011554.

Anderson, M.G. 2006. The Northern Appalachian/Acadian Ecoregion: Conservation Assessment – Status and Trends. The Nature Conservancy.

Baldwin, R.F., S.C. Trombulak, K. Beazley, C. Reining, G. Woolmer, J.R. Nordgren, and M. Anderson. 2007. The Importance of Maine for Ecoregional Conservation Planning. Maine Policy Review 16(2):66-77.

Barton, A.M., A.S. White and C.V. Cogbill. 2012. The Changing Nature of the Maine Woods. University of New Hampshire Press, Durham, New Hampshire. 349 pp.

Beckage, B., B. Osborne, D. Gavin, C. Pucko, T. Siccama, and T. Perkins. 2008. A Rapid Upward Shift of a Forest Ecotone During 40 years of Warming in the Green Mountains of Vermont. PNAS 105:4197–4202.

Birdsey, R.A. 1992. Carbon Storage and Accumulation in United States Forest Ecosystems. General Technical Report WO-59. Northeastern Forest Experiment Station, Radnor, Pennsylvania.

Bonney, F. 2009. Brook Trout Management Plan. Maine Department of Inland Fisheries and Wildlife. Augusta, Maine.

Brown, T.C., M.T. Hobbins, and J.A. Ramirez. 2008. Spatial Distribution of Water Supply in the Coterminous United States. Journal of the American Water Resources Association. 44(6): 1474–1487.

Burtelow, A.E., P.J. Bohlen, and P.M. Groffman. 1998. Influence of Exotic Earthworm Invasions on Soil Organic Matter, Microbial Biomass and Denitrification Potential in Forest Soils of the Northeastern United States. Applied Soil Ecology 9 (1998):197-202.

Carroll, C. 2007. Interacting Effects of Climate Change, Landscape Conversion, and Harvest on Carnivore Populations at the Range Margin: Marten and Lynx in the Northern Appalachians. Conservation Biology, 21: 1092–1104.

Carroll, C. 2005. Carnivore Restoration in the Northeastern U.S. and Southeastern Canada: A Regional-Scale Analysis of Habitat and Population Viability for Wolf, Lynx, and Marten (Report 2: Lynx and Marten Viability Analysis). Wildlands Project Special Paper No. 6. Richmond, VT: Wildlands Project. 46 pp.

DeGraaf, D. 2014. Report Back to Legislature on Public Law 2013 Chapter 358, Section 8: Proposed Plan for Managing State Heritage Fish Waters. Maine Department of Inland Fisheries and Wildlife. Augusta, Maine.

DeGraaf, R.M. and M. Yamasaki. 2001. New England Wildlife: Habitat, History, and Distribution. University Press of New England. Hanover and London.

Delcourt, H.R. and P.A. Delcourt. 2000. Eastern Deciduous Forests. Pp. 357-396 in M.G. Barbour and W.D. Billings (Eds.) North American Terrestrial Vegetation. Cambridge University Press.

Fernandez, I.J., C.V. Schmitt, S.D. Birkel, E. Stancioff, A.J. Pershing, J.T. Kelley, J.A. Runge, G.L. Jacobson, and P.A. Mayewski. 2015. Maine's Climate Future: 2015 Update. University of Maine, Orono, Maine. 24 pp.

Flatebo, G, 1999. Vertical Structure and Crown Closure. Pp. 17-22 and Appendix H in C.A. Elliott (Ed.). Biodiversity in the Forests of Maine: Guidelines for land management. University of Maine Cooperative Extension Bull. #7147. University of Maine, Orono, Maine.

Morneau, F., J.A. Tremblay, C. Todd, T.E. Chubbs, C. Maisonneuve, J. Lamaitre, and T. Katzner. 2015. Known Breeding Distribution of Golden Eagles in Eastern North America. Northeastern Naturalist 22(2): 236-247.

Frelich, L.E., C.M. Hale, S., Scheu, A.R. Holdsworth, L. Heneghan, P.J. Bohlen, and P.B. Reic. 2006. Invasion into Previously Earthworm-free Temperate and Boreal Forests. Biological Invasions 8: 1235-1245.

Fuller, A.K. and D.J. Harrison. 2005. Influence of Partial Timber Harvesting on American Martens in North-Central Maine. Journal of Wildlife Management 69(2):710-722.

Gawler, S.C. and A. Cutko. 2010. Natural Landscapes of Maine: A Guide to Natural Communities and Ecosystems. Maine Natural Areas Program. Maine Department of Conservation, Augusta, Maine.

Hagan, J.M, and A.A. Whitman. 2004. Late Successional Forest: A Disappearing Age Class and Implications for Biodiversity. Forest Mosaic Science Notes-2004-2. Manomet, Brunswick, Maine.

Hansk, I. 2000. Extinction Debt and Species Credit in Boreal Forests: Modeling the Consequences of Different Approaches to Biodiversity Conservation. Annales Zool. Fennici 37:271-280.

Haskell, D.G. 2012. The Forest Unseen: A Year's Watch in Nature. Viking, New York. 168 pp.

Heller, N.E. and Zavaleta E.S. 2009. Biodiversity Management in the Face of Climate Change: A Review of 22 Years of Recommendations. Biological Conservation 142: 14-32.

Hepinstall, J.A. and D.J. Harrison (in preparation). Department of Wildlife Ecology, University of Maine.

Homyack, J.A., D.J. Harrison, and W.B. Krohn. 2010. Effects of Precommercial Thinning on Snowshoe Hares in Maine. Journal of Wildlife Management 71(1):4-13.

Holling, C.S. 1973. Resilience and Stability of Ecosystems. Ann. Rev. Ecol. Syst. 4: 1-23.

Hopfensperger, K.N., G.M. Leighton, and T.J. Fahey 2011. Influence of Invasive Earthworms on Above and Belowground Vegetation in a Northern Hardwood Forest. The American Midland Naturalist 166(1):53-62.

Hunter, M. L. Jr., 1990. Wildlife, Forests, and Forestry. Prentice Hall, New Jersey. 358 pp.

Jacobson, G. L., I. J. Fernandez, P. A. Mayewski, and C. V. Schmitt (editors). 2009. Maine's Climate Future: An Initial Assessment. Orono, ME: University of Maine. Accessed online at: http://www.climatechange.umaine.edu/mainesclimatefuture/.

Kauppi, P.E., R.A. Birdsey, Y. Pan, A. Ihalainen. P. Nöjd and A. Lehtonen. 2015. Effects of Land Management on Large Trees and Carbon Stocks. Biogeosciences, 12:855–862.

Kimball, K.D., M.L. Davis, D.M. Weihrauch, G.L.D. Murray, and K. Rancourt. 2014. Limited Alpine Climatic Warming and Modeled Phenology Advancement for Three Alpine Species in the Northeast United States. American Journal of Botany 101(9): 1437–1446.

Laliberte, A.S. and J. Ripple. 2004. Range Contractions of North American Carnivores and Ungulates. BioScience 54(2):123-138.

Lautzenheiser, R. E. 1978. Climates of the States: Maine. Pages 426-448 in Climates of the States, National Oceanic and Atmospheric Administration. Gale Research Co., Detroit, Michigan.

Lee, R. 1981. Forest Hydrology. Columbia University Press, New York. pp. 498–509.

Leopold, A. 1949. A Sand County Almanac and Sketches from Here and There. Oxford University Press, New York. 226pp.

Maine Department of Inland Fisheries and Wildlife. 2015. Maine's Wildlife Action Plan. Maine Department of Inland Fisheries and Wildlife. Augusta, Maine.

McCaskill, G.L., W.H. McWilliams, C.J. Barnett, B.J. Butler, M.A. Hatfield, C.M. Kurtz, R.S. Morin, W.K. Moser, C.H. Perry, and C.W. Woodall. 2011. Maine's Forests 2008. Resource Bulletin NRS-48. Northern Research Station. U.S. Forest Service. Newtown Square, Pennsylvania.

McCollough, M.A., B. Todd, P. Swartz, P. deMaynadier, and H. Givens. 2003. Maine's Endangered and Threatened Wildlife. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine. 117pp.

McKinley, P. 2007. An Ecological Study of the High Peaks Region of Maine's Western Mountains. Maine Appalachian Trail Land Trust. Portland, Maine. 63 pp.

McMahon, J.S. 1990. The Biophysical Regions of Maine: Patterns in the Landscape and Vegetation. M.S. Thesis. University of Maine, Orono. 120 pp.

Maine Beginning With Habitat Program (Maine Natural Areas Program and Maine Department of Inland Fisheries and Wildlife, Focus Areas of Statewide Significance Descriptions. on line: (www.beginningwithhabitat.org/about_bwh/focusareas.html)

National Audubon Society. 2015. Audubon's Birds and Climate Change Report: A Primer for Practitioners. National Audubon Society, New York. Contributors: G. Langham, J. Schuetz, C. Soykan, C. Wilsey, T. Auer, G. LeBaron, C. Sanchez, and T. Distler. Version 1.3.

National Audubon Society. 2012. Atlantic Flyway Priority Forest Mapping Summary Report. (shared by Sally Stockwell, Maine Audubon Society).

Niemi, G., J. Hanowski, P. Helle, R. Howe, M. Mönkkönen, L. Venier, and D. Welsh. 1998. Ecological Sustainability of Birds in Boreal Forests. Conservation Ecology [online] 2(2):17. http://www.consecol.org/vol2/iss2/art17/.

Oliver, C.D., N.T Nassar, B.R. Lippke, and J.B. McCarter. 2014. Carbon, Fossil Fuel, and Biodiversity Mitigation with Wood and Forests. Journal of Sustainable Forestry 55: 248-275.

Packham, J.R. and D.J.L. Harding. 1982. Ecology of Woodland Processes. Arnold, London. 262 pp.

Pan, Y., R.A. Birdsey, J. Fang, R. Houghton, P.E. Kauppi, W.A. Kurz, O.L. Phillips, A. Shvidenko, S.L. Lewis, J.G. Cnadell, P. Ciais, R.B. Jackson, S.W. Pacala, A.D. McGuire, S. Piao, A. Rautianen, S. Sitch, and D. Hayes. . 2011. A Large and Persistent Carbon Sink in the World's Forests. Science 333:988-993.

Publicover, D.A. and K.D. Kimball. 2012. High-elevation Spruce-fir Forest in the Northern Forest: An Assessment of Ecological Value and Conservation Priorities. Appalachian Mountain Club Research Department, Gorham, New Hampshire.

Randin, C.F., Engler, R., Normand, S.. Zappa, M.. Zimmermann, N., Pearman, P.B., Vittoz, P., Thuiller, W. and A. Guisani. 2008. Climate Change and Plant Distribution: Local Models Predict High-elevation Persistence. Global Change Biology 15(6):1557-1569.

Reining, C., K. Beazley, P. Doran and C. Bettigole. 2006. From the Adirondacks to Acadia: A Wildlands Network Design for the Greater Northern Appalachians. Wildlands Project Special Paper No. 7. Richmond, Vermont. 58 pp.

Riitters, K., J. Wickham, R. O'Neill, B. Jones, and E. Smith. 2000. Global-scale Patterns of Forest Fragmentation. Conservation Ecology 4(2):3.

Rull, V. 2009. Microrefugia. Journal of Biogeography 36:481-484.

Russell, F.L., D.B. Zippin and N.L. Fowler. 2001. Effects of White-tailed Deer *(Odocoileus virginianus)* on Plants, Plant Populations and Communities: A Review. American Midland Naturalist 146:1-26.

Ryan, M.G., M.E. Harmon, R.A. Birdsey, C.P. Giardina, L.S. Heath, R.A. Houghton, R.B. Jackson, D.C. McKinley, J.F. Morrison, B.C. Murray, D.E. Pataki, and K.E. Skog. 2010. A Synthesis of the Science of Forests and Carbon for U.S. Forests. Issues in Ecology Report No. 13. Ecological Society of America.

Seidel, T.M., D.M. Weihrauch, K.D. Kimball, A.A.P. Pszenny, R. Soboleski, E. Crete, and G. Murray. 2009. Evidence of Climate Change Declines with Elevation Based on Temperature and Snow Records from 1930s to 2006 on Mount Washington, New Hampshire, U.S.A. Arctic, Antarctic, and Alpine Research 41(3):362-372.

Simmons-Legaard, E.M., D.J. Harrison, W.B. Krohn, and J.H. Vashon. 2013. Canada Lynx Occurrence and Forest Management in the Acadian Forest. The Journal of Wildlife Management 77(3):567-578.

Simons, E., D. Harrison, A. Whitman, and J. Wilson. 2010. Quantifying Biodiversity Across Managed Landscapes in Northern and Western Maine. Final Report to the Maine Cooperative Forestry Research Unit, University of Maine, Orono. 29 pp.

Spear, R.W. 1989. Late-Quaternary History of High-Elevation Vegetation in the White Mountains of New Hampshire. Ecological Monographs, 59(2): 125-151.

Stephenson, N. L., A. J. Das, R. Condit, S. E. Russo, P. J. Baker, N. G. Beckman, D. A. Coomes, E. R. Lines, W. K. Morris, N. Ruger, E. Alvarez, C. Blundo, S. Bunyavejchewin, G. Chuy-ong, S. J. Davies, A. Duque, C. N. Ewango, O. Flores, J. F. Franklin, H. R. Grau, Z, Hao, M. E. Harmon, S. P. Hubbell, D. Kenfack, Y. Lin, J. R. Makana, A. Malizia, L. R. Malizia, R. J. Pabst, N. Pongpattananurak, S-H, Su, I-F Sun, S. Tan, D. Thomas, P. J. van Mantgem, X. Wang, S. K. Wiser, and M. A. Zavala. 2014. Rate of Tree Carbon Accumulation Increases Continuously with Tree Size. Nature 507:90–93.

Sun, G. and Y. Liu. 2013. Forest Influences on Climate and Water Resources at the Landscape to Regional Scale. Pages 309-333 in B. Fu and K. B. Jones (Eds.), Landscape Ecology for Sustainable Environment and Culture. Springer Science.

The Nature Conservancy. 2013. Staying Connected in the Northern Appalachians: Mitigating Fragmentation and Climate Change Impacts on Wildlife Through Functional Habitat Linkages. Final Performance Report-Summary. New Hampshire Fish and Game Department and the U.S. Fish and Wildlife Service.

The Nature Conservancy. 2008. Life in Maine's Lakes and Rivers: Our Diverse Aquatic Heritage. The Nature Conservancy, Brunswick, Maine. 32pp.

Thompson, J.R., D.N. Carpenter, C.V. Cogbill, and D.R. Foster. 2013. Four Centuries of Change in Northeastern United States Forests. PLoS ONE 8(9): e72540. doi:10.1371/journal. pone. 0072540

Thoreau, H. D. 1984. The Maine Woods. Thomas Y. Crowell and Co., New York.

Trombulak, S.C., M.G. Anderson, R.F. Baldwin, K. Beazley, J.C. Ray, C. Reining, G. Woolmer, C. Bettigole, G. Forbes, and L. Gratton. 2008. The Northern Appalachian/Acadian Ecoregion: Priority Locations for Conservation Action. Two Countries, One Forest Special Report No. 1.

Whitman, A., A. Cutko, P. deMaynadier, S. Walker, B. Vickery, S. Stockwell, and R. Houston. 2013a. Climate Change and Biodiversity in Maine: Vulnerability of Habitats and Priority Species. Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Working Group) Report SEI-2013-03. Brunswick, Maine. 96 pp.

Whitman, A., B. Vickery, P. deMaynadier, S. Stockwell, S. Walker, A. Cutko, and R. Houston. 2013b. Climate Change and Biodiversity in Maine: A Climate Change Exposure Summary for Species and Key Habitats (Revised). Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Adaptation Working Group) Report NCI-2013-01. Brunswick, Maine. 29 pp.

Whitman, A. and J.M. Hagan. 2007. An Index to Identify Late-successional Forest in Temperate and Boreal Zones. Forest Ecology and Management 246:144–154.



The Environmental Consequences of FOREST FRAGMENTATION in the Western Maine Mountains

Janet McMahon, M.S.



Occasional Paper #2

Maine Mountain Collaborative

P.O. Box A, Phillips, ME 04966

© 2018 Janet McMahon.

Permission to publish and distribute has been granted by the author to the Maine Mountain Collaborative.

This paper is published by the Maine Mountain Collaborative as part of an ongoing series of informational papers. The information and views expressed in this paper are those of the author and do not necessarily reflect the views of the Maine Mountain Collaborative or its members.

I thank Dr. Malcolm Hunter, Jr., Dr. Ray "Bucky" Owen and Barbara Vickery for their peer review of this paper. I also thank the many ecologists, biologists, foresters and others who provided information, analysis and, in some cases, early review of all or parts of this paper, including: Mark Anderson, George Appell, Maisie Campbell, Andrew Cutko, Thomas R. Duffus, Phillip deMaynadier, Merry Gallagher, R. Alec Giffen, Sarah Haggerty, Daniel Harrison, Peter McKinley, Michael Pounch, David Publicover, Jeffrey Reardon, Sally Stockwell, Karin Tilberg and Andrew Whitman. Finally, I give special thanks to Daniel Coker, senior spatial scientist at The Nature Conservancy, Maine for his analysis of state road and habitat block data and map preparation and to Ann Gosline, for her tireless logistical support and encouragement.

Cover photos:
Western Maine Mountain vista by Charlie Reinertsen Photography.
Photo-illustration of development by Waterview Consulting.

Photo on page 1:
Western Maine Mountains by Charlie Reinertsen Photography.

Photos on page 5:
Moose by Maine Department of Inland Fisheries and Wildlife.
Black bear by Terry Spivey—Image Number: 1374239, CC BY-SA 3.0.
Canada lynx by Eric Kilby, https://www.flickr.com/photos/ekilby/8154273321
River otter and brook trout by U.S. Fish and Wildlife Service.
American marten by U.S. Department of Agriculture.
Spruce grouse by Dick Daniels (http://carolinabirds.org/)—Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=10767940



The Environmental Consequences of Forest Fragmentation in the Western Maine Mountains

ABSTRACT

The extraordinary ecological values of the Western Maine Mountains region are under threat from a process called "habitat fragmentation." Habitat fragmentation occurs when habitats are broken apart into smaller and more isolated fragments by permanent roads, utility corridors, buildings, clearings or changes in habitat conditions that create discontinuities in the landscape. Research in Maine, the Northeast and around the world demonstrates unequivocally that fragmentation—whether permanent or temporary—degrades native terrestrial and aquatic ecosystems and reduces biodiversity and regional connectivity over time and in a number of ways. Negative effects include:

- increased mortality and habitat loss from construction of roads and other fragmenting features
- increased mortality and other direct impacts associated with infrastructure after construction
- changes in species composition and reduced habitat quality from edge effects
- changes in species composition and behavior as habitat patch size declines
- changes in hydrology and reduced aquatic connectivity
- introduction and spread of exotic species
- changes in the chemical environment
- pressures on species resulting from increased fishing, hunting, and foraging access
- loss of scenic qualities and remote recreation opportunities

Fragmentation has already significantly degraded ecosystems in much of the eastern United States and in temperate forests throughout the world. By contrast, in large part because historical forest management maintained vast connected forest blocks in the region, the Western Maine Mountains' biodiversity, resilience and connectivity are unparalleled in the eastern United States. The region is a haven for populations of many of Maine's iconic species, including moose, lynx, marten, brook trout, and rare forest birds, and provides an essential corridor for species to move to other northeastern states, the North Woods and Canada in a time of climate change. To maintain the region's unique values, it is essential to avoid introduction of new fragmenting features, especially those that would permanently intrude into intact blocks of forest habitat, such as new utility corridors and new high volume roads. It is also critically important to find ways to support landowners who seek to maintain large intact forest blocks and to support them in managing forests for connectivity and structural complexity. If proactive steps are taken now, there is a tremendous opportunity to avoid habitat fragmentation and maintain the region's many ecological values—values that have defined Maine for generations and are of critical importance in North America.

INTRODUCTION

The Western Maine Mountains lie at the heart of the most intact and least fragmented landscape remaining in the eastern United States. This vast region lies near the northern terminus of the Appalachian Mountain range in the United States and includes some of its highest peaks. It extends from the Katahdin region 160 miles southwest to Boundary Bald Mountain and the Mahoosucs Range on Maine's western border, encompassing an area of more than five million acres. It is a region of extraordinary ecological importance, both because it is the key ecological linkage between the forests of the northern Appalachians and those to the north, south and west, and because of the biodiversity it harbors.[1]

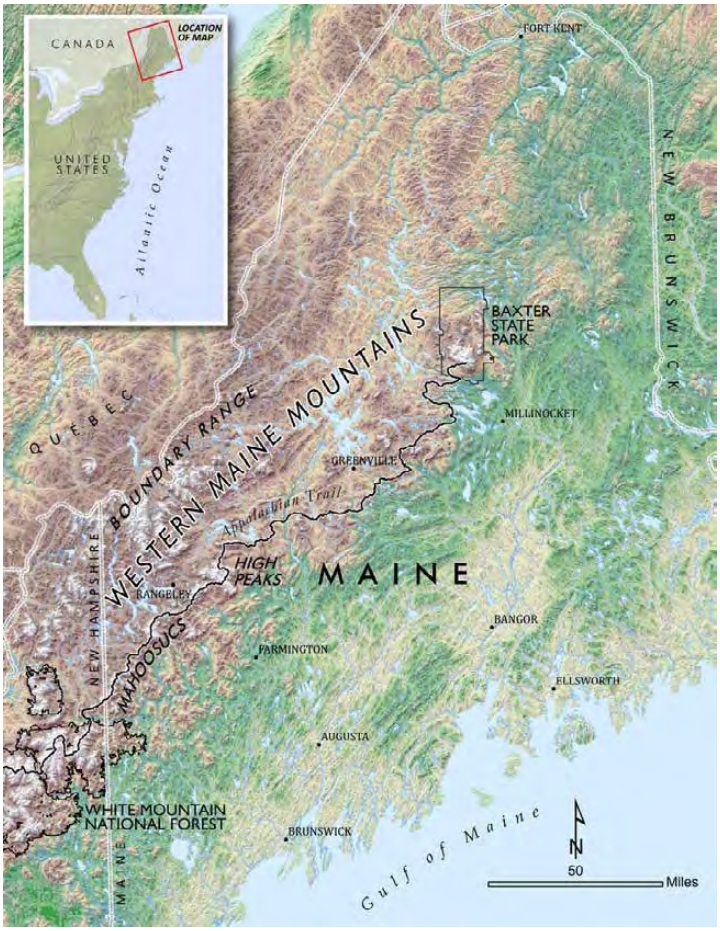


Figure 1. The Western Maine Mountains region.

The southern edge of the Western Maine Mountains region marks the divide between the most resilient[2] and connected landscapes of the Northern Appalachian-Acadian Forest Ecoregion[3] and more fragmented and less resilient landscapes to the south and west. This paper summarizes the potential deleterious impacts of forest fragmentation on the flora, fauna and ecosystems of the region. Fragmentation is generally defined as the breaking apart of a continuous landscape into smaller and more isolated fragments (Forman 1995). In the Western Maine Mountains, fragmentation occurs when permanent features such as roads, utility corridors, buildings or clearings create breaks in the forested landscape (Charry 1996). Recent work by Di Marco et al. (2018) shows that there is a direct correlation between the risk of species extinction and human footprint. Impacts such as direct habitat loss, habitat degradation through increased isolation of plant and animal populations, greater exposure to edge effects, and invasion by disturbance-adapted species are cumulative, leading to degraded ecosystems over time and, eventually, loss of regional connectivity and biodiversity (Watson et al. 2018; Lindenmayer and Fischer 2006; Haddad et al. 2015). This is the situation in much of the eastern United States and in temperate forests throughout the world.

---

1 For a detailed description of the ecological values of the Western Maine Mountains, see McMahon (2016).

2 Resiliency refers to the ability of a region to maintain species diversity and ecological function as the climate changes.

3 Ecoregions are large units of land with similar environmental conditions–especially landforms, geology and soils, which share a distinct assemblage of natural communities and species. The Northern Appalachian-Acadian Forest Ecoregion includes the mountainous regions and boreal hills and lowlands in northern New England and Maritime Canada. The ecoregion includes the Adirondack Mountains, Tug Hill, the northern Green Mountains, the White Mountains, the Aroostook Hills, New Brunswick Hills, the Fundy coastal section, the Gaspé peninsula and all of New Brunswick, Nova Scotia and Prince Edward Island (Anderson 2006).

In the classic definition of fragmentation, habitat patches are surrounded by a "matrix"[4] of lands dominated by human activities, such as farmland or urban centers (Hunter and Gibbs 2007). By contrast, the Western Maine Mountains region is a forested landscape, largely unfragmented by major roads and other permanent features. This matrix of managed forestland provides valuable habitat for most of Maine's forest species and generally serves to connect patches of mature or undisturbed habitat. However, changes in the forest landscape from harvesting can also have fragmenting effects, especially for species that require mature forest or forest interior habitat. The degree of impact depends on factors such as the species in question, harvest intensity, and the size of harvest blocks. Although these impacts are generally temporary, they are of concern—particularly in combination with impacts of permanent fragmentation—and are in need of further study.

This paper begins with an overview of the ecological significance and condition of the Western Maine Mountains' landscape and a brief review of how the region has changed over time due to forest fragmentation associated with land use change and forest management. This is followed by a summary of the potential impacts of current and future fragmentation on the region's biodiversity, resilience in the face of climate change, and ability to serve as the critical link between the forests of the northern Appalachians and those to the north, south and west. To paraphrase Aldo Leopold (1966), the region needs to be viewed as an integrated whole rather than a collection of conservation lands and private commercial land holdings. Private and public landowners, through their land use decisions and management, will play a key role in maintaining the region's ecological values into the future.

Habitat fragmentation and why it matters

Hunter and Gibbs (2007) wrote that a modern traveler looking down from a plane generally does not see vast expanses of unbroken landscape but instead will likely see a landscape like a patchwork quilt—a mosaic of different land uses. Hunter and Gibbs define "habitat fragmentation" as the gradual breaking apart of a natural landscape into smaller habitat blocks. They wrote that fragmentation typically begins when people build roads into a natural landscape and then "perforate" the landscape further with associated development. This typically leads to additional roads, energy infrastructure and land conversion and, over time, results in "patches" of natural habitat that are smaller and farther apart (Fig. 2). Larger habitat patches in a landscape mosaic are better able to support stable populations of more species than small ones. Hunter and Gibbs attribute this to three things: First, larger patches have a greater variety of environments—different elevations, soils, geology, streams and wetlands, which in turn support a greater variety of species. Second, larger patches will support more species that require larger home ranges. Finally, animals and plants from other patches can more easily migrate in to replenish struggling or declining species if similar habitat patches are close by and if the areas in between (matrix habitat) are connected and allow for movement. Fragmenting landscapes into smaller habitat patches over time is a leading cause of degradation of ecosystems and loss of biodiversity.

[4] Matrix forest can be defined as the largest background patch in a landscape and is characterized by extensive cover, high connectivity, and/or exerts a dominant role on ecological processes (Forman 1995). In the Western Maine Mountains, most of the region is considered matrix forest.

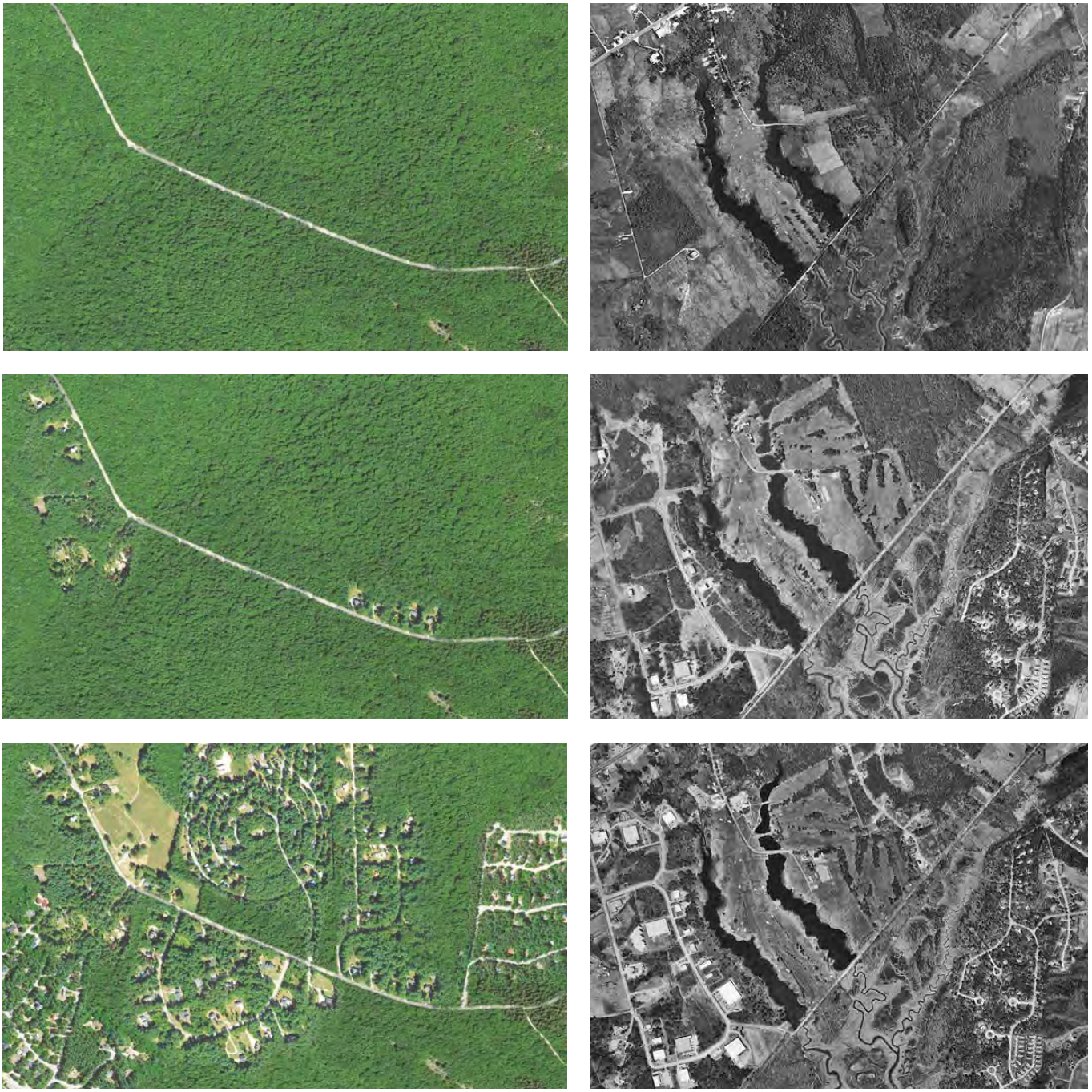


Figure 2. The left column shows a hypothetical progression from: (1) initial fragmentation by a new road or other linear feature, (2) a landscape fragmented by the road and associated development "perforating" the landscape and (3) a landscape with additional sprawling fragmenting features, resulting in progressive fragmentation of the landscape into smaller natural areas. The right column shows an actual example of change between 1956 to 1995 from a partially fragmented landscape to a highly fragmented landscape in a southern Maine community. Photo-illustrations in left column by Waterview Consulting. Photos in right column courtesy of the Greater Portland Council of Governments.

Figure 3. (following page) The Western Maine Mountains provide critically important core habitat for species that are iconic to Maine and a host of rare animals and plants. Photos are of moose, black bear, Canada lynx, river otter, American marten, spruce grouse, and brook trout. Photo credits, see inside front cover.

THE REGION TODAY

A diverse, resilient and connected landscape[5]

From the standpoint of biodiversity, the Western Maine Mountains region is exceptional. It includes all of Maine's high peaks and a rich diversity of ecosystems, from alpine tundra and boreal forests to ribbed fens and floodplain hardwood forests. It is home to more than 139 rare plants and animals, including 21 globally rare species and many others that are found only in the northern Appalachians. It includes more than half of the United States' largest globally important bird area,[6] which provides crucial nesting habitat for 34 northern woodland songbird species and critical habitat for high-elevation and coniferous-forest specialist birds such as Bicknell's thrush—a state endangered species—bay-breasted warbler and black-backed woodpecker. Maine is the last stronghold for wild brook trout in the eastern United States, supporting 97% of its intact lake and pond wild trout populations. Seventy-three percent of these wild brook trout lakes are in the Western Maine Mountains (Whitman et al. 2013; DeGraaf 2014). The region provides core habitat for umbrella species[7] such as American marten and Canada lynx–habitat that supports more than 85% of all of Maine's terrestrial vertebrate wildlife species, including iconic species of the north, such as the common loon, black bear, bobcat and moose (Hepinstall and Harrison in prep.; DeGraaf and Yamasaki 2001).

In addition to its remarkable biodiversity, the region is exceptional because it remains a largely unfragmented, lightly settled and connected landscape. It lies at the heart of the Northern Appalachian-Acadian Forest Ecoregion, which is the largest and most continuous area of temperate forest in North America, and perhaps the world (Haselton et al. 2014; Riitters et al. 2000). This high degree of connectivity, combined with large elevation gradients and a diversity of physical landscapes, makes the Western Maine Mountains a highly resilient landscape in the face of climate change and a critical ecological link between undeveloped lands to the north, south, east and west. Resilient sites are those that are projected to continue to support biological diversity, productivity and ecological function even as they change in response to climate change. In The Nature Conservancy's Conservation Gateway climate resilience map of the eastern United States, the Western Maine Mountains stand out in terms of biodiversity, climate flow[8] and









5 This summary of the region's ecological significance is adapted from McMahon (2016).

6 The National Audubon Society gave this global designation to the region because of its high bird richness and abundance as well as the extent and intactness of its forests, which lie within the Eastern Atlantic Flyway—the major migratory route for hundreds of neotropical bird species.

7 Hunter and Gibbs (2007) define umbrella species as those with large home ranges and broad habitat requirements. Protecting habitat for their populations protects habitat for many other species across a broad set of ecosystems.

8 Climate flow is defined by The Nature Conservancy as the movement of species populations over time in response to the climate. Intact forested areas typically allow high levels of plant and animal movement.

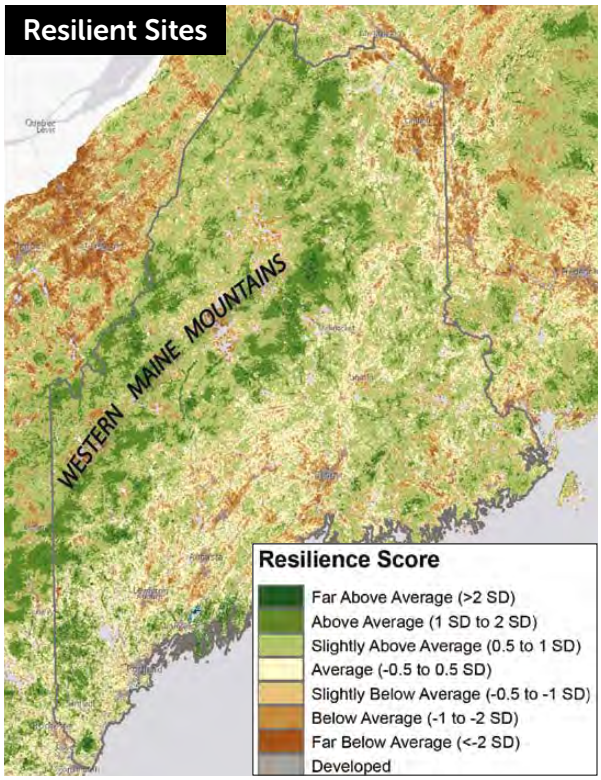


Figure 4. This map shows that the Western Maine Mountains provide sites of above and far-above-average resiliency throughout the region. Resilient sites are expected to buffer their resident species from climate change and continue to support biodiversity, productivity, and ecosystem function even as they change in response to climate change. Analysis and graphic courtesy of The Nature Conservancy, Maine.

Sources and Sinks

Hunter and Gibbs (2007) define "sources" as subpopulations that produce a substantial number of emigrants that disperse to other patches and "sinks" as subpopulations that cannot maintain themselves without a net immigration of individuals from other subpopulations. The Western Maine Mountains region harbors significant source populations of many species and already serves as a north-south and east-west link between peripheral sink populations in New Hampshire and Vermont and source populations in northeastern Maine and the Gaspé (Carroll 2007).

climate-resilient sites.[9] Eighty percent of the region is of above-average resilience, based on geophysical setting and local connectedness (Fig. 4).[10] This compares to 60% for the state as a whole and an average of 39% in southern Maine. A review of The Nature Conservancy's Conservation Gateway maps for the rest of New England and the eastern United States indicates that resiliency is even lower outside of Maine, making the Western Maine Mountains one of the most resilient and connected landscapes east of the Mississippi. In addition, it is the critical link between the other highly resilient areas in the Northern Appalachian-Acadian Forest Ecoregion—the Adirondacks, the St. John and Allagash valleys and the Gaspé.

Climate-resilient sites are more likely to sustain native plants, animals and natural processes into the future. The region is expected to retain more species as the climate changes than other parts of the state because its varied topography offers ample microclimates and thus more options for rearrangement (Anderson et al. 2012; Anderson et al. 2013). Northern Maine already has the highest species richness of mammalian carnivores in the eastern United States,[11] and the Western Maine Mountains support the largest moose, lynx, and marten populations in the lower 48 states. Furthermore, the region is a stronghold for brook trout, land-locked salmon, spruce grouse and a host of other species. In addition to providing a refuge for northern and coldwater species, the region serves as a source of individuals that can recolonize new habitats as they become avail-

9 Resilient sites buffer their resident species from the direct effects of climate change by providing temperature and moisture options in the form of connected microclimates that can differ by as much as 10–15°C. Sites with high microclimate diversity allow plants and animals to persist locally even as the regional climate appears unsuitable, thus slowing down the rate of change.

10 Geophysical setting is a landscape classification that considers topography, elevation range, wetland density and soil variety. Local connectedness is the absence of barriers or fragmenting roads, dams, development, etc. that prevent plant and animal populations from taking advantage of local microclimates.

11 The region supports breeding populations of 7 species of mustelids (fisher, marten, mink, ermine, long-tailed weasel, river otter, striped skunk), 3 species of canids (grey fox, red fox, coyote), and 2 cats (bobcat, lynx).

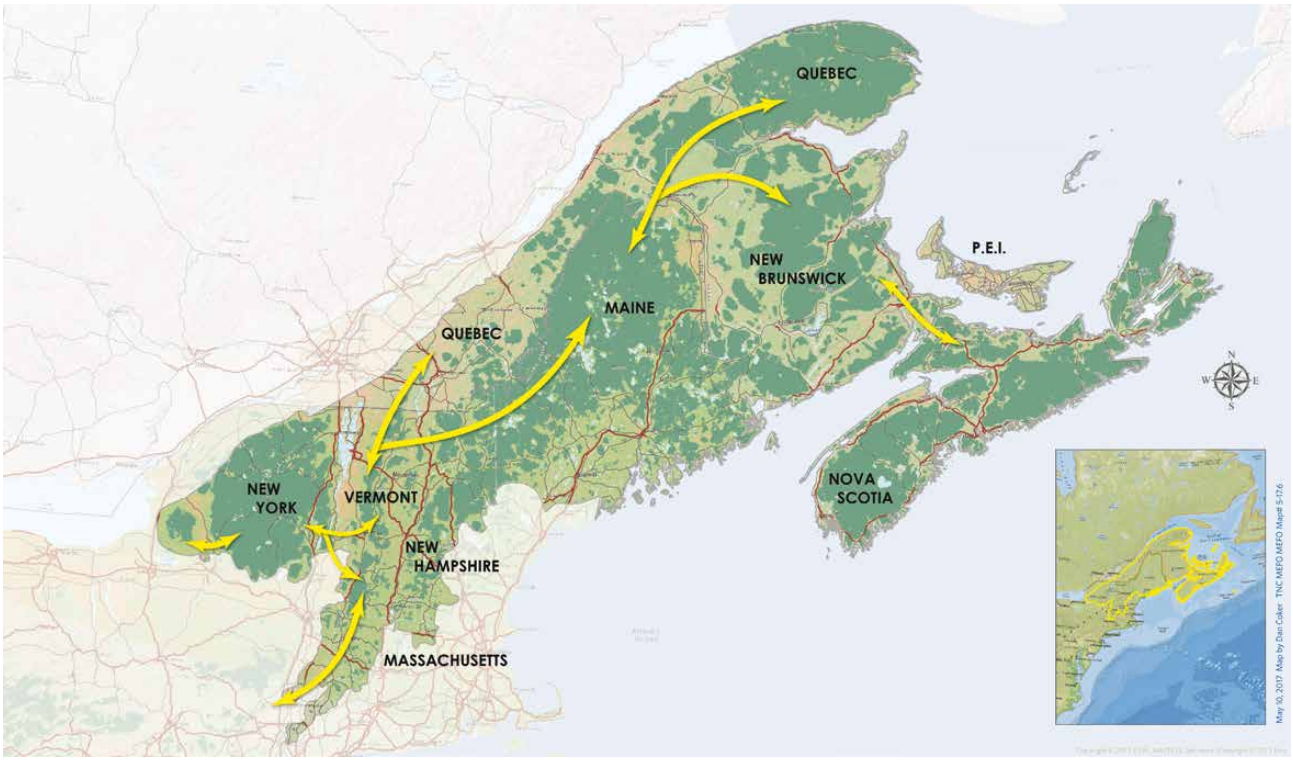


Figure 5. Northern Appalachian Region Forest Cover and Critical Linkages.
Map courtesy of The Nature Conservancy, Maine.

able. For example, the region links moose populations at the southern edge of their range in New Hampshire and Vermont that are increasingly impacted by climate change and parasitic infections by ticks with larger, healthier populations in northern Maine and Quebec.

At a continental scale, northern Maine will become an increasingly important dispersal corridor as species move north into Canada (Trombulak and Baldwin 2010) (Fig. 5). Species survival may depend not only on the presence of refugia but also on how quickly the climate changes. Loarie and others (2009) modeled projected rates of temperature change in different ecosystems under different emissions scenarios during the 21st century. They found that the rate of change is expected to be lowest in mountainous biomes and temperate coniferous forests, suggesting that the landscapes of the Western Maine Mountains are more likely to effectively shelter many species into the next century than areas with low relief (Loarie et al. 2009; Loarie et al. 2008; Thuiller et al. 2005). Whitman et al. (2013) emphasize the importance of conserving cool refuges such as cold stream networks, mountains, and closed canopy forests to help species survive and transition as Maine's climate changes.

A forested landscape

The Western Maine Mountains region is ~97% forested (excluding water), which is about 8% higher than the average forest cover in Maine, the most forested state in the nation (Fig. 6, following page, for a regional comparison) (New England Forestry Foundation, NEFF, in press).[12] The North Woods of Maine, of which the

[12] Percentages of land in conservation ownership and forest management for the Western Maine Mountains are derived from other studies that focused on slightly different geographic boundaries. Schlawin and Cutko percentages were calculated for the Central-Western-White Mountains section of the USFS Bailey Ecoregion map of Maine (Bailey 1995). The 2018 NEFF analysis is of an area they refer to as the Mountains of the Dawn region.

region is a part, is the only place in the eastern United States where such a large area of contiguous land has remained continuously forested since European settlement. This is due to a variety of factors, including limited suitability for agriculture, soils that are productive for tree growth, remoteness from more heavily settled areas, and the timber and nontimber values of its vast forest—most of which has been in private and corporate ownership and actively managed for forest products for more than two centuries.

State/Region	% Forestland		% Change from 2007–2017	Approximate Change in Acres
	2007	2017		
Western Maine Mountains	**96.8%**	**96.5%**	**–0.3%**	**–12,000**
Maine	89.8%	89.2%	–0.6%[13]	–116,000
Connecticut	55.3%	58.4%	3.1%	95,000
Massachusetts	61.2%	60.6%	–0.5%	–26,000
New Hampshire	83.8%	82.8%	–1.0%	–57,000
Rhode Island	54.0%	54.4%	0.4%	3,000
Vermont	77.3%	76.0%	–1.3%	–80,000
New England (incl. ME)	80.3%	79.8%	–0.5%	–184,000
New England (excl. ME)	71.1%	70.8%	–0.3%	–67,000

Figure 6. Forested Area as a Percent of Total Area (excluding water) in the New England states. Percent change is change in percent of forestland from 2007–2017.[14] Adapted from NEFF (in press).

