1. INTRODUCTION

Freshwater ecosystems are an integral part of Maine's landscape diversity. Approximately 10% of Maine's surface area is covered by freshwaters – lakes, ponds, rivers, streams and wetlands. Diversity among Maine's lakes is truly impressive. In terms of size, they range from large, deep bodies of water, like Sebago and Moosehead lakes, to the many thousands of shallow ponds less than ten acres. In addition to the spectrum of lake sizes, lake types range from high elevation ponds of western Maine, to the acidic, bog ponds of Washington County and a series of high alkalinity ponds found in Aroostook County and southern Maine. There are hydrologically isolated ponds, remote ponds, flood-plain ponds and a large number of impounded ponds and lakes. Some impounded lakes are completely artificial systems, whereas others are natural waterbodies that have been enlarged by damming.

The diversity among the flowing waters of Maine is similarly impressive, ranging from large river systems like the Kennebec and Penobscot Rivers to tens of thousands of miles of small streams. Many of the State's lakes and streams are fringed with wetland habitat. In addition, extensive freshwater wetlands also characterize several regions of Maine. Many lower elevation rivers have extensive flood plains.

Topography, climate, geology, soils, and current and past land-use all contribute to the diversity of Maine's freshwater systems. Many currently-forested regions of the state have been logged in the past. Logging history may continue to influence streams in ways that we do not fully understand. Since the 1700s, many thousands of dams and other barriers have been built across rivers and streams. While many of these no longer exist (many of the old logging dams, for example), other dams continue as a significant factor affecting aquatic biodiversity. In recent years, some large dams have been removed, and future years will likely see additional removals. This process presents great restoration opportunities for a number of Maine's river systems.

Water quality in many of Maine's principal rivers has improved substantially over the past thirty years as a result of legislation and changes in the industrial landscape. However, urban development, industry, agriculture, and other forms of land management continue to have significant impacts on freshwater systems and their biodiversity. In addition, Maine's freshwater ecosystems are influenced by contaminants brought into the state via atmospheric transport.

A broad review of status and trends in Maine's biodiversity (Gawler et al. 1996) underscored the fact that little was known about many components of freshwater ecosystems. Furthermore, much the information that did exist was dispersed and in a relatively unavailable format. The Maine Aquatic Biodiversity Project (MABP) is an outgrowth from the 1994-1998 Maine Forest Biodiversity Project. The over-arching goal of MABP was to review and evaluate the current knowledge base for Maine's freshwater flora and fauna. Key issues addressed by MABP are:

- What plant and animal species inhabit lakes and streams in Maine, and where are they found?
- What are the geographic patterns in biodiversity across the state?
- How much do we know about the composition of assemblages of species in lakes and streams? How are these assemblages associated with landscape-level ecosystem attributes?
- How do biological communities in key lake and stream types vary across different regions of the state?
- How much is known about the extent to which freshwater communities are changing / have changed through time?
- What are the key threats confronting freshwater biodiversity in Maine? What information exists to document the impacts of these threats?
- Where are major data gaps?

- What is an effective approach for sharing with a broader audience the biodiversity data accessed by MABP?

MABP was spearheaded by The Nature Conservancy, the Department of Environmental Protection and the Department of Inland Fisheries and Wildlife, with additional funding coming from the Maine Outdoor Heritage Fund and the Atlantic Salmon Commission. The project focused on lakes and streams, and on the following taxonomic groups: (i) vascular aquatic plants, (ii) macro-invertebrates, (iii) fish, and (iv) amphibians and reptiles. Wetlands and estuaries were excluded from MABP. While wetlands and estuaries are clearly integral to the functioning of many freshwater ecosystems and species assemblages, the decision to exclude them from the project was based on practical considerations (i.e. availability of time and resources). Mammals and birds associated with freshwater systems also were not covered by MABP. Similarly, micro-invertebrates (e.g. plankton) were not included.

MABP was coordinated by a steering committee composed of representatives from The Nature Conservancy, several state agencies and the University of Maine. The project collected no new field data, but instead focused entirely on existing data resources. These data resources included previously published data (many of which were digitized during this project), as well as data from on-going or recently completed monitoring and survey programs. Most of the data were compiled in a single database – an effort that was essential in view of the extremely heterogeneous nature of the data. Two workshops were organized as part of MABP, the first occurring in 2000, just before the project got underway, and the second in 2002. These workshops provided forums for soliciting information and discussions of regional patterns in freshwater biodiversity.

Structure of this report: This report is organized in two major sections. Part 1 provides a series of overview chapters that focus on: Maine's freshwater landscape (Chapter 2), freshwater biodiversity (Chapter 3), and threats to freshwater systems (Chapter 4). Part 2 provides a more in-depth presentation of data and analyses on each of the major taxonomic groups covered in MABP (Chapter 6). This presentation is preceded by a general discussion (Chapter 5) about the information resources tapped by MABP – a topic that is essential to fully interpret the data themselves. Additional information about specific resources used for specific taxonomic groups is included in the appropriate sections of Chapter 6. The final chapter (Chapter 7) provides an introduction to a series of analyses conducted collaboratively with The Nature Conservancy that evaluate the extent to which various regionalizations (stratification frameworks) are able to capture spatial variation in a number of biological and physico-chemical attributes of aquatic ecosystems and watersheds.

While all chapters are clearly inter-related, individual chapters are intended as relatively stand-alone documents. Readers interested in an introductory view of Maine's freshwater ecosystems and their biodiversity should focus on Part 1. Those interested in learning more about individual taxonomic groups, should focus on Part 2. Individuals who would like to work with the compiled data should consider data files presented in the appendices. Throughout the report, we attempt to provide a concise review of related scientific literature. In general, the articles and reports we cite are Maine-focused, and are not intended to provide in-depth background syntheses for each topic being presented.

PART 1

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Maine's Freshwater Landscape

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Freshwater Species and Ecosystems: An Overview

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Management and Conservation of Freshwater Ecosystems: Threats and Challenges

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2. MAINE'S FRESHWATER LANDSCAPE

2.1 Major River Basins of Maine: An Overview

Maine's freshwater ecosystems are within six major river basins and the watersheds of a series of smaller coastal rivers that drain into the Gulf of Maine. The Penobscot is the largest river basin entirely within the State. Together, the Penobscot and Kennebec Rivers drain almost half the total area of Maine.

St. John River: This river drains the northern third of the state (Figure 2.1). This basin comprises the Upper St. John River (including the Allagash and Fish Rivers) and three smaller rivers that enter the mainstem of the St. John in Canada (Aroostook, Meduxnekeag and Prestile Rivers). There is a strong contrast between the eastern half of the basin, which has considerable agriculture, and the western half, which is largely forested. The last obstruction to fish migration on the mainstem of the St. John River is at Grand Falls in New Brunswick (see Chapter 4 for additional information on dams). The approximately 250 miles of unobstructed river above Grand Falls is the longest free-flowing stretch of river east of the Mississippi (Baum 1982a). Compared to other regions of Maine, there are relatively fewer lakes in the Upper St. John River basin. One result of this is that the river tends to be more 'flashy' than other large rivers of Maine – fewer lakes provide less water storage, with the result that river flows respond more rapidly to precipitation events.

Penobscot River: Draining approximately 8,750 square miles, the Penobscot consists of five major sub-basins: the West and East Branches, Piscataquis, Mattawamkeag and the lower Penobscot (Figure 2.1). The main river drops 231 feet between the confluence of the West and East Branches in Brownville and Bangor. While much of the basin is forested, the northeastern section is more agricultural. Extensive wetland systems characterize much of the Mattawamkeag drainage. The Penobscot Estuary is about 32 miles long from head of tide to Searsport, and the tidal basin is shallow with a mean depth of about 29 feet at mean sea level (Baum 1983). There are currently seven main-stem dams on the lower Penobscot River, including the Stillwater branch. Current proposals for dam removal, fishway modification and operational changes hold the promise of substantial changes in the Penobscot River system. Currently, there is little, if any, passage beyond Veazie by most diadromous species: shad, alewife, smelt, blueback herring, striped bass, sturgeon, and tomcod. There is passage by Atlantic salmon. Water quality has improved remarkably in the Penobscot River over the last two decades.

St. Croix River: This river drains approximately 1,500 square miles, part of which (primarily the East Branch) is in New Brunswick. The West Branch drains parts of Washington, Hancock and Penobscot Counties and consists almost entirely of large lakes separated by short, inundated thoroughfares (Fletcher and Meister, 1982). The river descends 374 feet from Vanceboro to head of tide at Calais and has six main-stem dams. The lower portion of the river is influenced by a pulp and paper mill in Woodland (Davies et al. 1999). The watershed is sparsely populated and almost entirely forested..

Kennebec River: With its source at Moosehead Lake, the Kennebec drains 5,893 square miles. The river descends about 1,000 feet over a distance of 129 miles between Moosehead Lake and Augusta (Foye et al., 1969). Major tributaries are the Dead, Carrabassett, Sandy and Sebasticook Rivers and Messalonskee Stream. The Kennebec, like many other rivers in the state, had many water quality problems until the late 1970s, stemming from pulp and paper mills, tanneries, dairy and potato processing, and other industries (Davies et al. 1999). Conditions improved substantially following implementation of the Clean Water Act and changes in the industrial landscape. Until it was removed in 1999, the Edwards Dam at Augusta had a "devastating" impact on the fisheries of the Kennebec because it obstructed fish passage upstream to spawning grounds (Foye et al., 1969). Now, the full suite of anadromous fishes have access from head of tide to Waterville. Above this point, eleven major dams currently obstruct fish passage. Water quality of the Kennebec River has improved remarkably in the last two decades.

