Ecological Monitoring in the 21st Century: Harnessing Emerging Technologies for Tracking Changes in Maine's Ecological Reserves

Summary Report for the Maine Outdoor Heritage Fund

Moose River/No. 5 Bog Ecological Reserve

Maine Natural Areas Program
September 2011

Funding for this project has been provided by The Nature Conservancy, Maine Bureau of Parks and Lands, and Maine Outdoor Heritage Fund (Project # 101-02-12)

Table of Contents

Acknowledgements

Beginning in 2002, the Ecological Reserve Monitoring Project has been funded by a variety of sources, including the Maine Outdoor Heritage Fund, The Nature Conservancy, the Sweetwater Trust, and the Maine Bureau of Parks and Lands. The Ecological Reserves Scientific Advisory Committee (David Courtemanch, Molly Docherty, Merry Gallagher, George Jacobson, Mac Hunter, Janet McMahon, David Publicover, Sally Stockwell, Barbara Vickery, Andy Whitman, and Joe Wiley) has provided continued oversight and feedback regarding monitoring methods and analysis.

Ecological Reserves field work in 2009 and 2010 was provided by Andy Cutko, Emily Stone, Erik Walling, Gwen Koslowski, Devin Witherell and Andy McEvoy. Other MNAP staff and contractors (Molly Docherty, Lisa St. Hilaire, Emily Chase, Justin Schlawin, Shonene Scott) provided accounting support, data management, and analytical assistance. Jake Metzler of the Forest Society of Maine and Greg Miller of the Maine Forest Service provided advice on landscape components of monitoring using GIS. Andy Cutko is the principal author of this report, and Shonene Scott and Justin Schlawin contributed to the portions on landscape level monitoring.

Executive Summary

Currently just over 100,000 acres of state-owned lands are managed as Ecological Reserves, including roughly 90,000 acres owned by the Department of Conservation (DOC) and 11,000 acres owned by the Department of Inland Fisheries and Wildlife (IFW). Reserves were established in 2000 to "serve as benchmarks against which change can be measured, to protect habitat for species whose needs may not be met on managed forests, and to serve as sites for scientific research, monitoring, and education" (Public Laws of Maine, Second Regular Session of the 119th, Chapter 592). In 2002, the Ecological Reserves Scientific Advisory Committee drafted an *Ecological Reserve Monitoring Plan* that guides periodic data collection at the landscape, stand, and species levels.

This Project Update, the third since inception of the Ecological Reserves Monitoring Program, summarizes data collection and analyses conducted at three Ecological Reserves in 2009 and 2010: Moose River/No. 5 Bog (DOC), Narraguagus (IFW), and Brownfield Bog (IFW). 32 permanent plots were established on these Reserves, bringing the total number of monitoring plots on state Reserves to over 500. With this work, a key milestone has been achieved: the first round of baseline monitoring on Ecological Reserves is complete. This report also summarizes the current potential of digital imagery (e.g. land use/land cover layers created from satellite imagery) to automate landscape-scale components of long term monitoring.