Managed forestland in the Western Maine Mountains is composed primarily of naturally regenerated forests. According to most recent FIA data,[15] only 2% is planted, and most of this is with native species (Ten Broek and Giffen 2018). Under natural conditions, forest types generally occur in predictable patterns associated with climatic gradients and soil conditions determined by glacial deposition (NEFF in press; Legaard et al. 2015). Northern hardwood species predominate across lower hilltops and mid-slopes, with higher site quality. Spruce-fir species predominate on ridge tops, high elevation slopes and poorly drained lowlands. Mixed wood stands commonly occur along ecotones or as a result of successional dynamics following disturbance.

[13] Considering just land area, Maine is 89% forested (FIA 2017 data).

[14] Data are from the Forest Inventory and Analysis (FIA) Program of the U.S. Department of Agriculture (USDA) Forest Service. Percentages are for forestland, as a percentage of sampled land area, as opposed to total area, which would include area in water. Percent change is measured from the first complete inventory cycle (generally 2002/3 to 2007) to the latest complete inventory cycle (2017 estimates) (NEFF, in press).

[15] The FIA Program of the USDA Forest Service annually surveys the country's forests to determine trends in forest area and location; tree species composition, size and health; total tree growth, mortality and removals by harvest; wood production and utilization rates by various products; and forest land ownership. The inventory has recently expanded to collect data on soils, understory vegetation (including invasives), tree crown conditions, coarse woody debris and lichen community composition on a subsample of plots.

Shade-intolerant hardwood species commonly follow intense disturbance. Periodic defoliation by spruce budworm is the most prominent large-scale natural disturbance. Small scale disturbances that result in small canopy gaps such as windthrow and senescence are also common (Legaard et al. 2015; Lorimer and White 2003; Seymour et al. 2002). Managed carefully, in time, these naturally regenerating forests should allow natural structural and successional processes to take place and provide habitat for a full suite of native wildlife species (NEFF in press).

A brief summary of current land use

Virtually all of the forestland in the Western Maine Mountains not specifically set aside for reserves or other conservation purposes is commercially managed for a variety of forest products. About 88% of these managed lands are privately held (NEFF in press). Since the 1990s, the North Maine Woods, including the Western Maine Mountains region, has undergone a dramatic transition in ownership. Large swaths of the region have passed from industrial landowners—who had long-term management goals because their timberland supplied their own mills—to timber investment management organizations, real estate investment trusts and other financial investors, whose investment strategies usually involve holding land for a much shorter period (Irland 2005; Lilieholm et al. 2010; Trombulak and Baldwin 2010). Between 1994 and 2005, forest products industry ownership of forestland declined from 59% to 16%, and the percentage held by investors such as publicly traded real estate investment trusts rose from 3% to 40% (Barton et al. 2012). Today, the majority of the Western Maine Mountains is owned by investors.[16] Some landowners, such as Weyerhaeuser (formerly Plum Creek), have secured rezoning of forestland to allow for resorts and residential subdivisions in remote, lightly settled landscapes (Lilieholm et al. 2010; Hagan et al. 2005). In addition to a shift in ownership, the number of landowners has increased and size of land holdings has decreased significantly in the past two decades (Hagan et al. 2005). For example, the 2.3 million-acre Great Northern Paper ownership of 1989 had been transferred to at least 15 different landowners as of 2005. The impacts of the increased parcelization and turnover of landholdings on biodiversity and connectivity are unclear, but likely to be negative.

Legally conserved lands[17] make up about 29% of the region's area. Forest management is allowed on 20 of this 29%. The remaining 9% is forever-wild or in reserves. Most conserved land that allows timber harvesting is privately held and under conservation easement. It is worth noting that most of Maine's forever-wild acreage is in the Western Maine Mountains, primarily in Baxter State Park, the White Mountain National Forest, The Nature Conservancy's Debsconeag Lakes Wilderness Area, Bureau of Parks and Land's Nahmakanta Ecological Reserve, Mahoosuc Unit and Bigelow Reserve, and additional lands within the 100-Mile Wilderness and the National Park Service's Appalachian Trail Corridor (Schlawin and Cutko 2014). Most of these reserves are centered around mountainous areas. They constitute some of the largest roadless areas in the state and New England (Publicover and Poppenwimer 2002) and contribute to the exceptional resilience of the region.

---

16 As of 2017, predominant landowners in the Western Maine Mountains included Weyerhaeuser, Wagner Forest Management, MacDonald Investment, BBC Land LLC, Katahdin Timberlands and E.J. Carrier (James W. Sewall Company 2017 map of Forest Land Owners of the State of Maine).

17 Conservation lands include those where forest management can take place (Type 1) and those where extractive uses are not allowed (Type 2). The latter are sometimes termed "forever wild" or "reserve" lands. These lands include places such as Acadia National Park, the National Park Service's Appalachian Trail, federal Wilderness Areas in the White Mountain National Forest and Moosehorn Wildlife Refuge, State Ecological Reserves, many land trust ownerships and much of Baxter State Park (Schlawin and Cutko 2014).

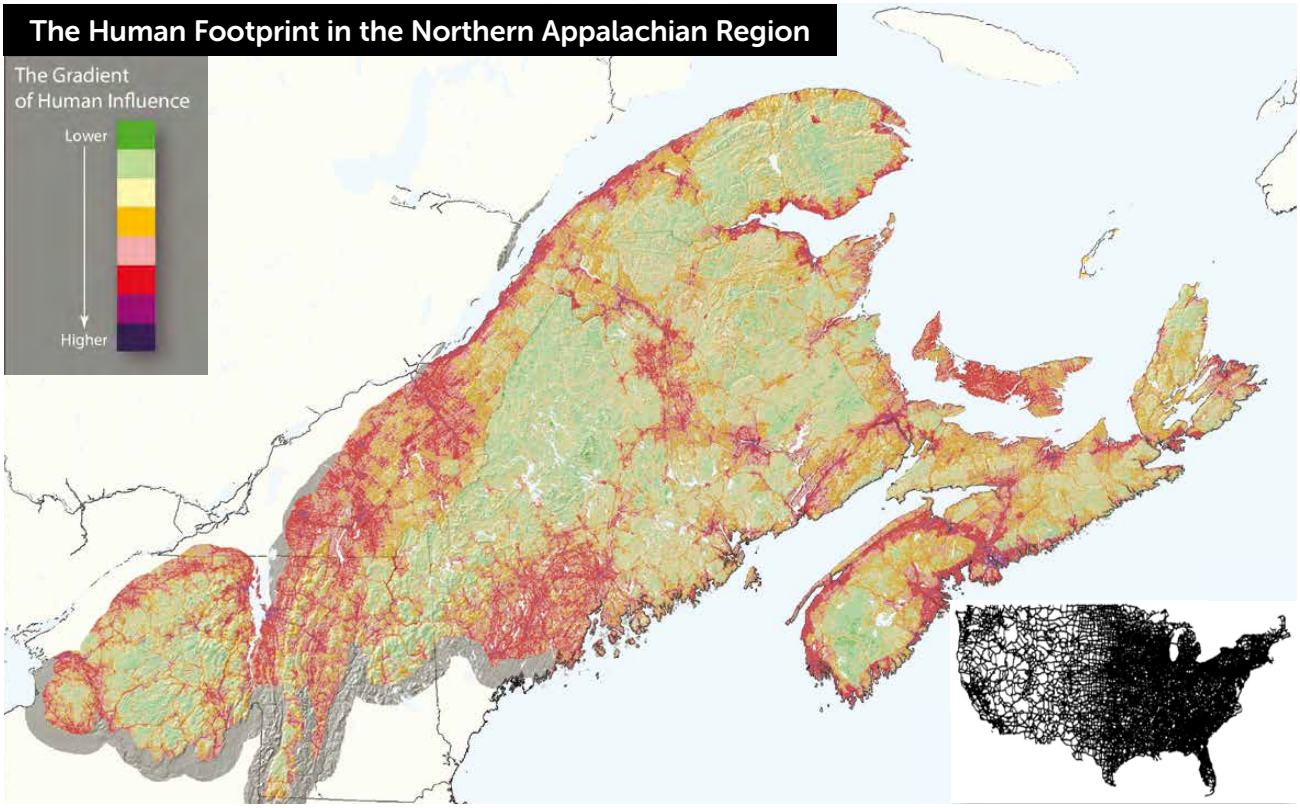


Figure 7. The Human Footprint map of the ecoregion and the map of the U.S. highway system (inset), viewed together, show that the Western Maine Mountains and Maine's North Woods are much less fragmented than any other area in the eastern half of the country. Human Footprint data from Two Countries One Forest, map courtesy of The Nature Conservancy, Maine.

Currently, the Western Maine Mountains region has a far lower density of major permanent roads than more developed areas of Maine, and New England as a whole.[18] The Land Use Planning Commission (2010) estimate of public road density in the unorganized towns was 0.1 miles per square mile compared to an average of 1 to 3 miles per square mile in the organized towns. In settled portions of the northern Appalachians, public road building remains an ongoing process. Baldwin and others (2007) found that approximately 1,200 miles of roads were built in settled landscapes in Maine between 1986–2003, impacting more than 92,000 acres of adjacent habitats. Furthermore, they estimated that regular, public roads in the Northern Appalachian-Acadian Forest Ecoregion as a whole—especially those that provide access to subdivisions, would double by 2013 (Baldwin et al. 2007). The majority (93.5%) of these new roads perform local functions and are short (<1,000 feet in length) residential roads typical of sprawl. Increased permanent road and energy infrastructure development within and along the boundaries of the Western Maine Mountains has the potential to impact tens of thousands of acres through direct habitat loss and edge effects, which will have a significant impact on regional connectivity.

Prior to the 1970s, there were few logging roads in the region. Those that existed were largely primitive and narrow and used for supplying remote logging and sporting camps. This changed when the river drives

[18] Good data on private roads in the unorganized towns are lacking. 2010 estimates from the Land Use Planning Commission indicate that there are on the order of 1,500 miles of public roads and over 20,000 miles of private roads in the unorganized towns.

ended and salvage operations during the spruce budworm outbreak of the 1970s and 1980s began. In 1997, the Maine Department of Conservation estimated that there were ~20,000 miles of private roads on the approximately 10 million acres of unincorporated land in Maine, with an anticipated 500 miles of new road being added each year (Publicover and Poppenwimer 2002; Maine Department of Conservation 1997). If this trend is accurate, based on a simple proportion and not accounting for roads that are reclaimed or abandoned, there would be between 10,000 and 15,000 miles of private logging roads within the five million-acre Western Maine Mountains region today. Aside from major haul roads, most logging roads in the region are low-volume, unimproved, single-lane, dirt or gravel roads without significant, cleared verges. Compared to public roads, these roads receive episodic use from forestry machinery and relatively light use by the public for fishing, hunting and other recreation where these activities are permitted (Alec Giffen, personal communication). Major haul roads such as the Golden Road, Telos Road, and Ragmuff Road receive more use and have a larger footprint and hence a greater fragmenting effect.

The Western Maine Mountains region, along with the Adirondacks, contains the most extensive roadless areas in Maine and the eastern United States (The Nature Conservancy Conservation Gateway). Publicover and Poppenwimer (2002) conducted a detailed inventory of "roadless areas" in the Northeast, which they defined as areas greater than 5,000 acres with no public roads, discernable active private logging roads or areas that have been heavily harvested in the past two to three decades. They estimated that, in 1996–1997, 43 roadless areas in the Western Maine Mountains fit this definition, encompassing about 870,000 acres, 15% of the region. The largest areas were Baxter State Park, the Debsconeag Lakes area and White Mountains National Forest. An additional 55 areas (mostly smaller tracts on private land) were scattered throughout other parts of the state to the north and east. By 2000, the number of roadless areas in the Western Maine Mountains had shrunk to 40 areas encompassing about 720,000 acres (Publicover and Poppenwimer 2006). Currently, the region is estimated to contain 46 such areas encompassing about 603,000 acres,[19] and most areas outside of the Western Maine Mountains have been eliminated due to road building and harvesting over the past two decades (Publicover and Poppenwimer, unpublished data).

Today, although there is an extensive system of logging roads in place, approximately 48% of the region's forest is more than one kilometer (3,300 feet) from the edge of a permanent public or major logging road,[20] which is beyond the distance where the most degrading road "edge" effects occur[21] (Laurance et al. 2002; Laurance et al. 2017).[22] This compares to only 5% of forestland beyond this threshold in southern Maine and a global average of 30% (Haddad et al. 2015) (Fig. 8a and 8b, following pages).

Rural development in the Western Maine Mountains is limited, occurring primarily along the region's southern and eastern edges, on some lake shores, and along permanently paved roads. This development consists primarily of single-family camps and homes, sporting camps, small subdivisions and small businesses, such

---

19 In a classic example of fragmentation, the increase in the number of roadless areas is due to several formerly large contiguous areas being separated into multiple much smaller areas.

20 The E911 roads dataset used here is the most comprehensive statewide dataset for permanent roads. It includes all public and major private roads in organized towns and should be a reasonable indicator of major/permanent roads in the North Maine Woods (Daniel Coker, senior spatial scientist, The Nature Conservancy, personal communication). It was not possible to determine which smaller roads were included or excluded.

21 See page 17 for a fuller discussion of edge effects.

22 The area included in the Western Maine Mountains region for purposes of this analysis include nearly all of the Central-Western–White Mountains biophysical section and approximately one third of the St. John Upland biophysical section, as defined in Bailey (1995).

as general stores. The only major highways in the region are Route 201, Route 6/15 and Route 16/27. There are no major transmission lines crossing the undeveloped portions of the Western Maine Mountains north of Indian Pond. Six wind farms have been constructed in the southwestern portion of the region (U.S. Energy Information Administration 2017).[23] Between 2007 and 2017, approximately 116,000 acres (0.6%) of Maine's forest were converted to nonforest land uses. The Western Maine Mountains lost an estimated 12,000 acres during this period (NEFF in press).

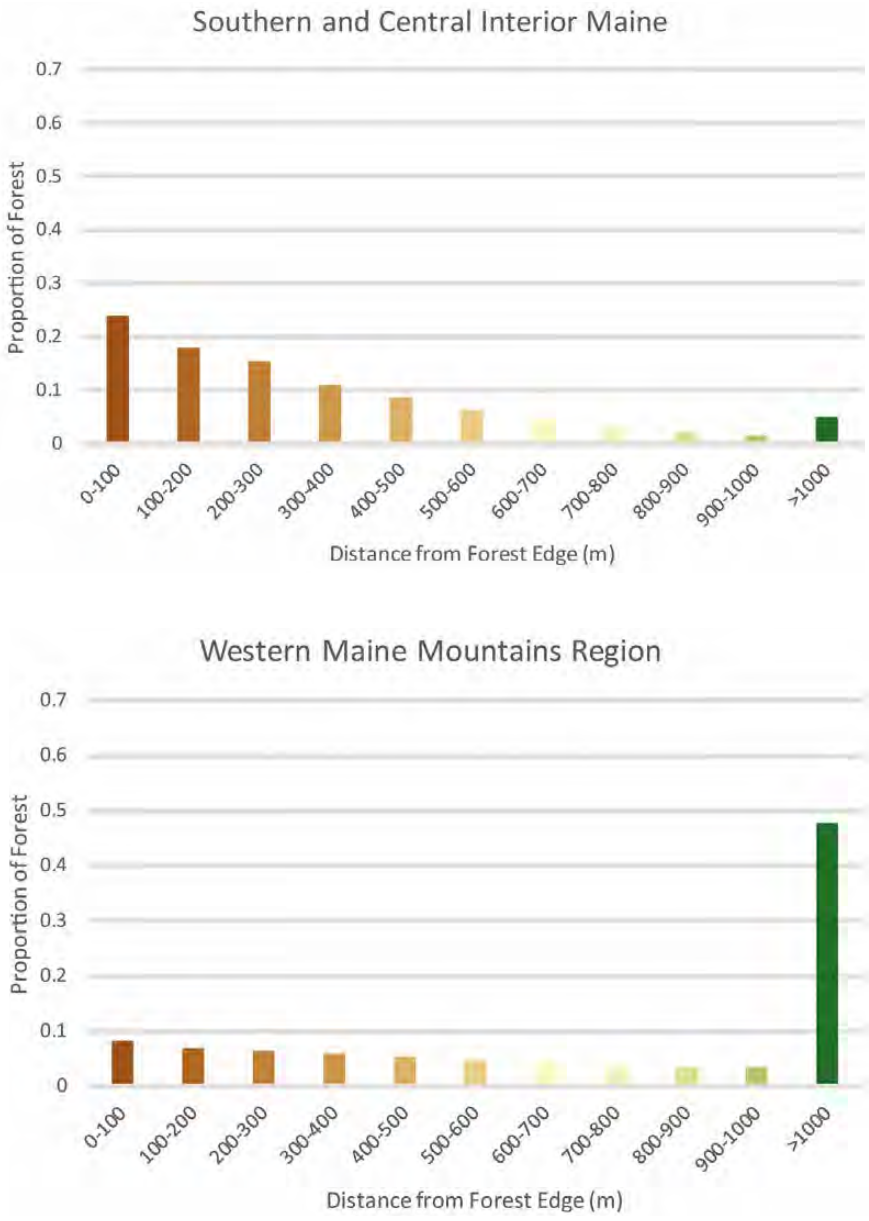


Figure 8a. Comparative percentage of distance to edge in southern and central interior Maine and in the Western Maine Mountains region based on data reflected in Figure 8b, following page. Analysis courtesy of The Nature Conservancy, Maine.

[23] As of 2017, wind farms in the region include Kibby and Chain of Ponds, Bingham Wind, Record Hill, Saddleback Ridge, Spruce Mountain Wind and Canton Mountain (U.S. Energy Information Administration 2017).

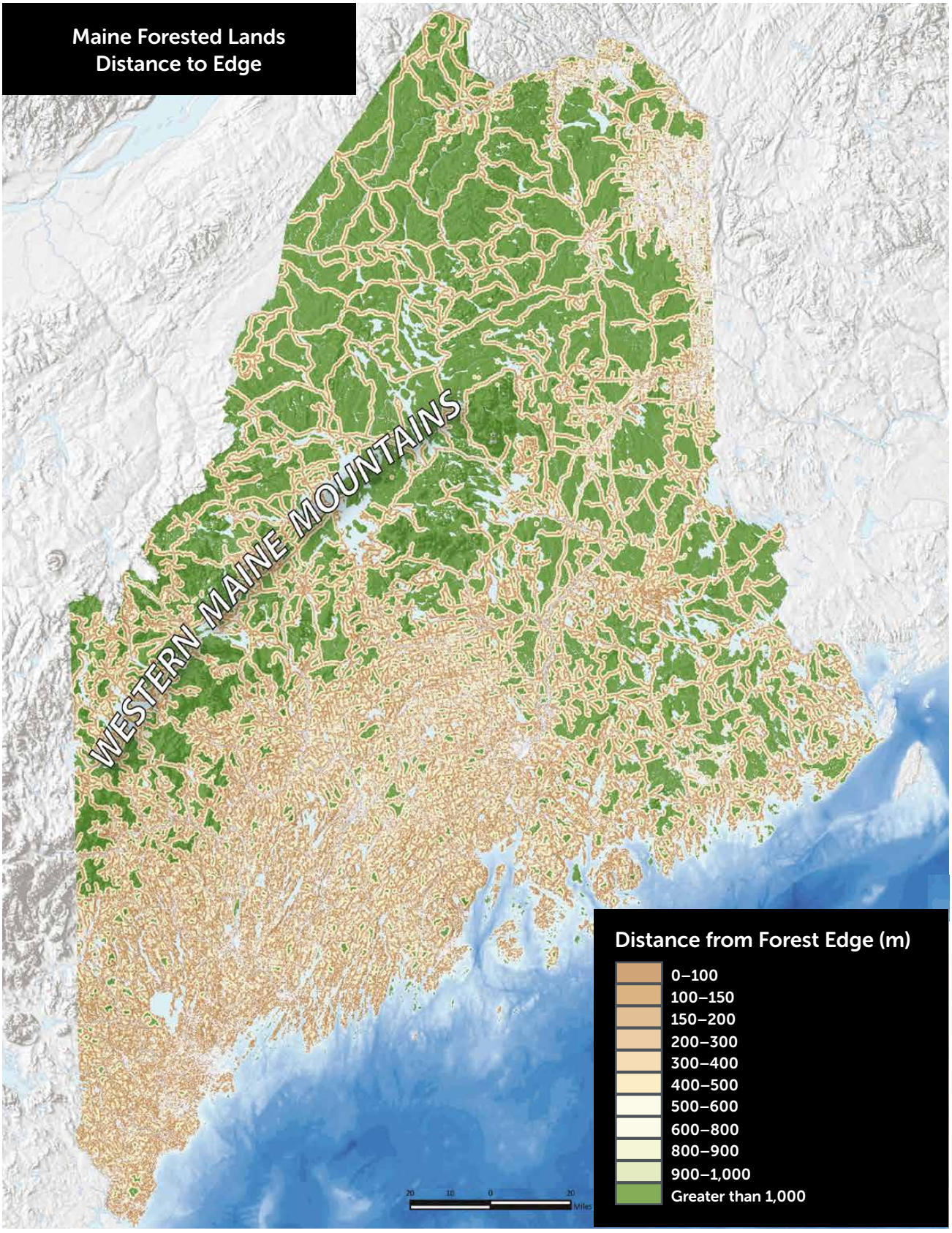


Figure 8b. Habitat blocks (green) and major roads are shown. Forest distance from an edge varies dramatically from northern Maine to southern Maine. Analysis and graphic courtesy of The Nature Conservancy, Maine.

A SUMMARY OF FOREST FRAGMENTATION IMPACTS

Forest fragmentation defined

Forest fragmentation is often defined as the breaking apart of forested landscapes into smaller and more isolated pieces. Implicit in this definition are changes in habitat patch size and distance between patches, as well as changes in the condition of the surrounding forest. These changes typically occur simultaneously and continuously, resulting in a large cumulative impact over time. However, it is a much more complicated process than this. In the Western Maine Mountains, fragmentation is largely caused by permanent features such as public roads, subdivisions and energy infrastructure. These features not only reduce the total amount of forest in a landscape, but they alter the environment in adjacent habitat because of edge effects. Fragmenting a forest landscape significantly increases the amount of forest edge next to a road, clearing or other fragmenting feature, which, in turn, greatly increases the total amount of land impacted. In addition, connectivity is impacted by the quality of habitat that remains in the surrounding forest. The extent that this forestland retains habitat value and is "permeable" to the movement of plants and animals depends on how it is managed and the species in question.

Forest fragmentation has the potential to compromise the Western Maine Mountains' biodiversity and connectivity and to drive ecological processes beyond the range of natural variability (Rowland et al. 2005). Different species are affected by fragmentation in different ways, depending on biological attributes such as habitat specialization, niche specialization, home range size, dispersal ability, mobility and a host of other factors (Lindenmayer and Fischer 2006). Some effects are immediate and local in extent while others occur at a landscape scale and are cumulative, playing out over decades or more. Other effects may be temporary, such as clearings created by timber harvests, or relatively minor, such as impacts associated with narrow, lightly used woods roads.

Research in Maine, the Northeast, and around the world demonstrates unequivocally that forest fragmentation—whether permanent or temporary—reduces native biodiversity and regional connectivity over time. A review of the literature indicates that fragmentation negatively affects terrestrial and aquatic ecosystems in a number of ways. The most severe effects, which are caused by roads, energy infrastructure, subdivisions and other permanent forms of fragmentation include:

- increased mortality and habitat loss from construction of roads and other fragmenting features
- increased mortality and other direct impacts associated with infrastructure after construction
- changes in species composition and reduced habitat quality from edge effects
- changes in species composition and behavior as habitat patch size delines[24]
- changes in hydrology and reduced aquatic connectivity
- introduction and spread of exotic species
- changes in the chemical environment
- pressures on species resulting from increased fishing, hunting, and foraging access
- loss of scenic qualities and remote recreation opportunities

In addition, forest management can have transitory fragmenting effects, such as acting as a barrier for species that need large connected areas of mature forest to thrive. New research suggests that this may compromise the ability of managed forestland to function as habitat or an ecological linkage for some species (see for example, Simons-Legaard et al. 2013).

---

[24] The terms "habitat patch," "patch," and "fragment" are used interchangeably in this paper.

Although each of these impacts are described separately on the following pages, they are interrelated and occur to varying degrees depending on the type of fragmenting feature, whether the feature results in permanent loss of habitat, the time elapsed since fragmentation began, and the habitat requirements of the species involved. It is essential to keep in mind that fragmentation is a continuous and cumulative process where the impacts of many smaller fragmenting features combine to create a large and often unpredictable regional impact, resulting in ongoing environmental degradation and species loss over time.

Mortality and habitat loss from construction of roads and other human infrastructure

Construction of roads, utility corridors and other human infrastructure kills any sessile or slow-moving animal and all vegetation in the path of the feature (Trombulak and Frissell 2000). Direct habitat loss from the footprint of these features can be significant. New projects have the potential to significantly increase the rate of fragmentation in the region. For example, the proposed New England Clean Energy Connect Project would destroy nearly 1,000 acres of wetland and forest habitat in the Western Maine Mountains, and edge effects from the permanently cleared utility corridor and access roads would increase the impacted area by an additional 13,000 acres, assuming a 1,000-foot edge effect on either side). In addition, during the 1–2 year construction period, an estimated 500 acres would be needed for roads and staging areas and additional wetlands would be filled. Other documented impacts of roads and utility corridor construction include elevated mortality of trees and other species in the adjacent forest, mortality of soil biota from physical changes in the soil under and adjacent to the roads, mortality of aquatic species from direct transfer of sediment into nearby streams and wetlands, and avoidance and other changes in behavior due to vehicle noise and light (Trombulak and Frissell 2000; Laurance et al. 2002; Laurance et al. 2017; Charry 2007).

Mortality and other impacts of infrastructure after construction is complete

Mortality of animals from road collisions is well documented (Van der Ree et al. 2015; Charry 2007; Trombulak and Frissell 2000). Roads and other linear infrastructure negatively impact wildlife through increased mortality, decreased habitat amount and quality, changing species movement patterns, and fragmentation of populations into smaller subpopulations, which are more vulnerable to local extinction. Roads are considered a driving factor in the decline of many species globally, from moose and grey wolves to insects and other invertebrates (Van der Ree et al. 2015; Benitez-Lopez et al. 2010; Andrews et al. 2008; Glista et al. 2007; Muñoz et al. 2015). They can also impede restoration efforts. For example, a 1989–1992 effort to reintroduce Canada lynx to New York state failed because the released lynx were largely transient and suffered high road mortality throughout the region (Daniel Harrison, professor of wildlife ecology, University of Maine, personal communication).



Figure 9. Canada lynx crossing road. Road collisions can be a major cause of lynx mortality. Photo by Jeremiah John McBride, CC BY-ND 2.0, https://www.flickr.com/photos/bullfrogphoto/3411471411.

In Maine and elsewhere, research indicates that amphibians and reptiles are particularly susceptible to roadkill because many species, such as wood frogs and spotted salamanders, migrate between wetlands where they breed and uplands where they live during the nonbreeding season. In addition, individuals are generally inconspicuous and sometimes slow-moving, and in the case of turtles, it takes a long time for individuals to become sexually mature—which increases the likelihood that animals will be killed by collision before they are able to reproduce, and young are vulnerable after hatching (Baldwin et al. 2007; Gibbs and Shriver 2002; Rosen and Lowe 1994; Fahrig et al. 1995). Road size, density and traffic volume and distance from wetlands, streams and pools affect the magnitude of these impacts. For example, dense networks of wide roads with high traffic volume can have significant impacts on breeding populations of turtles. Roads are the major cause of decline of spotted and Blandings turtles in southern Maine (Beaudry et al. 2008) and are contributing to the decline of wood turtles in the state, since these species move from streams to uplands to nest (Compton 1999). According to Gibbs (2002), "as little as 2–3% additive annual mortality is likely more than most turtle species can absorb and still maintain positive population growth rates."



Figure 10. Wood turtle crossing road. Declining turtle populations in many parts of Maine are attributed to road collisions. Photo by John Mays.

In addition to direct mortality, roads and utility corridors may serve as conduits for the movement of organisms across the landscape that are detrimental to native forest species—fostering the spread of alien plants and predators, or as a barrier or filter that prevents or impedes the movement of some sensitive species (Forman and Alexander 1998). For example, white-footed mice and some other rodent species are reluctant to cross roads (Merriam et al. 1989; Oxley et al. 1974). Others, such as black bears, have been documented to shift their home ranges away from areas with high road densities, and some predator and prey species may preferentially travel along road corridors, increasing the risk of collision and altering predator-prey interactions (Brody and Pelton 1989; Trombulak and Frissell 2000). Highly fragmented landscapes that result in unsuitable habitat around ponds at distances greater than 3,300 feet (1 kilometer) can preclude the recolonization of pools by amphibians and result in local extinctions of other wetland-dependent taxa, including small mammals, nonbreeding amphibians, and reptiles (Laan and Verboom 1990; Gibbs 1993). DeMaynadier and Hunter (2000) found that salamander populations avoid crossing wide (~40 feet) heavily used logging roads, while the impacts of narrow (<16 feet) woods roads were insignificant. Hung culverts and other drainage infrastructure associated with roads can also act as barriers, preventing upstream fish passage and access to breeding and feeding habitat for aquatic species. This is discussed further under aquatic connectivity.

As energy infrastructure expands in the Northeast and elsewhere, additional impacts are becoming apparent, such as avian and bat collisions with transmission lines and wind turbines; altered reproductive success and physiology of insects, mammals, birds, trout, and other species groups associated with electromagnetic radiation; loss of roosting sites; and altered movement patterns (Rytwinski and Fahrig 2015, Smallwood 2013; Jochimsen et al. 2004; Fensome and Matthews 2016; Van der Ree et al. 2015). In addition to direct collisions, there is growing evidence that electromagnetic radiation from transmission lines can have significant impacts on wildlife. For example, Fernie and Reynolds (2005) conclude that exposure of birds to electromagnetic radiation "altered the behavior, physiology, endocrine system, and the immune function of birds, which generally resulted in negative repercussions on their reproduction or development. Such effects were observed in multiple species, including passerines, birds of prey, and chickens in laboratory and field situations, and in North America and Europe." Long-term and before-and-after studies are needed on other species groups.

Changes in species composition and reduced habitat quality from edge effects

When a forest is fragmented by a road, clearing or other disturbance, there will be a zone of impact along the forest edge.[25] Edge habitat is typically windier, warmer, and drier than the forest interior (Hunter and Gibbs 2007). The extent of this "edge effect" is greater along high contrast edges—such as between a utility corridor and a forest, than along low contrast edges—such as between a regenerating clearcut and adjacent uncut forest. The relative amount of edge increases as patches become smaller and more complex in shape (Fig. 11a and Fig. 11b). The amount of edge is also greater for long narrow clearings, such as roads and utility corridors, than for more compact clearings of the same size, such as clearcuts.

The habitat lost or altered by edge effects can be many times greater than the footprint of the fragmenting feature itself (Laurance et al. 2017; Harper et al. 2005; McGarigal et al. 2001; Tinker et al. 1997). The longest-running forest fragmentation study from the Amazon indicates that the impact zone of fragmenting features such as permanent roads can extend from 30 feet to more than 1,300 feet into adjacent forestland (Laurance et al. 2002; Laurance et al. 2017). Increased insolation, changes in air temperature and humidity, altered plant, animal and microbial species composition, species invasions, and a host of other edge effects were observed. South of the Western Maine Mountains, most forests are well within the range where human activities, altered microclimate, and nonforest species may influence and degrade forest ecosystems. Here, habitat fragmentation often leads to the establishment of early successional habitat along forest edges because plants adapted to interior mature forest conditions typically have low dispersal capacities compared to disturbance-adapted "weedy" plants (Harper et al. 2005). This favors generalist species at the expense of forest interior species. In the United States, there is a great body of research that documents the impacts of development and edge habitat on birds (see reviews by Forman and Alexander 1998, Lindenmayer and Fischer 2006, and Van der Ree et al. 2015). For exam-

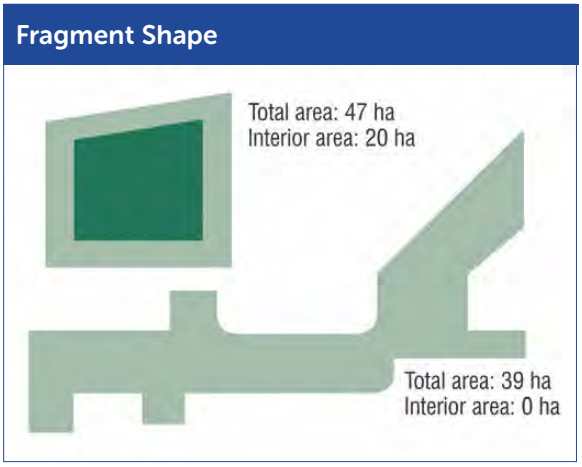


Figure 11a. Shape affects the percent of area affected by edge effects, as is shown by a comparison of the interior area available in two different shaped blocks of land. Adapted by Barbara Charry for Maine Audubon, from Verner et al. Wildlife 2000 1986, reprinted by permission of Wisconsin Press.

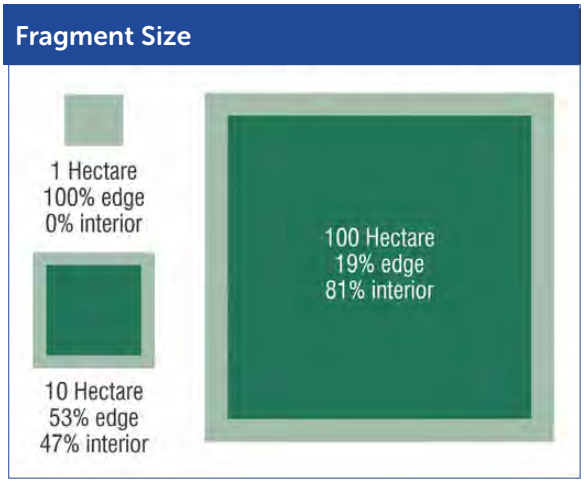


Figure 11b. Size affects the percent of interior area affected by edge effects, as shown in this comparison of the interior area of three different sized blocks. As fragment (block) size increases, the relative proportion of edge habitat decreases and interior habitat increases. Adapted by Barbara Charry for Maine Audubon, from Landscape and Urban Planning (36) Collinge, pg. 64, reprinted with permission from Elsevier Science.

[25] The edge of a habitat patch can be broadly defined as a marginal zone where the microclimatic and other ecological conditions differ from the those in the patch's interior (Lindenmayer and Fischer 2006; Matlack 1993).

ple, the decline of many ground-nesting, forest-interior species in the Northeast, such as the ovenbird and wood thrush, have been attributed to increased predation pressure from raccoons, cats and other generalist species that thrive along forest edges (Ortega and Capen 1999; De Camargo et al. 2018). Increased nest predation and reduced reproductive success can extend more than 2,000 feet into the adjacent forest. Other forest species, such as interior-forest–feeding bats, are affected by changes in insect prey, roosting habitat and other habitat features in forest edges (Grindal and Brigham 1998). The relationship between edge effects and patch size is complicated. Rosenberg et al. (1999) found that tanager species respond differently in different parts of their range and that landscape features interact to create population sources and sinks. The more continuity of forest cover and presence of many forest age classes on the landscape may reduce some species' sensitivity to edge effects.

The following table (Fig. 12) provides a summary of penetration distances of different edge effects associated with permanent fragmenting features documented from a 22-year experiment on forest fragmentation in the Amazon (Laurance et al. 2002; Laurance et al. 2017). Although analogous studies have yet to been done in the Northeast, there is abundant evidence that many of these edge effects are contributing to species declines and extinctions in the region (see reviews by Pfiefer et al. 2017 and Harper et al. 2005). One type of edge effect—invasion by exotic species—is discussed in more detail on page 22.

Disturbances that penetrate > 100 m	Disturbances that penetrate 50–100 m	Disturbances that penetrate 20–50 m
Increased wind disturbance	Reduced soil moisture	Higher understory foliage density
Elevated tree mortality/damage	Lower canopy-foliage density	Increased seedling growth
Invasion of disturbance-adapted butterflies	Increased air temperature	Invasion of disturbance-adapted plants
Altered species composition of leaf-litter ants	Increased temperature and vapor pressure deficit	Lower leaf relative-water contents
Invasion of disturbance-adapted beetles	Reduced understory bird abundance	Lower soil moisture content
Altered species composition of leaf-litter invertebrates	Elevated litter fall	Higher vapor pressure deficit
Altered abundance and diversity of leaf-litter invertebrates	Increased photosynthetically active radiation in understory	Higher leaf conductance
Altered height of greatest foliage density	Lower relative humidity	Increased phosphorus content of falling leaves
Lower relative humidity	Increased number of treefall gaps	Reduced density of fungal fruiting bodies
Faster recruitment of disturbance-adapted trees		
Reduced canopy height		

Figure 12. Documented Edge Effects Associated with Permanent Fragmenting Features from the Biological Dynamics of Forest Fragments Project. (Adapted from Laurance et al. 2002; Laurance et al. 2017.)

Although the Western Maine Mountains region has an estimated 10,000 miles of logging roads, the edge effects along most of these are less than that of typical roads in developed parts of the state because of lower traffic volumes, narrower road widths, unpaved surfaces, limited verge clearing and because some roads are gated when not in use. Nevertheless, studies in other areas suggest the cumulative impact of logging road networks can be significant (McGarigal et al. 2001; Forman and Alexander 1998). While the pace of private road construction has likely slowed as landowners have their modern transportation network mostly built out and some older roads have been abandoned, others are being replaced with newer, better and likely larger surfaces. The only place where road density is decreasing is in designated reserves where public agencies and conservation organizations have worked to close roads. More information is needed to evaluate the overall impacts of the logging road system on forest fragmentation in the region.

Changes in species composition and behavior as habitat patch size declines

A habitat patch is a relatively homogeneous habitat area that differs from its surroundings. Hunter and Gibbs (2007) give three main reasons why large habitat patches have more species than small ones. First, a large patch will almost always have a greater variety of environments than a small fragment, and each will provide niches for different species. Second, a large patch is likely to have both common and uncommon species, but small fragments are likely to have only common species. For instance, species with larger home ranges, such as black bear or bobcat, are unlikely to survive in smaller fragments. Finally, small fragments will, on average, have smaller populations that are more susceptible to being extirpated than a large population.[26]

Habitat requirements are species-specific. In Maine, patch size appears to be particularly critical for species associated with mature forest conditions, larger patch sizes and forest interiors. Many Maine birds, such as red-shouldered hawk, black-throated blue warbler, Canada warbler, ovenbird and wood thrush, require hundreds of acres of continuous, relatively closed-canopy forest to reproduce successfully, as do mammals with large home ranges, such as moose, bobcat, black bear and American marten (Charry 1996; Askins 2002). For example, Chapin et al. (1998) found that resident American martens established home ranges in areas where median intact forest patch size ranged from 375 to 518 acres, for males and females respectively. These area-sensitive and habitat specialist species will start disappearing when the size of habitat blocks falls below a certain threshold (Askins 2002; Blake and Karr 1984; Whitcomb et al. 1981). Roads, clearings, residential development and other features can act as barriers, preventing animals from using habitat that is nearby for breeding or feeding. Populations can become subdivided, and eventually animal species are lost from an area as it gets too small to support an isolated population, or is too far from a source population for recolonization to occur (Lindenmayer and Fischer 2006; Charry 1996; Forman and Alexander 1998; Laurance et al. 2017; and others). Conversely, species sensitivity to fragmentation may be lower in regions with greater overall forest cover (Rosenberg et al. 1999).

Hanski (1998) hypothesizes that when the total amount of suitable habitat in the landscape falls below 20–30%, the viability of local populations is reduced. Other studies suggest that population declines accelerate when available habitat falls below even higher thresholds (Andrén 1994). For example, Homan et al. (2004) found that wood frogs were less likely to occupy breeding pools where the amount of suitable forest habitat

---

[26] In 1967, MacArthur and Wilson put forward the groundbreaking theory that island size and degree of isolation are highly correlated with biodiversity. Hunter and Gibbs observed that while island biogeography theory does not always directly apply to terrestrial landscapes, it provided insights fundamental to understanding the effects of reducing patch size and connectivity in terrestrial landscapes.

within approximately ~3,300 feet (1 kilometer) was less than 45% and spotted salamanders were less likely where forest habitat within ~1,150 feet of a pool was less than 40%.

Forest fragmentation also influences plant populations. In their *State of the Plants* report, the New England Wildflower Society (2015) documented a mean 67% loss of previously recorded range for 71 rare plant species. One of the main contributing factors was fragmentation of habitat across species' ranges, which isolated populations and reduced their ability to disperse.

Small size combined with increased isolation of habitat patches can also affect behavior, biology and interactions of species. Impacts include reduced breeding success, changes in predator-prey relationships, changes in ability to disperse and increased competition for resources (Lindenmayer and Fischer 2006). For example, before their demise as a result of chestnut blight, it was believed that stands of American chestnut needed to be above a certain size to produce enough seed to overcome pressure from seed predators (Rosenzweig 1995; Lindenmayer and Fischer 2006).

Changes in hydrology and reduced aquatic connectivity

Fragmentation of terrestrial habitats often leads to fragmentation of river and stream networks. The division and isolation of watersheds and stream networks by dams, roads and culverts is one of the primary threats to aquatic species in Maine and the United States (Martin and Apse 2011). Intact forested blocks are essential to protecting stream networks. Forested stream corridors intercept sunlight, moderating water temperature (Moore et al. 2005). Riparian trees also contribute the majority of coarse organic material, in the form of leaves and downed wood, and fallen leaves frequently form the base of the food webs of small streams (Vannote et al. 1980). Large woody material generated from large fallen trees adjacent to streams has a major influence on stream ecosystem structure and function (Dolloff and Warren 2003).

The impact of aquatic fragmentation on aquatic species generally involves loss of access to quality habitat for one or more life stages of a species. For example, dams and impassable culverts prevent brook trout populations from reaching upstream thermal refuges, which are critically important as the climate warms. In addition, roads can have significant effects on the physical environment. Roads can interrupt subsurface flows and patterns in aquatic systems when water flows are rerouted into road ditches and culverts (Lindenmayer and Fischer 2006; Forman and Alexander 1998). The impervious nature of roads increases runoff, erosion, sedimentation and water-level fluctuations, and can flood adjacent wetlands (Andrews et al. 2008; Al-Chokhachy et al. 2016). Temporary pools in ditches and ruts can be population sinks for amphibians that breed there instead of higher quality vernal pools (Andrews et al. 2008).

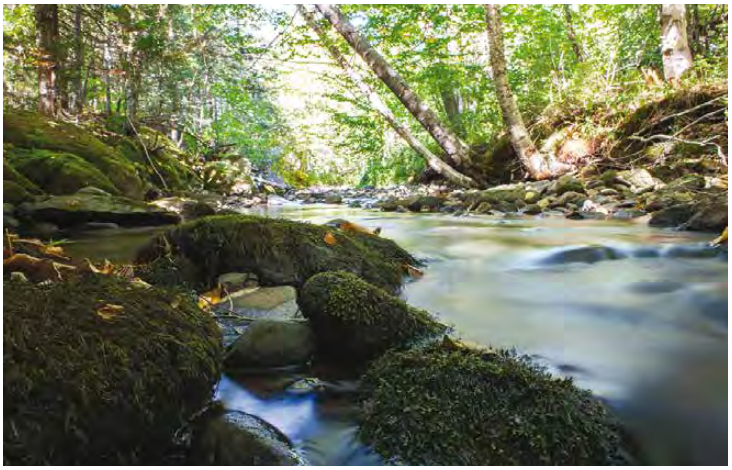


Figure 13. Cool mountain streams, like this one in the High Peaks region of the Western Maine Mountains, provide critical habitat for brook trout and other coldwater species. Photo by Charlie Reinertsen Photography.

