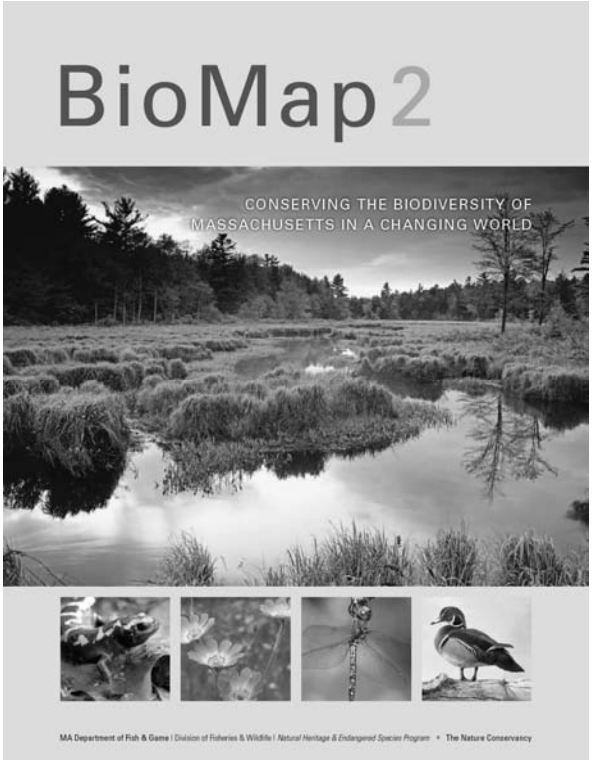
BioMap2 Technical Report -
Building a Better BioMap

A supplement to
BioMap2: Conserving the Biodiversity of Massachusetts in a Changing World



A Project of the

Massachusetts Department of Fish & Game and

The Nature Conservancy

Produced by the
Natural Heritage & Endangered Species Program of the
Massachusetts Division of Fisheries & Wildlife
and the
Massachusetts Program of
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November 2011

The preferred citation for *BioMap2* is:
Woolsey, H., A. Finton, J. DeNormandie. 2010. *BioMap2*: Conserving the Biodiversity of Massachusetts in a Changing World. MA Department of Fish and Game/Natural Heritage & Endangered Species Program and The Nature Conservancy/Massachusetts Program.
http://www.mass.gov/dfwele/dfw/nhesp/land_protection/biomap/biomap2_summary_report.pdf

The preferred citation for this technical report is:
Natural Heritage & Endangered Species Program. 2011. *BioMap2* Technical Report – Building a Better BioMap: A supplement to *BioMap2*: Conserving the Biodiversity of Massachusetts in a Changing World. Natural Heritage & Endangered Species Program, Massachusetts Division of Fisheries and Wildlife, Westborough, MA.
http://www.mass.gov/dfwele/dfw/nhesp/land_protection/biomap/biomap2_technical_report.htm

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Commonwealth of Massachusetts, Deval Patrick, Governor

Executive Office of Energy & the Environment, Richard K. Sullivan, Jr., Secretary

Department of Fish & Game, Mary B. Griffin, Commissioner

November 2011

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Chapter One: Introduction

History of the Project

Although the need to update NHESP's original BioMap and Living Waters projects was frequently remarked upon, it wasn't until December of 2008 that the idea began to take hold. That month at the Doyle Center in Leominster, the Open Space Institute held a meeting on its Massachusetts Amplification Program, part of its New England Wildlife Conservation Initiative. The meeting's objective was to explore how private conservation dollars could "amplify" their overall conservation impact. During the wide-ranging discussion among various conservation partners from in and outside of government, the desirability of updating and expanding the original Massachusetts BioMap came up several times.

Then the internal work of how to launch the next BioMap project began. The need to prepare an updated strategic land conservation plan for the Commonwealth was clear. Considerations about a possible new BioMap project quickly lead to the recognition of the need and desirability of addressing the potential impacts that climate change will likely have on the state's biodiversity, and thus the desired land conservation "footprint". In addition, the Division of Fisheries and Wildlife (DFW) had produced their State Wildlife Action Plan (SWAP) in 2005 and, to broaden the scope of the biodiversity conservation plan, we wanted to include both SWAP habitats and SWAP wildlife species. Mary Griffin, Commissioner of the Department of Fish & Game (DFG), contacted the Massachusetts Office of The Nature Conservancy (TNC) about undertaking the BioMap revision project collaboratively. The Conservancy's Massachusetts State Director, Wayne Klockner, agreed with the importance of the project and committed TNC resources to accomplishing a collaborative project. The Commissioner also had discussions with the Executive Office of Energy and Environmental Affairs about the feasibility of bond funding and they were supportive. The *BioMap2* project team then started to submit proposals seeking additional funding to various potential funders such as the Open Space Institute.

By the spring of 2009, the project had the green light. In early July, the Natural Heritage & Endangered Species Program prepared and posted a solicitation for a *BioMap2* Project Coordinator. James DeNormandie of the Massachusetts Audubon Society was selected and a contract was quickly executed with MassAudubon for his services in this critical role. Various other subcontracts were subsequently signed with the following entities: Glenn Motzkin (landscape ecology), Jeanne Anderson (coastal analyses), Joanna Grand (freshwater fisheries), Charley Eiseman (Wetland Core field checking), Gile Beye and Margaret Lowry (protected open space mapping), and UMass Amherst (for CAPS analyses). The total amount of bond funding made available for the project by the DFG was $400,000 over two fiscal years. The Nature Conservancy also raised money for the project and covered costs such as the printing of the final products. However, most of the work fell to existing NHESP and TNC staff. The project was ultimately slated to be, and largely was, completed in 16 months.

After presenting the developing *BioMap2* project at both the Massachusetts Association of Conservation Commissions and the Northeast Fish and Wildlife conferences during the spring of 2010, the *BioMap2* team held an "external review" session on June 17, 2010, to solicit feedback

from over 25 people in the Massachusetts biodiversity conservation field. (See list of attendees in Appendix A.) This meeting provided important input to the project at a critical stage.

In addition to using their fish data, consultation and collaboration with both the DFW's Fisheries Section and the Division of Marine Fisheries during the summer of 2010 was critical to the development of important subcomponents of the Aquatic Core Habitats. Meetings were also held with the DFW Wildlife section on how to incorporate SWAP wildlife species into *BioMap2*.

The final *BioMap2* summary report and poster were released on October 14, 2010, at a quarterly meeting that the Massachusetts Land Trust Coalition's steering committee held in Grafton.

Funding

Commonwealth of Massachusetts

- MA Department of Fish & Game capital bond funds
- Natural Heritage & Endangered Species Fund
- Open Space Institute

The Nature Conservancy

- The Ackerman Conservation Fund
- Toward Sustainability Foundation
- Elinor M. and Joel L. Siner

Staffing

Massachusetts Natural Heritage & Endangered Species Program

- Henry Woolsey, Program Manager
- James DeNormandie, under contract from the Massachusetts Audubon Society Ecological Extension Service
- Sarah Haggerty, Information Manager

Massachusetts Program, The Nature Conservancy

- Andrew Finton, Director of Science and Conservation
- Jessica Dyson, GIS Manager

Purpose of the Project

Figure 1 shows the different stages of the *BioMap2* process. The initial phase was *identification* of the species and habitats that we are attempting to conserve.

Our conservation targets included species listed under the Massachusetts Endangered Species Act (MESA), additional non-listed species of conservation concern from the State Wildlife Action Plan (SWAP), vulnerable natural communities and species, and the best examples of more common habitat types and ecosystems.

As we *mapped and delineated* the *BioMap2* conservation targets, we paid special attention to their size and connectivity, identifying portions of the landscape large enough to allow ecological processes to function, as well as identifying the critical portions of the landscape surrounding the core habitat that, if protected, will limit stressors.

Then, we *selected and balanced* areas across the entire spectrum of the state's ecoregions and ecological settings. We made sure that we selected biological elements in each of the state's varied ecoregions to insure that protection efforts account for *representation* of each element in each area of the state. In addition, this will insure *replication* of each element. Both are important components of a climate adaptation strategy. For example, we took great pains to select the least disturbed wetlands in the state across a spectrum of elevation, geological settings, and within each ecoregion. This type of "stratification" by ecoregion was repeated for most of the elements in the *BioMap2*.

Figure 1. *BioMap2* process.

The overall goals for the *BioMap2* project were to:

- Update the species and natural community information that were the basis of the first BioMap (2001) and Living Waters (2003) plans.
- Integrate the methodology of the first BioMap (terrestrial) and Living Waters (aquatic) plans.
- Account for recent land protection and land development.
- Enhance the conservation scope to include species and habitats in the Massachusetts State Wildlife Action Plan (2005).
- Target intact ecosystems and landscapes.
- Incorporate resiliency in the face of climate change.
- Balance and stratify targeted biological resources across the state.

Summary of Results

Core Habitat

Core Habitat, as identified in *BioMap2*, consists of 1,242,000 acres (see Table 1) deemed critical for the long-term persistence of rare species and other Species of Conservation Concern, as well as a wide diversity of natural communities and intact ecosystems across the Commonwealth.

Core Habitat, which may overlap with Critical Natural Landscape, includes:

- Species of Conservation Concern
- Priority Natural Communities
- Vernal Pool Core Habitats

- Forest Core Habitats
- Wetland Core Habitats
- Aquatic Core Habitats

Critical Natural Landscape
Critical Natural Landscape (CNL), as identified in *BioMap2*, consists of 1,783,000 acres (see Table 1) complementing Core Habitat, including large natural Landscape Blocks that provide habitat for wide-ranging native wildlife species, support intact ecological processes, maintain connectivity among habitats, and enhance ecological resilience; and buffering uplands around coastal, wetland and aquatic Core Habitats to help ensure their long-term integrity.

Critical Natural Landscape, which may overlap with Core Habitat, includes:
- Landscape Blocks
- Upland Buffers of Wetland Cores
- Upland Buffers of Aquatic Cores
- Coastal Adaptation Areas
- Tern Foraging Habitat

Table 1. Acres of *BioMap2* Components.

	Component	**Acres**
Core Habitat	Species of Conservation Concern	914,361
	Priority Natural Communities	90,535
	Vernal Pool Core Habitats	36,183
	Forest Core Habitats	325,449
	Wetland Core Habitats	93,251
	Aquatic Core Habitats	219,101
Critical Natural Landscape	Landscape Blocks	1,473,593
	Wetland Buffers	237,359
	Aquatic Buffers	375,407
	Coastal Adaptation Areas	80,488
	Tern Foraging Habitat	236,360

Relationship between Core Habitat and Critical Natural Landscape
The original BioMap included Core Habitats as the highest priority for protection, and Supporting Natural Landscape areas as additional targets for protection in order to help maintain the viability of the Core Habitats. *BioMap2* uses a targeted approach to explicitly include a more comprehensive assemblage of native biodiversity. It specifically addresses both coarse and fine filter elements of biodiversity and incorporates strategies to help ecosystems adapt to the impacts of climate change. These innovations in the creation of *BioMap2* influence its application. **In *BioMap2*, the Core Habitat and Critical Natural Landscape are complementary and overlapping, and were delineated based on separate criteria. Each represents a different scale of biodiversity in Massachusetts, yet the protection of both is important to conserve the full suite of biodiversity in the state.**

Core Habitats in *BioMap2* are based on rare species habitat mapped from actual observations, habitat for wildlife of conservation concern, exemplary natural communities, least disturbed wetlands, forest interior habitat, clusters of Potential Vernal Pools, and other conservation targets. They therefore represent the areas in which land protection and stewardship will contribute most significantly to the conservation of specific elements of biodiversity.

Critical Natural Landscapes, on the other hand, are areas that are critically important to conserving a broad range of biodiversity, delineated at a larger scale than the Core Habitats, and the patterns and processes that support it. These areas minimize impacts from development on natural systems, allow connectivity among habitats, and provide adequate area for natural processes that support diverse species.

In addition to differences in scale, Core Habitat and Critical Natural Landscape differ in the amount of human impact each can tolerate and still retain their conservation value. Simple land protection may be the best conservation strategy within most areas of Core Habitat, but portions of Critical Natural Landscape will support moderate levels of compatible human use such as timber harvesting in working forests and specific agricultural practices. By the same notion, conservation efforts within Critical Natural Landscapes should address the requirement to support natural processes for the long term. Therefore targeting small areas of Critical Natural Landscape for land protection without addressing the conservation needs for the entire block fails to achieve the conservation goals represented by the delineation of these large areas.

Chapter Two: *BioMap2* General Methodology

Section A: Study Area and Ecoregions

Study Area
The *BioMap2* study area encompasses Massachusetts town boundaries as well as a portion of the state's nearshore marine waters.

Town survey data was obtained from MassGIS (TOWNSURVEY_Poly.shp) and defines the political boundaries of the state at a scale of 1:25:000. This data layer uses the mean high water line as its seaward boundary and thus does not include the mouths of coastal rivers or coastal embayments. Since these areas contain important habitats for coastal species and natural communities, the *BioMap2* study area boundary was modified to encompass a narrow coastal zone. The Nearshore Ocean Management Planning Area Boundary (NOMPAB) was adopted as the logical marine limit for *BioMap2*, as it is the landward limit of the Massachusetts Ocean Management Planning Area. This boundary was defined by the Massachusetts Office of Coastal Zone Management and extends 0.3 nautical miles from the mean high water shoreline, with modifications around coastal embayments, ports, and harbors. Figure 2 illustrates the final extent of the *BioMap2* study area.

Figure 2. *BioMap2* study area boundary.
The study area boundary combines town administrative boundaries and the nearshore limit of the Ocean Management Planning Area Boundary.

The *BioMap2* study area shown in Figure 2 totals 5.4 million acres. The coastal zone added beyond town boundaries accounts for roughly 250,000 acres of this total. A total of 58,940 acres of Core Habitat and 158,481 acres of Critical Natural Landscape fall beyond boundaries of the town survey polygons, much of which are tern foraging areas. Piping Plover, Bald Eagle, and anadromous fish also have significant habitat within this coastal zone. Where mapped species habitats extend into the ocean beyond the NOMPAB boundary, they were excluded from *BioMap2*. The inclusion of this coastal area was also due to feedback from the external review session, in which participants stated that this area should not be neglected in prioritization efforts.

Table 2 shows the breakdown of acreages within the study area. In some cases, statistics reported in the *BioMap2* Summary Report may exclude acreage beyond the mean high water boundary. This is true for the summary of protected lands, where percentages are based upon just the terrestrial/freshwater portion of *BioMap2*.

Table 2. Study area extent, showing portion of study area added through addition of coastal zone.

	Study area	**Core Habitat**	**Critical Natural Landscape**	***BioMap2* Core/CNL Combined**
Within Town Boundaries	5,174,620	1,224,421	1,757,328	2,071,117
Within Coastal zone	246,368	58,940	158,481	163,877
Study area	5,420,988	1,283,361	1,915,809	2,234,995

Ecoregions

The U. S. Environmental Protection Agency has designated thirteen ecoregions in Massachusetts (http://www.epa.gov/wed/pages/ecoregions/mactri_eco.htm) by assessing geology, hydrology, climate, the distribution of species, and other criteria (Figure 3). Ecoregions denote areas within which ecosystems are generally similar; they are designed to serve as a spatial framework for conservation and environmental resource management. The 13 Massachusetts ecoregions, defined as Level IV Ecoregions, nest within larger and coarser-scale Level III Ecoregions. The Ecoregions in Figure 3 were compiled at a scale of 1:250,000 and depict revisions and subdivisions of earlier Level III ecoregions that were originally compiled at a smaller scale (Omernik 1987). Compilation of this map was part of a collaborative project between the U.S. EPA Environmental Research Laboratory-Corvallis and the Massachusetts Department of Environmental Protection, Division of Water Pollution Control during 1992-1994. More detailed explanations of the methods used to define the USEPA ecoregions are given in Omernik 1995, 2004, and other papers.

In general, New England contains low coastal plains, rocky coasts, river floodplains, alluvial valleys, glacial lakes, forested mountains, and alpine peaks. Ecological diversity is great. There are 5 level III ecoregions and 40 level IV ecoregions in the New England states and many continue into ecologically similar parts of adjacent states or provinces.

Several of the original 13 Level IV ecoregions in Massachusetts (Figure 3) were merged to develop a smaller set of eight ecoregions (Figure 4) used in stratifying ecosystem components for *BioMap2*. This simplified set of ecoregions facilitated the conceptual and technical aspects of selecting, and thereby effectively representing, ecosystems across the diversity of settings found in Massachusetts (see Chapter 2, Section C for more detail on this process). Combining was primarily done for smaller ecoregions that are part of larger land features on the Berkshire Plateau and the Worcester Plateau. For example, all four Level IV ecoregions that make up the "Berkshire Plateau" (58b, 58c, 58d, and 58e) were merged into one larger ecoregion. All contain similar vegetation and are part of the larger Level III "Northeastern Highlands" Ecoregion. Rather than segment these larger features into their component ecoregions, we merged them in order to select ecosystems across the entire plateau. The second example, despite being in two different Level III ecoregions, combined the Level IV Worcester Plateau (58g) and Lower Worcester Plateau (59b) Ecoregions, merged into one "Worcester Plateau" ecoregion. Finally, the Boston Basin (59d) was merged with the Southern New England Coastal Plains and Hills ecoregion (59c) to form a larger "Coastal Plain" ecoregion. These simplified ecoregions allowed analyses that selected ecosystems among distinctly different settings, geomorphologically and biologically, rather than allowing the smaller differences within the plateaus and the Coastal Plain to drive the stratification, representation, and prioritization processes.

Shapefiles, metadata, symbology, and maps are available from US EPA for:

- Massachusetts, CT, and RI at: http://www.epa.gov/wed/pages/ecoregions/mactri_eco.htm
  For MA through MassGIS: http://www.mass.gov/mgis/eco-reg.htm
- New England at: http://www.epa.gov/wed/pages/ecoregions/new_eng_eco.htm
- North America at: http://www.epa.gov/wed/pages/ecoregions.htm

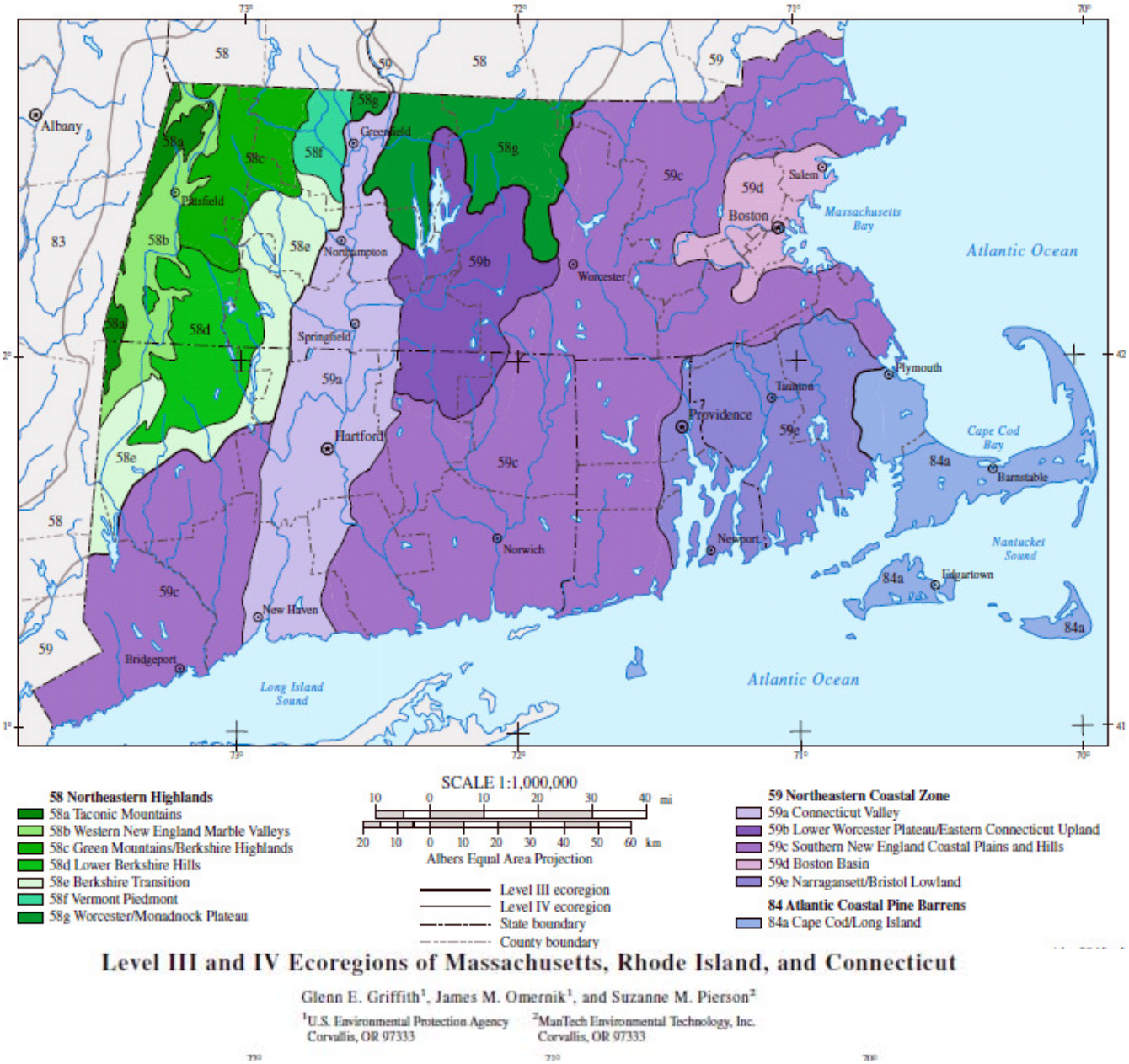


Figure 3. Level III and IV Ecoregions of Massachusetts, Rhode Island, and Connecticut.

The 13 Massachusetts ecoregions are as follows:

Northeastern Highlands

- 58a: Taconic Mountains: An area of high hills and low mountains that contain the highest point in the state, Mt. Greylock. Streams are high gradient and lakes and ponds are rare. Vegetation is generally northern hardwoods with some spruce-fir at higher elevations.
- 58b: Western New England Marble Valleys/Berkshire Valley/Houstonic and Hoosic Valleys: This area is drained by the Hoosic and Housatonic Rivers. This area harbors

farms, evergreen forests, transition and northern hardwood forests, and calcareous fens. The limestone in the area creates alkaline lakes and streams.

- 58c: Berkshire Highlands/Southern Green Mountains: The Deerfield, upper Westfield, Hoosic, and Housatonic Rivers drain this area. Lakes and ponds are relatively abundant. This area has deep soils that support northern hardwoods and spruce-fir forests.
- 58d: Lower Berkshire Hills: Similar to the Berkshire Highlands with its common northern hardwoods, but lacks spruce-fir and harbors transition hardwoods. Lakes and ponds are relatively abundant.
- 58e: Berkshire Transition: Forests are transition hardwoods and northern hardwoods. This area drains to the Westfield and Connecticut River basins.
- 58f: Vermont Piedmont: Forests are transition hardwoods and northern hardwoods. Hills are sometimes quite steep. Surface waters are highly alkaline. This area drains to the Deerfield and Connecticut River basins.
- 58g: Worcester Plateau: This area includes the most hilly areas of the central upland with a few high monadnocks and mountains. Forests are transition hardwoods and some northern hardwoods. Forested wetlands are common. Surface waters are acidic. Many major rivers drain this area.

Northeastern Coastal Zone

- 59a: Connecticut River Valley: The borders of this region are easily defined by the bedrock geology. It has rich soils, a mild climate and low rolling topography. The valley floor is primarily cropland and built land. Central hardwoods and transition hardwood forests cover the ridges.
- 59b: Lower Worcester Plateau: Comprises of open hills and transition hardwood and central hardwood forests. Most parts drain to the Chicopee and Quinebaug Rivers.
- 59c: Southern New England Coastal Plains and Hills: Comprises plains with a few low hills. Forests are mainly central hardwoods with some transition hardwoods and some elm-ash-red maple and red and white pine. Many major rivers drain this area.
- 59d: Boston Basin: Low hills and outlying hilly suburban towns mark this area's rim. The basin itself has low rolling topography and numerous urban reservoirs, lakes, and ponds. The flat areas were once tilled, but are now almost exclusively urban and suburban developments.
- 59e: Bristol Lowland/Narragansett Lowland: This region has flat gently rolling plains. Forests are mostly central hardwoods and some elm-ash-red maple and red and white pine. There are numerous wetlands, some cropland/pasture, and many cranberry bogs. Many rivers drain this area.

Atlantic Coastal Pine Barrens

- 84a: Cape Cod and Islands: This region was formed by three advances and retreats of the Wisconsin Ice Sheet. The resulting terminal moraines. outwash plains, and coastal deposits characterize the area with their sandy beaches, grassy dunes, bays, marshes, and scrubby oak-pine forests. There are numerous kettlehole ponds, swamps, and bogs. Much of the surface water is highly acidic.

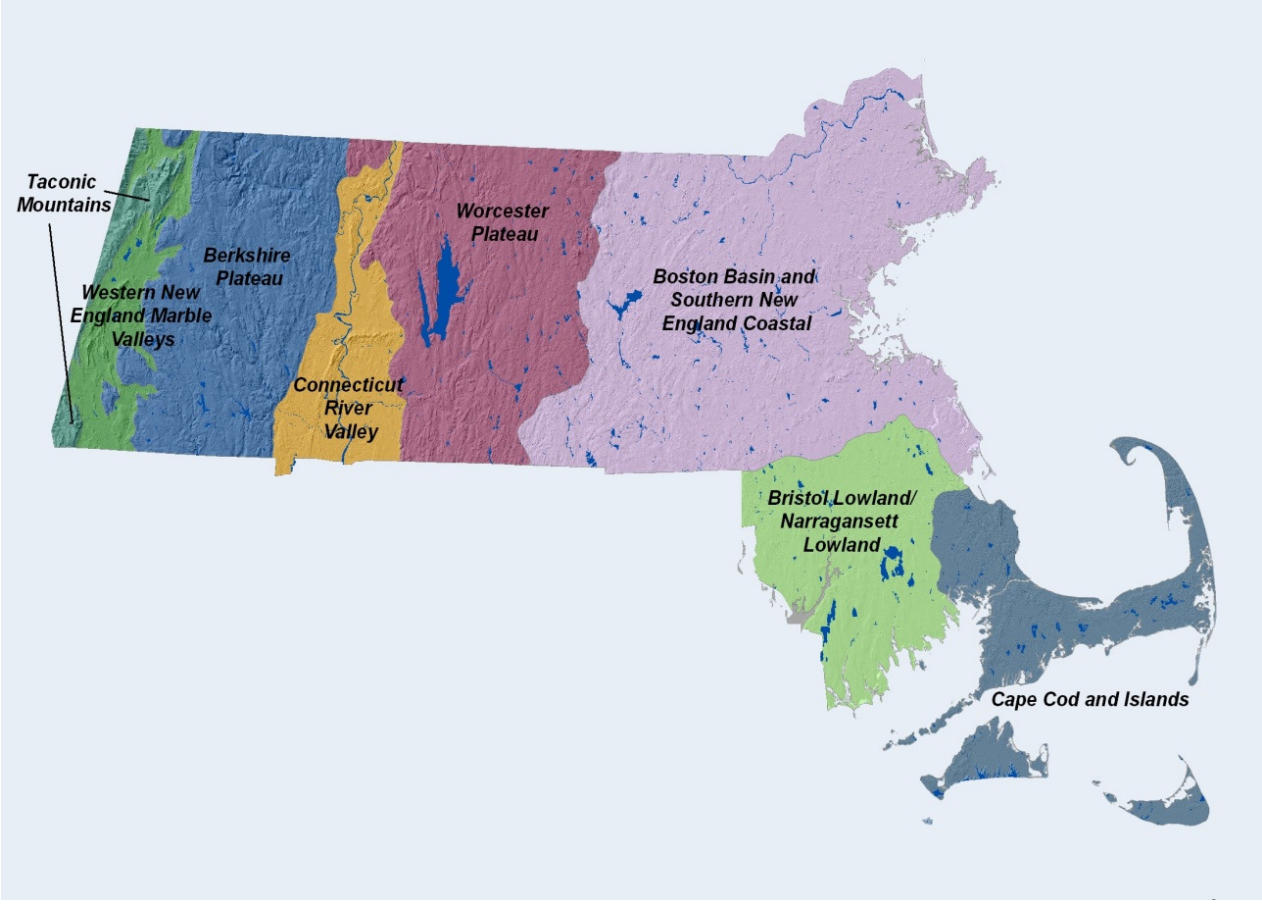


Figure 4. The eight ecoregions used to stratify and select ecosystems in *BioMap2*.

Section B: Incorporating SWAP into BioMap2

In 2005, the Massachusetts Division of Fisheries & Wildlife completed its *Comprehensive Wildlife Conservation Strategy*, the State Wildlife Action Plan. This plan targeted 257 wildlife species determined to be in greatest need of conservation, along with 22 habitats that harbor these species.

BioMap2 incorporated these SWAP species and habitats in one of several ways:

- Most SWAP species are also listed under the Massachusetts Endangered Species Act (MESA). Habitats for these species are delineated by NHESP biologists using detailed guidelines; see Section A: Species of Conservation Concern in the chapter on *BioMap2* Core Habitats, below, for a fuller explanation.
- Some SWAP wildlife species are not listed under MESA, but NHESP had sufficient locality data to map their habitats explicitly, as for MESA-listed species. See Section A in Chapter 3.
- The habitats for some non-MESA-listed SWAP species were included indirectly in the creation of other components of *BioMap2*.
- A few SWAP species were not covered at all in *BioMap2*, because of insufficient data, because of the generalist nature of their habitat use, or because their habitats in Massachusetts are primarily marine.
- SWAP habitats were included either explicitly, in the species habitats delineated for individual occurrences of most species, or indirectly, in the creation of other *BioMap2* components.

See Appendices B and C for lists of all SWAP wildlife species and SWAP habitats and how they were incorporated into *BioMap2*.

Fishes
The treatment of non-MESA-listed fish species can be found in the description of Aquatic Core.

Birds
Eight species of birds were mapped indirectly by other analyses used in *BioMap2*. Table 3 lists these species and the other analyses that "swept" these species along.

Table 3. Non-MESA-listed birds included in *BioMap2* and mapped indirectly.

Non-MESA-listed Bird Species	Scientific Name	Analyses that identified habitat for this species
Broad-winged Hawk	*Buteo platypterus*	Forest Core, Landscape Blocks
Green Heron	*Butorides virescens*	Wetland Core
Prairie Warbler	*Dendroica discolor*	Other MESA-listed species identify the important Pine-Barrens Scrub habitat in which Prairie Warbler resides
American Oystercatcher	*Haematopus palliatus*	Other MESA-listed shorebirds identify important habitat for American Oystercatcher

Non-MESA-listed Bird Species	Scientific Name	Analyses that identified habitat for this species
Wood Thrush	*Hylocichla mustelina*	Forest Core, Landscape Blocks
Louisiana Waterthrush	*Parkesia motacilla*	Smaller streams in Aquatic Core identified for Brook Trout and Slimy Sculpin
Canada Warbler	*Wilsonia canadensis*	Wetland Core, Forest Core, Landscape Blocks
White-throated Sparrow	*Zonotrichia albicollis*	Forest Core, Landscape Blocks

Mammals

Beach Vole (*Microtus breweri*): The only habitat for the Beach Vole, on Muskeget Island, is already present within Core Habitat due to other MESA-listed species habitats.

Moose (*Alces alces*), Bobcat (*Lynx rufus*), and Black Bear (*Ursus americanus*): Although individual observation records were not used for these three species to delineate species habitats, the Forest Cores and Landscape Blocks, as well as many of the other large Core Habitat polygons, act to target thousands of acres that will benefit these wide-ranging species.

Invertebrates

Habitats for four species of non-MESA-listed invertebrates, all Lepidoptera, were mapped using an indirect mapping technique. Table 4 lists the four species. Note that Northern Flower Moth is not a SWAP species.

Table 4. Non-MESA-listed invertebrates included in *BioMap2* indirectly.

Non-MESA-listed Invertebrate Species	Scientific Name	Mapping Technique
West Virginia White	*Pieris virginiensis*	Indirect
Northern Flower Moth	*Schinia septentrionalis*	Indirect
Plain Schizura	*Schizura apicalis*	Indirect
Northeastern Pine Zale	*Zale curema*	Indirect

Plants

There were no plant species identified in the State Wildlife Action Plan, so no additional plants were added to *BioMap2* beyond the MESA-listed species.

Additional Species Not Mapped

There were 30 additional species listed in the State Wildlife Action Plan that were not mapped explicitly or indirectly for *BioMap2* for various reasons, such as: insufficient data, because of the generalist nature of their habitat use, or because their habitats in Massachusetts are primarily marine. Table 5 below lists these species.

Table 5. SWAP species not included in *BioMap2*.

Common Name	**Scientific Name**
Birds	
American Black Duck	*Anas rubripes*
Ruffed Grouse	*Bonasa umbellus*
Long-tailed Duck	*Clangula hyemalis*
Northern Bobwhite	*Colinus virginianus*
Willow Flycatcher	*Empidonax traillii*
American Kestrel	*Falco sparverius*
Harlequin Duck	*Histrionicus histrionicus*
Eskimo Curlew	*Numenius borealis*
Eastern Towhee	*Pipilo erythrophthalmus*
American Woodcock	*Scolopax minor*
Common Eider	*Somateria mollissima*
Field Sparrow	*Spizella pusilla*
Eastern Meadowlark	*Sturnella magna*
Brown Thrasher	*Toxostoma rufum*
Blue-winged Warbler	*Vermivora pinus*
Mammals	
Silver-haired Bat	*Lasionycteris noctivagans*
Eastern Red Bat	*Lasiurus borealis*
Hoary Bat	*Lasiurus cinereus*
Harbor Porpoise	*Phocoena phocoena*
Invertebrates	
A Stonefly	*Alloperla voinae*
Spiny Oakworm	*Anisota stigma*
Coastal Plain Apamea Moth	*Apamea mixta*
Feminine Clam Shrimp	*Caenestheriella gynecia*
Appalachian Brook Crayfish	*Cambarus bartonii*
Mount Everett Pond Sponge	*Corvomeyenia everettii*
Hanson's Appalachian Stonefly	*Hansonoperla appalachia*
Sylvan Hygrotus Diving Beetle	*Hygrotus sylvanus*
A Stonefly	*Perlesta nitida*
Vernal Physa	*Physa vernalis*
Olive Vertigo	*Vertigo perryi*

Section C: Incorporating Climate Change Adaptation into BioMap2

A variety of emerging strategies, collectively termed Climate Change Adaptation, are designed to help ecosystems and populations cope with the adverse impacts of climate change. *BioMap2* incorporates a suite of these strategies to promote **resistance** and **resilience** of plant and animal populations and ecosystems, and to assist anticipated **transformations** caused by climate change and other stressors (Heller and Zavaleta 2009, Lawler 2009) (Table 6).

- **Resistance:** The ability of an ecosystem or population to persist and to *remain relatively stable in response to climate change and other stressors*. The concept of resistance is incorporated into *BioMap2* for species like the Threatened Blanding's Turtle by identifying extensive habitat patches that support large populations, allow movement from wetlands to uplands, and allow movement among wetlands, all of which impart resistance to populations in the face of projected summer droughts, spring flooding, and other threats.

- **Resilience:** The ability of an ecosystem or population to *recover from the impacts of climate change and other stressors*. In many cases, ecosystems will change in species composition and structure in response to climate change; increased resilience supports an ecosystem's ability to adapt to climate change and maintain ecological function. For example, wetlands will likely experience changes in temperature and hydrological regime (i.e., the timing and amount of water) due to projected climate changes, resulting in changes in plant and animal composition. By selecting large, unfragmented wetlands that are well buffered, *BioMap2* prioritizes wetlands that are best able to maintain function and support native biodiversity.

- **Transformation:** The transition of an ecosystem or population *to another ecological state in response to climate change and other stressors*. *BioMap2*, recognizing such transformations are particularly likely along the coast, identifies low-lying, intact uplands adjacent to salt marshes to allow the migration of estuarine ecosystems up-slope in the context of rising sea levels.

The strategies adopted for *BioMap2* are critical components of a comprehensive strategy needed to address climate change. Ultimately, *BioMap2* should be combined with on-the-ground stewardship and restoration efforts, such as dam removal, forest management, and rare species habitat management, providing a comprehensive approach to biodiversity conservation in the face of climate change. This set of strategies must complement international, national, and regional emission reductions in order to reduce the threat of climate change to species and ecosystems.

Table 6. Climate Adaptation strategies incorporated into the mapping of *BioMap2* natural communities and ecosystems ("X" denotes strategies that are directly built into the *BioMap2* through one or more spatial analyses).

Ecosystem	Size	Connectivity			Limit Stressors[a]	Ecological Processes[b]			Representation		Replication
		Local connectivity[c]	Regional connectivity	Ecosystem migration	Development and Roads, Pollution, Biotic and Hydrological alterations	Hydrologic regimes[b]	Disturbance regimes[b]	Buffers	Ecological settings	Ecoregions (Watersheds)	
Vernal pools	X	X			X	X				X	X
Forest Core	X	X			X		X	X[d]		X	X
Wetland Core	X	X			X	X	X	X	X	X	X
Aquatic Core	X	X						X		X	X
Landscape Blocks	X	X	implicit		X	X	X			X	X
Coastal Habitat				X[e]			X[e]	X[e]			X

[a] These stressors are represented by metrics within the UMass CAPS Index of Ecological Integrity (See Chapter 2, Section D (Index of Ecological Integrity) and Appendix G (Integrity metrics) for a complete list of metrics and explanations.
[b] The persistence of these processes in the ecosystems noted is based on the assumption that large, intact, ecosystems with limited stressors will maintain most or all of these ecological processes.
[c] Through UMass CAPS Index of Ecological Integrity
[d] Forest cores are buffered by Landscape Blocks in every case.
[e] Through the coastal adaptation analysis

The ecosystem analyses and resulting *BioMap2* priorities were developed using the latest climate adaption approaches, employing the strategies described below to impart resistance and resilience to *BioMap2* habitats, natural communities, and ecosystems (The Heinz Center 2008, Heller and Zavaleta 2009, Hansen et al. 2003, Lawler 2009) (Table 6). These strategies include:

- **Prioritize habitats, natural communities, and ecosystems of sufficient size.** Large wetlands, forests, river networks, and other intact ecosystems generally support larger populations of native species, a greater number of species, and more intact natural processes than small, isolated examples. Large examples are also likely to help plants and animals survive extreme conditions expected under climate change. *BioMap2* includes the largest examples of high-quality forest and wetland ecosystems and intact landscapes, as well as extensive species habitats and intact river networks.

- **Select habitats, natural communities, and ecosystems that support ecological processes.** Ecological processes sustain the diversity of species within ecosystems. Examples include natural disturbances, like windstorms in forests that result in a mosaic of forest ages, each of which supports a different suite of plants and animals. Similarly, intact rivers support functional hydrological regimes, such as flooding in the spring, that support the diversity of fish and other species found in a healthy river. *BioMap2* identifies ecosystems with the best chance of maintaining ecological processes over long time periods; these resilient habitats are most likely to recover from ecological processes that are altered by climate change.

- **Build connectivity into habitats and ecosystems.** Connectivity is essential to support the long-term persistence of populations of both rare and common species. Local connectivity provides opportunities for individual animals to move through the landscape. For instance, wood frogs and blue-spotted salamanders need to move between springtime vernal pool habitats where they breed and upland forest habitats where they feed in summer and overwinter. *BioMap2* maximizes local connectivity in forest, wetland, vernal pool, river, and rare species habitats. Regional connectivity allows long-distance dispersal, which helps to maintain vital populations. The intact landscapes of *BioMap2* support regional connectivity, including several cross-state areas of critical importance.

    - **Salt Marsh Migration: A special case for connectivity**. The coastal habitats of Massachusetts are particularly vulnerable to potential sea-level rise in the next century, which some estimates suggest is likely to exceed one meter. Therefore, in addition to prioritizing current coastal habitats, *BioMap2* includes an analysis of low lying, undeveloped and ecologically connected upland areas adjacent to salt marshes and coastal habitat to determine where these habitats might extend into or migrate to adjacent uplands as sea levels rise (See Chapter 4, Section C for detailed description and methodology, as well as additional background). Many salt marshes are encroached upon by roads and other forms of developed infrastructure. By identifying adjacent upland habitat still connected to salt marsh habitat, *BioMap2* identifies those areas with the highest probability of supporting ecosystem migration. However, the presence of these low-lying lands adjacent to existing salt marsh does not ensure the future migration of salt marshes into this new zone. Many biotic and abiotic processes, including salt marsh accretion, erosion, and collapse, will determine which

of several outcomes will occur as the sea level rises. Research and observation over the coming decades will identify which of these outcomes will occur in the various salt marshes of Massachusetts. The identification of the land to which these marshes could move is just one of many steps that might be necessary to protect these habitats into the future.

- **Represent a diversity of species, natural communities, ecosystems, and ecological settings.** To ensure that the network of protected lands represents the full suite of species, both currently and into the future, *BioMap2* includes rare and common species, natural communities, and intact ecosystems across the state. *BioMap2* also includes ecosystems across the full range of ecoregions and ecological settings; such diverse physical settings support unique assemblages of plants and animals and serve as 'coarse filters' for protecting biological diversity. As species shift over time in the context of changing climate, a diversity of physical settings and ecosystems will be available to support biodiversity.

  Representing physical diversity: Protecting the stage using Ecological Land Units and ecoregions: Climate plays an important role in determining which species may occur in a region such as the Northeast. However, within the region, the close relationship of the physical environment to ecological process and biotic distributions means that species and ecosystem distributions are strongly influenced by features such as local geology and topography because these factors affect the availability of water, nutrients, and other resources needed by plants and animals (Anderson and Ferree 2010, Beier and Brost, 2010). It is important to incorporate such variation in physical (or ecological) settings into long-term biodiversity conservation because these settings will endure over time even as species shift in response to climate change. An understanding of patterns of environmental variation and biological diversity is fundamental to conservation planning at any scale—regional, landscape level, or local. From this perspective, conserving a physical setting is analogous to conserving an ecological "stage", knowing that the individual ecological "actors" will change with time. Protecting the stage will help to conserve varied habitats and to retain functioning ecosystems in place, even though the exact species composition may change.

  The *BioMap2* Wetland Core analysis (Chapter 3, Section E) used these concepts to select the most intact wetlands and to ensure that they represent the diversity of physical settings across Massachusetts based on unique combinations of the underlying geology and elevation (Figure 5). For instance, wetlands were selected on sandy soils at low elevations along the coast, at moderate elevations in the marble valleys of western Massachusetts, and in other ecological settings. Wetlands representing these enduring features should support functional ecosystems with a diversity of species over time.

  To build these concepts into *BioMap2*, the Wetland Core analyses were based on underlying "Ecological Land Unit" (ELU) data. See Chapter 3, Section E for a detailed description of ELU applications to *BioMap2* Wetland Core selection. The ELU dataset was developed as a tool for assessing the physical character of landscapes, and for mapping the distribution of ecosystems of varying physical character across those landscapes. The ELU is a composite of several layers of abiotic information: elevation, bedrock geology, distribution of deep glacial sediments that mask bedrock's geochemical effects, moisture availability, and

landform. An ELU grid of 30 meter cells was developed by The Nature Conservancy for the Northeast United States. A brief discussion of the background and each of the component layers can be found in Appendix D. The ELU dataset describes the "ecological potential" of the landscape. The ELU dataset itself carries no information about actual landuse or landcover, however. The *BioMap2* Wetland Core analysis used Elevation and Geology components of the ELU data layer, but did not employ the Landform component since nearly all wetlands fall within the "wetflat" landform type, and therefore these data do not assist in further categorizing Massachusetts wetlands.