Androscoggin River: Extending from Umbagog Lake to Merrymeeting Bay, the Androscoggin River flows over 161 miles through a drainage that covers 3,460 square miles (2,750 of which are in Maine). Hydrology is highly altered by 15 main-stem dams and over 100 dams throughout the rest of the basin (Davies et al. 1999). The river has been the "victim of man's abuse" (DeRoche 1967), with extensive industrial pollution and destruction of fish habitat. Substantial improvements in water quality have occurred over the past 30 years, but dams remain a problem despite improvements in fish passage facilities, as do industrial discharges.

Saco River: Straddling the interstate line, about half of the Saco River basin is in Maine (ca. 827 square miles). Many dams obstruct fish migration and inundate most of the coldwater habitat in the drainage (Dube 1983). The upper part of the Saco basin is relatively rich in lakes and wetlands and represents a transition area between the lowlands of southern Maine and the foothills of the western part of the state. This lowland area is also rich in groundwater aquifers.

Salmon Falls / Piscataqua River: Also an interstate water, the Piscataqua is the tidal portion of the Salmon Falls River. Just over half the drainage is in New Hampshire. The lower section of the Salmon Falls is impounded by a series of four dams and water quality problems persist in the lower parts of the river and the Piscataqua River estuary (MDEP 2004).

Coastal Rivers: Maine's coastal region is drained by a series of smaller rivers, including the Presumpscot, St. George, Sheepscot and Union Rivers and the rivers of Downeast Maine (including the Narraguagus, Pleasant, Machias, East Machias and Dennys). Background information on many of these is available in a series of publications by the Atlantic Salmon Commission (Meister 1982, Baum 1982b, Beland et al. 1982, Fletcher et al.1982, Baum and Jordan 1982). On the Presumpscot River, negotiations relating to dam re-licensing are currently underway. Although each of these coastal drainages is distinct in a number of ways, there is a major division between the rivers west and east of Penobscot Bay. Rivers to the east tend to be more acidic (Johnson and Kahl, 2005), with higher percentages of their watersheds in wetlands. The Sheepscot River and Cove Brook, a small tributary of the Penobscot, and the Downeast rivers are designated as containing the Atlantic Salmon Distinct Population Segment.

The Maine Rivers Study (MDOC 1982) identified the following relatively large watersheds as having "… high significance as undeveloped and interdependent hydrologic units. These sub-basins are characterized by a general lack of major artificial river impoundments, minimal river corridor development, a high degree of hydrologic and ecologic interdependence, and a consistency of resource quality among all segments" (MDOC 1982):

- Upper St. John watershed, including the NW, SW and Baker Branches.
- Allagash watershed.
- Fish River watershed, including the Fish Lakes Chain.
- Aroostook and Big Machias watershed above Sheridan.
- East Branch of the Penobscot watershed, including the Seboeis River and Wassataquoik Stream.

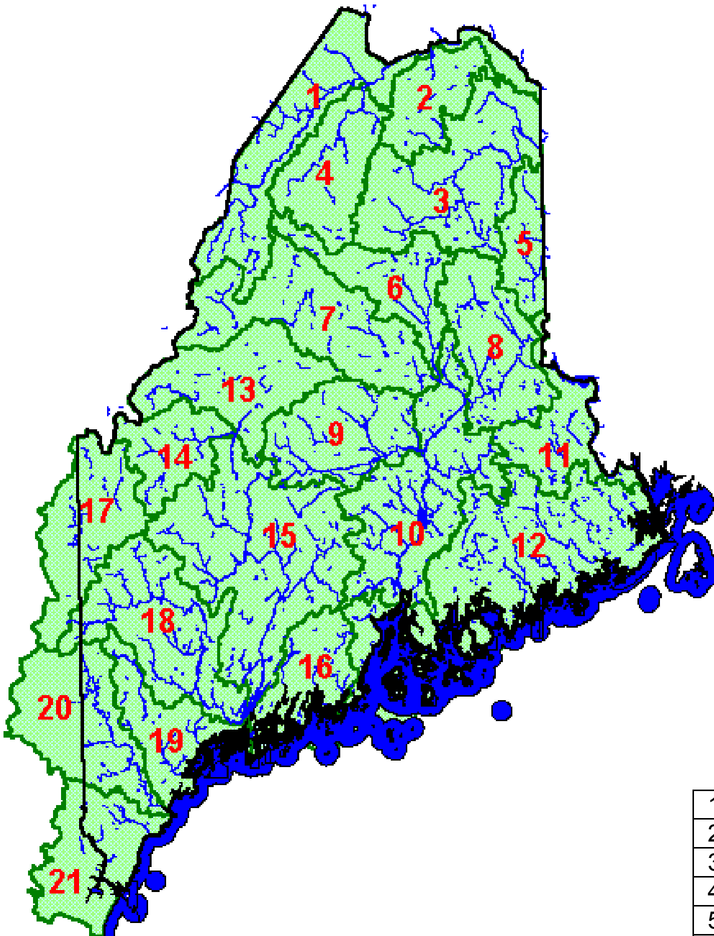
- Mattawamkeag watershed.
- Machias River watershed in Washington County.

Many of the information summaries in this report are based on watersheds and aggregations of watersheds. We use a series of three nested watershed layers, designated as HUC-8, HUC-10 and HUC-12 (HUC stands for Hydrologic Unit Code, a USGS system for coding drainages across the U.S.; these units are here simply termed HUCs). The drainage basins shown in Figure 2.1 are HUC-8s. Most of the HUC-8 drainages range between 500 and 3,000 square miles, whereas the medium-scale drainages (HUC-10) are primarily between 100 and 300 square miles (Figure 2.2). HUC-12 watersheds are in the tens of square miles range[1].
Aggregation of HUC-10 watersheds produced the six regions depicted in Figure 2.3[2].

Two other stratification frameworks for Maine are also shown in Figure 2.3: The Nature Conservancy's (TNC) Ecological Drainage Units (EDUs) and McMahon's (1990) biophysical regions. The EDU's are part of a national-level stratification system in which HUC-10 watersheds are aggregated on the basis of broad patterns of hydrography, landform and zoogeography (similar to TNC's aquatic ecoregions). McMahon's biophysical regions are based on climate variables, topography and soil characteristics, with the additional input from terrestrial vegetation community structure. Along with the HUC-10 based "systems" discussed in Chapter 7, these stratification frameworks are useful approaches for 'dividing up' the state and analyzing patterns of biodiversity and other aspects of the Maine environment. Chapter 7 presents an evaluation of these different stratification frameworks.

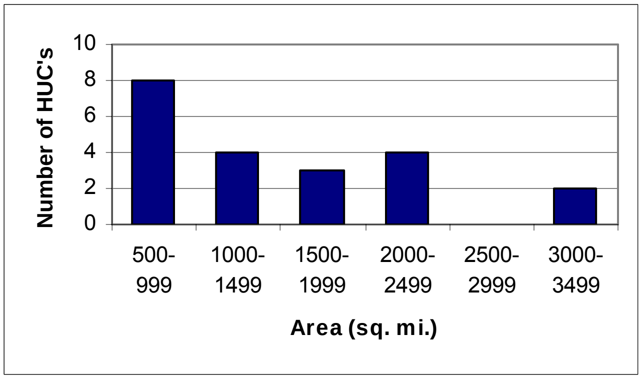
[1] Many HUCs are not true watersheds, i.e. water enters them from adjacent HUCs (Omernik 2003, Omernik and Bailey 1997). However, because they are readily available as GIS coverages and they are nested, they provide a useful stratification framework. None of the analyses presented in the report that are based on HUCs are affected by the fact that some of these units are not true watersheds.

[2] Chapter 7 provides information on how the regions were derived from a statistical clustering of HUC-10 watersheds.