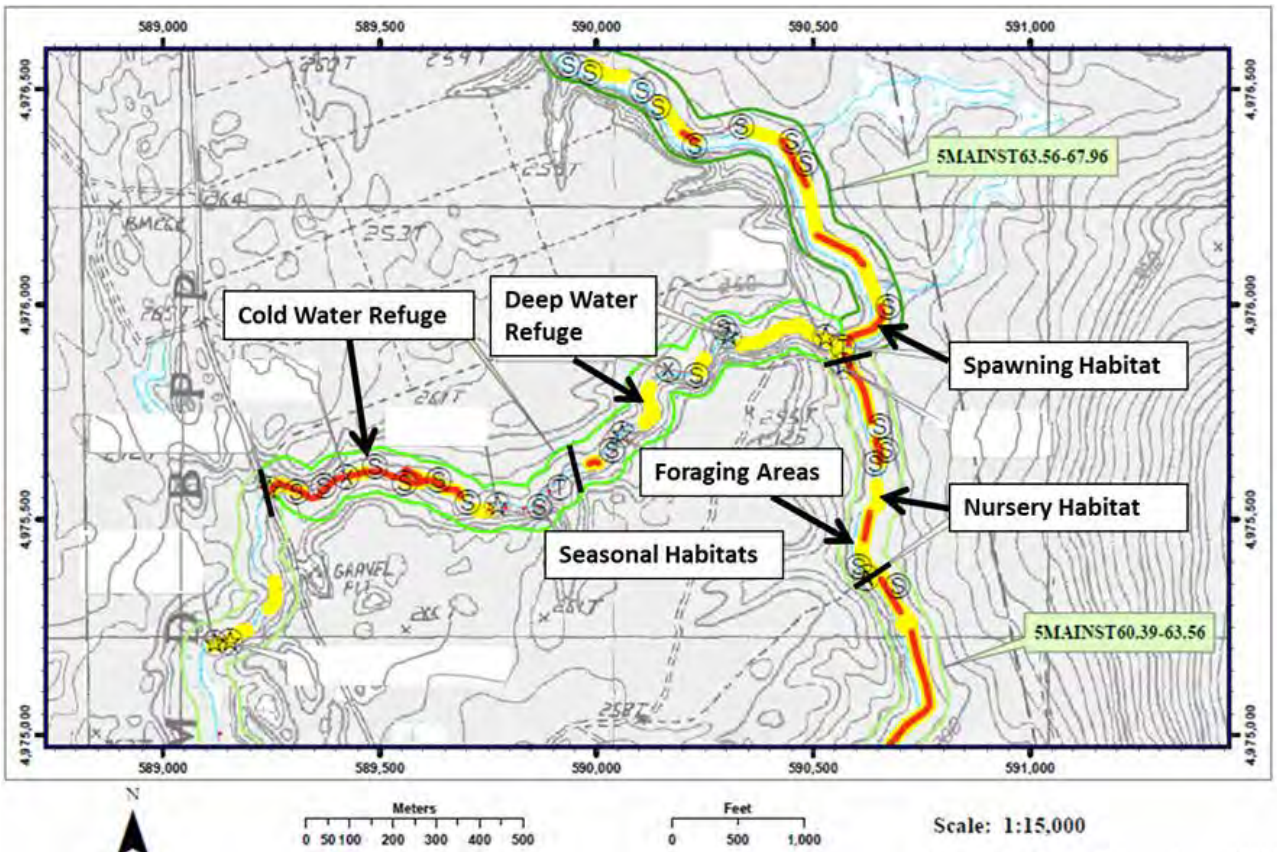


Figure 14. Fish need to move: brook trout use a variety of in-stream habitats to meet their daily and annual needs for feeding, resting and breeding. They often move up and down streams and into tributaries to find food and refuge. Graphic modified from the Maine Atlantic Salmon Atlas (2006) by Alex Abbot and the U.S. Fish and Wildlife Service's Gulf of Maine Coastal Program.

A bellwether species in the Western Maine Mountains is brook trout, which requires cool, clean, connected networks of streams and lakes (Fig. 14). A 2006 range-wide study of this species found that Maine is the only state in the eastern United States with extensive intact populations of wild, self-reproducing brook trout in lakes and ponds. Furthermore, Maine is the last true stronghold for stream-dwelling populations of wild brook trout, supporting more than twice the number of intact subwatersheds than the other sixteen states in their eastern range combined (Trout Unlimited 2006). Although wild brook trout waters are found elsewhere in northern Maine, they are most prevalent in the Western Maine Mountains (Trout Unlimited 2006; DeGraaf 2014). The high habitat integrity of the region is due to a combination of cool temperatures and an abundance of large, connected stream networks. The cooler region provides optimal conditions, with fewer competing, nonnative fish species than the southern or coastal parts of the state. Large patch size of intact brook trout habitat allows fish to migrate to cooler water when portions of their habitat grow too warm.

The Nature Conservancy's Conservation Gateway maps show a region with few dams and high stream connectivity. This is not the case for much of southern Maine, where many public- and private-road stream crossings in the region do not meet recommended standards.[27] Maintaining aquatic connectivity is critical to

[27] These include: (1) spanning the entire width of the natural stream; (2) setting the elevation to match the natural stream; (3) matching the slope to the natural stream; and (4) ensuring that the stream bed is made up of natural materials (see Maine Department of Transportation and www.maineaudubon.org/projects/stream-smart).

maintaining brook trout populations in northern Maine (Trout Unlimited 2006; Fesenmyer et al. 2017; Coombs and Nislow 2014). Conserving habitat for this umbrella species, in turn, will ensure the survival of other plants and animals that require pristine aquatic habitats.

Introduction and spread of exotic species

Invasion by exotic plant species is a common and widespread impact of fragmentation that can result in displacement of native species. In general, non-native invasive plant species thrive in disturbed and early successional habitats. Invasive plants can become established in roadside ditches, along utility corridors, on soils disturbed by residential or commercial development and on soils disturbed by timber harvests that border developed areas. In addition, seeds can be introduced in road fill and through planting of exotic ornamental species. Common traits of invasives include rapid growth, light and drought tolerance, bird-disseminated seeds, and the ability to outcompete native plants (Webster et al. 2006).

Invasive non-native woody plant species have the potential to profoundly alter the structure and function of forest ecosystems. Invasive woody and herbaceous plants rapidly colonize forest edges and may penetrate more than 330 feet into the forest interior, altering or eliminating habitat for native plants (Charry 1996). Wetland and aquatic invasives pose a similar threat in wetland and aquatic ecosystems. Because many invasive plant species have the ability to form dense monocultures, they have a competitive advantage in forest understories, particularly in edge habitat. In addition, most species have relatively few—if any—natural predators in their introduced ranges (Webster et al. 2006; Woods 1993). Other impacts include changes in soil chemistry and biota—which may suppress native tree regeneration—and reduced or eliminated foods used by pollinators, fruit and seed eaters and herbivores (Silander and Klepeis 1999; Charry 1996; Webster et al. 2006; Burnham and Lee 2010; Ehrenfield et al. 2001; Heneghan et al. 2006; Hunter and Mattice 2002).

Large forest blocks appear to resist woody plant invasions better than land that has a history of agricultural or residential use (Mosher et al. 2009). The resistance of large intact forest blocks to invasion probably stems from two main factors: the deep shade created by mature trees and the buffering effect of large block size, which serves to isolate interior portions of the forest from invasive seeds. If present land use trends continue, increased fragmentation of forest parcels may allow edge-adapted invasive plants such as glossy buckthorn, oriental bittersweet, Japanese barberry, and bush honeysuckles to get a deeper foothold into forest blocks. Eventually, this could allow woody invaders to take advantage of disturbances such as logging within the major forest blocks of the region, displacing native species as a result (Mosher et al. 2009; Webster et al. 2006; Silveri et al. 2001).



Figure 15. Oriental bittersweet infestation in Cape Elizabeth, Maine. Photo from Maine Natural Areas Program, Maine.gov.

Many terrestrial invasive plant species and wetland invasives, such as purple loosestrife and phragmites, are already well established in southern Maine and have expanded to the edges of the Western Maine Mountains (*iMapInvasives Database*). These species thrive in utility corridors and roadside ditches (Fig. 16). With roughly one third of Maine's flora comprised of non-native plant species (and most of these already established in the southern part of the state), the cause-and-effect relationship between fragmentation and the establishment of non-native plant species poses a significant threat to native species and habitats in northern Maine (Mosher et al. 2009; Charry 1996).

Woody invasive plants are part of a much larger invasion of alien species of plants, insects, and disease that has the potential to fundamentally alter the composition and structure of eastern forests (Webster et al. 2006). Invasions by insects such as emerald ash borer, Asian longhorn beetle, and browntail moth are tied to both inadvertent transport by people and climate change. The relationship between the spread of these species and forest fragmentation is unclear, although new roads will increase the likelihood of transport by people and vehicles into the region.



Figure 16. Phragmites, an invasive exotic grass, established along a southern Maine highway. Photo by Janet McMahon.

There is currently a low incidence of terrestrial invasives in the Western Maine Mountains, although invasive plant species are established along the southern border of the region. No aquatic invasive plant species, invasive insect pests or invasive tree species, such as Norway maple and black locust, are currently documented in the Western Maine Mountains. Three invasive herbs have been confirmed in the interior of the Western Maine Mountains and sixteen invasive herbs and shrubs have been confirmed at the region's margin, primarily in developed areas[28] (*iMapInvasives Database*) (Fig. 17, following page). Fragmentation from major utility corridors, roads and new residential and commercial development has the potential to open the region to these and other invasives.

[28] MNAP lists 68 species of invasive plant species that are currently documented in Maine or are probable. I reviewed MNAP's *iMapInvasives Database* to determine presence/absence of all documented species in the region. The three species confirmed in the Western Maine Mountains' interior include reed canary grass, common reed and coltsfoot. Because field effort in the region is low compared to other parts of the state, invasive species occurrences may be under-reported. I have not surveyed the Western Maine Mountains systematically, however, my observations in areas visited suggest that most terrestrial invasive plant species are absent or rare, especially in the region's interior.

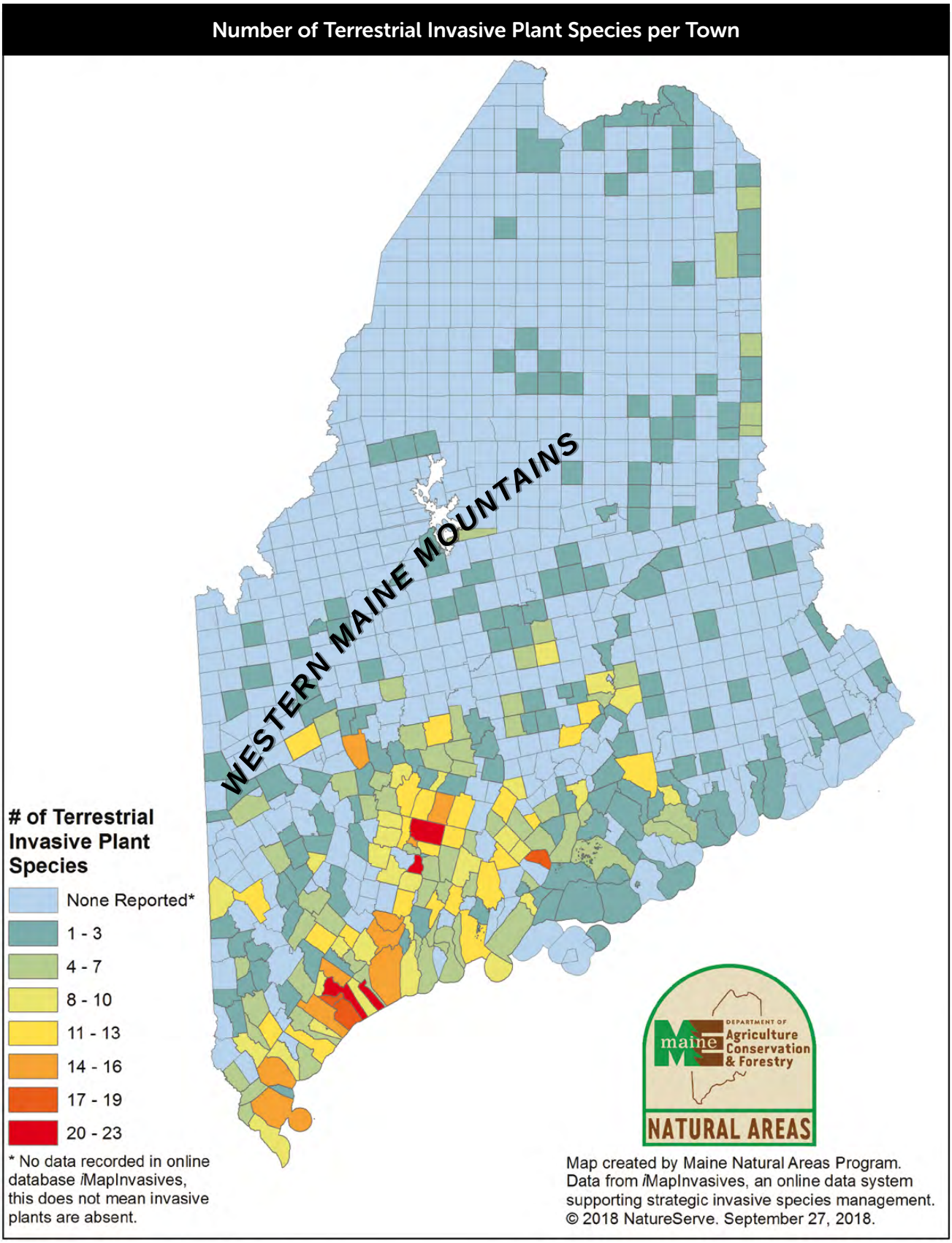


Figure 17. Documented terrestrial invasive plant species in Maine. The Western Maine Mountains are relatively free of terrestrial plant species. Fragmentation from major utility corridors, roads and new residential and commercial development has the potential to open the region to these invasives. Map courtesy of the Maine Natural Areas Program in the Maine Department of Agriculture, Conservation and Forestry.

Changes in the chemical environment

Use and maintenance of roads, utility corridors and windfarms contribute at least five different general classes of chemicals to the environment: heavy metals, salt, organic molecules, ozone and nutrients (Trombulak and Frissell 2000). These are mostly derived from fuel additives, deicing salts and herbicides. Contamination of soils, plants and animals can extend tens to hundreds of meters from a road or power line right of way depending on the contaminant, wind, and if the chemicals reach flowing water. Trombulak and Frissell summarize a number of impacts on plants and animals, such as the poisoning of habitats so they no longer have adequate carrying capacity, mortality or reduced health and growth from exposure, bioaccumulation of chemicals that makes species toxic to predators and increased concentrations of salts that can attract large mammals to roadsides, increasing vehicle collision risk. The high skin permeability of amphibians make them particularly susceptible to toxins from road salts and other chemicals (Andrews et al. 2008).

Pressures on species resulting from increased fishing, hunting and foraging access

Increased road density and access into remote areas can lead to increased hunting, trapping, fishing, poaching, disturbance to wildlife, trampling and other direct human impacts on biodiversity in forest and aquatic ecosystems (Laurance et al. 2002 and 2017; Haddad et al. 2015; Brocke et al. 1988). A study of the relationship between density of publicly accessible roads and moose populations in Nova Scotia found that natural populations declined when road density exceeded a threshold of 0.6 km/km^2 (~1.4 mi/mi^2). This was attributed to the fact that most moose hunting occurred along roads (Beazley et al. 2004). They concluded that road density may be among the key factors influencing habitat productivity, and thus critical habitat area and population viability, for moose in mainland Nova Scotia, as well as for other species sensitive to the effects of roads, such as Canada lynx, American marten and black bear.

The USDA Forest Service has found that illegal introduction and harvest of fish species are more likely to occur in areas with ready access (Gucinski et al. 2000). Increased road density and improved access into remote ponds have been linked to regional declines of lake trout and introduction of invasive fish species such as smallmouth bass in northern Ontario (Kaufman et al. 2009). In Maine, unauthorized introductions of invasive fish species, such as small and largemouth bass, are threatening native fish species populations—especially brook trout—and can ultimately impact entire aquatic systems. In the past, the majority of introductions occurred in populated portions of the state, but in the past decade, introductions are occurring at a higher rate in western and northern Maine where most of the state's wild brook trout populations are located. Improved road access and development are likely contributing factors (Merry Gallagher, research fisheries biologist, Maine Department of Inland Fisheries and Wildlfe, personal communication). Increased access is also likely to lead to overharvesting of species such as chaga, ginseng and ramps that are collected for food, medicine and other purposes.

Loss of scenic qualities and remote recreation opportunities

Maine has a long tradition of hunting, fishing, guiding and remote camping that is closely bound to the undeveloped and scenic character of its northern forests, lakes and mountains. These uses are a major and growing economic driver in northern Maine (David Publicover, senior staff scientist, Appalachian Mountain Club, personal communication). Degradation of the skyline caused by utility corridors, major road right of ways, sprawl from development, wind farms and associated light pollution are general aesthetic impacts of for-



Figure 18. Fishing at Lake Mooselookmeguntic. Photo by Sarah Haggerty.

est fragmentation. These affect remote recreation and other human values associated with large undeveloped areas. Most vistas from mountains and water bodies in the Western Maine Mountains provide long scenic and unbroken views. Roads are generally screened by the forest canopy, but wind towers and transmission lines with wide, cleared right of ways are conspicuous features on the landscape. Other than Routes 201, 16/27 and 6/15, there are currently no major highways or transmission corridors impacting the high scenic value of the region. The proposed New England Clean Energy Connect Project transmission corridor would be one of the largest fragmenting features in the Western Maine Mountains region, dividing it in two and crossing 53.5 miles of forest.

Potential fragmenting effects associated with forest management

Many species that need intact forest patches for their core habitat are also affected by the condition of the matrix forest surrounding these patches. It is well recognized that the condition of the matrix forest that surrounds intact mature habitat patches can affect regional biodiversity and landscape connectivity. In general, connectivity and biodiversity are reduced when the matrix forest becomes simplified in terms of species and structural diversity. Prevedello and Vieira (2010) found that a matrix that is more similar in structure to intact habitat patches will increase functional habitat and decrease isolation of patches. Timber harvesting can have a significant fragmenting effect, although the degree of impact depends on the extent, intensity and frequency of harvesting. As the extent and intensity of harvesting increases, the extent of interior forest habitat—especially large contiguous blocks—decreases. And while the impact of any individual harvest is temporary, cumulative harvesting patterns typically create a shifting mosaic of early successional stands, edge habitat and interior forest habitat across the landscape.[29]

Managed forest makes up about 90% of the Western Maine Mountains. While this forest remains largely unfragmented by permanent features such as public roads and residential development, it has been greatly

[29] It is important to note that forest management and timber harvesting can be practiced in a manner that maintains or enhances wildlife habitat over time (DeGraaf et al. 2007).

modified by forest practices in the past half century. In the presettlement forest, where large-scale stand-replacing disturbances were rare events, the majority of the landscape would have been composed of older stands that were allowed to develop uninhibited into a late-successional condition (Lorimer 1977; NEFF in press). Today, although a full suite of native tree species remains, there has been a broad ecological shift away from late successional taxa, such as red spruce and hemlock, in favor of early- and mid-successional taxa, such as red maple and aspens (Thompson et al. 2013). In the past half century, large areas of spruce-fir forest have been converted to deciduous and mixed types due to regeneration of hardwoods after high-intensity spruce-fir harvests. In addition, the total amount of mature forest on the landscape has decreased along with the patch sizes in which these mature forests occur, and there is a correspondingly larger amount of edge between intact mature forest and harvested forest (NEFF in press; Legaard et al. 2015). Today only 1.4% of Western Maine Mountains forests are in a late-successional condition[30] and only 3% are classified as large saw timber[31] by the Maine Forest Service (NEFF in press). This compares to a presettlement forest where 59% or more of the forest was older than 150 years (Thompson et al. 2013; Lorimer and White 2003; Barton et al. 2012). An initial assessment of Ecological Reserve Monitoring data quantifies differences in forest structure between older stands in reserves and Maine's managed forests. Ecological reserves have greater average live-tree basal area, more large and very large trees, more standing dead trees, and more downed woody material (Kuehne et al. 2018). In short, the combination of spruce budworm era salvage cuts in the 1970s and 1980s and widespread partial harvesting[32] since the 1990s has created a modern forest that is younger, more homogeneous, and less coupled to local climatic controls (Thompson et al. 2013).[33]

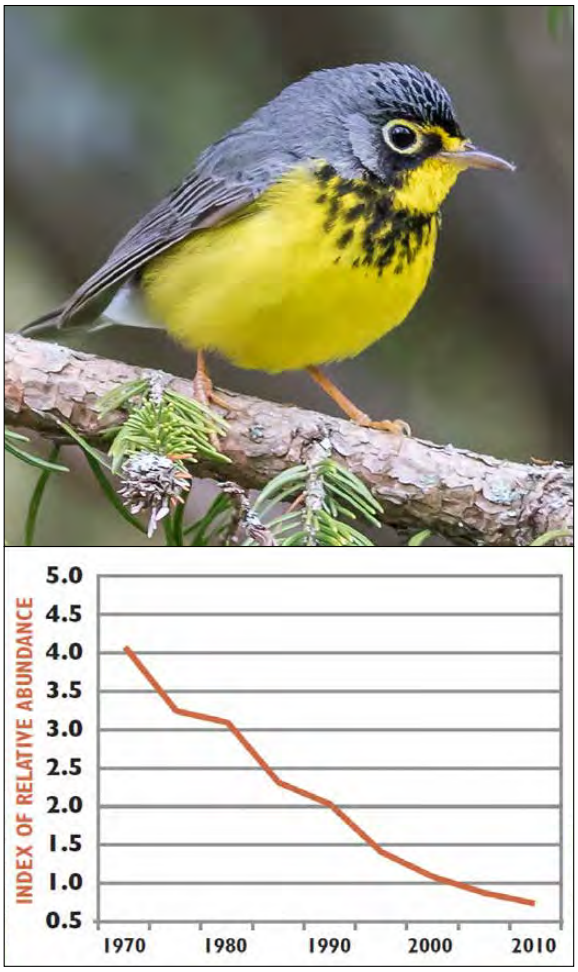


Figure 19. Species requiring mature coniferous or mixed forest habitat, such as the Canada warbler, are decreasing due in part to loss of summer breeding habitat. Graphic courtesy of Maine Audubon.

The result of these structural changes is a change in both plant and animal species composition at all forest stages (Legaard et al. 2015).[34] Species that require larger connected patches of older forest are particularly susceptible. For ex-

[30] Late-successional stands are greater than 120 years old, have a multi-storied canopy, and have at least 15 trees per acre (either alive or standing dead) > 16" DBH (diameter at breast height). Unmanaged late-successional stands tend to have cohorts of trees of different ages, large living and dead trees, large-diameter logs on the forest floor, vertical structural complexity and different-sized canopy gaps (Franklin et al. 2002).

[31] Stands with > 100 ft^2 basal area in trees > 5.0" DBH in which trees > 15" comprise at least 50% of the basal area.

[32] Partial harvests are areas that have been subject to a commercial partial harvest, including shelterwood and any other harvest method involving partial overstory removal (McGarigal et al. 2001; Legaard et al. 2015). The result is typically a dispersed low-density canopy.

[33] See Legaard et al. (2015), Simons-Legaard et al. (2018) and NEFF (in press) for detailed analyses of current forest condition.

[34] Legaard et al. (2015) used a time series of Landsat satellite imagery (1973–2010) to evaluate cumulative landscape changes in an area of western and northern Maine that included about half of the Western Maine Mountains.

ample, Payer and Harrison (2003) found that forests with large patches of large trees in a mature condition, either deciduous or coniferous, generally provide the structural stand attributes required by a wide variety of species such as American marten, northern flicker, wood thrush and northern long-eared myotis (a bat) (NEFF in press). Although not researched in Maine, a similar pattern is evident for forest birds in boreal habitats to the north. For example, Schmiegelow et al. (1997) found that, as the acreage of older forest declined, neotropical migrant bird species that require mature forest conditions declined in both connected and isolated fragments of such habitat, and resident species declined in isolated fragments.

Changes in forest structure also impact pool-breeding amphibians, which in the Northeast are sensitive to harvesting practices that reduce overstory canopy levels to less than 50%. Canopy closure, along with natural litter composition and coarse woody material within 100 to 400 feet of vernal pools, are important habitat elements required by salamanders and other amphibians (deMaynadier and Houlahan 2008; Popescu and Hunter 2011; Ross et al. 2000).

Changes in the composition and structure of the matrix forest as a result of harvesting, although temporary, can also impact generalist species such as white-tailed deer. Near the northern edge of their geographic range, where snow can restrict mobility and access to forage, white-tailed deer depend on mature conifer forests for wintering habitat. In a 1975–2007 time-series Landsat imagery analysis, Simons-Legaard et al. (2018) documented that fragmentation and reduction of mature conifer forest habitat significantly reduced the amount of deer wintering areas[35] in the Western Maine Mountains. The extent of currently zoned deer wintering habitat and habitat under cooperative agreement in the region is currently estimated to be only 34% of what is recommended (Nathan Bieber, personal communication). Simons-Legaard et al. conclude that continued forest-type conversion is expected to extend the effects of habitat fragmentation on northern deer populations and other species that require mature conifer forest into the future (Simons-Legaard et al. 2018).

Other than research on forest trees, there has been little research on the impacts of patch size and condition on vascular and nonvascular plants. Some lichen, liverwort and bryophyte species are dependent on the woody debris and dead and dying trees associated with older stages of spruce-fir forest development. These structural features can require several decades to recover, unless the woody material is intentionally left (Selva 1994; Gawler et al. 1996; Rowland et al. 2005). Small isolated populations can become too far apart to recolonize the areas in between and exchange genetic information.

We are just beginning to understand the scope of these changes in the forest matrix and their long-term effects on species dispersal, richness, abundance and persistence, community composition and ecosystem function. While connectivity within the matrix forest of the Western Maine Mountains is currently high, there is growing evidence that American marten, forest birds and other species that require larger patches of mature forest are declining in the region as the stepping stones of suitable habitat become fewer and farther between. This topic is in urgent need of study by the scientific community.

---

35 The Maine Department of Inland Fisheries and Wildlife defines deer wintering areas as forested areas used by deer when (a) snow gets to be more than 12 inches deep in the open and in hardwood stands, (b) the depth that deer sink into the snow exceeds 8 inches in the open and in hardwood stands, and (c) when mean daily temperature is below 32 degrees Fahrenheit. Ideal wintering areas (primary winter shelter) are dominated by mixed or monospecific stands of cedar, hemlock, spruce and fir, with a stand height of 35 feet.

LONG-TERM CONSEQUENCES OF FOREST FRAGMENTATION

Fragmentation is a continuous and cumulative process that leads to degraded habitats and loss of species over time. There is a growing body of research that suggests that the ecological dynamics in fragmented landscapes are a stark contrast to the dynamics in intact landscapes (Haddad et al. 2015). Although there are currently few long-term studies of the impacts of permanent forms of forest fragmentation on biodiversity and connectivity in the Northern Appalachian-Acadian Forest Ecoregion, research from elsewhere shows strong and consistent responses of organisms and ecosystem processes to fragmentation arising from decreased habitat patch size, decreased connectivity and the creation of habitat edges (Haddad et al. 2015; Lindenmayer and Fischer 2006). In general, the greater the difference between forested patches and their surrounding environment and the smaller and more isolated patches become, the greater the impact on biodiversity and ecosystem function. Haddad et al. (2015) identify three processes that drive long-term and progressive impacts of fragmentation: (1) temporal lags in extinction, (2) immigration lags and (3) ecosystem function debt.

Extinction debt

Temporal lags in extinction, or "extinction debt" is simply the delayed loss of species due to fragmentation. Hagan and Whitman (2004) suggest that we may be accruing "extinction debt" in Maine forests, describing the process as follows:

> Once old forest elements such as large trees or logs are lost from a stand (e.g., as a result of a clearcut, or even a selection cut), it can take centuries for the species [dependent on such features] to return to that location. A species first has to wait for these structural features to redevelop, and then the species has to find them. Scientists are beginning to understand that forest continuity is key to many forest species. [This temporal] continuity refers to the persistence of big trees and big logs in a forest stand over a very long period of time (centuries), even though the stand might be subjected to many different disturbances, such as fire, wind, disease, or even selection logging. Species that move or disperse slowly through the landscape, and prefer large old trees or logs, are the species most at risk to the loss of older forests.

In addition to the inability of organisms to disperse, extinction debt from fragmentation may be tied to genetic traits of populations, rarity, reproductive mode, life span and a host of other factors (Haddad et al. 2015). Extinction debt is often overlooked because many of the species lost tend to be small and uncharismatic, such as insects, fungi and mosses—and yet these species may be critical for ecosystem function. In the Western Maine Mountains, changing land use patterns from permanent and temporary forms of fragmentation have already caused changes in species composition and will likely cause changes in plant and animal abundance over time. Two of these changes include the increased proportion of early successional species and the large-scale reduction in the structural complexity of forest stands on which other forest organisms and ecological processes may depend (Rowland et al. 2005; Hagan and Whitman 2004). To fully understand the implications of extinction debt in the forests of the Western Maine Mountains, more long-term studies are needed.

Immigration lag

In general, smaller and isolated fragments are slower to accumulate species after disturbance than large or connected habitat blocks. In other words, because it takes longer for species to recolonize small patches, the successional transition from cleared land to mature forest conditions may take longer to occur (Haddad et al. 2015; Cook et al. 2005). This phenomenon is called "immigration lag" (Haddad et al. 2015). Most fragmen-

tation studies have been done in agricultural or suburban landscapes, long after the onset of fragmentation. Research on industrial forest land suggests that the process of immigration lag is a complex one. For example, Hagan et al. (1996) found that densities of several forest-dwelling bird species can increase within a forest stand soon after the onset of fragmentation as a result of displaced individuals packing into remaining habitat. However, because forest songbirds are highly territorial during the breeding season they cannot simply shift elsewhere unless there is unoccupied habitat. Furthermore, it is widely thought that these species establish territories in the best habitat available. If displaced, they could be forced into poorer quality habitat resulting in reduced pairing success and productivity over time. This was the case for ovenbirds in the Hagan et al. (2015) study. Their models and data suggest that large tracts of forest are important because they are relatively free from the variety of plant and animal population dynamics that might take place near new edges, including the encroachment of individuals displaced by habitat loss. Immigration lag may also mask the risk of invasion by exotic species since there may be a long lag between introduction, colonization, and rapid range expansion of some invasive species (Webster et al. 2006).

Ecosystem function debt

Ecosystem functions, such as nutrient cycling and decomposition rates, can also be reduced or lost over time—a process called ecosystem function debt. Evidence suggests that during forest succession, this delayed loss of function is greater in smaller, more isolated fragments (Cook et al. 2005; Billings and Gaydess 2008). The mechanisms for this are complex. Functional debt can result when fragmentation causes food webs to be simplified as species are lost, or when altered forest succession patterns resulting from permanent fragmentation or forest practices that cause changes in tree density, light and moisture, which impair ecosystem function (Haddad et al. 2015).

While there is abundant evidence that the forests of the Western Maine Mountains continue to change as silvicultural practices interact with natural successional processes and a changing climate, Legaard et al. (2015) and Simons-Legaard et al. (2018) are the first two studies to document spatial changes in the forest over time in Maine. Their research suggests that the long-term processes described above are beginning to play out in the Western Maine Mountains. The American marten provides an example of how a species responds to long-term habitat changes associated with fragmentation. While the forests of the region currently support marten, recent research suggests that forest harvest practices on two-thirds of Maine's commercial forestland are creating habitat that no longer serves the needs of this umbrella species, and by implication the many other terrestrial forest vertebrate species that use similar habitat (Hepinstall and Harrison in prep.); Simons-Legaard et al. 2013; Fuller and Harrison 2005; Homyack et al. 2010; McMahon 2016).

A changing climate

If left unchecked, increased fragmentation from permanent and temporary features is expected to exacerbate the impacts of climate change on biodiversity and connectivity in the region. Whitman et al. (2013) summarize how Maine's biodiversity and ecosystems are likely to change in the coming decades.

> The region can anticipate shifting species distributions, with an increasing number of novel species moving in from the south and many species with northern distributions moving north. Changes in seasonal rainfall patterns may exacerbate late summer dryness and increase levels and frequency of drought stress for plant communities and aquatic systems. Increasing temperatures may allow wildlife parasites such as winter moose tick (*Dermacentor albipictus*) and forest pests such as hemlock woolly adelgid (*Adelges*



Figure 20. Northern Maine and the Western Maine Mountains are now a stronghold for moose in the eastern United States. Photo by Charlie Reinertsen Photography.

tsugae) to become more prevalent, stressing native wildlife populations and degrading their habitats. Because each species will respond individually to these threats, the composition of natural communities and wildlife habitats that we take for granted will change. While populations of some species and their habitats will increase, climate change could lead to extirpation of other species and significant changes to natural communities and wildlife habitats (Cahill et al. 2012).

Forest fragmentation increases the vulnerability of Maine's native flora and fauna to climate change (Fernandez et al. 2015; Rustad et al. 2012). For example, declines in the diversity of native flora in New England's mixed northern hardwood forests are attributed to a high degree of habitat specialization, a highly fragmented range, depauperate understories due to repeated clearing and barriers to dispersal (New England Wildflower Society 2015). Three of the top four stressors are caused or aggravated by forest fragmentation, including habitat conversion, invasives and succession. All of these stressors are expected to become more pronounced as the climate changes.

The resiliency of the Western Maine Mountains in the face of climate change is largely due to the extent and connectivity of the region's forests. These forests provide far greater benefits to climate stabilization than the alternative of land development (Fahey et al. 2010). Because heavily forested areas sequester more carbon than they emit and the wood they produce can be used to substitute for more energy- and emissions-intensive building materials, keeping forested lands intact will help mitigate climate change regionally. Conversely, developed lands are net sources of carbon dioxide to the atmosphere (Fahey et al. 2010).



Figure 21. Fall in the Western Maine Mountains. Photo by Charlie Reinertsen Photography.

CONCLUSIONS

The Western Maine Mountains region is an ecological treasure that faces unprecedented threats from forest fragmentation. New land uses and policies that fragment the region's forests—such as the proposed New England Clean Energy Connect transmission corridor, the Land Use Planning Commission's proposed changes to the adjacency rule, which would allow new commercial and residential development to stretch for miles along currently undeveloped public roads, and large scale developments, such as Weyerhaeuser's Moosehead Lake concept plan—have the potential to profoundly change the ecology of the region by bringing extensive new human infrastructure into remote areas and creating new nodes of development (Lilieholm et al. 2010). In addition, forest practices have created a younger more homogeneous forest, conditions that threaten species that require large patches of older forest, such as American marten and many songbirds. However, when the land remains forested, even if harvesting temporarily modifies forest composition and structure, the potential for connectivity is retained because forest patches can regrow and expand. By contrast, once a utility corridor, road or development is in place, it effectively forever disrupts the connectivity of the landscape.

Fragmentation increases the risk of species extinctions and exotic invasions and decreases the ability of species to respond to a warming climate. The capacity of the Western Maine Mountains to sustain biological diversity and ecosystem integrity into the future will hinge upon the total amount and quality of its forests, wetlands and streams and their degree of connectivity. Unless proactive steps are taken, these changes have the potential to forever alter and degrade one of the most intact forested landscapes in the eastern United States and compromise its ability to serve as a critical ecological link between forests of the Northeast and Canada.

To maintain the region's unique values, it is essential to avoid introduction of new fragmenting features, especially those that would permanently intrude into intact forest blocks, such as new utility corridors, new

centers of development, and new high volume roads. It is also critically important to find ways to support landowners who seek to maintain large intact forest blocks and to find ways to support them in managing forests for greater spatial and temporal connectivity and structural complexity. Maintaining an unfragmented and intact forest is not only critical to the region's biodiversity and ecological health, but it is crucial to Maine's economy and a defining part of the Maine way of life.

The biodiversity, resilience and connectivity of the Western Maine Mountains are unparalleled in the eastern United States. The region offers one of the last opportunities for large landscape-scale conservation with protected areas connected through linkages and stepping stones embedded within an intact forest matrix (Keeley et al. 2018). As one of the few temperate forests in the world managed through natural regeneration, the Western Maine Mountains region continues to support a full complement of native forest wildlife and is the last regional stronghold for brook trout, moose, lynx, marten and a host of other species. It remains a highly connected forested landscape—one that is far less fragmented than increasingly developed lands to the south. The actions of landowners, conservation organizations, government officials and agencies, and local communities and citizens together will determine whether these species and the region's many unique values persist into the future.



Figure 22. Canoeing on Flagstaff Lake. Photo by Sally Stockwell.



Figure 23. Unbroken view in the High Peaks region of the Western Maine Mountains. Photo by Charlie Reinertsen Photography.

LITERATURE CITED

Al-Chokhachy, R., T.A. Black, C. Thomas, C.H. Luce, B. Rieman, R. Cissel, A. Carlson, S. Hendrickson, E.K. Archer, and J.L. Kershner. 2016. Linkages between unpaved forest roads and streambed sediment: Why context matters in directing road restoration. *Restoration Ecology 24*(5), 589–598.

Anderson, M.G. 2006. *The Northern Appalachian/Acadian Ecoregion: Conservation assessment, status and trends*. The Nature Conservancy.

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2012. *Resilient sites for terrestrial conservation in the Northeast and Mid-Atlantic Region*. The Nature Conservancy, Eastern Conservation Science. 122 pp.

Anderson, M.G., M. Clark, C.E. Ferree, A. Jospe, and A. Olivero Sheldon. 2013. *Condition of the northeast terrestrial and aquatic habitats: A geospatial analysis and tool set*. The Nature Conservancy, Eastern Conservation Science. Boston, Massachusetts. 171 pp.

Andrén, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: A review. *Oikos, 71*(3): 355–366.

Andrews, K.M, J.W. Gibbons, and D.M. Jochimsen. 2008. Ecological effects of roads on amphibians and reptiles: A literature review. *Herpetological Conservation, 3*: 121–143.

Askins, R.A. 2002. *Restoring North America's birds: lessons from landscape ecology*. Yale University Press, New Haven, Connecticut.

Bailey, R. 1995. *Description of the ecoregions of the United States* (2nd ed; revised and expanded 1st ed., 1980). Misc. Publ. No. 1391, USDA Forest Service, Washington DC. 108 pp. with map.

Baldwin, R.F., S.C. Trombulak, M.G. Anderson, and G. Woolmer. 2007. Projecting transition probabilities for regular public roads at the ecoregion scale: A Northern Appalachian/Acadian case study. *Landscape and Urban Planning*, 80: 404–411.

Barton, A.M., A.S. White, and C.V. Cogbill. 2012. *The changing nature of the Maine woods*. University of New Hampshire Press, Durham, New Hampshire.

Beaudry, F., P.G. deMaynadier, and M.L. Hunter, Jr. 2008. Identifying road mortality threat at multiple scales for semi-aquatic turtles. *Biological Conservation, 141*: 2550–2563.

Beazley, K.F., T.V. Snaith, F. MacKinnon, and D. Colville. 2004. Road density and potential impacts on wildlife species such as American moose in mainland Nova Scotia. *Proceedings of the Nova Scotia Institute of Science, Vol. 42, Pt. 2*: 339–357.

Benitez-Lopez, A., R. Alkemade, and P.A. Verweij. 2010. The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. *Biological Conservation, 143*: 1307–1316.

Billings, S.A., and E.A. Gaydess. 2008. Soil nitrogen and carbon dynamics in a fragmented landscape experiencing forest succession. *Landscape Ecology, 23*(5): 581–593.

Blake, J.G., and J.R. Karr. 1984. Species composition of bird communities and the conservation benefit of large versus small forests. *Biological Conservation, 30*(2): 173–187.

Brocke, R.H., J.P. O'Pezio, and K.A. Gustafson. 1988. A forest management scheme mitigating impact of road networks on sensitive wildlife species. In Degraaf, R.M., and W.M. Healy (eds.), *Is forest fragmentation a management issue in the northeast?* GTR-NE-140, USDA Forest Service, Northeastern Forest Experimental Station, Radnor, Pennsylvania: 13–17.

Brodey, A.J., and M.R. Pelton. 1989. Effects of roads on black bear movements in North Carolina. *Wildlife Society Bulletin, 17*: 5–10.

Burnham, K.M., and T.D. Lee. 2010. Canopy gaps facilitate establishment, growth, and reproduction of invasive *Frangula alnus* in a *Tsuga canadensis* dominated forest. *Biological Invasions, 12*: 1509–1520.

Cahill, A., M. Aiello-Lammens, M. Fisher-Reid, X.Hua, C. Karanewsky, H. Ryu, G. Sbeglia, F. Spagnolo, J. Waldron, O. Warsi, and J. Wiens. 2012. How does climate change cause extinction? Proceeding of the Royal Society B doi:10.1098/rspb.2012.1890.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: Marten and lynx in the Northern Appalachians. *Conservation Biology, 21*: 1092–1104.

Chapin, T.G., D.J. Harrison, and D.D. Katnik, 1998. Influence of landscape pattern on habitat use by American marten in an industrial forest. *Conservation Biology, 12*(6): 1327–1337.

Charry, B. 2007. *Conserving wildlife on and around Maine's roads*. Beginning with Habitat, Maine Audubon Society, and the Maine Department of Transportation. Maine Audubon Society, Falmouth, Maine.

Charry, B. 1996. *Conserving wildlife in Maine's developing landscape*. Maine Audubon Society, Falmouth, Maine.

Compton, B.W. 1999. *Ecology and conservation of the wood turtle (*Clemmys insculpta*) in Maine* (thesis). University of Maine, Orono, Maine, USA.

Coombs, J.A., and K.H. Nislow. 2014. *Riparian prioritization and status assessment for climate change resilience of coldwater stream habitats within the Appalachian and Northeastern regions*. University of Massachusetts Department of Environmental Conservation and USDA Forest Service Northern Research Station. Amherst, Massachusetts.

Cook, W.M., J. Yao, B.L. Foster, R.D. Holt, and L.B. Patrick. 2005. Secondary succession in an experimental fragmented landscape. Community patterns across space and time. *Ecology, 86*(5): 1267–1279.

De Camargo, R.X., V. Boucher-Lalonde, and D.J. Currey. 2018. At the landscape level, birds respond strongly to habitat amount but weakly to fragmentation. *Diversity and Distributions, 24*: 629–639. https://doi.org/10.1111/ddi.12706

DeGraaf, D. 2014. *Report back to the legislature on public law 2013, Chapter 358, Section 8: Proposed plan for managing state heritage fish waters*. Maine Department of Inland Fisheries and Wildlife. Augusta, Maine.

DeGraaf, R.M., and M. Yamasaki. 2001. *New England wildlife: Habitat, natural history, and distribution*. University Press of New England. Hanover, New Hampshire and London.

DeGraaf, R.M., M. Yamasaki, W.B. Leak and A. Lester. 2007. Technical guide to forest wildlife habitat management in New England. University of Vermont Press, Lebanon, New Hampshire.

deMaynadier, P.G., and J.E. Houlahan. 2008. Conserving vernal pool amphibians in managed forests. In Calhoun, A.L., and P.G. deMaynadier (eds.), *Science and Conservation of Vernal Pools in Northeastern North America* (pp. 253–289). CRC Press, Boca Raton, Florida.

deMaynadier, P.G., and M.L.J. Hunter. 2000. Road effects on amphibian movements in a forested landscape. *Natural Areas Journal, 20*(1): 56–65.

Di Marco, M., O. Venter, H.P. Possingham, and J.E.M. Watson. 2018. Changes in human footprint drive changes in species extinction risk. *Nature Communications, 9*(1): 4621 (2018) doi: 10.1038/s41467-18-07049-5

Dolloff, C.A., and M.L. Warren. 2003. Fish relationship with large wood in small streams. In S. Gregory, K. Boyer, A. Gurnell (eds.), *The ecology and management of wood in world rivers (*pp. 179–194). American Fisheries Society, Bethesda, Maryland.

Ehrenfield, J.G., P. Kourtev, and W. Huang. 2001. Changes in soil functions following invasions of exotic understory plants in deciduous forests. *Ecological Applications, 11*(5): 1287–1300.

Fahey, T.J., P.B. Woodbury, J.J. Battles, C.L. Goodale, S.P. Hamburg, S.V. Ollinger, and C.W. Woodall. 2010. Forest carbon storage: Ecology, management, and policy. *Frontiers in Ecology and the Environment, 8*: 245–252.

Fahrig, L., J.H. Pedlar, S.E. Pope, P.D. Taylor, and J.F. Wegner. 1995. Effect of road traffic on amphibian density. *Biological Conservation, 73*: 177–182.

Fensome, A.G., and F. Mathews. 2016. Roads and bats: A meta-analysis and review of the evidence on vehicle collisions and barrier effects. *Mammal Review, 46*(4): 311–323.

Fernandez, I.J., C.V. Schmitt, S.D. Birkel, E. Stancioff, A.J. Pershing, J.T. Kelley, J.A. Runge, G.L. Jacobson, and P.A. Mayewski. 2015. *Maine's climate future: 2015 update*. University of Maine, Orono, Maine. 24 pp.

Fernie, K.J., and J. Reynolds. 2005. The effects of electromagnetic fields from power lines on avian reproductive biology and physiology: A review. *Journal of Toxicology and Environmental Health, Part B, 8*: 127–140.

Fesenmyer, K.A., A.L. Haak, S.M. Rummel, M. Mayfield, S.L. McFall, and J.E. Williams. 2017. *Eastern brook trout conservation portfolio, range-wide habitat integrity and future security assessment, and focal area risk and opportunity analysis*. Final report to National Fish and Wildlife Foundation. Trout Unlimited, Arlington, Virginia.