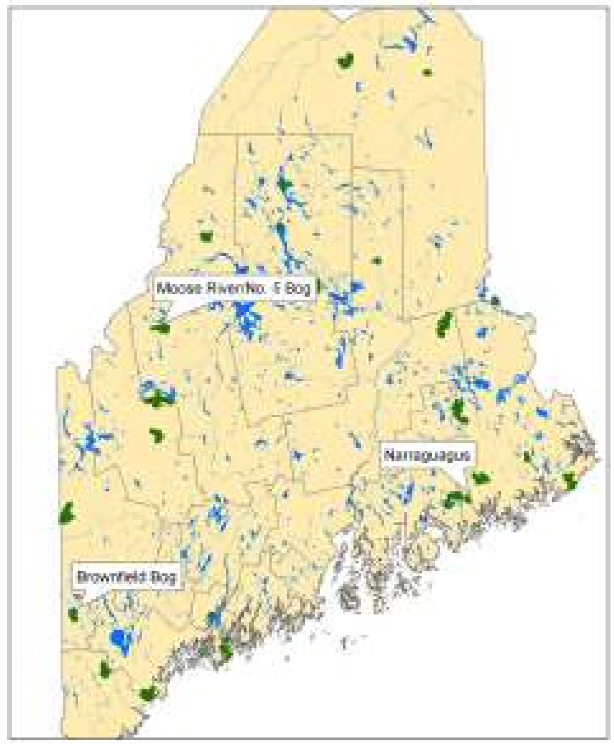

Figure 1: Maine Ecological Reserves

Data from the long term monitoring effort are assessed to compare how forest structure and processes differ between Reserves and managed forests. Although most of the forests within Ecological Reserves are younger and lacking many of the structural attributes of true 'old growth' (e.g., density of large snags downed trees) inventory data indicates that Reserves have higher stocking, more large trees and more coarse woody debris than the "average acre" of Maine woods (see MNAP 2005 and MNAP 2009). However, the uplands within the new Number 5 Bog and Narraguagus Ecological Reserves have been heavily harvested within two decades prior to state acquisition. Forest structure in these two Reserves reflects their regenerating stature: on average, Number 5 Bog and Narraguagus contain forests that are similar in age (55 years old) and canopy height (44' tall) and but are lower in stocking than the 'average acre' of Maine forest. In contrast, The Brownfield Bog Reserve supports a hardwood floodplain forest that is older, taller, and more fully stocked than Maine's forest on average. These data and others emphasize that the state's Ecological

Reserves vary in their ability to represent ‘unmanaged’ forest for ecological and forestry research.

Because the acreage of Ecological Reserves spread over a broad area and difficult to monitor on the ground, satellite imagery and related digital land use/land cover data can be valuable to automate long term landscape monitoring. One finding of this effort is that the most widely available and frequent free imagery (LandSat, with images captured every sixteen days at 30 meter X 30 meter resolution) remains insufficient for detecting small scale (<1/2 acre) changes such as the frequent tree fall gaps that occur within Reserves. However, such imagery, along with derived ‘land use change’ layers, may be effective at monitoring stand-clearing natural disturbances that occur on a larger scale within Reserves. In addition, such imagery is useful for detecting anthropogenic changes in adjoining lands, where roads and harvesting are evident. Examples of such imagery are provided in the report.

1. Stand/Natural Community Monitoring

Monitoring Plots

In 2010, 24 permanent monitoring plots were placed on the 4,597 acre Number 5 Bog Ecological Reserve (Figure 2). In 2009, five plots were placed at the 398-acre Narraguagus Reserve and three plots were placed at the 1,200 acre Brownfield Bog Reserve.