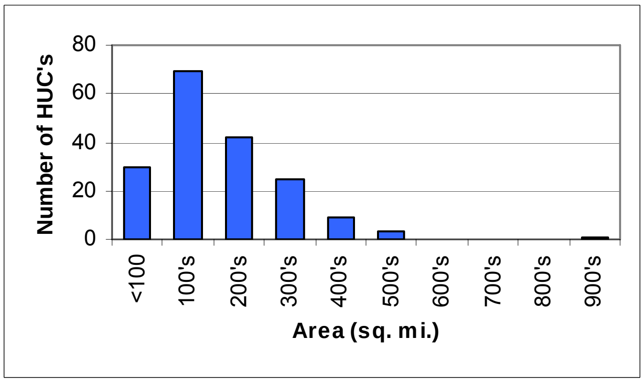


1	Upper St. John
2	Fish
3	Aroostook
4	Allagash
5	Meduxnekeag
6	Penobscot – East Branch
7	Penobscot – West Branch
8	Mattawamkeag
9	Piscataquis
10	Penobscot - Lower
11	St. Croix
12	Downeast - coastal
13	Kennebec – Upper
14	Dead
15	Kennebec - Lower
16	St. George - Sheepscot
17	Androscoggin - Upper
18	Androscoggin - Lower
19	Presumpscot
20	Saco
21	Piscataqua – Salmon Falls

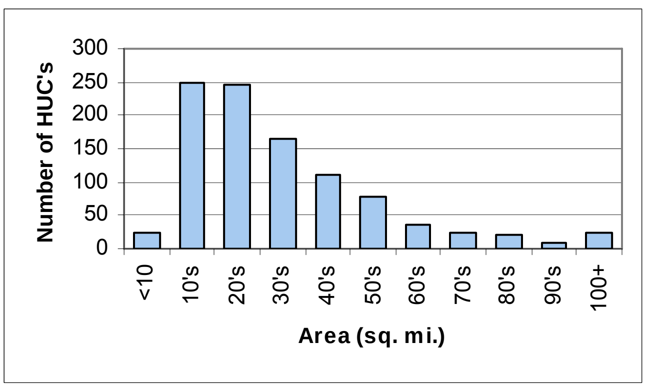
Figure 2.1: Major drainage basins and rivers in Maine.
Watersheds are 8-digit Hydrologic Unit Codes (HUCs). Note that although the HUCs shown here do not extend into Canada, the actual watersheds do.



HUC-8

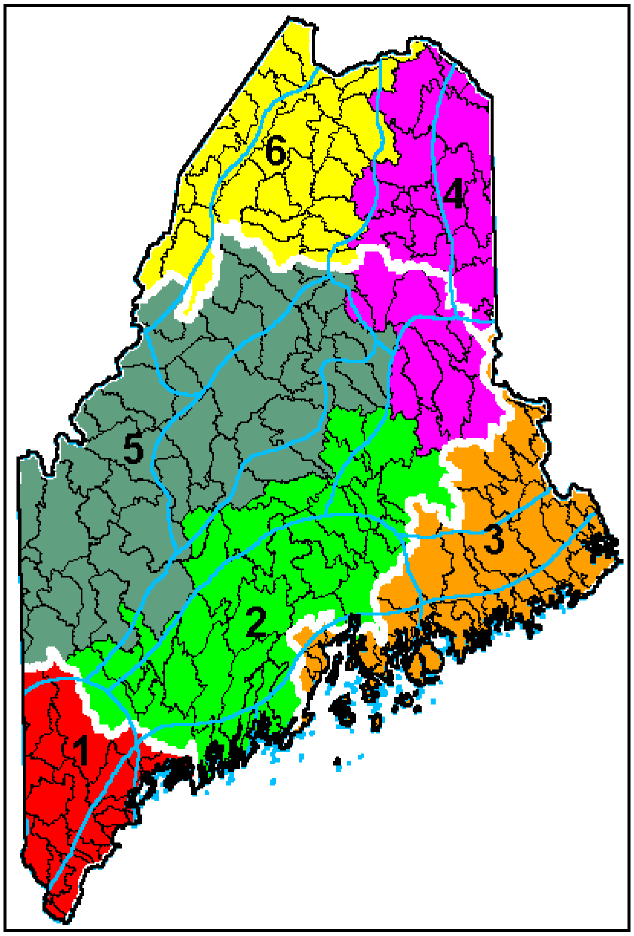


HUC-10

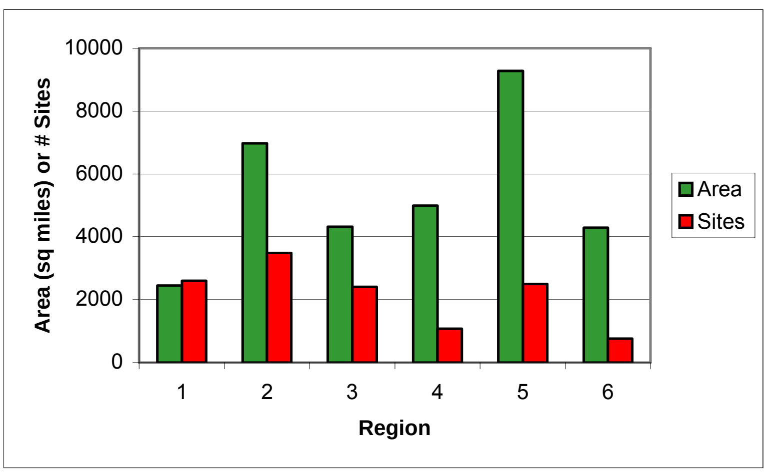


HUC-12

Figure 2.2: Size frequency distributions of three scales of watersheds in Maine. All watersheds within or intersecting Maine are included in these distributions. For watersheds straddling the state border, the area of the entire watershed is used for this analysis. Of the three scales, HUC-10 watersheds are used most frequently in this report for data summaries.



(A)



(B)

Figure 2.3: Regions of Maine, with one measure of sampling effort for biodiversity information.
(A) Regions are based on aggregations of GIS-derived watershed clusters based on elevation, geology and landform (see Chapter 7 for more information on methodology used to derive clusters). White lines denote TNC's Ecological Drainage Units. Blue lines indicate McMahon's biophysical regions.
(B) Area (sq. miles) and total number of sampling sites in the MABP database, by region.

2.2 Lakes and Ponds

Maine's lakes and ponds cover about 4.4% of the state's area (Table 2.1A). There are 6,035 lakes and ponds that are recognized in the MIDAS coding system[3]. About 55% of these are < 10 acres surface area. "Great Ponds" are lakes 10 acres and larger; they represent about 45% of MIDAS-coded lakes. Great Ponds is a legal designation in which the water and submerged area is the property of the State. The MIDAS system, however, fails to include many ponds smaller than 10 acres. This is illustrated by analysis of the GIS coverage for lakes and ponds in Maine (MDEP, 12/2003 version). The coverage contains a total of over 33,000 surface water features (Table 2.1B). Most of these are very small and many are probably not even true ponds, but rather wetlands or incorrectly assigned land features. Nevertheless, many of the GIS features are true ponds. Under the GIS system, waterbodies one acres or smaller comprise about 70% of the total number (Table 2.1B), whereas for MIDAS-numbered lakes this total is 13%.

In terms of total lake area, the under-accounting of small ponds is relatively insignificant. For example, the 2,314 lakes designated by MDEP as being "significant" [4] make up about 97% of total lake acreage (Table 2.1A; MDEP 2004). However, the smaller ponds are important in terms of biodiversity and habitat connectivity.

Note that while ponds are generally considered to be small lakes, the terms are used interchangeably in this report. In terms of lake names, there are no convenient distinctions between "lake" and "pond". Forty two so-called ponds in Maine are over 1000 acres, while 469 are between 100 acres and 999 acres.

MDEP assesses the trophic state (level of productivity) of Maine's lakes and ponds. Of the 2,314 "significant" lakes, 1,740 have been assessed as of 2004 (MDEP 2004). Of these, 7% are considered oligotrophic (low productivity), 59% mesotrophic, and 34% eutrophic (high productivity). None of Maine's assessed lakes are hypereutrophic, and 0.1% are classified as dystrophic (highly colored because of organic acids). These data did not come from a statistically-derived sample of the state's lakes, so care should be taken in interpreting the information. The USEPA's Environmental Monitoring and Assessment Program (EMAP) did sample a "random" collection of lakes. From those data, 37% of lakes in upland regions of New England (which includes much of western and northern Maine) were estimated to be oligotrophic, 51% mesotrophic, and 12% eutrophic (Whittier et al., 2002). For lakes in the lowlands region of New England (which includes southern and much of the central region of Maine), equivalent numbers were 14%, 39%, and 47%.

The most frequently-collected water quality parameter for Maine lakes is Secchi depth, which measures water transparency. Secchi depth in most Maine lakes (at least, those that have been surveyed) is between 3 and 5 meters (Figure 2.4 A, B). There is no obvious regional pattern in the distribution of transparent and turbid lakes – waterbodies with a broad range of transparencies are found throughout the state. Phytoplankton density, non-biological turbidity (sediments) and water color (from dissolved organic acids) all can influence water transparency. When these components are taken into account, some regional patterns in lake type become evident. Using MDEP data on chlorophyll concentrations and water color, we assigned lakes to four classes: "blue", "green", "brown" and "turbid". Blue lakes have low chlorophyll concentrations and low color; green lakes have higher chlorophyll and low color; brown lakes have low chlorophyll and high color; and turbid lakes have high chlorophyll and color. The spatial distribution of these lake classes is shown in Figure 2.4 C. Green lakes tend to be concentrated

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[3] MIDAS codes have been assigned to all Great Ponds (lakes greater than 10 acres) and a limited number of smaller ponds.

[4] Significant lakes are defined by MDEP as publicly-owned lakes for which bathymetric surveys exist or vulnerability modeling has been performed or some trophic data gathered. These are the lakes that the State is most interested in managing.

in central and eastern sections of the state, while blue and brown lakes are distributed statewide. There are relatively few highly turbid lakes; these are found in south, central and northeast Maine.

Maine's deepest lake is Sebago, with maximum and average depths of 316 and 107 feet, respectively. Moosehead is the second deepest lake in the state with a maximum depth of 246 feet. Statewide, there is a tendency for lakes over 100 acres surface area to be shallower at lower elevations (< 1000 feet) than at higher elevations (Figure 2.5).