Ford, S.E., and W.S. Keeton. 2017. Enhanced carbon storage through management for old-growth characteristics in northern hardwood-conifer forests. *Ecosphere, 8*(4): e01721. 10.1002/ecs2.1721

Forman, R.T.T. 1995. *Land mosaics: The ecology of landscapes and regions*. Cambridge University Press, New York.

Forman, R.T.T., and L.E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecological Systematics, 29*: 207–231.

Forman, R.T.T., and R.D. Deblinger. 2000. The ecological road-effect zone of a Massachusetts (USA) suburban highway. *Conservation Biology, 14*: 36–46.

Franklin, J.F., T.A. Spies, R. van Pelt, A. Carey, D. Thornburgh, D.R. Berg, D.B. Lindenmayer, M. Harmon, W. Keeton, and D.C. Shaw. 2002. Disturbances and the structural development of natural forest ecosystems with some implications for silviculture. *Forest Ecology and Management, 155*: 399–423.

Frelich, L.E., C.M. Hale, S., Scheu, A.R. Holdsworth, L. Heneghan, P.J. Bohlen, and P.B. Reic. 2006. Invasion into previously earthworm-free temperate and boreal forests. *Biological Invasions, 8*: 1235–1245.

Fuller, A.K., and D.J. Harrison. 2005. Influence of partial timber harvesting on American martens in North-Central Maine. *Journal of Wildlife Management, 69*: 710–722.

Gawler, S.C., J.J. Albright, P.D. Vickery, and F.C. Smith. 1996. *Biological diversity in Maine: An assessment of status and trends in the terrestrial and freshwater landscape*. Report prepared for the Maine Forest Biodiversity Project. Maine Natural Areas Program, Augusta. 80 pp. + appendices.

Gibbs, J. P. 1998. Distribution of woodland amphibians along a forest fragmentation gradient. *Landscape Ecology, 13*: 263–268.

Gibbs, J.P. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. *Wetlands, 13*: 25–31.

Gibbs, J.P., and W.G. Shriver. 2002. Estimating the effect of road mortality on turtle populations. *Conservation Biology, 16*(6): 1647–1652.

Glista, D.J., T.L. DeVault, and J.A. DeWoody. 2007. Vertebrate road mortality predominantly impacts amphibians. *Herpetological Conservation and Biology, 3*(1): 77–87.

Grindal, S.D., and R.M. Brigham. 1999. Short-term effects of small-scale habitat disturbance on activity by insectivorous bats. *Journal of Wildlife Management, 62*(3): 996–1003.

Gucinski, H., M.J. Furniss, R.R. Ziemer, and M.H. Brookes (eds.). 2000. *Forest roads: A synthesis of scientific information*. USDA Forest Service.

Haddad, N.M., L.A. Brudvig, J. Clobert, K.F. Davies, A. Gonzalez, R.D. Holt, T.E. Lovejoy, J.O. Sexton, M.P. Austin, C.D. Collins, W.M. Cook, E.I. Damschen, R.M. Ewers, B.L. Foster, C.N. Jenkins, A.J. King, W.F. Laurance, D.J. Levey, C.R. Margules, B.A. Melbourne, A.O. Nicholls, J.L. Orrock, D. Song, and J.R. Townshend. 2015. Habitat fragmentation and its lasting impacts on Earth's ecosystems. American Association for the Advancement of Science. *Science Advances, 1*(2), 9 pp.

Hagan, J.M., L.C. Irland, and A.A. Whitman. 2005. *Changing timberland ownership in the Northern Forest and implications for biodiversity*. Manomet Center for Conservation Sciences. Report # MCCS-FCP- 2005-1. 25 pp. Brunswick, Maine.

Hagan, J.M., and A.A. Whitman. 2004. Late successional forest: A disappearing age class and implications for biodiversity. *Forest Mosaic Science Notes, 2*: Manomet, Brunswick, Maine.

Hagan, J.M., W.M. Vander Haegen, and P.S. McKinley. 1996. The early development of forest fragmentation effects on birds. *Conservation Biology, 10*(1): 188–202.

Hanski, I. 2000. Extinction debt and species credit in boreal forests: Modeling the consequences of different approaches to biodiversity conservation. *Annals of Zoology, 37*: 271–280.

Harper, K.A., S.E. Macdonald, P.J. Burton, J. Chen, K.D. Brosofske, S.C. Saunders, E.S. Euskirchen, D. Roberts, M. Jaiteh, and P.A. Esseen. 2005. Edge influence on forest structure and composition in fragmented landscapes. *Conservation Biology, 19*: 768–782.

Haselton, B., D. Bryant, M. Brown, and C. Cheeseman. (2014 draft analysis). *Assessing relatively intact large forest blocks in temperate broadleaf and mixed forests major habitat type*. Tierra Environmental and The Nature Conservancy.

Heneghan, L., F. Fatemi, L. Umek, K. Grady, K. Fagen, M. Workman. 2006. The invasive shrub European buckthorn (*Rhamnus cathartica, L.*) alters soil properties in Midwestern U.S. woodlands. *Applied Soil Ecology, 32*: 142–148.

Hepinstall, J.A., and D.J. Harrison (in preparation). Department of Wildlife Ecology, University of Maine.

Homan, R.N., B.S. Windmiller, and J.M. Reed. 2004. Critical thresholds associated with habitat loss for two vernal pool-breeding amphibians. *Ecological Applications, 14*: 1547–1553.

Homyack, J.A., D.J. Harrison, and W.B. Krohn. 2010. Effects of precommercial thinning on snowshoe hares in Maine. *Journal of Wildlife Management, 71*(1): 4–13.

Hunter, J.C., and J.A. Mattice. 2002. The spread of woody exotics into the forests of a northeastern landscape, 1938–1999. *Journal of the Torrey Botanical Society, 129*(3): 220–227.

Hunter, M.L., Jr., and J. Gibbs. 2007. *Fundamentals of conservation biology* (3rd ed.). Blackwell Publishing. 482 pp.

iMapInvasives Database. NatureServe. www.imapinvasives.org

Irland, L.C. 2005. U.S. forest ownership: Historic and global perspective. *Maine Policy Review, 14*(1): 16–22.

Jochimsen, D.M., C.R. Peterson, K.M. Andrews, and J.W. Gibbons. 2004. Literature review of the effects of roads on amphibians and reptiles and the measures used to minimize those effects. Idaho Fish and Game Department, USDA Forest Service.

Kaufman, S.D., E. Snucins, J.M. Gunn, and W. Selinger. 2009. Impacts of road access on lake trout (*Salvelinus namaycush*) populations: Regional scale effects of overexploitation and the introduction of smallmouth bass (*Micropterus dolomieu*). *Canadian Journal of Fisheries and Aquatic Sciences, 66*: 212–223.

Keeley, A.T.H., D.D. Ackerly, D.R. Cameron, N.E. Heller, P.R. Huber, C.A. Schloss, J.H. Thorne, and A.M. Merenlender. 2018 (in press). New concepts, models and assessments of climate-wise connectivity. *Environmental Research Letters, 13*(7). https://doi.org/10.1088/1748-9326/aacb85

Kuehne, C., Puhlick. J.J., and A.R. Weiskittel. 2018. *Ecological reserves in Maine: Initial results of long-term monitoring*. General Technical Report. 62 pp.

Laan, R., and B. Verboom. 1990. Effect of pool size and isolation on amphibian communities. *Biological Conservation, 54*(3): 251–262.

Laurance, W.F., J.L.C. Camargo, P.M. Fearnside, T.E. Lovejoy, G.B. Williamson, R.C.G. Mesquita, C.F.J. Meyer, P.E.D. Brobrowiec, and S.G.W. Laurance. 2017. An Amazonian rainforest and its fragments as a laboratory of global change. *Biological Reviews, 93*(1). 25 pp. doi: 10.1111/brv.12343

Laurance, W.F., T.E. Lovejoy, H.L. Vasconcelow, et al. 2002. Ecosystem decay of Amazonian forest fragments: A 22 year investigation. *Conservation Biology, 16*: 605–618.

Legaard, K.R., S.A. Sader, and E.M. Simons-Legaard. 2015. Evaluating the impact of abrupt changes in forest policy and management practices on landscape dynamics: Analysis of a Landsat image time series in the Atlantic Northern Forest. *PLoS ONE, 10*(6): e0130428. doi: 10.1371/journal. pone.0130428

Leopold, Aldo. 1966. *A Sand County almanac: With essays on conservation from Round River*. Oxford University Press.

Lilieholm, R.J., L.C. Irland, and J.M. Hagan. 2010. Changing socio-economic conditions for private woodland protection. In Trombulak, S.C., and R.F. Baldwin (eds.), *Landscape-scale conservation planning* (pp. 67–98). Springer, New York.

Lindenmayer, D.B., and J. Fischer. 2006. *Habitat fragmentation and landscape change: An ecological and conservation synthesis*. Island Press, Washington, DC.

Loarie, S.R., P.B. Duffy, H. Hamilton, G.P. Asner, C.B. Field, and D.D. Ackerly. 2009. The velocity of climate change. *Nature, 462*(24): 1052–1055.

Loarie, S.R., B.E. Carter, K. Hayhoe, S. McMahon, R. Moe, C.A. Knight, and D.D. Ackerly. 2008. Climate change and the future of California's endemic flora. *PLoS One, 3*: e2502.

Lorimer, C.G. 1977. The presettlement forest and natural disturbance cycle of Northeastern Maine. *Ecology* (58): 139-148.

Lorimer, C.G., and A.S. White. 2003. Scale and frequency of natural disturbances in the northeastern US: Implications for early successional forest habitats and regional age distributions. Forest Ecology and Management 185: 41–64.

LUPC. 2010. Comprehensive Land Use Plan. Maine Department of Agriculture, Conservation and Forestry. https://digitalmaine.com/lupc_docs/6

MacArthur, R.H., and E.O. Wilson. 1967. *The theory of island biogeography.* Princeton University Press, Princeton, New Jersey. 203 pp.

Maine Department of Conservation. 1997. Comprehensive land use plan for areas within the jurisdiction of the Maine Land Use Regulation Commission. MDOC Land Use Regulation Commission, Augusta, Maine.

Maine Department of Inland Fisheries and Wildlife (no date). *Guidelines for wildlife: Managing deer wintering areas in northern, western and eastern Maine*. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine.

Maine Department of Transportation (no date). Stream Smart road crossing pocket guide. State of Maine Aquatic Resources Management Strategy Forum.

Martin, E.H., and C.D. Apse. 2011. *Northeast aquatic connectivity: An assessment of dams on northeastern rivers*. The Nature Conservancy, Eastern Freshwater Program.

Matlack, G.R. 1993. Microenvironment variation within and among forest edge sites in the eastern United States. *Biological Conservation, 66*: 185–194.

McGarigal, K., W.H. Romme, M. Crist, and E. Roworth. 2001. Cumulative effects of roads and logging on landscape structure in the San Juan Mountains, Colorado (USA). *Landscape Ecology, 16*: 327–349.

McMahon, J. 2016. *Diversity, continuity and resilience: The ecological values of the Western Maine Mountains*. Occasional Paper No. 1. Maine Mountains Collaborative, Phillips, Maine. 20 pp.

Merriam, G.M., M. Kozakiewiez, E. Tsuchya, and K. Hawley. 1989. Barriers as boundaries for metapopulations and demes of *Peromyscus leucopus* in farm landscapes. *Landscape Ecology, 2*: 227–236.

Mosher, E.S., J.A. Silander, Jr., and A.M. Latimer. 2009. The role of land-use history in major invasions by woody plant species in the northeastern North American landscape. *Biological Invasions, 11*: 2317. doi: 10.1007/s10530-008-9418-8

Muñoz, P.T., F.P Torres, and A.G. Megìas. 2015. Effects of roads on insects: a review. *Biodiversity Conservation, 24*: 659–682.

New England Forestry Foundation (NEFF) (in press). *Landscape scale resource inventory and wildlife habitat assessment for the Mountains of the Dawn*. New England Forestry Foundation, Littleton, Massachussetts.

New England Wild Flower Society. 2015. *State of the plants: Challenges and opportunities for conserving New England's native flora*. Framingham, Massachusetts.

Ortega, Y.K., and D.E. Capen. 1999. Effects of forest roads on habitat quality for ovenbirds in a forested landscape. *The Auk, 116*(4): 937–946.

Oxley, D.J., M.B. Fenton, and G.R. Carmody. 1974. The effects of roads on populations of small mammals. *Journal of Applied Ecology, 11*: 51–59.

Payer, D.C., and D.J. Harrison. 2003. Influence of forest structure on habitat use by American marten in an industrial forest. *Forest Ecology and Management, 179*(1–3): 145–156.

Pfiefer, M., V. Lefebvre, C.A. Peres, C. Banks-Leite, O.R. Wearn, C.J. Marsh, S.H.M. Butchart, V. Arroyo-Rodriquez, J. Barlow, A. Cerezo, L. Cisneros, N. D'Cruze, D. Faria, A. Hadley, S. Harris, B.T. Klingbeil, U. Kormann, L. Lens, G.F. Medina-Rangel, J.C. Morante-Filho, P. Oliveir, S.L. Peters, A. Pidgeon, D.B. Ribeiro, C. Scherber, L. Schneider-Maunory, M. Struebig, N. Urbina-Cardona, J.I. Watling, M.R. Willig, E.M. Wood, and R.M. Ewers. 2017. Creation of forest edges has a global impact on forest vertebrates. *Nature, 551*: 187–191.

Popescu, V.D., and M.L. Hunter, Jr. 2011. Clear-cutting affects habitat connectivity for a forest amphibian by decreasing permeability to juvenile movements. *Ecological Applications, 21*(4): 1283–1295.

Prevedello, J.A. and M.V. Vieira. 2010. Does the type of matrix matter? A quantitative review of the evidence. Biodiversity Conservation 19: 1205–1223.

Publicover, D.A., and C.J. Poppenwimer. 2006. *Roadless areas in the northern forest of New England: An updated inventory*. AMC Technical Report 06-1. Appalachian Mountain Club Research Department, Gorham, New Hampshire.

Publicover, D.A., and C. Poppenwimer. 2002. *Delineation of roadless areas in the Northern Forest of New England using satellite imagery*. AMC Technical Report 02-1. Appalachian Mountain Club Research Department, Gorham, New Hampshire.

Riitters, K., J. Wickham, R. O'Neill, B. Jones, and E. Smith. 2000. Global-scale patterns of forest fragmentation. *Conservation Ecology, 4*(2): 3.

Rolek, B.W., D.J. Harrison, C.S. Loftin, and P.B. Wood. 2018. Regenerating clear cuts combined with postharvest forestry treatments promote habitat for breeding and post-breeding spruce-fir avian assemblages in the Atlantic Northern Forest. *Forest Ecology and Management, 427*: 392–413.

Rosen, P., and C. Lowe. 1994. *Highway mortality of snakes in the Sonoran Desert of southern Arizona. Biological Conservation, 68*: 143–148.

Rosenberg, K.V., J.D. Lowe, and A.A. Dhondt. 1999. Effects of forest fragmentation on breeding tanagers: A continental perspective. *Conservation Biology, 13*(3): 568–583.

Rosenzweig, M.L. 1995. *Species diversity in space and time*. Cambridge University Press, Cambridge.

Ross, B., T. Fredericksen, E. Ross, W. Hoffman, M.L. Morrison, J. Beyea, M.B. Lester, B.N. Johnson, and N.J. Fredericksen. 2000. Relative abundance and species richness of herpetofauna in forest stands in Pennsylvania. *Forest Science, 46*: 139–146.

Rowland, E.L., A.S. White, and W.H. Livingston. 2005. *A literature review of the effects of intensive forestry on forest structure and plant community composition and the stand and landscape levels*. Maine Agricultural and Forest Experiment Station. Miscellaneous Publication 754.

Rustad, L., J. Campbell, J.S. Dukes, T. Huntington, K.F. Lambert, J. Mohan, and N. Rodenhouse,. 2012. *Changing climate, changing forests: The impacts of climate change on forests of the northeastern United States and eastern Canada*. Gen. Tech. Rep. NRS-99. USDA Forest Service, Northern Research Station. Newtown Square, Pennsylvania. 48 pp.

Rytwinski, T., and L. Fahrig. 2015. The impacts of roads and traffic on terrestrial wildlife populations. In Van der Ree, R., D.J. Smith, and C. Grilo (eds), *Handbook of road ecology (*Chapter 28). John Wiley & Sons.

Schlawin, J., and A. Cutko. 2014. *A conservation vision for Maine using ecological systems*. Maine Natural Areas Program, Maine Department of Agriculture, Conservation and Forestry, Augusta, Maine. http://www.maine.gov/dacf/mnap/about/publications/ra.htm

Schmiegelow, F.K.A., C.S. Machtans, and S.J. Hannon. 1997. Are boreal birds resilient to forest fragmentation? An experimental study of short-term community responses. *Ecology, 78*(6): 1914–1932.

Selva, S.B. 1994. Lichen diversity and stand continuity in the northern hardwoods and spruce-fir forests of northern New England and western New Brunswick. *The Bryologist, 97*: 424–429.

Seiler, A. 2001. *Ecological effects of roads: A review*. Department of Conservation Biology, Uppsala University, Uppsala, Uppland, Sweden. 40 pp.

Seymour, R.S., A.S. White and P.G. deMaynadier. 2002. Natural disturbance regimes in northeastern North America—evaluating silvicultural systems using natural scales and frequencies. *Forest Ecology and Management, 155*(1-3): 357–367.

Silander, J.A,. Jr., and D.M. Klepeis. 1999. The invasion ecology of Japanese barberry (*Berberis thunbergii)* in the New England landscape. *Biological Invasions, 1*: 189–201.

Silveri, A., P.W. Dunwiddie, and H.J. Michaels. 2001. Logging and edaphic factors in the invasion of an Asian woody vine in a mesic North American forest. *Biological Invasions, 3*: 379–389.

Simons-Legaard, E.M., D.J. Harrison, and K.R. Legaard. 2018. Ineffectiveness of local zoning to reduce regional loss and fragmentation of deer wintering habitat for white-tailed deer. *Forest Ecology and Management, 427*: 78–85.

Simons-Legaard, E.M., D.J. Harrison, W.B. Krohn, and J.H. Vashon. 2013. Canada Lynx occurrence and forest management in the Acadian Forest. *The Journal of Wildlife Management, 77*(3): 567–578.

Smallwood, K.S., 2013. Comparing bird and bat fatality-rate estimates among North American wind energy projects. *Wildlife Society Bulletin, 37*(1): 19–33.

Talluto, M.V., I. Boulangeat, S. Vissault, W. Thuiller, and D. Grave. 2017. Extinction debt and colonization credit delay range shifts of eastern North American trees. *Nature Ecology and Evolution, 1*(0182): 1–9.

Ten Broeck, C., and R.A. Giffen. 2018. *The potential role of intensive forest management in meeting needs for forest products, restoring forest types to lands they historically occupied, and relieving harvest pressures on natural forests*. New England Forestry Foundation, Littleton, Massachusetts.

The Nature Conservancy. 2013. *Staying connected in the northern Appalachians: Mitigating fragmentation and climate change impacts on wildlife through functional habitat linkages*. Final Performance Report-Summary. New Hampshire Fish and Game Department and the U.S. Fish and Wildlife Service.

Thompson, J.R., D.N. Carpenter, C.V. Cogbill, and D.R. Foster. 2013. Four centuries of change in Northeastern United States forests. *PLoS ONE, 8*(9): e72540. doi: 10.1371/journal.pone.0072540

Thuiller, W., S. Lavorel, M.B. Araujo, M.T. Sykes, and I.C. Prentice. 2005. *Climate change threats to plant diversity in Europe*. Proceedings of the National Academy of Sciences. USA 102: 8245–8250.

Tinker, D. B., C.A.C. Resor, G.P. Beauvai, K.F. Kipfmueller, C.I. Fernandes, and W.L. Baker, W. L. 1997. Watershed analysis of forest fragmentation by clearcuts and roads in a Wyoming forest. *Landscape Ecology, 12*: 1–17.

Trombulak, S.C., and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology, 14*: 18–30.

Trombulak, S.C., and R.F. Baldwin (eds.). 2010. *Landscape-scale conservation planning*. Springer, New York.

Trout Unlimited. 2006. *Eastern brook trout: Status and trends*. Produced by Trout Unlimited for the Eastern Brook Trout Joint Venture. Trout Unlimited, Arlington, Virginia.

U.S. Energy Information Administration. 2017. Maine State Energy Profile. https://www.eia.gov/state/?sid=ME

Van der Ree, R., D.J. Smith, and C. Grilo (eds). 2015. *Handbook of road ecology*. John Wiley & Sons.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences, 37*(1): 130–137.

Villard, M.A., M.K. Trzcinski, and G. Merriam. 1999. Fragmentation effects on forest birds: Relative influence of woodland cover and configuration on landscape occupancy. *Conservation Biology, 13*: 774–783.

Watson, J.E., T. Evans, O. Venter, B. Williams, A. Tullock, C. Stewart, I. Thompson, J.C. Ray, K. Murray, A. Salazar, C. McAlpine, P. Potapov, J. Walston, J.G. Robinson, M. Painter, D. Wilkie, C. Filardi, W.F. Laurance, R.A. Houghton, S. Maxwell, H. Grantham, C. Samper, S. Wang, L. Laestadius, R.K. Runting, G. A. Silva-Chavez, J. Ervin, and D. Lindenmayer. 2018. The exceptional value of intact forest ecosystems. *Nature Ecology and Evolution, 2*: 599–610. https://doi.org/10.1038/s41559-018-0490-x.

Webster, C.R, M.A. Jenkins, and S. Jose. 2006. Woody invaders and the challenges they pose to forest ecosystems in the eastern United States. *Journal of Forestry, 104*: 366–374.

Whitcomb, R.F., C.S. Robbins, J.F. Lynch, B.L. Whitcomb, M.K. Klimkiewicz, and D. Bystrak. 1981. Effects of forest fragmentation on avifauna of the eastern deciduous forest. In R.L. Burgess and D.M. Sharpe (eds.), *Forest island dynamics in man-dominated landscapes* (pp. 125–205). Springer-Verlag, New York.

Whiteley, A.R., J.A. Coombs, M. Hudy, Z. Robinson, A.R. Colton, K.H. Nislow, and B.H. Letcher, 2013. Fragmentation and patch size shape genetic structure of brook trout populations. *Canadian Journal of Fisheries and Aquatic Sciences, 70*(5): 678–688.

Whitman, A., A. Cutko, P. deMaynadier, S. Walker, B. Vickery, S. Stockwell, and R. Houston. 2013. *Climate change and biodiversity in Maine: Vulnerability of habitats and priority species*. Manomet Center for Conservation Sciences (in collaboration with Maine Beginning with Habitat Climate Change Working Group). Report SEI-2013-03. 96 pp. Brunswick, Maine.

A Land Manager's Guide to

Improving Habitat for Forest Thrushes



CORNELL LAB *of* ORNITHOLOGY

Acknowledgements

Funding for the Birds in Forested Landscapes project and production of this publication was provided by the National Fish and Wildlife Foundation, the USDA Forest Service, the Environmental Protection Agency, and voluntary contributions from many Birds in Forested Landscapes participants.

We would also like to thank our many colleagues at the Cornell Lab of Ornithology, Cornell University, and federal and state wildlife agencies for discussions of forest-bird management and for helping us improve this document. Special thanks to Cristina Faustino for her numerous contributions to the data analysis and Barb Kott for her coordination of the project in conjunction with the Forest Service. Most importantly we appreciate the dedication, time, and continued effort of thousands of Birds in Forested Landscapes participants who collected the data on forest birds. Without their support and hard work in the field this publication would not be possible.



Spotted Thrushes by James Coe

Please cite this publication as Rosenberg, K.V., R.S. Hames, R.W. Rohrbaugh, Jr., S. Barker Swarthout, J.D. Lowe, and A.A. Dhondt. 2003. A land manager's guide to improving habitat for forest thrushes. The Cornell Lab of Ornithology.

© 2003 by the Cornell Lab of Ornithology

A Land Manager's Guide to Improving Habitat for Forest Thrushes

Kenneth V. Rosenberg, Ralph S. Hames, Ronald W. Rohrbaugh, Jr.,
Sara Barker Swarthout, James D. Lowe, André A. Dhondt



Varied Thrush by James Coe

Contents

Preface 2
Summary 2
Introduction 3
Managing the Contemporary Forest 5
    What Is Forest Fragmentation? 5
    Birds in Forested Landscapes: A scientific approach to managing forest birds 6
General Guidelines: Key Forest Characteristics 7
    Forest Size and Isolation 7
    Edges 8
    Brood Parasitism and Nest Predation 8
    Landscape Context 9
    Forest Structure 10
Regional Management Guidelines for Thrushes 11
    Using These Guidelines 11
    Using Minimum-Area Tables 11
East/Midwest Forest Region 12
    Management Summary 15
Northern Forest Region 16
    Management Summary 18
Western Forest Region 19
    Management Summary 21
Biographies of Forest Thrushes 22
    Veery 22
    Swainson's Thrush 23
    Hermit Thrush 24
    Wood Thrush 25
    Varied Thrush 26
Literature Cited 27

Preface

Purpose and Use of this Guide

This publication is a tool to help improve habitat for populations of forest-interior birds. These guidelines are written for two types of land managers: those responsible for large landscapes, such as public lands or entire states; and private landowners who manage small blocks of forest. We first discuss concepts associated with forest fragmentation at both landscape and smaller habitat scales and provide general management suggestions that benefit many forest-interior birds. We then focus directly on the habitat-area requirements of the Veery, Swainson's Thrush, Hermit Thrush, Wood Thrush, and Varied Thrush. Specifically, we provide estimates of how much appropriate forest habitat is necessary to sustain breeding populations of each of these species in three geographic regions of the U.S. and Canada.

Why thrushes?

Nearly every forest in North America is inhabited by one or more thrush species. These drab-colored songbirds are not often seen, yet their beautiful, flute-like songs are one of the most characteristic sounds of our forested landscapes in summer. Forest thrushes, like their more familiar cousin the American Robin, feed primarily on the ground and build their nests on or near the ground in low, dense vegetation. Each species selects its own habitat, in terms of forest type, elevation, and moisture regime, and all are sensitive to the structure, productivity, and configuration of the forest. These birds are therefore good indicators of forest health and the ability of our forests to support healthy bird populations. As several thrush species continue to decline, managing forest habitats for these and other songbirds is one way that landowners and managers can contribute to bird conservation efforts.

Summary

This is the second publication in a series of forest habitat management guidelines produced by the Cornell Lab of Ornithology as a tool to help those interested in managing and protecting habitat for birds. The first publication, *A Land Manager's Guide to Improving Habitat for Scarlet Tanagers and other Forest-interior Birds*, was published in 1999 and has been used widely by agencies and private landowners. These guidelines offer a set of "management prescriptions"—descriptions of the kinds and amounts of habitat that are required to sustain healthy bird populations. This guide is focused on improving habitat for five forest-dwelling thrushes, including the Veery (*Catharus fuscescens*), Swainson's Thrush (*Catharus ustulatus*), Hermit Thrush (*Catharus guttatus*), Wood Thrush (*Hylocichla mustelina*), and Varied Thrush (*Ixoreus naevius*). Providing well-managed habitat for these wide-ranging species that use a variety of forest habitats also will benefit a host of other forest birds. We first offer a series of general management guidelines that are applicable in both eastern and western landscapes. These include preventing the fragmentation of large forest tracts, minimizing the creation of edge habitats, establishing forested corridors to reduce isolation of small patches, and maintaining structural and plant-species diversity within existing forests.

Unlike tanagers, thrushes are birds of the forest understory, requiring dense shrub or sapling layers and a well-developed layer of leaf litter on the forest floor. These conditions exist in some mature and old-growth forest types, but most often are enhanced by small-scale disturbances within forested regions. Silvicultural practices that mimic natural disturbance and promote deciduous shrubs and saplings can benefit thrush populations, as long as overall forest cover in a landscape is not permenantly reduced. In all forested regions, general guidelines for thrushes and other forest species include: (1) maintaining large and unfragmented forest blocks; (2) promoting understory growth through natural disturbance or management; and (3) limiting overbrowsing by deer, livestock, and other ungulates. In the western region, protection and enhancement of riparian forest are critical for thrush and other bird populations. In eastern and northern forests, patches of 150 acres (62 ha) or larger generally will provide thrushes with high to moderate levels of habitat suitability.



Figure 1. *Vast coniferous forests of western North America support diverse bird communities, including large populations of Hermit Thrush, Swainson's Thrush, and in some regions, Varied Thrush. Photo by Melissa S. Barker.*

Introduction

Few choices that a bird makes during its life will affect its survival and ability to reproduce as profoundly as its choice of habitat. A bird's habitat must contain all the resources needed for that individual's growth, survival, and reproduction, including food, water, cover, and roosting and nesting sites. The process can be complicated, as each bird is faced with a mosaic of acceptable habitats from which to choose, and each choice often occurs at different geographic scales (Hames et al. 2001). For example, a migratory Wood Thrush returning to its breeding grounds must first select an appropriate forest patch, then a territory within the patch, and finally a nest site within the territory (Figure 2). These choices are made based on habitat type and quality. Each bird species has a unique set of habitat requirements based on its ecology and behavior. Some species, such as the Bicknell's Thrush, which only nests in montane forest dominated by balsam fir, have very specific habitat requirements. Other species may key in on a specific habitat type, such as forest, but will tolerate a range of conditions within that habitat type. Suites of species may respond similarly to variation in basic forest characteristics such as size, shape, and surrounding land use. For this reason, targeted forest management for selected species will often benefit a larger guild of forest-dwelling birds.

Sometimes two locations may contain all the basic requisites for appropriate breeding habitat, but they may differ in overall habitat quality. For example, one location may contain more food, better nest sites, or fewer brood parasites (i.e., Brown-headed Cowbirds) and nest predators. Such quality differences among habitats often are revealed by their rate of occupancy by breeding birds (Hames et al. 2001) and the nesting success experienced by those occupants. The guidelines contained in this publication were created by statistically modeling the relationships between thrush occupancy rates and numerous forest characteristics thought to affect habitat quality.

In our first forest management publication, *A Land Manager's Guide to Improving Habitat for Scarlet Tanagers and other Forest-interior Birds*, we focused on eastern forests, as this was the extent of the Scarlet Tanager's breeding distribution (Rosenberg et al. 1999b). In this publication, the second in our management series, we expand our taxonomic and geographic scope by providing management guidelines for the Wood Thrush, Hermit Thrush, Swainson's Thrush, Veery, and Varied Thrush. Like the tanager management guidelines, the thrush guidelines will also benefit many other forest-dwelling birds. The five forest thrushes considered in this publication have a combined geo-

graphic distribution that includes much of the forested habitat in North America, spanning eastern deciduous forest, boreal forest, and western montane forest. As a group, the forest thrushes require a set of similar habitat conditions. Each species, however, occupies a unique ecological niche and thus requires a specific set of forest conditions to breed successfully and sustain viable populations. Furthermore, individuals of the same species breeding in geographically disjunct populations, may have somewhat different habitat needs, thus requiring slightly different management actions. For example, appropriate forest patch size is important for Hermit Thrushes nesting in both Vermont and Idaho (Hames et al. 2002); however, because of differences in forest type and the amount of forest available in the landscape, management actions designed to achieve the same population goals for this species may be very different in the two states. The degree to which individual characteristics, such as forest size or shape, play a role in determining habitat quality is highly variable from place to place (Rosenberg et al. 1999b), as geographic location can have profound effects on factors like climate and presence of competitors and predators. To measure geographic variation in species-specific habitat requirements, we studied each thrush species throughout its range (see sidebar, page 6). The goal of this publication is to provide forest managers with regionally specific, science-based guidelines for assessing habitat quality, making important forest planning and mitigation decisions, and improving habitat conditions for thrushes and other forest birds.

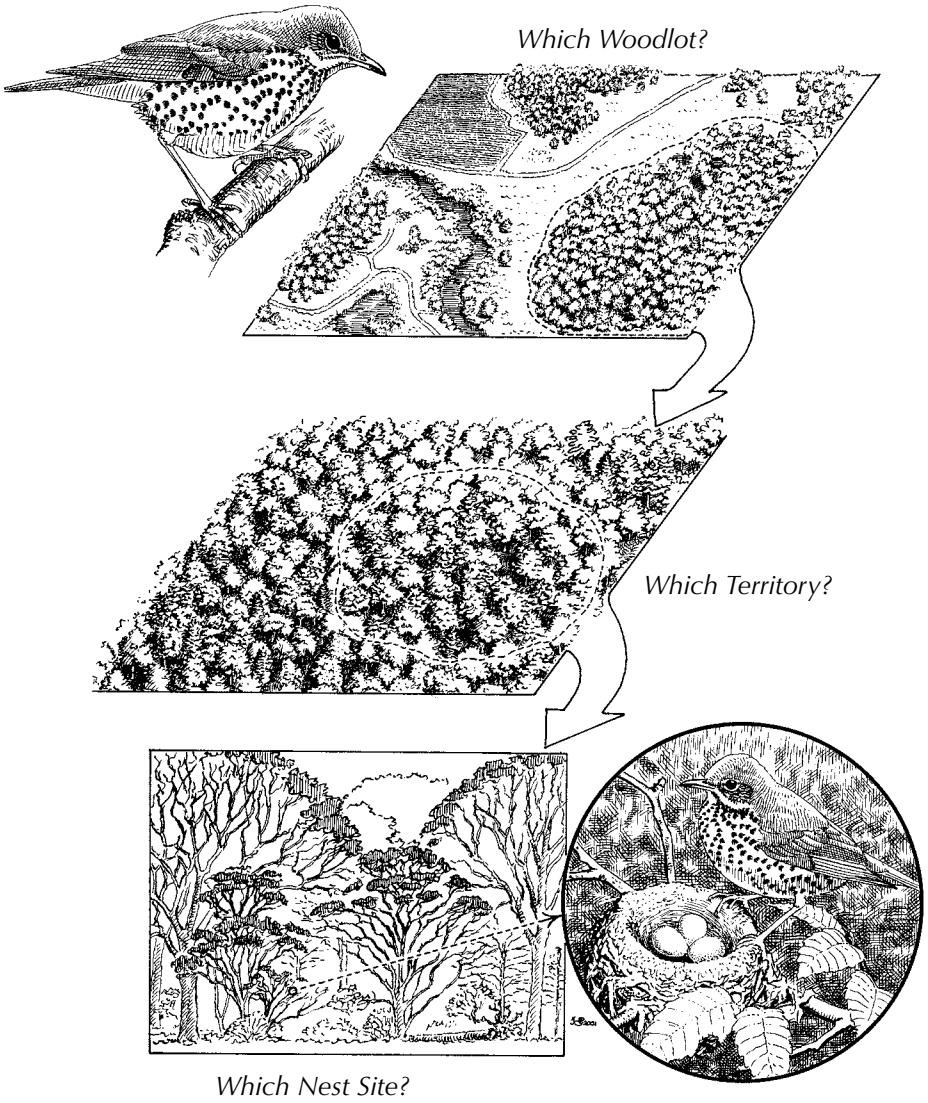


Figure 2. Wood Thrush Habitat Selection: *For many species, including the Wood Thrush, selecting a place to nest involves making choices at several geographic scales. A migrating Wood Thrush returning to its natal breeding area in an agricultural setting is first faced with locating a woodlot suitable for establishing a breeding territory. The woodlot must be of appropriate size, age, shape, and distance to key landscape features, such as water. After selecting a woodlot, the bird must then stake out a territory of about five acres (2 ha), usually containing a mix of understory and canopy trees. Finally, the bird must select an appropriate place within the territory to build its nest, which is placed on a forked branch of an understory tree or shrub, such as flowering dogwood. From the Lab's* Home Study Course in Bird Biology *(Podulka et al. 2001). Illustration by N. John Schmitt.*

Managing the Contemporary Forest

Throughout North American history, forests have received intense pressure because of their ability to provide renewable resources and sites for agriculture and development. The amount and quality of forest habitat available for breeding birds is constantly changing because of a cycle of forest clearing followed by regrowth. In the 1800s, millions of acres of forest in the East and Midwest were cleared for agriculture and the wood products they provided. Much of the farmland created during this era of agriculture has been subsequently abandoned and replaced by forest, causing a net increase in forest area in the rural Northeast during the past 100 years. Conversely, residential and commercial development is outpacing forest regrowth in the suburban Southeast and Midwest, causing a net forest decline in those regions. The amount of forest in the mountainous West has remained roughly stable during the past few decades because of vast acreages owned and protected by the federal government. The end result is a dynamic situation where the amount of forest is constantly changing within and among major geographical regions.

In addition to forest loss, there are a variety of threats that degrade habitat quality for forest birds. A number of forest health issues, such as hemlock wooly adelgid, beech bark scale, viburnum leaf beetle, acid rain deposition, and overbrowsing by white-tailed deer, threaten eastern forests. In western coniferous forests, fire suppression has altered the natural forest structure and composition. Furthermore, increased fuel loads in fire-suppressed areas lead to wildfires that are devastating as opposed to rejuvenating. Finally, pervasive forest fragmentation reduces habitat quality for breeding birds in both eastern and western landscapes (Hames et al. 2002).

Effective forest management for bird populations relies on long-term planning, periodic needs assessment to ensure adequate amounts of high-quality forest habitat in all regions, and science-based guidelines that consider forest bird ecology and contemporary threats. The responsibility for long-term planning at ecoregional scales falls mostly to state and federal agencies and some large conservation landowners such as The Nature Conservancy. Yet, the contributions of private landowners, individual natural resource managers, and commercial forest owners is paramount to providing adequate amounts of quality breeding habitat for forest birds.

Some key characteristics that determine a forest's quality as breeding bird habitat include its size and shape, how isolated it is from other forests, the land-use surrounding it, and its age and structural development. Most of these characteristics can be manipulated by forest managers to benefit birds. Furthermore, these characteristics are interrelated and influenced by the amount of forest fragmentation in the surrounding landscape, permitting managers to focus on one or two key characteristics that can potentially improve the overall quality of the habitat. Management activities that benefit forest birds will often involve the replication of small-scale natural disturbances that would naturally influence ecological succession. For instance, removal of selected overstory trees can create gaps in the forest canopy, thus simulating damage caused by storms. These gaps stimulate understory growth, which ultimately provides food and nest sites for forest birds.



Figure 3. *Forests fragmented by agricultural development persist as isolated patches that may vary in size, shape, and degree of isolation. Photo by Kenneth V. Rosenberg.*

What Is Forest Fragmentation?

Forest fragmentation occurs when large, contiguous forests are divided into smaller patches by residential and commercial development, roads, agriculture, and, in some cases, timber harvesting (Figure 3). Clear-cutting can temporarily fragment mature, contiguous forest until the clear-cut area has regenerated to a successional stage in which it no longer poses an ecological barrier to forest-interior birds. As mature forests become fragmented, less habitat is available for breeding

birds, and a variety of factors, such as increased brood parasitism and nest predation, result in lower reproductive success in the habitat that remains (Brittingham & Temple 1983; Wilcove 1985; Martin 1988; Robinson et al. 1995). Thus, forest fragmentation not only causes a net loss of habitat, it can also reduce the suitability of remaining habitat in a region.

It is important to distinguish between a forest that is fragmented by agricultural or urban development and a forested landscape composed of a mosaic of mature and regenerating stands that result from timber harvesting. The first situation typically is more damaging to forest bird populations and may represent permanent habitat loss, whereas the latter situation may only cause a temporary reduction in habitat for certain forest-interior species that rely on mature forests. Furthermore, early successional forests do provide habitat for many bird species, including some Neotropical migrants that are declining. Forest fragmentation plays an important role in determining the characteristics described below.



Figure 4. *The Varied Thrush breeds primarily in the wet coniferous forests of the Pacific Northwest. Photo by Donald Waite/CLO.*

Birds in Forested Landscapes: A scientific approach to managing forest birds



Photo by Kenneth V. Rosenberg

The Birds in Forested Landscapes (BFL) project began in 1997, evolving from the highly successful Project Tanager. Together, these projects amassed perhaps the largest dataset ever collected on forest fragmentation and birds. Project Tanager and BFL have proved that it is possible for birders and amateur scientists alike to conduct continent-wide field research, helping to answer important scientific questions that can only be addressed through the collective efforts of thousands of volunteer citizen-scientists.

BFL, with support from the National Fish and Wildlife Foundation, the USDA Forest Service, and the Environmental Protection Agency has focused its efforts on forest hawks, thrushes, and, since 2001, additional species identified as high conservation priorities. Over 1,000 trained volunteers surveyed more than 3,000 study sites throughout North America, helping to determine the habitat and landscape requirements of forest-dwelling birds.

BFL participants follow a simple yet rigorously tested protocol that includes selecting suitable study sites, visiting these sites at least twice during the breeding season to search for thrushes and hawks and look for evidence of breeding, measure a suite of habitat variables, and then return data to Cornell for analysis. Many land managers contributed to the project as active participants and site coordinators, helping volunteers with landscape measurements, obtaining maps, or gaining access to study sites. The management guidelines for thrushes, resulting directly from this important study, are the second in a series of conservation plans developed to help maintain and enhance populations of forest birds into the future.

General Guidelines: Key Forest Characteristics

Forest Size and Isolation

Effects

The number of bird species breeding in a forest patch is directly related to the size of the patch (Freemark and Collins 1992). As the size of the forest increases, the number of breeding bird species increases. Bird species whose occurrence or reproductive success is reduced in small habitat patches are referred to as *area sensitive* (Robbins et al. 1989). For example, some species will only establish breeding territories in the interior of large forest tracts, far from an edge; these are known as forest-interior specialists. Area-sensitive species may attempt to nest in small forest patches but are often unable to raise young successfully because of high rates of nest predation or brood parasitism. For area-sensitive species, the size and shape of forest tracts are crucial factors for successful breeding (Whitcomb et al. 1981). Forest patches that are too small may not offer enough interior habitat to sustain breeding individuals. Similarly, a forest in the shape of a long corridor or peninsula does not offer as much interior habitat as a circular or square forest.

The degree of isolation, or the distance between a patch and the surrounding forest, may also be important in determining the long-term persistence of bird populations (Hames et al. 2001). For nonmigratory species, such as woodpeckers and owls, the ability of young birds to disperse and establish new territories is greatly reduced when the habitat is isolated (Figure 5). Forested corridors connecting isolated patches may be critical for these populations. Also, if fragments are separated by agriculture or regenerating forest, the possibility for dispersal may be greater than between fragments that are separated by residential or commercial development where movement is limited.