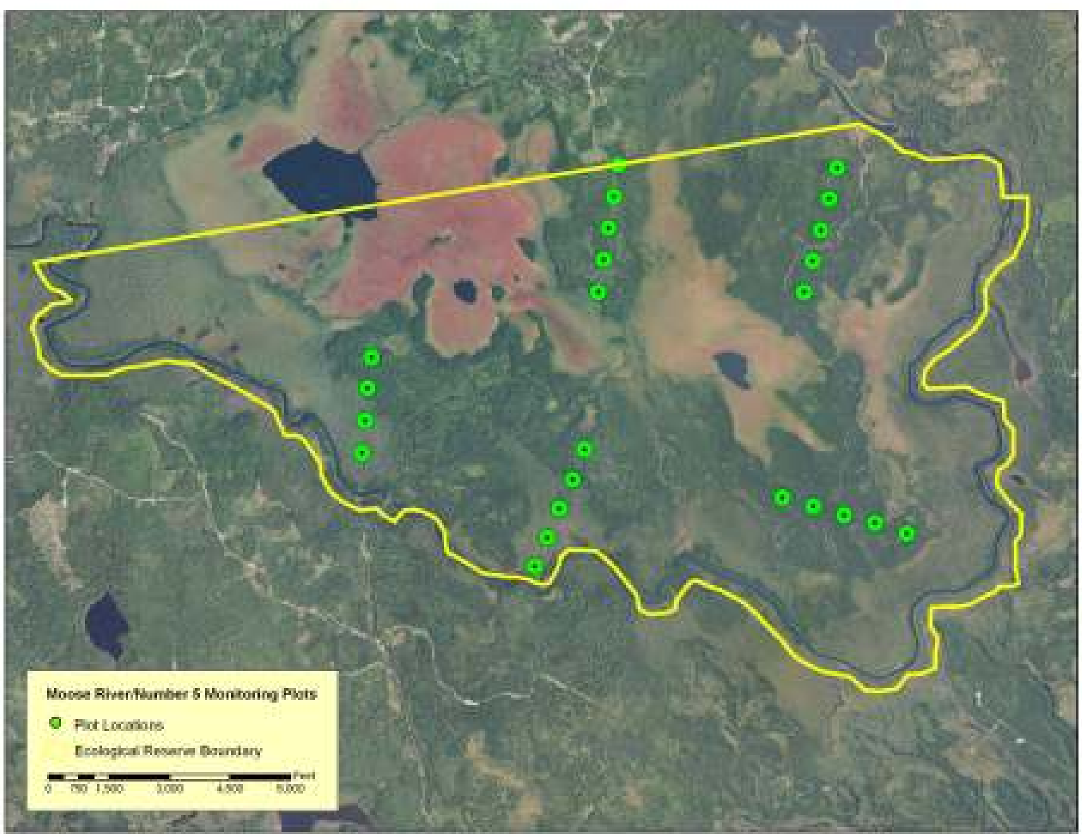

Figure 2: Location of Forest Monitoring Plots on the Moose River/No. 5 Bog Ecological Reserve

To date 487 forest monitoring plots have been placed on DOC Ecological Reserves. Overall plot density averages 1 plot/186 acres but ranges from 1 plot per 75 acres at Salmon Brook Lake to 1 plot per 345 acres at the Mahoosucs. Together with forest monitoring plots on lands managed by the Appalachian Mountain Club, The Nature Conservancy, and MDIFW, there are now over 800 permanent plots from reserves across the state – a robust dataset on which to conduct analysis.

Forest Structure

In prior analyses (Maine Natural Areas Program, 2005; Maine Natural Areas Program 2009), Ecological Reserves were shown to have older trees, higher basal areas, more large trees (live and dead), more dead trees, and more coarse woody debris than the "average acre" of Maine woods. Brownfield Bog has not been harvested in recent decades and supports a mature floodplain forest similar to others within Ecological Reserves. In contrast, data from Number 5 Bog and Narraguagus reflect their recent harvest histories. These Reserves are characterized by early to mid-successional forest, with average live basal area of 53 square feet/acre – well below the Maine average of 74 square feet/acre (K, Laustsen, personal communication 2011). Nearly all plots within these Reserves showed evidence of past harvesting.

Stand Size Classes

Stand size class is perhaps the simplest measure of forest structure. As Figure 3 illustrates, Maine's forests are divided more or less evenly between seedling/sapling, pole timber, and saw timber stages (Maine Forest Service 2005). Given its history of harvesting and fire, Number 5 Bog is weighted toward young, regenerating stands, with most plots