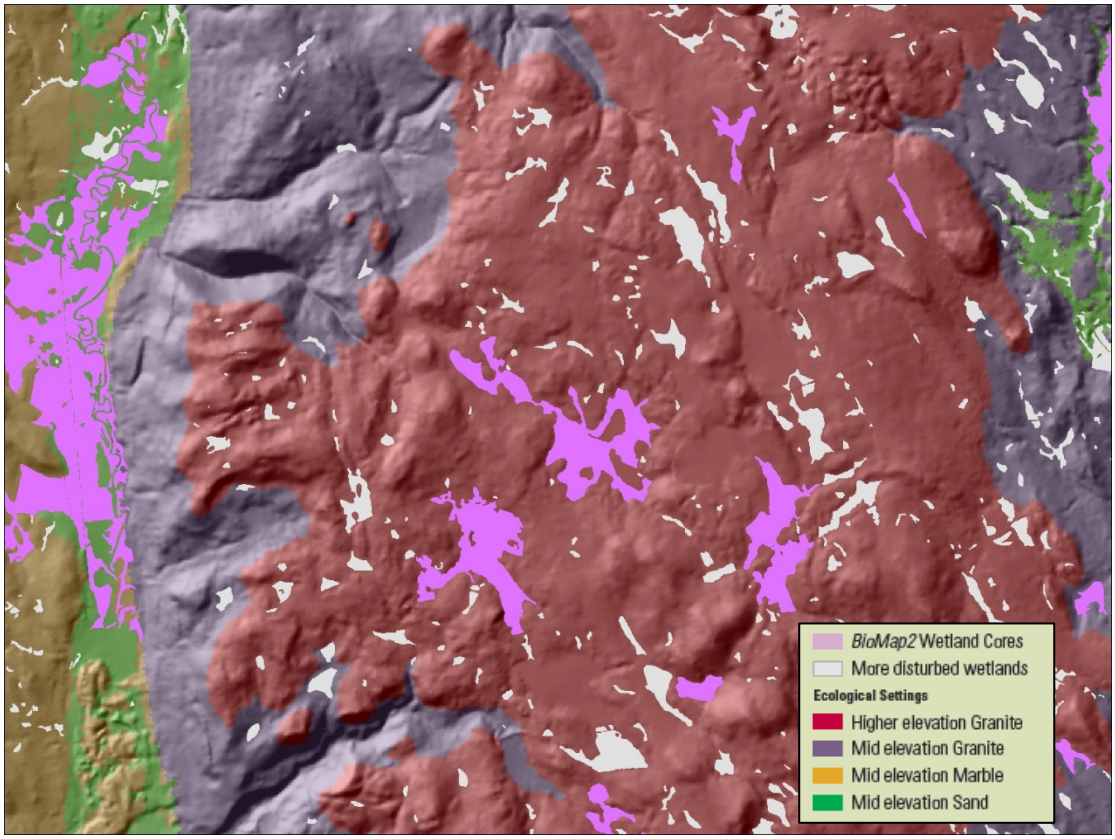


Figure 5. *BioMap2* wetlands on various physical settings.

Using similar principles, *BioMap2* used ecoregions (see Chapter 2, Section A for an explanation of ecoregions) to stratify selection of Forest Cores, Vernal Pools, and Landscape Blocks across the state, and thereby effectively represent the diversity of settings in which they occur. A similar approach using watersheds was used to stratify, or geo-balance, the high-priority habitat for non-MESA-listed fishes. Ecoregions are geographic areas with similar geology, physiography, predominant vegetation, climate, soils, wildlife, and hydrology, and therefore represent areas of relatively homogeneous ecological settings. By recognizing the spatial differences in the capacities and potentials of ecosystems, ecoregions stratify the environment. These general purpose regions are critical for structuring and implementing ecosystem protection and management strategies across federal agencies, state agencies, and nongovernmental organizations. By including intact forest, vernal pool, river, and landscape-scale ecosystems in each ecoregion, *BioMap2* highlights the need to protect a

diversity of functional ecosystems across the state and across physical settings in the context of a changing climate.

- **Protect multiple examples of each species habitat, natural community, and ecosystem.** Simply put, by selecting multiple examples of each species habitat, natural community, ecosystem, and landscape, *BioMap2* reduces the risk of losing critical elements of the biodiversity of Massachusetts. The extreme weather events projected under climate change, and the uncertainties of ecosystem response, will likely mean that some populations will not persist, and some ecosystems will cease to function as they have in the past. By selecting multiple examples and distributing them geographically and among different settings, *BioMap2* increases the likelihood that one or more examples will survive into the future.

- **Minimize non-climate stressors to species and ecosystems.** Limiting other stressors is one of the most important strategies to impart resistance and resilience to species and ecosystems. *BioMap2* identifies those habitats least impacted by roads and traffic, development, dams, water withdrawals, and other sources of stress, which also have the least likelihood of related stressors such as edge effects, invasive species, and alterations to water quantity and quality. Despite efforts to select the least-altered habitats, these areas are not pristine, and stewardship to reduce additional stressors is often required.

Protection of the lands identified in *BioMap2* will not be sufficient, in and of itself, to ensure the persistence of the biodiversity of Massachusetts. Other adaptive strategies to climate change that complement *BioMap2* include:

- **Manage and restore populations, habitats, and ecosystems.** Ecological restoration of degraded habitats—to restore composition, structure, and function—enhances resistance and resilience. Stewardship needs include the control of invasive species, forest management to enhance young forest for declining species, and prescribed burning to increase habitat diversity and reduce wildfire hazard. The restoration of aquatic connectivity and flow regimes may benefit from dam removal and improvement of road stream-crossings. In some cases, translocation or reintroduction of imperiled species may be warranted.

- **Adaptive management of species and ecosystems.** Although important for all conservation actions, measuring and monitoring the results of climate change adaptation strategies, and learning from these actions and analyses, are especially important due to the uncertainties of future climate changes and impacts.

Section D: Index of Ecological Integrity (IEI)

Introduction

A primary goal of *BioMap2* is to identify the most resistant and resilient ecosystems in Massachusetts. To accomplish this, *BioMap2* used the Conservation Assessment and Prioritization System (CAPS, http://www.umass.edu/landeco/research/caps/caps.html) developed over the past decade by researchers in the Landscape Ecology Program at the University of Massachusetts, Amherst.

This sophisticated spatial model produces an Index of Ecological Integrity (IEI) that *BioMap2* used to objectively assess the forests, wetlands, large landscapes, and vernal pool clusters across Massachusetts. The tool was also used to identify intact stream reaches for some aquatic ecosystems. This chapter describes the concepts and assumptions of the CAPS IEI model, and how it works, and the subsequent chapters describe how the IEI model was applied to identify intact ecosystems.

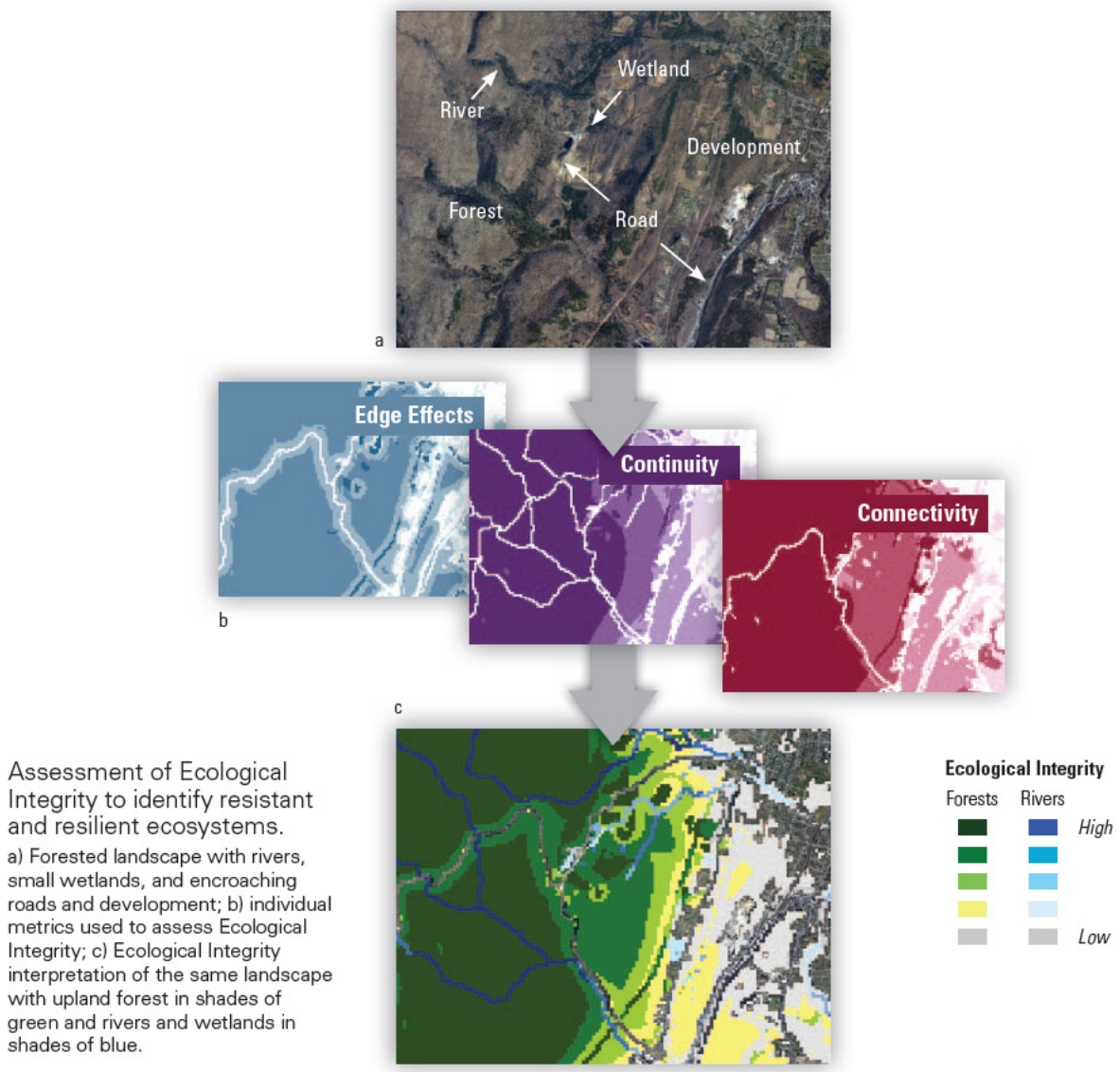
Overview of the Conservation Assessment and Prioritization System (CAPS)

CAPS is a spatial model designed to assess the ecological integrity of lands and water and thereby inform conservation priorities. Ecological integrity can be thought of as the ability of an area to support plants and animals and the natural processes necessary to sustain them over the long term. The CAPS model rests on the assumption that by conserving intact natural areas, we can conserve most species and ecological processes. CAPS is a "coarse-filter" approach, based on spatial data that are available statewide. It does not consider information on rare species (typically considered "fine-filter"), nor does it consider other site-specific information such as land use history. Rare species habitats may or may not have high IEI (*e.g.*, some fragmented wetlands in eastern Massachusetts contain many rare species). Therefore, *BioMap2* final products combine high-integrity ecosystems based on CAPS IEI data with site-specific species habitat and natural community data (a "coarse filter-fine filter approach") as both are crucial for long term biodiversity conservation in a given geography.

The CAPS model divides the entire state into small cells (30 by 30 meter pixels) and then calculates an index of ecological integrity score (IEI) for each cell. The IEI is scaled from 0 to 1, 1 being a high score and 0 being a low score. An IEI score of 1 indicates maximum integrity, and an IEI score of 0 indicates minimum integrity. A cell with an IEI of 1 would typically be in natural cover, far from roads or development. Development, whether it is a lone house or within an urban center, is given an IEI of 0. Calculating the IEI for each pixel begins with a digital base map depicting various classes of developed and undeveloped land and a number of auxiliary layers representing anthropogenic alterations (such as road traffic or impervious surface) and information on ecological variables (such as wetness or stream gradient) (Appendices E and F). *BioMap2* uses the 2009 version of CAPS.

Integrity metrics - Starting with the data described above, the Index of Ecological Integrity (IEI) is developed by computing a variety of landscape metrics to evaluate overall ecological integrity for every 30m pixel (Figure 6). Integrity metrics include 16 stressor metrics and 2 resiliency metrics (Appendix G: CAPS Integrity Metrics). Stressor metrics are meant to capture impacts

that will decrease the ecological integrity of an area if they are present, such as habitat loss from development, effects associated with roads and traffic, invasive species, and edge predators like raccoons, blue jays, and cowbirds. Resiliency metrics are meant to quantify an area's ability to resist and recover from degradation. For instance, the connectedness metric would score a patch of isolated forest lower than an equally sized patch of forest that was well connected to adjacent natural areas. The isolated patch would be less "resilient" because of its inability to support interconnected metapopulations for multiple species, inability to absorb and recover from infrequent and severe natural disturbances, and inability to support other ecological processes. For each integrity metric, models are constructed to compute the intensity of that metric at every pixel across the state.



Assessment of Ecological Integrity to identify resistant and resilient ecosystems.
a) Forested landscape with rivers, small wetlands, and encroaching roads and development; b) individual metrics used to assess Ecological Integrity; c) Ecological Integrity interpretation of the same landscape with upland forest in shades of green and rivers and wetlands in shades of blue.

Figure 6. Building the IEI.

Land cover and other data are used to develop Ecological Integrity metrics, which are then weighted, combined, and scaled to develop a final Index of Ecological Integrity (IEI). Note the "Edge Effects" metric in Figure 6 is a synonym for the actual "Edge Predators" metric, and the "Continuity" metric in the figure is a synonym for the actual "Similarity" metric (Appendix G).

Combining Metric Results – Once individual integrity metrics are computed, they are integrated into a model for predicting ecological integrity. This model is constructed and parameterized for specific ecological communities (for a list of the ecological communities used in this analysis, see Appendix E). For each ecological community, each integrity metric is scaled by percentiles so that, for instance, the best 10% of marshes have values ≥ 0.90, and the best 25% have values ≥ 0.75. This is done to adjust for differences in units of measurement among metrics and to account for differences in the range of metric values for each community. The rescaling by community is done to facilitate identifying the "best" of each community, as opposed to the best overall – which is strongly biased towards the dominant, matrix-forming communities. Metrics are then integrated in a weighted linear combination, to reflect the relative importance of each metric for each ecological community (Appendix H: Metric Parameterizations). For instance, the metric for salt runoff from roads factors into the model for wetland communities but not for forests, since wetlands are more sensitive to this stressor than forests. The resulting models for each community type are then scaled again by percentiles, and combined to compute an overall index of ecological integrity for each point in the landscape. Thus, the final index of ecological integrity for each cell is a weighted combination of the integrity metric outputs for that cell, based on the community the cell falls in. Interpretation of scaled metrics and IEI is straightforward: an IEI of 0.95 means that this cell is in the 95th percentile of highest integrity across the state. Intermediate results are saved to facilitate analysis—thus one can examine not only a map of the final indices of ecological integrity, but maps of road traffic intensity, connectedness, microclimate alterations, and so on.

Scale – CAPS IEI is assessed at different geographic scales (*e.g.*, watershed, ecoregion, and statewide) (Figure 7). Since IEI scores are scaled by percentiles within these geographic extents, the same wetland cell may have a different IEI score depending upon whether it is being compared to other wetlands in the same watershed, as in the watershed scaling, or all wetlands statewide, as in the statewide scaling. A fourth "integrated" scaling attempts to balance ecoregional and watershed scaling with statewide scores, by selecting the highest score among these for each pixel and rescaling the resulting scores to values between 0 and 1. *BioMap2* used each of these scales, depending on which ecosystem was assessed and which subsequent analyses were run, to assure that the best ecosystem examples, both statewide and regionally, were incorporated into *BioMap2*.

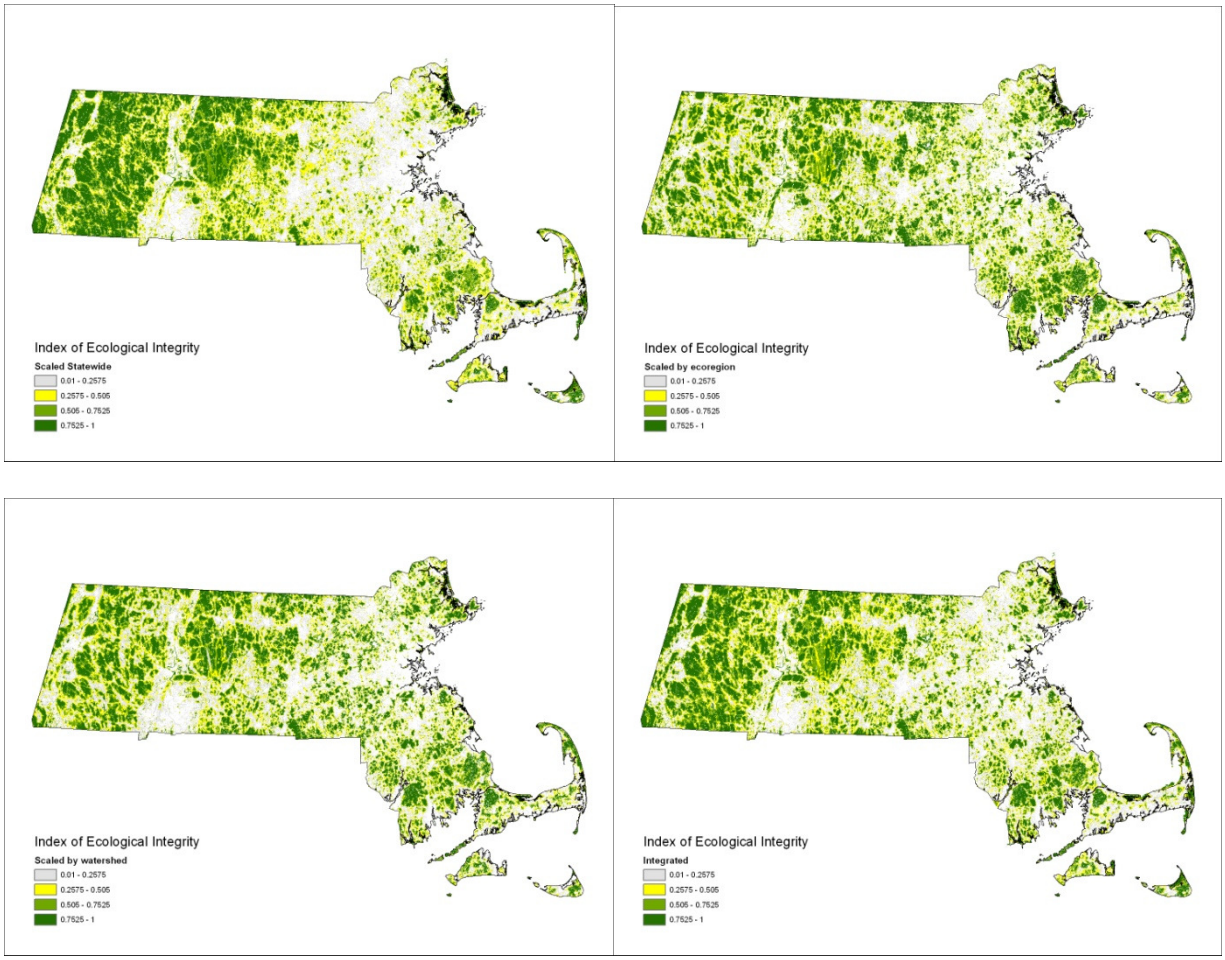


Figure 7. IEI scaled by 4 different extents (statewide, ecoregion, watershed, and integrated)

Finally, the UMass CAPS team also carried out field work to test and validate CAPS predictions of ecological integrity. They sampled several field-based metrics, including exotic invasive earthworms, exotic invasive plants, macrolichens, and native plant species richness. Nearly 100 plots in forested uplands were sampled in the Deerfield River watershed. Further details on methods and the results of field validation can be found on the UMass CAPS website (either http://masscaps.org/ or http://www.umass.edu/landeco/research/caps/caps.html).

IEI for BioMap2 *Landscape Blocks – BioMap2* used a modified version of the CAPS IEI to identify large intact landscapes across the state. Since the goal of identifying Landscape Blocks was to capture large and intact mosaics of natural cover types, rather than identify the best examples of particular ecological communities, in this IEI version we reclassified the land cover types listed in Appendix E into natural vs. non-natural, resulting in a single "natural cover" class. The treatment of natural cover as a single class has the consequence of 1) limiting the number of relevant integrity metrics used to build the IEI and 2) smoothing the resulting IEI values as compared to the finer-scaled community-specific IEI, since scores are parameterized and rescaled for the single combined class rather than for each community type (Figures 8 and 9). For example, in the community-scaled model of CAPS, IEI scores might spike or decline along a river running through a forest (see Figure 8). Although the two ecological communities share a

similar landscape context, each is scaled by percentile to the scores of other forests or rivers, and not to each other. The natural cover version of IEI results in neighboring forest and river pixels having similar IEI values (Figure 9).

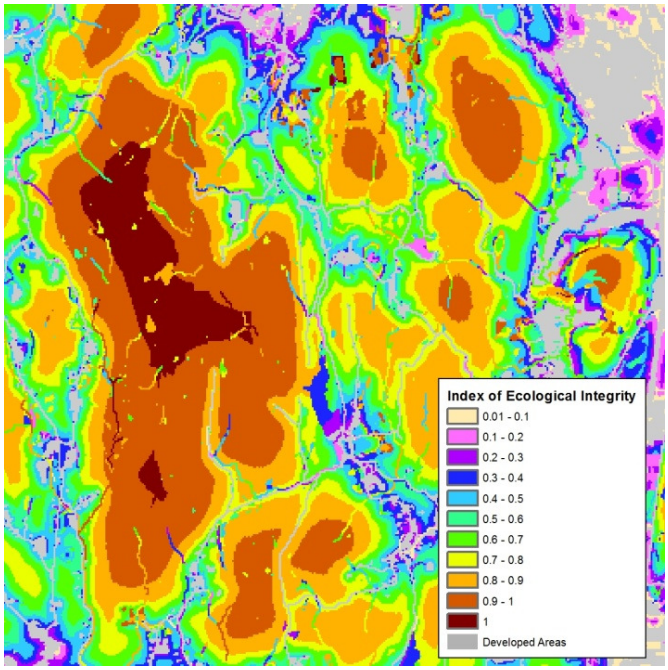


Figure 8. CAPS IEI for ecological communities.

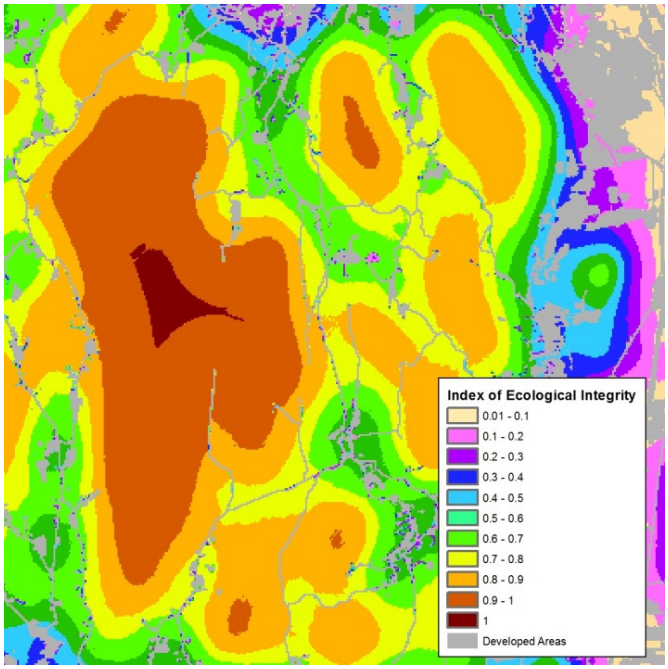


Figure 9. CAPS IEI for natural cover.

To create this customized run, we reclassified the land cover types listed in Appendix E into natural vs. non-natural types. To the developed land classes we added cranberry bogs and transitional lands, which are treated as palustrine and terrestrial community types in the original CAPS analysis. We retained the classification of pasture lands and power lines as natural types, since they provide habitat and contribute to other ecological functions. Integrity metrics were simplified from 18 metrics to the 4 metrics that had the most consistent impact across all types of natural cover (Connectedness, Habitat Loss, Similarity, and Traffic). These integrity metrics were each rescaled from 0 - 1 and then combined in a weighted linear model of ecological integrity for natural cover, then rescaled again by percentile. The final natural cover IEI can be interpreted in an analogous way to the original CAPS IEI, so that pixels with a value ≥ 0.90 represent the highest integrity 10% of natural cover statewide.

Conclusion

The CAPS GIS model located the most intact and least fragmented ecosystems— those with few "edge effects," high local habitat connectivity, low road density and traffic volumes, etc., by looking at all the points across Massachusetts and identifying clusters of high Ecological Integrity. Because these areas are not heavily impacted by development, they are likely to have high ecological resistance and resilience, and to support the natural processes necessary to sustain biodiversity over the long term. The areas identified through this coarse-filter approach support a broad range of species and ecological processes, and complement other approaches and data used in *BioMap2* to prioritize areas for land protection and stewardship.

Chapter Three: Components of Core Habitat -

Section A: Species of Conservation Concern

BioMap2 includes areas delineated to capture the habitats specifically required for the long-term survival of 448 species of conservation concern. This group of species includes those listed under the Massachusetts Endangered Species Act (MESA; M.G.L. c131A) as well as additional species included in the Massachusetts State Wildlife Action Plan (SWAP), and they include vertebrate, invertebrate, and plant species. These species represent specific elements of the native biodiversity of Massachusetts that might not otherwise be captured through more coarse-filter conservation efforts. Except for tern foraging habitat and the broad habitats of the generalist Eastern Box Turtle, these species-specific habitat areas are included as Core Habitats within *BioMap2*. Tern foraging habitat (which includes extensive areas, mainly marine and salt marsh) and some Eastern Box Turtle habitat (based on the largest, highest quality habitat areas currently occupied by the Eastern Box Turtle) were included in Critical Natural Landscape.

MESA-listed Species

Mapping

Species listed under the MESA are some of the most imperiled species in the state, as evidenced by their rarity, population trends, and vulnerability to outside threats. Beginning in 2004, for species listed as Endangered, Threatened, or Special Concern pursuant to MESA, biologists at NHESP with species-specific expertise delineated species-specific habitat areas based on records of observations of those species that are currently in the NHESP database (see Appendix I, Rare Species Observation Forms). These records were evaluated against several criteria for inclusion into the database, such as the expertise of the observer, the documentation provided to confirm identification (photos, description, specimens, etc.), appropriateness of habitat and time of year, whether it was observed within the known range for the species, etc. The NHESP staff developed and implemented mapping guidelines unique to each species, based on a review of the literature, data in the NHESP database, ongoing research, and expert knowledge. These mapping guidelines were developed to include all aspects of a species' life cycle that is spent within the state, and to include all habitats necessary for the long-term survival of each local population (see Appendix J, Mapping Guidelines Outline). For example, the mapping guidelines for a turtle species would include guidelines for delineating overwintering, foraging, and nesting habitat, as well as corridors connecting all these habitat types. A variety of GIS data layers, such as aerial photographs, DEP wetlands, DOT roads, land use, and surficial geology, as well as information in the individual observations records themselves, were used to delineate the habitats of these species. The maximum distance mapped from an individual observation is based on a conservative estimate—again, based on the latest scientific information—of the distance an individual of that species is likely to travel. Features that may act as barriers to movement, whether they are manmade highways or areas of open water, are also included as limiting factors in the guidelines. Developed areas or areas that do not provide high-quality habitat for the species were removed from mapped habitat areas. Only records that meet the strict data

acceptance criteria of NHESP were used in this delineation (see Appendix K, Data Acceptance Guidelines), and only those records of observations between 1985 and 2010 were used.

The areas delineated as habitat for MESA-listed species are used by NHESP staff for many conservation purposes, including land protection prioritization, regulation, habitat restoration, and definition of survey areas. These mapped areas are updated as new information is received (such as additional observation records, the results of new research, new spatial data including new aerials or land use layers, etc.). In that way, NHESP is always using the latest information available for conservation, restoration, regulation, and research. The species-specific habitat polygons used in *BioMap2* were extracted from the NHESP database on August 12, 2010, and are based on records documenting nearly 5,000 current populations of state-listed species reported to NHESP.

NHESP staff involved in mapping species habitat include:

- Plants: Bryan Connolly, Jennifer Garrett
- Invertebrates: Marea Gabriel, Lynn Harper, Kim Justham, Michael Nelson, Tim Simmons
- Vertebrates: Kristin Black, Chris Buelow, Lori Erb, Jacob Kubel, Lisa MacGillivray, Misty-Anne Marold, Scott Melvin, Carolyn Mostello
- GIS Staff: Tara Boswell
- Data Staff: Tara Huguenin, Kim Justham, Sarah Maier

Although the NHESP currently (2010) lists 435 species under the MESA, only habitats for 413 of these species were included in *BioMap2*. This is true for three reasons:

- A number of species are strictly marine in Massachusetts (whales, sea turtles).
- Others require such ephemeral terrestrial habitats that are so fleeting on the landscape that it would be impossible to delineate meaningful habitat for them that would persist and be occupied for any length of time (Golden-winged Warbler).
- Several species are currently included on the MESA List, but have not been seen in Massachusetts in more than 25 years.

Because *BioMap2* is intended to represent areas that will support the long-term persistence of the native biodiversity of Massachusetts, some poor quality habitats for MESA-listed species were not included. NHESP staff followed standard Natural Heritage Element Occurrence Ranking Methodology in order to evaluate the estimated viability (probability of persistence) of populations of a given species. This system is used to rank populations on their overall relative quality based on population size, abiotic and biotic conditions, and landscape context. Populations of listed species with poor probability of persistence for the long term (usually D-ranked occurrences) were not included in *BioMap2*.

Table 7. Natural Heritage Element Occurrence Rankings and their descriptions

Viability Rank	Estimated Viability	Descriptions
A	Excellent	If current conditions prevail, population is very likely to persist for the foreseeable future in its current condition or better
B	Good	If current conditions prevail, population is likely to persist for the foreseeable future in its current condition or better
C	Fair	Population persistence is uncertain under current conditions but may persist for the foreseeable future with appropriate protection or management
D	Poor	Population has a high risk of extirpation

Additionally, for two Special Concern species of turtle—the Eastern Box Turtle and the Wood Turtle—only the very highest quality sites are included in *BioMap2*. This is because they require such large areas of habitat for long-term persistence, and because they are still fairly well represented on the landscape, as indicated by their listing as Species of Special Concern, the lowest category of vulnerability under the MESA. Because the Eastern Box Turtle is a wide-ranging generalist species, the large landscape needed by this species was included in Critical Natural Landscape and only the very site-specific high priority sites (nesting areas, areas of high turtle density, etc.) are included in Core Habitat.

Also included in Critical Natural Landscape rather than Core Habitat is the foraging habitat for four species of tern. The MESA lists three species of tern (Arctic, Common, and Least) as Species of Special Concern and one species (Roseate) as Endangered. These species nest on beaches, islands, and in salt marshes along the Massachusetts coast, foraging over the open ocean, in bays and inlets, and in salt marshes. Because of the wide-ranging habitat of these species when they forage, and the fact that most of it is open ocean, tern foraging habitat was included in *BioMap2* as Critical Natural Landscape, while breeding and staging areas are included in Core Habitat.

Vertebrate Species

Fish

There are 10 species of fish listed under the Massachusetts Endangered Species Act; habitats for all of these species are included in *BioMap2*. Freshwater habitat for these species is delineated based on current observation records, and generally includes aquatic habitats (rivers, streams, lakes, and ponds depending on the species) that are within 2 kilometers of a current observation record. Dams without fish ladders were considered barriers to movements of these species, and therefore are limiting factors in habitat delineation. Depending on the species, changes to the flow rates (such as impoundments for riverine species, changes in stream class size such as where tributaries join main stems, etc.) can also limit the extent of habitat delineated. Habitats included in the fish species' "footprint" include those used during different seasons of the year and different portions of the animals' lives such as breeding habitat, spawning habitat, juvenile habitat, foraging habitat, and migration routes where applicable.

Table 8. MESA-listed fish species, as of 2010.

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Shortnose Sturgeon	*Acipenser brevirostrum*	E	Mapped
Atlantic Sturgeon	*Acipenser oxyrinchus*	E	Mapped
Longnose Sucker	*Catostomus catostomus*	SC	Mapped
Lake Chub	*Couesius plumbeus*	E	Mapped
Threespine Stickleback	*Gasterosteus aculeatus*	T	Mapped
Eastern Silvery Minnow	*Hybognathus regius*	SC	Mapped
American Brook Lamprey	*Lampetra appendix*	T	Mapped
Burbot	*Lota lota*	SC	Mapped
Bridle Shiner	*Notropis bifrenatus*	SC	Mapped
Northern Redbelly Dace	*Phoxinus eos*	E	Mapped

Amphibians

There are four species of amphibians listed in Massachusetts under MESA—three salamanders and one toad. Habitats for all of these species are included in *BioMap2*. Habitat delineations for these species incorporate the ephemeral breeding/larval habitats as well as the upland habitats used by the terrestrial metamorphs and adults for the bulk of their lives, and enough contiguous habitat between breeding pools and terrestrial habitats to allow for successful movements between them. For the Ambystomid salamanders, the upland habitat is primarily forested areas within 2,000 feet of a current observation record. For the Spadefoot toad, the preferred upland habitat includes much more open areas with scattered bushes and loose sandy soils. Roads with moderate to heavy traffic are considered to be barriers to movement for all of these species, and therefore limit the extent of habitat delineated within populated areas.

Table 9. MESA-listed amphibian species, as of 2010.

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Jefferson Salamander	*Ambystoma jeffersonianum*	SC	Mapped
Blue-spotted Salamander	*Ambystoma laterale*	SC	Mapped
Marbled Salamander	*Ambystoma opacum*	T	Mapped
Eastern Spadefoot	*Scaphiopus holbrookii*	T	Mapped

Reptiles

There are 15 reptile species on the MESA list, including five sea turtle species, six non-marine turtle species, and four species of snake. Because *BioMap2* is not intended to be a marine conservation plan and because they do not nest in Massachusetts, no habitats are included for the sea turtles listed as imperiled in Massachusetts. Habitat for the Diamond-backed Terrapin, a brackish-water species, is included in *BioMap2* because the life cycle of this resident species is primarily played out within the 0.3 nautical miles of the shore of Massachusetts that is included in *BioMap2*. Habitats for all MESA-listed non-marine turtle and snake species are included in *BioMap2*. Areas incorporated into the conservation plan include overwintering habitat (such as hibernacula for snakes, large ponds for the Northern Red-bellied Cooter, forested areas with

loose soils for Eastern Box Turtles), foraging habitat, breeding and nesting habitat, and migration corridors between these different areas.

Because the Wood Turtle and Eastern Box Turtle require such large habitat areas within Massachusetts, only the largest, highest quality, occupied habitat areas for them are included in *BioMap2*.

- Eastern Box Turtle
  The most critical habitats, such as nest sites and areas with the highest densities of Eastern Box Turtles within the broader landscape, were included within Core Habitat. The larger landscape blocks required for this species were included in Critical Natural Landscape rather than Core Habitat, because the Eastern Box Turtle is a habitat generalist which needs large intact areas for long-term persistence in Massachusetts. These large habitat areas are based on Eastern Box Turtle home range information from various research studies as well as population viability models, and are usually larger than 500 acres each, balanced across four conservation management regions (loosely based on ecoregions, but more broadly defined to include only the areas within which the Eastern Box Turtle is found in Massachusetts, and separated by barriers to Eastern Box Turtle movements, such as the Cape Cod Canal). Observation records more than 25 years old could be considered in the delineation of these large landscape areas where there is every reason to believe the habitat is still suitable and populations still exist, particularly since individuals of this species can live for many decades, sometimes as long as 100 years. Some of these Eastern Box Turtle landscapes exist in areas where the Landscape Blocks were delineated through computer modeling, so there can be overlap of Eastern Box Turtle landscape areas and Landscape Blocks defined by the IEI modeling.
- Wood Turtle
  The best populations of this species were included in *BioMap2* as Species of Conservation Concern Core Habitat.

Table 10. MESA-listed reptile species, as of 2010.

Common Name	**Scientific Name**	**MESA Status (2010)**	**Mapped/Not Mapped in *BioMap2***
Copperhead	*Agkistrodon contortrix*	E	Mapped
Loggerhead Seaturtle	*Caretta caretta*	T	Not Mapped
Eastern Worm Snake	*Carphophis amoenus*	T	Mapped
Green Seaturtle	*Chelonia mydas*	T	Not Mapped
Timber Rattlesnake	*Crotalus horridus*	E	Mapped
Leatherback Seaturtle	*Dermochelys coriacea*	E	Not mapped
Blanding's Turtle	*Emydoidea blandingii*	T	Mapped
Hawksbill Seaturtle	*Eretmochelys imbricate*	E	Not Mapped
Wood Turtle	*Glyptemys insculpta*	SC	Mapped
Bog Turtle	*Glyptemys muhlenbergii*	E	Mapped
Kemp's Ridley Seaturtle	*Lepidochelys kempii*	E	Not Mapped
Diamond-backed Terrapin	*Malaclemys terrapin*	T	Mapped
Eastern Rat Snake	*Pantherophis alleghaniensis*	E	Mapped
Northern Red-bellied Cooter	*Pseudemys rubriventris* pop. 1	E	Mapped
Eastern Box Turtle	*Terrapene carolina*	SC	Mapped

Birds

The Massachusetts Endangered Species List includes 28 bird species, and *BioMap2* contains habitat areas delineated for all but one of those species. Because of the ephemeral and unstable nature of the habitat needed by the Golden-winged Warbler, no habitat areas were included in *BioMap2* for this species. For birds, because so many species may use Massachusetts as a stopover area in their annual movements, and because conservation efforts are most effective for listed species by focusing on breeding areas, only observation reports of breeding occurrences are mapped by NHESP staff. There were two exceptions. One exception is the four species of tern that breed in Massachusetts. Staging areas which include large congregations of terns gathering to migrate south for the winter are also delineated by NHESP staff for conservation purposes and are included in *BioMap2*. Habitat types delineated for tern species and included in *BioMap2* are breeding habitats, nesting habitats, foraging habitat used by adults and young, and staging areas. The foraging areas delineated for the four tern species are included in Critical Natural Landscape rather than Core Habitat, because they are so broad and include primarily open ocean, inlets, bays, and salt marshes. These brackish and marine landscape areas are based on actual data collected on terns observed foraging in Nantucket Sound and Buzzard's Bay, but also on estimates of foraging habits of birds nesting or staging in particular parts of the state. High density colonies would require individuals to travel further to forage, so foraging areas could contain habitat out to 1 or 8 miles from shore, depending on the species and the density of birds utilizing a particular site. The other exception is significant wintering areas of Bald Eagle; these were also included in *BioMap2*.

Table 11. MESA-listed bird species, as of 2010.

Common Name	**Scientific Name**	**MESA Status (2010)**	**Mapped/Not Mapped in *BioMap2***
Sharp-shinned Hawk	*Accipiter striatus*	SC	Mapped
Henslow's Sparrow	*Ammodramus henslowii*	E	Mapped
Grasshopper Sparrow	*Ammodramus savannarum*	T	Mapped
Short-eared Owl	*Asio flammeus*	E	Mapped
Long-eared Owl	*Asio otus*	SC	Mapped
Upland Sandpiper	*Bartramia longicauda*	E	Mapped
American Bittern	*Botaurus lentiginosus*	E	Mapped
Piping Plover	*Charadrius melodus*	T	Mapped
Northern Harrier	*Circus cyaneus*	T	Mapped
Sedge Wren	*Cistothorus platensis*	E	Mapped
Blackpoll Warbler	*Dendroica striata*	SC	Mapped
Peregrine Falcon	*Falco peregrinus*	E	Mapped
Common Moorhen	*Gallinula chloropus*	SC	Mapped
Common Loon	*Gavia immer*	SC	Mapped
Bald Eagle	*Haliaeetus leucocephalus*	E	Mapped
Least Bittern	*Ixobrychus exilis*	E	Mapped
Leach's Storm-petrel	*Oceanodroma leucorhoa*	E	Mapped
Mourning Warbler	*Oporornis philadelphia*	SC	Mapped
Northern Parula	*Parula americana*	T	Mapped
Pied-billed Grebe	*Podilymbus podiceps*	E	Mapped
Vesper Sparrow	*Pooecetes gramineus*	T	Mapped
King Rail	*Rallus elegans*	T	Mapped
Roseate Tern	*Sterna dougallii*	E	Mapped
Common Tern	*Sterna hirundo*	SC	Mapped

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Arctic Tern	*Sterna paradisaea*	SC	Mapped
Least Tern	*Sternula antillarum*	SC	Mapped
Barn Owl	*Tyto alba*	SC	Mapped
Golden-winged Warbler	*Vermivora chrysoptera*	E	Not Mapped

Mammals

Eleven species of mammal are listed under the Massachusetts Endangered Species Act, but only habitats for four of these species have been delineated and included in *BioMap2*. Six of the species not included in *BioMap2* are whales, which are marine and therefore not included in this conservation plan, and the seventh species is the Indiana Myotis—a federally Endangered bat species that has not been seen in Massachusetts since the 1930s. The four MESA-listed mammal species included in *BioMap2* are all small animals with very limited habitats, and the areas delineated for their conservation include areas that provide all the necessary elements needed for their survival such as foraging habitat, breeding and nesting habitat, and overwintering habitat.

Table 12. MESA-listed mammal species, as of 2010.

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Sei Whale	*Balaenoptera borealis*	E	Not Mapped
Blue Whale	*Balaenoptera musculus*	E	Not Mapped
Fin Whale	*Balaenoptera physalus*	E	Not Mapped
Northern Right Whale	*Eubalaena glacialis*	E	Not Mapped
Humpback Whale	*Megaptera novaeangliae*	E	Not Mapped
Small-footed Myotis	*Myotis leibii*	SC	Mapped
Indiana Myotis	*Myotis sodalus*	E	Not Mapped
Sperm Whale	*Physeter catodon*	E	Not Mapped
Rock Shrew	*Sorex dispar*	SC	Mapped
Water Shrew	*Sorex palustris*	SC	Mapped
Southern Bog Lemming	*Synaptomys cooperi*	SC	Mapped

Invertebrate Species

Freshwater Mussels

There are seven species of freshwater mussel listed under the Massachusetts Endangered Species Act; habitats for all of these species are included in *BioMap2*. Delineation of habitat for these species incorporates areas for juvenile and adult mussels by including areas with appropriate substrate, water flows, and habitat connectivity, as well as considering larval host fish dispersal. Dams and other barriers limit the extent of the areas mapped for MESA-listed mussel species, and a riverine population's delineated habitat extends no more than 2 to 5 kilometers, depending on intervening habitat conditions, from a current observation record in any given area. Habitat for lake and pond populations includes the entire water body unless dispersal between observation records is obstructed.

Table 13. MESA-listed freshwater mussel species, as of 2010.