The spatial distribution of lakes can be summarized in terms of their cumulative surface area. Expressed as a percentage of watershed area (HUC-8), western and Downeast Maine have the largest area of surface water, while the Upper St. John River basin (excluding the Allagash and Fish Rivers) exhibit the lowest values of cumulative lake area (Figure 2.7). Land cover data, derived from satellite imagery, can also be used to estimate the areal density of surface waters. These data are summarized in Figure 2.8, where densities of open water and wetlands are shown at the level of HUC-12 watersheds. The general pattern is, as expected, similar to that in Figure 2.7, but resolution is finer.

Lake Water Quality Classification

Maine law designates one standard for all Great Ponds and natural lakes < 10 acres. This standard stipulates that lakes should:

(i) be suitable for drinking water after disinfection; be suitable for recreation, including fishing; and provide habitat for fish and other aquatic life;

(ii) have a stable or declining trophic state and be free of culturally-induced algal blooms;

(iii) not receive new discharges of any pollutants.

The vast majority of lakes currently meet this standard (MDEP 2004). For a total of 5,719 lakes (854,013 acres), no designated use is considered threatened and either (i) all designated uses and water quality standards are met (EPA Listing Category 1), or (ii) data are insufficient to determine whether all designated uses are met (EPA Listing Category 2). A few lakes, however, do not meet the standard (MDEP 2004). Nine lakes are non-attaining because of water level fluctuations resulting from hydropower generation. Twenty one lakes are impaired or threatened for one or more designated uses as a result of pollutant loading (generally nutrient enrichment). These lakes are subject to TMDL (Total Maximum Daily Load) analysis, in which nutrient loading sources are estimated and remediation measures proposed and implemented. In addition to these 21 lakes that require TMDL studies, another twelve are impaired but have already been subjected to TMDL analysis. All lakes in Maine are non-attaining for mercury, the primary source for which is atmospheric deposition (MDEP 2004). Overall, the following lake acreages are currently considered to be supporting / non-supporting of designated uses are (data from MDEP 2004, Table 4-8):

Designated Use	Lake Acres Fully Supporting	Lake Acres Non-Attaining
Aquatic life support:	881,351	105, 821
Fish consumption	987,172	0
Swimming	955,264	31,908
Secondary contact	987,172	0
Drinking water source	987,172	0

Table 2.1 (A): Surface water resources of Maine.

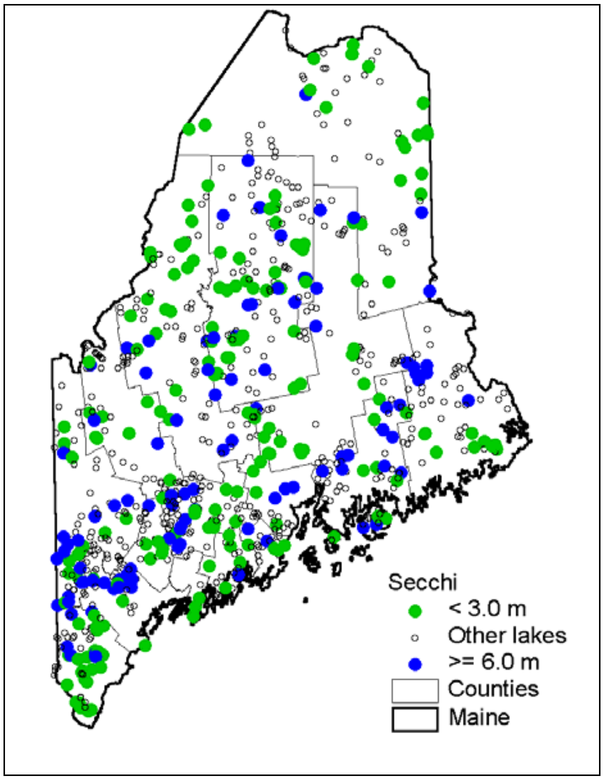
Resource	Square Miles or Miles*	% State Area
Total Freshwater	1,850	6.2
Shallow water	90	0.3
Open water	1,760	5.9
Lakes: GIS data	1,563	4.4
Lakes: MIDAS-numbered lakes	1,519	4.3
Lakes: MDEP "significant" lakes	1,477	4.2
Total Freshwater Wetlands	600	2.0
Fresh aquatic bed	0.6	0.0
Fresh emergent	327	1.1
Wet meadow	81	0.3
Peatlands	191	0.6
Total Saltwater Wetlands	116	0.4
Salt aquatic bed	83	0.3
Salt emergent	34	0.1
Flowing Waters: Total Length	31,672	
Rivers	3,704	
Streams	3,909	
Brooks	22,829	
Creeks	1,230	

* River /stream lengths in miles. Other data are areas in square miles.
Data source: MDEP (2004)

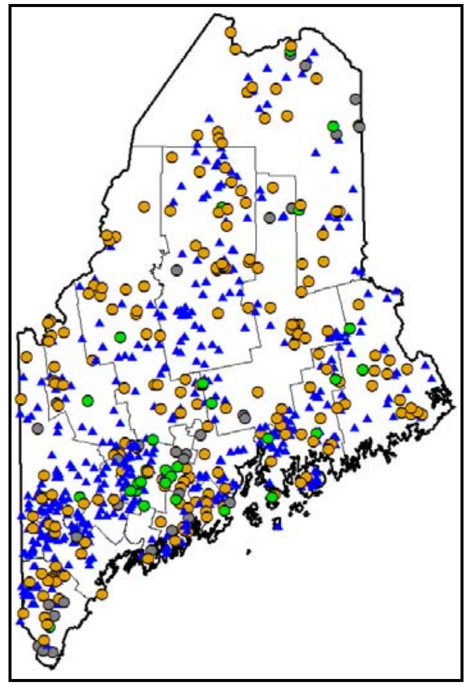
Table 2.1 (B): Number of lakes and ponds in Maine, by size class.

GIS-derived data are from 24K lakes coverage (12/2003 version, from MDEP) and represent surface-water features. These include an unknown number of small features that are wetlands, beaver ponds, etc. The MIDAS-based data include only waterbodies that have been assigned a MIDAS code by MDEP/MDIFW. A few MIDAS lakes (including some large ones) are river impoundments that do not appear in the GIS lakes coverage. These lakes have been included in the MIDAS-based summary, but do not appear in the GIS-based summary. MIDAS-based data are thus a combination of data from (i) the 24K coverage and (ii) MDIFW lake index database. The discrepancy between the number of lakes >100 acres in the two systems probably results from waters that are digitized as > 1 polygon being considered the same lake in the MIDAS system. ("Retired" lakes in the GIS coverage were not included in this analysis.)

Lake Area Class (acres)	Number of Lakes: GIS	% of Total - GIS	Number of Lakes: MIDAS-coded	% of Total – MIDAS-coded
< 1	23,242	70.2	823	13.6
1 – 9.9	7,031	21.2	2,530	42.0
10 – 99.9	1,906	5.8	1,807	29.9
100 – 999.9	749	2.3	702	11.6
1000 +	183	0.5	173	2.9
TOTAL	33,111	100	6,035	100



(A)



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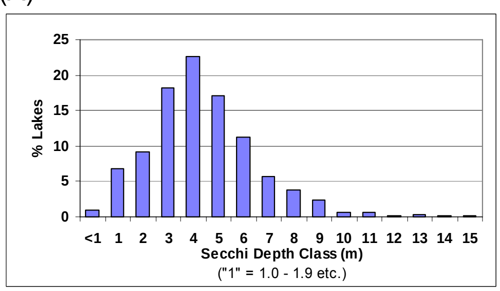


(B)

Figure 2.4: Water transparency (A and B) and color (C) in Maine lakes.
(A) Highest transparency lakes (Secchi ≥ 6 meters) are indicated by blue dots; lowest transparency lakes (< 3 meters) by green dots. Lakes with intermediate transparency are shown as open circles. Transparency is measured by Secchi depth (depth in meters at which a white disk just disappears from view when lowered through the water column). Readings are generally taken at the deepest point in the lake. Data in this Figure are grand means across multiple years.
(B) Frequency distribution of Secchi data for sampled Maine lakes (N=887). Note that the population of sampled lakes is not a statistically-derived sample of all Maine lakes.
(C) Color / turbidity classes, derived from chlorophyll concentrations and water color, as follows:

BLUE:	Chlorophyll < 8 ppb, Color < 30 SPU	(blue triangles)
GREEN:	Chlorophyll > 8 ppb, Color < 30 SPU	(green circles)
BROWN:	Chlorophyll < 8 ppb, Color > 30 SPU	(brown circles)
TURBID:	Chlorophyll > 8 ppb, Color > 30 SPU	(gray circles)

Data source: MDEP/VLMP.