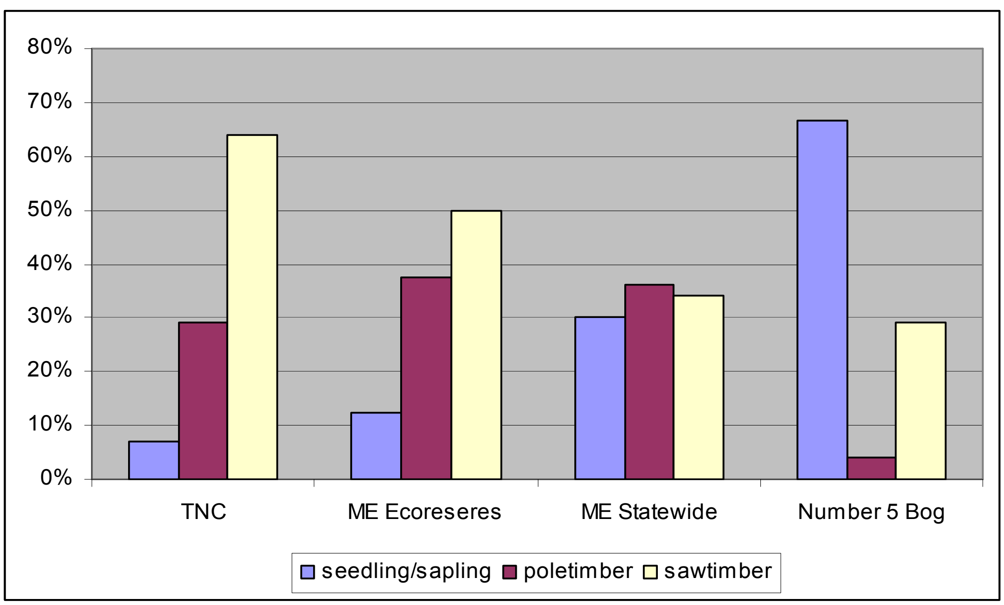

Figure 3: Comparison of stand size classes between Number 5 Bog, Maine Ecological Reserves and Maine statewide averages

falling in the seedling/sapling category. Narraguagus is not shown but indicates a similar pattern, and Brownfield Bog consists mostly of sawtimber stands. Excluding recently harvested Reserves such as Number 5 Bog and St. John Ponds, the age class distribution on Ecological Reserves is close to that hypothesized for pre-settlement forests by Lorimer (1977), Lorimer and White (2002), and others, who suggested that the majority of forest acres were in late-successional to old growth conditions. The overall Ecological Reserve size class distribution is also closer to the idealized distribution for Northeastern wildlife species proposed by Degraaf (1992).

Canopy Tree Ages

Over 430 trees have now been aged on DOC Ecological Reserves. Based on the initial data analyses, trees are younger in Ecological Reserves than in two reference cases of late successional/old growth forest (Fraver 2004, Lorimer and White 2002). Only one of the seventeen DOC Reserves (Chamberlain Lake) had a mean canopy tree age older than Big Reed Forest, Maine's best known example of old forest. Trees cored at Number 5 Bog and Narraguagus were on average younger than the mean tree age determined across the state (all private and public lands) by Maine Forest Service inventory plots, while trees cored at Brownfield Bog were older (Figure 4).

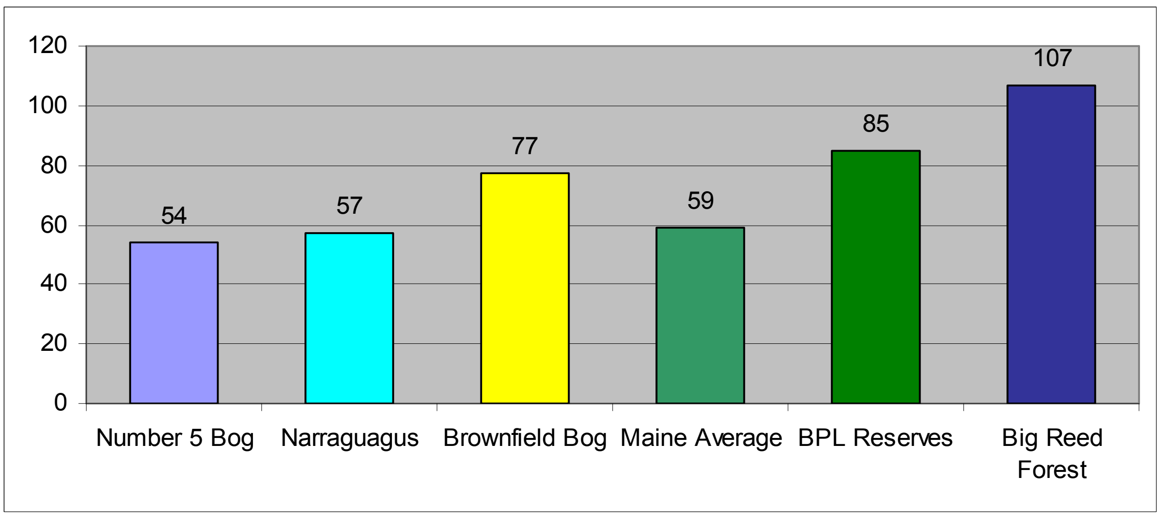

Figure 4: Mean age (years) of canopy trees cored on plots.