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Dwarf Wedgemussel	*Alasmidonta heterodon*	E	Mapped
Triangle Floater	*Alasmidonta undulata*	SC	Mapped
Brook Floater	*Alasmidonta varicosa*	E	Mapped
Yellow Lampmussel	*Lampsilis cariosa*	E	Mapped
Tidewater Mucket	*Leptodea ochracea*	SC	Mapped
Eastern Pondmussel	*Ligumia nasuta*	SC	Mapped
Creeper	*Strophitus undulatus*	SC	Mapped

Dragonflies and Damselflies

Twenty-five species of dragonfly (insects in the order Odonata and suborder Anisoptera) and five species of damselfly (insects in the order Odonata and suborder Zygoptera) are on the MESA list, and critical habitats for all of them are mapped and included in *BioMap2*. Species-specific habitats for odonates are focused around the aquatic larval habitats (rivers, streams, bogs, coastal plain ponds, and other wetlands) as well as upland habitat for adults to sexually mature, feed, roost, and breed. The necessary adult foraging and upland habitat includes a wide variety of habitat types depending on the species in question, and may contain open fields, forests, wetlands, streams, agricultural areas, and shrublands. Because habitat needs and adult foraging distances are poorly known for a number of odonate species, upland habitat areas are conservatively delineated and are primarily limited to within 100 m from the aquatic larval habitat. Heavily developed sites, including residential areas which may provide some foraging habitat in backyards, are excluded from areas mapped for MESA-listed odonates as they are not ideal long-term conservation targets.

Table 14. MESA-listed dragonfly and damselfly species, as of 2010.

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Subarctic Darner	*Aeshna subarctica*	T	Mapped
Comet Darner	*Anax longipes*	SC	Mapped
Ocellated Darner	*Boyeria grafiana*	SC	Mapped
Tule Bluet	*Enallagma carunculatum*	SC	Mapped
Attenuated Bluet	*Enallagma daeckii*	SC	Mapped
New England Bluet	*Enallagma laterale*	SC	Mapped
Scarlet Bluet	*Enallagma pictum*	T	Mapped
Pine Barrens Bluet	*Enallagma recurvatum*	T	Mapped
Spine-crowned Clubtail	*Gomphus abbreviatus*	E	Mapped
Harpoon Clubtail	*Gomphus descriptus*	E	Mapped
Midland Clubtail	*Gomphus fraternus*	E	Mapped
Rapids Clubtail	*Gomphus quadricolor*	T	Mapped
Cobra Clubtail	*Gomphus vastus*	SC	Mapped
Skillet Clubtail	*Gomphus ventricosus*	SC	Mapped
Umber Shadowdragon	*Neurocordulia obsoleta*	SC	Mapped
Stygian Shadowdragon	*Neurocordulia yamaskanensis*	SC	Mapped
Brook Snaketail	*Ophiogomphus aspersus*	SC	Mapped
Riffle Snaketail	*Ophiogomphus carolus*	T	Mapped

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Spatterdock Darner	*Rhionaeschna mutata*	SC	Mapped
Ski-tipped Emerald	*Somatochlora elongata*	SC	Mapped
Forcipate Emerald	*Somatochlora forcipata*	SC	Mapped
Coppery Emerald	*Somatochlora georgiana*	E	Mapped
Incurvate Emerald	*Somatochlora incurvata*	T	Mapped
Kennedy's Emerald	*Somatochlora kennedyi*	E	Mapped
Mocha Emerald	*Somatochlora linearis*	SC	Mapped
Riverine Clubtail	*Stylurus amnicola*	E	Mapped
Zebra Clubtail	*Stylurus scudderi*	SC	Mapped
Arrow Clubtail	*Stylurus spiniceps*	T	Mapped
Ebony Boghaunter	*Williamsonia fletcheri*	E	Mapped
Ringed Boghaunter	*Williamsonia lintneri*	E	Mapped

Beetles

Eight of the nine beetle species listed under the Massachusetts Endangered Species Act are tiger beetles (*Cicindela* spp.). The ninth species is the American Burying Beetle—a federally Endangered species that is currently supported through a supplementation program in a small area in Massachusetts—and due to its fossorial habits and the difficulty in identifying critical supporting habitat, it is not included in *BioMap2*. Tiger beetle habitat, on the other hand, is fairly specific although dynamic over time, so habitats are delineated for the eight remaining MESA-listed beetle species. As larvae, tiger beetles live in burrows underground and require species specific substrates for those burrows, all of which are fairly void of vegetation regardless of beetle species. Substrates that support tiger beetle populations may be sandy beaches, rocky outcrops, stream banks, or simple paths through shrublands depending on the species. Appropriate habitat patches are delineated based on the current observation records contained in the NHESP database, and include enough of the local habitat to allow for movements of the local populations as the dynamic substrates on which they depend change from year to year.

Table 15. MESA-listed beetle species, as of 2010.

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Northeastern Beach Tiger Beetle	*Cicindela dorsalis dorsalis*	E	Mapped
Twelve-spotted Tiger Beetle	*Cicindela duodecimguttata*	SC	Mapped
Bank Tiger Beetle	*Cicindela limbalis*	SC	Mapped
Cobblestone Tiger Beetle	*Cicindela marginipennis*	E	Mapped
Barrens Tiger Beetle	*Cicindela patruela*	E	Mapped
Puritan Tiger Beetle	*Cicindela puritana*	E	Mapped
Purple Tiger Beetle	*Cicindela purpurea*	SC	Mapped
Hentz's Redbelly Tiger Beetle	*Cicindela rufiventris hentzii*	T	Mapped
American Burying Beetle	*Nicrophorus americanus*	E	Not Mapped

Butterflies and Moths

Forty-five MESA-listed moth and butterfly species are mapped based on the extent of breeding habitat. For each species, breeding habitat is defined as a vegetation community of particular composition and structure. Presence of larval host plants is a critical compositional factor.

Where the breeding habitat is fairly widespread, mapped habitat is limited to that occurring within 1 or 2 kilometers (depending on the species) from an observation record. Heavily developed areas are excluded from delineated habitat. The Straight Lined Mallow Moth (*Bagisara rectifascia*) was once thought to be limited in its food source, habitat, and range in the state, but recent survey efforts have demonstrated that this species is more widespread and its habitat requirements less limiting than previously thought. Therefore, it is proposed for de-listing as a Species of Special Concern in Massachusetts, and is not included in *BioMap2*.

Table 16. MESA-listed butterfly and moth species, as of 2010.

Common Name	**Scientific Name**	**MESA Status (2010)**	**Mapped/Not Mapped in *BioMap2***
Coastal Heathland Cutworm	*Abagrotis nefascia*	SC	Mapped
Barrens Daggermoth	*Acronicta albarufa*	T	Mapped
Drunk Apamea Moth	*Apamea inebriata*	SC	Mapped
New Jersey Tea Inchworm	*Apodrepanulatrix liberaria*	E	Mapped
Straight Lined Mallow Moth	*Bagisara rectifascia*	SC	Not Mapped
Hessel's Hairstreak	*Callophrys hesseli*	SC	Mapped
Frosted Elfin	*Callophrys irus*	SC	Mapped
Bog Elfin	*Callophrys lanoraieensis*	T	Mapped
Gerhard's Underwing Moth	*Catocala herodias gerhardi*	SC	Mapped
Precious Underwing Moth	*Catocala pretiosa pretiosa*	E	Mapped
Waxed Sallow Moth	*Chaetaglaea cerata*	SC	Mapped
Melsheimer's Sack Bearer	*Cicinnus melsheimeri*	T	Mapped
Chain Dot Geometer	*Cingilia catenaria*	SC	Mapped
Unexpected Cycnia	*Cycnia inopinatus*	T	Mapped
Three-lined Angle Moth	*Digrammia eremiata*	T	Mapped
Imperial Moth	*Eacles imperialis*	T	Mapped
Early Hairstreak	*Erora laeta*	T	Mapped
Persius Duskywing	*Erynnis persius persius*	E	Mapped
Sandplain Euchlaena	*Euchlaena madusaria*	SC	Mapped
Dion Skipper	*Euphyes dion*	T	Mapped
The Pink Streak	*Faronta rubripennis*	T	Mapped
Phyllira Tiger Moth	*Grammia phyllira*	E	Mapped
Slender Clearwing Sphinx Moth	*Hemaris gracilis*	SC	Mapped
Barrens Buckmoth	*Hemileuca maia*	SC	Mapped
Buchholz's Gray	*Hypomecis buchholzaria*	E	Mapped
Pine Barrens Itame	*Itame* sp. 1 nr. *inextricata*	SC	Mapped
Pale Green Pinion Moth	*Lithophane viridipallens*	SC	Mapped
Twilight Moth	*Lycia rachelae*	E	Mapped
Pine Barrens Lycia	*Lycia ypsilon*	T	Mapped
Barrens Metarranthis Moth	*Metarranthis apiciaria*	E	Mapped
Coastal Swamp Metarranthis Moth	*Metarranthis pilosaria*	SC	Mapped
Northern Brocade Moth	*Neoligia semicana*	SC	Mapped
Dune Noctuid Moth	*Oncocnemis riparia*	SC	Mapped
Pitcher Plant Borer Moth	*Papaipema appassionata*	T	Mapped
Ostrich Fern Borer Moth	*Papaipema* sp. 2 nr. *pterisii*	SC	Mapped
Chain Fern Borer Moth	*Papaipema stenocelis*	T	Mapped
Water-willow Stem Borer	*Papaipema sulphurata*	T	Mapped
Mustard White	*Pieris oleracea*	T	Mapped
Pink Sallow	*Psectraglaea carnosa*	SC	Mapped
Southern Ptichodis	*Ptichodis bistrigata*	T	Mapped

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Orange Sallow Moth	*Rhodoecia aurantiago*	T	Mapped
Oak Hairstreak	*Satyrium favonius*	SC	Mapped
Spartina Borer Moth	*Spartiniphaga inops*	SC	Mapped
Faded Gray Geometer	*Stenoporpia polygrammaria*	T	Mapped
Pine Barrens Zale	*Zale* sp. 1 nr. *lunifera*	SC	Mapped
Pine Barrens Zanclognatha	*Zanclognatha martha*	T	Mapped

Miscellaneous Invertebrates

There are an additional 16 species of invertebrate that are not insects or mussels but are listed under the Massachusetts Endangered Species Act. Of these, three species are not included in *BioMap2* because they have not been documented in the state within the last 25 years. The remaining 13 invertebrate species include crustaceans, snails, a sponge, and a flatworm. These species all have habitats that are fairly constrained and very limited in the landscape, and can be defined by the aquatic or wetland habitat in which they are found.

Table 17. MESA-listed miscellaneous invertebrate species, as of 2010.

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Intricate Fairy Shrimp	*Eubranchipus intricatus*	SC	Mapped
Agassiz's Clam Shrimp	*Eulimnadia agassizii*	E	Mapped
Walker's Limpet	*Ferrissia walkeri*	SC	Mapped
New England Siltsnail	*Floridobia winkleyi*	SC	Mapped
Northern Spring Amphipod	*Gammarus pseudolimnaeus*	SC	Mapped
American Clam Shrimp	*Limnadia lenticularis*	SC	Mapped
Coastal Marsh Snail	*Littoridinops tenuipes*	SC	Mapped
New England Medicinal Leech	*Macrobdella sestertia*	SC	Not Mapped
Boreal Marstonia	*Marstonia lustrica*	E	Mapped
Sunderland Spring Planarian	*Polycelis remota*	E	Mapped
Slender Walker	*Pomatiopsis lapidaria*	E	Mapped
Smooth Branched Sponge	*Spongilla aspinosa*	SC	Mapped
Taconic Cave Amphipod	*Stygobromus borealis*	E	Not Mapped
Piedmont Groundwater Amphipod	*Stygobromus tenuis tenuis*	SC	Mapped
Coastal Swamp Amphipod	*Synurella chamberlaini*	SC	Mapped
Boreal Turret Snail	*Valvata sincera*	E	Not Mapped

Plant Species

The Massachusetts Endangered Species Act lists 259 species of vascular plant as Endangered, Threatened, or Special Concern, as of 2010. Of these 259, only four species are not included in *BioMap2*, and they are excluded because none of these species has been seen within Massachusetts in the last 25 years. The habitats for the remaining 255 species are delineated based on the specific needs of each species—whether the limestone-rich dolomite ledges of western Massachusetts, or the seasonally variable coastal plain ponds of Cape Cod. The stable or ephemeral nature of each species is taken into account when reviewing the records and when mapping habitats, and soil types, seed dispersal and longevity, and site successional stage are

incorporated into habitat mapping guidelines. Species-specific habitats are conservatively delineated based on observation records in the NHESP database.

Table 18. MESA-listed plant species, as of 2010.

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Black Maple	*Acer nigrum*	SC	Mapped
Black Cohosh	*Actaea racemosa*	E	Mapped
Climbing Fumitory	*Adlumia fungosa*	SC	Mapped
Sandplain Gerardia	*Agalinis acuta*	E	Mapped
Purple Giant Hyssop	*Agastache scrophulariifolia*	E	Mapped
Lesser Snakeroot	*Ageratina aromatica*	E	Mapped
Small-flowered Agrimony	*Agrimonia parviflora*	E	Mapped
Hairy Agrimony	*Agrimonia pubescens*	T	Mapped
Mountain Alder	*Alnus viridis* ssp. *crispa*	T	Mapped
Bartram's Shadbush	*Amelanchier bartramiana*	T	Mapped
Nantucket Shadbush	*Amelanchier nantucketensis*	SC	Mapped
Roundleaf Shadbush	*Amelanchier sanguinea*	SC	Mapped
Annual Peanut-grass	*Amphicarpum amphicarpon*	E	Mapped
Putty-root	*Aplectrum hyemale*	E	Mapped
Lyre-leaved Rock-cress	*Arabidopsis lyrata*	E	Mapped
Dwarf Mistletoe	*Arceuthobium pusillum*	SC	Mapped
Arethusa	*Arethusa bulbosa*	T	Mapped
Green Dragon	*Arisaema dracontium*	T	Mapped
Purple Needlegrass	*Aristida purpurascens*	T	Mapped
Seabeach Needlegrass	*Aristida tuberculosa*	T	Mapped
Purple Milkweed	*Asclepias purpurascens*	E	Mapped
Linear-leaved Milkweed	*Asclepias verticillata*	T	Mapped
Mountain Spleenwort	*Asplenium montanum*	E	Mapped
Wall-rue Spleenwort	*Asplenium ruta-muraria*	T	Mapped
Swamp Birch	*Betula pumila*	E	Mapped
Eaton's Beggar-ticks	*Bidens eatonii*	E	Mapped
Estuary Beggar-ticks	*Bidens hyperborea*	E	Mapped
Downy Wood-mint	*Blephilia ciliata*	E	Mapped
Hairy Wood-mint	*Blephilia hirsuta*	E	Mapped
Smooth Rock-cress	*Boechera laevigata*	T	Mapped
Green Rock-cress	*Boechera missouriensis*	T	Mapped
River Bulrush	*Bolboschoenus fluviatilis*	SC	Mapped
Reed Bentgrass	*Calamagrostis pickeringii*	E	Mapped
New England Northern Reed Grass	*Calamagrostis stricta* ssp. *inexpansa*	E	Mapped
Low Bindweed	*Calystegia spithamaea*	E	Mapped
Purple Cress	*Cardamine douglassii*	E	Mapped
Long's Bitter-cress	*Cardamine longii*	E	Mapped
Fen Cuckoo Flower	*Cardamine pratensis* var. *palustris*	T	Mapped
Foxtail Sedge	*Carex alopecoidea*	T	Mapped
Back's Sedge	*Carex backii*	E	Mapped
Bailey's Sedge	*Carex baileyi*	T	Mapped
Bush's Sedge	*Carex bushii*	E	Mapped
Chestnut-colored Sedge	*Carex castanea*	E	Mapped
Creeping Sedge	*Carex chordorrhiza*	E	Mapped
Davis's Sedge	*Carex davisii*	E	Mapped

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Handsome Sedge	*Carex formosa*	T	Mapped
Glaucescent Sedge	*Carex glaucodea*	E	Mapped
Slender Woodland Sedge	*Carex gracilescens*	E	Not Mapped
Gray's Sedge	*Carex grayi*	T	Mapped
Hitchcock's Sedge	*Carex hitchcockiana*	SC	Mapped
Shore Sedge	*Carex lenticularis*	T	Mapped
Glaucous Sedge	*Carex livida*	E	Not Mapped
False Hop-sedge	*Carex lupuliformis*	E	Mapped
Midland Sedge	*Carex mesochorea*	E	Mapped
Michaux's Sedge	*Carex michauxiana*	E	Mapped
Mitchell's Sedge	*Carex mitchelliana*	T	Mapped
Few-fruited Sedge	*Carex oligosperma*	E	Mapped
Few-flowered Sedge	*Carex pauciflora*	E	Mapped
Variable Sedge	*Carex polymorpha*	E	Mapped
Schweinitz's Sedge	*Carex schweinitzii*	E	Mapped
Dioecious Sedge	*Carex sterilis*	T	Mapped
Walter's Sedge	*Carex striata*	E	Mapped
Fen Sedge	*Carex tetanica*	SC	Mapped
Hairy-fruited Sedge	*Carex trichocarpa*	T	Mapped
Tuckerman's Sedge	*Carex tuckermanii*	E	Mapped
Cat-tail Sedge	*Carex typhina*	T	Mapped
Nodding Chickweed	*Cerastium nutans*	E	Mapped
Devil's-bit	*Chamaelirium luteum*	E	Mapped
Fogg's Goosefoot	*Chenopodium foggii*	E	Mapped
Narrow-leaved Spring Beauty	*Claytonia virginica*	E	Mapped
Purple Clematis	*Clematis occidentalis*	SC	Mapped
Hemlock Parsley	*Conioselinum chinense*	SC	Mapped
Autumn Coralroot	*Corallorhiza odontorhiza*	SC	Mapped
Broom Crowberry	*Corema conradii*	SC	Mapped
Bicknell's Hawthorn	*Crataegus bicknellii*	E	Mapped
Bushy Rockrose	*Crocanthemum dumosum*	SC	Mapped
Fragile Rock-brake	*Cryptogramma stelleri*	E	Mapped
Northern Wild Comfrey	*Cynoglossum virginianum* var. *boreale*	E	Mapped
Engelmann's Umbrella-sedge	*Cyperus engelmannii*	T	Mapped
Houghton's Flatsedge	*Cyperus houghtonii*	E	Mapped
Ram's-head Lady's-slipper	*Cypripedium arietinum*	E	Mapped
Small Yellow Lady's-slipper	*Cypripedium parviflorum* var. *makasin*	E	Mapped
Showy Lady's-slipper	*Cypripedium reginae*	SC	Mapped
Tufted Hairgrass	*Deschampsia cespitosa* ssp. *glauca*	E	Mapped
Large-bracted Tick-trefoil	*Desmodium cuspidatum*	T	Mapped
Mattamuskeet Panic-grass	*Dichanthelium dichotomum* ssp. *mattamuskeetense*	E	Mapped
Commons's Panic-grass	*Dichanthelium ovale* ssp. *pseudopubescens*	SC	Mapped
Rough Panic-grass	*Dichanthelium scabriusculum*	T	Mapped
Wright's Panic-grass	*Dichanthelium wrightianum*	SC	Mapped
Cornel-leaved Aster	*Doellingeria infirma*	E	Mapped
American Waterwort	*Elatine americana*	E	Mapped
Wright's Spike-rush	*Eleocharis diandra*	E	Mapped
Intermediate Spike-sedge	*Eleocharis intermedia*	T	Mapped
Tiny-fruited Spike-sedge	*Eleocharis microcarpa* var. *filiculmis*	E	Mapped

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Ovate Spike-sedge	*Eleocharis ovata*	E	Mapped
Few-flowered Spike-sedge	*Eleocharis quinqueflora*	E	Mapped
Three-angled Spike-sedge	*Eleocharis tricostata*	E	Mapped
Hairy Wild Rye	*Elymus villosus*	E	Mapped
Dwarf Scouring-rush	*Equisetum scirpoides*	SC	Mapped
Frank's Lovegrass	*Eragrostis frankii*	SC	Mapped
Parker's Pipewort	*Eriocaulon parkeri*	E	Mapped
Slender Cottongrass	*Eriophorum gracile*	T	Mapped
New England Boneset	*Eupatorium novae-angliae*	E	Mapped
Northern Bedstraw	*Galium boreale*	E	Mapped
Labrador Bedstraw	*Galium labradoricum*	T	Mapped
Purple Cudweed	*Gamochaeta purpurea*	E	Mapped
Andrews' Bottle Gentian	*Gentiana andrewsii*	E	Mapped
Dwarf Rattlesnake-plantain	*Goodyera repens*	E	Mapped
Spurred Gentian	*Halenia deflexa*	E	Not Mapped
Long-leaved Bluet	*Houstonia longifolia*	E	Mapped
Mountain Firmoss	*Huperzia selago*	E	Mapped
Golden Seal	*Hydrastis canadensis*	E	Mapped
Saltpond Pennywort	*Hydrocotyle verticillata*	T	Mapped
Broad Waterleaf	*Hydrophyllum canadense*	E	Mapped
Creeping St. John's-wort	*Hypericum adpressum*	T	Mapped
Giant St. John's-wort	*Hypericum ascyron*	E	Mapped
St. Andrew's Cross	*Hypericum hypericoides* ssp. *multicaule*	E	Mapped
Mountain Winterberry	*Ilex montana*	E	Mapped
Acadian Quillwort	*Isoetes acadiensis*	E	Mapped
Lake Quillwort	*Isoetes lacustris*	E	Mapped
Small Whorled Pogonia	*Isotria medeoloides*	E	Mapped
Weak Rush	*Juncus debilis*	E	Mapped
Thread Rush	*Juncus filiformis*	E	Mapped
Redroot	*Lachnanthes caroliana*	SC	Mapped
Bead Pinweed	*Lechea pulchella* var. *moniliformis*	E	Mapped
Saltpond Grass	*Leptochloa fusca* ssp. *fascicularis*	T	Mapped
Sea Lyme-grass	*Leymus mollis* ssp. *mollis*	E	Mapped
New England Blazing Star	*Liatris scariosa* var. *novae-angliae*	SC	Mapped
Sandplain Flax	*Linum intercursum*	SC	Mapped
Rigid Flax	*Linum medium* var. *texanum*	T	Mapped
Lily-leaf Twayblade	*Liparis liliifolia*	T	Mapped
Dwarf Bulrush	*Lipocarpha micrantha*	T	Mapped
Heartleaf Twayblade	*Listera cordata*	E	Mapped
Great Blue Lobelia	*Lobelia siphilitica*	E	Mapped
Hairy Honeysuckle	*Lonicera hirsuta*	E	Mapped
Many-fruited False-loosestrife	*Ludwigia polycarpa*	E	Mapped
Round-fruited False-loosestrife	*Ludwigia sphaerocarpa*	E	Mapped
Black-fruited Woodrush	*Luzula parviflora* ssp. *melanocarpa*	E	Mapped
Foxtail Clubmoss	*Lycopodiella alopecuroides*	E	Mapped
Gypsywort	*Lycopus rubellus*	E	Mapped
Climbing Fern	*Lygodium palmatum*	SC	Mapped
Sweetbay Magnolia	*Magnolia virginiana*	E	Mapped
Bayard's Green Adder's-mouth	*Malaxis bayardii*	E	Mapped
White Adder's-mouth	*Malaxis monophyllos* var. *brachypoda*	E	Mapped

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Oysterleaf	*Mertensia maritima*	E	Mapped
Woodland Millet	*Milium effusum*	T	Mapped
Winged Monkey-flower	*Mimulus alatus*	E	Mapped
Muskflower	*Mimulus moschatus*	E	Mapped
Michaux's Sandwort	*Minuartia michauxii*	T	Mapped
Large-leaved Sandwort	*Moehringia macrophylla*	E	Mapped
Red Mulberry	*Morus rubra*	E	Mapped
Alternate-flowered Water-milfoil	*Myriophyllum alterniflorum*	E	Mapped
Farwell's Water-milfoil	*Myriophyllum farwellii*	E	Mapped
Pinnate Water-milfoil	*Myriophyllum pinnatum*	SC	Mapped
Comb Water-milfoil	*Myriophyllum verticillatum*	E	Mapped
Lion's Foot	*Nabalus serpentarius*	E	Mapped
Tiny Cow-lily	*Nuphar microphylla*	E	Mapped
Adder's-tongue Fern	*Ophioglossum pusillum*	T	Mapped
Prickly Pear	*Opuntia humifusa*	E	Mapped
Golden Club	*Orontium aquaticum*	E	Mapped
Violet Wood-sorrel	*Oxalis violacea*	E	Mapped
Ginseng	*Panax quinquefolius*	SC	Mapped
Gattinger's Panic-grass	*Panicum philadelphicum* ssp. *gattingeri*	SC	Mapped
Philadelphia Panic-grass	*Panicum philadelphicum* ssp. *philadelphicum*	SC	Mapped
Long-leaved Panic-grass	*Panicum rigidulum* ssp. *pubescens*	T	Mapped
Silverling	*Paronychia argyrocoma*	E	Mapped
Swamp Lousewort	*Pedicularis lanceolata*	E	Mapped
Hairy Beardtongue	*Penstemon hirsutus*	E	Mapped
Strigose Knotweed	*Persicaria setacea*	T	Mapped
Sweet Coltsfoot	*Petasites frigidus* var. *palmatus*	E	Mapped
Crested Fringed Orchis	*Platanthera cristata*	E	Mapped
Leafy White Orchis	*Platanthera dilatata*	T	Mapped
Pale Green Orchis	*Platanthera flava* var. *herbiola*	T	Mapped
Drooping Speargrass	*Poa saltuensis* ssp. *languida*	E	Mapped
Threadfoot	*Podostemum ceratophyllum*	SC	Mapped
Sea-beach Knotweed	*Polygonum glaucum*	SC	Mapped
Pondshore Knotweed	*Polygonum puritanorum*	SC	Mapped
Braun's Holly-fern	*Polystichum braunii*	E	Mapped
Swamp Cottonwood	*Populus heterophylla*	E	Mapped
Algae-like Pondweed	*Potamogeton confervoides*	T	Mapped
Fries' Pondweed	*Potamogeton friesii*	E	Mapped
Hill's Pondweed	*Potamogeton hillii*	SC	Mapped
Ogden's Pondweed	*Potamogeton ogdenii*	E	Mapped
Straight-leaved Pondweed	*Potamogeton strictifolius*	E	Mapped
Vasey's Pondweed	*Potamogeton vaseyi*	E	Mapped
Sandbar Cherry	*Prunus pumila* var. *depressa*	T	Mapped
Pink Pyrola	*Pyrola asarifolia* ssp. *asarifolia*	E	Not Mapped
Bur Oak	*Quercus macrocarpa*	SC	Mapped
Yellow Oak	*Quercus muehlenbergii*	T	Mapped
Tiny-flowered Buttercup	*Ranunculus micranthus*	E	Mapped
Bristly Buttercup	*Ranunculus pensylvanicus*	SC	Mapped
Maryland Meadow Beauty	*Rhexia mariana*	E	Mapped
Great Laurel	*Rhododendron maximum*	T	Mapped
Capillary Beak-sedge	*Rhynchospora capillacea*	E	Mapped

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Inundated Horned-sedge	*Rhynchospora inundata*	T	Mapped
Short-beaked Bald-sedge	*Rhynchospora nitens*	T	Mapped
Long-beaked Bald-sedge	*Rhynchospora scirpoides*	SC	Mapped
Torrey's Beak-sedge	*Rhynchospora torreyana*	E	Mapped
Bristly Black Currant	*Ribes lacustre*	SC	Mapped
Northern Prickly Rose	*Rosa acicularis* ssp. *sayi*	E	Mapped
Toothcup	*Rotala ramosior*	E	Mapped
Seabeach Dock	*Rumex pallidus*	T	Mapped
Swamp Dock	*Rumex verticillatus*	T	Mapped
Slender Marsh Pink	*Sabatia campanulata*	E	Mapped
Plymouth Gentian	*Sabatia kennedyana*	SC	Mapped
Sea Pink	*Sabatia stellaris*	E	Mapped
Wapato	*Sagittaria cuneata*	T	Mapped
Estuary Arrowhead	*Sagittaria montevidensis* ssp. *spongiosa*	E	Mapped
River Arrowhead	*Sagittaria subulata*	E	Mapped
Terete Arrowhead	*Sagittaria teres*	SC	Mapped
Sandbar Willow	*Salix exigua* ssp. *interior*	T	Mapped
Canadian Sanicle	*Sanicula canadensis*	T	Mapped
Long-styled Sanicle	*Sanicula odorata*	T	Mapped
Pod-grass	*Scheuchzeria palustris*	E	Mapped
Northeastern Bulrush	*Scirpus ancistrochaetus*	E	Mapped
Long's Bulrush	*Scirpus longii*	T	Mapped
Papillose Nut Sedge	*Scleria pauciflora*	E	Mapped
Tall Nut-sedge	*Scleria triglomerata*	E	Mapped
Sclerolepis	*Sclerolepis uniflora*	E	Mapped
Wild Senna	*Senna hebecarpa*	E	Mapped
Bristly Foxtail	*Setaria parviflora*	SC	Mapped
Sandplain Blue-eyed Grass	*Sisyrinchium fuscatum*	SC	Mapped
Slender Blue-eyed Grass	*Sisyrinchium mucronatum*	E	Mapped
Large-leaved Goldenrod	*Solidago macrophylla*	T	Mapped
Upland White Aster	*Solidago ptarmicoides*	E	Mapped
Rand's Goldenrod	*Solidago simplex* ssp. *randii* var. *monticola*	E	Mapped
Northern Mountain-ash	*Sorbus decora*	E	Mapped
Small Bur-reed	*Sparganium natans*	E	Mapped
Salt Reedgrass	*Spartina cynosuroides*	T	Mapped
Shining Wedgegrass	*Sphenopholis nitida*	T	Mapped
Swamp Oats	*Sphenopholis pensylvanica*	T	Mapped
Hooded Ladies'-tresses	*Spiranthes romanzoffiana*	E	Mapped
Grass-leaved Ladies'-tresses	*Spiranthes vernalis*	T	Mapped
Small Dropseed	*Sporobolus neglectus*	E	Mapped
American Sea-blite	*Suaeda calceoliformis*	SC	Mapped
Snowberry	*Symphoricarpos albus* var. *albus*	E	Mapped
Eastern Silvery Aster	*Symphyotrichum concolor*	E	Mapped
Crooked-stem Aster	*Symphyotrichum prenanthoides*	T	Mapped
Tradescant's Aster	*Symphyotrichum tradescantii*	T	Mapped
Arborvitae	*Thuja occidentalis*	E	Mapped
Pygmyweed	*Tillaea aquatica*	T	Mapped
Cranefly Orchid	*Tipularia discolor*	E	Mapped
Weft Bristle-fern	*Trichomanes intricatum*	E	Mapped
False Pennyroyal	*Trichostema brachiatum*	E	Mapped

Common Name	Scientific Name	MESA Status (2010)	Mapped/Not Mapped in *BioMap2*
Broad Tinker's-weed	*Triosteum perfoliatum*	E	Mapped
Nodding Pogonia	*Triphora trianthophora*	E	Mapped
Northern Gama-grass	*Tripsacum dactyloides*	E	Mapped
Spiked False Oats	*Trisetum spicatum*	E	Mapped
Resupinate Bladderwort	*Utricularia resupinata*	T	Mapped
Subulate Bladderwort	*Utricularia subulata*	SC	Mapped
Mountain Cranberry	*Vaccinium vitis-idaea* ssp. *minus*	E	Mapped
Narrow-leaved Vervain	*Verbena simplex*	E	Mapped
Sessile Water-speedwell	*Veronica catenata*	E	Mapped
Culver's-root	*Veronicastrum virginicum*	T	Mapped
Downy Arrowwood	*Viburnum rafinesquianum*	E	Mapped
Sand Violet	*Viola adunca*	SC	Mapped
Britton's Violet	*Viola brittoniana*	T	Mapped
Barren Strawberry	*Waldsteinia fragarioides*	SC	Mapped
Smooth Woodsia	*Woodsia glabella*	E	Mapped

Non-MESA-listed Species

The habitats of 27 non-MESA-listed wildlife species were included in *BioMap2* as Species of Conservation Concern Core Habitat. Most of these species are SWAP species in greatest need of conservation; a few species are neither MESA-listed nor listed in the Massachusetts SWAP. These few species were included because of emerging concerns about their conservation status in the state.

Non-MESA-listed species were mapped using one of three methods:

- Individual mapping technique: A method that is similar to the delineation of species habitats for MESA-listed species.
- Exemplary mapping technique: The best (most viable) populations for each species were chosen; then, each was mapped using a method similar to delineating species habitats for MESA-listed species.
- Indirect mapping technique: The habitats for these species were assumed to be "swept up" in creating other types of Core Habitat or Critical Natural Landscape.

This section of the technical report deals only with those non-MESA-listed species that were mapped in *BioMap2* using an Individual or an Exemplary mapping technique. SWAP species that were mapped indirectly or were not considered at all are discussed in Section B of the General Methodology chapter, above.

Table 19. Numbers of Non-MESA-listed Species of Conservation Concern mapped explicitly in *BioMap2*.

Taxa	Non-MESA Species of Conservation Concern
Amphibians	3
Reptiles	5
Birds	13
Mammals	1
Invertebrates	5
TOTAL	**27**

Amphibians
Two species of non-MESA-listed amphibians, Four-toed Salamander and Northern Leopard Frog, were mapped using an individual technique. The remaining amphibian, Spring Salamander, was mapped using an exemplary technique.

Table 20. Non-MESA-listed amphibians included in *BioMap2*.

Non-MESA-listed Amphibians	Scientific Name	Mapping Technique
Four-toed Salamander	*Hemidactylium scutatum*	Individual
Northern Leopard Frog	*Lithobates pipiens*	Individual
Spring Salamander	*Gyrinophilus porphyriticus*	Exemplary

Reptiles
Five reptile species were mapped: Eastern Ribbon Snake, Smooth Green Snake, Eastern Hognose Snake, Spotted Turtle, and Black Racer. Two of these species (Eastern Ribbon Snake and Smooth Green Snake) were mapped using a method that is similar to the delineation of species habitats (Individual mapping technique). Smooth Green Snake is neither MESA-listed nor a SWAP species.

For Black Racer, an Individual mapping technique was used, but only those areas delineated that were in Core Habitat for other reasons were included in *BioMap2*.

For Eastern Hognose Snake and Spotted Turtle, an Exemplary mapping technique was used.

Table 21. Non-MESA-listed reptiles included in *BioMap2*.

Non-MESA-listed Reptile Species	Scientific Name	Mapping Technique
Spotted Turtle	*Clemmys guttata*	Exemplary
Northern Black Racer	*Coluber constrictor*	Individual (but only in Core Habitat)
Eastern Hognose Snake	*Heterodon platirhinos*	Exemplary
Smooth Green Snake	*Opheodrys vernalis*	Individual
Eastern Ribbon Snake	*Thamnophis sauritus*	Individual

Birds
Thirteen non-MESA-listed bird species were mapped explicitly, with either an Individual or Exemplary mapping technique. Habitat for four of these species were delineated using individual species occurrences (individual in table below) that have been submitted to or are tracked by NHESP. For the remaining nine species, exemplary habitat was delineated by NHESP biologists

using expert knowledge and the best available information. Table 22 lists these species and the mapping technique used. Cerulean Warbler is neither MESA-listed nor a SWAP species.

Table 22. Non-MESA-listed birds included in *BioMap2* and mapped explicitly.

Non-MESA-listed Bird Species	Scientific Name	Mapping Technique
Saltmarsh Sharp-tailed Sparrow	*Ammodramus caudacutus*	Exemplary
Seaside Sparrow	*Ammodramus maritimus*	Exemplary
Ruddy Turnstone	*Arenaria interpres*	Exemplary
Sanderling	*Calidris alba*	Exemplary
Red Knot	*Calidris canutus*	Exemplary
Whip-poor-will	*Caprimulgus vociferus*	Individual
Cerulean Warbler	*Dendroica cerulea*	Exemplary
Snowy Egret	*Egretta thula*	Individual
Laughing Gull	*Larus atricilla*	Individual
Short-billed Dowitcher	*Limnodromus griseus*	Exemplary
Whimbrel	*Numenius phaeopus*	Exemplary
Black-crowned Night-heron	*Nycticorax nycticorax*	Individual
Sora	*Porzana carolina*	Exemplary

Mammals

The only non-MESA-listed mammal included in *BioMap2* was the New England Cottontail.

Documented occurrences of New England Cottontail (*Sylvilagus transitionalis*) from 1980 to 2010 in southeastern Massachusetts and on Cape Cod were used to delineate cottontail habitat. The five observations in southwestern Massachusetts during that period were not used, because the observations did not reflect the amount of habitat that likely exists in this portion of Massachusetts. Other *BioMap2* analyses will likely do a much better job of identifying high priority areas in southwestern Massachusetts for New England Cottontail.

To identify the habitat for New England Cottontail for Core Habitat, the following steps were taken:

- Buffered the historic and recent observations by 1000 meters.
- Removed all areas within 10 meters of development from these polygons.
- Removed all areas of open water from the remaining polygons.
- Clipped out of the area remaining the buffered roads (see Appendix L: Road Buffer Polygon Layer for how the roads were buffered).
- Dissolved all of these polygons, exploded them, and then recalculated the acres of each polygon.
- For the remainder of the analysis, only the polygons that were 100 acres or larger were used.

- For each 100+-acre polygon, the area surrounding each polygon was manually reviewed. If there was contiguous natural habitat beyond the 1000-meter buffer from the actual observation, the original polygon was enlarged to the extent of appropriate habitat. Figure 10 below shows an example of this.

Figure 10. An example of Core Habitat polygon delineated for New England Cottontail.

Invertebrates

Habitats for five species of non-MESA-listed invertebrates were mapped using an Individual mapping technique. Table 23 lists the five species. Sandplain Heterocampa and Gold-spotted Ghost Moth are neither MESA-listed nor SWAP species.

Table 23. Non-MESA-listed invertebrates explicitly included in *BioMap2*.

Non-MESA-listed Invertebrate Species	Scientific Name	Mapping Technique
Little Bluet	*Enallagma minusculum*	Individual
Appalachian Coronet	*Hadena ectypa*	Individual
Sandplain Heterocampa	*Heterocampa varia*	Individual
Two-striped Cord Grass Moth	*Macrochilo bivittata*	Individual
Gold-spotted Ghost Moth	*Sthenopis auratus*	Individual

Section B: Priority Natural Communities

Introduction

Natural communities include distinct assemblages of species (both rare and common) in distinct habitats. NHESP's data layer, Priority Natural Communities, includes most occurrences of the least common community types occurring in Massachusetts, as well as the best (outstanding or exemplary) examples of common (or secure) types of natural communities. NHESP Priority Natural Communities were included in *BioMap2* in order to provide additional identification of important areas for biodiversity in the Commonwealth.

In order to incorporate as much biodiversity as possible, *BioMap2* included the rarest and most viable occurrences of uncommon natural community types as well as exemplary examples of more common community types (together "Priority Natural Communities," as identified by the NHESP ecologist; see Table 24). NHESP's database has extensive records of occurrences of Priority Natural Communities throughout the state; most of these were included in *BioMap2*.

Table 24. Priority Natural Communities included in *BioMap2*.

Natural Community	S Rank
Acidic Graminoid Fen	S3
Acidic Rock Cliff Community	S4
Acidic Rocky Summit/Rock Outcrop Community	S4
Acidic Shrub Fen	S3
Acidic Talus Forest/Woodland	S4
Alluvial Atlantic White Cedar Swamp	S2
Alluvial Hardwood Flat	S2
Alluvial Red Maple Swamp	S3
Atlantic White Cedar Bog	S2
Black Ash Swamp	S2
Black Ash-Red Maple-Tamarack Calcareous Seepage Swamp	S2
Black Gum Swamp	S2
Black Gum-Pin Oak-Swamp White Oak "Perched" Swamp	S2
Black Oak - Scarlet Oak Forest/Woodland	S3S4
Calcareous Basin Fen	S1
Calcareous Forest Seep Community	S2
Calcareous Pondshore/Lakeshore	S2
Calcareous Rock Cliff Community	S3
Calcareous Rocky Summit/Rock Outcrop Community	S2
Calcareous Seepage Marsh	S2
Calcareous Sloping Fen	S2
Calcareous Talus Forest/Woodland	S3
Circumneutral Rock Cliff Community	S3
Circumneutral Rocky Summit/Rock Outcrop Community	S2S3
Circumneutral Talus Forest/Woodland	S3
Coastal Atlantic White Cedar Swamp	S2
Coastal Forest/Woodland	S3
Coastal Interdunal Marsh/Swale	S1
Coastal Plain Pondshore	S2
Cobble Bar Forest	S2
Deep Emergent Marsh	S4

Natural Community	S Rank
Dry Riverside Bluff	S2
Dry, Rich Acidic Oak Forest	S4
Estuarine Intertidal: Brackish Tidal Marsh	S1
Estuarine Intertidal: Coastal Salt Pond Marsh	S2
Estuarine Intertidal: Fresh/Brackish Tidal Swamp	S1
Estuarine Intertidal: Freshwater Tidal Marsh	S1
Estuarine Intertidal: Saline/Brackish Flats	S3
Estuarine Intertidal: Salt Marsh	S3
Estuarine Subtidal: Coastal Salt Pond	S2
Forest Seep Community	S4
Hemlock Ravine Community	S4
Hemlock-Hardwood Swamp	S4
Hickory - Hop Hornbeam Forest/Woodland	S2
High Elevation Spruce - Fir Forest/Woodland	S2
Highbush Blueberry Thicket	S4
High-Energy Riverbank	S3
High-Terrace Floodplain Forest	S2
Inland Acidic Pondshore/Lakeshore	S4
Inland Atlantic White Cedar Swamp	S2
Kettlehole Level Bog	S2
Kettlehole Wet Meadow	S3
Level Bog	S3
Low-Energy Riverbank	S4
Major-River Floodplain Forest	S2
Marine Intertidal: Flats	S4
Marine Intertidal: Rocky Shore	S2
Marine Subtidal: Flats	S4
Maritime Beach Strand Community	S3
Maritime Dune Community	S2
Maritime Juniper Woodland/Shrubland	S1
Maritime Pitch Pine On Dunes	S1
Maritime Rock Cliff Community	S2
Maritime Shrubland Community	S3
Mixed Oak Forest	S5
Northern Atlantic White Cedar Swamp	S2
Northern Hardwoods - Hemlock - White Pine Forest	S5
Oak - Hemlock - White Pine Forest	S5
Oak - Hickory Forest	S4
Oak - Holly Forest / Woodland	S3
Oak - Tulip Tree Forest	S1
Pitch Pine - Scrub Oak Community	S2
Red Maple - Black Ash - Bur Oak Swamp	S2
Red Maple Swamp	S5
Red Oak - Sugar Maple Transition Forest	S4
Rich, Mesic Forest Community	S3
Ridgetop Chestnut Oak Forest/Woodland	S4
Ridgetop Pitch Pine - Scrub Oak Community	S2
Riverine Pointbar And Beach	S3
Riverside Rock Outcrop Community	S3
Riverside Seep	S2
Sandplain Grassland	S1
Sandplain Heathland	S1

Natural Community	S Rank
Scrub Oak Shrubland	S1
Sea-Level Fen	S1
Shallow Emergent Marsh	S4
Shrub Swamp	S5
Small-River Floodplain Forest	S2
Spruce - Fir - Northern Hardwoods Forest	S4
Spruce-Fir Swamp	S3
Spruce-Tamarack Bog	S2
Transitional Floodplain Forest	S2
Wet Meadow	S4
Yellow Oak Dry Calcareous Forest	S2

S-Rank Definitions:

- S1 – Typically 5 or fewer occurrences, very few remaining acres or miles of stream, or especially vulnerable to extirpation in Massachusetts for other reasons.
- S2 – Typically 6-20 occurrences, few remaining acres or miles of streams, or very vulnerable to extirpation in Massachusetts for other reasons.
- S3 – Typically 21-100 occurrences, limited acreage or miles of stream in Massachusetts.
- S4 – Apparently secure in Massachusetts.
- S5 – Demonstrably secure in Massachusetts.