Management Tips

- **Maintaining Large Forest Tracts:** Whenever possible, avoid fragmenting large contiguous forest

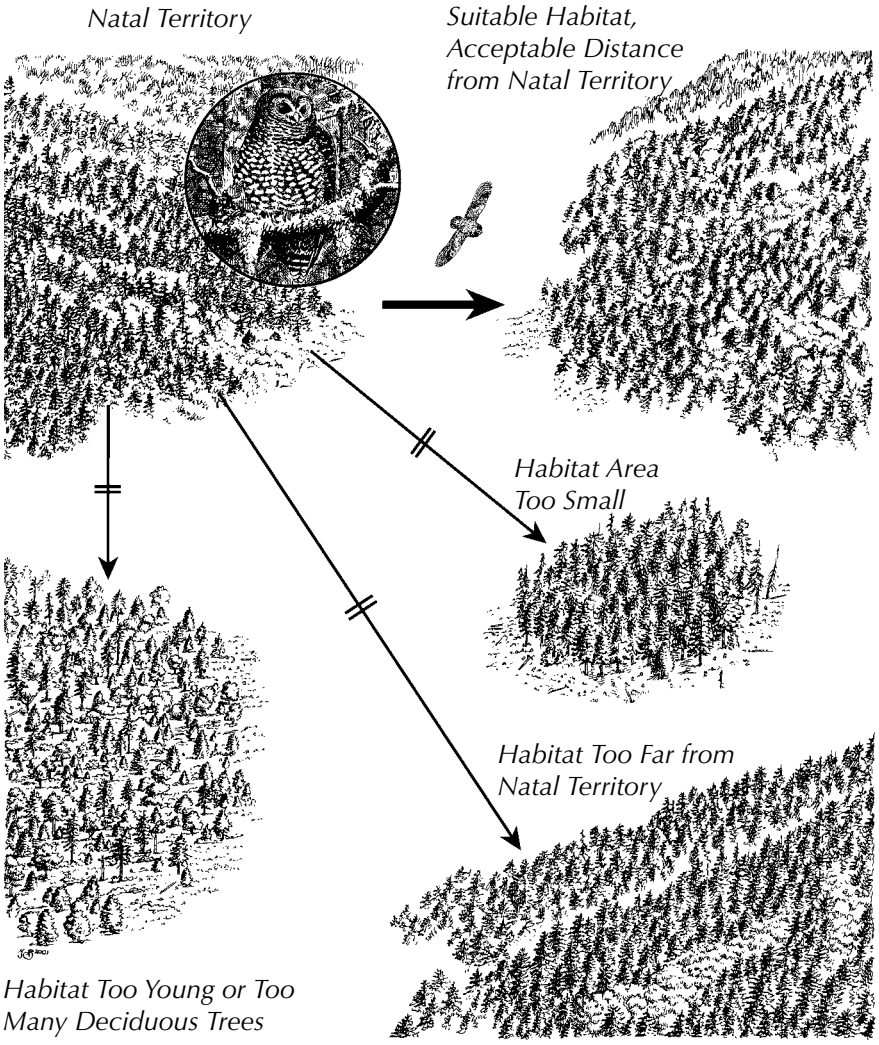


Figure 5. Dispersal of Fledgling Northern Spotted Owl: *When young birds disperse from their natal areas, their survival often depends on their ability to find suitable habitat nearby. Dwindling habitat in the Pacific Northwest makes this especially true for the Northern Spotted Owl: loss and fragmentation of the old-growth coniferous forests where the subspecies makes its home leave young owls with few habitat choices and expose them to many risks. Studies indicate that if immature Northern Spotted Owls cannot find suitable habitat within approximately 12 miles (about 20 km) of their natal territory soon after dispersing, they often succumb to starvation or predation by Great Horned Owls. Some old-growth forest patches fail to meet the bird's needs because they are too far away or are too small in area. Other unsuitable forests are too young, or contain a high proportion of deciduous trees. From the Lab's* Home Study Course in Bird Biology *(Podulka et al. 2001). Illustration by N. John Schmitt.*

Brood Parasitism and Nest Predation

Among the primary causes of lowered reproductive success of forest-interior birds in fragmented habitats are increased rates of both brood parasitism and nest predation. Brood parasites, notably Brown-headed Cowbirds (*Molothrus ater*), are birds that do not build nests or raise young on their own; instead, they lay eggs in a host bird's nest. The cowbird nestling generally hatches first, outcompetes the host's nestlings for food, and receives the majority of the parental care. As cowbirds expanded their historic range from midwestern prairies into newly created agricultural land and fragmented forests in the East, they encountered many new potential host species (Robinson et al. 1995). Forest birds that have had no long-term exposure to cowbirds often do not have mechanisms for rejecting cowbird eggs and are particularly vulnerable to parasitism. Researchers believe that parasitism by Brown-headed Cowbirds is a significant factor contributing to declining numbers of many songbirds in North America (Robinson et al. 1995).

In addition to parasitic cowbirds, nest predators such as jays, crows, raccoons, and domestic and feral cats that are not usually found in extensive forests gain access to the interior of forest patches via roads, power-line cuts, and other openings. Studies consistently show that nest predators have a greater affect on the reproductive success of forest birds in forest fragments than in contiguous forest (Wilcove 1985, Small and Hunter 1988).



Brown-headed Cowbird nestlings grow rapidly, frequently outcompeting the host's nestlings for food and parental care. This adult Common Yellowthroat is feeding a cowbird fledgling that's more than twice its size. Photo by John Gavin/CLO.

tracts; these areas have the ability to support the largest number of forest-interior birds and will also be more likely to provide habitat for area-sensitive species. Also, it is much easier to protect existing forest than to "create" new forested areas. The total amount of contiguous forest required to support healthy populations depends on a given species' area sensitivity. Some area-sensitive species such as the Northern Goshawk require hundreds of acres to breed successfully, while other less sensitive species may require only 25 acres (10 ha). In addition, it's important to note that the landscape context (see page 9) plays a critical role in determining a species' habitat-area requirements.

- **Minimizing Isolation:** Minimize isolation of forest patches by promoting reforestation of gaps between disconnected forest tracts. Forest birds generally have higher reproductive success in forest that is either connected to or in close proximity to other forest patches. This also facilitates dispersal and territory establishment.

Edges

Effects

The plight of many forest-nesting songbirds has brought into question the benefits of certain traditional wildlife management techniques. For example, historically land managers were trained to "develop as much 'edge' habitat as possible because wildlife is a product of the places where two habitats meet" (Giles 1971). Creating edges increases local diversity by attracting game species such as rabbits and deer, as well as a variety of nongame bird species such as Song Sparrows and Northern Cardinals. We now know, however, that forest-interior species may disappear from areas that contain extensive edge habitat. Gates and Gysel (1978) proposed the idea that edges may serve as "ecological traps" for some breeding birds by providing a variety of attractive habitat characteristics, while at the same time subjecting the birds to higher rates of nest predation and parasitism. Evidence from several studies indicates that the detrimental effects of an edge can extend from 150–300 feet (45–90 m) into the forest interior.

Management Tips

- **Managing Forest Shape:** Attempt to manage for forest shapes that create the least amount of edge. Circular plots are the best at maximizing forest interior, whereas square or rectangular plots are better than long, narrow strips (Figure 6). Circular forest plots offer less access to the interior for predators and nest parasites while maximizing habitat for area-sensitive species. Research shows that area-sensitive species tend to use forested areas that are at least 330 feet (100 m) from an edge.

Landscape Context

Effects

The amount of forest in the landscape plays a critical role in determining the suitability of forest patches, especially regarding patch size. In general, as the amount of forest in the surrounding landscape increases, the minimum required forest patch size for many species decreases. In the Midwest, for example, landscapes that remain at least 70% forested tend to minimize adverse effects of fragmentation on Scarlet Tanagers (Rosenberg et al. 1999b; Figure 7).

Management Tips

- **Developing a Broad-scale Plan:** Develop a long-range forest management plan at as large a scale as possible. Plan to designate tracts that will be mature at each stage in the management plan and maintain connections (corridors) between regenerating forests and mature tracts to facilitate repopulation by birds. In regions where public lands contain the majority of contiguous or large forest tracts, the most beneficial management strategies may involve protection or minimal disturbance to compensate for habitat loss and fragmentation on adjacent private lands.
- **Promoting Reforestation:** Promote reforestation of artificial forest openings, areas surrounding forest peninsulas, gaps between isolated forest tracts, and riparian corridors to create more forest interior for area-sensitive species. Reforestation can be achieved by succession, essentially leaving the area untouched for a number of years, or by planting native trees. Avoid planting monocultures, especially of exotic species; these are less attractive to most forest birds. Monitor forested plots for nonnative, invasive plants, and devise a removal plan if necessary.
- **Working Within Your Community:** Work with your neighbors and adjoining landowners to conserve adjoining forest to maintain contiguously forested areas. Consider creating a landowners association, or work with a land trust or forest manager to produce guidelines for people within your community who wish to maintain the commercial value and ecological integrity of their forests. Take part in your state or regional Partners in Flight Working Group.

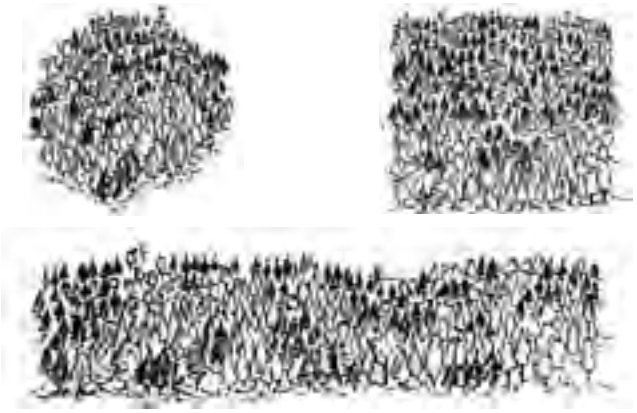


Figure 6. *The shape of a forest patch affects the amount of edge and forest-interior habitat that is present. Round and square patches have less edge and more forest interior than long narrow-shaped patches. From the Lab's* Home Study Course in Bird Biology *(Podulka et al. 2001). Illustration by Keila Sydenstricker.*

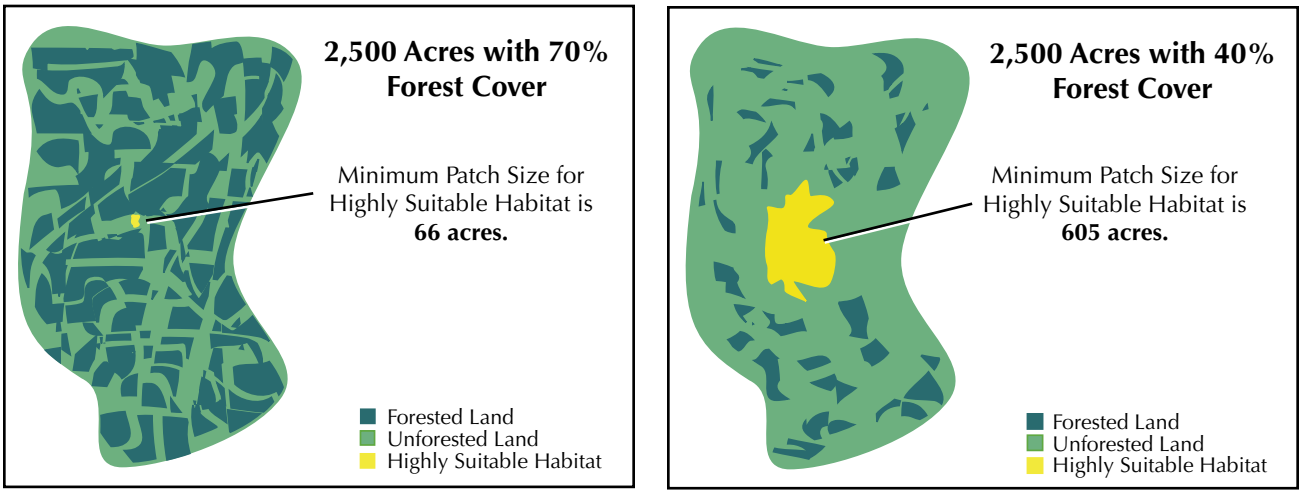


Figure 7. *Minimum area requirements for area-sensitive species may depend on the amount of forest remaining in the surrounding landscape. In this example from the midwestern US, Scarlet Tanagers in a landscape that is 70% forested require only a 66-acre (27 ha) forest patch for breeding. If the landscape is reduced to 40% forest, however, the minimum area required by tanagers is 605 acres (245 ha).*

Forest Structure

Effects

When all the landscape level characteristics, such as forest size, degree of isolation, and landscape context are acceptable, forest structure and age become the key characteristics that determine a habitat's suitability for a particular bird species. A healthy forest aging under the natural forces of ecological succession typically has the most diverse vegetation structure. An important aspect of forest structure is the amount of vertical layering. Early and mid-successional forests often have two layers—an understory of shrubs and young trees and an overstory (canopy) of interlocking branches created by mature trees. Late-successional (mature) forests usually provide the greatest amount of vertical layering. It's possible to have several layers, including herbaceous ground cover, an understory of shrubs and saplings, an intermediate layer of small trees, a lower canopy of medium sized trees, and a primary canopy of mature trees (Figure 8). The diverse habitat associated with this vertical layering supports a wide variety of birds. For example, you may have Wood and Hermit thrushes in the understory, Red-eyed Vireos and Rose-breasted Grosbeaks in the intermediate layers, and Scarlet Tanagers and Black-throated Green Warblers in the canopy. Many forest birds, including the thrushes, depend on the cover, food, and nest sites provided by a diverse and well-developed understory.



Figure 8. *Late-successional forests often provide a high degree of vertical layering, including a dense shrubby understory important for thrushes and other birds. Photo by Kenneth V. Rosenberg*

Management Tips

- **Creating a Broken Canopy:** Permitting sunlight to reach the forest floor by creating gaps in the forest canopy will help to stimulate a poorly developed understory in mid-successional and mature forests. When understory vegetation is very deficient or absent, planting appropriate native, shade-tolerant shrubs, in addition to maintaining a broken canopy, may be required to establish an understory layer.
- **Employing Silviculture:** Silvicultural practices that create uneven-aged forests with well-developed, but broken, canopies usually provide the best habitat for forest birds. Avoid loss or change in tree-species diversity and fitness by minimizing "high-grading" (the removal of only the most valuable species and the most structurally superior trees). Where possible, preserve existing old-growth stands and provide for the development of future old growth by leaving areas undisturbed or unharvested for 150 years or more.
- **Controlling Ungulates:** Given the tremendous increase in white-tailed deer densities during the past three decades, it may be necessary to control deer numbers or forest access to preserve a well-developed understory (Figure 9). Where appropriate, hunting can help to control deer numbers. When hunting isn't feasible, deer exclosures (fences) can help to protect understory vegetation. In addition, grazing by livestock should be monitored carefully to detect signs of damage to the understory layer.



Figure 9. *Heavy browsing by white-tailed deer sometimes results in complete loss of understory shrubs and saplings, reducing the suitability of forests to thrushes and many other birds. Photo by Kenneth V. Rosenberg.*

Regional Management Guidelines for Thrushes

Using These Guidelines

The following sections provide specific information about the habitat requirements of forest thrushes in three forested regions—Eastern/Midwestern Forests, Western Forests, and Northern Forests. These guidelines are based primarily on the results of the Birds in Forested Landscapes project and focus on mitigating the effects of forest fragmentation on breeding thrushes. They describe the minimum area required to provide thrushes with high, moderate, or low levels of habitat suitability. In addition, for some species they describe the importance of selected patch-level characteristics, such as forest structure and amount of core habitat area.

Results from Birds in Forested Landscapes suggest that each species of forest thrush responds differently to forest fragmentation, and the degree of area sensitivity expressed varies by geographic region. We present specific guidelines for each of the three forest regions to assess more accurately the effects of forest fragmentation, and provide guidelines that are relevant within various portions of each thrush species' breeding range. For each forest region, we provide information designed to help land managers evaluate and improve habitat for thrushes in their area. Each regional profile includes:

- a map and description of available forest types
- literature review of habitat relationships for thrushes in that region
- estimates of minimum habitat areas required to support each thrush species
- the most common trees at sites containing thrushes
- results of forest structure analyses for each thrush species
- regional summaries that briefly present the most important management strategies for that region.

Using Minimum-Area Tables

Within each region, the likelihood that a forest patch of a given size will attract a given species of thrush varies based on the amount of forest remaining in the surrounding landscape and how close the patch is to the nearest large forest (more than 500 acres or 200 ha). We define a landscape as a 2,500-acre (1,000-ha) block surrounding each forest patch. Because the probability of finding thrushes in a forest patch may be dependent on the amount of forest in the surrounding landscape, we offer a range of minimum-area estimates for landscapes with differing proportions of forest. The minimum-area estimates are arranged in Minimum Area Tables that provide a range of patch sizes required to achieve varying levels of habitat suitability.

The Minimum-Area Tables can be used to help improve habitat for breeding thrushes. For instance, the tables can be used:

- In conjunction with topographical maps, aerial photos, and Geographic Information Systems (GIS), to remotely identify forest patches with a high probability of supporting breeding thrushes. Identifying forest patches remotely allows managers to maximize their inventory and management efficiency by first focusing their efforts on sites with the greatest need for protection and management.
- To predict the impacts of proposed management actions or land-use changes on the suitability of habitat for breeding thrushes.
- To determine the degree of habitat enhancement (reforestation) needed to increase the probability of attracting thrushes to a given forest patch.
- To develop long-term management plans at local, state, and regional scales.
- To make planning and mitigation decisions when habitat loss and fragmentation are unavoidable.

In the Minimum-Area Tables provided with each regional profile, acreage estimates are listed for three levels of habitat suitability. These are defined as follows:

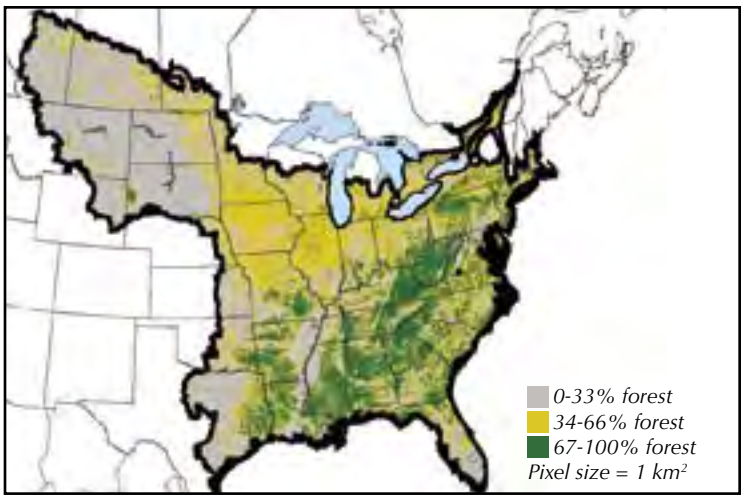
- **High Suitability:** Habitats of this size have the same probability of supporting breeding thrushes as a large patch of unfragmented forest.
- **Moderate Suitability:** Habitats of this size are 25% less likely to support breeding thrushes relative to unfragmented forest.
- **Low Suitability:** Habitats of this size are 50% less likely to support breeding thrushes relative to unfragmented forest.

To use the minimum-area tables, first estimate the percentage of forested land occurring in a roughly 2,500-acre (1,000-ha) block surrounding your area of interest. Then, read across the row to determine the minimum area required to achieve desired habitat suitability for thrushes. You can also use the tables to determine the suitability of your particular forest patch based on its size.

East/Midwest Forest Region

Description

We define the East/Midwest Forest Region as the vast area east of the Great Plains dominated by deciduous forest. Although highly variable in tree composition and forest structure, this large region tends to support a rather uniform bird community, including many widespread forest-breeding species such as the Wood Thrush.



Because the Great Plains experiences less precipitation than areas to the east, the broadleaf deciduous forests of this area tend to include more of the drought-tolerant oak-hickory association (Bailey 1995). Forests in the northern and eastern parts of the Midwest contain more maples, American beech, and basswood, whereas the western part becomes savanna-like as it gradually gives way to prairie. Oaks and hickories dominate upland forests in the prairie region, whereas farther west, floodplain forests contain cottonwood, willows, and elms (Bailey 1995). The more mountainous areas of Arkansas support oak-hickory forests that include coniferous trees, especially pines. Forests of the Midwest are typically highly fragmented by agricultural and, more recently, by urban development.

The Appalachian Mountains area is more heavily forested, with tree species composition changing with elevation. Vast forests are dominated by oaks, yet include some of the most diverse forests in North America. Lower valleys support mixed oak-pine forests, which are largely cleared, while at higher elevations the composition includes birches, American beech, maples, elms, oaks, and basswood, with some eastern hemlock and white pine. Finally, spruce-fir forests and meadows can be found on the highest peaks in some areas.

Along the Atlantic Coast, relatively small forested areas are typically found within a largely urban and suburban landscape. This is especially true in the corridor between Boston and Washington, D.C. Some extensively forested areas occur in central Massachusetts, southern New Jersey, and Virginia. The forests of the northern part of this area are mostly deciduous, especially the Appalachian oak association. Pine-oak forests (pine barrens) are also found in dry sandy locations that are frequently exposed to naturally occurring fires (Bailey 1995). Oaks, hickories, sweetgum, blackgum, red maple, and winged elm are also common.

Farther south along the coastal plain, evergreen oaks, laurels, and magnolias are common, while gum and cypress dominate coastal swamps. Historically, savannas of pine forests (longleaf, slash, and loblolly) with an understory of grasses and sedges dominate most of the uplands in this area. The piedmont forms a transition between the southeastern coastal plain and the Appalachian Mountains. It is dominated by both southern pines (such as loblolly and shortleaf) and mixed southern hardwoods (such as oak, hickory, sweetgum, blackgum, red maple, and winged elm). The Lower Mississippi River Valley was covered by huge tracts of bottomland-hardwood forest; however, most of the forests have now been cleared for agriculture. Other large and small river valleys still support important tracts of bottomland hardwoods.

Habitat Guidelines for Thrushes

Wood Thrush

The Wood Thrush is the most common thrush species throughout most of the East/Midwest Forest Region, occurring in many forest types from southern Canada to the Gulf Coast and the Great Plains. Although often considered a bird of mature, intact forests, this species shows much variability in habitat preferences across its range, and it certainly inhabits small woodlots in highly fragmented landscapes. A number of studies have shown, however, that habitats used by Wood Thrushes do not always provide the requisites for positive reproductive success, and that populations in highly fragmented forests may not be sustainable, perhaps contributing to regional population declines. Therefore, our guidelines below regarding minimum areas for Wood Thrush occupancy must be considered in combination with other habitat features that may be necessary for successful breeding.

In the Birds in Forested Landscapes study, Wood Thrushes were detected at 848 (54%) of 1,568 sites surveyed in the East/Midwest Region. Fifty-three percent of sites with Wood Thrushes were located in deciduous forest, 45% in mixed forest, and 1% in co-

niferous forest. The most common trees on sites occupied by Wood Thrush were oaks (65%), maples (62%), pines (25%), American beech (22%), and hickories (19%). Results from this study indicate that Wood Thrushes choose habitats based more on the structure of the forest than on the degree of forest fragmentation in the landscape. Specifically, Wood Thrushes selected areas at lower elevations with a higher density of saplings in the understory and a taller canopy. They avoided areas with a high proportion of coniferous trees. In addition, the Wood Thrush proved to be area sensitive, although the size of patches required did not appear to change with amount of forest fragmentation in the landscape. High suitability forest patches are at least 200 acres (80 ha), and suitability declines rapidly in patches less than 100 acres (40 ha; Figure 10). Small patches offer moderate suitability in terms of occurrence during the breeding season, but other research has shown that Wood Thrushes in small patches suffer decreased reproductive success.

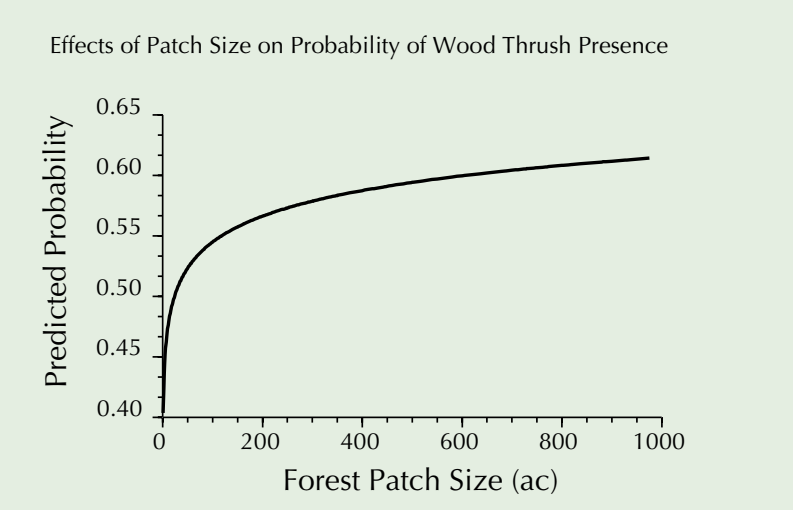


Figure 10. *The probability of finding breeding Wood Thrushes in the East decreases sharply in forest patches less than 200 acres (80 ha).*

In addition to landscape level considerations, most studies, including Birds in Forested Landscapes, indicate that a dense understory of saplings and shrubs is a key habitat requirement. In fragmented landscapes, an appropriate combination of habitat characteristics, such as forest size, amount of core area, amount of edge, and vegetation structure must be met to ensure adequate levels of reproduction that offset adult and fledgling mortality (Hoover 1992, Robinson and Wilcove 1994, Driscoll et al. in press). Driscoll et al. (in press) further documented that Wood Thrush populations in fragmented habitat with much edge suffered negative population growth rates, whereas populations in forest interiors or fragmented forests with less edge experienced positive population growth.

In a study of two riparian areas in central Ohio, Groom and Grubb (2002) found that the width of forested riparian corridors was less important than the amount of forest in the landscape for predicting Wood Thrush presence. Hoover (1992) found that nesting success was significantly higher in large (1,200 acre or 480 ha) forest patches versus small patches (23 acre or 9.2 ha) in Pennsylvania. The author also indicated that nesting survival was positively correlated with percent forest within a 1.2-mile (2-km) radius and the amount of forest core area. High rates of nest predation in small forest tracts (less than 200 acres or 80 ha) explained the lower nesting success in highly fragmented landscapes (Hoover et al. 1995). Numerous authors have found Wood Thrushes to be more abundant and successful in large forest patches, especially in highly fragmented landscapes such as the Midwest (Whitcomb et al. 1981, Galli et al. 1976, Lynch 1987). In general, forest patches exceeding 250 acres (100 ha) foster adequate rates of nesting success by mitigating the effects of predation and sometimes cowbird parasitism.

Robinson and Wilcove (1994) suggest that the effects of silvicultural practices depend on the landscape context and that low-volume selective logging is preferable to clear-cutting. Crawford et al. (1981) found that Wood Thrush tolerate uneven-age forest management and selective removal of mature trees scattered throughout a stand creates favorable conditions for the species.

In the Piedmont National Wildlife Refuge in central Georgia, which is actively managed for Red-cockaded Woodpeckers, Lang et al. (2002) found that small-scale thinning and burning had little effect on Wood Thrush populations. In southeastern Missouri, Wood Thrushes were most abundant in mature forest stands when compared with forest stands harvested by clearcut, shelterwood, group selection, and single-tree selection forest regeneration methods (Annand and Thompson 1997).

Veery

The Veery is a common thrush in the northern portions of the East/Midwest Forest Region and throughout the higher Appalachian Mountains. They tend to occur at higher elevations than the Wood Thrush and are associated more with northern-hardwood forests than with oak-hickory or bottomlands. The Veery has a strong affinity for wet sites, and although they may be common in disturbed or regenerating forests, they are highly area sensitive and not tolerant of high levels of forest fragmentation.

In the Birds and Forested Landscapes study, Veeries were detected at 302 (31%) of 971 sites surveyed in the East/Midwest Region. Fifty-five percent of

sites with Veeries were located in mixed forest, 44% in deciduous forest, and 1% in coniferous forest. The most common trees on sites occupied by Veeries were maples (73%), oaks (60%), pines (28%), American beech (21%), and hemlock (20%).

Results from this study indicate that Veeries are most affected by the degree of fragmentation in the landscape and by the size of forest patches, especially the amount of "core forest" away from edges. The most suitable sites are also those with a denser deciduous shrub understory. Highest-suitability habitat only occurs in landscapes with at least 70% forest cover, and in these landscapes, patches larger than 1,000 acres (400 ha) are required (Table 1). Even in landscapes with 80% forest, patches of roughly 400 acres (165 ha) are required; minimum area is reduced to 127 acres (51 ha) if forest cover increases to 90%. Smaller forest patches in more fragmented landscapes do provide moderate habitat suitability, however, patches greater than 300 acres (120 ha) are still required in landscapes with 40% forest.

Other studies suggest that Veeries use a variety of habitats in different parts of their range. In New York State, Veeries select early successional forest for breeding (Kendeigh 1945, 1946). In highland areas of North Carolina, it's a bird of mature oak forest (Odum 1950) and on Apostle Island in Wisconsin, it's found primarily in aspen and red oak forests where the understory is most dense (Beals 1960). In New Jersey, Veeries prefer moist forests that are 40–60 years old with a dense understory (Suthers 1987–1988).

Unlike the other forest thrushes, Veeries show a strong tolerance for disturbed forest with a well-developed understory (Dilger 1956). Noon et al. (1976) found that Veeries bred in 77% of available disturbed and successional forests, but only 18% of mature undisturbed habitat. Bertin (1977) suggested that in mature woodlands, moisture regime was the primary factor driving habitat selection, with the dampest areas occupied first and pointed to available shrub cover as the most critical habitat component. Veeries may benefit from selective harvesting that opens up the canopy and allows the understory to develop (Webb et al. 1977, Thompson and Capen 1988). Derleth et al. (1989) found that Veeries tolerated small clearcuts (2–20 acres or 1–8 ha), but Morgan and Freedman (1986) noted that Veeries were absent from large clearcuts for six years following the harvest.

Habitat selection may vary when other thrushes are present. In many portions of their range, Veery breed primarily in deciduous forest, even when coniferous forest is available. In a study conducted in Tennessee, in areas where their breeding range overlapped with Swainson's Thrush, the Veery used deciduous, coniferous, and mixed forests (Noon 1977). Although it was once absent from higher elevation spruce forests in the Appalachian Mountains, Veerys have expanded into the southern Appalachian spruce forests when congeners are not present (Noon 1981).

Hermit Thrush

In the East/Midwest Forest Region, Hermit Thrushes are restricted largely to the northernmost portions and also to higher elevations through the Appalachians where coniferous forests are dominant. Small populations occur in other coniferous habitats at lower elevations, including cedar swamps, hemlock ravines, conifer plantations, and pine barrens. Although this thrush is common and apparently increasing, it is nonetheless shown to be highly area sensitive and intolerant of forest fragmentation within its range.

In the Birds in Forested Landscapes study, Hermit

Table 1. *Minimum area required to provide high, moderate, or low habitat suitability for Veery based on analysis of 685 study sites in the East/Midwest region (see page 11 for definitions of habitat suitability).*

Percentage of forest in 2,500-acre block	Minimum area (acres) required for		
	High	Moderate	Low
90	127	3	Any size
80	396	10	Any size
70	1004	26	Any size
60	NA[a]	61	1
50	NA	136	2
40	NA	305	4
30	NA	708	9
20	NA	NA	24
10	NA	NA	74

[a]*Not Available—acreage values exceed the amount of forest in the 2,500-acre block.*

Table 2. *Minimum area required to provide high, moderate, or low habitat suitability for Hermit Thrush based on analysis of 347 study sites in the East/Midwest region (see page 11 for definitions of habitat suitability).*

Percentage of forest in 2,500-acre block	Minimum area (acres) required for		
	High	Moderate	Low
90	32	5	Any size
80	56	9	1
70	88	14	1
60	132	22	2
50	196	32	3
40	289	47	4
30	435	71	6
20	NA[a]	111	10
10	NA	193	18

[a]*Not Available—acreage values exceed the amount of forest in the 2,500-acre block.*

Thrushes were detected at 142 (26%) of 553 sites surveyed in the East/Midwest region. Seventy-seven percent of sites with Hermit Thrushes were located in mixed forest, 20% in deciduous forest, and 2% in coniferous forest. The most common trees present at sites occupied by Hermit Thrush were maples (75%), oaks (53%), pines (41%), hemlock (32%), and beech (27%).

Results from this study indicate that Hermit Thrushes are most attracted to forests with a high coniferous component, and they avoid sites with a largely deciduous shrub understory. They are also area sensitive, although less so than the Veery or Wood Thrush. In highly fragmented landscapes, single large forest patches may still offer highly suitable habitat for Hermit Thrush (Table 2), and even in more intact (50% forest) landscapes, patches roughly 200 acres (80 ha) in size are required. Smaller forest patches do offer moderately suitable habitat, especially if they contain the conifers.

In New York, Hermit Thrushes selected sites in dry coniferous, mixed, or deciduous forests and were sometimes associated with internal forest edges (Andrle and Carroll 1988, Dilger 1956). In forest communities in northwestern Wisconsin the abundance of Hermit Thrushes was related to the amount of edge and variables relating to patch shape (Hawrot and Niemi 1996).

Researchers compared two harvest techniques in riparian areas of northern Wisconsin (full tree harvest and cut-to-length (CTL)). Bird surveys one year prior to harvest and three years after harvest showed that bird communities were affected by both harvest types. Hermit Thrush, along with Ovenbird and Black-throated Green Warbler showed significant declines. Within three years of harvest no individuals of these species were observed (Hanowski et al. 2003).

Management Summary for the East/Midwest Forest Region

Landscape Level

In this region, the primary consideration for all thrush species is the maintenance of large contiguous forest patches that promote reproductive rates that compensate for adult and nestling mortality. Thrushes in this region will tolerate and may even benefit from patch-level disturbances such as light selective harvesting that does not contribute to forest fragmentation. The Veery and Wood Thrush are the most area sensitive of the three species in this region and thus set the bar for minimum forest size. The required forest patch size needed for consistent successful reproduction is highly related to surrounding land use (see Tables 1 and 2); in general however, forest patches of 150 acres (62 ha) or larger will be adequate to provide moderate levels of habitat suitability, except in landscapes with little forest. In landscapes with greater than 50% forest, smaller woodlots can provide suitable habitat. In highly fragmented forests or landscapes with very little forest cover, minimizing edge and increasing connectivity among forest patches may increase habitat quality in small patches. For Veeries, maximize core forest by reducing the amount of edge habitat associated with forest fragments. This can be done by managing patch shape, creating transitional, as opposed to abrupt edges, and reforesting areas between disconnected patches. In lowlands, especially in damp sites, management should focus on Wood Thrush; at higher elevations and in moist, mixed forests management should focus on both Veeries and Wood Thrushes; and in mostly coniferous forests and on drier sites, management should focus on Hermit Thrushes.

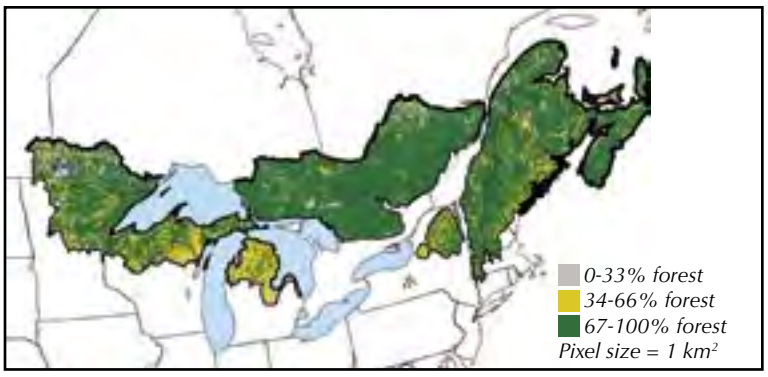
Site Level

For Wood Thrush and Veery, create and maintain forest habitat with a dense understory of deciduous saplings and shrubs. Because of its area sensitivity, focus site-level management for Wood Thrushes on patches greater than 200 acres (80 ha). This can be accomplished by planting appropriate native trees and shrubs, creating gaps in the canopy that permit sunlight to reach the forest floor, and controlling browsing by white-tailed deer and livestock. Moderate selective harvesting of timber is often tolerated by thrushes, and serves to increase the shrub layer. Clear cutting and heavy selective cutting are not recommended for thrush management. Hermit Thrush prefer a strong coniferous component and may benefit from conifer plantings or silvicultural practices that favor existing conifers, especially pines and eastern hemlock. Protecting stands of hemlock and cedar swamps within hardwood forests, as well as protecting large areas of pine-barrens habitat will also benefit Hermit Thrushes.

Northern Forest Region

Description

We define the Northern Forest Region as a wide band of coniferous and northern hardwood forest from the western Great Lakes to the Adirondacks of New York, northern New England, and the Canadian Maritime Provinces. This region corresponds to the Boreal-Hardwood Transition and Atlantic Northern Forest Bird Conservation Regions (U.S. NABCI Committee 2000).



The region is heavily forested throughout. The northern portion is boreal spruce-fir forest with deciduous species becoming more common further south. The area surrounding the Great Lakes and along the Atlantic coast is transitional between southern deciduous forests and the northern boreal spruce-fir forest. Deciduous forests tend to occur on favorable sites with good soils whereas coniferous forests are found on less-favorable sites with poor soils. Common tree species are yellow birch, sugar maple, American beech, white pine, and eastern hemlock (Bailey 1995). The mountainous areas of New York and New England have a vertical zonation of tree species. The valleys have deciduous forests of sugar maple, yellow birch, beech, and some hemlock. The lower slopes have mixed forests of spruce, fir, maple, beech, and birch. Finally, pure stands of balsam fir and red spruce can be found above the mixed-forest zone (Bailey 1995).

Habitat Guidelines for Thrushes

Wood Thrush

Within the Northern Forest Region, Wood Thrushes are common only in the transitional mixed-hardwood forests around the Great Lakes, southeastern Canada, and the Adirondack Mountains. They are strongly tied to the deciduous component of these forests and occur primarily at lower elevations. Wood Thrushes are a declining species in this region, and management to enhance populations is a high conservation priority.

In the Birds in Forested Landscapes study, Wood Thrushes were detected at 71 (30%) of 236 sites surveyed in the Northern Forest Region. Sixty-nine percent of sites with Wood Thrushes were located in mixed forest, 14% in deciduous forest, and 15% in coniferous forest. The most common trees on sites occupied by Wood Thrush were maples (70%), pines (51%), hemlock (38%), birch (38%), and beech (30%).

The relatively small sample of Wood Thrushes from this region indicates a high degree of area sensitivity that increases with degree of fragmentation in the landscape. For example, in landscapes with 70% forest cover, 200-acre (80-ha) patches are required to achieve high suitability for the Wood Thrush, and as forest cover drops below 40%, high habitat suitability cannot be achieved (Table 3). For moderate suitability, smaller patches may suffice; for example, a 50-acre (20-ha) patch in a 50% forested landscape (Table 3).

In Quebec, preferred habitat for this species is described as mature, undisturbed forest, with damp ground, dense shrubby undergrowth, and a thick layer of ground litter (Gauthier and Aubry 1996). Thus, Wood Thrush may be more of a habitat specialist in the northern portion of its range than further south.

Veery

The Veery is common throughout the southern and eastern portions of the Northern Forest Region, from Manitoba to the Maritime Provinces, northern New England, and the Adirondack Mountains. They

Table 3. *Minimum area required to provide high, moderate, or low habitat suitability for Wood Thrush based on analysis of 108 study sites in the Northern region (see page 11 for definitions of habitat suitability).*

Percentage of forest in 2,500-acre block	Minimum area (acres) required for		
	High	Moderate	Low
90	69	8	1
80	125	14	1
70	201	22	2
60	310	35	2
50	470	52	4
40	712	79	6
30	NA[a]	123	9
20	NA	198	14
10	NA	NA	26

[a]*Not Available—acreage values exceed the amount of forest in the 2,500-acre block.*

are most abundant in northern hardwood and transitional forests with a strong deciduous component at lower elevations. In Ontario, the range extends north where deciduous growth occurs in wetlands, after forest fires, or following timber harvest (Cadman et al. 1987).

In the Birds and Forested Landscapes study, Veeries were detected at 124 (49%) of 253 sites surveyed in the Northern Forest Region. Seventy-four percent of sites with Veeries were located in mixed forest, 17% in deciduous, and 8% in coniferous forest. The most common trees present on sites occupied by Veeries were maples (67%), birches (38%), pines (37%), hemlock (35%), and ash (21%).

Results of this study indicate that Veeries are less area sensitive than they are further south, with virtually any size forest patch providing suitable habitat in landscapes that are at least 50% forested. They are most strongly associated with dense deciduous shrubs in the forest understory.

In Maine, where Veery and Wood Thrush overlap, successional stage was found to be the most important difference in their habitat. Veeries inhabit younger forests and wetter areas than the Wood Thrush, while Hermit Thrushes and Veeries are sometimes found together in mixed coniferous-deciduous and/or mixed alder and maple forests (Morse 1971). Hagan and Grove (1999) found Veery to be most abundant in partially-cut forest in northern Maine. In Quebec, Veeries prefer an open canopy and dense understory (Gauthier and Aubry 1996), and they were predicted to benefit from tree removal in mature forests, resulting in greater shrub cover and understory development (Clark et al. 1983). In the White Mountains of New Hampshire, Welsh and Healy (1993) found Veeries significantly more abundant in managed rather than unmanaged stands.

Swainson's Thrush

The range of the Swainson's Thrush overlaps the entire northern forest region and extends northward into the boreal forest. In the southern portions, they occur generally at higher elevations than the Veery or Wood Thrush and are associated more with coniferous forests, especially spruce and fir.

In the Birds in Forested Landscapes study, Swainson's Thrushes were detected at 37 (25%) of 146 sites surveyed in the Northern Forest Region. Seventy-three percent of sites with Swainson's Thrushes were located in mixed forest, 22% in coniferous forest, and 5% in deciduous forest. The most common trees present on sites occupied by Swainson's Thrushes were birches (41%), maples (41%), firs (35%), spruces (35%), and aspens (32%). The small sample in this study did not indicate an affect of forest fragmentation on the Swainson's Thrush or allow the calculation of minimum area of forest required for high habitat suitability.

This species has been described as a bird of the extensive spruce-fir forests of Quebec, in areas of relatively mature forest with "not very heavy understory" (Gauthier and Aubry 1996). In Maine, Hagan and Grove (1999) found Swainson's Thrush to be the only thrush showing a significant association with mature forest, and to be more abundant in landscapes managed with partial-cut, rather than clearcut techniques. In a comparison of forest management techniques in Labrador that attempted to emulate natural disturbance, researchers compared bird abundances among burned and clear cut former black spruce sites after 5, 14, and 27 years of succession. Hermit Thrushes and Swainson's Thrushes were lower in clear-cut sites and peaked in the 14-year old burns where abundance exceeded that of mature forests. Swainson's Thrush was positively correlated with deciduous tree cover and negatively correlated with conifer cover. Logged areas did support some of the same bird species but did not mimic fire. This study suggests that forest managers may want to allow some forests to burn naturally (Simons et al. 2002).

Hermit Thrush

The Hermit Thrush occupies the entire northern forest region and extends northward through the boreal forest. It is common in both northern-hardwood and coniferous forests and is more strongly associated with conifers than the other thrush species. It also occurs on drier sites, such as jack pine and deciduous forests on sandy soils.

In the Birds in Forested Landscapes study, Hermit Thrushes were detected at 143 (54%) of 265 sites surveyed in the Northern Forest Region. Eighty percent of sites with Hermit Thrushes were located in mixed forest, 10% in deciduous forest, and 10% in coniferous

Table 4. *Minimum area required to provide high, moderate, or low habitat suitability for Hermit Thrush based on analysis of 111 study sites in the Northern region (see page 11 for definitions of habitat suitability).*

Percentage of forest in 2,500-acre block	Minimum area (acres) required for		
	High	Moderate	Low
90	25	2	Any size
80	71	7	Any size
70	166	16	1
60	359	34	2
50	750	71	4
40	NA[a]	148	9
30	NA	321	19
20	NA	NA	45
10	NA	NA	127

[a]*Not Available—acreage values exceed the amount of forest in the 2,500-acre block.*

forest. The most common trees present on sites occupied by Hermit Thrushes were maples (66%), birches (48%), pines (39%), hemlock (30%), and oaks (23%).

Results of this study indicate that Hermit Thrushes are adversely affected by forest fragmentation and are highly area sensitive in this region. In landscapes that are 70% forested, highly suitable habitat consists of forest patches at least 166 acres (67 ha). In 50% forested landscapes, the minimum area required increases to 750 acres (304 ha) (Table 4). Smaller patches provide moderately suitable habitat, however, except in highly fragmented landscapes with less than 20% forest cover. Sites with a high proportion of coniferous trees in the canopy are strongly favored.

The Hermit Thrush is often described as the most versatile of the thrushes in terms of habitat use, occurring in conifer or mixed forests on damp or dry sites (Gauthier and Aubry 1996). Morse (1971) found that Hermit Thrushes bred in dry mixed forests, while Veery and Wood Thrush were most commonly associated with wetter sites. In New Hampshire, Holmes and Robinson (1988) reported similar results with Hermit Thrush using dry forests away from streams with relatively little understory. They are also tolerant of clearings, burns, and regenerating areas within the forested matrix, as well as conifer plantations. Freedman et al. (1981) noted that in hardwood forests of Nova Scotia, Hermit Thrushes were present in "strip cuts," but not in clear cuts or thinned forests. In a comparison of burned and clear cut spruce forests 5, 14, and 27 years after succession in Labrador, Hermit Thrush density peaked in 14-year-old burns and was positively correlated with snag density (Simons et al. 2002). They were also most abundant in partially cut forest in northern Maine (Hagan and Grove 1999). Thus, this species appears tolerant of, or even to benefit from disturbance, including active management, within large expanses of forest, but not tolerant of high levels of forest fragmentation.

Management Summary for the Northern Forest Region

Landscape Level

In general, the Northern Forest Region is more heavily forested than the East/Midwest and Western Forest Regions. For this reason, habitat protection through long-term planning and enhancement of forest structure are the most important management considerations. A shifting mosaic of forest habitats at various successional stages will likely benefit the most species as long as disturbance and silvicultural practices don't lead to forest loss or fragmentation over the long-term. Small-scale timber harvesting may be compatible with forest bird management (including all thrushes) as long as forests don't become fragmented. In the Northern Forest Region, the most area sensitive species are the Wood Thrush and Hermit Thrush. Generally, forests of 150 acres (62 ha) or larger will provide these two species with high to moderate levels of habitat suitability. In highly fragmented landscapes with less than 40% forest, patches of 350 acres (140 ha) or larger are needed to supply high to moderate habitat suitability for Wood and Hermit thrushes. Enhancement of forest structure in small forest patches may be beneficial for the less area sensitive Swainson's Thrush and Veery.