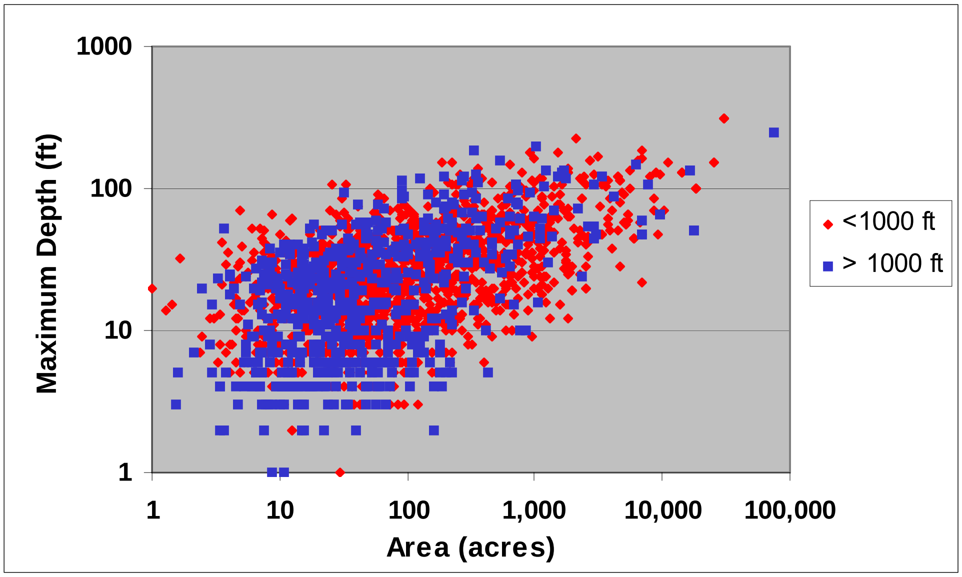


Figure 2.5. Relationship between surface area and maximum depth for two elevation classes of lakes. Note that the lake area axis is logarithmic.
Data are from MIDAS-numbered lakes that have been surveyed.

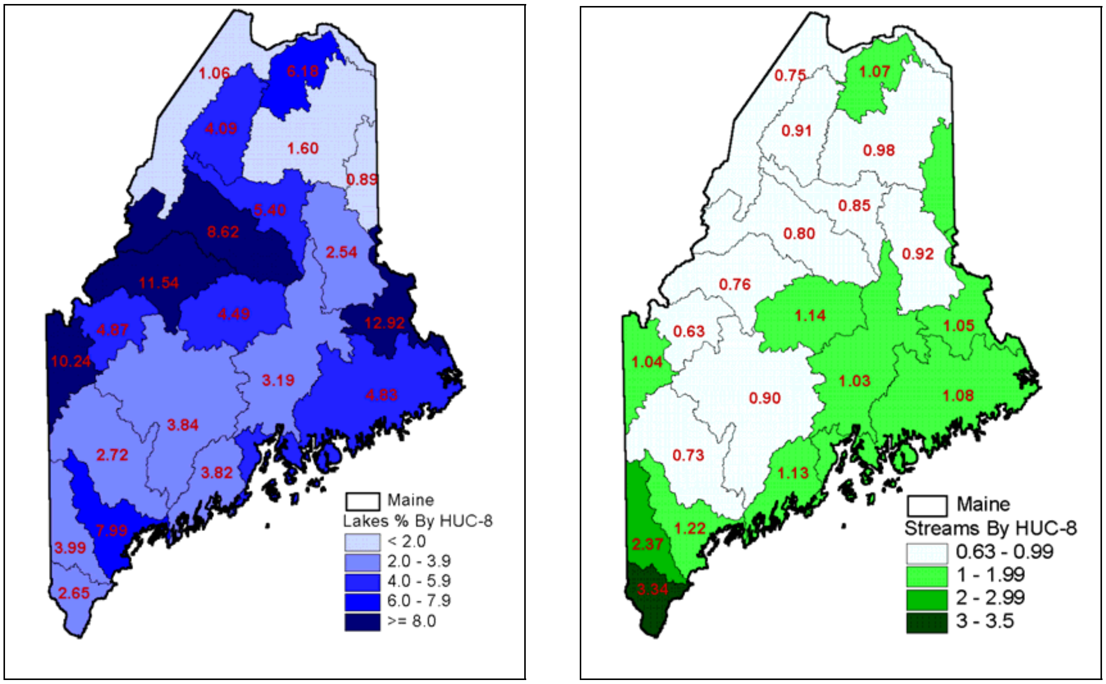


Figure 2.6: Lake (left panel) and stream (right panel) density by watershed (HUC-8). Lake data are total surface area of lakes expressed as % of watershed area. Stream data are as miles of stream / mile^2 watershed area. Lake and watershed areas, and stream miles were derived from GIS coverages. Lake hydrography from 24k lakes GIS coverage. Stream hydrography from NHD (National Hydrographic Dataset) GIS coverage, which is at the 1:100k level for most of Maine (except for the southern part of the state, i.e. below a line approximately between Brunswick and Fryeburg). Higher stream densities in southern Maine reflect level of resolution in the hydrographic map.

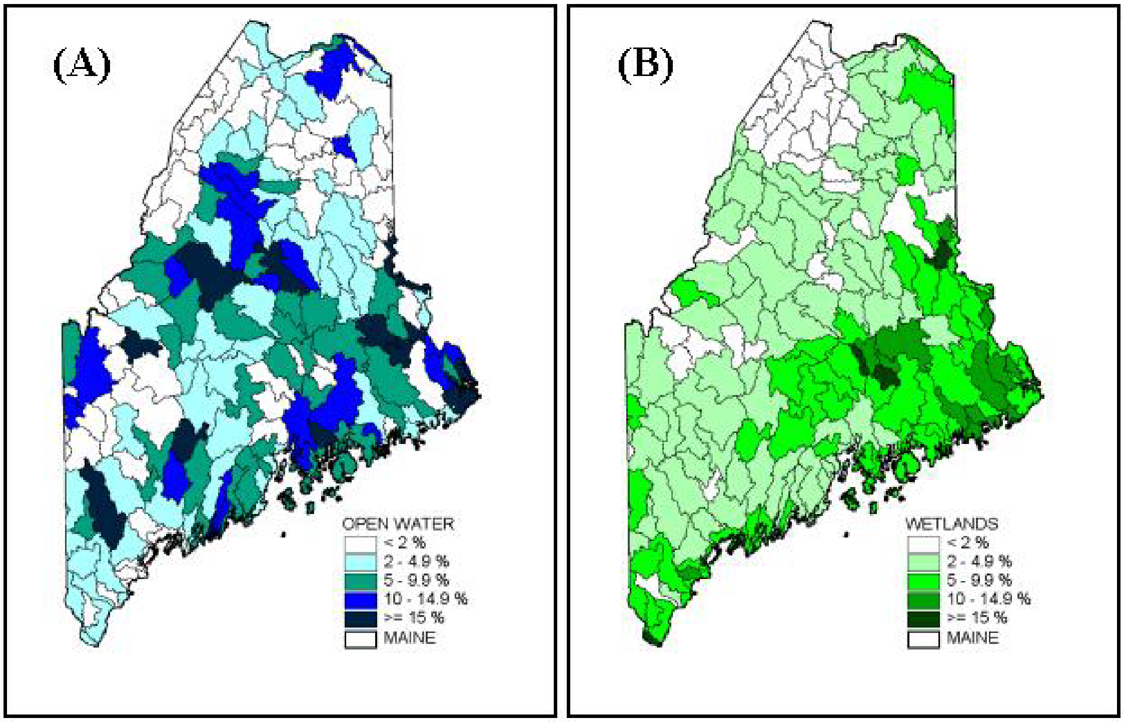


Figure 2.7: Spatial distribution of open-water (left panel) and wetlands (right panel), expressed as % cover by watershed (HUC-10).
Wetlands include both herbaceous and forested categories. Data from National Land Cover Dataset (1992 imagery), provided by The Nature Conservancy.

2.3 Streams and Rivers

There are an estimated 31,672 miles of permanently flowing rivers and streams[5] in Maine, and 13,461 miles of intermittent streams (Table 2.1B: MDEP 2004). These values are underestimates because many small streams are missed as a result of mapping resolution (e.g. Figure 2.12). The USGS National Hydrographic Dataset (NHD) GIS coverage contains approximately 35,526 miles of streams in Maine. Based on the NHD streams coverage, we estimated stream density by watershed (Figure 2.6). Highest mapped stream densities tend to be in the Downeast and southern regions of the state. The broad spatial patterns in stream density do not closely parallel the patterns in lake density Figure 2.6). Over 60 rivers flow into the ocean along the Maine coast.

The 1982 Maine Rivers Study (MDOC 1982) identified about 22% of the state's river/stream resources as having natural and/or recreational resource values that were deemed significant or outstanding at either the state or regional levels. As part of its ecoregional planning process, the Nature Conservancy is currently evaluating and ranking Maine's rivers and their watersheds from a series of landscape-level and biodiversity perspectives.

Maine law establishes four water quality classes for rivers and streams (MDEP 2004).

- Class AA. Waters in this class are "managed for their outstanding natural ecological, recreational, social or scenic qualities. Discharges, dams or other significant human disturbances are prohibited".
- Class A waters are similar to class AA except that limited human interference is allowed; direct pollutant discharges are highly restricted.
- Class B waters are "general-purpose waters and are managed to attain good quality water. Well-treated discharges of pollutants that have ample dilution are allowed."
- Class C waters are managed to "at a minimum attain the fishable/swimmable goals of the Clean Water Act and maintain the structure and function of the biological community".