Mapping

In the NHESP database, natural communities are mapped using field data, supplemented for boundary delineation by the most recent aerial photographs available and various other spatial data layers, such as the DEP Wetlands delineations, available in MassGIS. Delineations of large patch and matrix community types are generally mapped conservatively and mapping is limited to known areas where field data are actually taken. All NHESP occurrences of natural communities have been visited by ecologists who supplied data on the sites.

Similar to the system used for ranking of rare species populations, community occurrences were evaluated on a statewide basis using three primary ranking factors: size, condition, and landscape context.

Based on detailed NHESP data on the distribution, composition, and status of natural communities, NHESP currently defines 108 types of terrestrial (upland), palustrine (freshwater wetland), and estuarine (coastal salt-influenced wetland) community types across the Commonwealth. Examples of terrestrial communities include forests, rocky ridgetops, shrublands, and beaches; palustrine (wetland) examples include red maple swamps, bogs, and marshes; and estuarine communities include salt marshes and tidal flats. Natural communities may be restricted or widespread in their distribution across the state. In evaluating sites to survey for the NHESP database, conservation priority is given to types of natural communities with limited distribution— regionally or globally—and to the best examples documented of more common types such as old-growth tracts of widespread forest types. Based on assessment of community size, condition, and landscape context, 782 examples of 94 of these Priority and Exemplary Natural Community types are included as Core Habitat in *BioMap2*. Data on natural communities for *BioMap2* were pulled from the NHESP database on August 5, 2010.

There are a small number (<5%) of "data-sensitive communities" present in the Priority and Exemplary Natural Community database. These communities were not included in *BioMap2* in order to protect individual species in them that might be targeted for illegal harvest. A very few additional occurrences are not included if the community substrate might be too easily damaged by visitors.

Overall, there are 90,535 acres of Priority Natural Communities present within Core Habitat. The tables in Appendix M place the communities into the broader "ecosystem type" used to describe the *BioMap2* project in the summary report.

Section C. Vernal Pool Core Habitats

Vernal pools are small seasonal wetlands that provide important wildlife habitat, especially for amphibians and invertebrate animals that use them to breed. The persistence of populations of vernal pool-breeding species, such as the Blue-spotted Salamander, relies not only on the presence of the vernal pool itself, but also on adjacent upland forest habitat for foraging, overwintering, and successful migration of individuals among pools. Individuals breeding at the different pools interact over time and maintain the overall population as breeding success shifts among pools with changing environmental conditions. For this reason, *BioMap2* analyzed not only the vernal pools, but also the quality of the habitat surrounding the pools and the connections among them. There is no map of all vernal pools in the state, but NHESP biologists have created a Potential Vernal Pool (PVP) database, systematically locating potential vernal pool habitat from aerial photographs.

There are close to 30,000 PVPs that were identified during the vernal pool inventory project. The challenge for *BioMap2* was to identify a model that could be used to prioritize among these many PVPs. Luckily, a paper published in 2007 had tackled exactly this problem in Massachusetts, using the PVP database by researchers at the University of Massachusetts. They developed a "resistant-kernel" modeling approach to develop a model of connectivity for amphibians that breed in vernal pools (Compton *et al.*, 2007). The model in the 2007 paper used information compiled on amphibian habitat and dispersal preferences. It also used two-dimensional land use data (1999 land use/land cover) to create a "cost surface" that represented "the willingness of an animal to cross each cover type, the physiological cost of moving, and the reduction in survival for an organism moving across the landscape" (Compton *et al*., 2007).

The model scores each vernal pool with a local, neighborhood, and regional score (between 0 and 1). The local score indicates that quality of habitat surrounding each vernal pool, from near 0 (for a pool with no accessible upland habitat) to 1 (for a pool with optimal upland habitat). The neighborhood score given to every vernal pool indicates the number of dispersers each pool was expected to receive directly from populations associated with neighboring pools, based on configuration of adjacent pools and the quality of habitat through which individuals would have to move. Again the value lies between 0 and 1. Finally, the regional score measured the size of pool clusters with a specified level of dispersal among pools (value from 0 to 1).

For our purposes of identifying the areas that would protect not only vernal pools, but also the habitat surrounding vernal pools, the neighborhood scale scores applied to each vernal pool were used to isolate the top 5% of vernal pools (1200) within each ecoregion. We then used the buffer tool (described in Chapter 4, Section B) to identify the intact upland habitat that connects and surrounds these vernal pool clusters to allow for successful breeding, dispersal, overwintering, foraging, and migration. This exercise identified 36,182 acres throughout the state that, if protected, would protect some of the densest and potentially most valuable vernal pool habitat in Massachusetts. Targeting clusters of pools, rather than individual pools, will maximize the resistance and resilience of vernal pool habitats and their resident species in the context of climate change. Table 25 shows the distribution of vernal pool core acres by ecoregion.

Figure 11. Two clusters of vernal pools identified by the model and the upland habitat surrounding and between the pools.

Table 25. Distribution of acres of Vernal Pool Cores by ecoregion.

Ecoregion	**Acres**
Berkshire Plateau	2,191
Boston Basin and Southern New England Coastal	14,073
Bristol/Narragansett Lowlands	7,450
Cape Cod and Islands	2,281
Connecticut River Valley	2,269
Taconic Mountains	254
Western New England Marble and Berkshire Valleys	1,031
Worcester Plateau	6,632

Section D: Forest Core Habitats

Introduction

Forests are the dominant vegetation type in the eastern United States, and Massachusetts has nearly three million acres of various forest communities (Figure 12). The Commonwealth's extensive forests provide valuable habitat for a wide range of woodland plants and animals. Forest-interior habitat—identified in *BioMap2* as Forest Core—is widely recognized as critically important for species sensitive to forest fragmentation and is becoming increasingly scarce in highly populated regions of the country like Massachusetts. Forest-interior habitats are the areas least impacted by roads, residential and commercial development, and other fragmenting features. Many bird species that breed in Massachusetts are sensitive to forest fragmentation, including Ovenbirds, Scarlet Tanagers, and many woodland warblers. Negative results of fragmentation include edge effects such as nest predation by species associated with development such as skunks, raccoons, and house cats; and nest parasitism by species such as the Brown-headed Cowbird that lay their eggs in the nests of other bird species and reduce their reproductive success. Our analyses were designed to identify the largest and least fragmented forest-interior habitats across Massachusetts, the most important as priorities for protection. With this approach, *BioMap2* Forest Cores include, for example, beech-birch-maple forests in western Massachusetts, oak-hickory forests in central Massachusetts, and oak-pine forests in eastern Massachusetts. By identifying important forested areas, we can protect both known and unknown biodiversity, serving as a "coarse filter" for biodiversity conservation.

Methods

Forest Cores capture the largest and highest integrity patches of forest cover in Massachusetts. We used the UMass CAPS Index of Ecological Integrity (IEI) to identify the most intact and least disturbed upland and wetland forests across the state (See Chapter 2, Section D for details on the CAPS IEI methods). In order to achieve representation of Cores across the state, we used the "integrated" scaling of IEI (see Figure 13). This version of the IEI combines the statewide scores with ecoregional (for upland forest) or watershed (for forested wetlands) scaling of the IEI scores. The higher of the two scores is selected for each pixel and then the scores are rescaled from 0 to 1. We chose the integrated scaling to capture the most intact areas of forest-interior habitat in each ecoregion, as well as the best examples statewide.

Using the integrated IEI raster layer, high integrity forest cover was identified by extracting forest and forested wetland cells with an integrated IEI value greater than 0.8. The results represent the most intact 20% of the overall forested landscape across the state and within each of the ecoregions (see Figure 14). The integrated IEI was used to ensure we captured Forest Cores in each of the ecoregions across the state, as each represents unique forest biodiversity and should be represented in *BioMap2*.

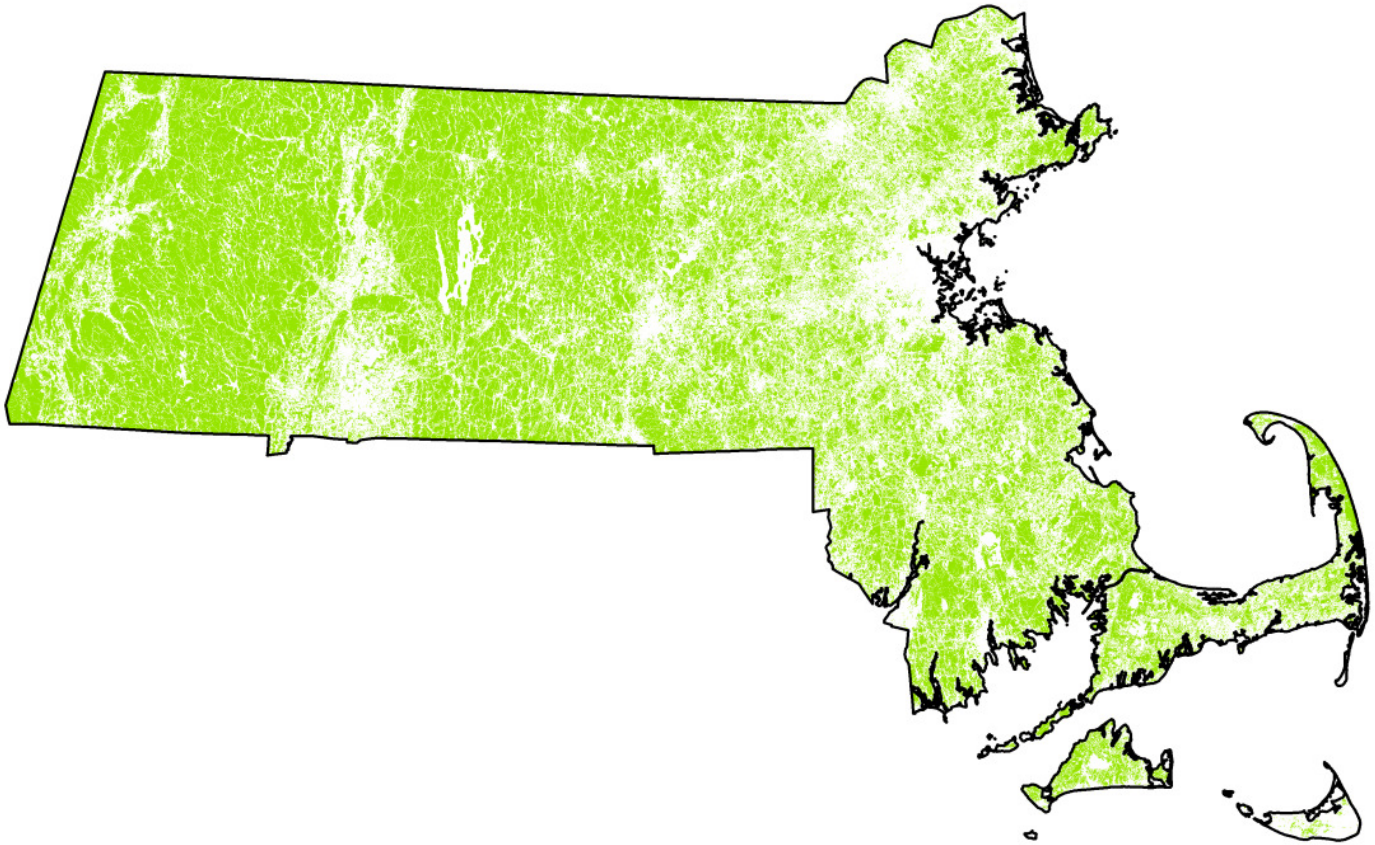


Figure 12. Forest Cover within Massachusetts.
(Upland Forest and Forested Wetlands, as mapped by the MassGIS 2005 Land Use/Land Cover data)

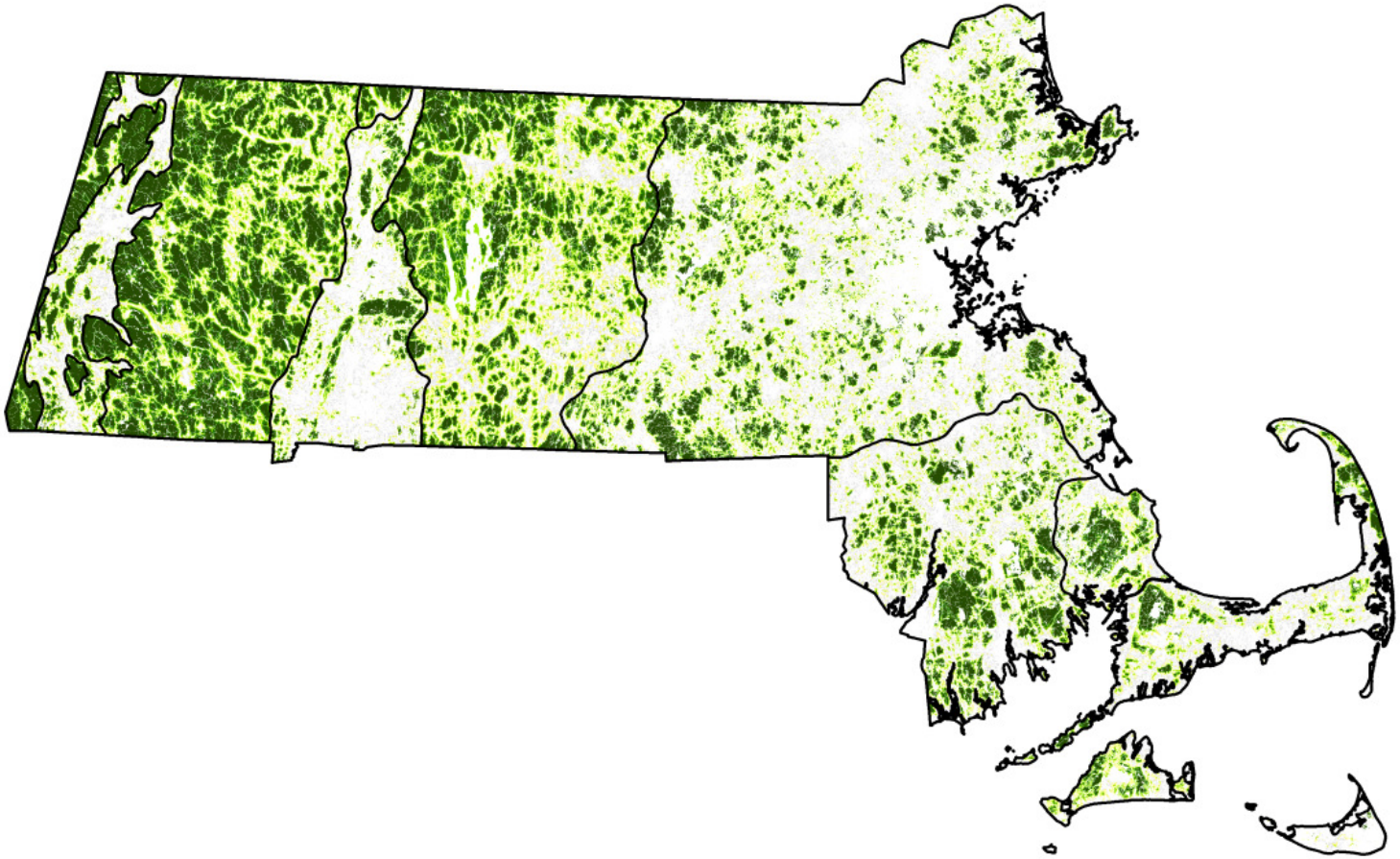


Figure 13. Forests scored by the Index of Ecological Integrity (IEI).
(Darkest green= highest integrity)

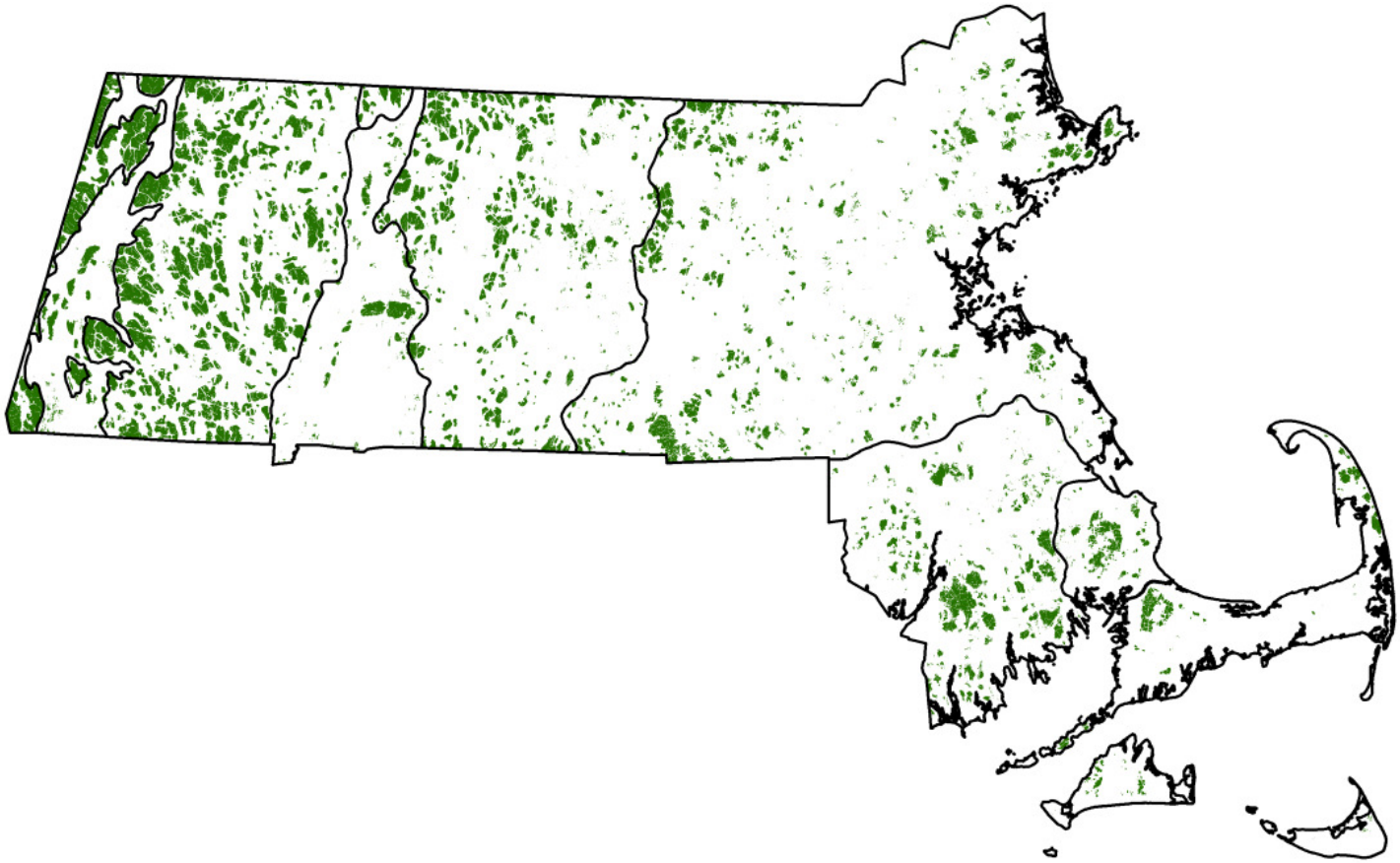


Figure 14. Forests with the top 20% Integrated IEI scores.
(combining statewide and ecoregional scaling)

To identify the largest examples of high-integrity forest, the resulting raster was converted to a vector layer. Polygons within 60 meters of each other were merged (aggregated). The purpose of aggregating polygons was to combine forest-interior patches that were separated by short distances of natural cover, such as a small stream or other natural habitat type, and are therefore minimally fragmented by these features. The 60-meter distance limit enabled Cores to merge across small streams and wetlands with a single pixel width, but kept Forest Cores separate when they were divided by larger rivers, other large natural features, or areas of less intact habitat defined by lower IEI.

Before calculating the final acreage of Forest Cores, a GIS "erase" was performed to remove roads and development that had been absorbed into Cores through the aggregation process. This ensured that no Forest Core polygons accidently included bisecting roads so that even Cores within 60 meters of each other across roads were separated. Acreages were then calculated and all Cores less than 100 acres were deleted from the dataset to facilitate subsequent analyses. Forest Cores were then assigned to a single ecoregion, according to the centroid of the Forest Core polygon. A total of 879 preliminary Forest Cores totaling 584,019 acres were identified in this analysis (Table 26). Final *BioMap2* Forest Core selection, described below, was based on polygon size thresholds defined for each ecoregion.

Table 26. Summary table of all preliminary Forest Cores >100 acres, showing number of Cores and total acres, by ecoregion.

Ecoregion	Number of Cores	Total Acres
Berkshire Plateau	238	230,697
Boston Basin and Southern New England Coastal	234	92,165
Bristol Lowland/Narragansett Lowland	101	47,555
Cape Cod and Islands	54	22,019
Connecticut River Valley	34	15,955
Taconic Mountains	21	53,839
Western New England Marble Valleys	23	11,790
Worcester Plateau	174	109,999
Total	**879**	**584,019**

Forest Core Selection

A review of the Forest Cores in each ecoregion showed that Class 6 roads (from the MassGIS EOT Roads layer) fragmented Cores excessively in certain areas of the state, such as around Mt. Greylock and the Quabbin Reservoir, where this road class often represented small dirt roads. To remedy that effect, a manual review of Cores was performed. In the manual review, Cores divided by Class 6 roads were merged into a single multipart polygon. Likewise, Cores were merged across powerlines less than 60 meters in width (according to 2005 orthophotos). Table 26 shows the number, total area, and distribution of preliminary Forest Cores across ecoregions after this manual adjustment.

A series of selections based on Forest Core size and ecoregion were then applied to the remaining set of Forest Cores. The top 10% of Cores by size were selected in each ecoregion. This selection was supplemented by a selection based on minimum acreage size (see Table 27 and Figure 15). These minimum size thresholds were based on research showing that Forest Cores as small as 500 acres provide effective forest-interior habitat. Adding the minimum acreage threshold served to improve Forest Core representation in the eastern Massachusetts and valley ecoregions. The process also added very large Cores in the Taconic Mountains ecoregion, such as Mt. Greylock, where selecting the largest 10% of the polygons did not work effectively to select from a very small number of very large polygons (*i.e.*, they were nearly all large and important). Polygons that met either the largest 10% or minimum size criteria per ecoregion defined the final set of *BioMap2* Forest Cores (Figure 16).

Table 27. Forest Core minimum size by ecoregion.

Ecoregion	**Minimum Size Threshold (acres)**
Berkshire Plateau	2,500
Southern New England Coastal and Boston Basin	500
Bristol Lowland/Narragansett Lowland	500
Cape Cod and Islands	500
Connecticut River Valley	500
Taconic Mountains	3,000
Western New England Marble Valleys	500
Worcester Plateau	1,500

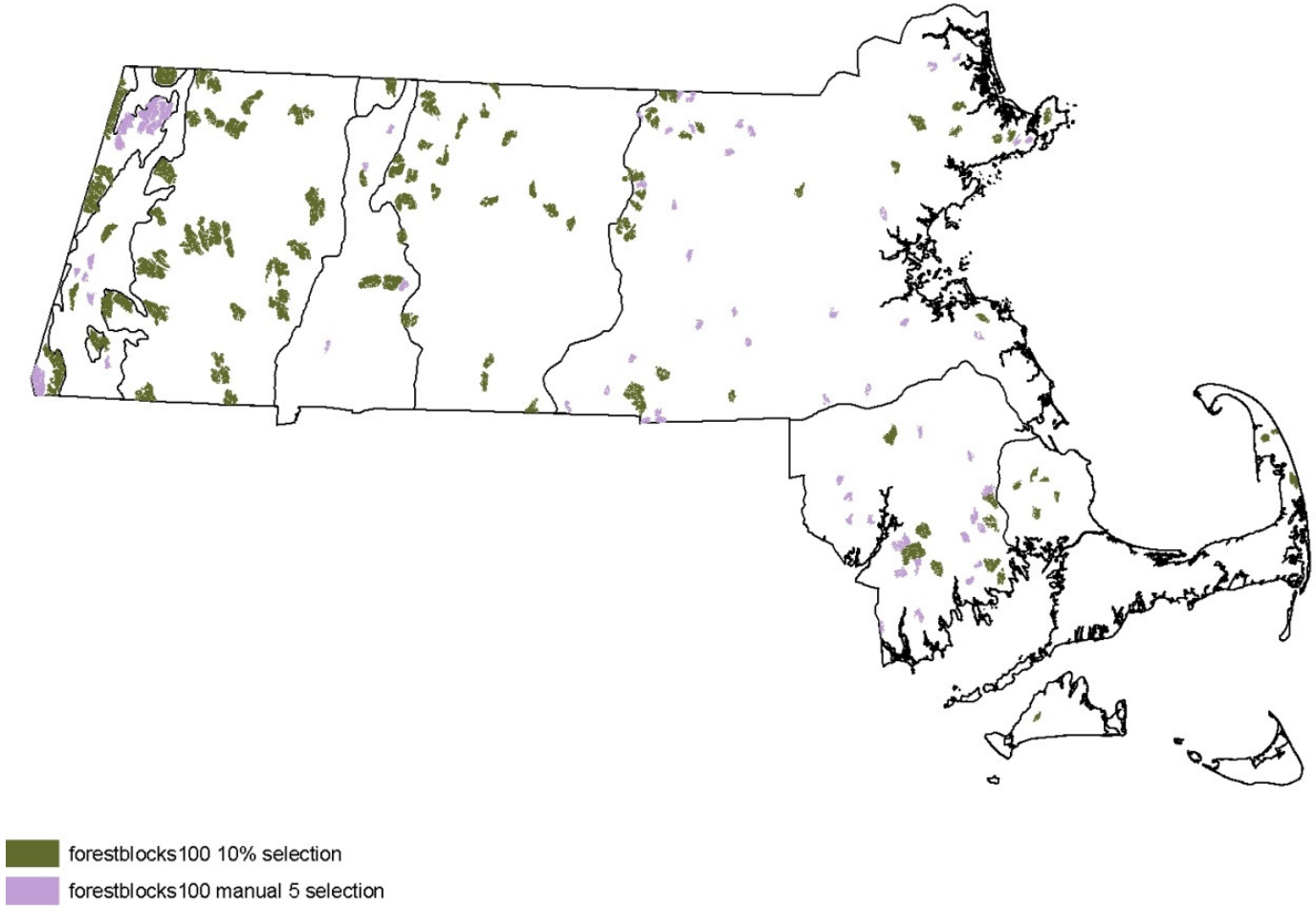


Figure 15. Forest Core selection criteria.

In green are the Cores within the top 10% by size for each ecoregion. In purple are the Cores that were added to the final selection using minimum size thresholds per ecoregion.

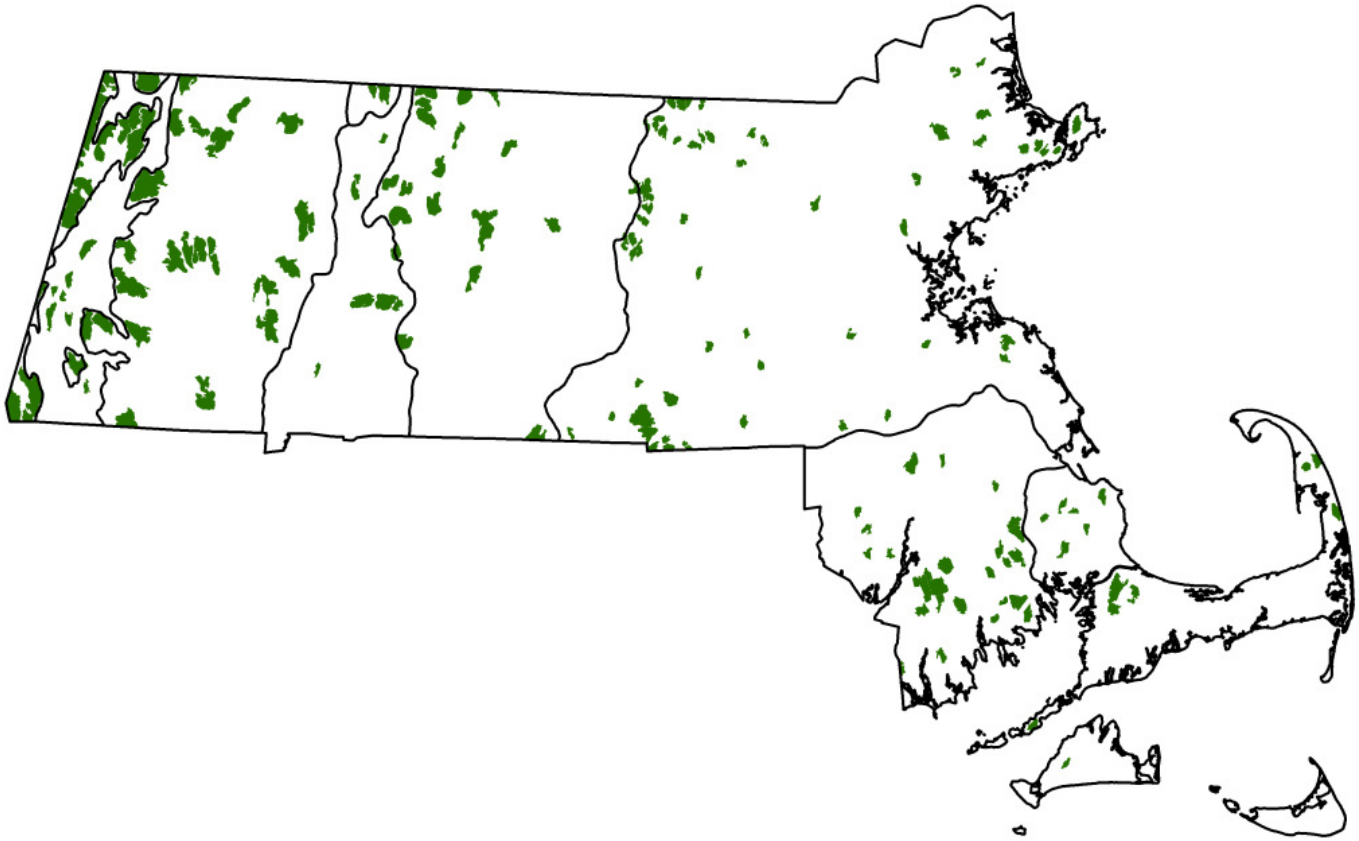


Figure 16. Final selection of Forest Cores
based on the largest 10% in each ecoregion, complemented by minimum size thresholds per ecoregion, and refined (post-processing) to define functional conservation units.

Final Forest Cores and post-processing
Selected Cores were reviewed through automated and manual post-processing steps to smooth and consolidate polygon boundaries, with the goal of creating consolidated and simplified Forest Core boundaries with solid interiors useful for conservation applications.

Particular attention was paid to the effect of Class 6 roads on the Forest Core periphery. The perimeter was edited to remove gaps created by Class 6 roads when those roads were not accompanied by development. Where Class 5 roads perforated the Core boundary, the boundary was left as defined by the IEI even where no development was apparent from the 2005 orthophotos, as we lack information to consistently distinguish levels of impact within the class 5 road category.

The Cores were also edited manually along ecoregional boundaries, where artifacts of the IEI rescaling resulted in non-contiguous Core boundaries across ecoregional boundaries in some places. Core boundaries were also edited to either exclude small irregularities around the perimeter, or fill in gaps and lobes within the overall shape of the Core. Edits were made to follow forest land cover types as shown in the orthophotos.

Five Forest Cores were added along the state boundary where small interior habitats within Massachusetts connected to large high-integrity forests in surrounding states.

These post-processing steps resulted in Forest Cores with lower edge-to-area ratios and solid interiors—optimal conservation units. However, while dominated by high-integrity forest acres, the final Cores do contain minimal areas of forest cover with IEI scores < 0.8 and minimal acres of other natural land cover types as a result of these steps.

After post processing, the final selections resulted in 163 Forest Cores totaling 325,449 acres, representing just over 10% of Massachusetts' forests (Figure 16, Table 28).

Table 28. Final Forest Core selection, after post-processing.

Ecoregion	# Cores	Minimum Acres	Maximum Acres	Average Acres	Total Acres
Berkshire Plateau	24	2,535	8,610	4,188	100,520
Western New England Marble Valleys	7	563	2,031	1,104	7,727
Bristol Lowland/Narragansett Lowland	27	569	3,118	1,271	34,319
Cape Cod and Islands	13	518	4,745	1,208	15,704
Connecticut River Valley	7	543	3,218	1,508	10,556
Southern New England Coastal Plains and Boston Basin	56	548	4,424	1,046	58,576
Taconic Mountains	10	595	9,987	5,056	50,555
Worcester Plateau	19	1,043	5,966	2,500	47,492
Total	**163**				**325,449**

Discussion

Massachusetts' nearly 3,000,000 forested acres provide numerous values, including wildlife habitat and biodiversity. *BioMap2* includes a conservative subset, just over 10%, of Massachusetts forests that provide the highest quality forest-interior habitat across Massachusetts. Additional and more expansive forest areas are included in the Landscape Block component of *BioMap2*. Forest Cores, as the most intact forest-interior habitats in Massachusetts, are crucial areas for the long-term persistence of forest-interior species and other species and ecological processes. They are a relatively rare and diminishing feature of the Massachusetts landscape, as roads and development fragment some of our last remaining intact habitats. Forest Cores are therefore high priorities for land protection.

Section E: Wetland Core Habitats

Introduction

BioMap2 Core Habitat includes a statewide assessment of the most intact wetlands in Massachusetts. This analysis identified the least disturbed wetlands—Wetland Cores—those with the most intact buffers and little fragmentation or other stressors associated with development. These wetlands are most likely to support critical wetland functions (*i.e.*, natural hydrologic conditions, diverse plant and animal habitats, etc.) and are most likely to maintain these functions into the future. To identify these high-quality wetlands, *BioMap2* incorporated the University of Massachusetts Conservation Assessment and Prioritization System (CAPS) Index of Ecological Integrity (IEI, see Chapter 2, Section D). The analysis combined individual wetland types (*e.g.,* shrub swamps, forested wetlands, marshes, bogs) into contiguous wetland complexes. To enhance the biodiversity value of selected wetlands as Core Habitat, further analyses were conducted to represent wetlands within the varied ecological settings found in Massachusetts, determined by geology and elevation, as different plant and animal assemblages occur in these unique settings. By mapping the most intact wetlands in each ecological setting, *BioMap2* identifies wetlands that support the broadest spectrum of wetland biodiversity, both currently and into the future, which will help prioritize conservation of wetland diversity in the context of climate change.

Methods

The analysis for Wetland Cores was based upon the Massachusetts DEP 1:12,000 wetland data layer (see Table 29). Inland wetland types (for example, Deep Marsh or Shrub Swamp) were selected from this data layer and dissolved in GIS to form "wetland complexes." This was done before the wetland prioritization process so that *BioMap2* included or excluded entire and contiguous wetlands, rather than partial wetlands. Where wetlands were separated by no more than 100 meters of open water, they were combined into the same "wetland complex" unit. This was done to ensure wetlands that are closely connected hydrologically were treated as one unit in the analysis.

Table 29. Size and distribution of DEP wetland types included in Wetland Cores analysis.

Wetland Type	# of Wetlands	Maximum Area (Acres)	Total Area (Acres)	Percent of Statewide Total
Bog	1,360	154	5,411	1%
Deep Marsh	13,657	332	34,903	8%
Shallow Marsh, Meadow or Fen	21,859	248	47,911	11%
Shrub Swamp	33,263	285	76,980	17%
Wooded Swamp Coniferous	5,494	246	23,894	5%
Wooded Swamp Deciduous	62,497	632	194,490	43%
Wooded Swamp Mixed Trees	14,905	431	67,167	15%
Total	**153,035**	**--**	**450,757**	**--**

The wetland complex data layer contained 110,265 polygons and totaled 450,586 acres. Small wetlands were removed from the dataset using a 10-acre size threshold. Once these small

wetlands were screened out, the wetlands dataset was reduced from 450,586 acres to 302,521 acres, and the number of individual complexes was reduced from 110,265 to just 7,544, a much more reasonable set for analysis.

Representation of Ecological Settings (*i.e.*, Ecological Land Units, or ELUs)
To enhance the biodiversity value of wetlands selected as Core Habitat, further analyses were conducted to identify and select wetlands within the varied ecological settings found in Massachusetts, determined by geology and elevation, as different plant and animal assemblages occur in these unique physical settings. For instance, 108,000 acres of wetlands occur on the sandy soils of southeastern Massachusetts in an elevation range between 20 and 800 feet. By contrast, fewer than 8,000 acres of wetlands are found on marble or calcareous bedrock in western Massachusetts between 800 and 1,700 feet. By mapping the most intact wetlands distributed across all ecological settings, *BioMap2* identifies wetlands that support the broadest spectrum of wetland types and wetland biodiversity, both currently and into the future. These intact wetlands in diverse settings may be thought of as representing the "ecological stage," and are most likely to support a diversity of wetland types over time, even as different plant and animal species (the "actors" on the ecological stage) shift in response to climate change (see Climate Change, Chapter 2, Section C).

To classify wetland complexes by their dominant physical setting, they were categorized by elevation class and geology type using the Ecological Land Unit categories and classification developed by The Nature Conservancy's Eastern Division (see Appendix D). That classification identifies elevation ranges that determine the distribution of ecological communities, and ecologically meaningful associations of bedrock and surficial geology types. Complexes were assigned elevation classes based on the following categories using the Massachusetts 1:5,000 Digital Elevation Model (Figure 17). Polygons that fell into multiple classes were assigned to a single class based on the polygon centroid.

Elevation classes

a. Coastal zone 0-20'
b. Low elevation 20-800'
c. Mid elevation 800-1700'
d. Mid-high 1700-2500' and High elevation > 2500' (these two classes were grouped, since there is very little elevation > 2500' in Massachusetts)

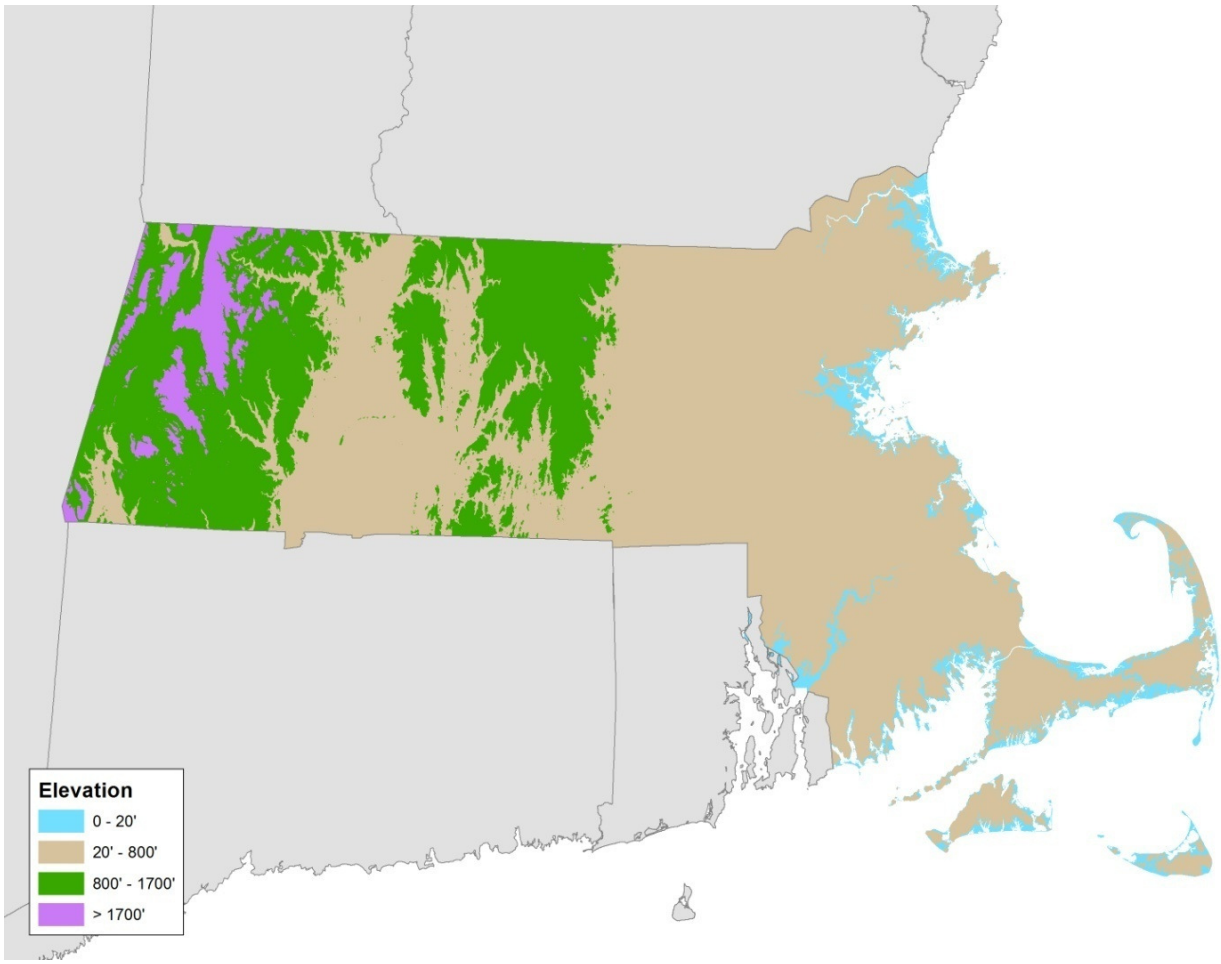


Figure 17. Elevation zones used to assign ELU type to wetland complexes.

Geology data was derived from the MassGIS bedrock lithology layer, originally obtained from USGS and based upon source data ranging from 1:100,000 to 1:500,000 (Figure 18). Where deep sediments prevail over bedrock as drivers of soil characteristics, 1:1 M USGS surficial Quaternary sediments dataset was used to map coarse and fine sediments. To assign geology type, acres of each geology type were tabulated for each wetland complex polygon. Geology classes were assigned significance in order of their rarity, with calcareous types most limited in distribution and acidic types most widely distributed. Where polygons contained two or more geology types, the single most significant geology type was assigned to that wetland complex polygon if it accounted for at least 25% of the complex area.