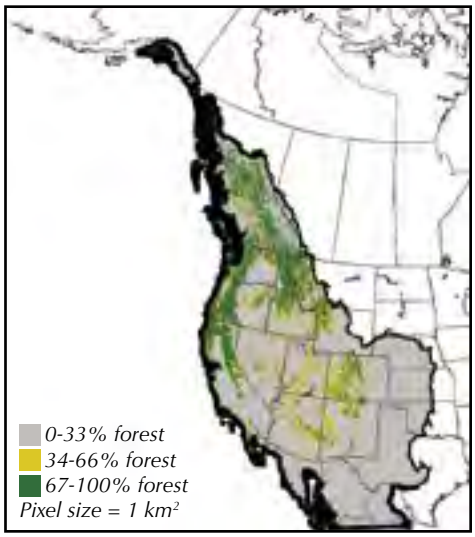
Site Level

In southern portions of the region with more deciduous trees, management should focus on Wood Thrush and Veery by promoting and retaining deciduous understory and maintaining deciduous riparian buffers. In coniferous forest areas, management should focus on Swainson's Thrush and Hermit Thrush—Swainson's Thrush seems to prefer mature, undisturbed spruce-fir forests with a sparser understory, whereas Hermit Thrushes are more tolerant of disturbance, but not forest loss or fragmentation. Create and maintain forest habitat with a dense understory of saplings and deciduous shrubs. This can be accomplished by planting appropriate native trees and shrubs, creating gaps in the canopy that permit sunlight to reach the forest floor, and controlling browsing by white-tailed deer and livestock. Moderate selective harvesting of timber is often tolerated by thrushes, and serves to increase the shrub layer. Clear cutting and heavy selective cutting are not recommended for thrush management. Hermit Thrush prefer a strong coniferous component and may benefit from conifer plantings or silvicultural practices that favor existing conifers, especially pines and eastern hemlock.

Western Forest Region

Description

We define the Western Forest Region as all areas west of the Great Plains, including vast, primarily coniferous forests from the Rocky Mountains west to the Pacific Ocean.



Along the Pacific coast, forests are dominated by cedar, hemlock, and sitka spruce to the north, and Douglas-fir, western red cedar, hemlock, and redwoods further south. Willow, cottonwood, alder, and birch can be found at lower elevations and along rivers (Bailey 1995). The coniferous forests of the Sierra Nevada Mountains are dominated by ponderosa pine on western slopes with lodgepole pine and Jeffrey pine replacing the ponderosa pine on the eastern slopes. Mountain hemlock, fir, spruce, and various pines can be found at higher elevations. In coastal California, the sclerophyll forest contains species such as live oak, laurel, madrone, and bayberry that have thick, leathery leaves that can tolerate dryness.

The remainder of the intermountain west consists primarily of coniferous forests at higher elevations, interspersed with grasslands, sagebrush, and shrubs in the lowlands. Some areas of broadleaf forest, especially aspen, are also found here. Tree species composition is strongly dependent on elevation and slope exposure. Throughout the Rocky Mountains, Engelmann spruce and subalpine fir dominate most of the subalpine areas. Douglas-fir, western redcedar, western hemlock, western white pine, western larch, grand fir, ponderosa pine, and lodgepole pine are common forest types below the subalpine zone (Bailey 1995). In the southern foothills and lower plateaus, scrub oaks are common along with pinyon-juniper woodlands. Mountains of Arizona, New Mexico, south through northern Mexico support diverse pine-oak forests, with important riparian woodlands occurring in canyons and along lowland river valleys.

Habitat Guidelines for Thrushes

Veery

The Veery is an uncommon species in western forests, where it is largely restricted to riparian and other deciduous vegetation at middle and lower elevations. In the Birds in Forested Landscapes study, Veeries were detected at only 15 (11%) of 138 sites surveyed in the Western Forest Region. This small sample did not allow analysis of habitat preference or affects of forest fragmentation.

Tewksbury et al. (2002) found that in riparian areas of the West (Montana, Idaho, Nevada, and Oregon), Veeries were less common in grazed sites, in heavily settled or agricultural landscapes, or in areas with little deciduous riparian habitat. They recommended that "management should focus on (1) preserving and enlarging deciduous habitats, (2) reducing cattle grazing in deciduous habitats, and (3) protecting the few relatively pristine landscapes surrounding large deciduous riparian areas in the West."

Swainson's Thrush

The Swainson's Thrush is widespread in the Western Forest Region, with two distinct populations showing rather different habitat associations. In the interior portions, this species is found in montane coniferous forests, but is often associated with deciduous or riparian vegetation at lower elevations. On the pacific slope, Swainson's Thrush is found to sea level, primarily in riparian forests.

In the Birds in Forested Landscapes study, Swainson's Thrushes were detected at 156 (43%) of 365 sites surveyed in the Western Region. Habitats occupied by Swainson's Thrushes differed between the Pacific and interior portions of the region; in the Pacific, 62% of occupied sites were in mixed forest, 20% in coniferous, and 16% in deciduous forest, whereas in the interior, 49% of sites were in mixed forest, 48% in coniferous, and only 2% in deciduous forest. The most common trees on sites occupied by Swainson's Thrushes were Douglas-fir (56%), pines (33%), alder (22%), cedar (21%), and spruce (21%). Results of this study indicate that Swainson's Thrush is highly associated with deciduous shrubs in the forest understory. In the Pacific portion of the region, this species was not adversely affected by reduction in forest area or patch size, but in the interior portion, they were strongly area sensitive and found highly suitable habitat only in the most extensively forested landscapes (Figure 11).

Although characterized as an area-sensitive species, results from several western studies report conflicting results. Swainson's Thrushes were found to be area sensitive in cedar-hemlock forest in Idaho and

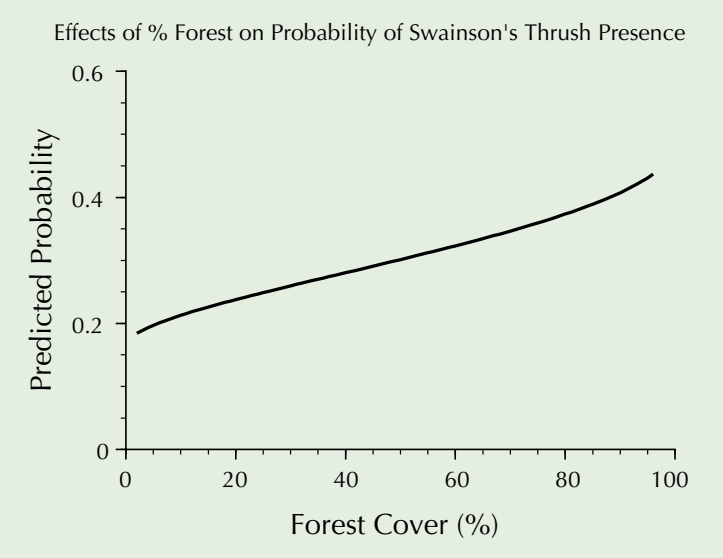


Figure 11. *The probability of finding breeding Swainson's Thrushes decreases as amount of forest in the landscape is reduced.*

riparian areas in Nevada (Freemark et al. 1995), but not in Douglas-fir forests of the Pacific Coast (Lehmkuhl et al. 1991). Evans 1995 found that abundance was not significantly correlated with patch size in mature forest or edge in mixed coniferous forest of the northern Rockies. Stands in more fragmented landscapes; however, had fewer nests and lower nest success than stands in more contiguous landscapes in the same study area (Evans et al. 1998). Hejl et al. (2002) reported that Swainson's Thrushes in the Central Rocky Mountains were positively associated with amount of forest and patch size, and negatively associated with edge in "all coniferous forest," but found no relationship among these habitat variables in "mixed conifer," "cedar/hemlock," or "ponderosa pine forest."

In coniferous forests of the northern Rockies, there is a generally consistent response to silvicultural practices, with the highest abundances occurring in unlogged old-growth stands (Johnston 1949, Hejl et al. 1995). Along the Oregon coast, immediate and significant declines were noted after substantial reductions in forest cover that resulted from silvicultural practices.

In British Columbia, Swainson's Thrushes are sensitive to the silvicultural practice of removing deciduous vegetation from regenerating coniferous forests. In a comparison of 11–22 year old conifer plantations (54–116 acres or 22–47 ha), nest sites were positively correlated with remaining deciduous vegetation. This relationship was strongest in areas with the fewest deciduous trees. Nest success was positively correlated with the amount of willow associated with the nest site (Easton and Martin 2002). In northwestern California, Swainson's Thrush occurred in highest densities along edges, but edges also experienced higher rates of nest predation, suggesting that these habitats may represent ecological traps in this region (Brand and George 2000).

Hermit Thrush

The Hermit Thrush is widespread throughout the Western Forest Region, in coniferous forests of the interior mountains, as well as on the Pacific Coast. In the Birds in Forested Landscapes study, Hermit Thrushes were detected at 142 (30%) of 470 sites surveyed in the Western Region. Fifty-seven percent of sites with Hermit Thrushes were located in coniferous forest, 42% in mixed forest, and 1% in deciduous forest. The most common trees present on sites occupied by Hermit Thrushes were pines (56%), Douglas-fir (44%), fir (30%), spruce (27%), and aspen (23%). Compared with other thrushes, Hermits occupied drier sites, with fewer than expected sites being close to streams or other surface water.

Results of this study indicate that Hermit Thrushes are highly area sensitive and associated with the most extensive forests. In landscapes with 70% forest cover, this species requires patches greater than 160 acres (65 ha) for high suitability habitat (Table 5). If forest cover is reduced to 50%, over 800 acres (320 ha) is required, and landscapes with less than 40% forest cover do not provide any highly suitable habitat. Smaller patches may provide moderately suitable habitat, however. Hermit Thrushes in the West are not as strictly associated with coniferous forest cover as this species is in the East.

A study in southeastern Wyoming of the effects of timber harvest that, at least initially, interrupted large expanses of old-growth forest with small strip or patch clearcuts compared avian species composition

Table 5. *Minimum area required to provide high, moderate, or low habitat suitability for Hermit Thrush based on analysis of 302 study sites in the Western region (see page 11 for definitions of habitat suitability).*

Percentage of forest in 2,500-acre block	Minimum area (acres) required for		
	High	Moderate	Low
90	20	1	Any size
80	64	2	Any size
70	163	5	Any size
60	385	12	Any size
50	873	26	Any size
40	NA[a]	60	1
30	NA	141	1
20	NA	361	4
10	NA	NA	12

[a]*Not Available—acreage values exceed the amount of forest in the 2,500-acre block.*

and abundance in uncut forests, forest interiors, meadow edges and clearcuts. Of the 16 species studied, Hermit Thrushes were one of the most negatively affected by fragmentation (Keller and Anderson 1992). The authors suggest that the distribution of birds may not strictly be a preference or avoidance of forest edges and interiors but a result of the loss of resources from clearcutting or preferences for the habitat adjacent to the forest stand (meadows or clearcuts). Franzreb and Ohmart (1978) found that in the White Mountains of Arizona the number of territories in unlogged 40-ha forests were almost twice that of selectively logged areas of the same size. Hejl et al. (2002) found that Hermit Thrushes were positively associated with patch size and negatively associated with edge in the central Rocky Mountains.

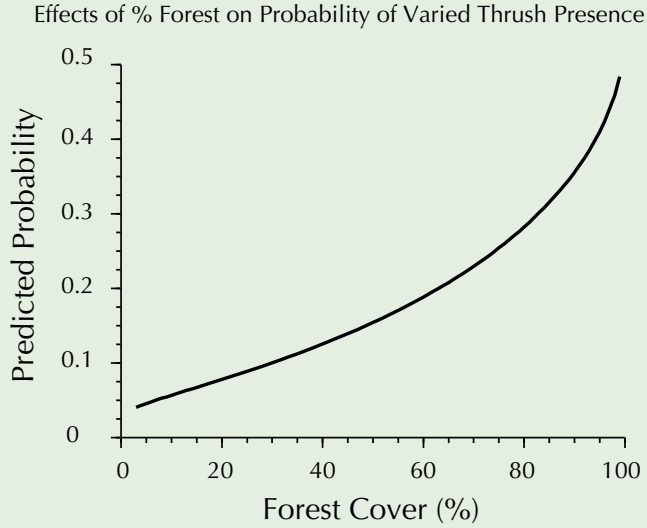


Figure 12. *The probability of finding breeding Varied Thrushes decreases sharply as amount of forest in the landscape is reduced.*

Varied Thrush

The Varied Thrush is a characteristic species of the tall coniferous forests of the northern Pacific Coast and northwestern mountain ranges. In the Birds in Forested Landscapes study, Varied Thrushes were detected at 40 (21%) of 186 sites surveyed in the Western Forest Region. Fifty-eight percent of sites with Varied Thrushes were located in coniferous forest, and 42% were in mixed forest. The most common trees on sites occupied by Varied Thrushes were spruce (58%), hemlock (43%), cedar (38%), pines (38%), and Douglas-fir (35%). Occupied sites were also more often closer to streams or other water than expected. The small sample in this study indicated a strong reduction in habitat suitability as the amount of forest in a landscape is reduced (Figure 12).

Studies throughout the Varied Thrush's range, indicated that this species has the highest breeding densities in mature and old-growth stands (Carey et al. 1991, Gilbert and Allwine 1991, Manuwal 1991, Tobalske et al. 1991, Bryant et al. 1992, Hazard and George 1999). There is no difference in breeding densities, however, between second-growth (20 year-old stands) in southeastern Alaska and old-growth stands (Dellasala et al. 1996). In northern California, Hurt (1996) found that Varied Thrushes rarely breed in suitable forest stands less than 40 acres (16 ha) in size but stands greater than 40 acres (16 ha) were almost always occupied. Also in northwestern California, Brand and George (2000) found Varied Thrushes to be associated with forest interiors and to avoid edges. In general, logging and fragmentation of mature old-growth forest will likely have negative impacts on Varied Thrush populations.

Management Summary for the Western Forest Region

Landscape Level

On large forests in the Western Region, especially on public lands, long-term management should focus on protecting existing forests and avoiding fragmentation whenever possible. Avoid creating edge by sub-dividing contiguous habitat. Protection and enhancement of riparian habitat will likely benefit Veery and Swainson's Thrush. Long-term planning for the Varied Thrush should include maintaining a high percentage of mature and old-growth forest in the overall landscape.

Site Level

In general, little is known about site-level habitat requirements for thrushes and other forest birds in the Western Region. Managers can contribute by monitoring the effects of pre- and post-fire management, silvicultural activities, grazing and other land uses. As in other regions, thrush populations in the West will most likely benefit from the creation and maintenece of dense understory. For Swainson's Thrush, protect and enhance deciduous shrubs in the understory in both coniferous and riparian forests. Reducing grazing-pressure, especially in riparian zones, will help promote understory vegetation used by western thrushes.

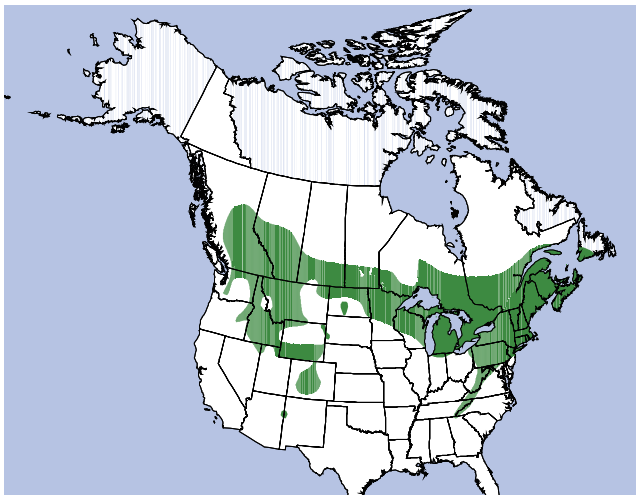
Veery (Catharus fuscescens)

Conservation Status

The Veery is of moderate conservation importance, primarily because of its declining population trend in much of its range (30% decline overall since 1966) and its vulnerability as a long-distance migrant wintering in tropical forests of South America. Fortunately it is still a very common species in most of its eastern range, where it also seems tolerant of some forest disturbance. In the West, this species is indicative of healthy riparian forests.

Habitat and Nest Site

Inhabits damp, deciduous forest and riparian habitats, generally younger stands and secondary growth areas with an open canopy and dense understory. Its preference for riparian areas is strong in several areas, including the Great Plains where forest is limited (Tubbs 1980). Habitat selection may depend on the presence of other thrush species in its breeding range. For example, the Veery may breed in mixed conifer-hardwood forest at middle elevations in areas where it overlaps with the Swainson's Thrush (higher elevations) or Wood Thrush (lower elevations). In other areas, they use alder or willow swamps, hemlock ravines, oak or beech-maple forests, or aspen woodlands. Nests on or just above the ground, generally not higher than 4 feet (1 m), often in a low shrub or brush pile. May be concealed in a grass tussock or under fallen limbs or a stump. Forest fragmentation increases the Veery's vulnerability to Brown-headed Cowbird parasitism. In Ontario, cowbirds parasitize 19% of nests, while in Alberta and Manitoba 87% of nests are parasitized (Friedmann et al. 1977). In winter, Veeries inhabit mature lowland rainforest, primarily in western Amazonia.



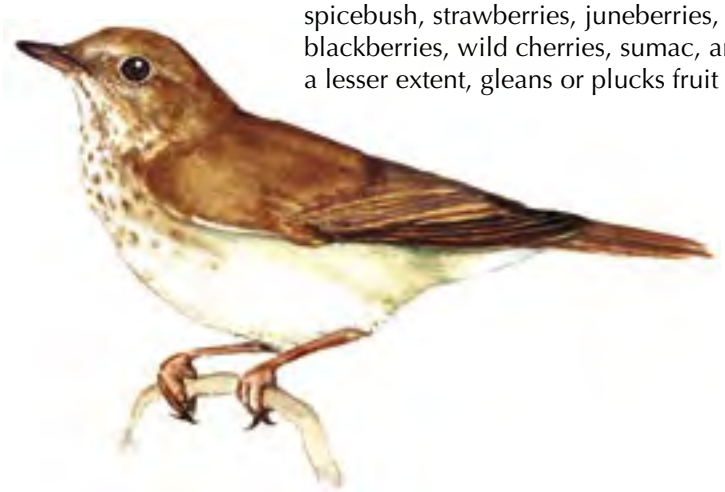
Vocalizations

Song: A resonating, ethereal *da-vee-ur, vee-ur, veer, veer*, consisting of a slurred series of downward inflected notes. Each note gets progressively lower in pitch, creating the sensation of spiraling or cascading down the scale. Some songs may begin with a simple, non-inflected note and end with a rolling note.

Call: The call notes are generally lower pitched than those of other thrushes. The most common call, used in a hostile situation, is a downward inflected *vee-ur* or *veee-oo*. They also have a *jerk* or *njernt* call.

Foraging Behavior/Diet

Forages mostly on the ground for beetles, caterpillars, spiders, centipedes, snails, pill bugs, ants, wasps, and tupulid flies by turning over leaves with bill. Sometimes searches for prey from a perch, such as a low branch in a shrub or tree or from a rock generally close to water. Swoops to the ground and grabs prey when sighted. In the fall and winter eats more fruit; spicebush, strawberries, juneberries, honeysuckle, blackberries, wild cherries, sumac, and blueberries. To a lesser extent, gleans or plucks fruit from the foliage.



Veery by Evan Barbour

Swainson's Thrush *(Catharus ustulatus)*

Conservation Status

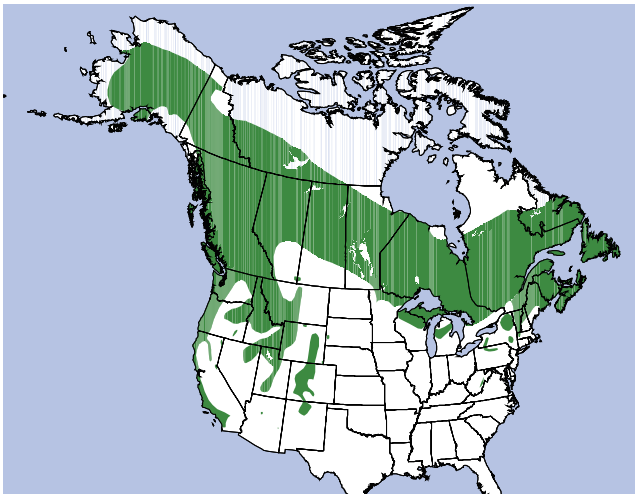
The Swainson's Thrush has a large range and is very common in many areas, yet it is experiencing steady population declines in regions such as California and the Maritime Provinces. It is of conservation importance because of its association with many types of coniferous as well as riparian forests for breeding, and because of its vulnerability to tropical deforestation in South America.

Habitat and Nest Site

Breeds primarily in coniferous forests, or mixed forest dominated by spruce, fir, white cedar, or tamarack. They may be found in both undisturbed and disturbed woodlands with dense understory, often near canopy gaps produced by fallen trees or other disturbances. Nest is typically 4–7 feet (1.2–2 m above ground in a small fir, spruce, hemlock, vine maple, alder, or willow on a horizontal branch near the trunk. In winter, Swainson's Thrushes inhabit mature Amazonian and Andean rainforests, as well as other mature tropical forests in Central America.

Vocalizations

Song: A slurred series of notes spiraling upward in pitch. It is quite complex and variable and has been characterized as *whip-poor-will-a-will-e-zee-zee-zee* with the last notes often running together in a high trill.



Call: The most common call is a loud, sharp *whit*; also a clear, slightly inflected whistled note, *feee-ee*. The nocturnal flight call is an abrupt whistle that sounds very similar to the spring peeper.

Foraging Behavior/Diet

Mostly a ground feeder; also forages from branches as well as by hawking insects on the wing. Eats beetles, weevils, ants, wild bees, wasps, caterpillars, spruce bud moths, mosquitoes, crane flies, treehoppers, cicadas, spiders, millipedes, snails, sowbugs, and earthworms. Most frequently hunts from a low branch, hopping from perch to perch searching for prey on the ground or within low branches. Becomes more frugivorous during the late summer, fall, and winter, when diet includes cherries, blackberries, raspberries, seeds of twinberry, and elderberry.



Swainson's Thrush by Evan Barbour

Hermit Thrush *(Catharus guttatus)*

Conservation Status

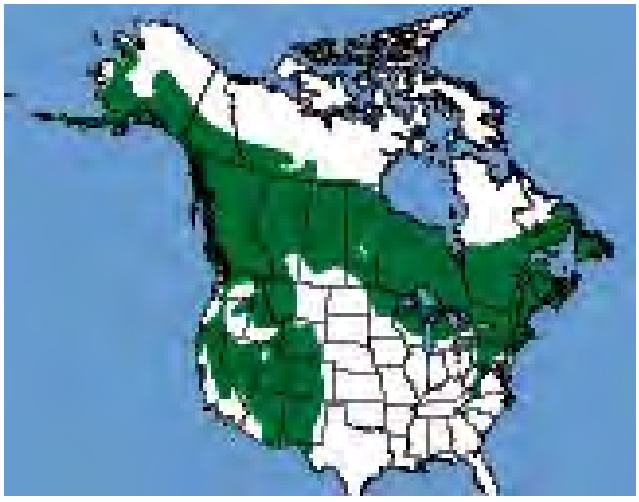
Among the forest thrushes, the Hermit Thrush is the one species that shows stable or even increasing population trends throughout its large range. It is seemingly tolerant of various disturbances, but in many areas it is a species associated with large and mature forests. Why this species is so successful while closely related thrushes are declining is one of the mysteries conservation biologists are presently studying.

Habitat and Nest Site

Inhabits coniferous and mixed coniferous-hardwood forests, chiefly at higher elevations up to tree line in the northern Appalachians and in the western mountains. Also breeds at lower elevations across the northern coniferous forests, in hemlock ravines, conifer plantations, and even to sea level in pine barrens and cedar swamps. In the East, the nest is usually on the ground, well hidden under a small tree, bush, fern, or in a natural depression. In the West, it generally nests above ground in a tree or shrub, conifer sapling, or on top of a stump or log. There are some accounts of nests under eaves of a building or on a rock ledge. Generally found near an edge or gap rather than in the interior of a forest. In winter, Hermit Thrushes are found in a variety of wooded habitats, including suburban yards and woodlots, in the southern United States and Mexico.

Vocalizations

Song: A melodious, flute-like warble, made up of a series of varied phrases separated by long pauses, beginning with a clear whistled introductory note. The



phrases vary considerably in pitch and seem to trail off at the end of each phrase.

Calls: Two common call notes: a soft *chuck* or *chup* and a harsh, rising *wee-er*, similar to the call of a catbird, given as an alarm or when the bird is agitated.

Foraging Behavior/Diet

Forages on ground by scanning and turning fallen leaves over with bill to search for beetles, ants, caterpillars, grasshoppers, crickets, spiders, sow bugs, snails, earthworms, and sometimes salamanders. Also gleans from foliage and branches in the understory and in young saplings, occasionally higher up in the trees. In the fall and winter eats more fruit: pokeberries, serviceberries, grapes, elderberries, mistletoe berries, and raspberries. Sometimes takes insects or berries from vegetation above ground while hovering.



Hermit Thrush by Evan Barbour

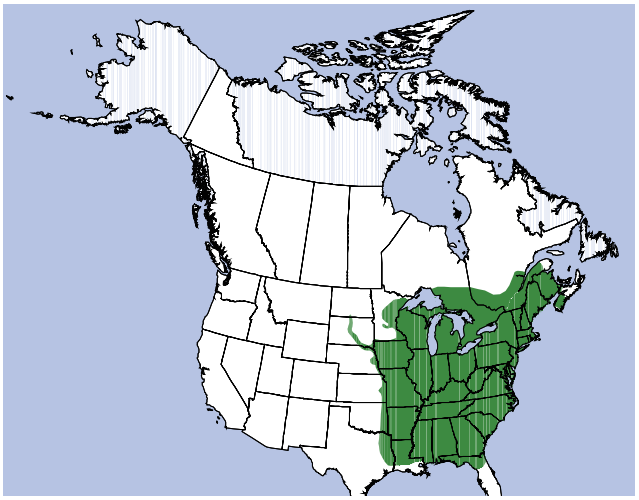
Wood Thrush *(Hylocichla mustelina)*

Conservation Status

Even though it's one of the most common species in eastern forests, the Wood Thrush is of high conservation concern because of long-term, range-wide declines that have resulted in a 43% overall population decline since 1966. It is included on Partners in Flight's Watch List for the United States and Canada. This species seems to be dependent on large tracts of mature forest in some parts of its range, but is tolerant of fragmentation in other areas. In winter, it is highly vulnerable to tropical deforestation in the lowlands of Central America.

Habitat and Nest Site

Breeds in the interior and edges of deciduous and mixed forests, generally in cool, moist sites, often near water. Requires moderate to dense understory with a lot of shade, moist soil, and decaying leaf litter. Shows much variation in habitat use, from mature deciduous forests in the Southeast, to shrubby second-growth forests and suburban parks in the Northeast to riparian habitats in the Great Plains. The nest is usually on the lower limbs of a tree or shrub, usually 10–13 feet (3–4 m) above ground; 2–70 feet (0.5–21 m) possible. Nest is placed generally near or against the trunk, hidden among leaves in a shady area. Also found in a crotch or fork supported by small branches. It may be anchored to a branch with mud. In winter, Wood Thrushes inhabit mature, lowland tropical forests.



Vocalizations

Song: A series of yodeled phrases with a pause in between each phrase. A phrase consists of three distinctive parts: one or two short, low notes, quickly followed by a complex, flute-like note. It ends with a short, high trill. The phrase sounds like *ee-oh-lay*.

Calls: A rapid series of notes that sound like *pit-pit-pit* or *wik, wik, wik, wik, wik*. Nocturnal flight call an emphatic buzzy *heeh*, given on the same tone or only slightly descending.

Foraging Behavior/Diet

Forages by gleaning and probing for beetles, ants, moths, caterpillars, millipedes, and isopods in the leaf litter on the forest floor. In the late summer and fall eats more fruit—spicebush, foxgrape, blueberry, holly, elderberry, Virginia creeper, pokeweed, dogwood, black cherry, and black gum. Sometimes hawks or hovers to glean insects or fruit from vegetation above the ground.



Wood Thrush by Evan Barbour

Varied Thrush *(Ixoreus naevius)*

Conservation Status

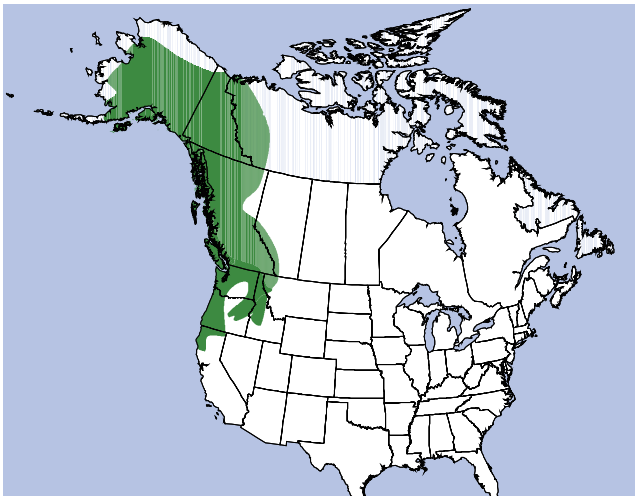
The Varied Thrush is of regional conservation importance, primarily because of its association with mature coniferous forests of the Pacific Northwest, and because of its relatively small total range. Populations appear to be stable at present, although they fluctuate greatly in many areas.

Habitat and Nest Site

This thrush loves shady, cool, and damp areas and is a characteristic species of the Pacific coastal rainforests. It inhabits mostly tall coniferous forests, such as redwoods, Douglas-fir, and spruce, from coastal to subapline, usually with a dense understory. Also inhabits some deciduous forests, especially at the northern edge of the range. Nest is usually 6–20 feet (2–6 m) above the ground in a small conifer, but occasionally built in a deciduous tree, small fir, spruce hemlock, vine maple, or willow. The nest is generally built against the trunk, supported by small branches and hidden in the foliage. Varied Thrush occupy a broad range of habitats in the winter and are most frequently observed in areas where fruiting shrubs provide a food source. Will also visit bird feeders in the southern part of their wintering range.

Vocalizations

Song: Each song phrase is a single note: a long, vibrating, metallic whistle, with a long pause between notes. Each note is delivered in a slightly different key and pitch, with no particular order. It may sing these notes in continuous succession for several minutes.



Call: Low *chook* and a variety of ringing whistles similar to the notes in the song. It will often call in a soft, faint tone while feeding on the ground.

Foraging Behavior/Diet

Commonly forages on the ground under damp and thickly matted leaves for beetles, ants, bees, wasps, flies, caterpillars, grasshoppers, crickets, some spiders, myriapods, snails, sowbugs, and earthworms. Scratches the dead leaves aside with both feet at once, seizing some litter in its beak and scattering leaves in various directions. Generally keeps under shady retreats among mosses and rocks. In the fall and winter feeds mostly on madrone berries, acorns, weed seeds, sowberries, juniper berries, blackberries, blueberries, raspberries, buckthorn, poison oak, and pepperberries. Occasionally gleans or picks invertebrates or fruit from vegetation.



Varied Thrush by Evan Barbour

Literature Cited

Andrle, R.F. and J.R. Carroll, eds. 1988. The atlas of breeding birds in New York State. Cornell Univ. Press, Ithaca, NY.

Annand, E.M. and F.R. Thompson. 1997. Forest response to regeneration practices in central hardwoods. Journal of Wildlife Management 61(1):159–171.

Artman, V.L. and J.F. Downhower. 2003. Wood Thrush (*Hylocichla mustelina*) nesting ecology in relation to prescribed burning of mixed-oak forest in Ohio. Auk 120(3): 874–882.

Bailey, R.G. 1995. Descriptions of the ecoregions of the United States. 2nd ed. Rev. and expanded (1st ed. 1980). Misc. Publ. No. 1391 (rev.), Washington, DC: USDA Forest Service. 108 pp. with separate map at 1:7,500,000.

Beals, E. 1960. Forest bird communities in the Apostle Islands of Wisconsin. Wilson Bulletin 72:156–181.

Bertin, R.I. 1977. Breeding habitats of the Wood Thrush and Veery. Condor 79:303–311.

Brand, L.A. 1998. Edge effects in coast redwood forest fragments. M.S. Thesis, Humboldt State University, Arcata, CA.

Brand, L.A. and T.L. George. 2000. Predation risk for nesting birds in coast redwood forests. Journal of Wildlife Management 64:42–51.

Brittingham, M.C. and S.A. Temple. 1983. Have cowbirds caused forest songbirds to decline? Bioscience 33:31–35.

Bryant, A.A., J.L. Savard, and R.T. McLaughlin. 1992. Avian communities in old-growth and managed forests of western Vancouver Island, British Columbia. Technical Report Series No. 167. Canadian Wildlife Service, Pacific and Yukon Region, BC.

Cadman, M.C., P.F. Eagles, F.M. Helleiner (eds.). 1987. Atlas of the breeding birds of Ontario. Univ. of Waterloo Press, Waterloo, ON. 617 pp.

Campbell, R.W., N.K. Dawe, I. McTaggart–Cowan, J. M. Cooper, G. W. Kaiser. 1997. The birds of British Columbia. Vol. 3–Passerines: flycatchers through vireos. R. Br. Columbia Mus., Victoria.

Carey, A.B., M.M. Hardt, S.P. Horton, and B.L. Biswell. 1991. Spring bird communities in the Oregon coast range. Pp. 123–143 *in* Wildlife and vegetation of unmanaged Douglas-fir forests (L.F. Ruggiero, K.B. Aubry, A.B. Carey, and M.H. Huff, eds.). U.S. Forest Service, General Technical Report PNW-GTR-285, Portland, OR.

Clark, K. D., D. Euler, and E. Armstrong. 1983. Habitat associations of breeding birds in cottage and natural areas of central Ontario. Wilson Bull. 95:77–96.

Crawford, H.S., R.G. Hooper, and R.W. Tilterington. 1981. Songbird population response to silvicultural practices in central Appalachian hardwoods. Journal of Wildlife Management 45: 680–692.

Dellasala, D.A., J.C. Hagar, K.A. Engel, W.C. McComb, R.L. Fairbanks, and E.G. Campbell. 1996. Effects of silvicultural modifications of temperate rainforests on breeding and wintering communities, Prince of Wales Island, southeast Alaska. Condor 89: 706–721.

Derleth, E.L., D.G. McAuley, and T.J. Dwyer. 1989. Avian communtiy response to small-scale habitat disturbance in Maine. Canadian Journal of Zoology 67:385–390.

Dilger, W.C. 1956. Adaptive modifications and ecological isolating mechanisms in the thrush genera *Catharus* and *Hylocichla*. Wilson Bull. 68:171–199.

Driscoll, M., T. Donovan, R. Mickey, A. Howard, K. Fleming. 2003. In preparation.

Easton, W.E. and K. Martin. 2002. Effects of thinning and herbicide treatment on nest site selection by songbirds in young managed forests. Auk 119(3):685–694.

Evans, D.M. 1995. Relationship between landscape patter and songbird abundance in mixed conifer forests of west-central Idaho. Master's Thesis, Northern Arizon Univ., Flagstaff.

Franzreb, K.E. and R.D. Ohmart. 1978. The effects of timber harvesting on breeding birds in a mixed coniferous forest. Condor 80:431–444.

Freedman, B., C. Beauchamp, I.A. McLaren, and S.I. Tingley. 1981. Forestry management practices and populations of breeding birds in a hardwood forest in Nova Scotia. Can. Field-Nat. 95: 307-311.

Freemark, K.E. and B. Collins. 1992. Landscape ecology of birds breeding in temperate forest fragments. pp 443-454 *in* J.M. Hagan and D.W. Johnston (eds.) Ecology and conservation of Neotropical migrant landbirds. Smithsonian Institution Press, Washington DC. 609 pp.

Freemark, K.E., J.B. Dunning, S.J. Hejl, and J.R. Probst. 1995. A landscape ecology perspective for research, conservation, and management. Pages 381–421 *in* Ecology and mangement of Neotropical migratory birds. (T.E. Martin and D.M. Finch, eds.) Oxford Univ. Press, New York.

Friedmann, H., L.F. Kiff, and S.J. Rothstein. 1977. A further contribution to knowledge of the host relations of parasitic cowbirds. Smithsonian Contributions to Zoology 235:1–75.

Galli, A.E., C. F. Leck, and R. T. T. Forman. 1976. Avian distribution patterns in forest islands of different sizes in central New Jersey. Auk 93:356–364.

Gates, J.E. and L.W. Gysel. 1978. Avain nest dispersion and fledging success in field-forest ecotones. Ecology 59: 871–883.

Gauthier, J. and Y. Aubry. (eds.). 1996. The breeding birds of Quebec: Atlas of the breeding birds of southern Quebec. Association quebecoise des groupes d'ornithologues, Province of Quebec Society for the Protection of Birds, Canadian Wildlife Service, Environment Canada, Quebec Region, Montreal. 1302 pp.

George, T.L. 2002. Varied Thrush (*Ixoreus naevius*). *in* The birds of North America, No. 541 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.

Gilbert, F.F., and R. Allwine. 1991. Spring bird communities in the Oregon cascade range. pp. 145–158 *in* Wildlife and vegetation of unmanaged Douglas-fir forests (L.F.

Ruggiero, K.B. Aubry, A.B. Carey, and M.H. Huff, eds.). U.S. Forest Service, General Technical Report PNW-GTR-285. Portland, OR.

Giles, R.H., ed. 1971. Wildlife Mangement Techniques. 3rd edition (revised). The Wildlife Society, Washington, D.C. 623 pp.

Groom, J.D., and T.C. Grubb, Jr. 2002. Bird species associated with riparian woodland in fragmented, temperate-deciduous forest. Conservation Biology 16(3):832–836.

Hagan, J.M. and S.L. Grove. 1999. Bird abundance and distribution in managed and old-growth forest in Maine. Report No. NM-9901 Manomet Center for Conservation Sciences. 14 pp.

Hames, R. S., K. V. Rosenberg, J. D. Lowe, S. E. Barker, and A. A. Dhondt. 2002. Effects of forest fragmentation on North American tanager and thrush species in eastern and western landscapes. Pages 81-92 *in* L. George and D. S. Dobkins, editors. The effects of habitat fragmentation on birds in western landscapes: Contrast with paradigms from the eastern United States. Cooper Ornithological Society, Seattle, WA.

Hames, R. S., K. V. Rosenberg, J. D. Lowe, and A. A. Dhondt. 2001. Site Reoccupation in fragmented landscapes: testing predictions of metapopulation theory. Journal of Animal Ecology 70:182-190.

Hanowski, J., N. Danz, J. Lind, and G. Niemi. 2003. Breeding bird response to riparian forest harvest and harvest equipment. Forest Ecology and Management 174(1–3): 315–328.

Hawrot, R.Y. and G.J. Niemi. 1996. Effects of edge type and patch shape on avian communities in a mixed conifer-hardwood forest. Auk 113(3):586–598.

Hazard, G.C. and T.L. George. 1999. Landbird abundance and diversity in different-aged stands of coast redwood forests in northwestern California. Northwest Naturalist 80:99–109.

Hejl, S.J., R.L. Hutto, C.R. Preston, and D.M. Finch. 1995. Effects of silvicultural treatments in the Rocky Mountains. Pp 220–224 *in* Ecology and management of Neotropical migrtory birds (T.E. Martin and D.M. Finch eds.). Oxford Univ. Press, New York.

Hejl, S.J., D. Evans Mack, J.S. Young, J.C. Bednarz, and R.L. Hutto. 2002. Birds and changing landscape patterns in conifer forests of the north-central Rocky Mountains. Studies in Avian Biol. 25:113–129.

Holmes, R.T. and S.K. Robinson. 1988. Spatial patterns, foraging tactics, and diets of ground-foraging birds in a northern hardwood forest. Wilson Bull. 100:377–394.

Hoover, J.P. 1992. Nesting success of Wood Thrush in a fragmented forest. The Pennsylvania State University, State College, PA. Ph.D. dissertation.

Hoover, J.P., M.C. Brittingham, and L.J. Goodrich. 1995. Effects of forest patch size on nesting Wood Thrushes. Auk 112:146–155.

Hurt, M. 1996. The influence of forest fragmentation and vegetation structure on the breeding distribution of Varied Thrushes in redwood forests. M.S. Thesis, Humboldt State University, Arcata, CA.

Johnston, D.W. 1949. Populations and distribution of summer birds in Latah County, Idaho. Condor 51:140–149.

Jones, P.W. and T.M. Donovan. 1996. Hermit Thrush (*Catharus guttatus)*. *in* The Birds of North America, No. 261 (A. Poole and F. Gill, eds.). The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, D.C.

Keller, J.K., M.E. Richmond, and C.R. Smith. 2003. An explanation of patterns of breeding birds species richness and density following clearcutting in northeastern USA forests. Forest Ecology and Management 174(1–3):541–564.

Keller, M.E. and S.H. Anderson. 1992. Avian use of habitat configurations created by forest cutting in southeastern Wyoming. Condor 94(1):55–65.

Kendeigh, S.C. 1945. Community selection by birds on the Helderberg Plateau of New York. Auk 62:418–436.

Kendeigh, S.C. 1946. Breeding birds of the beech-maple hemlock community. Ecology 27:226–245.

Lang, J.D., L.A. Powell, D.G. Krementz, and M.J. Conroy. 2002. Wood Thrush movements and habitat use: Effects of forest management for Red-cockaded Woodpeckers. Auk 119(1):109–124.

Lehmkuhl, J.F., L.F. Ruggiero, and P.A. Hall. 1991. Landscape-scale patterns of forest fragmentation and wildlife richness and abundance in the southern Washington Cascade Range. pp 425–442 *in* Wildlife and vegetation of unmanaged Douglas fir forests (L.F. Ruggiero, K.B. Aubry, A.B. Carey, and M.H. Huff, eds.). U.S. Dep. Agric., For. Serv. Gen. Tech. Rep. PNW-GTR-285, Portland, OR.

Manuwal, D.A. 1991. Spring bird communities in the southern Washington cascade range. pp. 161–174 *in* Wildlife and vegetation of unmanaged Douglas-fir forests (L.F. Ruggiero, K.B. Aubry, A.B. Carey, and M.H. Huff, eds.). U.S. Forest Servcie, General Technical Report PNW-GTR-285, Portland, OR.

Martin, T.E. 1988. Habitat and area effects on forest bird assemblages: is nest predation an influence? Ecology 69: 74–84.

Morgan, K. and B. Freedman. 1986. Breeding bird communities a hardwood forest succession in Nova Scotia. Canadian Field Naturalist 100:506–519.

Morse, D.H. 1971. Effects of the arrival of a new species upon habitat utilization by forest thrushes in Maine. Wilson Bulletin 83:57–65.

Moskoff, W. 1995. Veery (*Catharus fuscescens*). *in* The Birds of North America, No. 142 (A. Poole and F. Gill, eds.). The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, D.C.

Noon B.R. 1977. The ecology of an avian ground-foraging guild in eastern montane forests. Ph.D. Dissertation, Sate University of New York, Albany.

Noon, B.R. 1981. The distribution of an avian guild along a temperate elevational gradient: the importance and expression of competition. Ecological Monographs 51: 105–124.

Noon, B.R., V.P. Bingman, and J.P. Noon. 1979. The effects of changes in habitat on northern hardwood forest bird

communities. Pp. 33–48 *in* Proceedings of the workshop: Management of North Central and Northeastern Forests for Nongame Birds (R.M. DeGraaf and K.E.Evans, compilers) U.S. Department of Agriculture, Forest Service general Technical Report INT-86. Washington, D.C.

Odum, E.P. 1950. Bird populations of the Highland (North Carolina) Plateau in relation to plant succession and avian invasion. Ecology 31:587–605.

Pinkowski, B. 1991. Wood Thrush. Pages 356–357 *in* R. Brewer, G.A. McPeck, and R.J. Adams, Jr. (eds.) The Atlas of Breeding Birds of Michigan. Michigan State University Press, East Lansing, MI.

Podulka, S., R. Rohrbaugh, and R. Bonney, eds. 2001. Home Study Course in Bird Biology. The Cornell Lab of Ornithology. Ithaca, NY.