Thus all water quality classes for Maine's rivers and streams stipulate a good to high quality. The most recent water quality assessment (MDEP 2004) provides the following distribution of classes (as percent of total assessed river miles): Class AA: 5.8%. Class A: 44.1%. Class B: 47.9%. Class C: 2.2%. A total of 1177 miles of rivers and streams were impaired for one or more designated uses, approximately 60% of which were impaired "by the effects of pollutants or a combination of pollutant and non-pollutant stressors" – non-pollutant stressors include large water level fluctuations (MDEP 2004). As with lakes, all Maine rivers and streams have a fish consumption advisory due to the presence of elevated levels of mercury. Chapter 4 provides additional information on causes of impairment in Maine's rivers and streams.

2.4 Wetlands

Among the lower 48 states, Maine is fourth in terms of wetlands coverage, when expressed as percent of total state area (Tiner 1999; note that "wetlands" in this context includes all wetland types employed by the National Wetlands Inventory, including open water and forested wetlands). While wetlands did not fall within MABP's primary focus, it is unrealistic to "separate" wetlands from lakes and streams when considering their ecology. Wetlands are an intrinsic feature of the riparian areas of many lakes and streams. Wetlands are critical to Maine's freshwater ecosystems and their biodiversity – in terms of providing habitat, modifying hydrology and enhancing water quality. Of the 250 rarest plant species tracked by MNAP, over 100 are associated with wetlands. On average, wetlands comprise 18% of the 200-meter buffer area

[5] While the term "river" is generally reserved for larger systems and "streams" for smaller systems, there is no clear boundary between the two terms. In this report, we often apply the term "streams" to all running waters, regardless of size.

around Maine's Great Ponds (lakes >10 acres)[6]. In just under one tenth of lakes examined with GIS, the amount of wetlands in the 200-meter buffer exceeded 50% of the buffer area. At the watershed level, lakes in the central and Downeast regions of the state have the highest proportions of wetlands in their watersheds (Table 2.2). About 35% of lakes in these regions have wetlands making up between 5 and 15% of their direct-draining watersheds (Table 2.2). See below (section 2.5) for added information on watershed landcover.

According to Widoff (1988), there are over five million acres of freshwater wetlands in Maine, and about 160,000 acres of tidal wetlands. The area of non-forested wetlands is much lower: about 458,240 acres, including both freshwater and saltwater wetlands (Table 2.1B; MDEP 2004). Figure 2.7B summarizes wetlands distribution across the state, by watershed. Highest wetland densities are found in the Downeast region. Since colonial times, approximately one fifth of Maine's wetlands have been lost (Tiner 1984). A number of studies have estimated wetland losses/gains for specific parts of the state (e.g. Foulis and Tiner 1994, Foulis et al. 1994.).

MDEP is currently developing wetland-specific biological criteria and will incorporate these into State water quality standards, as has already been done for rivers and streams. Monitoring by MDEP includes macroinvertebrates, algae (including diatoms) and macrophytes (MDEP 2004).

The Maine State Planning Office (MSPO), in collaboration with MDIFW, is currently developing a wetlands conservation plan. Amongst other issues, this plan will focus on strategies to protect vernal pools which, because of their small size, are not currently protected.

2.5 The Landscape Context of Maine's Lakes and Watersheds

Grouping lakes into classes for management / regulatory purposes is frequently based on productivity-associated measures, for example transparency, chlorophyll and phosphorus concentrations. While these classes are clearly relevant to aquatic biodiversity, using landscape-level properties also provides a useful approach for thinking about the entire population of the state's lakes from both conservation and management perspectives (e.g. Wolock et al. 2005, Emmons et al. 1999, Sorrano et al. 1999). In this section we first provide an overview of land-cover and land-use in the watersheds of Maine lakes. Second, we present four landscape-based groupings that, from an a priori perspective, would appear to be highly relevant to aquatic biodiversity issues. Two of these groupings (lakes in conservation lands and remote lakes) are culturally based, i.e. they are related to human actions. One grouping is based on topography and the fourth is associated with hydrology. As will be shown in Chapters 3 and 6, data availability limit the extent to which each of these lake groups can be characterized from a biodiversity perspective. Chapter 7 further explores and evaluates a landscape-level approach to grouping lakes and their watersheds in Maine.

Land-Cover and Land-Use: Land cover data were summarized at the watershed level, using either direct-draining watersheds (GIS coverage provided by MDEP) or HUC-12 watersheds if the former were not available. There were two steps in this analysis. First, we determined, for each lake, the amount of watershed that is covered by each of four composite land-cover categories: forest, wetlands and agriculture. Second, for each size class and region, we calculated the proportion of lakes that have various land-cover characteristics.

Land cover in the watersheds of Maine's lakes is dominated by forest (Table 2.2). As expected, more of the lakes in the north and west tend to have a greater proportion of their watersheds in forest. However, even in the south and central-eastern parts of the state, most lake watersheds have a forest coverage of > 50%. It is only in the south and, to a lesser extent in the northeast,

[6] Data generated from NLCD GIS coverage and provided by A. Olivero, TNC, Boston.

that there is much agricultural activity in many lake watersheds. Lakes in the central and eastern parts of the state show the greatest representation of wetlands in their watershed (Table 2.2.). While the data in Table 2.2 aggregate the central and Downeast regions of the state, Figure 2.9 demonstrates that it is the Downeast region that has the greatest extent of wetlands.

Table 2.2: Land use / cover in lake watersheds.
Data are % of MIDAS-numbered lakes by size class and land cover category. For example, in the western region of the state, 33% of size-class 2 lakes have forest covering between 50 and 85% of their watersheds. Note that lakes sum to 100% within major land-cover category (e.g. forest) and size class/region (1). Watersheds are direct-draining catchments from MDEP or HUC-12 units for those lakes not included in MDEP's direct-draining watersheds database. Land-cover data are aggregrated classes from NLCD (1992 imagery). Land use/cover data summaries provided by The Nature Conservancy.

REGION (2)	**SIZE CLASS (3)**	**FOREST**			**AGRICULTURE**			**WETLAND**			**DEVELOPED**		
		<50%	50-85%	>85%	<5%	5-15%	>15%	<5%	5-15%	>15%	<5%	5-15%	>15%
W	2	2	33	66	98	1	<1	88	10	2	100	<1	0
W	3	<1	57	42	96	3	2	92	7	<1	100	0	0
W	4	0	80	20	100	0	0	83	17	0	100	0	0
W	5	0	100	0	100	0	0	100	0	0	100	0	0
S	2	5	56	39	58	30	12	69	26	6	90	7	2
S	3	<1	88	12	38	51	11	79	19	1	93	7	<1
S	4	0	93	7	26	50	24	81	19	0	98	2	0
S	5	0	100	0	0	100	0	100	0	0	100	0	0
C-E	2	7	60	34	91	8	1	57	34	9	95	4	<1
C-E	3	2	78	20	90	8	2	626	36	2	98	2	0
C-E	4	2	90	8	94	6	0	56	38	6	100	0	0
C-E	5	0	100	0	100	0	0	50	50	0	100	0	0
N	2	8	30	62	79	5	16	82	16	2	98	1	<1
N	3	4	43	53	90	3	7	93	7	0	98	2	0
N	4	0	67	33	90	0	10	91	9	0	100	0	0
N	5	--	--	--	--	--	--	--	--	--	--	--	--
	MEAN	**2**	**72**	**26**	**77**	**18**	**6**	**79**	**19**	**2**	**98**	**2**	**<1**

(1) Rounding of the data mean that some totals are just below or just above 100%.

(2) Regions are groups of HUC-8 watersheds:
West: Upper Androscoggin, Dead, Upper Kennebec, Penobscot East & West Branches, Piscataquis.
South: Saco, Pisacataqua-Salmon Falls, Presumpscot, Lower Androscoggin & Kennebec, St. George, Sheepscot.
Central-East: Lower Penobscot, Maine Coastal, St. Croix, Mattawamkeag.
North: Upper St. John, Allagash, Fish, Aroostook, Meduxnekeag.

(3) Lake size classes:
2: 1 – 99 acres. 3: 100 – 999 acres. 4: 1,000 – 9,999 acres. 5: ≥ 10,000 acres.

Four Landscape-Level Lake Groupings:

<u>Lakes in Conservation Lands:</u> Using GIS, we quantified the number of lakes that are buffered by conservation ownership, easements or some other form of protection. The degree of conservation afforded to any land parcel in Maine is indicated by its GAP status (Scott et al. 1993):

GAP 1: An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state, within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management. Example: Baxter State Park.

GAP 2: An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality or existing natural communities, including suppression of natural disturbance. Example: Many state parks.

GAP 3: Forest lands managed for timber harvesting, recreation, or water supply with a mandate of no conversion to residential or developed land. Land is subject to extractive uses of either a high or low-intensity.