Geology classes (listed here in order of significance)

a. Calcareous sedimentary/metasedimentary
b. Moderately calcareous sedimentary/metasedimentary
c. Mafic/intermediate granitic and Ultramafic (combined two classes here)
d. Fine sediments
e. Coarse sediments
f. Acidic granitic and Acidic sedimentary/metasedimentary (combined two classes here)

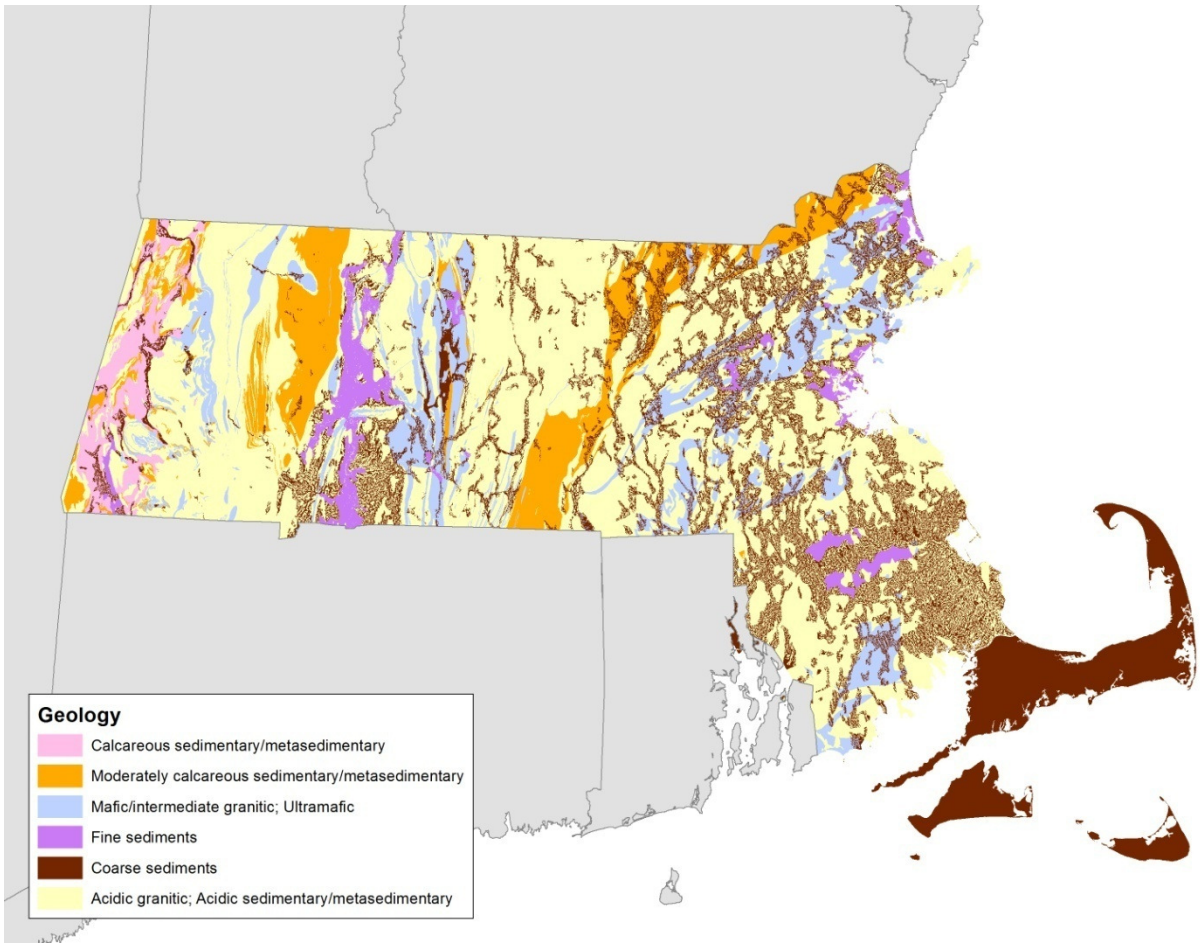


Figure 18. Distribution of geology types used to assign ELUs to wetland complexes.

The elevation and geology analyses described above resulted in wetland complexes categorized into 19 unique Ecological Land Unit (ELU) classes (*e.g.*, 20-800' and Coarse Sediments, or 800-1700' and Acidic Granitic or Acidic Sedimentary/Metasedimentary). Table 30 shows the list of 19 unique ELU settings and the distribution of wetland complexes above 10 acres within these groupings.

Table 30. Wetland Core selection by ELU type. This table shows the breakdown of wetland complexes > 10 acres by ELU type. ELU selection of wetland complexes for *BioMap2* was based on either the top IEI decile or top quartile (selection threshold for each ELU type indicated in red and bold) depending on the rarity of the ELU type.

ELU	# Wetland Complexes	Total Acres	% Total Acres	IEI threshold (statewide scaling) Top decile	IEI threshold (statewide scaling) Top quartile	# Selected Wetland Cores	Selected Acres	% of Total Selected Acres
0-20' and Acidic Granitic or Acidic Sed/Metased	59	2,780	1%	0.73	**0.61**	15	1,842	2%
0-20' and Coarse Sediments	308	10,500	3%	0.63	**0.47**	77	5,000	6%
0-20' and Fine Sediments	36	1,563	1%	0.69	**0.55**	9	936	1%
0-20' and Mafic/intermediate granitic or Ultramafic	24	648	< 1%	0.72	**0.58**	6	125	< 1%
0-20' and Moderately Calcareous Sed/Metased	3	94	< 1%	0.58	**0.53**	1	69	< 1%
20-800' and Acidic Granitic or Acidic Sed/Metased	1,531	58,523	19%	**0.73**	0.58	154	14,901	17%
20-800' and Calcareous Sed/Metased	58	3,273	1%	0.80	**0.68**	15	1,842	2%
20-800' and Coarse Sediments	2,594	108,237	36%	**0.61**	0.44	260	27,043	31%
20-800' and Fine Sediments	309	23,101	8%	**0.67**	0.48	31	10,380	12%
20-800' and Mafic/intermediate granitic or Ultramafic	719	32,151	11%	**0.75**	0.58	72	7,051	8%
20-800' and Moderately Calcareous Sed/Metased	342	10,908	4%	0.72	**0.57**	86	3,940	4%
800-1700' and Acidic Granitic or Acidic Sed/Metased	818	24,913	8%	**0.83**	0.74	82	4,010	5%
800-1700' and Calcareous Sed/Metased	197	7,572	3%	0.70	**0.56**	50	3,116	4%
800-1700' and Coarse Sediments	155	8,608	3%	0.65	**0.57**	39	4,828	5%
800-1700' and Mafic/intermediate granitic or Ultramafic	101	2,377	1%	0.83	**0.76**	26	870	1%
800-1700' and Moderately Calcareous Sed/Metased	148	3,331	1%	0.81	**0.71**	37	829	1%
> 1700' and Acidic Granitic or Acidic Sed/Metased	73	2,023	1%	0.87	**0.82**	19	731	1%
> 1700' and Mafic/intermediate granitic or Ultramafic	67	1,886	1%	0.89	**0.85**	17	603	1%
> 1700' and Moderately Calcareous Sed/Metased	2	32	< 1%	0.87	**0.86**	1	15	< 1%
Total	7,544	302,521	100%			997	88,130	100%

Selection of Wetland Cores using Index of Ecological Integrity (IEI), by ELU type
Next, wetland complexes were scored using the University of Massachusetts Conservation Assessment and Prioritization System (CAPS) Index of Ecological Integrity (IEI, see Chapter 2, Section D). The mean IEI was calculated for each wetland complex (*i.e.,* mean of all pixel scores within the complex) using both statewide scaling and ecoregional scaling rescaled to eight ecoregions. These scores were used to select wetland complexes for inclusion in *BioMap2* as Wetland Cores.

Using the mean IEI scores for each wetland complex from the statewide scaling, the top quartile (top 25%) of wetlands within less common ELU groups (defined as ELU groups accounting for less than 10% of the statewide wetland area) was selected as Wetland Cores. For all other ELU groups, those more common in Massachusetts, a smaller percentage, the top decile (top 10%), was used. Table 30 indicates the IEI thresholds used to select the highest scoring complexes within each ELU group. Of the 302,521 acres of wetlands in the full wetland complex dataset, 88,130 acres were selected through this process.

Selection by Ecoregion
To make certain selected wetlands were well distributed across ecoregions, the top decile of wetland complexes in each ecoregion were selected for inclusion as wetland cores, using the mean ecoregionally scaled IEI for each wetland complex. One hundred and thirty eight Wetland Cores, totaling 6,708 acres, were added as a result of this ecoregion-based selection (Table 31). As a second step in this ecoregional balancing, the limited set of wetlands in the Taconic Mountains ecoregion were reviewed and added if they proved to be in good landscape context according to the 2005 orthoimagery. In the Cape Cod and Islands ecoregion, the acreage threshold was lowered from 10 to 5 acres to allow for the generally smaller size of wetlands in this ecoregion, which also added additional Wetland Cores to *BioMap2*.

Final Wetland Cores
Finally, selected wetlands were reviewed on screen using 2005 orthoimagery. Some selected wetlands in Southeast Massachusetts were found to include cranberry bogs. These were likely misclassified in the DEP wetlands data. As a final processing step, these wetlands were either excluded or edited to remove cranberry bogs from the final set of wetland cores.

The net result of all wetland complex selections, combining ELU stratification and ecoregional balancing and including final editing, are reported in Table 31. The final set of Wetland Cores totals 92,862 acres. Table 32 shows the final breakdown of wetlands selected for *BioMap2* by DEP wetland type and by ecoregion.

Table 31. Acreages of final wetland cores. After selecting the highest ranked wetlands within each ELU group, an additional 6,708 acres of wetlands were selected using the ecoregionally-scaled IEI, while an additional 1,093 acres of wetlands were added in the Taconic Mountains and Cape Cod and Islands to improve representation across ecoregions.

Ecoregions	Top 10% of all ELU types (both rare and common)	Top 10-25% of rare ELU types	Top 10% of wetlands by Ecoregional IEI (NOT already identified by ELU analysis)	Additional Ecoregional Balancing	Grand Total
Berkshire Plateau	4,781	1,741	1,081		7,603
Boston Basin and Southern New England Coastal	20,010	2,838	2,531		25,379
Bristol Lowland/ Narragansett Lowland	30,481	1,582			32,064
Cape Cod and Islands	3,451	1,005	113	885	5,454
Connecticut River Valley	2,527		717		3,243
Taconic Mountains	28	58	26	205	317
Western New England Marble Valleys	4,183	3,085		3	7,272
Worcester Plateau	7,906	1,385	2,240		11,531
Total	**73,367**	**11,694**	**6,708**	**1,093**	**92,862**

Discussion

This series of analyses resulted in the inclusion of 92,862 acres of Wetland Cores in *BioMap2* Core Habitat. This set of wetlands is representative of the full suite of wetland types defined in the original DEP wetland types (bogs, swamps, etc.) as shown in Table 32. Because these wetlands represent the full suite of physical settings defined by elevation and geology (Table 30), if they are effectively conserved, they serve to protect both current and future wetland biodiversity. This set of wetlands is well distributed throughout the state and across ecoregions. These wetlands acres added to and complemented wetlands included in *BioMap2* through rare species habitats and priority natural communities.

Table 32. Selected Wetland Cores by ecoregion and DEP wetland type. Total wetland core acres reported here do not include 57 acres of open water and other mapped land uses included during manual revision of wetland cores.

	Ecoregion	Bog	Deep Marsh	Shallow Marsh Meadow or Fen	Shrub Swamp	Wooded Swamp Coniferous	Wooded Swamp Deciduous	Wooded Swamp Mixed Trees	Total
Total Wetland Acres in Massachusetts	Berkshire Plateau	663	3,217	4,838	8,259	7,516	6,075	3,975	34,544
	Boston Basin and Southern New England Coastal	1,376	12,472	22,842	27,153	2,740	96,358	17,919	180,860
	Bristol Lowlands/Narragansett Lowlands	1,007	4,422	6,001	10,453	3,355	49,842	27,741	102,820
	Cape Cod and Islands	489	1,707	2,906	7,719	1,238	4,707	2,163	20,930
	Connecticut River Valley	222	1,608	2,990	4,933	952	14,070	1,931	26,706
	Taconic Mountains	1	88	49	238	39	497	81	993
	Western New England Marble Valleys	44	1,563	2,741	6,537	929	6,025	3,497	21,337
	Worcester Plateau	1,608	9,826	5,545	11,690	7,126	16,919	9,862	62,575
	Total	5,411	34,904	47,911	76,982	23,895	194,493	67,169	450,765
Wetland Cores (Acres)	Ecoregion	Bog	Deep Marsh	Shallow Marsh Meadow or Fen	Shrub Swamp	Wooded Swamp Coniferous	Wooded Swamp Deciduous	Wooded Swamp Mixed	Total*
	Berkshire Plateau	271	721	1,388	2,092	1,746	782	604	7,603
	Boston Basin and Southern New England Coastal	215	1,669	3,707	4,792	313	12,156	2,526	25,377
	Bristol Lowlands/Narragansett Lowlands	411	1,120	1,343	2,288	1,816	14,625	10,411	32,012
	Cape Cod and Islands	169	251	916	1,893	360	1,025	837	5,450
	Connecticut River Valley	13	85	356	497	425	1,538	331	3,243
	Taconic Mountains		45	18	82	9	123	39	317
	Western New England Marble Valleys	11	724	1,061	2,277	461	1,228	1,509	7,272
	Worcester Plateau	553	2,795	1,344	2,197	1,686	1,719	1,236	11,531
	Grand Total	1,641	7,410	10,133	16,118	6,815	33,196	17,493	92,805
Wetland Cores (% of total)	Ecoregion	Bog	Deep Marsh	Shallow Marsh Meadow or Fen	Shrub Swamp	Wooded Swamp Coniferous	Wooded Swamp Deciduous	Wooded Swamp Mixed	Total
	Berkshire Plateau	41%	22%	29%	25%	23%	13%	15%	22%
	Boston Basin and Southern New England Coastal	16%	13%	16%	18%	11%	13%	14%	14%
	Bristol Lowland/Narragansett Lowland	41%	25%	22%	22%	54%	29%	38%	31%
	Cape Cod and Islands	34%	15%	32%	25%	29%	22%	39%	26%
	Connecticut River Valley	6%	5%	12%	10%	45%	11%	17%	12%
	Taconic Mountains	0%	51%	37%	35%	22%	25%	49%	32%
	Western New England Marble Valleys	24%	46%	39%	35%	50%	20%	43%	34%
	Worcester Plateau	34%	28%	24%	19%	24%	10%	13%	18%
	Grand Total	30%	21%	21%	21%	29%	17%	26%	21%

Section F: Aquatic Core Habitats

BioMap2 Aquatic Core is composed of several separate analyses of aquatic resources, each targeting different sets of species. The following sub-analyses were conducted separately and then brought together in order to assemble the final Aquatic Core data layer:

1. Analysis to identify high-quality habitat supporting four anadromous fish species (Rainbow Smelt and three SWAP fish species indicated in Table 33 below).
2. Analysis to identify high-quality stream habitat supporting the remaining 13 non-MESA-listed fish species using the DFW Fisheries Section database and expert review by the DFW Fisheries Section.
3. Enhancements to Living Waters streams and to small or short stream segments for MESA-listed fish species.
4. Delineation of other MESA-listed aquatic species (includes 139 species).

After the stream segments or aquatic resources were identified by the above analyses, additional steps were taken to delineate the final Aquatic Core polygons. These steps are detailed below.

Finally, an upland buffer to the Aquatic Core was created using the buffer tool described in Chapter 4, Section B. This Aquatic Buffer is part of Critical Natural Landscape.

Table 33. Non-MESA-listed fish species included in *BioMap2*.

Common Name	Scientific Name	Subset	Identification Method
Blueback Herring	*Alosa aestivalis*	Anadromous	Use of DMF database and CT River*
Alewife	*Alosa pseudoharengus*	Anadromous	Use of DMF database and CT River*
American Shad	*Alosa sapidissima*	Anadromous	Use of DMF database and CT River*
American Eel	*Anguilla rostrata*	Inland streams	Fisheries database queries and expert review
White Sucker	*Catostomus commersoni*	Inland streams	Fisheries database queries and expert review
Slimy Sculpin	*Cottus cognatus*	Inland streams	Fisheries database queries and expert review
Banded Sunfish	*Enneacanthus obesus*	Inland streams	Fisheries database queries and expert review
Creek Chubsucker	*Erimyzon oblongus*	Inland streams	Fisheries database queries and expert review
Swamp Darter	*Etheostoma fusiforme*	Inland streams	Fisheries database queries and expert review
Tessellated Darter	*Etheostoma olmstedi*	Inland streams	Fisheries database queries and expert review
Common Shiner	*Luxilus cornutus*	Inland streams	Fisheries database queries and expert review
Blacknose Dace	*Rhinichthys atratulus*	Inland streams	Fisheries database queries and expert review
Sea Lamprey	*Petromyzon marinus*	Inland streams	Fisheries database queries and expert review
Longnose Dace	*Rhinichthys cataractae*	Inland streams	Fisheries database queries and expert review

Common Name	Scientific Name	Subset	Identification Method
Atlantic Salmon	*Salmo salar*	Restoration	Manual selection / confirmation with DFW anadromous fish biologist
Eastern Brook Trout	*Salvelinus fontinalis*	Inland streams	Fisheries database queries and expert review
Creek Chub	*Semotilus atromaculatus*	Inland streams	Fisheries database queries and expert review
Fallfish	*Semotilus corporalis*	Inland streams	Fisheries database queries and expert review

Anadromous Fish

Anadromous fish are an important part of the aquatic biodiversity of Massachusetts. These species hatch in coastal ponds and rivers, then travel to the ocean where they spend most of their lives. Upon reaching maturity, they migrate up coastal rivers to spawn in the same river or pond where they were born.

Anadromous rivers for inclusion in *BioMap2* were identified for Rainbow Smelt, American Shad, Alewife, and Blueback Herring. Atlantic and Shortnose Sturgeon, both anadromous, are MESA-listed species, and habitats for these species were mapped according to rare species protocols (see Species of Conservation Concern section above). Atlantic Salmon are included in coldwater tributaries where they are stocked, since juvenile salmon are resident in these habitats for several years.

River selection and the spatial extent of anadromous runs were based on a review of various datasets by The Nature Conservancy's freshwater ecologist Alison Bowden. Rivers for Alewife, Blueback Herring, and American Shad were identified using base data from the Northeast Aquatic Connectivity Initiative, which recorded rivers with a presence or absence of these species (NEAFWA Aquatic Connectivity Anadromous Fish Presence data [computer files]. The Nature Conservancy Eastern Freshwater Program, 2011. Source data ASMFC 2006). This initial presence/absence data was reviewed and edited according to the best available knowledge about the current status of these runs, including run count data and habitat assessments. Figure 19 shows the rivers selected for anadromous fish and included in Aquatic Core.

<u>American Shad</u>

Selection of runs for shad was based on personal communication with Phil Brady at MA Division of Marine Fisheries as well as fish counts at hydro dams for the Connecticut and Merrimack Rivers. Selection was targeted at places with self-sustaining populations and apparent suitable habitat; shad are formally counted only on the Connecticut and Merrimack Rivers, so judgment and local knowledge (*e.g.*, personal knowledge from Alison Bowden and postings to fishing blogs) were used to supplement data.

<u>River Herrings (Alewife and Blueback Herring)</u>

For river herrings, runs were selected that have consistently been the strongest in the state, as well as representing all the major watersheds where these species occur. Note that few locations are consistently counted and that comparison can be difficult, so this is a largely a qualitative method. Also referenced was Belding's report upon the history, present condition, and possibility of development of the alewife fishery of Massachusetts 1912-1920 for historical context.

For river herrings, no runs were selected in the north coastal basin because the status of river herring there is quite poor due to a combination of passage barriers, flow conditions, and water quality (Purinton, *et al.* 2003). This condition is long standing and restoration efforts have been made, but to date have not been successful. No runs were selected on the Islands because freshwater habitats are limited, although river herring do occur there and probably spawn in fair numbers in some of the coastal ponds, at least in seasons where pond openings and salinity favor successful spawning.

Technical reports referenced:

TR-15 Reback, K.E., P.D. Brady, K.D. McLauglin, and C.G. Milliken. 2004. A survey of anadromous fish passage in coastal Massachusetts: Part 1. Southeastern Massachusetts.

TR-16 Reback, K.E., P.D. Brady, K.D. McLauglin, and C.G. Milliken. 2004. A survey of anadromous fish passage in coastal Massachusetts: Part 2. Cape Cod and the Islands.

TR-17 Reback, K.E., P.D. Brady, K.D. McLauglin, and C.G. Milliken. 2004. A survey of anadromous fish passage in coastal Massachusetts: Part 3. South Coastal.

TR-18 Reback, K.E., P.D. Brady, K.D. McLauglin, and C.G. Milliken. 2004. A survey of anadromous fish passage in coastal Massachusetts: Part 4. Boston and North Coastal.

Tim Purinton, Frances Doyle and Dr. Robert D. Stevenson. 2003. Status of River Herring on the North Shore of Massachusetts.

David L. Belding. 1920. A Report upon the Alewife Fisheries of Massachusetts. Commonwealth of Massachusetts, Department of Conservation, Division of Fisheries and Game.

Rainbow Smelt

Rainbow Smelt runs are based on a review of GIS data from a Massachusetts Division of Marine Fisheries (DMF) survey of Gulf of Maine coastal streams which documented areas of egg deposition (TR-30). River/estuary systems with a minimum of 4,000 m^2 (aggregate) of occupied spawning habitat in Table 2.1 of that document were selected. The definitive source for designated smelt runs is TR-30; DMF considers all runs referenced in TR-30 as priorities for regulatory purposes. Buzzards Bay sites were added using TR-15 notes on smelt, as well as recent photos of Weweantic River smelt eggs at Horseshoe dam posted on the web by a local resident. For selected runs, the extent of the run was defined in GIS as extending from the upstream point of the data supplied by DMF to the mouth of the river.

Technical reports and websites referenced:

TR-30 Chase, B. C. 2006. Rainbow smelt (*Osmerus mordax*) spawning habitat on the Gulf of Maine coast of Massachusetts. PDF. (3,621 kb) http://www.mass.gov/dfwele/dmf/publications/technical.htm

TR-15 Reback, K.E., P.D. Brady, K.D. McLauglin, and C.G. Milliken. 2004. A survey of anadromous fish passage in coastal Massachusetts: Part 1. Southeastern Massachusetts. http://glooskapandthefrog.org/weweantic%20river%20revisited.htm

Atlantic and Shortnose Sturgeon
Both runs indicated in the Atlantic State Marine Fisheries Commission (ASMFC) data were selected, since they were confirmed with NHESP records.

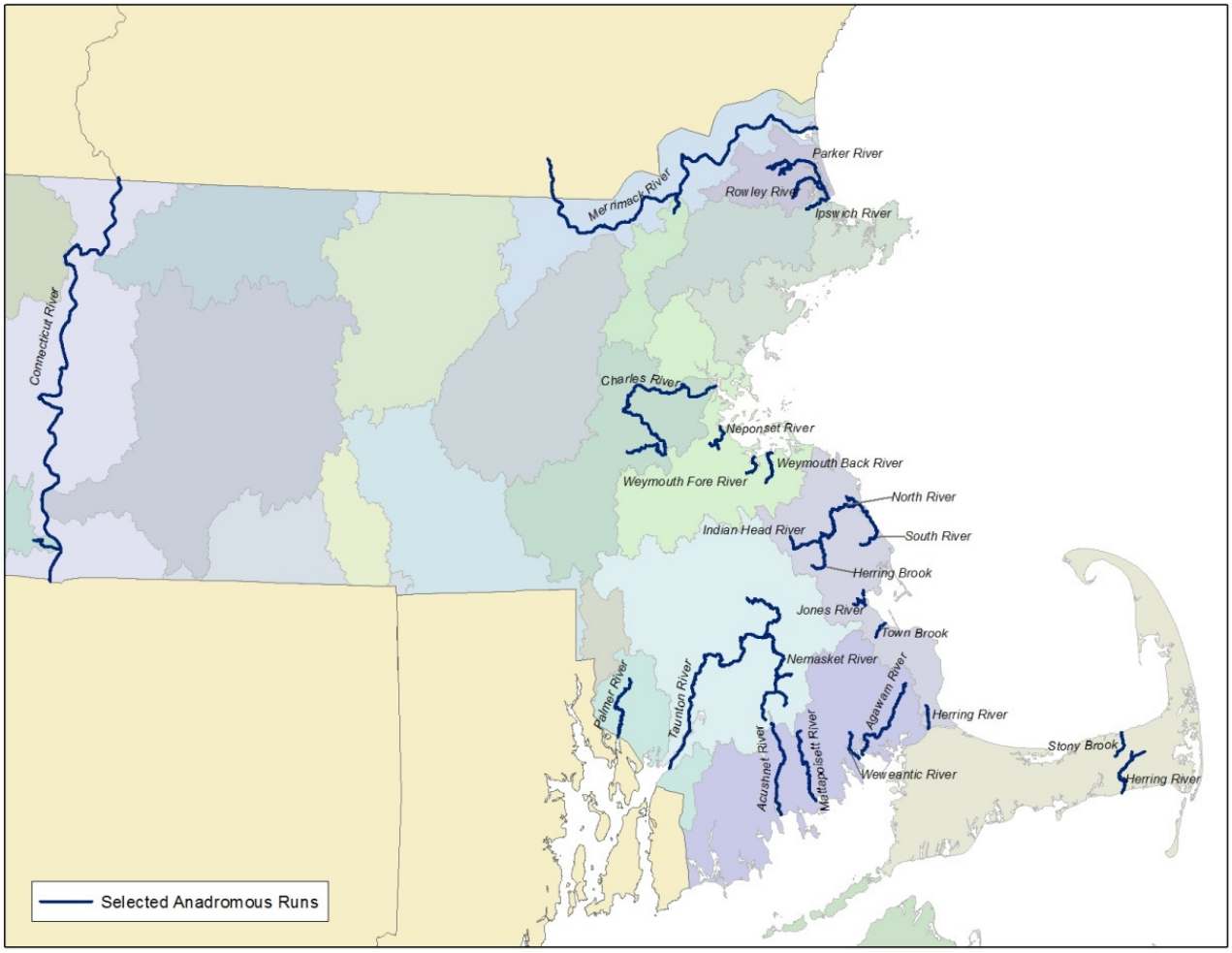


Figure 19. All anadromous runs selected for inclusion in Aquatic Core.

GIS Methods for Anadromous Fish Mapping

Spatial delineation of the anadromous fish runs began with GIS data from TNC's Northeast Connectivity (NEC) Initiative. It is based on the National Hydrography Dataset, a 1:100K dataset for rivers. The first step of the GIS analysis was to review and select from within the NEC data the appropriate rivers and extents for the species in question. This was done with the aid of Alison Bowden, TNC freshwater ecologist. Once the proper extents were defined within this 1:100K dataset, they were transferred to a stream centerline dataset based upon the 1:25K MassGIS Hydrography dataset. A 30-meter fixed-width buffer was applied to selected stream centerlines. Open water polygons from the DEP wetlands data that fell within this buffer were selected, then edited to snip off long tributaries before also being buffered by 30 meters. The

result of these two buffering steps was to create a polygon layer incorporating the best representation of the stream with a 30-meter buffer from its banks.

Next, wetlands that intersected this stream buffer were selected from the DEP wetland dataset. A dissolved version of the DEP wetlands was used to ensure that all contiguous wetlands were captured. Several secondary selections and reviews were necessary to ensure accuracy of selection. Where long tails of wetlands were selected, these were curtailed through manual editing. Finally, the selected wetlands were unioned with the buffered stream polygon, and the resulting layer was dissolved. The end result is a polygon layer of the open water portion of streams, a 3-meter buffer of those streams, and the wetlands that intersect that buffer.

A set of post-processing decisions were made during the final editing of this layer. They are in summary:

- Cranberry bogs were not included in the wetland selection.
- Where contiguous wetlands extend far from the original anadromous run, they were clipped at the first road.
- The same treatment (clipping at the first road) was applied to large tributaries and their associated wetlands.
- Enclosed gaps between wetlands and the buffered stream channel were not filled in; however, if there were wetlands within this gap, they were added to the final layer.
- Certain rivers were clipped at the dam or bridge rather than the ocean.
    - Taunton - clipped at bridge that according to convention is the extent of the Taunton River (it is the extent of the Wild and Scenic designation).
    - Charles River - cut off at dam.
- Beaches, dunes, and barrier beaches were erased from the final layer where they fell beyond the 30-meter buffer.
- The Merrimack, Charles, Agawam, and Taunton rivers were reviewed manually and development along the banks was excised from the final layer.

As an example, Figure 20 below shows the detailed components of the anadromous core for the Mattapoisett River. Figure 21 shows the dissolved union of these components, and the extent that was added to Aquatic Core.

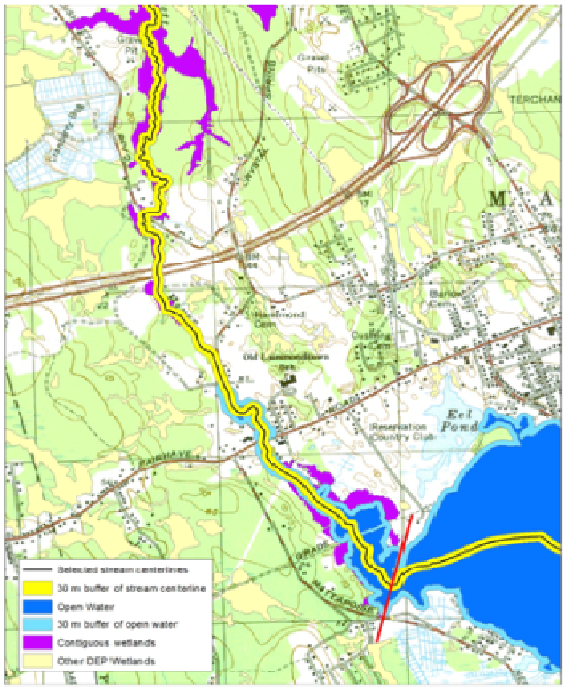


Figure 20. Components of the Aquatic Core for the mouth of the Mattapoisett River.

Figure 21. Aquatic Core extent for the Mattapoisset River.

Identification of Selected High-Priority Habitat for Remaining Non-MESA-listed SWAP Fishes

There are over 3000 data points in the DFW Fisheries Section database. Information contained in the database includes a unique sample ID for each point, link to the SARIS/PALIS stream code, date of sample, town, method of sample (*e.g.*, barge shocking, backpack shocking, gillnetting), the species and length of every fish captured during the sample, duration of sample effort (seconds) at each point, and crew names, as well as several other fields. Given such detailed information, it was possible to use the species present, species richness, and density to identify a subset of the sample points that would likely identify high-quality stream habitat that should be targeted for protection.

Identification of the target points was the first of a three-step process to identify high-quality habitat. The second step involved manual review of every target to identify if the point represented high-quality habitat. The third step involved identifying the upstream and downstream river/stream segments that likely have similar habitat characteristics. It is important to note that while this process identified high-quality habitat for the 14 "inland fish" (non-MESA-listed), there are other methods that could and will be used to identify "high-quality" stream habitat. The high-quality habitat identified does not represent all of the important habitat needed to protect these 14 fish species.

The set of targets were identified using the following criteria:

- Points where 100% of fish caught were Brook Trout and/or Slimy Sculpin and are in the top 25% most dense samples (catch per unit effort) - 64 points identified.
- Tthe top 10% of points ranked by density of Brook Trout only (Brook Trout catch per unit effort) - 116 points identified.
- The top 10% of points ranked by fluvial SWAP density (number of fluvial species at a site/number of seconds of electro-shocking). Fluvial SWAP fish included all species except the anadromous species from Table 33 - 153 points identified.

There was overlap in some of the points selected. Table 34 indicates how many were identified within multiple queries.

Table 34. Queries used to identify targets supporting non-MESA-listed fish species.

Query / Selection Criteria	Number of Targets
100% Brook Trout and Slimy Sculpin (Top 25%) **ONLY**	14
Brook Trout Density (Top 10%) **ONLY**	53
Fluvial SWAP Density (Top 10%) **ONLY**	140
Fluvial SWAP Density (Top 10%) and Brook Trout Density (Top 10%)	13
100% Brook Trout and Slimy Sculpin (Top 25%) and Brook Trout Density (Top 10%)	50

These criteria identified 270 targets. Every one of those targets was investigated and the species composition, the aerial photo, and expert knowledge of each sample point and stream were used

to determine if the target should be selected as the "seed" of a stream segment that extends from that point. When investigating each point, a variety of factors were considered, including:

- Relative abundance of fish species present at point;
- Presence of species that indicated poor habitat quality;
- Amount of urban / suburban development located near the sample point; and
- "Point-specific" knowledge derived from field notes or familiarity of the DFW Fisheries Section staff with the point.

The following staff from the Division of Fisheries and Wildlife took part in the expert panel review of each of the targets: Kristin Black, Leanda Fontaine, Alicia Norris, Dana Ohman, and Todd Richards. Caleb Slater and Steve Hurley of the Division reviewed the streams selected for Atlantic Salmon and the streams and rivers in the Southeast District, respectively.

After an initial full-day retreat concentrating on selection criteria, the remaining MassWildlife districts were used to divide up and complete analysis. Dana Ohman conducted this analysis for DFW's Western District. Leanda Fontaine and Alicia Norris conducted this analysis in coordination with Todd Richards for the Central District. Todd Richards, Leanda Fontaine, Alicia Norris, Dana Ohman, and Kristin Black conducted the analysis for the Connecticut Valley district. Todd Richards, Leanda Fontaine, and Alicia Norris conducted this analysis for the Northeast and Southeast districts. James DeNormandie provided GIS support throughout these meetings.

In the eastern portion of the state, the fluvial richness and the density of Brook Trout fell so much that there were almost no points identified by the criteria in the Northeast and Southeast DFW Districts. In these areas and a few watersheds in the west, the top 10%, or no fewer than two points, were selected from each of the following watersheds in order to represent more fully the biodiversity of the state's aquatic systems: Bashbish, Buzzards Bay, Cape Cod and Islands, Charles, Farmington, Ipswich, Kinderhook, Merrimack, North Coastal, Neponset, Parker, Shawsheen, South Coastal, and Taunton. Each of these additional targets was analyzed manually as described above, to determine if they should serve as the seed of an aquatic core.

Once the "seed" points were selected, we made another sweep to identify the extent of the river upstream and downstream of the point that would be included in the Aquatic Core. This process was also expert-driven, although considerations such as the following were used when determining how far upstream or downstream to map from the "seed" sample point:

- Nearby sample points that indicated a consistently high fluvial species richness that extended upstream or downstream until the richness dropped off.
- Presence of a dam that was known to disrupt passage of fish between upstream and downstream segments.
- Intersection with a higher order stream whose characteristics and species composition are known to be different than those found at the "seed" sample.
- Consideration of the species composition and abundance at adjacent sample sites paying specific attention for presence of fluvial species in high numbers, or of habitat-generalist species, which indicates a degradation of habitat or water quality at that sample.

Enhancements to Living Waters Data and MESA-listed Fish Species Habitats
The final Living Waters GIS data layer created by NHESP in 2003 included areas key to the protection of rare species and exemplary aquatic habitats. For the purposes of *BioMap2*, we identified the portions of the Living Waters project that could be updated or superseded using the current information present in the Heritage databases, and those portions of the analysis that cannot be replicated and should be incorporated into *BioMap2*.

Information that was updated using more current information:

- Rare aquatic plants
- Rare aquatic fish
- Rare aquatic invertebrates – freshwater mussels
- Rare aquatic invertebrates - non-insect aquatic invertebrates
- Exemplary aquatic habitats – invertebrate habitat in rivers (coarse-filter rivers)
  The location of rare odonate habitat was used as an indicator for those portions of rivers that should be included in Living Waters. All rare odonate habitat will be considered and added into *BioMap2* as a result of inclusion of the species habitats of odonates.
- Exemplary aquatic habitats – habitat for inland fishes
  We incorporated information from a database that the Fisheries section maintains to consider multiple non-listed SWAP fish species. This analysis will be used to replace the analysis in Living Waters that identified important habitat for inland and coastal fishes.

Living Waters analyses that were preserved in *BioMap2*:

- Exemplary aquatic habitats – invertebrate habitat in streams (coarse-filter streams)
  A large amount of work was conducted for Living Waters to identify high-quality small streams (1st and 2nd order) throughout the state. From an initial 697 reaches of small acidic perennial streams, a subset was identified and then verified using field work to represent very high quality aquatic habitat. These stream segments were retained and entered into *BioMap2*.
- Exemplary aquatic habitats – lake and pond habitats (coarse-filter lakes)
  A large amount of work was also conducted for Living Waters to identify high-quality lake and pond habitat throughout the state. The final lakes and ponds that were selected and verified using field work were added directly to *BioMap2*.
- Difference between rare species habitat in Living Waters and current version of rare species habitat: We conducted an analysis of all of the rare species habitat identified in Living Waters that was no longer present in the aquatic rare species "footprint" as represented by the current Heritage databases. We identified those portions of the *old* rare species footprint (as depicted by Living Waters) that were no longer being identified by the current footprint. Then we analyzed why these areas dropped from consideration. In the cases where an aquatic habitat was "down-ranked" (*e.g.*, due to increased impacts of development), the removal from *BioMap2* was allowed to remain. However, in some cases where the habitat was removed only because the rare species observation had become out of date (historic) but the habitat was otherwise intact, we elected to maintain this Living Waters habitat in *BioMap2*.

To create a more robust network of Aquatic Core, stream segments below a minimum length were extended through a GIS analysis that used the CAPS Index of Ecological Integrity to

identify adjacent high quality stream habitat. This treatment was applied to stream segments from the Living Waters "Coarse Filter Streams" (described in section 3.1b of the Living Waters Technical Report) as well as MESA-listed fish habitats.

There are 84 Living Waters coarse-filter stream segments; all are below 0.5 miles in length and total 24 miles. Fish species habitats total 22,190 acres, which translates roughly to 463 miles in length. Of these fish habitat polygons, those 20 acres in size or less were selected for extension, excluding lakes or ponds.

The CAPS-integrated IEI data was averaged across stream segments. Segments with scores >0.8, or the top 20% of streams, were selected and dissolved. Where these high-scoring streams intersected or were within 30 m of targeted short segments, they were selected as potential stream additions. The length of stream additions varied according to the extent of high-scoring adjacent habitat.

Where Living Waters segments had low IEI scores and no high-scoring adjacent habitat, they were deleted. Eighteen such segments were deleted for this reason. No MESA-listed fish habitat was deleted due to low IEI scores.

Finally, potential stream extensions were reviewed by DFW/NHESP fisheries biologist Kristen Black and manually edited for corrections.

Inclusion of Remaining MESA-listed Aquatic Species Habitats

A subset of all of the MESA-listed species live all of, or a portion of their lives, in aquatic habitat. We isolated these 139 species and identified the 30 meters of upland adjacent to their species habitats. These species habitats plus the 30 meters were included as Aquatic Core Habitat (see Appendix N for list of these species). While almost all of these polygons were included, some of the specific species habitats were removed for species such as Crooked-stem Aster, which can exist in areas that are removed from the hydrological network of rivers, streams, and wetlands. For instance, some occurrences were mapped on hillsides where only a seep was present. These types of species habitat polygons were removed since it does not make sense to include them as part of Aquatic Core.

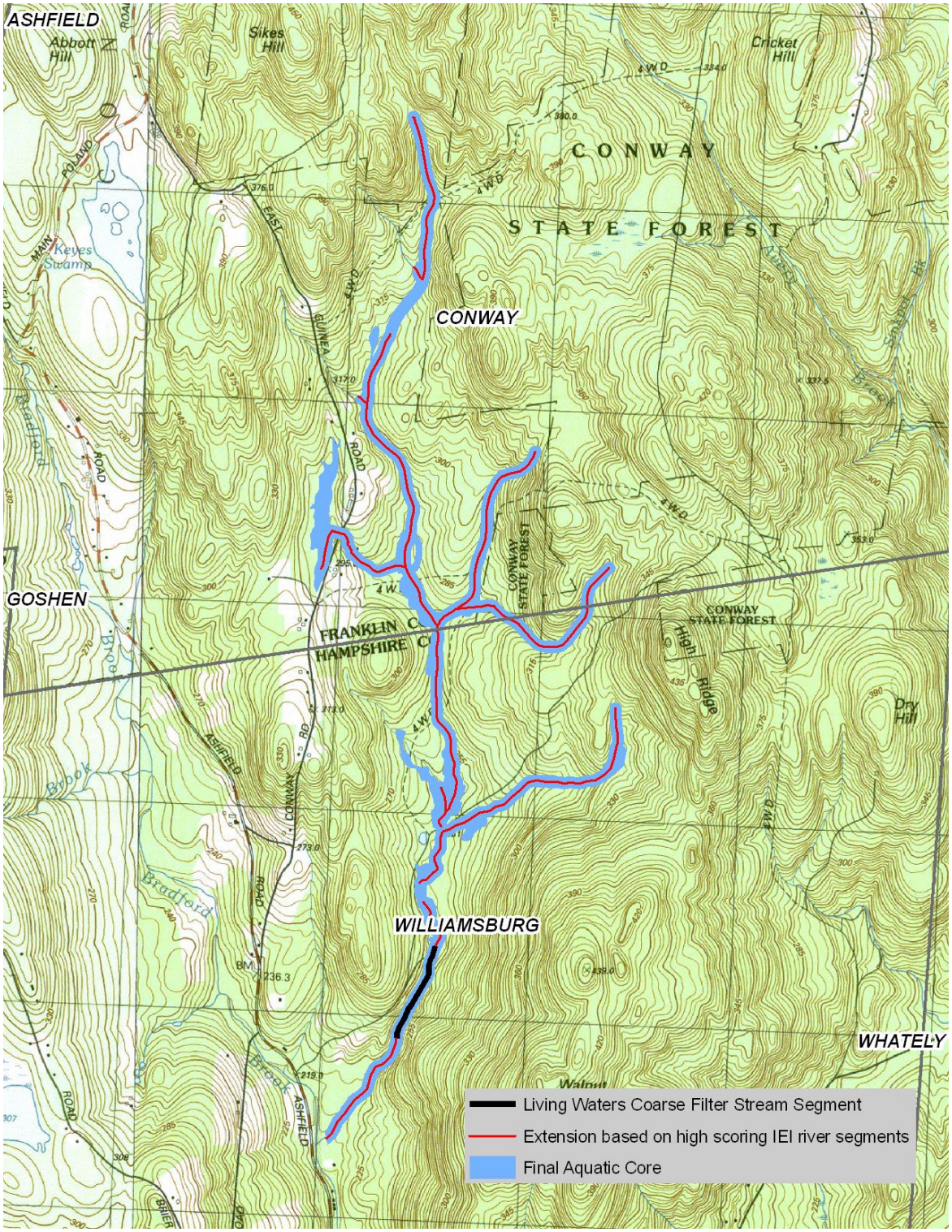


Figure 22. Example of a Living Waters coarse-filter stream segment that was "enhanced."