Robbins, C.S., D.K. Dawson, and B.A. Dowell. 1989. Habitat area requirements of breeding forest birds of the middle Atlantic states. Wildlife Monographs 103, The Wildlife Society, pp.1–34.

Robinson, S.K. and D.S. Wilcove, 1994. Forest fragmentation in the temperate zone and its effects on migratory songbirds. Bird Conservation International 4:233–249.

Robinson, S.K., F.R. Thompson, III, T.M. Donovan, D.R. Whitehead, and J. Faaborg. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science 267:1987–1990.

Rosenberg, K. V., J. D. Lowe, and A. A. Dhondt. 1999a. Effects of forest fragmentation on breeding tanagers: A continental perspective. Conservation Biology 13:568-583.

Rosenberg, K. V., R. W. Rohrbaugh, S. E. Barker, J. D. Lowe, R. S. Hames, and A. A. Dhondt. 1999b. A Land manager's guide to improving habitat for Scarlet Tanagers and other forest-interior birds. The Cornell Laboratory of Ornithology, Ithaca, NY.

Roth, R.R. 1987. Assessment of habitat quality for Wood Thrush in a residential area. Pages 139–149 in L.W. Adams and D.L. Leedy, eds. Integrating man and nature in the metropolitan environment. Proceedings of the National Symposium on Urban Wildlife, Chevy Chase, Maryland, 4–7 November, 1986. National Institute of Urban Wildlife, Columbia, MD.

Roth, R.R., M.S. Johnson, and T.J. Underwood. 1996. Wood Thrush (*Hylocichla mustelina*). *In* The Birds of North America, No. 246 (A. Poole and F. Gill, eds.). The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, D.C.

Sargent, R.A., J.C. Kilgo, B.R. Chapman, and K.V. Miller. 2003. Nesting ecology of Wood Thrush (Turdidae: Passeriformes) in hardwood forests of South Carolina. Southeasten Naturalist 2(2):217–222.

Simons, N.P.P., F.E. Schwab, and R.D. Otto. 2002. Songbird abundance in clear-cut and burned stands: A comparison of natural disturbance and forest management. Canadian Journal of Forest Research – Revue Canadienne de Recherche Forestiere 32(8):1343–1350.

Small, M.F. and M.L. Hunter. 1988. Forest fragmentation and avian nest predation in forested landscapes. Oecologia 76:62–64.

Small, A. 1994. California Birds: Their Status and Distribution. Ibis Publishing Co., Vista, CA.

Suthers, H.B. 1987–1988. Old field succession and bird life in the New Jersey sourlands. Records of New Jersey Birds 13:54–64.

Tewksbury, J. A.E. Black, N. Nur, V.A. Saab, B.D. Logan, and D.S. Dobkin. 2002. Effects of anthropogenic fragmentation and livestock grazing on western riparian bird communities. Studies in Avian Biol. 25:158–202.

Thompson, F.R. III and D.E. Capen. 1988. Avian assemblages in seral stages of a Vermont forest. J. of Wildl. Mange. 52: 771–777.

Tobalske, B.W., R.C. Shearer, R.C. Hutto. 1991. Bird populations in logged and unlogged western larch/Douglas-fir forest in northwestern Montana. Research Paper INT-442. U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT.

Tubbs, A.A. 1980. Riparian bird communities of the Great Plains Pp. 419–433 *in* Proceedings of the workshop: Management of Western Forests and Grasslands for Nongame Birds (R.M. DeGraaf and K.E.Evans, compilers). U.S. Department of Agriculture, Forest Service General Technical Report INT-86, Washington, D.C.

U.S. NABCI Committee. 2000. Bird conservation region descriptions: a supplement to the North American Bird Conservation Initiative bird conservation regions map. 38 pp.

Welsh, J.E. and W.M. Healy. 1993. Effect of even-aged timber management on bird species diversity and composition in northern hardwoods of New Hampshire. Wildl. Soc. Bull. 21:143–154.

Webb, W.L., D.F. Behrend, and B. Saisorn. 1977. Effects of logging on songbird populations in a a northern hardwood forest. Wildl. Monogr. 55:1–34.

Whitcomb, R.F., C.S. Robbins, J.F. Lynch, B.L. Whitcomb, M.K. Klimciewicz, and D. Bystrak. 1981. Effects of forest fragmentation on avifauna of the eastern deciduous forest. Pages 125–206 *in* R.L. Burgess and B.L. Sharpe, editors. Forest island dynamics in man-dominated landscpes. Ecological Studies No. 41, Springer-Verlag, New York.

Wilcove, D.S. 1985. Nest predation in forest tracts and the decline of migratory songbirds. Ecology 66:1211–1214.



This publication was published in cooperation with the USDA Forest Service.
Graphic design by Diane L. Tessaglia-Hymes and Julie Hart
Cover photo by Lang Elliott
Back cover photo by Roger Eriksson

© 2003

CORNELL LAB *of* ORNITHOLOGY

nature ecology & evolution

PERSPECTIVE

https://doi.org/10.1038/s41559-018-0490-x

The exceptional value of intact forest ecosystems

James E. M. Watson[1,2,15*], Tom Evans[2,15], Oscar Venter[3], Brooke Williams[1,2], Ayesha Tulloch[1,2], Claire Stewart[1], Ian Thompson[4], Justina C. Ray[5], Kris Murray[6], Alvaro Salazar[1], Clive McAlpine[1], Peter Potapov[7], Joe Walston[2], John G Robinson[2], Michael Painter[2], David Wilkie[2], Christopher Filardi[8], William F. Laurance[9], Richard A. Houghton[10], Sean Maxwell[1], Hedley Grantham[1,2], Cristián Samper[2], Stephanie Wang[2], Lars Laestadius[11], Rebecca K. Runting[1], Gustavo A. Silva-Chávez[12], Jamison Ervin[13] and David Lindenmayer[14]

As the terrestrial human footprint continues to expand, the amount of native forest that is free from significant damaging human activities is in precipitous decline. There is emerging evidence that the remaining intact forest supports an exceptional confluence of globally significant environmental values relative to degraded forests, including imperilled biodiversity, carbon sequestration and storage, water provision, indigenous culture and the maintenance of human health. Here we argue that maintaining and, where possible, restoring the integrity of dwindling intact forests is an urgent priority for current global efforts to halt the ongoing biodiversity crisis, slow rapid climate change and achieve sustainability goals. Retaining the integrity of intact forest ecosystems should be a central component of proactive global and national environmental strategies, alongside current efforts aimed at halting deforestation and promoting reforestation.

Although Earth has lost at least 35% of its pre-agricultural forest cover over the past three centuries[1], forests are still widely distributed, covering a total of 40 million km^2 (~25%) of Earth's terrestrial surface[2]. Of the remaining forests, as much as 82% is now degraded to some extent as a result of direct human actions such as industrial logging, urbanization, agriculture and infrastructure[3,4]. This figure is probably an underestimate of the true level of anthropogenic impact as it does not incorporate other, more cryptic forms of degradation, such as over-hunting[5]. As the human footprint continues to expand[4], remaining forest free of significant anthropogenic degradation is in rapid decline (Fig. 1).

Over the past decade, there has been increasing international concern around the loss of forest and the impact this has on climate change, the loss of biodiversity and the provision of ecosystem services[1]. The 2015 Paris Agreement, together with earlier agreements under the United Nations Framework Convention on Climate Change (UNFCCC), acknowledges the importance of forests for limiting a future temperature increase to well below 2 °C above pre-industrial levels[6]. The United Nations' Sustainable Development Goals (adopted in 2016) have the ambitious aim of fully halting deforestation by 2020[7]. However, while these targets are clearly warranted, they fall short of specifically prioritizing the crucial qualities of a forest that contribute most to achieving each convention's specific goals[1]. For example, indicators tracking progress towards the 2015 New York Declaration on Forests — among the most significant global forest conservation targets to date — focus on forest extent and make almost no acknowledgement of forest condition[8].

In this Perspective, we argue that to achieve the goals of global international environmental accords it is insufficient to treat all forests as equal regardless of their condition. Instead, forest that is free of significant anthropogenic degradation (which we term 'intact forest') should be identified and accorded special consideration in policymaking, planning and implementation. Anthropogenic degradation here includes all human actions that are known to cause physical changes in a forest that lead to declines in ecological function[9,10]. Well-studied examples include forest fragmentation, stand-level damage due to logging, over-harvesting of particular species (such as over-hunting) and changes in fire or flooding regimes.

We first summarize published evidence that intact forests support an exceptional confluence of globally significant environmental values relative to forests that have experienced those damaging human actions. We show that intact forests are indispensable not only for addressing rapid anthropogenic climate change, but also for confronting the planet's biodiversity crisis, providing critical ecosystem services and supporting the maintenance of human health. We then show that the relative value of intact forests is likely to become magnified as already-degraded forests experience further intensified pressures (including anthropogenic climate change). While it is beyond the scope of this paper to set thresholds for acceptable forest fragment size and configuration, logging intensity or any other measure of damage, we provide evidence that human activity that exceeds the natural range of variation in a forested system reduces key ecological functions, and the greater the level of alteration, the greater the reduction in function. Here we outline the significant,

[1]School of Earth and Environmental Sciences, The University of Queensland, St. Lucia, Brisbane, Queensland, Australia. [2]Wildlife Conservation Society, Global Conservation Program, Bronx, New York, NY, USA. [3]Natural Resources & Environmental Studies Institute, University of Northern British Columbia, Prince George, British Columbia, Canada. [4]Canadian Forest Service, Sault Ste, Marie, Ontario, Canada. [5]Wildlife Conservation Society Canada, Toronto, Ontario, Canada. [6]The Grantham Institute - Climate Change and the Environment and Department of Infectious Disease Epidemiology, Imperial College London, London, UK. [7]University of Maryland, College Park, MD, USA. [8]Division of Ornithology, American Museum of Natural History, New York, NY, USA. [9]Centre for Tropical Environmental and Sustainability Science (TESS) and College of Science and Engineering, James Cook University, Cairns, Queensland, Australia. [10]Woods Hole Research Center, Falmouth, MA, USA. [11]Swedish University of Agricultural Sciences, Umeå, Sweden. [12]Forest Trends Association, Washington DC, USA. [13]Global Programme on Nature for Development, United Nations Development Programme, New York, NY, USA. [14]Fenner School of Environment and Society, The Australian National University, Canberra, Australian Capital Territory, Australia. [15]These authors contributed equally: James E. M. Watson and Tom Evans. *e-mail: jwatson@wcs.org

© 2018 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

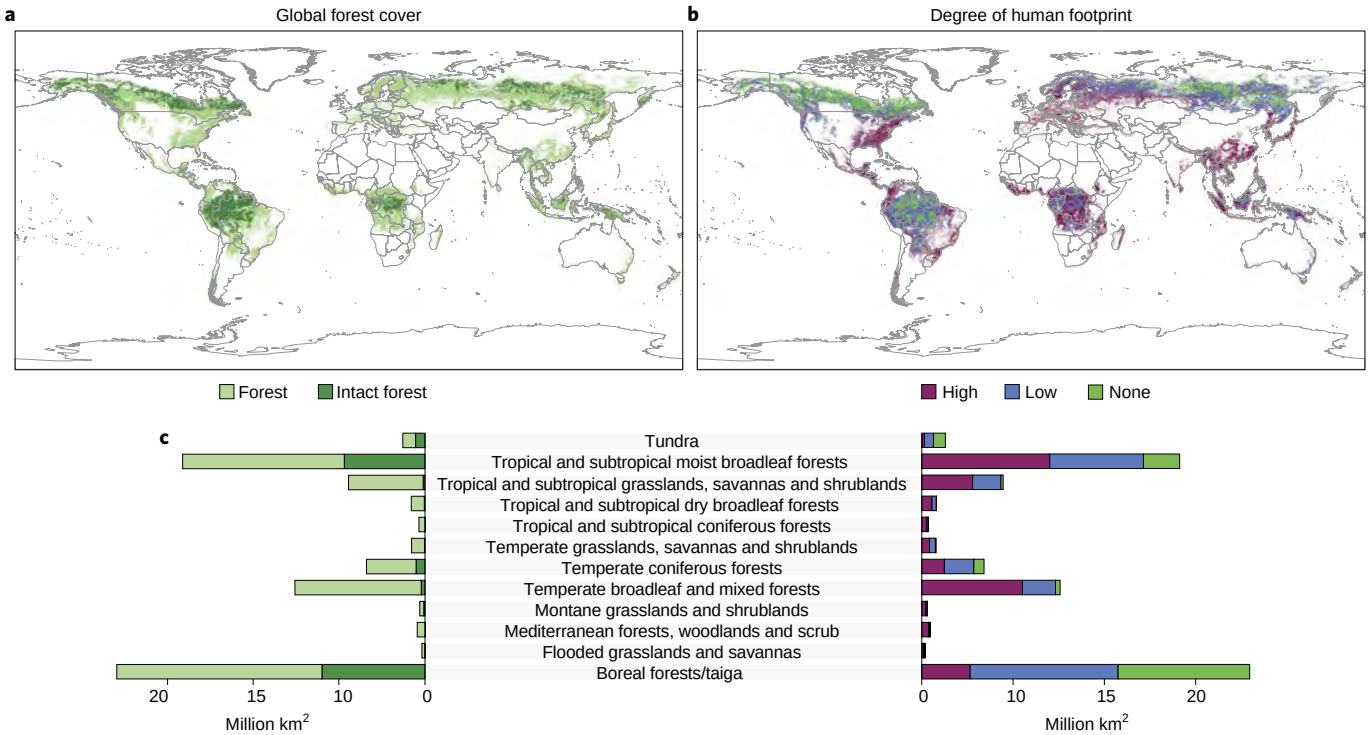


Fig. 1 | The global extent of intact forest. a–c, There are many ways to map intact forest: the first example is mapped as defined by Intact Forest Landscape methodology[3] (**a**), the second example by the global Human Footprint methodology[138] (**b**) and, for both measures, by biome (**c**). The definition of overall forest estate was based on ref. [136], with forests defined as >75% tree coverage.

and probably intensifying, threats to intact forests and argue that action is required to halt and reverse their loss. Such action requires explicit consideration on global, national and sub-national scales, and we conclude by identifying specific policy mechanisms where intact forests should be addressed.

Our call for an increased emphasis on intact forests does not imply that other forms of forest are unimportant. Given the scale of the environmental challenges facing humanity, there is also an undoubted need to cease deforestation and degradation at forest frontiers[11], and to promote large-scale reforestation[12]. We believe that coherent environmental policy should give due weight to intact forests, clearance frontiers and restoration opportunities, because all three have crucial and complementary roles to play. The primary reasons why we focus on intact forests are twofold. First, they are overlooked in international policy. Second, intact forest protection can typically secure very high environmental values with often relatively low implementation and opportunity costs[13], which serves to reinforce the need for their direct inclusion in global environmental accords.

Evidence for the exceptional values of intact forest ecosystems

There has been rapid growth in our understanding of the link between anthropogenic pressures on forest and impacts on ecosystem service values across a range of forest types (Box 1). Anthropogenic pressures, especially at industrial intensities and large spatial scales, have been shown to alter forest characteristics, including physical structure, species composition, diversity, abundance and functional organization compared with their natural state, and as a result, to reduce a wide range of environmental values[14–17]. These pressures also interact with natural disturbance regimes such as fire and pests to perturb forests beyond their capacity to regenerate[18]. The following sections show how the loss of forest intactness leads to declines or changes in these key environmental values: global and regional scale climate regulation; local climate and watershed regulation; biodiversity conservation; indigenous cultures; and human health.

Climate mitigation. Climate change is causing pervasive and potentially irreversible impacts on ecosystems and people[19]. Of the anthropogenic contribution to atmospheric CO_2 since 1870, 26% is due to emissions from deforestation and forest degradation[20]. It is now accepted that actions that avoid emissions from the land sector, especially forests, and maximize removals of greenhouse gases are critical if the goals of the UNFCCC Paris Agreement are to be achieved[12,21].

Degradation typically causes fewer emissions per hectare than deforestation, but is much more widespread[3,4,9]. In the tropics, where most net forest emissions occur, degradation may account for 10–40% of total emissions of aboveground carbon[22]. Industrial-scale logging (that is, large-scale market-orientated logging using heavy machinery, with offtakes that exceed natural rates of tree mortality) directly reduces carbon stocks through a combination of tree removal, collateral damage to non-target trees, decomposition of logging waste and wood fibre products[23], and the depletion of soil and peatland carbon stocks[24,25]. Industrial logging creates forested systems dominated by regenerating stands of younger, smaller trees, and although some regrowth does occur during each logging cycle, the cyclical peaks in biomass typically do not return to pre-logging levels, and the time-averaged carbon stocks can be expected to decline progressively over subsequent cutting cycles in many cases[26]. Reported carbon losses through industrial logging vary widely across forest types and due to the different types of logging undertaken (Fig. 2).

As forest patches are fragmented by agriculture and infrastructure, the area exposed to edge effects increases disproportionately; already 70% of the world's forests lie within 1 km of a forest edge and this proportion is rising[27]. Globally, locations up to 500 m from a forest edge average 25% less biomass carbon than locations

© 2018 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

Box 1 | Evidence of the exceptional values intact forest ecosystems have when compared with degraded ecosystems

Climate change mitigation

More above- and belowground carbon stored. Intact forests store more carbon than logged, degraded or planted forests in ecologically comparable locations. Industrial logging and conversion of forest to cropland causes heavy erosion and contributes to the loss of belowground carbon[21,22,144] (see Fig. 2 and Supplementary Table 1).

More faunal complexity, which helps carbon storage and sequestration. Defaunation can significantly erode the long-term carbon storage potential of forests by depriving key, high-carbon tree species of seed-dispersal agents, and through other ecological disruptions such as reduced vegetation diversity and composition or increased herbivory by non-hunted species (see Box 2)[29,31].

Major carbon sequestration. Intact forests continue to function as major net carbon sinks, actively sequestering carbon into soils and living biomass[12,34,37].

Regulating local and regional weather regimes

Effects on weather. Local and regional weather patterns are partly a function of the amount of intact forest cover and its condition[40,42,167].

Generation of rain and reduced risk of drought. When intact forests are cleared or degraded, there is a reduction in cloud cover and rainfall. Degradation and loss of intact forest can increase the number of dry and hot days, decrease daily rainfall intensity and wet day rainfall, and increase drought duration during El Niño years[41,168,169].

Ensuring hydrological services are maintained

Effects on water runoff availability. Intact forests have a positive effect on the redistribution of runoff, stabilize water table levels and retain soil moisture by altering soil permeability. These processes interact with physiography to regulate the flow distribution of energy and materials across the land surface and help stabilize slopes, prevent water and wind erosion, and regulate the transport of nutrients and sediments[48,50].

Buffer human settlements against negative effects of extreme climatic events. Non-degraded forests diminish the impact of heavy rain events by decreasing runoff and reducing the negative consequences of climate extremes[50,170].

Conserving biodiversity

Consistently higher numbers of forest-dependent species. More forest-dependent species are found in intact ecosystems than degraded ones. In some regions, the loss of large tracts of forest has meant wide-ranging forest-dependent species have either retreated to the last remaining intact forest systems or gone extinct[14,68,171].

More effectively sustain important large-scale ecological processes. Key functions supported by intact forests include natural disturbance regimes that sustain habitat resources, constitute selective forces to which species are adapted, or otherwise influence community composition[17,172,173].

Intact forests have higher functional diversity. Degrading activities such as selective logging lead to trait shifts in communities that can affect ecosystem functioning, in addition to taxonomic diversity[5,33,173] (see also Box 2).

Higher intra-species genetic diversity. The larger populations of forest-dependent species that inhabit intact forests provide greater options for local adaptation and phenotypic plasticity, which will facilitate species' potential for evolutionary and plastic responses to the rapidly changing environmental conditions[69,126,128].

Higher ability for species to undertake dispersal or retreat to refugia. The connectivity provided by large, contiguous areas spanning environmental gradients, such as latitude, altitude, rainfall or temperature, maximize the potential for key processes such as gene flow and genetic adaptation to play out, while also allowing species to track shifting climates[131,152].

Refuge for forest species from increased fire frequencies in degraded landscapes under changing climates. Intact forests act as fire refuges in landscapes where non-intact forests burn too frequently to support persistence of plant and animal communities dependent on long time intervals between burning[100,124].

Increased likelihood of providing key pollination and dispersal processes. Direct logging and secondary effects of degradation such as loss of vertebrate seed dispersers or pollinators leads to reduced ecosystem functions, such as seed dispersal and pollination services, for example, reduced fruit set due to reduced pollinations in fragmented forests[31,174].

Indigenous cultures

Increased basis for the material and spiritual aspects of traditional indigenous cultures to function. Long-established cultural norms intricately linked to the ecology of intact areas and vulnerable to damaging change[80,91,92].

Human health benefits

Reduced health impacts of wildfires. Fires attributed to forest degradation activities such as burning for land clearing result in premature deaths due to generation of haze. Lower burning rates in intact forests mean that health effects of wildfires are lower than in degraded landscapes with larger, more frequent fires[99].

Reduced infectious disease risks. The emergence of novel diseases from forests and the increase of endemic disease impacts in forested landscapes are thought to be related to encroachment and degradation arising from increasing human presence in these habitats[96,97,175].

remote from forest edges, and even locations up to 5 km from an edge can have >10% less biomass carbon[28]. These edge effects are mediated by a wide range of ecological changes, including increased windthrow and evaporation, and increased access for people, fire and invasive species[27]. Another form of degradation is loss of fauna through over-hunting, which can significantly disturb vegetation composition and the long-term carbon storage potential of tropical forests by depriving key, high-carbon tree species of their seed dispersal agents, and through other ecological disruptions[29,30] (see Box 2). Such effects can extend over vast areas (for example, at least 36% of the Amazon[31]) because over-hunting is pervasive where human access is facilitated by new infrastructure, and can also occur even in very remote areas[32,33].

Degradation reduces the capacity of forests to function as major net carbon sinks, actively sequestering carbon into soils and living biomass[34,35]. The global residual terrestrial sink, much of which is considered to take place in intact forests, removes an extraordinary 25% (2.4 Pg C yr^{-1}) of anthropogenic emissions from all sources, and hence greatly slows the pace of climate change[36,37]. This aspect of global carbon dynamics is often under-emphasized in climate policy because it is seen as part of the background of natural fluxes. However, the large-scale degradation of intact forests would result in a major anthropogenic reduction in this critical ecosystem service[38]. The intact forest sink is distinct from the sink resulting from reforestation and forest recovery following cessation of degradation. Both are large and both are likely to be indispensable in efforts to meet global climate targets[36,39].

Regulating local climate regimes and providing watershed services. There is increasing evidence that forests are a key factor in the regulation of local and regional climate regimes through the exchange of radiation, moisture and wind energy between the

© 2018 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

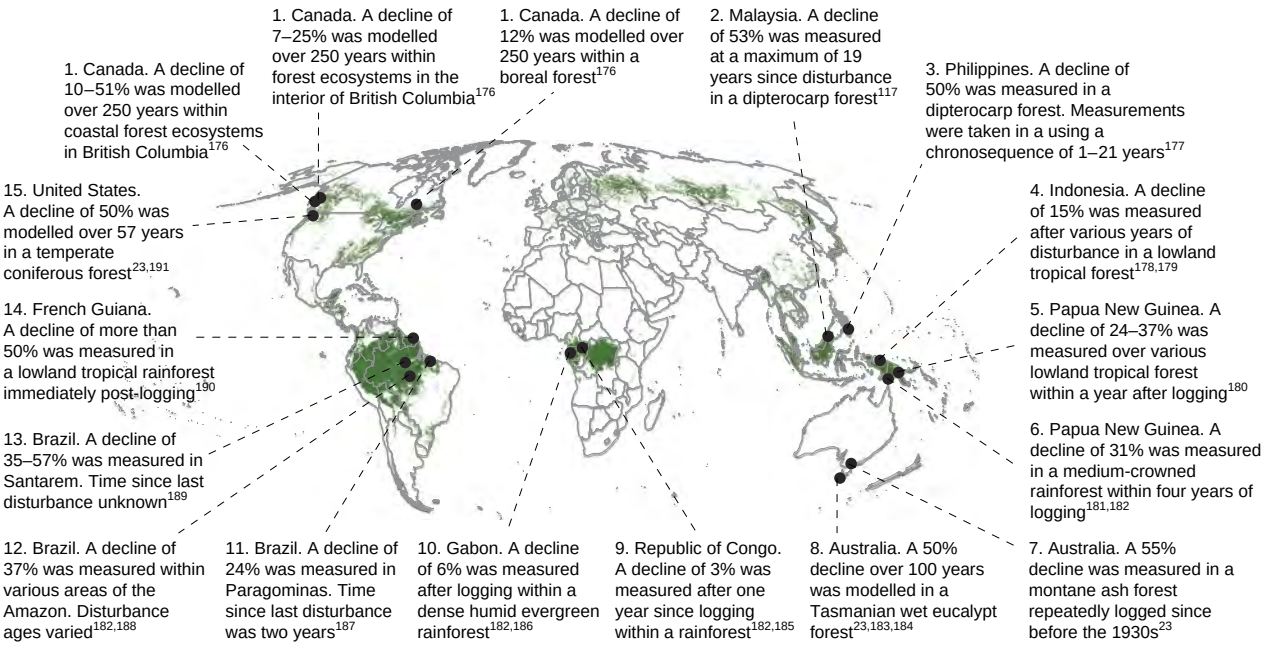


Fig. 2 | Forest degradation and carbon loss. Examples of published case studies that have examined the effects of forest degradation on carbon loss[23,117,176–191]. Supplementary Table 1 provides in-depth summaries of each of the 15 case studies.

land and atmosphere. Local and regional weather patterns are therefore a function of not just the amount of forest cover but also its state and condition[40].

Intact tropical forests are critical for rain generation because air that passes over these forests produces at least twice as much rain as air that passes over degraded or non-forest areas[41]. When intact forests are degraded, there is a resulting reduction in convective cloud cover and rainfall[42]. The influence of intact forests on precipitation, temperature and surface hydrology is particularly relevant in reducing the risks of drought imposed by climate extremes[42]. In Australia, the degradation and loss of intact forest can increase the number of dry and hot days, decrease daily rainfall intensity, and increase drought duration during El Niño years[43]. The last pattern also has been shown in Amazonia, where deforestation and forest degradation produce warmer and drier conditions that favour more frequent and intense droughts than in the past[44]. Importantly, the local climate benefits of tropical and sub-tropical forests occur primarily during the dry season and in regions with low rainfall, and during heat waves where the temperature is buffered by the cooling effects of evapotranspiration[45].

Intact forests also have a direct influence on water availability through the redistribution of runoff, water table levels and soil moisture by altering soil permeability[46]. These processes interact with physiography to regulate the flow distribution of energy and materials across the land surface and help stabilize slopes, prevent water and wind erosion, and regulate the transport of nutrients and sediments[46]. Several studies have shown that when forests are degraded, the soil infiltration rates and water infiltration capacity are decreased because of changes in soil structure and aggregation by organic matter and plant litter production[47]. For example, intact mountain ash (*Eucalyptus regnans*) forested ecosystems of southern Australia have been shown to produce >12 Ml ha^{-1} yr^{-1} more water than equivalent forested ecosystems that have been degraded through logging[48]. In many cases, intact forests also buffer the negative effects of heavy rainfall events by reducing peak discharge and regulating runoff, and by diminishing the negative consequences of climate extremes[49,50].

Conservation of biodiversity. The global biodiversity crisis is heavily driven by anthropogenic threats to forests[51], as forested ecosystems support the majority of global terrestrial biodiversity[52]. Biodiversity has intrinsic value and there is also increasing evidence that diverse, intact species assemblages underpin ecosystem functions such as tree productivity, nutrient cycling, seed dispersal, pollination, water uptake and pest resistance that are critical for human well-being[53].

Intact forests have particular value for the conservation of biodiversity[54]. Beyond outright forest clearance (which is the greatest threat facing biodiversity[51]), forest degradation from logging is the most pervasive threat facing species inhabiting intact forests[3]. Many species are sensitive to logging, and studies across many taxonomic groups have shown impacts increasing with the intensity of logging and with the number of times a forest has been logged[17,55]. Fragmentation of intact forest blocks (and associated edge effects) is also a severe threat to forest-dependent species, especially those requiring large areas to maintain viable populations (for example, wide-ranging predators and tree species that occur naturally at very low densities)[27,56]. In temperate, boreal and tropical forest regions, the loss of large contiguous tracts of forest has meant wide-ranging forest-dependent species have either retreated to the last remaining intact forest systems or are extinct[57–60]. Furthermore, there is evidence that — even for some forest species that may persist for a time in degraded fragments — intact forests are necessary to ensure their persistence over the long term[18,61,62].

Defaunation resulting from commercial and subsistence hunting is a critical threat for large-bodied forest vertebrates, especially in the tropics[5,63]. Many large carnivores and ungulates that play important roles as ecosystem engineers (for example, Sumatran serow (*Capricornis sumatraensis*), gaur (*Bos gaurus*) and forest elephant (*Loxodonta cyclotis*)) are now found only as remnant populations in the remaining intact tropical forests[33,64]. The synergistic interaction of stand damage, fragmentation and hunting is an increasingly significant challenge for biodiversity conservation[65,66] as it is well known that forest fragmentation increases access for hunters[67], and logging damage has more severe impacts when combined with fragmentation[17]. Forest biodiversity is best conserved by minimizing the

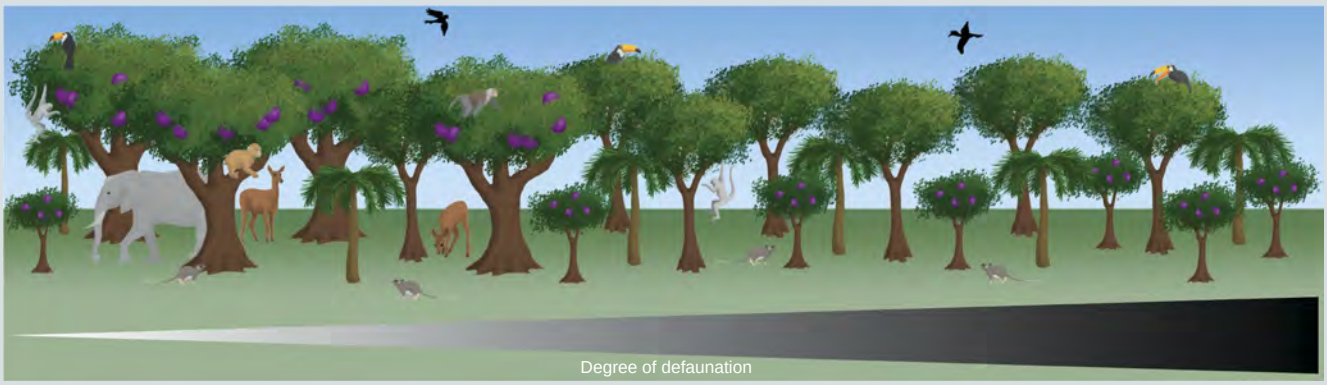
© 2018 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

Box 2 | The effect of defaunation on carbon storage and sequestration in intact forests

Even where forests have not been cleared, many are not functioning as they once were[166]. Species such as the Asian and South American tapirs (*Tapirus* spp.), forest elephant (*L. cyclotis*) and the great apes have disappeared across much of their ranges. Habitat degradation and fragmentation are major causes of this defaunation, as many large-bodied species depend on great expanses of high-quality forest to sustain viable populations[5,192]. Increased human accessibility to forests is another, with unsustainable hunting now affecting greater areas of tropical forest than the combined extent of deforestation, selective logging and wildfires[193]. Wildlife species are not equally affected by hunting, with stronger impacts of hunting pressure on larger-bodied primates and ungulates compared with smaller-bodied vertebrates such as birds and rodents[31,75,194].

Defaunation significantly erodes key ecosystem services and functions through direct and indirect cascading effects on species diversity and trophic webs[195–197]. There is evidence for negative effects on pollination, seed dispersal, pest control, nutrient cycling, decomposition, water quality and soil erosion[192,198]. Studies across the African and Atlantic tropical forests indicate that the disappearance of large frugivores and subsequent loss of seed dispersal reduces recruitment and natural regeneration of large-seeded hardwood plant species, which are key contributors to carbon storage[199–201]. By simulating the local extinction of trees that depend on large frugivores in 31 Atlantic forest communities, one study[29] found that defaunation has the potential to significantly erode carbon storage even when only a small proportion of large-seeded trees are extirpated. This is because of strong functional relationships between seed diameter, wood density and tree height, which are traits related to carbon storage[202]. Similar results have been shown for the Amazon[31] and other parts of the tropics[203].

There is also likely to be another link between defaunation and lowered carbon storage in tropical forests; lower herbivory rates in defaunated forests allow fast-growing herbivore-sensitive plants to outcompete slower-growing animal-dispersed trees that have better defence mechanisms against hunted frugivores[31,204,205]. In defaunated forests, carbon storage is potentially reduced when these fast-growing carbon-poor plants replace an equal basal area of carbon-rich animal-dispersed trees[206] — a process that may be irreversible once the seed stock is lost.



Schematic representation of the transition (from left to right) of a non-hunted, faunally intact tropical forest to an overhunted, defaunated forest. Shown is the degree to which large arboreal or terrestrial forest frugivores such as elephants and apes decline in abundance and, with these declines, the associated replacement of large-fruited high-biomass trees by smaller-fruited and wind-dispersed trees that have lower biomass and carbon storage. Credit: Blake Alexander Simmons.

encroachment of productive activities that promote forest loss and fragmentation because the initial intrusion leads to rapid degradation of intact forests, via not only the direct effects of habitat loss, but also the coinciding effects of wildfires, overhunting, selective logging and biological invasions, alongside other stressors[65,68]. For example, a recent global analysis of nearly 20,000 vertebrate species showed that even minimal initial deforestation within an intact landscape had severe consequences for vertebrate biodiversity in a given region, emphasizing the special value of intact forests in minimizing extinction risk[68]. Moreover, those forest ecosystems that are more affected by humans support less genetic diversity than those systems that are still intact, which has potentially significant ramifications for evolutionary change[69].

Indigenous peoples. At least 250 million people[70] live in forests, and for many of them, their cultural identities are deeply rooted in the plant and animal species found there[71]. Archaeological and ethnographical evidence indicate that forests have been inhabited by people for millennia: in Latin America, records go back 13,000 years[72]; in Asia, some 40,000 years[73]; and in Central Africa, more than 250,000 years[74]. Forest-dwelling indigenous peoples have tended to do so at very low population densities distributed in dispersed settlements[75]. Today, tropical forest societies that depend almost exclusively on the direct use of natural resources to meet their basic needs seldom exceed population densities of 1–2 people km^{-2} (ref. [76]), and tend to change location from time to time to ensure that their taking of food and other products will not permanently deplete an area of key resources. Through their selection and management of useful plants and animals, these communities have significant and long-lasting impacts on the structure and composition of the forests in which they live[77,78].

Industrial-scale degradation of intact forest erodes the material basis for the livelihoods of indigenous forest peoples, depleting wildlife and other resources[79]. It also renders traditional resource management strategies ineffective, and undermines the value of traditional knowledge and authority[80]. Fragmentation and degradation of the forest makes a traditional life style no longer tenable, pushing indigenous peoples off their land[81], and driving people to adopt

© 2018 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

production systems that are incompatible with the maintenance of intact forests[82–85]. As traditional forest peoples become increasingly sedentary and connected to urban markets, gender roles, diets and cultural values also change[86–88]. These changes in the life styles of indigenous and traditional peoples create greater dependence on urban markets for provisioning, which can lead to effects that erode their cultural identities[89]. Indeed, for many indigenous forest peoples their cultural sense of self is inextricably linked to intact forests[80].

Forcible alienation from their territories has even more severe impacts, with the forest homes of many indigenous and traditional peoples being taken from them, often by force, by more powerful state, corporate and private actors, whose interests often involve forest conversion for cattle pasture, agricultural fields, oil-palm plantations[90] and mining concessions[91–93]. This can have serious impacts on the health of these peoples as they are often exposed to new disease vectors and hostile settlers and ranchers. As many indigenous and traditional peoples are motivated to conserve their forests (because they are the foundation of their economic and cultural well-being), there is now mounting evidence (which we discuss below) that strengthening the land tenure of indigenous peoples is a powerful way to protect intact forests[94,95].

Human health. Forested ecosystems are major sources of many medicinal compounds that supply millions of people with medicines worldwide[96,97]. Degradation and outright forest loss compromise the supply of these benefits as medically relevant species decline or are lost[98]. Degradation can also cause substantial negative health impacts. For example, during the 2015 human-caused forest fires in Indonesia, the haze generated after 261,000 ha of degraded forest and peatland was burned caused more than 100,000 premature deaths across Indonesia, Malaysia and Singapore[99]. Fragmented forests experience more numerous and intense edge-related wildfires in comparison with intact forests[100], which severely exacerbates the extent of health impacts of both intentional and unintentional burning.

Forest degradation may also lead to infectious disease impacts. Against a backdrop of declining overall burden of infectious diseases on a global scale[101], an increasing rate of novel disease emergence and an increase in the incidence of some endemic diseases in forested landscapes have been, at least in part, attributed to increasing human presence in, and degradation of, these habitats[102,103]. For example, deforestation and resultant environmental changes are considered key drivers of zoonotic malaria in Malaysian Borneo[104]. Although wildlife and arthropod vector species within forests are natural sources of potential human infections[105], increasing human presence and anthropogenic land-use changes often promote opportunities for disease transmission, as human-reservoir/vector contact rates increase or as impacts on host or vector distributions or community composition perturb natural disease dynamics[106]. Numerous infectious diseases associated with forests, including Ebola virus[103], dengue fever[107], Zika virus[108], several hantaviruses[109], yellow fever[110] and malaria[111], are undergoing changes in risk to humans due to deforestation, forest degradation and human encroachment.

The increasing significance of intact forests

The differences in important environmental and social values of intact forests relative to degraded forests are likely to become magnified in the future due to two negative processes in degraded areas: progressive anthropogenic damage and reduced resilience to environmental change.

Vulnerability of degraded forests to further degradation. Once initiated, forest degradation often intensifies over time[112]. This is mediated by: (1) increased levels of human accessibility; (2) successive cycles of logging of often progressively lower value trees[113]; (3) increased hunting pressure[5]; (4) forest clearance and fragmentation due to colonization by farmers and loggers facilitated by new roads[114]; and (5) the entry of new extractive development projects such as mining[55]. For example, in the Brazilian Amazon, 16% of logged areas are cleared for agriculture in the first year following logging, with further losses of more than 5% per year for the next four years[115]. This cycle is exacerbated if conversion becomes more politically acceptable once a forest has been labelled 'degraded'[116]. Once identified as 'lower value' for conservation, degraded forests can mistakenly be considered to have 'no value' by some stakeholders, despite extensive evidence to the contrary[17,117].

Degraded forests also have increased risk of, and susceptibility to, natural disturbances such as fire, as forests are drier along their edges[118]. There is clear evidence that forests that are logged are at high risk of burning at uncharacteristically high severity[119], with an elevated fire proneness lasting for decades[120]. Degraded forests are also at higher risk from invasion by exotic invasive species[18] when compared with non-degraded forests. With fire frequency in many forest areas predicted to increase under climate change scenarios[121–123], intact forests might become refuges from fire in many landscapes where degraded forests burn too frequently to support the persistence of plant and animal communities dependent on old forests. This cascade of damage, referred to as a 'landscape trap'[124], is becoming more common and many forests are now subject to repeated disturbances that lock them in early successional states.

Loss of resilience following forest degradation. In addition to present direct anthropogenic threats, forested ecosystems also have to adapt to large-scale environmental changes, including changes in climate[19], which interact with the myriad of current threats that they already face[125]. Intact forest ecosystems have greater capability to overcome these regional and global stressors than degraded ones, as they have inherent properties that enable them to maximize their adaptive capacity[126]. For example, intact forested ecosystems often house important populations of forest-dependent species and high intraspecific genetic diversity, which both provide options for the local adaptation and phenotypic plasticity[127] that facilitates species' ability to survive changing environmental conditions[128]. Large, connected and functionally intact forest ecosystems also enable species to undertake adaptive responses such as dispersal or retreating to refugia[129], which will be critical as the climate changes and species react[130]. Moreover, the connectivity provided by large, contiguous areas spanning multiple environmental gradients, such as altitude, latitude, rainfall or temperature, will maximize the potential for key processes such as gene flow and genetic adaptation to play out naturally, while also allowing species to track shifting climates in space[131,132]. Intact forests have been shown to be more resilient in response to short-term climatic anomalies (for example, droughts and wildfires during drought) than degraded forests[133].

Intact forest ecosystems sustain large-scale ecological processes, such as natural disturbance regimes, which maintain disturbance-adapted species that influence native community composition[18,127]. For example, the biodiversity of boreal and temperate forests includes evolutionary lineages that are uniquely adapted to survive major seasonal temperature changes and landscape-level disturbances over time, such as large fires and insect infestations[134].

The future of intact forests

The capacity to map human pressures on the environment on global scales is rapidly improving[135] and published results so far show that not only has loss of global forest cover accelerated since the 1990s[8,136,137] but also that there are higher levels of degradation within the shrinking forest estate. The recently updated global Human Footprint[138], a composite index of eight human pressures that is believed to be a good proxy for overall intactness, found that in 2009, 18% of forests had no detectable human pressure, a 35%

© 2018 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

decline since 1993 (Fig. 1b). According to a related but distinct metric, Intact Forest Landscapes covered 24% of the world's forests in 2013, a decline of 7.2% since 2000[3]. Recent mapping of roadless forest[139] and hinterland forest[140] shows similar declines using alternative data sources.

These assessments underestimate the total loss of intactness as they do not fully take into account other forms of forest degradation, including invasive species, some forms of logging, over-hunting, and altered fire and flood regimes, nor do they address the impacts of climate change. For example, vast areas of Central Africa that are mapped as 'intact' by both satellite imagery and the Human Footprint have lost their forest elephant (*L. cyclotis*) populations in the past 20 years due to poaching. This causes dramatic long-term ecological changes, given the role of this species as an 'ecosystem engineer' though seed dispersal, trampling and herbivory[33].

These figures suggest that even if existing global targets to halt deforestation are achieved, much of what is saved will be no longer intact. Outright deforestation is currently concentrated in the tropics and sub-tropics[136], but the loss of intactness is a pervasive global forest phenomenon[3]. It seems likely that this rapid decline in forest intactness will accelerate in line with the underlying drivers of change (including human economic demands, which are growing rapidly as a result of rising population and even more quickly rising per-capita consumption[141]). One stark forecast is that 25 million km of new roads will be built globally by 2050[142], threatening many intact areas.

Focal mechanisms for action on intact forests. It is clear that many intact forests are under severe and rising pressure, and there is an urgent need for greater conservation efforts[3]. Below, we offer some potential avenues for enhanced action, while acknowledging that the scale of the challenge is very significant, and will achieve long-term success only if nations turn away from 'business as usual' activities that extract natural resources without appropriately valuing the cost of lost natural capital. An essential first step towards greater success is achieving widespread recognition that rapid loss of forest intactness represents a major threat to sustainable development and human well-being. Policymakers need to understand the challenge that the loss of forest intactness represents for achieving strategic goals outlined in key multilateral environmental agreements, including the Convention of Biological Diversity, the UNFCCC and the UN Sustainable Development Goals[139,143], and this recognition needs to be translated into meaningful changes on the ground.

A fundamental constraint to progress is the fact that international definitions of forests have not differentiated among types of forest and, in most policy settings, they treat all forests, regardless of their condition, as equivalent[1,144]. As such, international policy processes seldom acknowledge the special qualities and benefits that flow from intact ecosystems as compared with those that are degraded. The consequence is that few policy processes (or participating nations) clearly articulate conservation goals for intactness, forest quality or integrity[143]. There is an emerging, critical role for the science community to develop policy-relevant metrics of forest intactness that account for the different forms and levels of forest degradation, and assess how they impact on different globally important social and environmental values. The lack of recognition of the varying qualities and condition among forest types has implications for targeting by international funding programmes such as the Global Environment Facility, Green Climate Fund and Critical Ecosystems Partnership Fund, which are distributing billions of dollars annually to help developing countries achieve the goals of multilateral environmental agreements. All three of these mechanisms could adjust their criteria for funding so as to explicitly recognize the value of investments that protect intact forests.