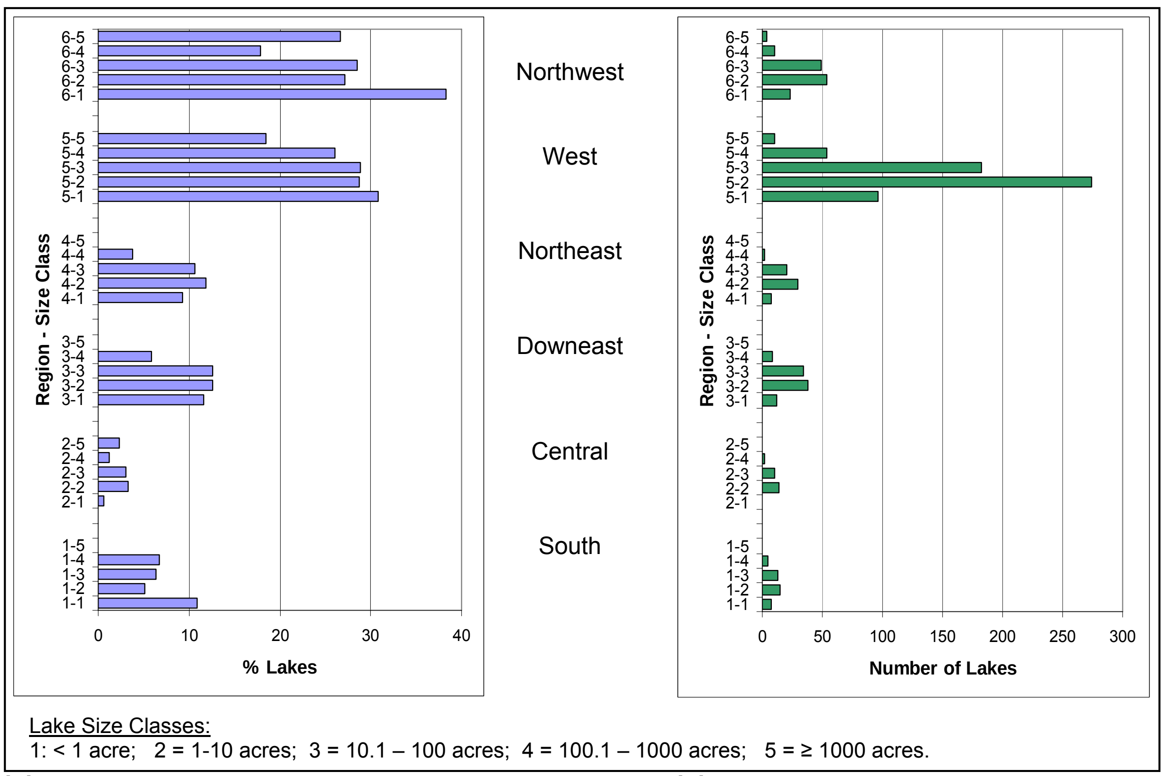
In the west and northwestern parts of the state, approximately 20-30% of lakes intersect with lands in GAP 1, 2, or 3 (Figure 2.8). For other parts of the state, values are generally < 10%. In terms of actual lake numbers, the western region has the most lakes in conservation land, followed by the northwest. These data are a fairly liberal characterization of the number of lakes within conservation lands, because (i) a large proportion of the total amount of 'conservation' land is Gap 3, for which there is only moderate protection, and (ii) no account is made for the size of the conservation land parcels; some parcels may not provide effective conservation value to the lake.

<u>"Remote" Lakes:</u> Remote lakes are significant from biodiversity and conservation perspectives because they may be more pristine than lakes that are settled or have easy road access. We used two approaches to identify remote lakes. First, GIS was used to locate all lakes and ponds that apparently do not have any roads (of any class) within a 500 meter zone around the lake. (Note that there was no ground-truthing of the data.) These remote lakes are distributed throughout the state (Figure 2.10), although there is, as expected, a higher concentration in the western and northern regions – particularly for ponds < 10 acres surface area. Interestingly, remote lakes in the 10-99 acre size class appear to be relatively evenly distributed across the state. Only a very few large lakes (> 100 acres) were classified as remote.

The other data set identifying remote lakes was the LURC-designated list of 175 remote ponds within the unorganized townships under LURC jurisdiction, i.e. ponds in LURC management class 6 (LURC 2004). These ponds are subject to special regulatory control designed to protect their relatively pristine nature, including buffers in which no development is permitted. They are located primarily in western Maine, with relatively few in the unorganized townships of northern Maine (Figure 2.10).

<u>High Elevation Lakes:</u> High-elevation lakes are important because there are not many of them and, in many respects, they are unique ecosystems. These lakes have been the focus of much of the research addressing the effects of acidic precipitation in Maine (Kahl and Scott 1988). For the purposes of this report, we identified all lakes that are either (i) > 2000 ft elevation, or (ii) part of the HELM (High Elevation Lake Monitoring) study operated by the Mitchell Center at the University of Maine (a few of the HELM lakes are below 2000 ft.). A total of 138 lakes are in these two groups, of which 73% are < 10 acres surface area (Figure 2.9). All but four of the high elevation lakes ≥10 acres have some biological data. In contrast, only 14 of the small ponds have any biological data.

Hydrologically Isolated Lakes: Lakes that are isolated from the surface drainage network are of particular interest from a biodiversity perspective because there are presumably reduced opportunities for species to migrate in or out of the system. Kahl et al. (1991) estimated that 5% of Maine lakes are seepage lakes. Seepage lakes were defined as being located on sand/gravel aquifers and having no surface outflow – an inflow may, however, be present (L. Bacon, MDEP, pers. comm.). We categorized isolated lakes using GIS to identify those that do not intersect with a stream segment or a wetland that itself connects to a stream. This process therefore identifies lakes without either inflow or outflow. A total of 353 lakes were identified using these criteria, of which about 12% are >10 acres (Figure 2.13). Isolated lakes are distributed across the state, but there is a relatively high concentration of larger isolated lakes in the Downeast region. (Note: these data have not been ground-truthed.)



(A) **(B)**

Figure 2.8: Distribution of lakes in conservation lands, by Maine region. (A) Percent of total lakes in region/size class grouping. (B) Number of lakes.

A lake was considered to be within conservation land if ≥80% of the 200-meter lake-shore buffer area is contained within conservation land of Gap status 1, 2 or 3. Within each regional grouping, smallest lakes are on bottom and largest lakes are on top. Note: only MIDAS-numbered lakes are included in this figure; consequently the smallest classes of lakes (1 and 2) are under-represented since many of these do not have MIDAS numbers. Data source: The Nature Conservancy, Boston.

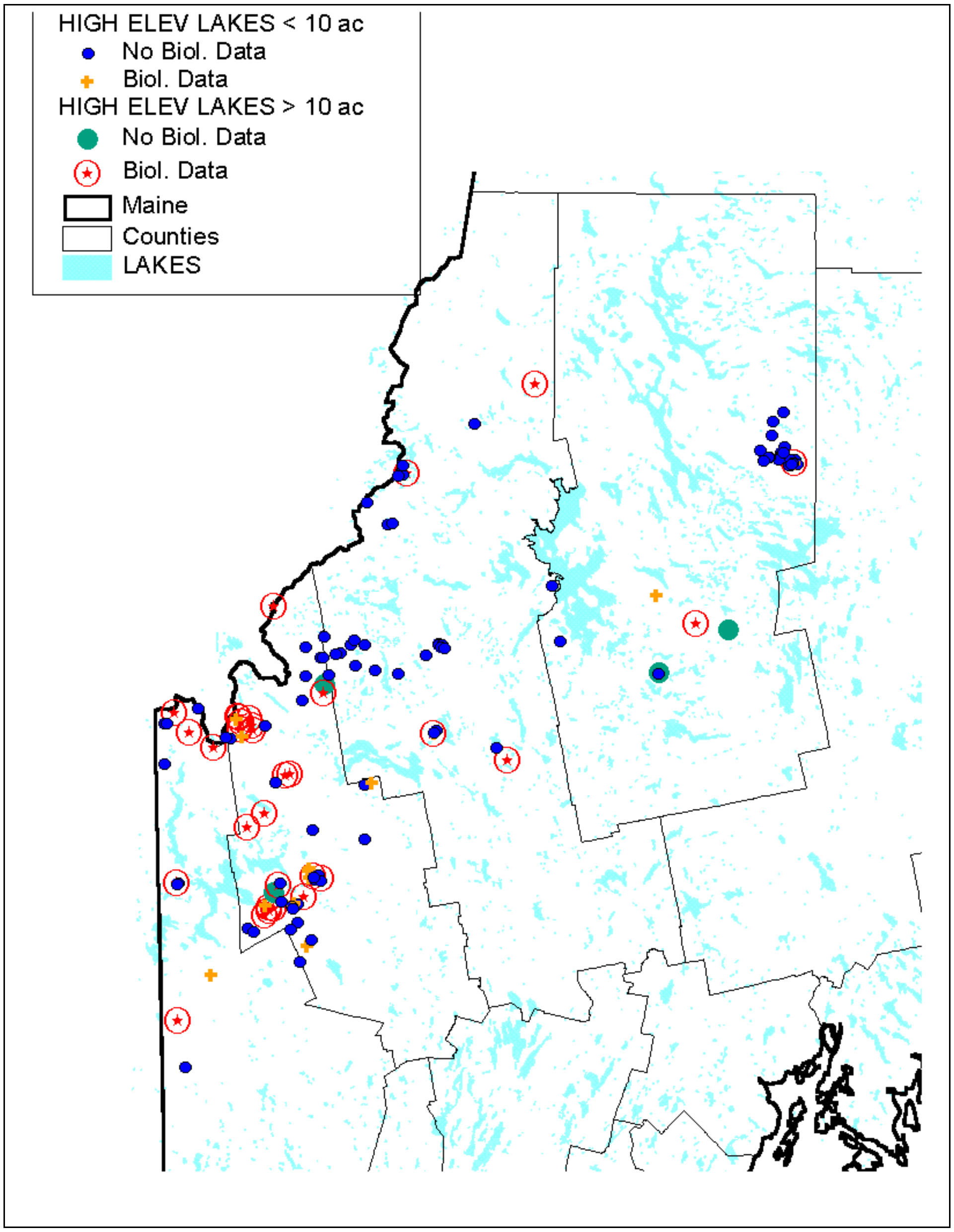


Figure 2.9: High elevation lakes in Maine.
Shown (as points) are all MIDAS lakes >= 2000 ft. elevation and the HELM (High Elevation Monitoring project) lakes, color-coded by whether or not they have biological data (in the MABP database). All lake polygons, regardless of elevation, are included in light blue.