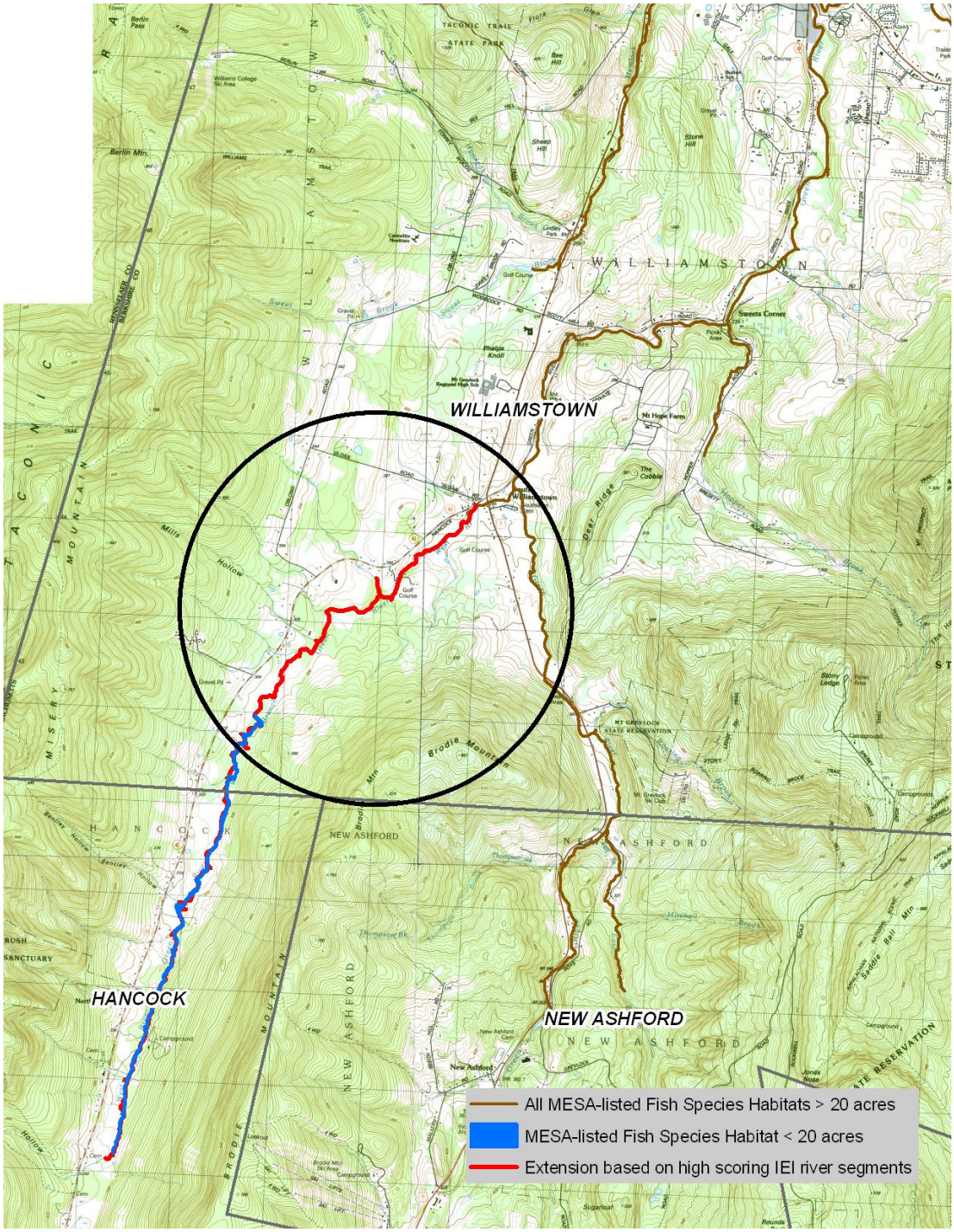


Figure 23. An example of a high-quality stream segment that bridged the gap between two MESA-listed fish species habitats.

Chapter Four: Components of Critical Natural Landscape -

Section A: Landscape Blocks

Introduction

Conserving the breadth of biodiversity, including species and ecological processes, requires protecting intact landscapes at large scales, which complements fine-filter species conservation. Landscapes are defined as mosaics of forests, wetlands, rivers, shrublands, and other habitats, often capturing broad ecological gradients, from valley bottoms to ridgetops. Intact landscapes provide an aggregation of contiguous habitats and connectivity among them, to support the long-term viability of wildlife populations and to help maintain ecosystem processes. Large intact landscapes, represented in *BioMap2* as Landscape Blocks, provide diverse habitats at a scale necessary to sustain healthy populations of local and wide-ranging species. The integrated patchwork of wetlands, uplands, and rivers that are found in unfragmented Landscape Blocks allows animals to move freely among habitats, supporting daily movements, migration, dispersal, and colonization of new habitats. Intact landscapes also facilitate shifts in the geographic distribution of species, a process that is likely to accelerate in response to climate change in the coming decades.

Intact landscapes also support ecosystem processes and interactions among different habitats. For example, large forested watersheds capture, filter, and gradually supply clean, cool water and nutrients to our river networks. Intact landscapes also buffer smaller and more sensitive species and natural communities—such as wetlands, vernal pool species, freshwater habitats, and rare ridgetop inhabitants—from the impacts of roads and development. Landscapes are naturally dynamic, described by some as shifting mosaics. The dynamic nature of landscapes, which can only occur in large intact areas, results in a mosaic of habitat types and patches that in turn support a wide array of species.

The intent of the Landscape Blocks included in *BioMap2* Critical Natural Landscape is to delineate those landscapes that provide for ecosystem processes, habitat for wide-ranging species, and a mosaic of natural land cover types. Landscape Blocks were derived from a GIS analysis designed to capture the largest and most intact extents of contiguous natural cover relative to the surrounding landscape in each of the ecoregions across Massachusetts. Representation of Landscape Blocks in each ecoregion was emphasized because different suites of biodiversity inhabit the landscapes of the different ecoregions across the state (see Ecoregions discussion in Chapter 2, Section A).

Methods

The Landscape Block analysis identified large and relatively unfragmented blocks of natural cover using a customized run of the University of Massachusetts CAPS Index of Ecological Integrity (IEI) (see Chapter 2, Section D for CAPS IEI methodology and the modifications for the customized run). The total area of all natural cover in Massachusetts, the starting point for this analysis, is 3,702,718 acres or about 70% of the state.

We selected the most intact areas of natural cover within each ecoregion by applying a minimum IEI threshold per ecoregion and then selected the largest blocks of high integrity landscape in each ecoregion as Landscape Blocks. The analyses described below were designed to represent the most intact landscapes across the ecoregions of the state, while at the same time the intent was also to identify a small but meaningful subset of the total natural cover in order to help prioritize conservation decisions and optimize limited resources.

The outcome of the IEI analysis is a 30m pixel raster layer that ranks the ecological integrity of each natural cover pixel on a scale of 0-1. We used these scores to select patches of high ranking pixels, or blocks of the most intact natural cover, by setting minimum IEI thresholds for each ecoregion to ensure that each ecoregion was well represented in the final Landscape Blocks (Table 35). However, we chose to use a statewide scaling of IEI, rather than an ecoregional scaling of IEI, because it resulted in more consistent scoring of intact areas of natural cover when comparing equivalent scores across ecoregions.

Table 35. IEI thresholds (0.0 – 1.0) and size thresholds used to select blocks.

Ecoregion	**IEI Threshold**	**Minimum Block Size (Acres)**
Berkshire Plateau	0.7	5,000
Boston Basin and Southern New England Coastal	0.5	1,000
Bristol Lowlands/ Narragansett Lowlands	0.5	1,000
Cape Cod and Islands	0.4	1,000
Connecticut River Valley	0.4	1,000
Taconic Mountains	0.7	10,000
Western New England Marble Valleys	0.5	1,000
Worcester Plateau	0.7	5,000 in northwest section, 1,000 in south and east

CAPS IEI was used to define Landscape Blocks for *BioMap2*, as opposed to using a consistent linear buffer distance from roads and development, because of the sensitivity of the IEI model to variables such as traffic volume, the similarity of each point to those around it, etc. However, with sensitivity comes complexity, and because of that complexity there is no one IEI threshold that works to optimize intact areas across the state. Therefore, for *BioMap2* Landscape Blocks, IEI thresholds for each ecoregion were selected subjectively by visually reviewing the areas selected by different thresholds across the IEI gradient between 0 and 1, and then selecting the IEI threshold that captured large and relatively regularly shaped patches of contiguous natural cover, but that did not include intrusions of roads, intensive agriculture, or other development, and did not extend into developed or otherwise fragmented habitat such as exurban and suburban development. Because the IEI thresholds are relative, not based on absolute ecological thresholds, a subjective threshold selection that maximized both integrity and representation within and across ecoregions worked well for this analysis. The selected IEI thresholds were highest in the least disturbed ecoregions and lowest in ecoregions with more development. Selecting Landscape Blocks based on these thresholds results in a set of areas that represent the most intact natural cover ***for each ecoregion***.

Once IEI thresholds were determined, and clusters of high IEI natural cover pixels were selected, areas that met these criteria were converted to a vector layer. Natural cover polygons were aggregated within a distance of 60 meters so that blocks could span small roads. Major roads (MA Department of Transportation (DOT) Roads classes 1 through 3) were burned in to split any polygons that might have been aggregated across a large road. The acreage of each polygon was calculated, and those less than 100 acres were deleted. This resulted in a set of nearly 600 polygons.

After a review of Landscape Block size distribution by ecoregion, we applied minimum size thresholds for each ecoregion to select a final set of Landscape Blocks (Table 36). As with IEI thresholds, size thresholds were used to select the largest, and therefore most important, blocks in each ecoregion, thus optimizing the Landscape Blocks as a conservation prioritization and decision-support tool.

As a final step, Landscape Block boundaries were reviewed and edited to smooth block boundaries and improve consistency across ecoregional lines. Hence, small pockets of development may be included within blocks in order to improve the overall shape of the block. Five Landscape Blocks were added around the state's borders, where they were connected to large unfragmented areas in neighboring states. Twelve Landscape Blocks were added where Forest Cores were present, so that each Forest Core was associated with and nested within a Landscape Block. Table 36 shows the number and size of Landscape Blocks after this post-processing. Because of these later additions, in some cases the smallest Landscape Blocks in each ecoregion fall below the minimum size thresholds reported in Table 35.

One hundred and ninety two Landscape Blocks, totaling 1,338,663 acres, were selected for the Critical Natural Landscape component of *BioMap2*. This represents the most intact 36% of the total area of natural cover in the state.

Table 36. Final set of selected Landscape Blocks, prior to addition of Eastern Box Turtle Conservation Areas.

Ecoregion	# Blocks	Minimum Size (Acres)	Maximum Size (Acres)	Average Size (Acres)	Total Area (Acres)
Berkshire Plateau	24	5,714	52,094	19,942	478,619
Western New England Marble Valleys	8	1,280	13,027	5,867	46,932
Bristol Lowland/ Narragansett Lowland	30	834	28,150	3,850	115,513
Cape Cod and Islands	23	475	23,940	5,532	127,242
Connecticut River Valley	7	964	10,268	3,967	27,770
S. New England Coastal Plains & Boston Basin	55	691	12,793	3,032	166,776
Taconic Mountains	6	1,104	25,365	13,589	81,534
Worcester Plateau	39	1,035	75,007	7,546	294,277
Total	**192**				**1,338,663**

The final step was to add in large habitat areas mapped for Eastern Box Turtles. Eastern Box Turtle is a Species of Conservation Concern with a habitat footprint mapped by Natural Heritage. Since this turtle is a habitat generalist, large portions of its mapped habitat were included in the Landscape Blocks while only the nesting sites and densest population concentrations were included in Core Habitat. The inclusion of Eastern Box Turtle habitat added an additional 135,000 acres to the final Landscape Block layer.

Discussion

Landscape Blocks comprise 1,474,000 acres of *BioMap2* Critical Natural Landscape (Figure 24). The largest Blocks are in rural areas of western Massachusetts, yet significant natural landscapes remain in eastern Massachusetts. It is important to protect these features across the state, as blocks in each ecoregion support unique and important wildlife habitat and biodiversity. The methods described here allowed for the comparison of ecological integrity of landscapes across the state (by using a statewide-scaled IEI), while also accounting for the different general levels of development and fragmentation within each ecoregion (by setting varying IEI thresholds and size criteria by ecoregion). Using the CAPS IEI rather than fixed-width buffers from roads and development made block boundaries more sensitive to the specific landscape context at each particular point within the landscape. Since this is a prioritization, the end result necessarily excludes some of the state's natural landscapes, particularly in western Massachusetts. However, the final set of Landscape Blocks represents a balanced set of large landscapes whose protection will be critical to the maintenance of the ecosystem processes, wide-ranging species, and overall biodiversity in Massachusetts.

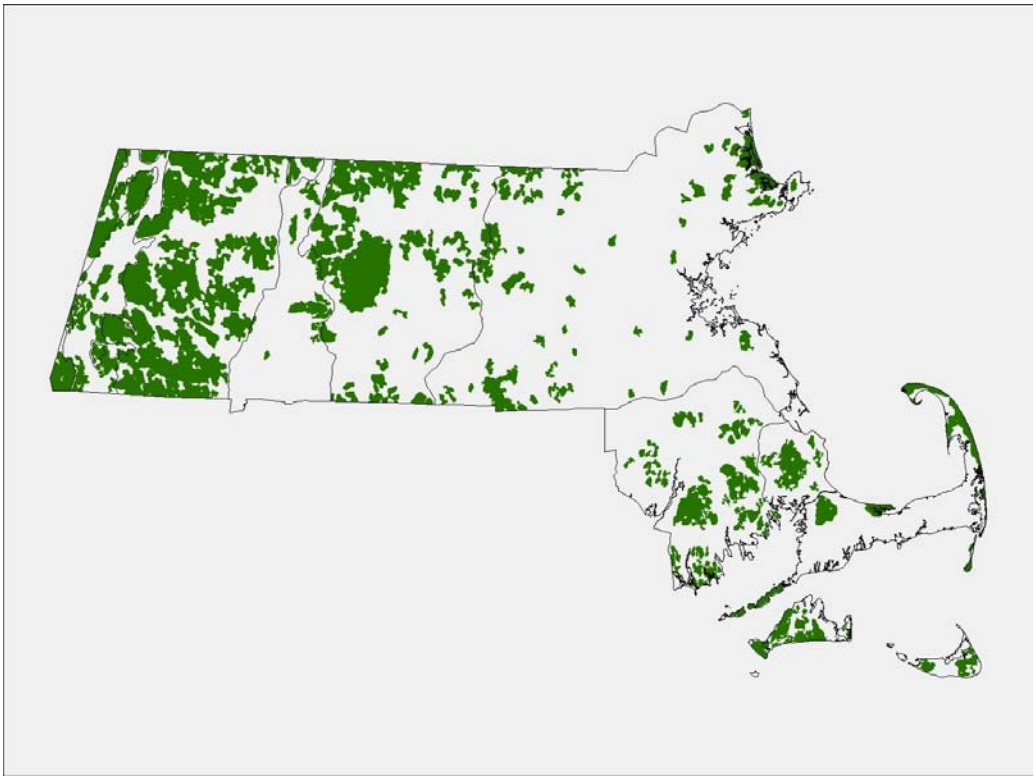


Figure 24. Landscape Blocks showing ecoregional boundaries.

Regional Additions to Forest Cores and Landscape Blocks
To assess ecological integrity along Massachusetts state boundaries, we used a regional analysis developed by The Nature Conservancy that applies CAPs methodology across thirteen states in the eastern United States (see Figure 25). Using the National Land Cover Dataset, the analysis assesses local connectivity by applying the CAPS connectedness metric. The result is a raster dataset scaled from 0 to 1 that represents the level of resilience, as measured by local connectivity, across this region.

This dataset was used to inform the selection of large Forest Cores and Landscape Blocks. The intent of this review was to identify Landscape Blocks and Forest Cores that straddle the state boundary, and were missed by the initial selection because they have only a portion of their acreage in Massachusetts. Where the total area of these blocks and cores met the size thresholds for their respective ecoregions, they were added to *BioMap2*. A total of two Landscape Blocks and five Forest Cores were added as a result of this review (see Figures 26 and 27).

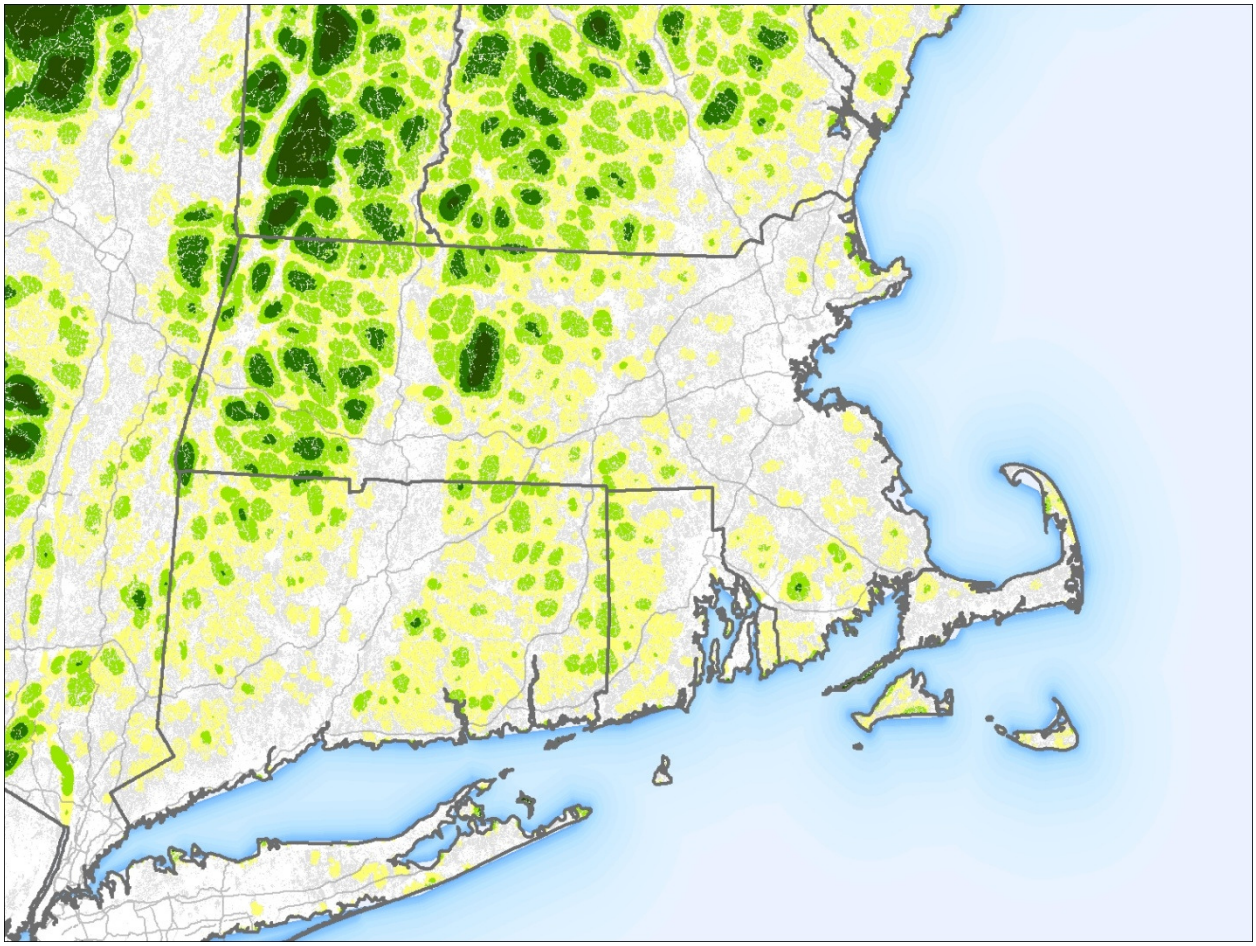


Figure 25. Regional connectedness
showing areas of highest local connectivity in dark green.

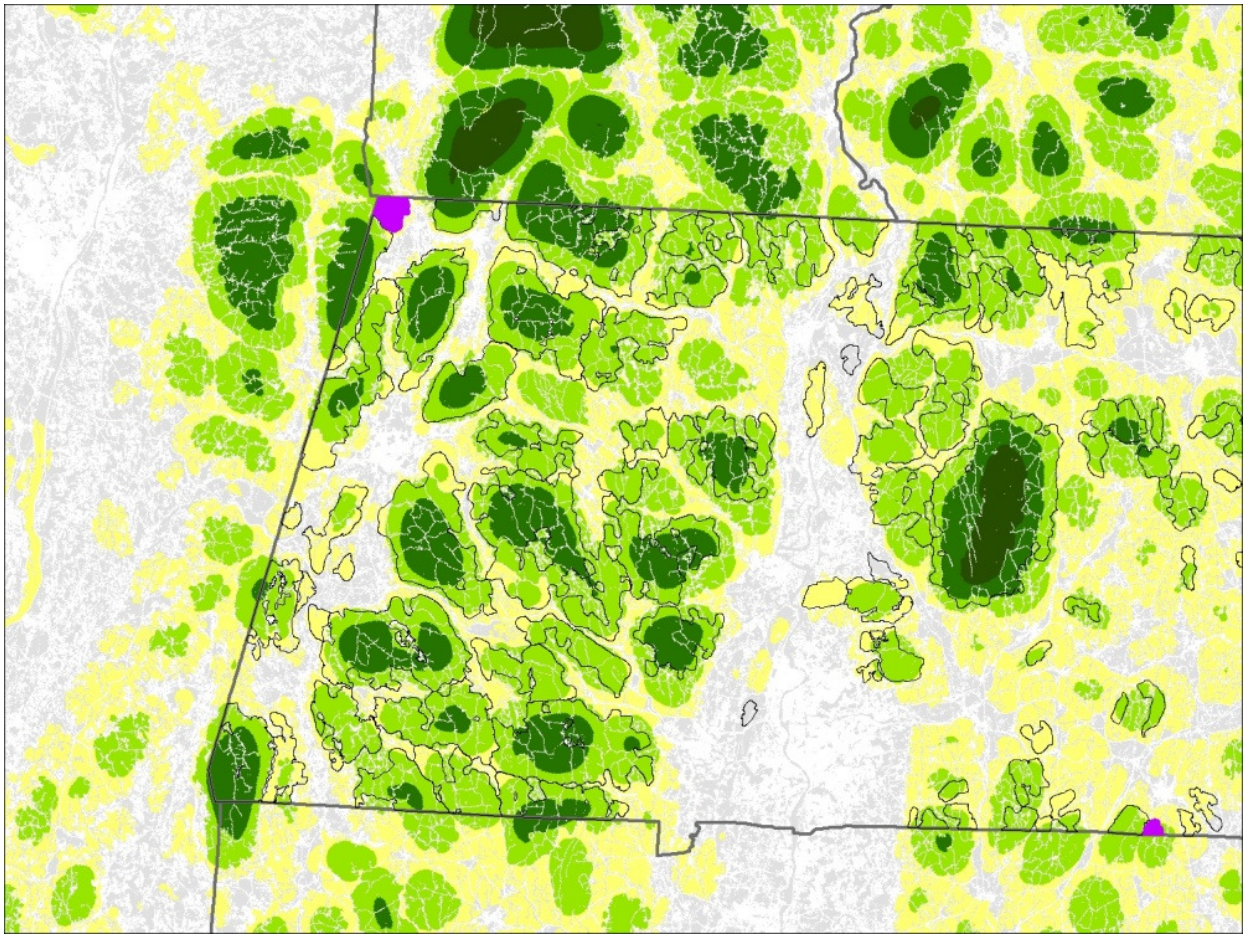


Figure 26. Landscape Blocks that were added
as a result of this review are shown here in purple.

Figure 27. Forest Cores that were added
as a result of this review are shown here in purple.

Forest Cores: Forest Cores were analyzed in a similar way to Landscape Blocks. Five Forest Cores were added after the state boundaries were reviewed.

Section B: Upland Buffers of Wetland and Aquatic Cores

Upland buffers were created for each Wetland and Aquatic Core in order to identify the upland habitat that, if protected, will help to increase the resilience of these important resources. In order to generate the buffers, we made use of a program written by Brad Compton (Research Associate, University of Massachusetts, Department of Natural Resources Conservation) that generated buffers surrounding resource polygons using the Index of Ecological Integrity from the CAPS model as a "cost surface". For instance, a buffer would be created surrounding a wetland, with the IEI values informing how far the buffer actually extended from the wetland. If dense development (low IEI values) existed on one side of the wetland, the buffer would not extend through the development, but instead would stop at the periphery of the development. In pristine areas (high IEI values), the buffer would extend unimpeded to the maximum buffer distance. In some instances, the buffer did extend across roads, but only if the areas on the other side of the road were in a natural state.

Use of this program had the result of creating buffers that were wider in areas with no or little development and narrower in areas constrained by development. Use of the buffer tool also resulted in significant savings of time over generating buffers using uniform buffer widths (*e.g.,* 30 meters or 100 meters), that then had to be manually altered to take into account the reality of roads, residential development and other types of development. While some manual editing was needed after the buffers were generated, we believe that overall, the process took less time. In Figure 28, note the absence of a buffer in the lower right hand corner of the Wetland Core that is directly adjacent to a residential subdivision. In the western portion of the figure, the buffer is wider in the upland areas where no development is nearby.

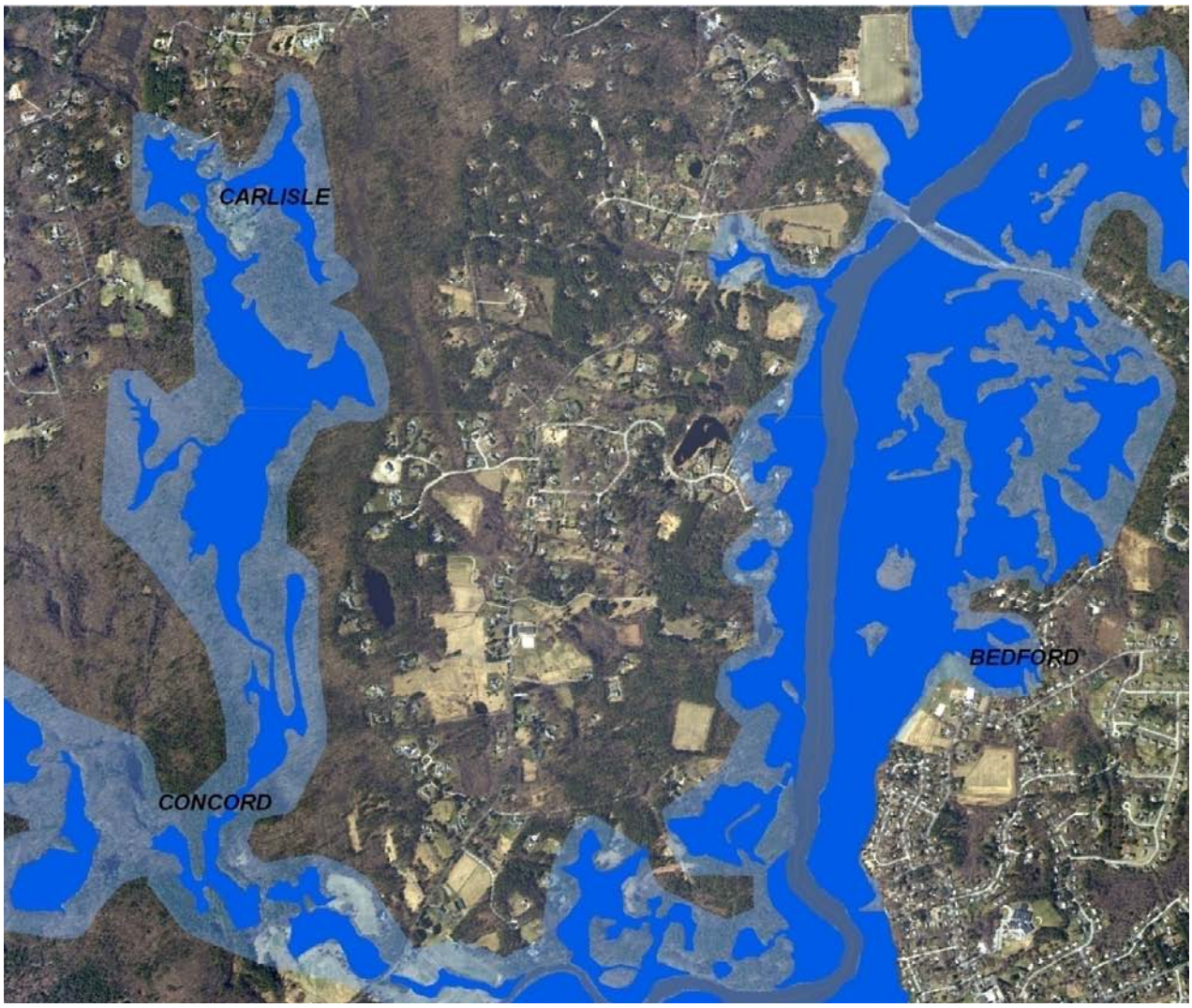


Figure 28. Example of the buffer created by the buffer tool surrounding a Wetland Core.

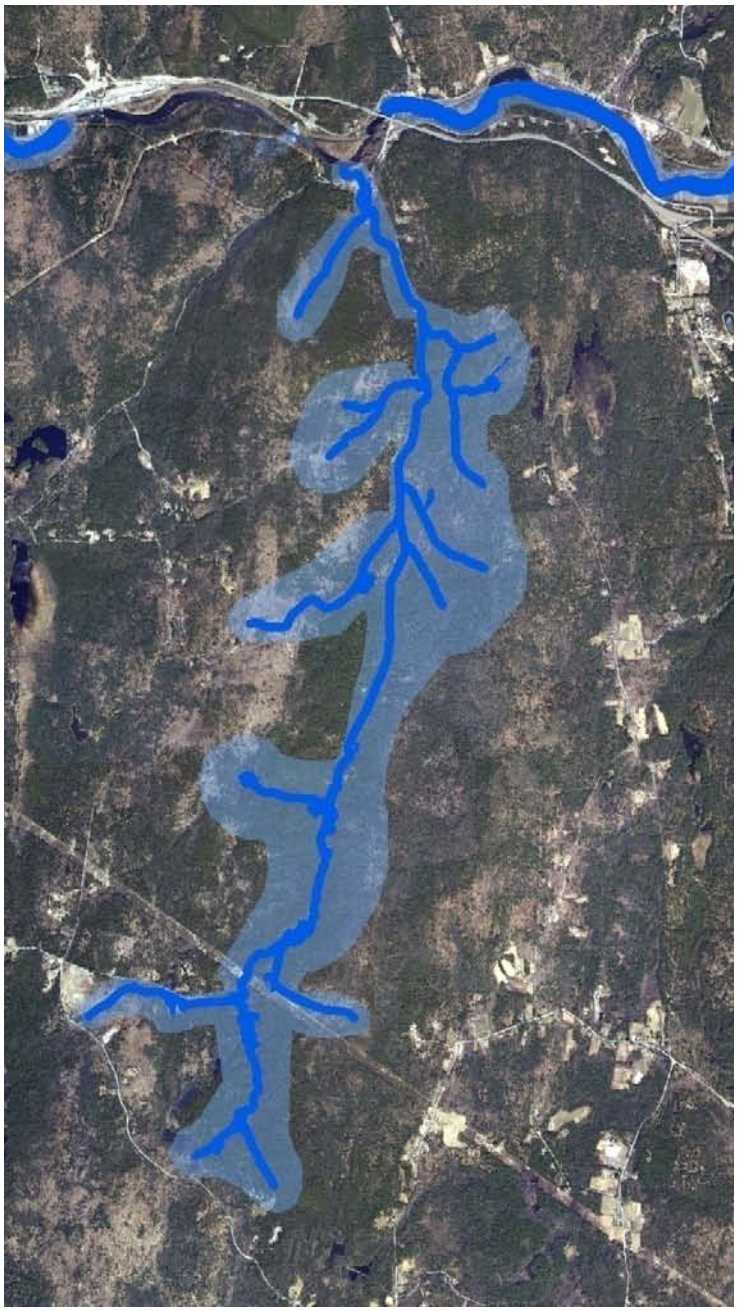


Figure 29. Example of the buffer created by the buffer tool surrounding an Aquatic Core.

The buffer tool created by Brad Compton is based on the "resistant-kernel" estimator that was used to isolate the top 5% of the vernal pools in Massachusetts for *BioMap2*. Originally, this "resistant-kernel" modeling approach was used to develop a model of connectivity for amphibians that breed in vernal pools (Compton, *et al.*, 2007). The model in the 2007 paper used information compiled on amphibian habitat and dispersal preferences. It also used two-dimensional land use data to create a "cost surface" that represented "the willingness of an animal to cross this cover type, the physiological cost of moving, and the reduction in survival for an organism moving across the landscape" (Compton, *et al.*, 2007). The habitat and dispersal

preferences, in conjunction with the land use cost surface, were used to generate a three-dimensional surface that represents the probability of an individual salamander dispersing from a focal cell and arriving at any other point in the landscape. This probability surface can be generated for salamanders with larger dispersal distances or those with smaller dispersal distances (this distance is referred to as "bandwidth" in the model). In addition, you can slice the probability surface at whichever percentage contour you wish (*e.g.*, 50% represents the contour that will encircle 50% of the volume of the probability surface as it emanates from the vernal pool). Both of these concepts, the bandwidth and the contour, were used in the buffer tool.

The model developed for the 2007 article was adapted so that rather than emanating from a point (a vernal pool) the probability surface could be generated surrounding a polygon (a wetland or aquatic core). The cost surface used in the model was the integrated IEI for all of Massachusetts, rather than being a cost surface tailored for amphibians. The bandwidth was simply the distance the kernel would spread in a sea of IEI = 1, rather than a dispersal distance. If an area in Massachusetts had an IEI of 1 for all cells, spreading in all directions, a bandwidth of 500 would generate a buffer that was roughly 500 meters from the edge of the polygon that needed to be buffered. Since the IEI is rarely equal to 1, the buffer that is generated is rarely larger than the bandwidth. We ended up using the bandwidth setting as a coarse setting; it set the maximum distance the buffer could spread from the edge of a polygon. We then used the contour setting as a fine adjustment, going farther from or closer to the edge of the source polygon, with the overall constraint set by the bandwidth.

As we experimented with the buffer tool, we noted that the area that the buffers generated varied widely based on the ecoregion of the state. In the more developed eastern portion of the state, the buffers were smaller, constrained by development and roads. In the less developed ecoregions, the areas of the buffers were larger. This ultimately led us to us the combination of bandwidth and contour settings outlined in Table 37 below for each ecoregion.

Table 37. Bandwidth and contour settings used in each ecoregion

Ecoregion	Bandwidth	Contour	Ratio of source acres to buffer acres
Taconic Mountains	250	50	3.1
Western New England Marble Valleys	250	95	1.0
Berkshire Plateau	250	50	2.1
Connecticut River Valley	250	100	1.7
Worcester Plateau	250	50	1.4
Bristol Lowland/Narragansett Lowlands	250	95	1.0
Boston Basin and Southern New England Coastal	250	95	1.1
Cape Cod and Islands	500	50	1.2

In the less developed ecoregions (Taconics, Berkshires, Worcester Plateau) the smaller bandwidth (250) and tighter contours (50%) were used to generate the buffers. In contrast, the largest bandwidth/contour combination was needed on the Cape. We set these so that the

acreage of source polygons (Wetland Cores or Aquatic Cores) was roughly the same as the acreage of buffer being identified. These settings were used to generate the buffers for the Wetland Core polygons as well as for the Aquatic Core polygons.

While the buffer tool was designed to avoid roads and other types of residential development when delineating the buffers, much of the analysis was run in a raster environment with a cell size of 30 meters. Given the inaccuracy with which roads and development can be depicted at that cell size, it was inevitable that some amount of unwanted development was enclosed within the buffers. In addition, in some cases of very limited development or a road being present in an otherwise natural setting, it was acceptable that the buffer could include limited amounts of buildings and/or roads. For these reasons, a manual review of the buffers was necessary to eliminate the unwanted roads, buildings, and other types of development. In general, the perimeter of every buffer was skirted, and residential and commercial development and roads were removed where they occurred near the edge of the buffer. In some cases, as described above, development was left within the buffer if it was limited in extent.

Section C: Coastal Adaptation Areas

The coastal habitats of Massachusetts are particularly vulnerable to potential sea-level rise in the next century, which some estimates suggest is likely to exceed one meter. Therefore, in addition to prioritizing current coastal habitats, we examined the landward side of salt marshes to determine where these habitats might move to as sea levels rise. We were not able to find any previous analyses that have mapped this band of coastal habitat that might mitigate the destruction of salt marsh habitat due to sea level rise over the coming decades. This analysis is a first pass at an exercise that will, inevitably, need to be repeated with more precise data sets in the future.

The upper limits of sea level rise outlined by the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios suggests that global sea level will increase by approximately 30 cm to 100 cm by 2100 (Nakicenvoic *et al*., 2000), with even higher ranges (50-140 cm by 2100) outlined in Rahmstorf (2007). Based on these frequently cited figures, we have elected to look, in a relative sense, at the extent and quality of the acreage affected by a 1.5 meter rise in elevation on the landward edge on Massachusetts salt marshes and coastal habitats.

Multiple ground and bare earth LIDAR data sets (consisting of the Plum Island Ecosystem LTER 2005 and 2006 imagery, 2002 Department of Homeland Security LIDAR coverage of metro Boston, 2007 EAARL LIDAR coverage of the Cape Cod National Seashore and National Coastal Mapping Program (2005-2007) Army Corps of Engineers Joint Airborne LIDAR Bathymetry Technical Center of Expertise LIDAR for much of the immediate coastline), the MassGIS 2005 DEM (floating point) 1:5000 elevation data layer, and a limited amount of field data were examined to establish the relative range of elevation values evident at the upper edges of high marsh systems along the coastline of Massachusetts. Each of these digital data sets share a reference to the National Vertical Datum of 1988 (NAV88). While elevation varies based on the age, maturity and geomorphological circumstances of the salt marsh complexes located around the Massachusetts coastline, in general and for the purposes of this project, the upper limit of elevation for the high marsh edge was found to be based at 1.5 to 2 meters above sea level.

The MassGIS 2005 DEM 1:5000 (floating point) data layer constitutes the only complete and detailed coverage of the Massachusetts coastline elevation at this point in time. As such, it was used as the initial baseline for this analysis. We isolated a low-lying zone using this data layer, extending from 0 to 3.5 meters above sea level, using the 2-meter height to approximate reaching the upper limit of the high marsh edge, and an additional 1.5 meters to accommodate the more extreme projections for sea level rise. We identified this zone *only* in near proximity to salt water wetlands and other coastal habitats such as coastal salt ponds.

Once this initial low-lying zone was extracted from the 1:5000 data set, the following steps were taken to create the *BioMap2* coastal adaptation data set that was ultimately incorporated into Critical Natural Landscape:

- Impervious surfaces that were located within this 0-3.5 meter band were removed. However, where hydrological connections beyond an impervious surface (for example, a paved road) were obvious, the connected land within the 0-3.5 meter band but beyond the impervious surface was retained.
- Addition of some coastal areas that fell below an elevation of 0 according to the 1:5000 DEM, but were actually above sea level were manually added back into the data set where necessary.
- *Extensive* manual review was then undertaken to manually remove many strips of upland adjacent to salt marsh that were not appropriate for inclusion in this analysis.
- Various "holes" in the data layer were filled in that were created by earlier processing steps (primarily due to the erase of impervious surfaces).
- Some bands of upland located directly adjacent to the coastal salt ponds on Nantucket and one such area in the northwest corner of Buzzards Bay were added into this analysis manually.

Tara Boswell, Natural Heritage and Endangered Species GIS Manager, deserves a special thanks for the *six weeks* of editing that she spent improving this data set and taking it well beyond the initial product that was created. Her work greatly improved the usability and accuracy of this *BioMap2* product.

These processing steps identified the undeveloped lands adjacent to and up to 1.5 meters above existing salt marshes. These areas are included as Critical Natural Landscapes with high potential to support inland migration of salt marsh and other coastal habitats over the coming century.

Overall, this analysis identified 34,600 acres of upland that lies directly adjacent to the roughly 50,000 acres of salt marsh habitat that currently exists in Massachusetts today. While it is heartening that more than 30,000 acres were identified, it is also worrisome to confirm that in many portions of the coast anthropogenic and natural barriers to salt marsh and coastal habitat migration are firmly in place and will leave the existing salt marshes nowhere to go.

It is worth mentioning that the presence of this low-lying, undeveloped 34,600 acres of land, adjacent to existing salt marsh and coastal habitat, does not ensure the future migration of salt marshes into this new zone. In fact, there are several outcomes for a salt marsh as the sea level rises:

1) Transgression: The salt marsh accretes at a pace at or above that of sea-level rise that allows it to survive, transgressing landward and migrating over the high marsh onto uplands while the seaward edge is eroded and reverts to intertidal mud flats (Donnelly and Bertness, 2001a; Goodman, *et al.*, 2007).

2) Barriers: The salt marsh is capable of accreting in pace with sea-level rise but meets a natural or man-made physical barrier such as a steep slope or seawall, preventing it from landward migration. In this case, either the marsh elevations will increase only in a vertical direction allowing it to survive or more likely it

will collapse as sea-level rise exceeds the accretion capacity of low marsh vegetation (Reed, 2002).

3) Partial Collapse: The salt marsh is incapable of accreting at a rate that can keep up with sea level rise, but the higher salinity tolerance and accretion rates of low marsh vegetation permit it to migrate over the high marsh for a time before ultimately it is outpaced by sea-level rise (Fitzgerald, *et al.*, 2008).

4) Collapse: Depending on the rate of sea-level rise, the marsh may be incapable of accreting enough sediment through both mineral and organogenic sources for survival. The marsh surface collapses into tidal pools and flats most likely from back to front as tidal channels and mosquito ditches allow penetration of salt waters deep into the high marsh system suffocating the vegetation (Reed, 1995; Tolley and Christian, 1999).

Which of the above outcomes are occurring along the many salt marshes of Massachusetts will become clear in future decades. The identification of the land to which these marshes could move is just the first of many steps that might be necessary to protect these habitats.

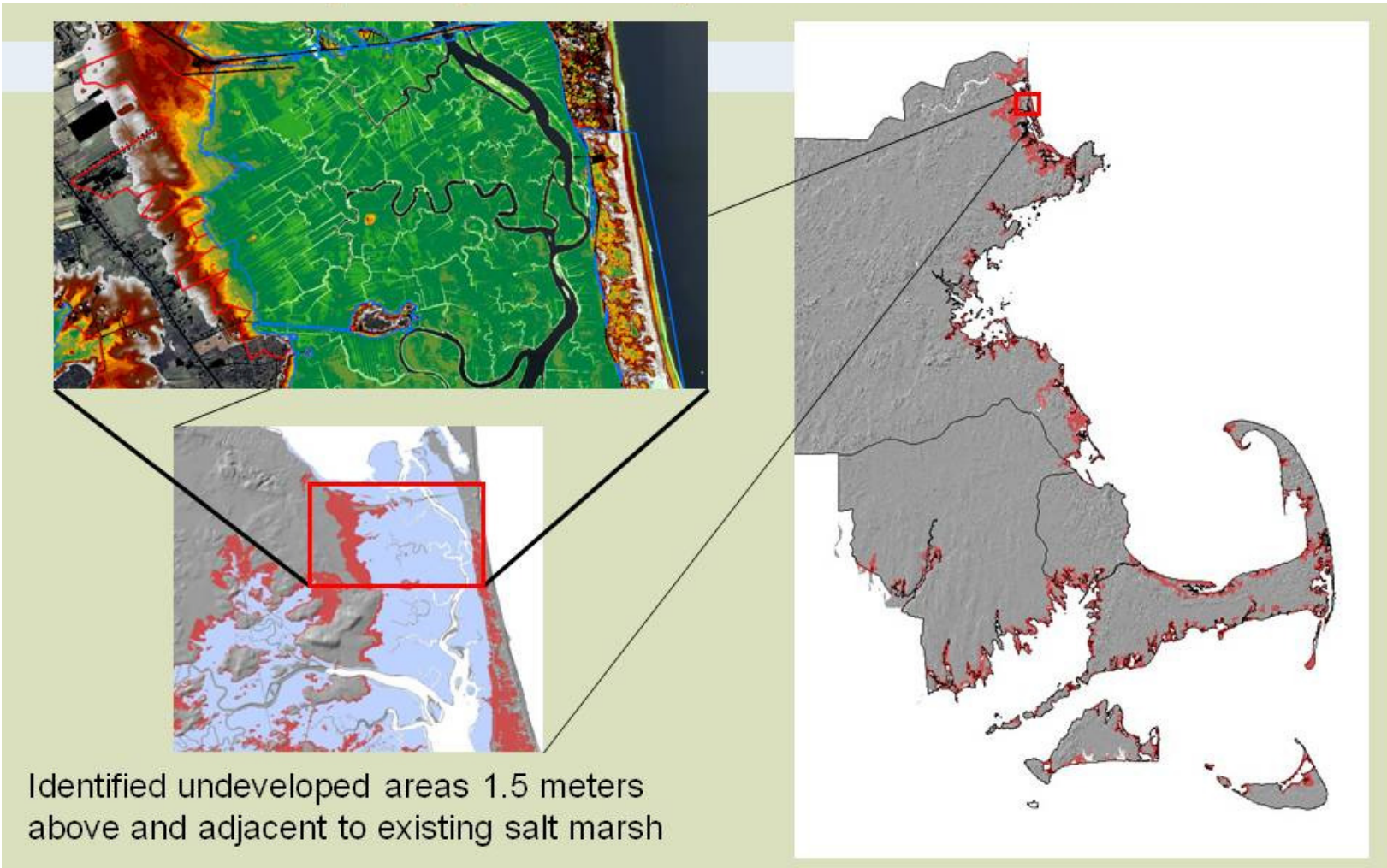


Figure 30. Identifying Coastal Adapation Uplands.