Numerous other metrics are appropriate for forest structure analysis (e.g., basal area, snag density, volume of large coarse woody debris), but time and funding constraints limited further analysis as part of this project.

2. Landscape Level Monitoring

The current Ecological Reserve monitoring protocol is designed to identify:

- the distribution and size of natural communities and how they change over time;
- the type, frequency, and size of major natural disturbances

- and land uses adjacent to Reserves and how they change over time.

Current protocols stipulate that natural communities are digitized from air photos and then classified using MNAP's natural community types, informed by on the ground plots. However, the manual delineation of natural community boundaries using this method is time-intensive and sensitive to different photo-interpreters. Consequently, there is an interest in using automated, remote means to improve upon the current methods and provide objective, repeatable, and reliable approaches to identify natural communities, map natural disturbances, and monitor changes over time.

Emerging geospatial and remote sensing technologies have the potential to enable complex large-scale landscape analysis and monitoring. Sophisticated classification algorithms for satellite image interpretation have been used to monitor conservation easements (Williams et al 2006, Metzler 2011), detect natural and anthropogenic forest disturbance (ex. Jin and Sader 2005, Rogan et al 2002), and classify vegetation communities (Gossman et al 1998).

New Ecological Systems Maps

As one alternative to aerial photo-interpretation, we explored the use of the NatureServe/Nature Conservancy Ecological System classification (Comer et al. 2003; Gawler et al 2008). As described in an earlier Ecological Reserves report (MNAP 2009), this classification system is a nationwide, coarse-scale vegetation classification, with approximately 40 types identified for Maine. In 2010 a map of Ecological Systems for the Northeast was produced by NatureServe, The Nature Conservancy, and the Northeast Association of Fish and Wildlife Agencies as part of the Northeast Wildlife Habitat Classification Project. In this project, the National Land Cover Dataset (NLCD, a 30-meter grid layer) was classified using thousands of ground-based plots, resulting in a region-wide GIS coverage of NatureServe's Ecological Systems (The Nature Conservancy 2011). (A similar process was undertaken by the federal LandFire Program).

Earlier investigations, using drafts of this data layer overlaid with on-the-ground plots and mapped natural community polygons, suggested that it has good accuracy (more than 80%) at depicting Ecological Systems at a coarse scale (MNAP 2009). However, more recent assessments using 2009 1-meter resolution air photos and field work results indicate the data layer is poorer at showing some fine-scaled, smaller patch natural communities (e.g., Laurentian-Acadian Calcareous Rocky Outcrop) or subtle spatial variations in matrix-forming types (e.g., hardwood patches within the Acadian Low-Elevation Spruce-Fir-Hardwood Forest). In addition, it is unclear whether the dataset will be repeated in the future, raising questions about its utility for long term monitoring.

LandSat Imagery

The oldest collection of satellite imagery in the US is the LandSat program, with imagery dating back to 1972. Early imagery had maximum spatial resolution of 30 meters (0.22 acres), but newer imagery is captured every 16 days by LandSat 5 and LandSat 7 and has a 15 meter maximum resolution. LandSat is free and widely available. Similar in resolution to the Ecological Systems maps discussed above, this imagery is fairly coarse scale for detailed ecological assessment. However, because it is repeated every 16 days, it offers a potentially useful method to track landscape change over time.