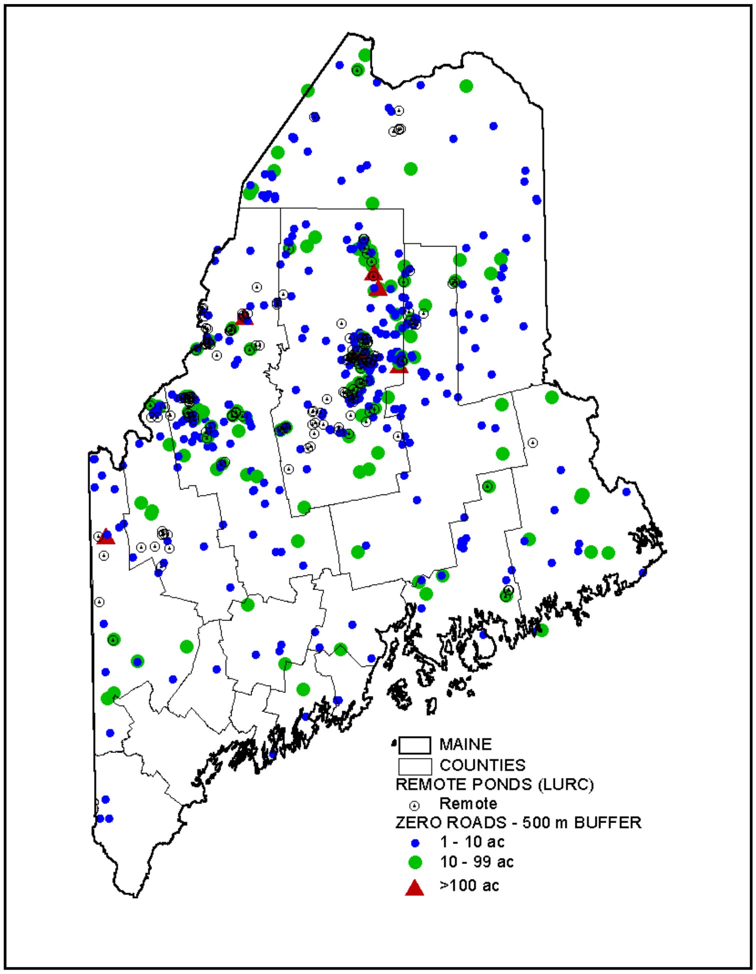


Figure 2.10: "Remote" lakes in Maine – lakes with no roads in the 500-meter shoreline buffer.

Lakes are classified by surface area class. Also shown are waterbodies that have been officially designated as "remote ponds" by the Maine Land-Use Regulatory Commission (LURC). Only some of the LURC-designated remote ponds are characterized by GIS as being remote. Those that are remote under both LURC and GIS designations are indicated with overlapping symbology in the map. LURC data supplied May 2004. Roads data from ME Office of GIS. .

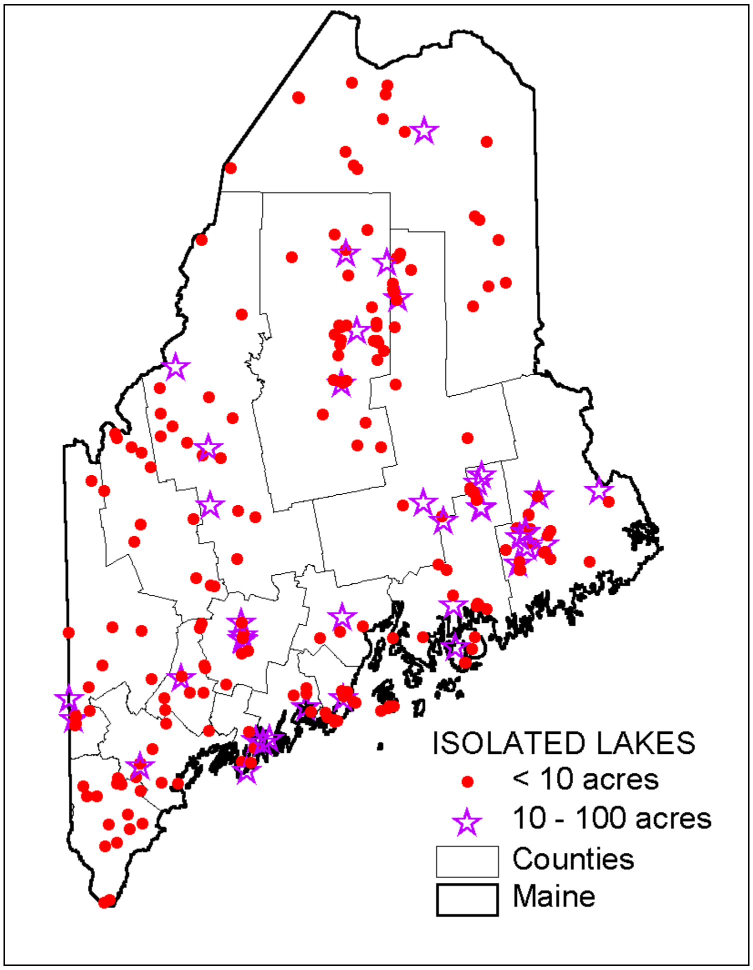


Figure 2.11: Distribution of lakes that appear to be hydrologically isolated from surface drainage features.

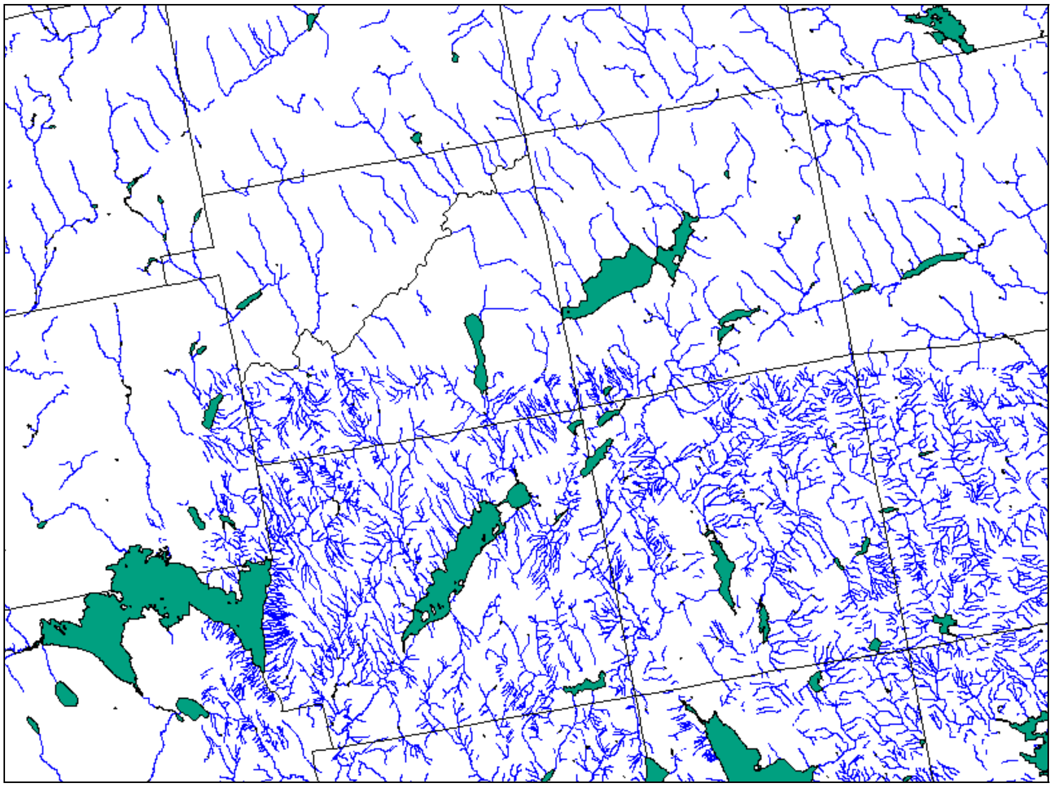


Figure 2.12: A section of the 1:24K streams GIS coverage illustrating variation in the level of detail at which streams are mapped.
The boundaries of the original topographic maps – source for the GIS coverage – are evident. This section is from the Dexter – St. Albans area of central Maine.