In upper left, the LIDAR elevation data sets that were used to inform the selection of 1.5-2 meters as the upper edge of high marsh habitat; lower left, an inset on the north shore showing polygons of undeveloped upland adjacent to existing salt marsh habitat, and right, the resulting GIS layer delineating the 34,600 acres important for coastal adaptation to climate change.

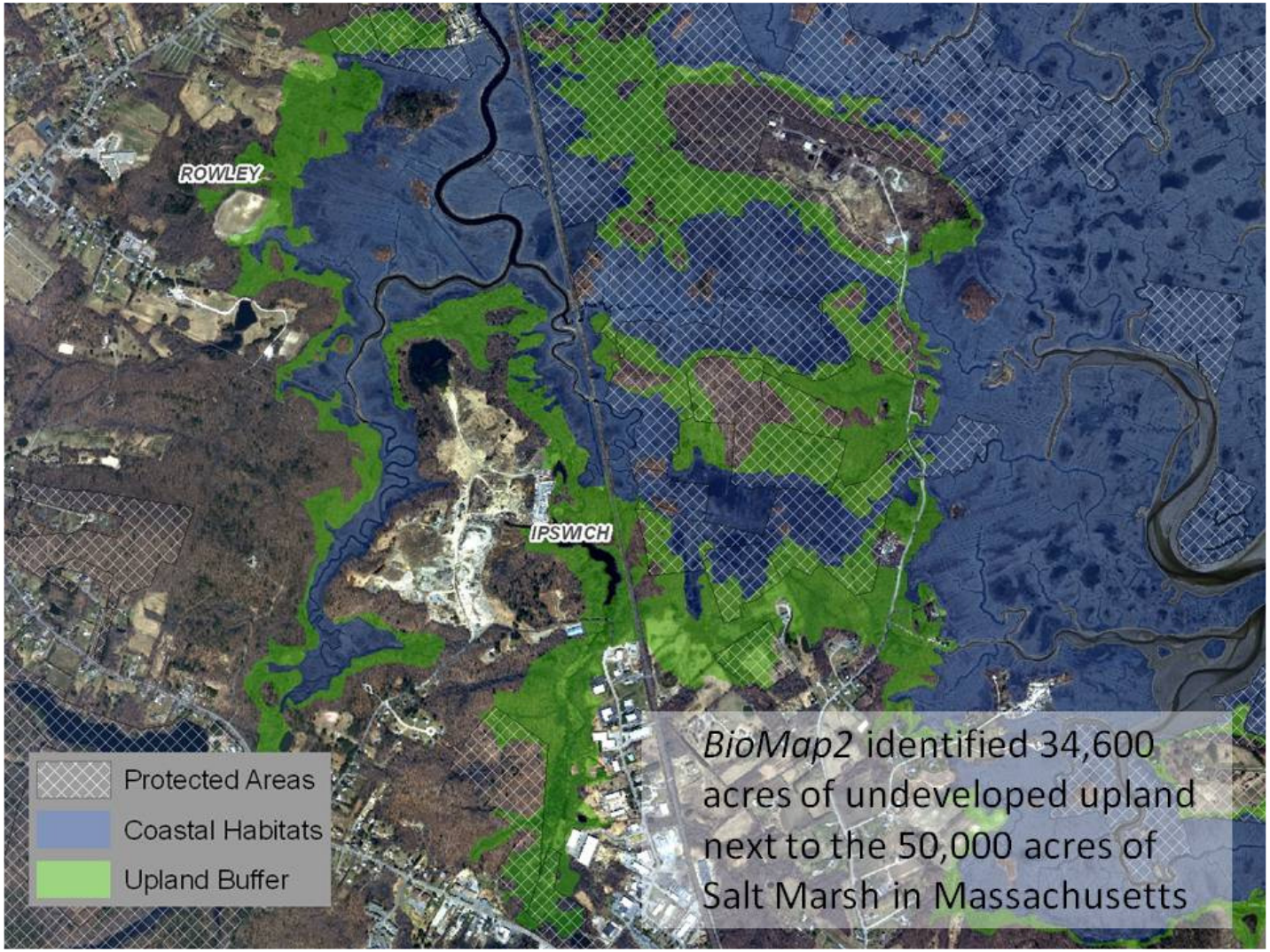


Figure 31. Example in Ipswich and Rowley.
This shows the unprotected land (not hatched) that falls in the coastal adaptation zone (green).

Section D: Tern Foraging Habitat

Terns range widely from their breeding colonies to forage. While the breeding and staging areas for Roseate, Arctic, Common, and Least Terns were included in Species of Conservation Concern Core Habitat for *BioMap2*, tern foraging areas were included in *BioMap2* as part of Critical Natural Landscape.

Arctic, Common, and Roseate Terns

The extent of foraging habitat for these three terns depends on the size of the breeding colony.

- For small tern colonies (<100 pairs), in any combination of Arctic, Common, and Roseate Terns, estuarine and nearshore (*i.e.*, ≤ 0.6 miles from shore) marine waters within two miles of mapped terrestrial habitats (*i.e.,* nesting, chick-rearing, resting, and roosting) were mapped as tern foraging habitat.
- For medium-sized tern colonies (100-499 pairs), in any combination of Arctic, Common, and Roseate Terns, estuarine and nearshore marine waters within four miles (6.4 km) of the mapped terrestrial habitats were mapped as tern foraging habitat.
- For large tern colonies (≥500 nesting pairs), in any combination of Arctic, Common, and Roseate Terns, estuarine, nearshore, and offshore marine waters within eight miles (12.9 km) of the mapped terrestrial habitats, to the extent of state jurisdiction, were mapped as tern foraging habitat.

The maximum number of nesting pairs within the past ten years was used to classify a colony by size. Other marine or estuarine waters were mapped as foraging habitat if they are known to be important feeding areas for breeding birds. Important areas are those that have been systematically or repeatedly shown to be used by terns.

Least Tern

All shallow (approximately ≤ 60 feet deep) marine and estuarine waters within two miles (3.2 km) of recent colony sites (*i.e.*, parallel to the shoreline), and up to one mile (1.6 km) offshore were mapped as Least Tern foraging habitat. Tidal creeks, salt ponds and pans were included. Shallow (approximately ≤ 60 feet deep) marine and estuarine waters within one mile (1.6 km) of important post-breeding concentration areas were also mapped as Least Tern foraging habitat.

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Appendices -

Appendix A. List of Attendees of External Review Session

These attendees were at the meeting of outside reviewers of the draft *BioMap2* project held in Westborough, MA, on June 17, 2010.

Biologists and Conservation Partners

Individuals	Title	Organization
Dan Perlman	Associate Professor	Brandeis University
Robert Bertin	Professor	College of the Holy Cross
Nancy Putnam	ESC Program Coordinator	Mass. Assoc. of Conservation Commissions
Robert Buchsbaum	Conservation Scientist	Massachusetts Audubon Society
Jeff Collins	Director, Ecological Extension	Massachusetts Audubon Society
Wayne Peterson	Director, IBA Program	Massachusetts Audubon Society
Heidi Ricci	Senior Policy Analyst	Massachusetts Audubon Society
Jennifer Ryan	Legislative Director	Massachusetts Audubon Society
Bob Wilbur	Director of Land Protection	Massachusetts Audubon Society
Mark Anderson	Director of Conservation Science	The Nature Conservancy
Robb Johnson	Director SE MA Program	The Nature Conservancy
Rob Warren	Director of Protection & Policy	The Nature Conservancy
Russ Hopping	Ecology Program Manager	The Trustees of Reservations
Julie Richburg	Regional Ecologist	The Trustees of Reservations
Chris Rodstrom	Deputy Director, L & CC	The Trustees of Reservations
Brad Compton	Senior Research Associate	University of Massachusetts
Scott Jackson	Program Director, NR & ECP	University of Massachusetts Extension
Leo Kenny	President	Vernal Pool Association
Matt Burne	Conservation Director	Walden Woods Project

Agency Staff and *BioMap2* Project Personnel

Individuals	Title	Organization
Mary Griffin	Commissioner	MA Dept. of Fish & Game
Kevin Robicheau	Senior GIS Specialist	MA Dept. of Fish & Game
Claire Corcoran	An Editor	MA NHESP / *BioMap2* project
James DeNormandie	Project Coordinator	MA NHESP / *BioMap2* project
Sarah Haggerty	NH Information Manager	MA NHESP
Glenn Motzkin	Landscape Ecologist	MA NHESP / *BioMap2* project
Jon Regosin	Regulatory Review Manager	MA NHESP
Henry Woolsey	Program Manager	MA NHESP
Jessica Dyson	GIS Manager	The Nature Conservancy
Andy Finton	Director of Sci. & Conservation	The Nature Conservancy

Appendix B. SWAP Species and BioMap2

Note that these are just the species listed in the 2005 SWAP; this list does not included any species added to the MESA list since 2005.

Type of Mapping:

- Individual
- Exemplary
- Indirect
- Not mapped

Taxon	MESA-listed? (in 2005)	Scientific Name	Common Name	*BioMap2* Mapping
Fishes	Yes	*Lampetra appendix*	American Brook Lamprey	Individual
	Yes	*Acipenser brevirostrum*	Shortnose Sturgeon	Individual
	Yes	*Acipenser oxyrinchus*	Atlantic Sturgeon	Individual
	Yes	*Couesius plumbeus*	Lake Chub	Individual
	Yes	*Hybognathus regius*	Eastern Silvery Minnow	Individual
	Yes	*Notropis bifrenatus*	Bridle Shiner	Individual
	Yes	*Phoxinus eos*	Northern Redbelly Dace	Individual
	Yes	*Catostomus catostomus*	Longnose Sucker	Individual
	Yes	*Lota lota*	Burbot	Individual
	Yes	*Gasterosteus aculeatus*	Threespine Stickleback	Individual
	No	*Alosa aestivalis*	Blueback Herring	Individual
	No	*Alosa pseudoharengus*	Alewife	Individual
	No	*Alosa sapidissima*	American Shad	Individual
	No	*Anguilla rostrata*	American Eel	Individual
	No	*Catostomus commersoni*	White Sucker	Individual
	No	*Cottus cognatus*	Slimy Sculpin	Individual
	No	*Enneacanthus obesus*	Banded Sunfish	Individual
	No	*Erimyzon oblongus*	Creek Chubsucker	Individual
	No	*Etheostoma fusiforme*	Swamp Darter	Individual
	No	*Etheostoma olmstedi*	Tessellated Darter	Individual
	No	*Luxilus cornutus*	Common Shiner	Individual
	No	*Rhinichthys atratulus*	Blacknose Dace	Individual
	No	*Rhinichthys cataractae*	Longnose Dace	Individual
	No	*Salmo salar*	Atlantic Salmon	Individual
	No	*Salvelinus fontinalis*	Brook Trout	Individual
	No	*Semotilus atromaculatus*	Creek Chub	Individual
	No	*Semotilus corporalis*	Fallfish	Individual
Amphibians	Yes	*Ambystoma jeffersonianum*	Jefferson Salamander	Individual
	Yes	*Ambystoma laterale*	Blue-Spotted Salamander	Individual
	Yes	*Ambystoma opacum*	Marbled Salamander	Individual
	Yes	*Gyrinophilus porphyriticus*	Spring Salamander	Exemplary
	Yes	*Hemidactylium scutatum*	Four-Toed Salamander	Individual
	Yes	*Scaphiopus holbrookii*	Eastern Spadefoot	Individual
	No	*Rana pipiens*	Northern Leopard Frog	Individual
Reptiles	Yes	*Caretta caretta*	Loggerhead Seaturtle	Not Mapped
	Yes	*Chelonia mydas*	Green Seaturtle	Not Mapped
	Yes	*Eretmochelys imbricata*	Hawksbill Seaturtle	Not Mapped
	Yes	*Lepidochelys kempii*	Kemp's Ridley Seaturtle	Not Mapped

Taxon	MESA-listed? (in 2005)	Scientific Name	Common Name	*BioMap2* Mapping
Reptiles	Yes	*Dermochelys coriacea*	Leatherback Seaturtle	Not Mapped
	Yes	*Clemmys guttata*	Spotted Turtle	Exemplary
	Yes	*Clemmys insculpta*	Wood Turtle	Exemplary
	Yes	*Clemmys muhlenbergii*	Bog Turtle	Individual
	Yes	*Emydoidea blandingii*	Blanding's Turtle	Individual
	Yes	*Malaclemys terrapin*	Diamondback Terrapin	Individual
	Yes	*Pseudemys rubriventris* pop. 1	Northern Red-Bellied Cooter	Individual
	Yes	*Terrapene carolina*	Eastern Box Turtle	Exemplary
	Yes	*Carphophis amoenus*	Eastern Wormsnake	Individual
	Yes	*Elaphe obsoleta*	Eastern Ratsnake	Individual
	Yes	*Agkistrodon contortrix*	Copperhead	Individual
	Yes	*Crotalus horridus*	Timber Rattlesnake	Individual
	No	*Coluber constrictor*	Black Racer	Individual (in Core)
	No	*Heterodon platirhinos*	Eastern Hognose Snake	Exemplary
	No	*Thamnophis sauritus*	Eastern Ribbon Snake	Individual
Birds	Yes	*Gavia immer*	Common Loon	Individual
	Yes	*Podilymbus podiceps*	Pied-Billed Grebe	Individual
	Yes	*Oceanodroma leucorhoa*	Leach's Storm-Petrel	Individual
	Yes	*Botaurus lentiginosus*	American Bittern	Individual
	Yes	*Ixobrychus exilis*	Least Bittern	Individual
	Yes	*Haliaeetus leucocephalus*	Bald Eagle	Individual
	Yes	*Circus cyaneus*	Northern Harrier	Individual
	Yes	*Accipiter striatus*	Sharp-Shinned Hawk	Individual
	Yes	*Falco peregrinus*	Peregrine Falcon	Individual
	Yes	*Rallus elegans*	King Rail	Individual
	Yes	*Gallinula chloropus*	Common Moorhen	Individual
	Yes	*Charadrius melodus*	Piping Plover	Individual
	Yes	*Bartramia longicauda*	Upland Sandpiper	Individual
	Yes	*Sterna dougallii*	Roseate Tern	Individual
	Yes	*Sterna hirundo*	Common Tern	Individual
	Yes	*Sterna paradisaea*	Arctic Tern	Individual
	Yes	*Sterna antillarum*	Least Tern	Individual
	Yes	*Tyto alba*	Barn Owl	Individual
	Yes	*Asio otus*	Long-eared Owl	Individual
	Yes	*Asio flammeus*	Short-eared Owl	Individual
	Yes	*Cistothorus platensis*	Sedge Wren	Individual
	Yes	*Vermivora chrysoptera*	Golden-winged Warbler	Not Mapped
	Yes	*Parula americana*	Northern Parula	Individual
	Yes	*Dendroica striata*	Blackpoll Warbler	Individual
	Yes	*Oporornis philadelphia*	Mourning Warbler	Individual
	Yes	*Pooecetes gramineus*	Vesper Sparrow	Individual
	Yes	*Ammodramus savannarum*	Grasshopper Sparrow	Individual
	Yes	*Ammodramus henslowii*	Henslow's Sparrow	Individual
	No	*Ammodramus caudacutus*	Saltmarsh Sharp-tailed Sparrow	Exemplary
	No	*Ammodramus maritimus*	Seaside Sparrow	Exemplary
	No	*Anas rubripes*	American Black Duck	Not mapped
	No	*Arenaria interpres*	Ruddy Turnstone	Exemplary
	No	*Bonasa umbellus*	Ruffed Grouse	Not mapped
	No	*Buteo platypterus*	Broad-Winged Hawk	Indirect
	No	*Butorides virescens*	Green Heron	Indirect

Taxon	MESA-listed? (in 2005)	Scientific Name	Common Name	*BioMap2* Mapping
Birds	No	*Calidris alba*	Sanderling	Exemplary
	No	*Calidris canutus*	Red Knot	Exemplary
	No	*Caprimulgus vociferus*	Whip-poor-will	Individual
	No	*Clangula hyemalis*	Long-tailed Duck	Not mapped
	No	*Colinus virginianus*	Northern Bobwhite	Not mapped
	No	*Dendroica discolor*	Prairie Warbler	Indirect
	No	*Egretta thula*	Snowy Egret	Individual
	No	*Empidonax traillii*	Willow Flycatcher	Not mapped
	No	*Falco sparverius*	American Kestrel	Not mapped
	No	*Haematopus palliatus*	American Oystercatcher	Indirect
	No	*Histrionicus histrionicus*	Harlequin Duck	Not mapped
	No	*Hylocichla mustelina*	Wood Thrush	Indirect
	No	*Larus atricilla*	Laughing Gull	Individual
	No	*Limnodromus griseus*	Short-billed Dowitcher	Exemplary
	No	*Numenius borealis*	Eskimo Curlew	Not mapped
	No	*Numenius phaeopus*	Whimbrel	Exemplary
	No	*Nycticorax nycticorax*	Black-crowned Night-Heron	Individual
	No	*Pipilo erythrophthalmus*	Eastern Towhee	Not mapped
	No	*Porzana carolina*	Sora	Exemplary
	No	*Scolopax minor*	American Woodcock	Not mapped
	No	*Seiurus motacilla*	Louisiana Waterthrush	Indirect
	No	*Somateria mollissima*	Common Eider	Not mapped
	No	*Spizella pusilla*	Field Sparrow	Not mapped
	No	*Sturnella magna*	Eastern Meadowlark	Not mapped
	No	*Toxostoma rufum*	Brown Thrasher	Not mapped
	No	*Vermivora pinus*	Blue-winged Warbler	Not mapped
	No	*Wilsonia canadensis*	Canada Warbler	Indirect
	No	*Zonotrichia albicollis*	White-throated Sparrow	Indirect
Mammals	Yes	*Sorex palustris*	Water Shrew	Individual
	Yes	*Sorex dispar*	Rock Shrew	Individual
	Yes	*Myotis sodalis*	Indiana Myotis	Not mapped
	Yes	*Myotis leibii*	Eastern Small-footed Bat	Individual
	Yes	*Synaptomys cooperi*	Southern Bog Lemming	Individual
	Yes	*Physeter catodon*	Sperm Whale	Not mapped
	Yes	*Balaenoptera physalus*	Fin Whale	Not mapped
	Yes	*Balaenoptera borealis*	Sei Whale	Not mapped
	Yes	*Balaenoptera musculus*	Blue Whale	Not mapped
	Yes	*Megaptera novaeangliae*	Humpback Whale	Not mapped
	Yes	*Eubalaena glacialis*	Northern Right Whale	Not mapped
	No	*Alces alces*	Moose	Indirect
	No	*Lasionycteris noctivagans*	Silver-haired Bat	Not mapped
	No	*Lasiurus borealis*	Eastern Red Bat	Not mapped
	No	*Lasiurus cinereus*	Hoary Bat	Not mapped
	No	*Lynx rufus*	Bobcat	Indirect
	No	*Microtus breweri*	Beach Vole	Indirect
	No	*Phocoena phocoena*	Harbor Porpoise	Not mapped
	No	*Sylvilagus transitionalis*	New England Cottontail	Exemplary
	No	*Ursus americanus*	Black Bear	Indirect
Misc. Invertebrates	Yes	*Spongilla aspinosa*	Smooth Branched Sponge	Individual
	No	*Corvomeyenia everetti*	Mount Everett Pond Sponge	Not mapped
	Yes	*Polycelis remota*	Sunderland Spring Planarian	Individual

Taxon	MESA-listed? (in 2005)	Scientific Name	Common Name	*BioMap2* Mapping
Misc. Invertebrates	Yes	*Macrobdella sestertia*	New England Medicinal Leech	Not mapped
	No	*Alloperla voinae*	A Stonefly	Not mapped
	No	*Hansonoperla appalachia*	Hanson's Appalachian Stonefly	Not mapped
	No	*Perlesta nitida*	A Stonefly	Not mapped
	Yes	*Cincinnatia winkleyi*	New England Siltsnail	Individual
	Yes	*Ferrissia walkeri*	Walker's Limpet	Individual
	Yes	*Littoridinops tenuipes*	Coastal Marsh Snail	Individual
	Yes	*Pomatiopsis lapidaria*	Slender Walker	Individual
	Yes	*Pyrgulopsis lustrica*	Pilsbry's Spire Snail	Individual
	Yes	*Valvata sincera*	Boreal Turret Snail	Individual
	Yes	*Vertigo perryi*	Olive Vertigo	Not mapped
	No	*Physa vernalis*	Vernal Physa	Not mapped
	Yes	*Cambarus bartonii*	Appalachian Brook Crayfish	Not mapped
	Yes	*Eubranchipus intricatus*	Intricate Fairy Shrimp	Individual
	Yes	*Eulimnadia agassizii*	Agassiz's Clam Shrimp	Individual
	Yes	*Gammarus pseudolimnaeus*	Northern Spring Amphipod	Individual
	Yes	*Limnadia lenticularis*	American Clam Shrimp	Individual
	Yes	*Stygobromus borealis*	Taconic Cave Amphipod	Not mapped
	Yes	*Stygobromus tenuis tenuis*	Piedmont Groundwater Amphipod	Individual
	Yes	*Synurella chamberlaini*	Coastal Swamp Amphipod	Individual
	No	*Caenestheriella gynecia*	Feminine Clam Shrimp	Not mapped
Freshwater Mussels	Yes	*Alasmidonta heterodon*	Dwarf Wedgemussel	Individual
	Yes	*Alasmidonta undulata*	Triangle Floater	Individual
	Yes	*Alasmidonta varicosa*	Brook Floater	Individual
	Yes	*Lampsilis cariosa*	Yellow Lampmussel	Individual
	Yes	*Leptodea ochracea*	Tidewater Mucket	Individual
	Yes	*Ligumia nasuta*	Eastern Pondmussel	Individual
	Yes	*Strophitus undulatus*	Creeper	Individual
Odonates	Yes	*Aeshna mutata*	Spatterdock Darner	Individual
	Yes	*Aeshna subarctica*	Subarctic Darner	Individual
	Yes	*Anax longipes*	Comet Darner	Individual
	Yes	*Boyeria grafiana*	Ocellated Darner	Individual
	Yes	*Enallagma carunculatum*	Tule Bluet	Individual
	Yes	*Enallagma daeckii*	Attenuated Bluet	Individual
	Yes	*Enallagma laterale*	New England Bluet	Individual
	No	*Enallagma minusculum*	Little Bluet	Individual
	Yes	*Enallagma pictum*	Scarlet Bluet	Individual
	Yes	*Enallagma recurvatum*	Pine Barrens Bluet	Individual
	Yes	*Gomphus abbreviatus*	Spine-Crowned Clubtail	Individual
	Yes	*Gomphus descriptus*	Harpoon Clubtail	Individual
	Yes	*Gomphus fraternus*	Midland Clubtail	Individual
	Yes	*Gomphus quadricolor*	Rapids Clubtail	Individual
	Yes	*Gomphus vastus*	Cobra Clubtail	Individual
	Yes	*Gomphus ventricosus*	Skillet Clubtail	Individual
	Yes	*Neurocordulia obsoleta*	Umber Shadowdragon	Individual
	Yes	*Neurocordulia yamaskanensis*	Stygian Shadowdragon	Individual
	Yes	*Ophiogomphus aspersus*	Brook Snaketail	Individual
	Yes	*Ophiogomphus carolus*	Riffle Snaketail	Individual
	Yes	*Somatochlora elongata*	Ski-Tailed Emerald	Individual
	Yes	*Somatochlora forcipata*	Forcipate Emerald	Individual

Taxon	MESA-listed? (in 2005)	Scientific Name	Common Name	*BioMap2* Mapping
Odonates	Yes	*Somatochlora georgiana*	Coppery Emerald	Individual
	Yes	*Somatochlora incurvata*	Incurvate Emerald	Individual
	Yes	*Somatochlora kennedyi*	Kennedy's Emerald	Individual
	Yes	*Somatochlora linearis*	Mocha Emerald	Individual
	Yes	*Stylurus amnicola*	Riverine Clubtail	Individual
	Yes	*Stylurus scudderi*	Zebra Clubtail	Individual
	Yes	*Stylurus spiniceps*	Arrow Clubtail	Individual
	Yes	*Williamsonia fletcheri*	Ebony Boghaunter	Individual
	Yes	*Williamsonia lintneri*	Ringed Boghaunter	Individual
Beetles	Yes	*Cicindela duodecimguttata*	Twelve-Spotted Tiger Beetle	Individual
	Yes	*Cicindela rufiventris hentzii*	Hentz's Redbelly Tiger Beetle	Individual
	Yes	*Cicindela dorsalis dorsalis*	Northeastern Beach Tiger Beetle	Individual
	Yes	*Cicindela limbalis*	Bank Tiger Beetle	Individual
	Yes	*Cicindela marginipennis*	Cobblestone Tiger Beetle	Individual
	Yes	*Cicindela patruela*	Barrens Tiger Beetle	Individual
	Yes	*Cicindela puritana*	Puritan Tiger Beetle	Individual
	Yes	*Cicindela purpurea*	Purple Tiger Beetle	Individual
	Yes	*Nicrophorus americanus*	American Burying Beetle	Not Mapped
	No	*Hygrotus sylvanus*	Sylvan Hygrotus Diving Beetle	Not Mapped
Lepidoptera	Yes	*Abagrotis nefascia*	Coastal Heathland Cutworm	Individual
	Yes	*Acronicta albarufa*	Barrens Daggermoth	Individual
	Yes	*Anisota stigma*	Spiny Oakworm	Not Mapped
	Yes	*Apamea inebriata*	Drunk Apamea Moth	Individual
	Yes	*Apamea mixta*	Coastal Plain Apamea Moth	Not Mapped
	Yes	*Apodrepanulatrix liberaria*	New Jersey Tea Inchworm	Individual
	Yes	*Bagisara rectifascia*	Straight Lined Mallow Moth	Not Mapped
	Yes	*Callophrys hesseli*	Hessel's Hairstreak	Individual
	Yes	*Callophrys irus*	Frosted Elfin	Individual
	Yes	*Callophrys lanoraieensis*	Bog Elfin	Individual
	Yes	*Catocala herodias gerhardi*	Gerhard's Underwing	Individual
	Yes	*Catocala pretiosa pretiosa*	Precious Underwing Moth	Individual
	Yes	*Chaetaglaea cerata*	Waxed Sallow Moth	Individual
	Yes	*Cicinnus melsheimeri*	Melsheimer's Sack Bearer	Individual
	Yes	*Cingilia catenaria*	Chain Dot Geometer	Individual
	Yes	*Cycnia inopinatus*	Unexpected Cycnia	Individual
	Yes	*Digrammia eremiata*	Three-lined Angle Moth	Individual
	Yes	*Eacles imperialis*	Imperial Moth	Individual
	Yes	*Erora laeta*	Early Hairstreak	Individual
	Yes	*Erynnis persius persius*	Persius Duskywing	Individual
	Yes	*Euchlaena madusaria*	Sandplain Euchlaena	Individual
	Yes	*Euphyes dion*	Dion Skipper	Individual
	Yes	*Faronta rubripennis*	The Pink Streak	Individual
	Yes	*Grammia phyllira*	Phyllira Tiger Moth	Individual
	Yes	*Hemaris gracilis*	Slender Clearwing Sphinx Moth	Individual
	Yes	*Hemileuca maia*	Barrens Buckmoth	Individual
	Yes	*Hypomecis buchholzaria*	Buchholz's Gray	Individual
	Yes	*Itame* sp. 1	Pine Barrens Itame	Individual
	Yes	*Lithophane viridipallens*	Pale Green Pinion Moth	Individual
	Yes	*Lycia rachelae*	Twilight Moth	Individual
	Yes	*Lycia ypsilon*	Pine Barrens Lycia	Individual
	Yes	*Metarranthis apiciaria*	Barrens Metarranthis	Individual

Taxon	MESA-listed? (in 2005)	Scientific Name	Common Name	*BioMap2* Mapping
Lepidoptera	Yes	*Metarranthis pilosaria*	Coastal Swamp Metarranthis	Individual
	Yes	*Neoligia semicana*	Northern Brocade Moth	Individual
	Yes	*Oncocnemis riparia*	Dune Noctuid Moth	Individual
	Yes	*Papaipema appassionata*	Pitcher Plant Borer	Individual
	Yes	*Papaipema* sp. 2	Ostrich Fern Borer	Individual
	Yes	*Papaipema stenocelis*	Chain Fern Borer	Individual
	Yes	*Papaipema sulphurata*	Water-Willow Stem Borer	Individual
	Yes	*Pieris oleracea*	Eastern Veined White	Individual
	Yes	*Psectraglaea carnosa*	Pink Sallow Moth	Individual
	Yes	*Ptichodis bistrigata*	Southern Ptichodis	Individual
	Yes	*Rhodoecia aurantiago*	Orange Sallow Moth	Individual
	Yes	*Satyrium favonius*	Oak Hairstreak	Individual
	Yes	*Spartiniphaga inops*	Spartina Borer	Individual
	Yes	*Stenoporpia polygrammaria*	Faded Gray Geometer	Individual
	Yes	*Zale* sp. 1	Pine Barrens Zale	Individual
	Yes	*Zanclognatha martha*	Pine Barrens Zanclognatha	Individual
	No	*Hadena ectypa*	A Noctuid Moth	Individual
	No	*Macrochilo bivittata*	Two-striped Cord Grass Moth	Individual
	No	*Pieris virginiensis*	West Virginia White	Indirect
	No	*Schizura apicalis*	Plain Schizura	Indirect
	No	*Zale curema*	Northeastern Pine Zale	Indirect

Appendix C. SWAP Habitats and BioMap2

SWAP Habitats	*BioMap2* Analyses that identified these habitats
Large-scale Habitats	
Connecticut & Merrimack Mainstems	Species of Conservation Concern Core Priority Natural Communities Core Wetland Core Aquatic Core Landscape Block Wetland and Aquatic Buffers
Large & Mid-sized Rivers	Species of Conservation Concern Core Priority Natural Communities Core Forest Core Wetland Core Aquatic Core Landscape Block Wetland and Aquatic Buffers
Marine & Estuarine Habitats	Species of Conservation Concern Core Priority Natural Communities Core Aquatic Core Wetland and Aquatic Buffers Coastal Adaptation Tern Foraging Areas
Upland Forest	Species of Conservation Concern Core Priority Natural Communities Core Vernal Pool Core Forest Core Landscape Blocks
Large Unfragmented Landscape Mosaic	Forest Core Landscape Blocks
Pitch Pine/Scrub Oak	Species of Conservation Concern Core Priority Natural Communities Core Landscape Blocks
Medium-scale Habitats	
Small Streams	Species of Conservation Concern Core Priority Natural Communities Core Forest Core Wetland Core Aquatic Core Landscape Block Wetland and Aquatic Buffers
Shrub Swamps	Species of Conservation Concern Core Priority Natural Communities Core Forest Core Wetland Core Aquatic Core Landscape Block Wetland and Aquatic Buffers

SWAP Habitats	*BioMap2* Analyses that identified these habitats
Forested Swamps	Species of Conservation Concern Core Priority Natural Communities Core Forest Core Wetland Core Aquatic Core Landscape Block Wetland and Aquatic Buffers
Lakes & Ponds	Species of Conservation Concern Core Priority Natural Communities Core Forest Core Wetland Core Aquatic Core Landscape Block Wetland and Aquatic Buffers
Salt Marsh	Species of Conservation Concern Core Priority Natural Communities Core Forest Core Wetland Core Aquatic Core Landscape Block Wetland and Aquatic Buffers Coastal Adaptation Tern Foraging Areas
Coastal Dunes, Beaches, and Small Islands	Species of Conservation Concern Core Priority Natural Communities Core Coastal Adaptation Tern Foraging Areas
Grasslands	Species of Conservation Concern Core Priority Natural Communities Core
Young Forests and Shrublands	Species of Conservation Concern Core Priority Natural Communities Core
Riparian Forest	Species of Conservation Concern Core Priority Natural Communities Core Wetland Core Aquatic Core Landscape Block Wetland and Aquatic Buffers
Small-scale Habitats	
Vernal Pools	Vernal Pool Core
Coastal Plain Ponds	Species of Conservation Concern Core Priority Natural Communities Core
Springs, Caves & Mines	Species of Conservation Concern Core
Peatlands & Associated Habitats	Species of Conservation Concern Core Priority Natural Communities Core Wetland Core
Marshes & Wet Meadows	Species of Conservation Concern Core Priority Natural Communities Core Wetland Core Wetland and Aquatic Buffers
Rocky Coastlines	Not included
Rock Cliffs, Ridgetops, Talus Slopes, & Similar Habitats	Species of Conservation Concern Core Priority Natural Communities Core

Appendix D. Ecological Land Units

This appendix describes supplementary metadata for the ELU30 raster data developed by the Eastern Resource Office of The Nature Conservancy. BioMap2 *used these data to inform the analysis of Wetland Cores. The Wetland Core analysis used Elevation and Geology components of the ELU data layer, but did not employ the Landform component since nearly all wetlands fall within the "wetflat" landform type, and therefore these data do not assist in further categorizing MA wetlands.*

Background

An understanding of patterns of environmental variation and biological diversity is fundamental to conservation planning at any scale—regional, landscape level, or local. This dataset was developed as a tool for assessing the biophysical character of landscapes, and for mapping the distribution and composition of community assemblages across those landscapes. Informed decisions on where to focus conservation efforts require such tools.

Data on biological distributions are very often inadequate to a large-scale analysis of biodiversity. The close relationship of the physical environment to ecological process and biotic distributions underpins the ecological sciences, and in the absence of suitable biological datasets, conservation science has recognized that physical diversity could be an acceptable surrogate for biological diversity. Research has repeatedly demonstrated especially strong links between ecosystem pattern and process and climate, bedrock, soils, and topography. This recognition led to the development of the ecological land unit, or ELU.

The ELU is a composite of several layers of abiotic information: elevation, bedrock geology, distribution of deep glacial sediments that mask bedrock's geochemical effects, moisture availability, and landform. An ELU grid of 30 meter cells was developed for the Lower New England-Northern Piedmont (LNE) and North Atlantic Coast (NAC) ecoregions. The ELU dataset describes the "ecological potential" of the landscape. A second dataset (a "systems" grid) was developed that informs ELUs with landcover data, bringing them to earth by telling us what is actually on the ground in a region where human alterations to the landscape have everywhere affected the natural vegetation. The ELU dataset itself carries no information about actual landuse or landcover, however. A brief discussion of each of the layers of information built into the ELUs follows.

Dataset content and development

<u>Elevation classes</u>

Elevation has been shown to be a powerful predictor of the distribution of forest communities in the Northeast. Temperature, precipitation, and exposure commonly vary with changing altitude. We broke continuous elevation data for the LNE and NAC ecoregions (from the National Elevation Dataset of the USGS) into discrete elevation classes with relevance to the distribution of forest types region-wide. Meaningful biotic zones would be defined with quite different elevation cut-offs in the northern and southern parts of the region, so class ranges necessarily approximate critical ecological values.

Appendix Table 1. Ranges for elevation classes.

Elevzone	*M (ft)*	*Characteristic forest type*
1000/2000	0-6 & 6-234 (0-20 & 20-800)	Oak, pine-oak, pine-hemlock, maritime spruce, floodplain forest
3000	234-533 (800-1700)	Hemlock-N. hardwoods, N. hardwoods, lowland spruce-fir
4000	533-762 (1700-2500)	Northern hardwoods, spruce-hardwoods
5000	762-1158 (2500-4000)	Krummholz, montane spruce-fir, alpine communities

Bedrock geology and deep sediments

Bedrock geology strongly influences area soil and water chemistry. Even in glaciated landscapes, studies suggest that soil parent material is commonly of local origin, rarely being ice-transported more than a few miles from its source. Bedrock types also differ in how they weather and in the physical characteristics of the residual soil type. Because of this, local lithology is usually the principle determinant of soil chemistry, texture, and nutrient availability. Many ecological community types are closely related to the chemistry and drainage of the soils or are associated with particular bedrock exposures.

We grouped bedrock units on the bedrock geology maps of ME, NH, VT, MA, CT, RI, NY, PA, NJ, and MD into seven general classes designed to have particular relevance to vegetation distributions (Appendix Table 2). We based our scheme on broad classification schemes developed by other investigators which emphasize chemistry and texture, and on bedrock settings that are important to many ecological communities, particularly to their herbaceous components. Please refer to another file accompanying this metadata, bedgeo_src.doc, for information on bedrock geology source materials.

In some settings deep sediments of glacial origin mantle the bedrock. The consolidated bedrock of valleys of pro-glacial lakes, for example, may lie under many meters of fine lacustrine sediments, and deep coarse deltaic or outwash deposits often overlay the bedrock in pine barrens and sand plains in the northeast. In these settings it is the nature of the sediments—their texture, compactness, and moisture-holding capacity, their nutrient availability, their ability to anchor overstory trees in a wind disturbance--that is ecologically relevant, and not the nature of the underlying bedrock. We used a USGS dataset of sediments of the glaciated northeast to identify such places. The USGS map was compiled at a coarse scale (1:1,000,000), but we made the data a little "smarter" by informing it with our landform map (please see the document on landforms that accompanies this metadata). Our landform layer was compiled at a much finer scale (the scale of the digital elevation models from which they were constructed, 1:24,000), and we allowed the deep coarse or fine sediments of the USGS dataset to be mapped only on those landforms on which they would naturally be expected to occur. In the case of sandy, coarse sediments, this would be in broad basin and valley/toe slope settings; in the case of fine clayey lacustrine or marine sediments, in these same settings, plus low hills and lower sideslopes. The seven bedrock classes were numbered 100 through 700 (Appendix Table 2), and the coarse and fine sediments classes were numbered 800 and 900, respectively.

Appendix Table 2. Bedrock geology classes.

Geology class	*Lithotypes*	*Meta-equivalents*	*Comments*	*Some characteristic communities*
100: ACIDIC SEDIMENTARY / METASEDIMENTARY: fine- to coarse-grained, acidic sed/metased rock	Mudstone, claystone, siltstone, non-fissile shale, sandstone, conglomerate, breccia, greywacke, arenites	(Low grade:) slates, phyllites, pelites; (Mod grade:) schists, pelitic schists, granofels	Low to moderately resistant rocks typical of valleys and lowlands with subdued topography; pure sandstone and meta-sediments are more resistant and may form low to moderate hills or ridges	Many: low- and mid-elevation matrix forests, floodplains, oak-pine forest, deciduous swamps and marshes
200: ACIDIC SHALE: Fine-grained acidic sedimentary rock with fissile texture	Fissile shales		Low resistance; produces unstable slopes of fine talus	Shale cliff and talus, shale barrens
300: CALCAREOUS SEDIMENTARY / META-SEDIMENTARY: basic/alkaline, soft sed/metased rock with high calcium content	Limestone, dolomite, dolostone, other carbonate-rich clastic rocks	Marble	Lowlands and depressions, stream/river channels, ponds/lakes, groundwater discharge areas; soils are thin alkaline clays, high calcium, low potassium; rock is very susceptible to chemical weathering; often underlies prime agricultural areas	Rich fens and wetlands, rich woodlands, rich cove forests, cedar swamps, alkaline cliffs
400: MODERATELY CALCAREOUS SEDIMENTARY / METASED: Neutral to basic, moderately soft sed/metased rock with some calcium but less so than above	Calc shales, calc pelites and siltstones, calc sandstones	Lightly to mod. metamorphosed calc pelites and quartzites, calc schists and phyllites, calc-silicate granofels	Variable group depending on lithology but generally susceptible to chemical weathering; soft shales often underlie agricultural areas	Rich coves, intermediate fens
500: ACIDIC GRANITIC: Quartz-rich, resistant acidic igneous and high grade meta-sedimentary rock; weathers to thin coarse soils	Granite, granodiorite, rhyolite, felsite, pegmatite	Granitic gneiss, charnockites, migmatites, quartzose gneiss, quartzite, quartz granofels	Resistant, quartz-rich rock, underlies mts and poorly drained depressions; uplands & highlands may have little internal relief and steep slopes along borders; generally sandy nutrient-poor soils	Many: matrix forest, high elevation types, bogs and peatlands

600: MAFIC / INTERMEDIATE GRANITIC: quartz-poor alkaline to slightly acidic rock, weathers to clays	(Ultrabasic:) anorthosite (Basic:) gabbro, diabase, basalt (Intermediate, quartz-poor:) diorite/ andesite, syenite/ trachyte	Greenstone, amphibolites, epidiorite, granulite, bostonite, essexite	Moderately resistant; thin, rocky, clay soils, sl acidic to sl basic, high in magnesium, low in potassium; moderate hills or rolling topography, uplands and lowlands, depending on adjacent lithologies; quartz- poor plutonic rocks weather to thin clay soils with topographic expressions more like granite	Traprock ridges, greenstone glades, alpine areas in Adirondacks
700: ULTRAMAFIC: magnesium-rich alkaline rock	Serpentine, soapstone, pyroxenites, dunites, peridotites, talc schists		Thin rocky iron-rich soils may be toxic to many species, high magnesium to calcium ratios often contain endemic flora favoring high magnesium, low potassium, alkaline soils; upland hills, knobs or ridges	Serpentine barrens

Landforms

Stanley Rowe called landform "the anchor and control of terrestrial ecosystems." It breaks up broad landscapes into local topographic units, and in doing so provides for meso- and microclimatic expression of macroclimatic character. It is largely responsible for local variation in solar radiation, soil development, moisture availability, and susceptibility to wind and other disturbance. As one of the five "genetic influences" in the process of soil formation, it is tightly tied to rates of erosion and deposition, and therefore to soil depth, texture, and nutrient availability. These are, with moisture, the primary edaphic controllers of plant productivity and species distributions. If the other four influences on soil formation (climate, time, parent material, and biota) are constant over a given space, it is variation in landform that drives variation in the distribution and composition of natural communities.

Of the environmental variables discussed here, it is landform that most resists quantification. Landform is a compound measure, which can be decomposed into the primary terrain attributes of elevation, slope, aspect, surface curvature, and upslope catchment area. The wide availability and improving quality of digital elevation data has made the quantification of primary terrain attributes a simple matter. Compound topographic indices have been derived from these primary attributes to model various ecological processes. We adopted the Fels and Matson (1997) approach to landform modeling. They described a metric that combines information on slope and landscape position to define topographic units such as ridges, sideslopes, coves, and flats on the landscape. That approach is described here: feel free to skip over the details, to the set of defined landforms that emerges from the process (Appendix Figure 1 and Appendix Table 3 below).