Summer LandSat imagery is excellent for distinguishing recently disturbed areas and hardwood vs. softwood forest. This imagery may also be used to determine where current timber harvesting activity is occurring (though this is not applicable to Ecological Reserves) or where wind storms or fire have created large, stand-clearing patch disturbances (several acres or more), as well as approximate boundaries of different natural community types. Color signatures quickly change over time as bare ground succeeds to shrubs and brush, and then to forest. As a result, there is potential to track timing of disturbance of larger scale events through the periodic review of accumulated imagery.

Based on a number of tests with LandSat imagery, one key finding is that both data sources are insufficient for detecting small scale (<1/2 acre) changes such as the frequent tree fall gaps or smaller beaver impoundments that occur within Reserves. Given its scale limitations, LandSat imagery is probably most useful in managed forests and in areas with large-scale natural disturbance. In this regard, LandSat may be used to quantify forest cover and forest change in a ½ mile zone adjacent to Ecological Reserves (see discussion on page 10). To quantify forest cover types, the imagery needs to be manipulated because it is captured in several disparate color bands. Interpreting this imagery is fairly straightforward, but there are subtle differences in color that can be used to distinguish similar forest types and young from old forest. Figure 5 is a sample image, with descriptions for how to interpret the different color bands.

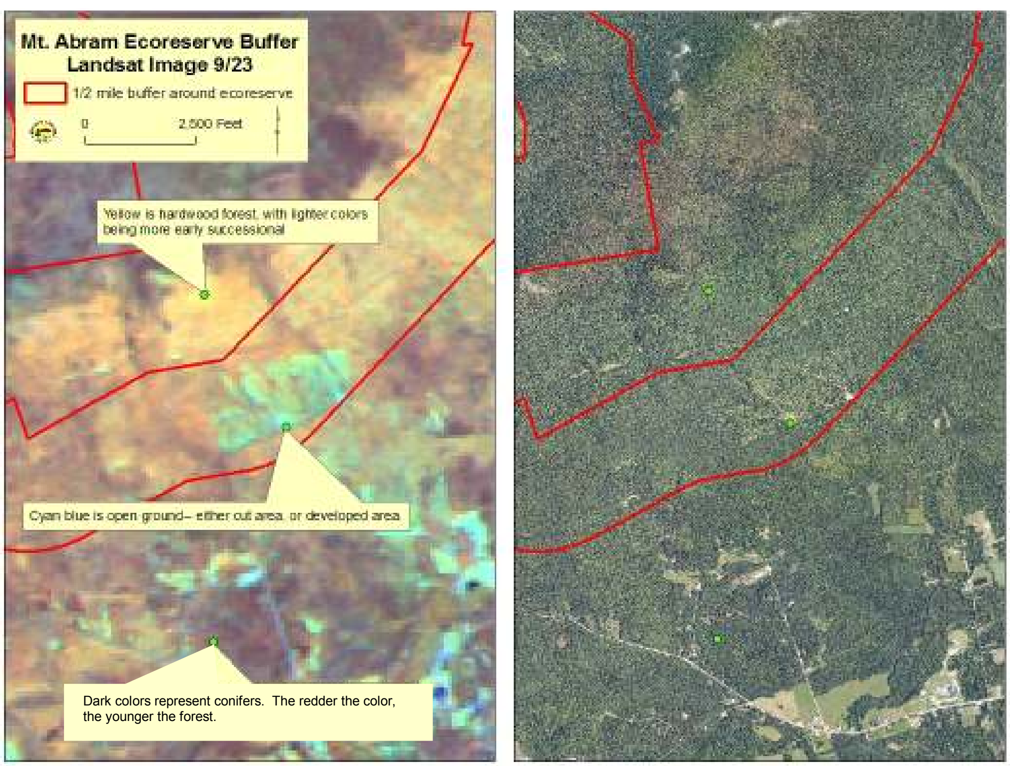

Figure 5: 2009 LandSat imagery and 2009 true color digital air photos of the perimeter of the Mt. Abraham Ecological Reserve.

Change detection (an analytical approach which quantifies change between multiple photo dates), requires additional manipulation of a temporal series of data. Change detection techniques have potential to identify and quantify large scale natural disturbances (as in large conservation easements) but are subject to the same scale limitations as the underlying data.