A number of emerging policy opportunities for the global community to recognize the special values that intact forests preserve, when compared with degraded ones, are within the UNFCCC. Because the scientific community has not worked out a practicable definition for emissions from land use, land use-change and forestry (LULUCF) that would separate direct human-induced effects from indirect human-induced and natural effects, parties to the UNFCCC in reporting on LULUCF in their greenhouse gas inventories may choose to apply the managed land proxy[145]. Under the managed land proxy, land where human practices have been applied is considered 'managed' and included in reporting under the UNFCCC. However, by definition, many intact forest landscapes are located on 'unmanaged lands' and therefore their contribution to meeting mitigation goals is not quantified or understood. Increased attention to unmanaged lands, and to transitions between the managed and unmanaged lands categories, through key venues such as the Intergovernmental Panel on Climate Change Special Reports and the Global Stocktake and Facilitative Dialogue will not just improve understanding of the climate mitigation role of intact forests but also support nations in articulating interventions, targets and funding needs for protecting these forests in formulating and implementing their nationally determined contributions.

Further policy enhancements could be identified in existing frameworks and programmes for financing for tropical intact forest conservation, such as the UNFCCC REDD+ process (reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries), the Green Climate Fund and the Forest Carbon Partnership Facility. To date, these processes have been focused on rewarding countries and jurisdictions with performance-based payments for reducing near-term threats of deforestation and (to a much lesser extent) degradation, based on a historical emissions baseline. Given this goal of achieving near-term climate mitigation results (that is, typically within five to ten years), programme rules often directly limit the eligibility or amount of support for conservation of intact forests that have, by definition, low historical emissions from deforestation and degradation, and that may be under threat over one or more decades. For example, so-called 'high forest, low deforestation' nations have relied on projections that implicitly or explicitly assume higher rates of emissions in the future. A more straightforward approach would focus on existing stocks and reservoirs of forest carbon, which could be elaborated within the '+' in REDD+ (the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries). Such an approach may require new incentives that differ from and are complementary to existing results-based payment approaches; instead, they would reward the long-term maintenance of existing carbon stocks and the other '+' activities, and bypass rules stipulating that this financing must target areas with high historical ('baseline') levels of emissions[146]. Additional climate-related policy approaches are also clearly needed for temperate and boreal intact forests, especially those in developed countries that would not expect to receive finance support under the Paris Agreement and related UNFCCC mechanisms.

There are current efforts underway to generate new 2030 global biodiversity targets, and operationalizing a clear, mandated target on preserving ecosystem intactness is critical to this[143]. The first steps are underway, with the International Union for the Conservation of Nature recently adopting a new key biodiversity area criterion (criterion C) covering those sites that contribute significantly to the global persistence of biodiversity because they are exceptional examples of ecological integrity and naturalness[147]. If the key biodiversity area standard becomes formally recognized within the 2030 strategic plan for biodiversity, this would be a very positive step in proactively conserving intact forests.

Change in policy at the global level should be reflected in the design and implementation of effective national and sub-national policies, and forest management plans that recognize the value of

© 2018 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

intact forests to the host nation and specify policies for their protection and restoration. National and sub-national policies can be supported by longer-term planning that is incentivized by climate funding streams (for example, conditional targets in nationally determined contributions, the Green Climate Fund) that recognize the mitigation contribution of intact forest landscapes. These policies will vary based on the specific context of different nations, but there is a clear need to focus on halting degrading activities, including limiting road expansion[142], reducing negative impacts of hunting through legal controls coupled with sustainable resource use strategies[5], preventing large-scale developments such as mining, forestry and agriculture in intact forests[51], and investing in restoration activities. One obvious intervention that nations can prioritize is the creation of large protected areas, including transboundary areas. When well designed, financed and enforced, protected areas have been shown to be effective in slowing the impacts of industrial logging[3], land clearance[148] and over-hunting[33,148].

A range of other designations exists beyond protected areas that can prevent the loss of intactness or promote its restoration. There is evidence that the designation of 'roadless areas' in the USA, for example, has led to an effective expansion in the degree of ecoregional representation under protection and increases in the number of areas big enough to provide refugia for species needing large tracts relatively undisturbed by people[149]. There is a need for mechanisms relating to the private sector that prioritize the protection and restoration of intact forest, including specific investment and performance standards for lenders and investors (for example, the World Bank, International Finance Corporation and regional development banks) and increasing the effectiveness of existing forest and extractive industry certification standards. Recent initiatives to make supply chains deforestation-free need to be strengthened, and to include measures to protect intact forests. While there are some signs of success (for example, the Brazil Soy Moratorium[150]), implementation is lagging well behind pledges and it is too early to demonstrate lasting impacts[151].

One emerging strategy that can be effective in slowing the degradation of intact forests is enabling indigenous communities to establish title and management over their traditional lands. Although comprehensive global analyses are lacking, some regional data reveal the remarkable contribution of stewardship by forest peoples to sustaining high-integrity forest systems, often in the face of substantial pressures to liquidate forest timber or mineral resources. For instance, the creation and management of indigenous territories has reduced (although, as with protected areas, not halted) deforestation across the Amazon Basin[152–154]. It is believed over half of the Amazon Basin's 7 million km^2 are under some form of protection, and nearly 1.8 million km^2 are indigenous lands[155]. In the boreal north of Canada, First Nations peoples have been able to sign formal agreements with the government and the private sector to ensure that national economic development policies and practices respect their rights and commit to conserving their lands and waters. For example, the Final Recommended Peel Regional Land Use Plan, co-developed by the government of Yukon and four First Nation governments, has an explicit goal of "managing development at a pace and scale that maintains ecological integrity", and has placed 81% of the 67,000 km^2 area under protection[156]. These examples are drawn mostly from regions where indigenous peoples live at very low densities and have made cultural choices not to exploit the territories they own for timber or minerals; where population densities are higher, or where communities make different cultural choices, levels of forest degradation associated with subsistence and income-generating activities will also tend to be proportionately higher, as with non-indigenous communities.

Funding for protection and restoration of intact forests could also be used to establish payments for ecosystem services. The approach has many challenges, but there are some encouraging examples where these types of activities are being undertaken. For example, in Brazil, the Amazon Regional Protected Areas programme, partly funded by international performance-based payments under a prototype REDD+ framework, supports the creation and management of protected areas and sustainable natural resource use[157]. This is being accomplished in collaboration with local peoples with the overarching aim to maintain forest carbon stocks and protect large-scale ecological processes[158].

There is also a need for increased efforts to restore the intactness of degraded systems. This should not be seen as a substitute for conserving fully intact systems in their current state, as forest degradation can often only be partially reversed over reasonable timescales[112], and it is generally more cost-effective to conserve at-risk intact forests than to protect or restore fragmented and degraded ones. If the goal of restoration is to achieve sustainably managed production forests, this may serve to alleviate pressure on intact forests, while also providing some biodiversity and ecosystem service benefits[159]. Further intensifying production systems in previously degraded land may allow even more intact forests to be spared. Such a 'land sparing' approach has been shown to achieve biodiversity benefits in agricultural landscapes relative to 'land sharing' (integrating biodiversity and production objectives on the same land)[160], and emerging evidence suggests the same is true in timber production landscapes[161]. In both cases, it is imperative that strong regulation and governance systems are in place to ensure intact forests are actually spared in practice; otherwise, the higher economic returns that come from intensifying production may create incentives for further forest degradation[162]. Nonetheless, in already-degraded systems, partial restoration will clearly bring significant environmental benefits in many cases[112]. Important efforts are being undertaken worldwide, for example through UN-REDD and the Bonn Challenge, ranging from enabling natural regeneration, active replanting of native forests, removal of invasive exotic species[163], fire management[164], reconnecting landscapes through the establishment of corridors[165], and 'rewilding' initiatives to re-establish top predators and large-scale ecosystem processes in regenerating forests[166].

Conclusion

There are still significant tracts of forest that are free from the damaging impacts of large-scale human activities. These intact forests typically provide more environmental and social values than forests that have been degraded by human activities. Despite these values, it is possible to envisage, within the current century, a world with few or no significant remaining intact forests. Humanity may be left with only degraded, damaged forests, in need of costly and sometimes unfeasible restoration, open to a cascade of further threats and lacking the resilience needed to weather the stresses of climate change. The practical tools required to address this challenge are generally well understood and include well-located and managed protected areas, indigenous territories that exemplify sound stewardship, regulatory controls and responsible behaviour by logging, mining, and agricultural companies and consumers, and targeted restoration. Currently these tools are insufficiently applied, and inadequately supported by governance, policy and financial arrangements designed to incentivize conservation. Losing the remaining intact forests would exacerbate climate change effects through huge carbon emissions and the decline of a crucial, under-appreciated carbon sink. It would also result in the extinction of many species, harm communities worldwide by disrupting regional weather and hydrology, and devastate the cultures of many indigenous communities. Increased awareness of the scale and urgency of this problem is a necessary pre-condition for more effective conservation efforts across a wide range of spatial scales.

Received: 14 July 2017; Accepted: 30 January 2018;

© 2018 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

References

1. Mackey, B. et al. Policy options for the world's primary forests in multilateral environmental agreements. *Conserv. Lett.* **8**, 139–147 (2015).
2. MacDicken, K. et al. *Global Forest Resources Assessment 2015: How are the World's Forests Changing?* 2nd edn (FAO, Rome, 2016).
3. Potapov, P. et al. The last frontiers of wilderness: tracking loss of intact forest landscapes from 2000 to 2013. *Sci. Adv.* **3**, e1600821 (2017).
4. Venter, O. et al. Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. *Nat. Commun.* **7**, 12558 (2016).
5. Redford, K. H. The empty forest. *Bioscience* **42**, 412–422 (1992).
6. *Adoption of the Paris Agreement: Proposal by the President* Draft Decision -/CP.21 (UNFCCC, Geneva, 2015).
7. *Progress Towards the Sustainable Development Goals: Report of the Secretary-General* (UN Economic and Social Council, 2016).
8. *Progress on the New York Declaration on Forests Achieving Collective Forest Goals: Updates on Goals 1-10* (Climate Focus, 2016).
9. Thompson, I. D. et al. An operational framework for defining and monitoring forest degradation. *Ecol. Soc.* **18**, 20 (2013).
10. Ghazoul, J. & Chazdon, R. Degradation and recovery in changing forest landscapes: a multiscale conceptual framework. *Annu. Rev. Environ. Resour.* **42**, 161–188 (2017).
11. Zarin, D. J. et al. Can carbon emissions from tropical deforestation drop by 50% in 5 years?. *Glob. Change Biol.* **22**, 1336–1347 (2016).
12. Houghton, R. A., Byers, B. & Nassikas, A. A. A role for tropical forests in stabilizing atmospheric CO_2. *Nat. Clim. Change* **5**, 1022–1023 (2015).
13. Balmford, A., Gaston, K. J., Blyth, S., James, A. & Kapos, V. Global variation in terrestrial conservation costs, conservation benefits, and unmet conservation needs. *Proc. Natl Acad. Sci. USA* **100**, 1046–1050 (2003).
14. Gibson, L. et al. Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature* **478**, 378–381 (2011).
15. Lewis, S. L., Edwards, D. P. & Galbraith, D. Increasing human dominance of tropical forests. *Science* **349**, 827–832 (2015).
16. De Leo, G. & Levin, S. The multifaceted aspects of ecosystem integrity. *Conserv. Ecol.* **1**, 3 (1997).
17. Edwards, D. P., Tobias, J. A., Sheil, D., Meijaard, E. & Laurance, W. F. Maintaining ecosystem function and services in logged tropical forests. *Trends Ecol. Evol.* **29**, 511–520 (2014).
18. Lindenmayer, D., Thorn, S. & Banks, S. Please do not disturb ecosystems further. *Nat. Ecol. Evol.* **1**, 0031 (2017).
19. Scheffers, B. R. et al. The broad footprint of climate change from genes to biomes to people. *Science* **354**, aaf7671 (2016).
20. Le Quéré, C. et al. Global carbon budget 2016. *Earth Syst. Sci. Data* **8**, 605–649 (2016).
21. Sanderson, B. M., O'Neill, B. C. & Tebaldi, C. What would it take to achieve the Paris temperature targets? *Geophys. Res. Lett.* **43**, 7133–7142 (2016).
22. Houghton, R. A. Carbon emissions and the drivers of deforestation and forest degradation in the tropics. *Curr. Opin. Environ. Sustain.* **4**, 597–603 (2012).
23. Keith, H. et al. Managing temperate forests for carbon storage: impacts of logging versus forest protection on carbon stocks. *Ecosphere* **5**, 1–34 (2014).
24. Page, S. E., Rieley, J. O. & Banks, C. J. Global and regional importance of the tropical peatland carbon pool. *Glob. Change Biol.* **17**, 798–818 (2011).
25. Turetsky, M. R. et al. Global vulnerability of peatlands to fire and carbon loss. *Nat. Geosci.* **8**, 11–14 (2015).
26. Zimmerman, B. L. & Kormos, C. F. Prospects for sustainable logging in tropical forests. *Bioscience* **62**, 479–487 (2012).
27. Haddad, N. M. et al. Habitat fragmentation and its lasting impact on Earth's ecosystems. *Sci. Adv.* **1**, e1500052 (2015).
28. Chaplin-Kramer, R. et al. Degradation in carbon stocks near tropical forest edges. *Nat. Commun.* **6**, 10158 (2015).
29. Bello, C. et al. Defaunation affects carbon storage in tropical forests. *Sci. Adv.* **1**, e1501105 (2015).
30. Sobral, M. et al. Mammal diversity influences the carbon cycle through trophic interactions in the Amazon. *Nat. Ecol. Evol.* **1**, 1670–1676 (2017).
31. Peres, C. A., Emilio, T., Schietti, J., Desmoulière, S. J. M. & Levi, T. Dispersal limitation induces long-term biomass collapse in overhunted Amazonian forests. *Proc. Natl Acad. Sci. USA* **113**, 892–897 (2016).
32. Robinson, J. G. & Bennett, E. L (eds) *Hunting for Sustainability in Tropical Forests* (Columbia Univ. Press, New York, 2000).
33. Maisels, F. et al. Devastating decline of forest elephants in Central Africa. *PLoS ONE* **8**, e59469 (2013).
34. Lewis, S. L. et al. Increasing carbon storage in intact African tropical forests. *Nature* **457**, 1003–1006 (2009).
35. Luyssaert, S. et al. Old-growth forests as global carbon sinks. *Nature* **455**, 213–215 (2008).
36. Houghton, R. A. The emissions of carbon from deforestation and degradation in the tropics: past trends and future potential. *Carbon Manag.* **4**, 539–546 (2013).
37. Pan, Y. et al. A large and persistent carbon sink in the world's forests. *Science* **333**, 988–993 (2011).
38. Griscom, B. W. et al. Natural climate solutions. *Proc. Natl Acad. Sci. USA* **114**, 11645–11650 (2017).
39. Bongers, F., Chazdon, R., Poorter, L. & Peña-Claros, M. The potential of secondary forests. *Science* **348**, 642–643 (2015).
40. Pielke, R. A., Mahmood, R. & McAlpine, C. Land's complex role in climate change. *Phys. Today* **69**, 40–46 (2016).
41. Sheil, D. & Murdiyarso, D. How forests attract rain: an examination of a new hypothesis. *Bioscience* **59**, 341–347 (2009).
42. Bonan, G. B. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *Science* **320**, 1444–1449 (2008).
43. Deo, R. C. et al. Impact of historical land cover change on daily indices of climate extremes including droughts in eastern Australia. *Geophys. Res. Lett.* **36**, L08705 (2009).
44. Medvigy, D., Walko, R. L., Otte, M. J. & Avissar, R. Simulated changes in northwest US climate in response to Amazon deforestation. *J. Clim.* **26**, 9115–9136 (2013).
45. Ahlström, A. et al. The dominant role of semi-arid ecosystems in the trend and variability of the land CO_2 sink. *Science* **348**, 895–899 (2015).
46. D'Odorico, P. et al. Ecohydrology of terrestrial ecosystems. *Bioscience* **60**, 898–907 (2010).
47. Ludwig, D., Brock, W. & Carpenter, S. Uncertainty in discount models and environmental accounting. *Ecol. Soc.* **10**, 13 (2005).
48. Vertessy, R. A., Watson, F. G. R. & Sharon, K. O. Factors determining relations between stand age and catchment water balance in mountain ash forests. *For. Ecol. Manag.* **143**, 13–26 (2001).
49. Alila, Y., Kuras, P. K., Schnorbus, M. & Hudson, R. Forests and floods: a new paradigm sheds light on age-old controversies. *Water Resour. Res.* **45**, W08416 (2009).
50. Brookhuis, B. J. & Hein, L. G. The value of the flood control service of tropical forests: a case study for Trinidad. *For. Policy Econ.* **62**, 118–124 (2016).
51. Maxwell, S. L., Fuller, R. A., Brooks, T. M. & Watson, J. E. M. Biodiversity: the ravages of guns, nets and bulldozers. *Nature* **536**, 143–145 (2016).
52. Pimm, S. L. et al. The biodiversity of species and their rates of extinction, distribution, and protection. *Science* **344**, 1246752 (2014).
53. Cardinale, B. J. et al. Biodiversity loss and its impact on humanity. *Nature* **486**, 59–67 (2012).
54. Morales-Hidalgo, D., Oswalt, S. N. & Somanathan, E. Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment 2015. *For. Ecol. Manag.* **352**, 68–77 (2015).
55. Venier, L. A. et al. Effects of natural resource development on the terrestrial biodiversity of Canadian boreal forests. *Environ. Rev.* **22**, 457–490 (2014).
56. Laurance, W. F. et al. The fate of Amazonian forest fragments: a 32-year investigation. *Biol. Conserv.* **144**, 56–67 (2011).
57. Peres, C. A. Why we need megareserves in Amazonia. *Conserv. Biol.* **19**, 728–733 (2005).
58. Lortkipanidze, B. Brown bear distribution and status in the South Caucasus. *Ursus* **21**, 97–103 (2010).
59. Festa-Bianchet, M., Ray, J. C., Boutin, S., Côté, S. D. & Gunn, A. Conservation of caribou (*Rangifer tarandus*) in Canada: an uncertain future. *Can. J. Zool.* **89**, 419–434 (2011).
60. Broadbent, E. N. et al. Forest fragmentation and edge effects from deforestation and selective logging in the Brazilian Amazon. *Biol. Conserv.* **141**, 1745–1757 (2008).
61. Hermy, M. & Verheyen, K. Legacies of the past in the present-day forest biodiversity: a review of past land-use effects on forest plant species composition and diversity. *Ecol. Res.* **22**, 361–371 (2007).
62. Lindenmayer, D. B. et al. How to make a common species rare: a case against conservation complacency. *Biol. Conserv.* **144**, 1663–1672 (2011).
63. Ripple, W. J. et al. Collapse of the world's largest herbivores. *Sci. Adv.* **1**, e1400103 (2015).
64. Gray, T. N. E., Prum, S., Pin, C. & Phan, C. Distance sampling reveals Cambodia's Eastern Plains Landscape supports the largest global population of the endangered banteng *Bos javanicus*. *Oryx* **46**, 563–566 (2012).
65. Barlow, J. et al. Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. *Nature* **535**, 144–147 (2016).
66. Edwards, D. P. The rainforest's 'do not disturb' signs. *Nature* **535**, 44–46 (2016).
67. Peres, C. A. Synergistic effects of subsistence hunting and habitat fragmentation on Amazonian forest vertebrates. *Conserv. Biol.* **15**, 1490–1505 (2001).
68. Betts, M. G. et al. Global forest loss disproportionately erodes biodiversity in intact landscapes. *Nature* **547**, 441–444 (2017).
69. Miraldo, A. et al. An Anthropocene map of genetic diversity. *Science* **353**, 1532–1535 (2016).

© 2018 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

70. Byron, N. & Arnold, M. What futures for the people of the tropical forests? *World Dev.* **27**, 789–805 (1999).
71. Lévi-Strauss, C. *The Savage Mind* (Univ. Chicago Press, Chicago, 1966).
72. Johnson, C. N., Bradshaw, C. J. A., Cooper, A., Gillespie, R. & Brook, B. W. Rapid megafaunal extinction following human arrival throughout the New World. *Quat. Int.* **308**, 273–277 (2013).
73. Hutterer, K. L. in *People of the Tropical Rain Forest* (eds Denslow, J. S. & Padoch, C.) 63–72 (Univ. California Press, Washington DC, 1988).
74. Mercader, J. Forest people: the role of African rainforests in human evolution and dispersal. *Evol. Anthropol.* **11**, 117–124 (2002).
75. Robinson, J. G. & Bennett, E. L. (eds) in *Hunting for Sustainability in Tropical Forests* 13–30 (Columbia Univ. Press, New York, 2000).
76. Bennett, E. L. & Robinson, J. G. *Hunting of Wildlife in Tropical Forests: Implications for Biodiversity and Forest Peoples* Biodiversity Studies Impact Series Paper No. 76 (World Bank, Washington DC, 2000).
77. Levis, C. et al. Persistent effects of pre-Columbian plant domestication on Amazonian forest composition. *Science* **355**, 925–931 (2017).
78. Schmidt, M. J. & Heckenberger, M. J. in *Amazonian Dark Earths: Wim Sombroek's Vision* (eds Woods, W. I. et al.) 163–191 (Springer, Dordrecht, 2009).
79. Foley, J. A. et al. Amazonia revealed: forest degradation and loss of ecosystem goods and services in the Amazon Basin. *Front. Ecol. Environ.* **5**, 25–32 (2007).
80. Rozzi, R. Biocultural ethics: recovering the vital links between the inhabitants, their habits, and habitats. *Environ. Ethics* **34**, 27–50 (2012).
81. Southgate, D., Wasserstrom, R. & Reider, S. Oil development, deforestation, and indigenous populations in the Ecuadorian Amazon. *Lat. Am. Stud. Assoc.* **11**, 1–38 (2009).
82. Bedoya Garland, E. in *The Social Causes of Environmental Destruction in Latin America* (eds Painter, M. & Durham, W. H.) 217–248 (Univ. Michigan Press, Ann Arbor, 1995).
83. Demmer, M. J. & Overman, J. P. M. *Indigenous People Conserving the Rain Forest? The Effect of Wealth and Markets on the Economic Behaviour of Tawahka Amerindians in Honduras* (Tropenbos Foundation, 2001).
84. Godoy, R. et al. Household determinants of deforestation by Amerindians in Honduras. *World Dev.* **25**, 977–987 (1997).
85. Reyes-García, V. et al. Indigenous land reconfiguration and fragmented institutions: a historical political ecology of Tsimane'lands (Bolivian Amazon). *J. Rural Stud.* **34**, 282–291 (2014).
86. Sirén, A. *Changing Interactions Between Humans and Nature in Sarayaku, Ecuadorian Amazon*. PhD thesis, Swedish Univ. Agricultural Sciences (2004).
87. Sirén, A. H. Population growth and land use intensification in a subsistence-based indigenous community in the Amazon. *Hum. Ecol.* **35**, 669–680 (2007).
88. Luz, A. C. et al. How does cultural change affect indigenous peoples' hunting activity? An empirical study among the Tsimane'in the Bolivian Amazon. *Conserv. Soc.* **13**, 382–394 (2015).
89. Gross, D. R. et al. Ecology and acculturation among native peoples of central Brazil. *Science* **206**, 1043–1050 (1979).
90. Sheil, D. et al. *The Impacts and Opportunities of Oil Palm in Southeast Asia: What do We Know and What do We Need to Know?* (Center for International Forestry Research, Bogor, 2009).
91. Finer, M., Jenkins, C. N., Pimm, S. L., Keane, B. & Ross, C. Oil and gas projects in the western Amazon: threats to wilderness, biodiversity, and indigenous peoples. *PLoS ONE* **3**, e2932 (2008).
92. Olivero, J. et al. Distribution and numbers of pygmies in Central African forests. *PLoS ONE* **11**, e0144499 (2016).
93. Parlee, B. L. Avoiding the resource curse: indigenous communities and Canada's oil sands. *World Dev.* **74**, 425–436 (2015).
94. Barraclough, S. & Ghimire, K. *Forests and Livelihoods: The Social Dynamics of Deforestation in Developing Countries* (Springer, London, 1995).
95. Oliveira, P. J. C. et al. Land-use allocation protects the Peruvian Amazon. *Science* **317**, 1233–1236 (2007).
96. Colfer, C. J. P. *Human Health and Forests: A Global Overview of Issues, Practice and Policy* (Routledge, London, 2012).
97. Karjalainen, E., Sarjala, T. & Raitio, H. Promoting human health through forests: overview and major challenges. *Environ. Health Prev. Med.* **15**, 1–8 (2010).
98. Shanley, P. & Luz, L. The impacts of forest degradation on medicinal plant use and implications for health care in eastern Amazonia. *Bioscience* **53**, 573–584 (2003).
99. Koplitz, S. N. et al. Public health impacts of the severe haze in equatorial Asia in September–October 2015: demonstration of a new framework for informing fire management strategies to reduce downwind smoke exposure. *Environ. Res. Lett.* **11**, 94023 (2016).
100. Laurance, W. F. Forest–climate interactions in fragmented tropical landscapes. *Phil. Trans. R. Soc. Lond. B* **359**, 345–352 (2004).
101. Murray, C. J. L. et al. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* **380**, 2197–2223 (2012).
102. Jones, K. E. et al. Global trends in emerging infectious diseases. *Nature* **451**, 990–993 (2008).
103. Myers, S. S. & Patz, J. A. Emerging threats to human health from global environmental change. *Annu. Rev. Environ. Resour.* **34**, 223–252 (2009).
104. Fornace, K. M. et al. Association between landscape factors and spatial patterns of *Plasmodium knowlesi* infections in Sabah, Malaysia. *Emerg. Infect. Dis.* **22**, 201–208 (2016).
105. Dunn, R. R. Global mapping of ecosystem disservices: the unspoken reality that nature sometimes kills us. *Biotropica* **42**, 555–557 (2010).
106. Murray, K. A. & Daszak, P. Human ecology in pathogenic landscapes: two hypotheses on how land use change drives viral emergence. *Curr. Opin. Virol.* **3**, 79–83 (2013).
107. Vasilakis, N., Cardosa, J., Hanley, K. A., Holmes, E. C. & Weaver, S. C. Fever from the forest: prospects for the continued emergence of sylvatic dengue virus and its impact on public health. *Nat. Rev. Microbiol.* **9**, 532–541 (2011).
108. Ali, S. et al. Environmental and social change drive the explosive emergence of Zika virus in the Americas. *PLoS Negl. Trop. Dis.* **11**, e0005135 (2017).
109. Jonsson, C. B., Figueiredo, L. T. M. & Vapalahti, O. A global perspective on hantavirus ecology, epidemiology, and disease. *Clin. Microbiol. Rev.* **23**, 412–441 (2010).
110. Norris, D. E. Mosquito-borne diseases as a consequence of land use change. *Ecohealth* **1**, 19–24 (2004).
111. Hahn, M. B., Gangnon, R. E., Barcellos, C., Asner, G. P. & Patz, J. A. Influence of deforestation, logging, and fire on malaria in the Brazilian Amazon. *PLoS ONE* **9**, e85725 (2014).
112. Chazdon, R. L. Beyond deforestation: restoring forests and ecosystem services on degraded lands. *Science* **320**, 1458–1460 (2008).
113. Putz, F. E. & Redford, K. H. The importance of defining 'forest': tropical forest degradation, deforestation, long-term phase shifts, and further transitions. *Biotropica* **42**, 10–20 (2010).
114. Laurance, W. F., Goosem, M. & Laurance, S. G. W. Impacts of roads and linear clearings on tropical forests. *Trends Ecol. Evol.* **24**, 659–669 (2009).
115. Asner, G. P. et al. Condition and fate of logged forests in the Brazilian Amazon. *Proc. Natl Acad. Sci. USA* **103**, 12947–12950 (2006).
116. Giam, X., Clements, G. R., Aziz, S. A., Chong, K. Y. & Miettinen, J. Rethinking the 'back to wilderness' concept for Sundaland's forests. *Biol. Conserv.* **144**, 3149–3152 (2011).
117. Berry, N. J. et al. The high value of logged tropical forests: lessons from northern Borneo. *Biodivers. Conserv.* **19**, 985–997 (2010).
118. Barlow, J. & Peres, C. A. Fire-mediated dieback and compositional cascade in an Amazonian forest. *Phil. Trans. R. Soc. B* **363**, 1787–1794 (2008).
119. Thompson, J. R., Spies, T. A. & Ganio, L. M. Reburn severity in managed and unmanaged vegetation in a large wildfire. *Proc. Natl Acad. Sci. USA* **104**, 10743–10748 (2007).
120. Taylor, C., McCarthy, M. A. & Lindenmayer, D. B. Nonlinear effects of stand age on fire severity. *Conserv. Lett.* **7**, 355–370 (2014).
121. Stephens, S. L. et al. Managing forests and fire in changing climates. *Science* **342**, 41–42 (2013).
122. Wang, X. et al. Increasing frequency of extreme fire weather in Canada with climate change. *Clim. Change* **130**, 573–586 (2015).
123. Bowman, D. Ecohydrology: when will the jungle burn? *Nat. Clim. Change* **7**, 390–391 (2017).
124. Lindenmayer, D. B., Hobbs, R. J., Likens, G. E., Krebs, C. J. & Banks, S. C. Newly discovered landscape traps produce regime shifts in wet forests. *Proc. Natl Acad. Sci. USA* **108**, 15887–15891 (2011).
125. Côté, I. M., Darling, E. S. & Brown, C. J. Interactions among ecosystem stressors and their importance in conservation. *Proc. R. Soc. B* **283**, 20152592 (2016).
126. Thompson, I., Mackey, B., McNulty, S. & Mosseler, A. *Forest Resilience, Biodiversity, and Climate Change* Technical Series No. 43 (Secretariat of the Convention on Biological Diversity, Montreal, 2009).
127. Mackey, B. G., Watson, J. E. M., Hope, G. & Gilmore, S. Climate change, biodiversity conservation, and the role of protected areas: an Australian perspective. *Biodiversity* **9**, 11–18 (2008).
128. Alberto, F. J. et al. Potential for evolutionary responses to climate change – evidence from tree populations. *Glob. Change Biol.* **19**, 1645–1661 (2013).
129. Watson, J. E. M., Iwamura, T. & Butt, N. Mapping vulnerability and conservation adaptation strategies under climate change. *Nat. Clim. Change* **3**, 989–994 (2013).
130. Shoo, L. P., Storlie, C., VanDerWal, J., Little, J. & Williams, S. E. Targeted protection and restoration to conserve tropical biodiversity in a warming world. *Glob. Change Biol.* **17**, 186–193 (2011).
131. Sgro, C. M., Lowe, A. J. & Hoffmann, A. A. Building evolutionary resilience for conserving biodiversity under climate change. *Evol. Appl.* **4**, 326–337 (2011).
132. Hole, D. G. et al. Projected impacts of climate change on a continent-wide protected area network. *Ecol. Lett.* **12**, 420–431 (2009).

© 2018 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

133. Saleska, S. R., Didan, K., Huete, A. R. & Da Rocha, H. R. Amazon forests green-up during 2005 drought. *Science* **318**, 612 (2007).
134. Piao, S. et al. Footprint of temperature changes in the temperate and boreal forest carbon balance. *Geophys. Res. Lett.* **36**, L07404 (2009).
135. Rose, R. A. et al. Ten ways remote sensing can contribute to conservation. *Conserv. Biol.* **29**, 350–359 (2015).
136. Hansen, M. C. et al. High-resolution global maps of 21st-century forest cover change. *Science* **342**, 850–853 (2013).
137. Kim, D.-H., Sexton, J. O. & Townshend, J. R. Accelerated deforestation in the humid tropics from the 1990s to the 2000s. *Geophys. Res. Lett.* **42**, 3495–3501 (2015).
138. Venter, O. et al. Global terrestrial Human Footprint maps for 1993 and 2009. *Sci. Data* **3**, 160067 (2016).
139. Ibisch, P. L. et al. A global map of roadless areas and their conservation status. *Science* **354**, 1423–1427 (2016).
140. Tyukavina, A., Hansen, M. C., Potapov, P. V., Krylov, A. M. & Goetz, S. J. Pan-tropical hinterland forests: mapping minimally disturbed forests. *Glob. Ecol. Biogeogr.* **25**, 151–163 (2016).
141. Steffen, W. et al. The Anthropocene: from global change to planetary stewardship. *AMBIO* **40**, 739–761 (2011).
142. Laurance, W. F. et al. A global strategy for road building. *Nature* **513**, 229–232 (2014).
143. Watson, J. E. M. et al. Catastrophic declines in wilderness areas undermine global environment targets. *Curr. Biol.* **26**, 2929–2934 (2016).
144. Chazdon, R. L. et al. When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. *AMBIO* **45**, 538–550 (2016).
145. Penman, J. et al. (eds) *IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry* (Institute for Global Environmental Strategies, Kanagawa, 2003).
146. Venter, O. & Koh, L. P. Reducing emissions from deforestation and forest degradation (REDD+): game changer or just another quick fix? *Ann. NY Acad. Sci.* **1249**, 137–150 (2012).
147. *A Global Standard for the Identification of Key Biodiversity Areas: Version 1.0* (IUCN, Gland, 2016).
148. Watson, J. E. M., Dudley, N., Segan, D. B. & Hockings, M. The performance and potential of protected areas. *Nature* **515**, 67–73 (2014).
149. DeVelice, R. L. & Martin, J. R. Assessing the extent to which roadless areas complement the conservation of biological diversity. *Ecol. Appl.* **11**, 1008–1018 (2001).
150. Gibbs, H. K. et al. Brazil's Soy Moratorium. *Science* **347**, 377–378 (2015).
151. Azhar, B., Saadun, N., Prideaux, M. & Lindenmayer, D. B. The global palm oil sector must change to save biodiversity and improve food security in the tropics. *J. Environ. Manag.* **203**, 457–466 (2017).
152. Schleicher, J., Peres, C. A., Amano, T., Llactayo, W. & Leader-Williams, N. Conservation performance of different conservation governance regimes in the Peruvian Amazon. *Sci. Rep.* **7**, 11318 (2017).
153. Nolte, C., Agrawal, A., Silvius, K. M. & Soares-Filho, B. S. Governance regime and location influence avoided deforestation success of protected areas in the Brazilian Amazon. *Proc. Natl Acad. Sci. USA* **110**, 4956–4961 (2013).
154. Santika, T. et al. Community forest management in Indonesia: avoided deforestation in the context of anthropogenic and climate complexities. *Glob. Environ. Change* **46**, 60–71 (2017).
155. Hardner, J., Gullison, R. E. & O'Neill, E. Staying the course: how a long-term strategic donor initiative to conserve the Amazon has yielded outcomes of global significance. *Found. Rev.* **9**, 14 (2017).
156. *Final Recommended Peel Watershed Regional Land Use Plan* (Peel Watershed Planning Commission, Whitehorse, 2011).
157. Soares-Filho, B. et al. Role of Brazilian Amazon protected areas in climate change mitigation. *Proc. Natl Acad. Sci. USA* **107**, 10821–10826 (2010).
158. *Amazon Region Protected Areas Programme* (World Wildlife Fund, 2016).
159. Paquette, A. & Messier, C. The role of plantations in managing the world's forests in the Anthropocene. *Front. Ecol. Environ.* **8**, 27–34 (2010).
160. Phalan, B., Onial, M., Balmford, A. & Green, R. Reconciling food production and biodiversity conservation: land sharing and land sparing compared. *Science* **333**, 1289–1291 (2011).
161. Edwards, D. P. et al. Land-sharing versus land-sparing logging: reconciling timber extraction with biodiversity conservation. *Glob. Change Biol.* **20**, 183–191 (2014).
162. Phelps, J., Carrasco, L. R., Webb, E. L., Koh, L. P. & Pascual, U. Agricultural intensification escalates future conservation costs. *Proc. Natl Acad. Sci. USA* **110**, 7601–7606 (2013).
163. D'Antonio, C. & Meyerson, L. A. Exotic plant species as problems and solutions in ecological restoration: a synthesis. *Restor. Ecol.* **10**, 703–713 (2002).
164. Brown, R. T., Agee, J. K. & Franklin, J. F. Forest restoration and fire: principles in the context of place. *Conserv. Biol.* **18**, 903–912 (2004).
165. Jantz, P., Goetz, S. & Laporte, N. Carbon stock corridors to mitigate climate change and promote biodiversity in the tropics. *Nat. Clim. Change* **4**, 138–142 (2014).
166. Galetti, M., Pires, A. S., Brancalion, P. H. S. & Fernandez, F. A. S. Reversing defaunation by trophic rewilding in empty forests. *Biotropica* **49**, 5–8 (2017).
167. Pielke, R. A. et al. Interactions between the atmosphere and terrestrial ecosystems: influence on weather and climate. *Glob. Change Biol.* **4**, 461–475 (1998).
168. Spracklen, D. V., Arnold, S. R. & Taylor, C. M. Observations of increased tropical rainfall preceded by air passage over forests. *Nature* **489**, 282–285 (2012).
169. Alkama, R. & Cescatti, A. Biophysical climate impacts of recent changes in global forest cover. *Science* **351**, 600–604 (2016).
170. Bathurst, J. C. et al. Forest impact on floods due to extreme rainfall and snowmelt in four Latin American environments. 1: Field data analysis. *J. Hydrol.* **400**, 281–291 (2011).
171. Barlow, J. et al. Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. *Proc. Natl Acad. Sci. USA* **104**, 18555–18560 (2007).
172. Bergeron, Y., Gauthier, S., Kafka, V., Lefort, P. & Lesieur, D. Natural fire frequency for the eastern Canadian boreal forest: consequences for sustainable forestry. *Can. J. For. Res.* **31**, 384–391 (2001).
173. Feeley, K. J. & Terborgh, J. W. The effects of herbivore density on soil nutrients and tree growth in tropical forest fragments. *Ecology* **86**, 116–124 (2005).
174. Rosin, C. & Poulsen, J. R. Hunting-induced defaunation drives increased seed predation and decreased seedling establishment of commercially important tree species in an Afrotropical forest. *For. Ecol. Manag.* **382**, 206–213 (2016).
175. Gottdenker, N. L., Streicker, D. G., Faust, C. L. & Carroll, C. R. Anthropogenic land use change and infectious diseases: a review of the evidence. *Ecohealth* **11**, 619–632 (2014).
176. Kurz, W. A., Beukema, S. J. & Apps, M. J. Carbon budget implications of the transition from natural to managed disturbance regimes in forest landscapes. *Mitig. Adapt. Strateg. Glob. Change* **2**, 405–421 (1998).
177. Lasco, R. D. et al. Carbon stocks assessment of a selectively logged dipterocarp forest and wood processing mill in the Philippines. *J. Trop. For. Sci.* **18**, 212–221 (2006).
178. Pearson, T. R. H., Brown, S. & Casarim, F. M. Carbon emissions from tropical forest degradation caused by logging. *Environ. Res. Lett.* **9**, 34017 (2014).
179. Brown, S., Casarim, F. M., Grimland, S. K. & Pearson, T. *Carbon Impacts from Selective Logging of Forests in Berau, East Kalimantan, Indonesia* Final Report to the Nature Conservancy (Winrock International, Arlington, 2011).
180. Bryan, J., Shearman, P., Ash, J. & Kirkpatrick, J. B. Impact of logging on aboveground biomass stocks in lowland rain forest, Papua New Guinea. *Ecol. Appl.* **20**, 2096–2103 (2010).
181. Fox, J. C. et al. Assessment of aboveground carbon in primary and selectively harvested tropical forest in Papua New Guinea. *Biotropica* **42**, 410–419 (2010).
182. Putz, F. E. et al. Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. *Conserv. Lett.* **5**, 296–303 (2012).
183. Dean, C. & Wardell-Johnson, G. Old-growth forests, carbon and climate change: functions and management for tall open-forests in two hotspots of temperate Australia. *Plant Biosyst.* **144**, 180–193 (2010).
184. Dean, C., Wardell-Johnson, G. W. & Kirkpatrick, J. B. Are there any circumstances in which logging primary wet-eucalypt forest will not add to the global carbon burden? *Agric. For. Meteorol.* **161**, 156–169 (2012).
185. Brown, S. et al. *Impact of Selective Logging on the Carbon Stocks of Tropical Forests: Republic of Congo as a Case Study* (Winrock International, Arlington, 2005).
186. Medjibe, V. D. P. *Carbon Dynamics in Central African Forests Managed for Timber.* PhD thesis, Univ. Florida (2012).
187. Vidal, E., West, T. A. & Putz, F. E. Recovery of biomass and merchantable timber volumes twenty years after conventional and reduced-impact logging in Amazonian Brazil. *For. Ecol. Manag.* **376**, 1–8 (2016).
188. Asner, G. P. et al. Selective logging in the Brazilian Amazon. *Science* **310**, 480–482 (2005).
189. Berenguer, E. et al. A large-scale field assessment of carbon stocks in human-modified tropical forests. *Glob. Change Biol.* **20**, 3713–3726 (2014).
190. Blanc, L. et al. Dynamics of aboveground carbon stocks in a selectively logged tropical forest. *Ecol. Appl.* **19**, 1397–1404 (2009).
191. Janisch, J. E. & Harmon, M. E. Successional changes in live and dead wood carbon stores: implications for net ecosystem productivity. *Tree Physiol.* **22**, 77–89 (2002).
192. Dirzo, R. et al. Defaunation in the Anthropocene. *Science* **345**, 401–406 (2014).

© 2018 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

193. Milner-Gulland, E. J. & Bennett, E. L. Wild meat: the bigger picture. *Trends Ecol. Evol.* **18**, 351–357 (2003).
194. Peres, C. A. & Lake, I. R. Extent of nontimber resource extraction in tropical forests: accessibility to game vertebrates by hunters in the Amazon Basin. *Conserv. Biol.* **17**, 521–535 (2003).
195. Camargo-Sanabria, A. A., Mendoza, E., Guevara, R., Martínez-Ramos, M. & Dirzo, R. Experimental defaunation of terrestrial mammalian herbivores alters tropical rainforest understorey diversity. *Proc. R. Soc. B* **282**, 20142580 (2015).
196. Galetti, M. et al. Functional extinction of birds drives rapid evolutionary changes in seed size. *Science* **340**, 1086–1090 (2013).
197. Nuñez-Iturri, G. & Howe, H. F. Bushmeat and the fate of trees with seeds dispersed by large primates in a lowland rain forest in western Amazonia. *Biotropica* **39**, 348–354 (2007).
198. Abernethy, K. A., Coad, L., Taylor, G., Lee, M. E. & Maisels, F. Extent and ecological consequences of hunting in Central African rainforests in the twenty-first century. *Phil. Trans. R. Soc. B* **368**, 20120303 (2013).
199. Blake, S., Deem, S. L., Mossimbo, E., Maisels, F. & Walsh, P. Forest elephants: tree planters of the Congo. *Biotropica* **41**, 459–468 (2009).
200. Harrison, R. D. et al. Consequences of defaunation for a tropical tree community. *Ecol. Lett.* **16**, 687–694 (2013).
201. Brodie, J. F. & Gibbs, H. K. Bushmeat hunting as climate threat. *Science* **326**, 364–365 (2009).
202. Wright, I. J. et al. Relationships among ecologically important dimensions of plant trait variation in seven neotropical forests. *Ann. Bot.* **99**, 1003–1015 (2006).
203. Osuri, A. M. et al. Contrasting effects of defaunation on aboveground carbon storage across the global tropics. *Nat. Commun.* **7**, 11351 (2016).
204. Jansen, P. A., Muller-Landau, H. C. & Wright, S. J. Bushmeat hunting and climate: an indirect link. *Science* **327**, 30 (2010).
205. Poulsen, J. R., Clark, C. J. & Palmer, T. M. Ecological erosion of an Afrotropical forest and potential consequences for tree recruitment and forest biomass. *Biol. Conserv.* **163**, 122–130 (2013).
206. van der Heijden, G. M., Powers, J. S. & Schnitzer, S. A. Lianas reduce carbon accumulation and storage in tropical forests. *Proc. Natl Acad. Sci. USA* **112**, 13267–13271 (2015).

Acknowledgements

We thank the John D. and Catherine T. MacArthur Foundation for funding this research, and C. Holtz, A. Rosenthal, B. Mackey, D. DellaSalla, C. Kormos, J. Funk, J. Feidler, S. Lewis, B. Mercer, S. Rumsey, P. Dargusch and E. Sanderson for conversations around different ideas that have been presented within this manuscript. A special thank you to B. Simmons for creating the figure in Box 2.

Author contributions

J.E.M.W. and T.E. conceived the study. The remaining authors provided ideas and critical feedback.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information is available for this paper at https://doi.org/10.1038/s41559-018-0490-x.

Reprints and permissions information is available at www.nature.com/reprints.

Correspondence and requests for materials should be addressed to J.E.M.W.

Publisher's note: Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

© 2018 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

View publication stats