There are several commercially available options for land cover imagery at higher resolution. The images have various costs (unlike LandSat, which is free) and would have to be purchased for the areas and years of interest. The same change detection algorithm used on the LandSat images could potentially be used on these images. Funding and staff limitations prevented the exploration of these options any further.

- GeoEye's IKONOS, available every 3 to 5 days, 1 meter (panchromatic, or black and white) and 4 meter multispectral resolution
- DigitalGlobe's QuickBird (sub-meter panchromatic and 2.4 meter multispectral)
- Spot (resolution ranging from 2.5 meter to 10 meter)

Monitoring Land Uses

The following land uses and roads have been mapped within ½ mile of the DOC Ecological Reserves during 2009 by digitizing information from NAIP areal photography.

- Mileage of paved roads
- Mileage of dirt roads
- Mileage of paved or dirt roads forming boundary
- Acreage of early regeneration
- Acreage of mature forest
- Acreage of conservation land (including easements)
- Acreage of agricultural land
- Number of structures

While many of the DOC Reserves are well embedded within conservation lands, others such as Great Heath are virtually surrounded (96%) by private lands. Nearly all DOC Reserves are abutted by mid-successional to mature forest. Even Great Heath, with the least amount of adjoining conservation land, has over 85 percent of its buffer in mid-successional forested condition (typically at least pole-size forest). The Number 5 Bog Reserve is mostly surrounded by water or conservation lands with a slightly lower road density than the average Reserve buffers (Table 1).

This manual approach to data collection lends itself to subjectivity and variation among individuals digitizing the data when mapping features such as early regeneration vs. mature forest. As a result, MNAP has explored the use of satellite imagery as a more objective method of tracking landscape change both within Ecological Reserves and in adjacent lands. Satellite imagery offers a more reliable, repeatable, and objective method for quantifying larger scale land uses and land use changes. Some of this landcover change data collected using this tool is presented in Table 1

Table 1: Land uses within ½ mile of perimeter of selected Ecological Reserves:

Landscape Metric	No. 5 Bog	Mean of All Reserves
Adjacent Road Density (miles/sq. mile)	0.78	0.92
1991 open uplands in adjacent lands (recently harvested areas, agriculture, bare ground) (acres, %)	858.0 (14.1%)	593.6 (10.0%)
Land cover change detection in adjacent lands 1996-2001 (acres; %)	267.0 (4.4%),	164.5 (2.5%)
Land cover change detection in adjacent lands 2001-2006 (acres, %)	210.0 (3.5%)	51.9 (0.8%)
% Conservation land or water in adjacent lands	93.0%	61.5%
Forest or Water in adjacent lands, 2011 (%)	93.0%	88.8%

1. "Protected land" includes both fee ownership and conservation easements.

3. Other Analyses

Significant effort, staff time, and Scientific Advisory Committee deliberatons in 2010 and 2011 were dedicated to continuing the 'representational analysis' of Maine's Ecological Reserves. These continuing efforts attempt to address the question, "How well do Maine's Ecological Reserves represent the state's landscape in terms of ecological systems (vegetation types), ecological land units (enduring features such as bedrock geology), and aquatic features?" Such analyses have focused on both state Ecological Reserves as well as the broader set of Maine's conservation lands, including working forest and 'reserve' like lands (e.g., Acadia National Park).

Initial GIS analyses indicate that the Maine's ecological land units and ecological Systems are well represented (>80%) on state conservation lands – on a strict 'pixel by pixel' (acre by acre) basis. However, subsequent analyses that incorporated minimum viable patch size (acreage) for ecological land units and ecological systems showed representation to be much poorer – roughly 37% for all 'fee' conservation lands and 20% for 'Reserve' status lands. In particular, southern Maine and the Aroostook Hills and Lowlands have poor representation. Because these analyses were not part of this particular funding grant, this report does not describe the results of those analyses in detail.

4. Literature Cited

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.

DeGraaf, R. 1992. New England wildlife: Management of forested habitats. USDA Forest Service, Northeast Forest Experiment Station.

Fraver, S. 2004. Spatial and temporal patterns of natural disturbance in old-growth forests of northern Maine, USA. PhD. dissertation. University of Maine, Orono, ME. 185 pp.

Gawler, S., Anderson, M., Olivero, A., and M. Clark. 2008. The Northeast Habitat Classification and Mapping Project: Final Report. NatureServe, The Nature Conservancy, and The Northeast Association of Fish and Wildlife Agencies.

Grossman, D. H., D. Faber-Langendoen, A. S. Weakley, M. Anderson, P. Bourgeron, R. Crawford, K. Goodin, S. Landaal, K. Metzler, K. D. Patterson, M. Pyne, M. Reid, and L. Sneddon. 1998. International classification of ecological communities: terrestrial vegetation of the United States. Volume I. The National Vegetation Classification System: development, status, and applications. The Nature Conservancy, Arlington, Virginia, USA.

Jin, S., and S.A. Sader. 2005. MODIS time-series imagery for forest disturbance detection and quantification of patch size effects. Remote Sensing of Environment 99(4): 462-470.

Laustsen, K.M., Maine Forest Service, personal communication September, 2011.

Lorimer, C.G., 1977. The presettlement forest and natural disturbance cycle of northeastern Maine. Ecology 58, 139–148.

Lorimer, C., and A. White 2002. 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 (2003) 41–64.

Maine Forest Service, 2005. The 2005 Biennial Report on the State of the Forest and Progress Report on Forest Sustainability Standards Report to the Joint Standing Committee of the 122nd Legislature on Agriculture, Conservation and Forestry.

Maine Natural Areas Program. 2003. Ecological Reserve Monitoring Plan. Maine Department of Conservation. 26 pp.

Maine Natural Areas Program. 2005. Ecological Reserve Monitoring Project Update. Maine Department of Conservation, Augusta.

Maine Natural Areas Program. 2009. Ecological Reserve Monitoring: Summary Report for the Maine Outdoor Heritage Fund and The Nature Conservancy. Maine Department of Conservation, Augusta.

Metzler, J. 2011. Forest Society of Maine. personal communications August 2011.

Rogan, J., Franklin, J., & Roberts, D. A. (2002). A comparison of methods for monitoring multitemporal vegetation change using Thematic Mapper imagery. *Remote Sensing of Environment*, 80, 143–156.

Sader, S., Hoppus, M., Metzler, J., and S. Jin. 2005. Perspectives of Maine Forest Cover Change from LandSat Imagery and Forest Inventory Analysis (FIA). *Journal of Forestry*. 103 (6): 299-303.

The Nature Conservancy. 2011. Northeast Wildlife Habitat Classification Project. http://conserveonline.org/workspaces/ecs/documents/ne-terrestrial-habitat-mapping-project

Williams, K., S.A. Sader, C. Pryor, and F. Reed. 2006. Application of geospatial technology to monitor forest legacy conservation easements. *Journal of Forestry* 104 (2):89-93.

5. Budget Summary for MOHF

Expenses		
Personnel		
	Data Management	$3,398.67
	Field Work	$3,876.79
	Financial Management	$247.42
	GIS Services	$5,918.83
	Presentation	$375.17
	Project Meeting	$1,771.61
	Project Planning	$250.09
	Project Report	$125.06
	Research	$541.86
	Technical Assistance	$184.89
	Technical Material	$4,438.36
	Personnel Benefits	$2,994.90
	Total Personnel	**$24,123.65**
All Other		
	Professional Fees (Field Intern)	$317.52
	Mileage	$41.12
	Rent State Vehicle	$280.93
	Total All Other	**$639.57**
Total Project Expenses		**$24,763.22**
Revenue Received		
MOHF	**102-02-12**	$19,919.00
BPL	**MOA Calendar 2010**	$4,844.22
Total Project Revenue		**$24,763.22**

Project Balance	**$0.00**