The parent dataset for the two grids used to construct the landforms is the 30 meter National Elevation Dataset digital elevation model (DEM) of the USGS. Step one was to derive a grid of discrete slope classes relevant to the Northern Appalachian landscape. We remapped slopes to

create classes of 0-2˚ (0.0-3.5%), 2-6˚ (3.5–10.5%), 6-24˚ (10.5–44.5%), 24-35˚ (44.5-70.0%), and >35˚ (>70.0%) (vertical axes of Figure1). Ground checks have shown that, because the NED dataset averages slopes over 30 meter intervals, raster cells in the 2 steepest elevation classes contain actual terrain slopes of from about 35 to 60 degrees (in the 24-35˚ class) and 60 to 90 degrees (in the steepest class).

The next step was the calculation of a landscape position index (LPI), a unitless measure of the position of a point on the landscape surface in relation to its surroundings. It is calculated, for each elevation model point, as a distance-weighted mean of the elevation differences between that point and all other elevation model points within a user-specified radius:

$$LPI_o = \left[\sum_{1,n} (z_i - z_o) / d_i \right] / n,$$

where z_O = elevation of the focal point whose LPI is being calculated,
z_i = elevation of point i of n model points within the specified search radius of the focal point,
d_i = horizontal distance between the focal point and point i, and
n = the total number of model points within the specified search distance.

If the point being evaluated is in a valley, surrounding model points will be mostly higher than the focal point and the index will have a positive value. Negative values indicate that the focal point is close to a ridge top or summit, and values approaching zero indicate low relief or a mid-slope position (Appendix Figure 1).

The specified search distance, sometimes referred to as the "fractal dimension" of the landscape, is half of the average ridge-to-stream distance. We used two methods to fix this distance for each subsection within the region, one digital and one analog. The "curvature" function of the ArcInfo Grid module uses the DEM to calculate change in slope ("slope of the slope") in the landscape. This grid, when displayed as a stretched grayscale image, highlights valley and ridge structure, the "bones" of the landscape, and ridge-to-stream distances can be sampled on-screen. For our analog approach we used 7.5' USGS topographic quadsheets. In each case, we averaged several measurements of ridge-to-stream distances, in landscapes representative of the subsection, to obtain the fractal dimension. This dimension can vary considerably from one subsection to another.

There is a third approach to fixing the landscape fractal dimension. A semivariogram of a clip of the DEM for a typical portion of the regional landscape can be constructed— it quantifies the spatial autocorrelation of the digital elevation points by calculating the squared difference in elevation between each and every pair of points in the landscape, then plotting half that squared difference (the “semivariance”) against the distance of separation. A model is then fitted to the empirical semiovariogram “cloud of points.” (This model is used to guide the prediction of unknown points in a kriging interpolation.) The form of the model is typically an asymptotic curve that rises fairly steeply and evenly near the origin (high spatial autocorrelation for points near one another) and flattens out at a semivariance “sill” value, beyond which distance there is little or no correlation between points. Though the sill distance, in the subsections where we tried this approach, was 2 or 3 times the “fractal distance” as measured with the first 2 methods,

the relationship between the two was fairly consistent. With a little more experimentation, the DEM semivariogram could prove to be a useful landscape analysis tool.

The next step was to divide the grid of continuous LPI values into discrete classes of high, moderately high, moderately low, and low landscape position. Histograms of the landscape position grid values were examined, a first set of break values selected, and the resulting classes visualized and evaluated. We did this for several different types of landscapes (rolling hills, steeply cut mountainsides, kame complexes in a primarily wet landscape, broad valleys), in areas of familiar geomorphology. The process was repeated many times, until we felt that the class breaks accurately caught the structure of the land, in each of the different landscape types. Success was measured by how well the four index classes represented the following landscape features:

High landscape position (very convex): sharp ridges, summits, knobs

Moderately high landscape position: upper side slopes, rounded summits and ridges, low hills and kamic convexities

Moderately low landscape position: lower sideslopes and toe slopes, gentle valleys and draws, broad flats

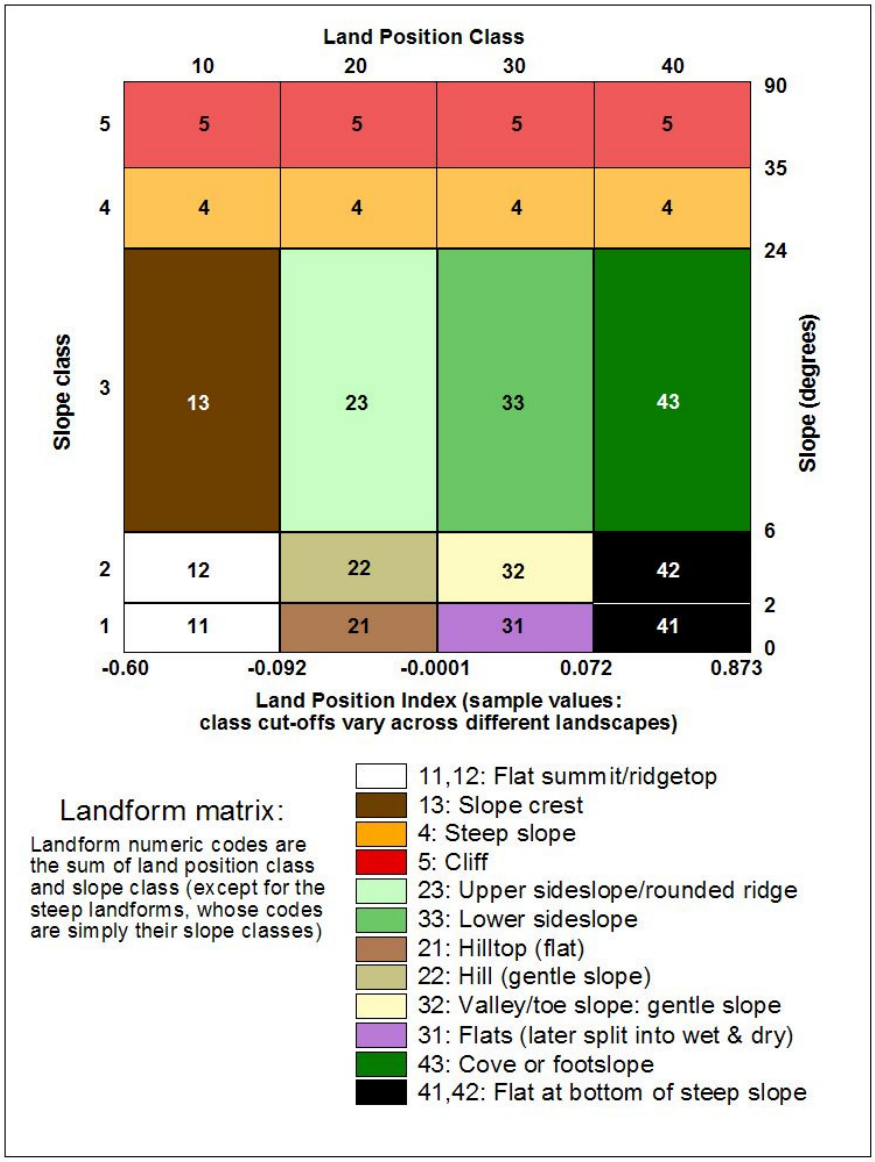
Low landscape position (very concave): steeply cut stream beds and coves, and flats at the foot of steep slopes

We assigned values 1-5 to the five slope classes, and 10, 20, 30, and 40 to the four LPI classes. Following Fels and Matson (1997), we summed the grids to produce a matrix of values (Appendix Figure 1), and gave descriptive names to landforms that corresponded to matrix values. We collapsed all units in slope classes 4 and 5 into "steep" and "cliff" units, respectively. The ecological significance of these units, which are generally small and thinly distributed, lies in their very steepness, regardless of where they occur on the landscape.

Recognizing the ecological importance of separating occurrences of “flats” (0-2˚ slope) into primarily dry areas and areas of higher moisture availability, we calculated a simple topographic moisture index that maps variation in moisture accumulation and soil residence time. We used National Wetlands Inventory datasets to calibrate the index and set a wet/dry threshold, then applied it to the flats landform to make the split. The formula for the moisture index is:

$$\text{Moist_index} = \ln [(\text{flow_accumulation} + 1) / (\text{slope} + 1)]$$

Grids for both flow accumulation and slope were derived from the DEM by ArcInfo Grid functions of the same names.

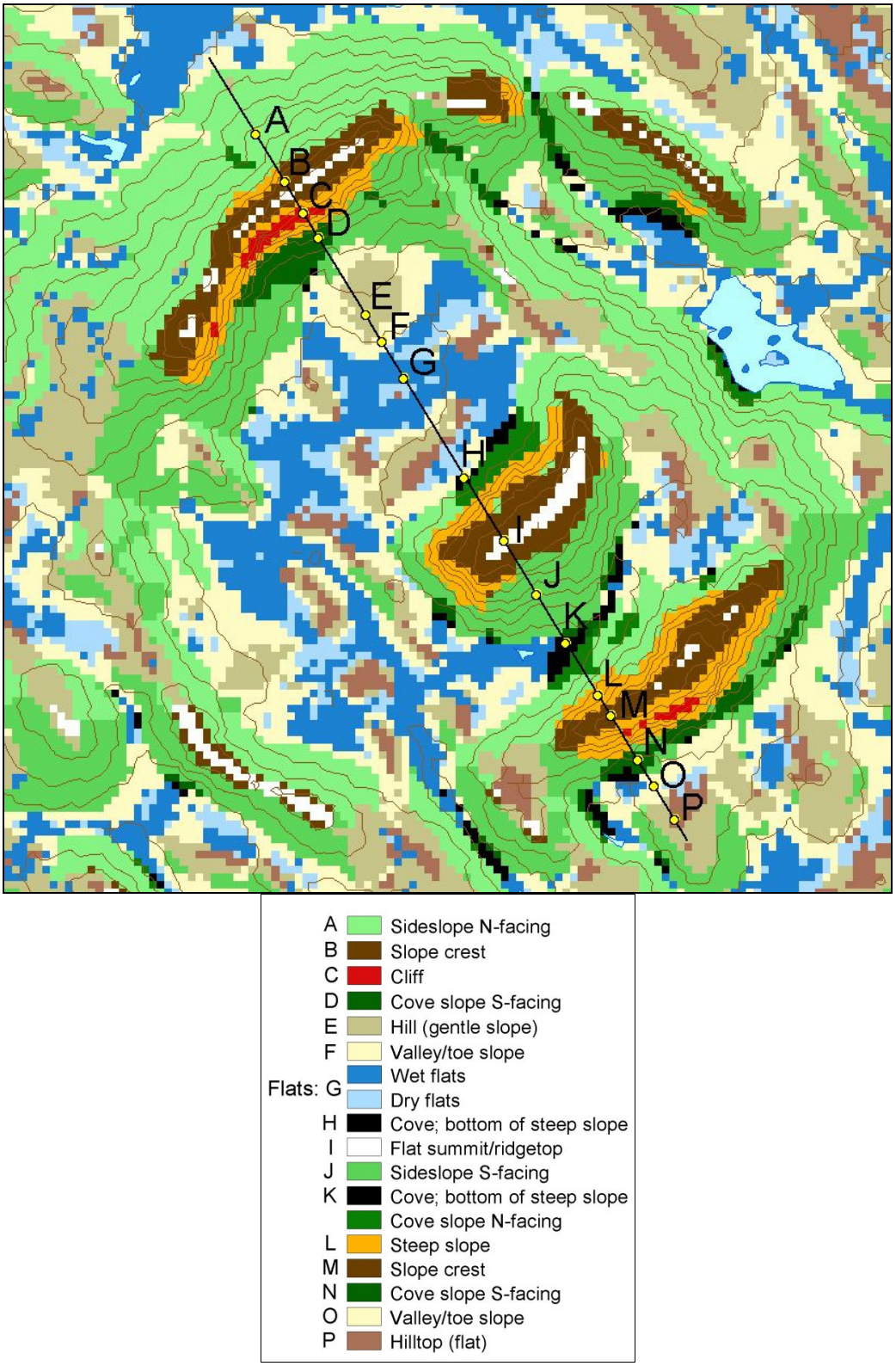


Appendix Figure 1: Formulation of landform models from land position and slope classes.

For the ecoregional ELU dataset, upper and lower sideslopes are combined, and a simple ecologically relevant aspect split is embedded in the sideslope and cove slope landforms (Appendix Figure 2 and Appendix Table 3).

Last, waterbodies from the National Hydrography Dataset (NHD), which was compiled at a scale of 1:100,000 and is available for the whole region, were incorporated into the landform layer with codes 51 (broader river reaches represented as polygons) and 52 (lakes, ponds, and reservoirs). Single-line stream and river arcs from the NHD were not burned into the landforms-- only those river reaches that are mapped as polygons.

Landform units for an area of varied topography in southeastern New Hampshire are shown in map view in Appendix Figure 2.



Appendix Figure 2: Landforms in Pawtuckaway State Park, NH

The ELU grid

With the elevation, substrate, and landform layers, all the elements for assembling ecological land units, or ELUs, are in place. ELU code values for each cell in the region-wide grid are simply the summed class values for elevation zone, substrate, and landform for that cell (Appendix Table 3). For example, a cell in a wet flat (landform 31) at 1400 feet (elevation class 2000) on granitic bedrock (substrate class 500) would be coded 2531.

Appendix Table 3: How the 4-digit ELU code is calculated.

Elevation class (ft)	+	**Substrate class**	+	**Landform**
1000 (0-800)		100 acidic sed/metased		4 steep slope
2000 (800-1700)		200 acidic shale		5 cliff
3000 (1700-2500)		300 calc sed/metased		11 flat summit/ridgetop
4000 (2500-4000)		400 mod. calc sed/metased		13 slope crest
5000 (> 4000)		500 acidic granitic		21 Hilltop (flat)
		600 mafic/intermed granitic		22 Hill (gentle slope)
		700 ultramafic		23 NW-facing sideslope
		800 coarse sediments		24 SE-facing sideslope
		900 fine sediments		30 Dry flat
				31 Wet flat
				32 Valley/toe slope
				41 Flat at bottom of steep slope
				43 NW-facing cove/draw
				44 SE-facing cove/draw
				51 Polygonal rivers from NHD
				52 NHD lakes/ponds/reservoirs

Waterbodies from the National Hydrography Dataset (NHD), which was compiled at a scale of 1:100,000 and is available for the whole region, were incorporated into the landform layer (landform codes 51 and 52). Single-line stream and river arcs from the NHD were not burned into the landforms-- only those river reaches that are mapped as polygons.

The ELU grid for the Lower New England/Northern Piedmont and North Atlantic Coast Ecoregions comprises 503 unique combinations of elevation zone, substrate type, and landform. We added an "ELU_color" item to the attribute table, and used it to construct a coding scheme that assigns ELU values to groups of a particular ecological character. Symbolizing on the ELU_color item creates a simplified display of the complex ELU dataset (see "Displaying the data" below). A fragment of the attribute table for the two-ecoregion ELU grid is reproduced in Appendix Table 4.

Appendix Table 4. Sample set of three ecological land unit codes ("value" item) from the ELU value attribute table for the LNE and NAC ecoregions.

VALUE	5113	3424	1831
COUNT	15655	339325	3606930
ELEVZONE	5000	3000	1000
ELEVZONE_DESC	2500-4000ft	1700-2500ft	0-20ft
SUBSTRATE	100	400	800
SUBSTR_DESC	acidic sedimentary/ metasedimentary	moderately calcareous sed/metased	coarse sediments
LANDFORM30	13	24	31
LF30_DESC	Slope crest	Sideslope S-facing	Wet flats
ELU_COLOR	12	22	32
ELUCOLOR_DESC	Slope crest	Sideslope S-facing	Wet flats on deep coarse sediments

Appendix E. Land Cover Classes used for Index of Ecological Integrity.

The following appendix is from the report "Conservation Assessment and Prioritization System (CAPS) Preliminary Statewide Massachusetts Assessment", June 2, 2009. Kevin McGarigal, Bradley W. Compton, Scott D. Jackson, and Kasey Rolih. Landscape Ecology Program, Department of Natural Resources Conservation, University of Massachusetts, Amherst.

Land cover classes are listed below, with numeric codes for each class.

Developed

1 Cropland
5 Mining
7 Participatory recreation
8 Spectator recreation
9 Water based recreation
10 Multi-family residential
11 High-density residential
12 Medium-density residential
13 Low-density residential
15 Commercial
16 Industrial
17 Urban open
18 Transportation
19 Waste disposal
26 Golf
29 Marina
31 Urban public
34 Cemetery
35 Orchard
36 Nursery
39 Junkyard
61 Large dam
62 Medium dam
63 Small dam
64 Tiny dam
71 Expressway
72 Primary highway
73 Secondary highway
74 Light duty road
75 Unpaved road
81 Railroad
82 Abandoned railbed
83 Rail trail
91 Bridge
92 Culvert

Terrestrial

102 Pasture
103 Forest
106 Open land
124 Powerlines
151 Sea cliff
152 Barrier beach system
156 Coastal dune
167 Barrier beach coastal beach
169 Barrier beach coastal dune
191 Deciduous forested wetland
192 Mixed forested wetland
193 Coniferous forested wetland

Palustrine

331 Pond
354 Bog
355 Cranberry bog
357 Deep marsh
358 Shallow marsh
362 Shrub swamp
396 Vernal pool

Riverine

411 First order flatwater
412 First order pool-riffle
413 First order plane-bed
414 First order step-pool
415 First order cascade
421 Second order flatwater
422 Second order pool-riffle
423 Second order plane-bed

424 Second order step-pool
425 Second order cascade
431 Third order flatwater
432 Third order pool-riffle
433 Third order plane-bed
434 Third order step-pool
435 Third order cascade
441 Fourth order flatwater
442 Fourth order pool-riffle
443 Fourth order plane-bed
444 Fourth order step-pool
445 Fourth order cascade
451 Fifth order flatwater
452 Fifth order pool-riffle
453 Fifth order plane-bed
454 Fifth order step-pool
455 Fifth order cascade
461 Sixth order flatwater
462 Sixth order pool-riffle
463 Sixth order plane-bed
464 Sixth order step-pool
465 Sixth order cascade

Lacustrine
532 Lake
581 Reservoir

Estuarine
621 Salt pond
622 Bay
652 Barrier beach pond
661 Salt marsh
668 Barrier beach bog
670 Barrier beach deep marsh
671 Barrier beach marsh
673 Barrier beach shrub swamp
674 Barrier beach deciduous forested wetland
675 Barrier beach coniferous forested wetland
676 Barrier beach mixed forested wetland
677 Barrier beach salt marsh
681 First order estuary
682 Second order estuary
683 Third order estuary
684 Fourth order estuary
685 Fifth order estuary
686 Sixth order estuary

Marine
753 Coastal beach
760 Rocky intertidal
763 Tidal flat
790 Ocean

Appendix F. Input Data Layers used for Index of Ecological Integrity

The following appendix is from the report "Conservation Assessment and Prioritization System (CAPS) Preliminary Statewide Massachusetts Assessment", June 2, 2009. Kevin McGarigal, Bradley W. Compton, Scott D. Jackson, and Kasey Rolih. Landscape Ecology Program, Department of Natural Resources Conservation, University of Massachusetts, Amherst.

Nonforested Uplands – Three of these communities came from the MassGIS 2005 Land Use: pasture, powerlines, and open land (formerly called old fields in CAPS).

Wetlands – We used Massachusetts DEP Wetlands. DEP wetlands were photo-interpreted, and are generally of high quality, although beaver pond disturbance/succession has introduced many "errors," most commonly current shrub swamps mapped as forested wetland. Note that many new coastal wetlands have been added for this run.

Lakes and Ponds – We used MassGIS 1:25k hydrography to represent lakes and ponds. Ponds were defined as being waterbodies smaller than 5 ha, lakes as those larger than 5 ha. This is based on a logistic regression of sizes of lakes and ponds in areas where NWI falls within the Highlands, because NWI distinguishes between lakes and ponds, whereas DEP wetlands depict all open water as one class.

Vernal Pools – We used Potential Vernal Pools from MassWildlife's Natural Heritage and Endangered Species Program. Potential vernal pools that fell within a terrestrial type were treated as a single pixel pool (30 m × 30 m). When a potential vernal pool fell within a wetland mapped by DEP, we retained DEP's classification.

Streams and Rivers – Streams and rivers are based on our work for Natural Heritage and Endangered Species Program's Living Waters project. MassGIS 1:25k stream centerlines were used to define streams. Streams are classified by order and gradient. Order is calculated from the stream centerline data; and gradient is based on the digital elevation model. We identified rivers that flow into the state to correct the order of these stream networks. For rivers wider than 30 m, the open water class from Land Use was used to represent the entire river basin, and the class based on order and gradient was applied to the entire width.

Developed Land – Developed land comes directly from the MassGIS 2005 Land Use.

Dams – Dams (in four size classes) were developed in collaboration with DEP and Mass Riverways as part of Natural Heritage's Living Waters project. Dams were derived from a MassDEP point shapefile and digitized as lines over stream centerlines overlaid on the MassGIS 1 meter, 1:5000 black and white orthophotos. Dams are treated as a developed type.

Roads and Railroads – Roads are railroads are from MassGIS's 1:25k EOT roads and trains layers. Roads were reclassified into five types based on original road classes as well as surface type (for unpaved roads). We also used interpolated traffic rates from the EOT roads layer. Railroads were mapped in three classes: railroad, abandoned railbed, and rail trail.

Elevation – A digital elevation model (DEM) was created by David Goodwin of the UMass Resource Mapping Unit from MassGIS digital terrain model (DTM) elevation contours, elevation points, and topographic breaklines as part of the Living Waters project.

Flow – A flow grid (giving the direction of expected water flow for each cell) based on a digital elevation model was created for all of mainland Massachusetts by our lab as part of the Living Waters project. This flow grid conforms to MassGIS centerline data. We used this flow grid directly.

Aquatic Resistance – We modified the approach of Randhir *et al*. 2001. (*Forest Ecology and Management* 143:47-56) to build a time-of-travel grid for each cell in the project area, based on land cover, slope, flow, and stream gradient. This grid was used to define the influence area within the watershed of each point for our watershed metrics.

Point-source Pollution – Point-source pollution was defined by Massachusetts Natural Heritage and Endangered Species Program as part of their Living Waters project. These data are based on an assessment of pollution risk compiled from six DEP and EPA data layers: TRI (Toxic Release Inventory), RCRIS (Resource Conservation and Recovery Information), PCS (Permit Compliance System), MINES (Mineral Industry Locations), IFD (Industrial Facility Discharge Sites), and CERCLIS (Superfund National Priority List Sites) from the EPA Basins 3.0 website (http://www.epa.gov/waterscience/basins/metadata.htm). UST (Underground Storage Tank Locations), GRWTR (Ground Water Discharge Permits), and DEP Solid Waste Facilities point sources are available from MassGIS. See Natural Heritage's Living Waters Technical Report for details.

Imperviousness – Impervious surfaces are from MassGIS. This layer is at 1 m resolution, based on the 2005 orthophotos. Imperviousness is summarized as percent impervious in 30 m cells.

Appendix G. CAPS Integrity Metrics.

The following appendix is from the report "Conservation Assessment and Prioritization System (CAPS) Preliminary Statewide Massachusetts Assessment", June 2, 2009. Kevin McGarigal, Bradley W. Compton, Scott D. Jackson, and Kasey Rolih. Landscape Ecology Program, Department of Natural Resources Conservation, University of Massachusetts, Amherst.

These ecological integrity metrics are included in the Conservation Assessment and Prioritization System (CAPS). Integrity metrics include both anthropogenic *stressor* metrics that measure the level of anthropogenic activities exclusively and *resiliency* metrics that measure the combined effect of anthropogenic stressor and landscape context.

Stressor Metrics	
Development & roads	
Habitat loss	Measures the intensity of habitat loss caused by all forms of development in the neighborhood surrounding the focal cell, based on a logistic function of Euclidean distance.
Wetland buffer insults	Measures the adverse effect of impervious surfaces within the 100-foot regulatory buffer around a wetland.
Road traffic intensity	Measures the intensity of road traffic (based on measured road traffic rates) in the neighborhood surrounding the focal cell, based on a logistic function of distance.
Microclimate alterations	Measures the adverse effects of induced (human-created) edges on the microclimate of patch interiors, such as moisture, temperature, and wind. The edge effects metric is based on the "worst" edge effect among all adverse edges in the neighborhood surrounding the focal cell, where each adverse edge is evaluated using a "depth-of-edge" function in which the "effect" is scaled using a logistic function of distance.
Pollution	
Road salt intensity	Measures the intensity of road salt application in the watershed above an aquatic focal cell weighted by road class and the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model. This metric is a surrogate for road salt application rates.

Road sediment intensity	Measures the intensity of road sediment production in the watershed above an aquatic focal cell weighted by road class (i.e., size, substrate, gradient) and the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model. This metric is a surrogate for road sediment production rates.
Fertilizer intensity	Measures the intensity of fertilizer application in the neighborhood surrounding the focal cell, based on the aquatic distance from the focal cell based on a time-of-flow model to development classes (primarily agriculture and residential land uses). This metric is a surrogate for fertilizer application rate.
Point-source pollution	Measures the intensity of actual or potential point-sources of pollution (such as permitted discharges into streams, municipal and industrial sewage plants, and underground storage tanks) in the watershed above an aquatic focal cell, weighted by type and size of point source and by the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model.
Biotic alterations	
Domestic predators	Measures the intensity of development associated with sources of domestic predators (e.g., cats) in the neighborhood surrounding the focal cell, based on a logistic function of distance to development classes. This metric is a surrogate for domestic predator abundance measured directly in the field.
Edge predators	Measures the intensity of development associated with sources of human commensal mesopredators (e.g., raccoons and skunks) and nest parasites (cowbirds) in the neighborhood surrounding the focal cell, based on a logistic function of distance to development classes. This metric is a surrogate for mesopredator/nest parasite abundance measured directly in the field.
Non-native invasive plants	Measures the intensity of development associated with sources of non-native invasive plants in the neighborhood surrounding the focal cell, based on a logistic function of distance to development classes. This metric is a surrogate for non-native invasive plant abundance measured directly in the field.

Non-native invasive earthworms	Measures the intensity of development associated with sources of non-native invasive earthworms in the neighborhood surrounding the focal cell, based on a logistic function of distance to development classes. This metric is a surrogate for non-native invasive earthworm abundance measured directly in the field.
Hydrological alterations	
Imperviousness	Measures the intensity of impervious surface in the watershed above the focal cell, based on imperviousness and the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model.
Percent impounded	Measures the proportion of the watershed above an aquatic focal cell that is impounded by dams, weighted by the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model.
Upstream road crossings	Measures the number of upstream road crossings per kilometer of stream above an aquatic focal cell weighted by the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model.
Dam intensity	Measures the number of dams in the watershed above an aquatic focal cell weighted by dam size and the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model.
Resiliency Metrics	
Connectedness	Measures the disruption of habitat connectivity caused by all forms of development between each focal cell and surrounding cells as well as the "resistance" of the surrounding undeveloped landscape. A hypothetical organism in a highly connected cell can reach a large area with minimal crossing of "hostile" cells. This metric uses a least-cost path algorithm to determine the area that can be reached from each focal cell. The focal cell gets a "bank account," which represents the distance a hypothetical organism could move through the undeveloped landscape. Each cell is assigned a travel cost, based on a resistance matrix, as a function of its ecological similarity to the focal cell. The algorithm then creates a least-cost hull around the focal cell, representing the maximum distance that can be moved from the cell until the "bank account" is depleted.

Similarity	Measures the amount of similarity between the ecological setting at the focal cell and those of neighboring cells, weighted by a logistic function of distance. Similarity is based on the ecological distance between the focal cell and each neighboring cell, where ecological distance is a multivariate distance across all ecological setting variables.

Appendix H. Metric Parameterizations.

The following appendix is from the report "Conservation Assessment and Prioritization System (CAPS) Preliminary Statewide Massachusetts Assessment", June 2, 2009. Kevin McGarigal, Bradley W. Compton, Scott D. Jackson, and Kasey Rolih. Landscape Ecology Program, Department of Natural Resources Conservation, University of Massachusetts, Amherst.

This table gives relative weights for each metric by community.

	Development & roads	Habitat loss	Watershed habitat loss	Wetland buffer insults	Road traffic intensity	Microclimate alterations	Pollution	Road salt intensity	Sedimentation	Nutrient loading	Point-source pollution	Biotic alterations	Domestic predators	Edge predators	Non-native invasive plants	Non-native invasive earthworms	Hydrological alterations	Imperviousness	Percent impounded	Upstream road crossings	Dam intensity	Resiliency metrics	Connectedness	Similarity
Terrestrial																								
Forest		2			2	1							1	2	2	2							5	3
Deciduous forested wetland		2		1	2	1		1	1	1	1			1	2	1							4	2
Mixed forested wetland		2		1	2	1		1	1	1	1			1	2	1							4	2
Coniferous forested wetland		2		1	2	1		1	1	1	1			1	2	1							4	2
Powerlines		4			2								1	2	2	1							5	3
Open land		4			2								1	2	2	1							5	3
Pasture		4			2								1	2	2								5	4
Sea cliff		4												1	1								2	1
Barrier beach system		4			2									2	1								2	1
Coastal dune		4			2									3	1								2	1
Barrier beach coastal beach		4			2									3	1								2	1
Barrier beach coastal dune		4			2									3	1								2	1
Palustrine																								
Bog		2		2	1			2	1	2	1			1	1			1					4	2
Deep marsh		2		2	2			1	1	1	1			1	2			1					4	2
Shallow marsh		2		2	2			1	1	1	1			1	2			1					4	2
Shrub swamp		2		2	2			1	1	1	1			1	2			1					4	2

	Development & roads	Habitat loss	Watershed habitat loss	Wetland buffer insults	Road traffic intensity	Microclimate alterations	Pollution	Road salt intensity	Sedimentation	Nutrient loading	Point-source pollution	Biotic alterations	Domestic predators	Edge predators	Non-native invasive plants	Non-native invasive earthworms	Hydrological alterations	Imperviousness	Percent impounded	Upstream road crossings	Dam intensity	Resiliency metrics	Connectedness	Similarity
Pond		2		2	2			1	1	2	1			1	1			1					4	2
Vernal pool		2			2			2	1	1	1			1	1			1					4	2
Cranberry bog		2		2	2			2	1	2	1			1	2			1					4	2
Lacustrine																								
Lake		2		2	1			1	1	2	2			1	1			1					4	2
Reservoir		2		2	1			1	1	2	2			1	1			1					4	2
Riverine																								
First order streams					1	1			1	1	1			1	1			2	1	1	1		6	
Second order streams					1	1			1	1	1			1	1			2	1	1	1		6	
Third order streams					1	1			1	1	1			1	1			2	1	1	1		6	
Fourth order streams					1				1	1	1			1	1			2	1	1	2		6	
Fifth order streams					1				1	1	1			1	1			2	1	1	2		6	
Sixth order streams					1				1	1	1			1	1			2	1	1	2		6	
Estuarine																								
First order estuary					1				1	1	1			1	1			1	1	1	1		6	
Second order estuary					1				1	1	1			1	1			1	1	1	1		6	
Third order estuary					1				1	1	1			1	1			1	1	1	1		6	
Fourth order estuary					1				1	1	1			1	1			1	1	1	2		6	
Fifth order estuary					1				1	1	1			1	1			1	1	1	2		6	
Sixth order estuary					1				1	1	1			1	1			1	1	1	2		6	
Salt pond		2		2	2				1	2	1			1				1					4	2
Bay					1				1	1	3												6	
Barrier beach pond		2		2	2				1	2	1			1	1			1					4	2
Salt marsh		2	2	2	1				1		2			1				1					3	3
Barrier beach bog		2		2	1				1	2	1			1	1			1					4	2
Barrier beach deep marsh		2		2	2				1	1	1			1	2			1					4	2
Barrier beach marsh		2		2	2				1	1	1			1	2			1					4	2
Barrier beach shrub swamp		2		2	2				1	1	1			1	2			1					4	2
Barrier beach deciduous		1		1	2	1			1	1	1			1	2								4	2

	Development & roads	Habitat loss	Watershed habitat loss	Wetland buffer insults	Road traffic intensity	Microclimate alterations	Pollution	Road salt intensity	Sedimentation	Nutrient loading	Point-source pollution	Biotic alterations	Domestic predators	Edge predators	Non-native invasive plants	Non-native invasive earthworms	Hydrological alterations	Imperviousness	Percent impounded	Upstream road crossings	Dam intensity	Resiliency metrics	Connectedness	Similarity
forested wetland																								
Barrier beach mixed forested wetland		2		1	2	1			1	1	1			1	2								4	2
Barrier beach coniferous forested wetland		2		1	2	1			1	1	1			1	2								4	2
Barrier beach salt marsh		2	2	2	1				1		2			1				1					3	3
Marine																								
Coastal beach		4			2									3	1								2	1
Rocky intertidal		2							1		1												2	1
Tidal flat		2							1	1	3												1	2

Appendix I. NHESP Rare Species Observation Forms

Natural Heritage & Endangered Species Program

Massachusetts Division of Fisheries & Wildlife

Please submit field forms, a copy of a USGS map, and all supporting documentation to:
Database Manager
Natural Heritage and Endangered Species Program
Massachusetts Division of Fisheries and Wildlife
Route 135, Westborough MA 01581
(508) 389-6360

Rare Animal Observation Form

Species name (scientific or common): _____

Date and time of observation: _____

Amount of time spent surveying area: _____

Location Information

Town: _____ County: _____ Waterbody: _____

Please attach a photocopy of the appropriate section of a USGS topo map (or similar map if a topo map is unavailable). **Please carefully mark the site where you observed this rare species**. Topo Name: _____

Describe how to get to the site of the observation using obvious permanent landmarks such as a road intersection (measuring to at least the nearest 1/10 mile): _____

_____

_____

_____

Population Information

Number, age and sex of animals observed: _____

_____

_____

Evidence (if any) of breeding activity at this site (e.g. eggs, nests, carrying food to young, copulation): _____

_____

_____

Behavioral notes (e.g. crossing road, basking): _____

Have you observed this species at this site in previous years? If yes, please give details: _____

_____

_____

Species Identification

Description of the specific characteristics upon which the ID was based (including how age and sex were determined):

_____

_____

Photographs or slides taken (Y / N)? If yes, please submit a clear photograph or slide of the animal. Please label the back of the photograph with the date it was taken, the location, and your signature.

Specimen taken (Y / N)? If yes, where will the specimen be deposited? _____

Site Information

Description of habitat at site where the species was observed. List dominant vegetation, size of habitat, and information on the physical environment such as substrate type, hydrology, moisture regime, slope, and aspect. If possible, provide information on the surrounding land use: _____

_____

_____

_____

Associated species: _____

_____

Alteration of ecological processes (e.g. damming, logging, rip-rapping of stream)? If yes, describe: _____

_____

_____

Observed or potential threats to the species or its habitat at this site (e.g. land clearing, development project)? If yes, describe:_____

_____

_____

Landowner's name and address, if known: _____

_____

Additional comments: _____

_____

Observer Information

Observer: Name: _____ Phone Number:_____

Address: _____

Affiliation/Qualifications: _____

Email Address: _____

Form filled out by: (if different from above) Name: _____ Phone Number:_____

Address: _____

Affiliation/Qualifications: _____

Briefly explain your previous field experience with this species: _____

_____

List names and qualifications of other observers (if any): _____

_____

Certification

I hereby certify under pains and penalties of perjury that the information contained in this report is true and complete to the best of my knowledge.

Signature: _____Date: _____

Thank you for contributing to the Natural Heritage & Endangered Species Program database. Your efforts are valuable and appreciated.

Natural Heritage & Endangered Species Program
Massachusetts Division of Fisheries & Wildlife

Please submit field forms, a copy of a USGS map, and all supporting documentation to:

Database Manager
Natural Heritage and Endangered Species Program
Massachusetts Division of Fisheries and Wildlife
Route 135, Westborough MA 01581
(508) 389-6360

RARE PLANT OBSERVATION FORM

SPECIES SCIENTIFIC NAME:_____ **Element Occurrence No**., if known: _____

Observation Date:_____ **Today's Date**:_____ **Population Found?** Yes____ No ____

Observed By:_____ **Other Observers**: _____

Observer's Address: _____

Observer's Email Address: _____ **Telephone**: _____

Photograph Taken? Yes____ No____ (if yes, please attach, and label back with your name, date taken, and the location)

Specimen Collected? Yes____ No____ Collection # _____ Repository: _____

Site Name (informal):_____ **USGS Topo Name**: _____

County:_____ **Town**:_____

Directions to the rare plant population (if found), or search area (if not found). **Mark the location on a copy of the USGS topo map.**

_____

_____

_____

_____

GPS Coordinates*:* System used (circle one): UTM Lat-Long Mass. State Plane Datum: _____

At, or near, the center of the population: _____ _____

Other waypoints and coordinates:

Has the full extent of the population been determined? (check one) ___ yes; ___no ; ___ uncertain whether full extent is known
Identification Problems? Yes____ No ____ **Explain:** _____
Diagnostic Characteristics used: _____
_____ **Reference used:** _____
Do other members of the genus or look-alike plants occur at this site? Yes____ No ____
Explain: _____

Population Data

Approximate Area Occupied by the Population (circle appropriate unit): _____ sq. meters hectares sq. feet sq. yards acres
Population Size:

Total number of "genets" (i.e., genetically distinct, or clearly separate individuals): _____ (Precise count *or* estimate?)
and/or
Total number of "ramets" (e.g., stems or shoots arising from clones): _____ (Precise count *or* estimate?)

Population Structure (check all that apply):

Age Classes Present	Reproductive Condition of the Population on this Date	
____ Seedlings	____ Vegetative (in leaf)	____ Mature fruit
____ Immature plants	____ In bud	____ Seed dispersing
____ Mature plants	____ In flower	____ Senescent
____ Plants of unknown age	____ Immature fruit	____ Dormant

How would you characterize the vigor of this population? Excellent Good Fair Poor

Evidence of Disease, Predation, or Injury?_____**Pollinators:** _____

Have you observed this species at this site in previous years? If yes, please give details: _____

_____

Environmental Setting

Describe the plant community and list the associated species:_____

_____

_____

_____

_____

List any exotic plant species present, and discuss their possible impacts:_____

_____

Describe evidence of natural or human-caused disturbance (including changes in ecological processes) **and effects on population**:

_____

_____

Surrounding Land Use:_____

Elevation: _____ ft. or m? **Soil Type(s)**: _____

Surficial Geology: _____ **Bedrock Geology:**_____

Circle Appropriate Habitat Descriptors:

Landform/Topography	Aspect ___°	Slope ___%	Light	Soil Moisture Regime	Important Ecological Processes
summit/crest	N NE	flat	open	xeric	seasonal or regular flooding
upper slope	E SE	gentle	filtered	dry	groundwater seepage
mid slope	S SW	average	shade	mesic	colluvial processes
lower slope	W NW	rather steep		wet	alluvial processes
rolling terrain/plain	flat/variable	steep		inundated	wind/salt spray
flood plain/terrace		very steep			erosion
wetland		abrupt			fire
shore/pond/lake/stream					none apparent

Describe Microhabitat Conditions:_____

Conservation Information

Land Owned/Managed by:

Name(s) Address Telephone

_____

_____

Managed Area Name: _____ **Contact Person:** _____

Owner Comments:_____

What additional factors might potentially threaten the population (e.g. land clearing, development project)? If yes, describe:_____

What are your recommendations for future inventory, monitoring, research, and/or management? _____

_____

What are your protection recommendations? _____

Additional Comments:

Certification

I hereby certify under pains and penalties of perjury that the information contained in this report is true and complete to the best of my knowledge.

Signature: _____ **Date:** _____

For office use only: *Relative Size: _____ Relative Condition: _____ Relative Landscape Context: _____ MA EO Rank: _____*

MA EO Rank Comments: _____

Global EO Rank: _____ Global EO Rank Comments: _____

Sketch:
Use this space to draw or diagram useful information about the rare plant occurrence, such as its location relative to landmarks and habitat features. Consider depicting, for instance, a vertical cross section of a population's position on a ledge or slope, or how a population is distributed in clumped patches in the habitat relative to boulders, stone walls, brooks, trees, etc.

Please:

Don't forget to attach a copy of a USGS topo map indicating the location of the rare plants or the search area!

Mark the location of the rare plants as precisely as possible, and label with the map source, date and species name.

Appendix J. NHESP Mapping Guidelines Outline

Species Common Name
Species Scientific Name (*Genus species*)
MESA Status (Endangered, Threatened, Special Concern)

Habitat Type: Very brief description of habitat type.

Key Habitat Elements: Bulleted list of most important habitat elements

Habitat Specificity: Options of high, medium, low to describe how selective/restrictive a species is in its habitat requirements.

Life History: General species life history; particularly includes characteristics that relate to habitat use or movements.

G Rank: Global Conservation Status Rank, as defined by NatureServe. The G rank indicates the overall status of a species or ecosystem; it is a range-wide assessment of condition.

Mapping Guidelines: The basic mapping recipe. This is a description of the step-by-step process used to delineate habitat for this particular species. May include the following:
Mapping Distances: how far to map from a particular habitat feature, observation point, etc. based on the biological needs of the species in question
Barriers: certain elements on the landscape may present a barrier to movement for particular species
Inclusions: certain elements on the landscape that should specifically be included based on the biological needs of the species
Exclusions: certain elements on the landscape that should specifically be excluded based on the biological needs of the species
Development: description of how to include or exclude particular classes of development (i.e. low density residential developments may still provide habitat for this species, while high density residential development or commercial development may not)

Mapping Rationale: This section provides the rationale for each of the steps outlined in the Mapping Guidelines section. It describes the rationale behind the choice of distances (including references supporting those distances where available) and habitat inclusions or exclusions.

Habitat Max:	A discrete distance representing the maximum distance the species habitat may extend from an observation point or habitat feature.
Habitat Max Basis:	Key references or synopsis of evidence for the Habitat Maximum distance (e.g., combination of MA field observations and expert advice) or (NatureServe inferred extent) or (Smith et al. 2004).
Supporting Habitat Mapping Guidelines:	Process used to delineate additional habitat for this species that supports the long-term health of the population, but may not have been captured by the Mapping Guidelines. For example, the habitat for aquatic species delineated under the Mapping Guidelines might only include the water in which the organism lives. Upland areas immediately adjacent to the aquatic habitat could be included as Supporting Habitat, as impacts to these areas could directly harm the species in question.
Supporting Habitat Mapping Rationale:	This section provides the rationale for the steps outlined in the Supporting Habitat Mapping Guidelines section.
Associated Species:	Identification of species with similar habitat requirements that are often found together (this field is most helpful for plants).
References:	Standard scientific citations for all references in the document.

Appendix K. NHESP Data Acceptance Guidelines

Guidelines for the Acceptance and Inclusion of Observation Records into the Natural Heritage & Endangered Species Program Database

Pursuant to the Massachusetts Endangered Species Act (MESA) regulations, specifically 321 CMR 10:12 (5), the Natural Heritage & Endangered Species Program (NHESP) evaluates all observation records in Massachusetts of rare plant and animal species listed under MESA to determine their validity and whether they should be accepted into the Program's database. Rare species reports received by the NHESP come from a variety of sources. Reports are submitted by NHESP staff, other Division of Fisheries & Wildlife personnel, professional biologists, experienced field naturalists and, for certain easily-identified species, from members of the general public. The NHESP generally requests that information be submitted on a Rare Animal or Rare Plant Observation Form with a valid signature, although other data formats may sometimes be acceptable (e.g. technical reports; published scientific literature). The following criteria are used by the NHESP in evaluating reports, although not all are required for record acceptance:

1. Qualifications and credibility of the observer. How much training or experience does the observer have in identifying rare species? This criterion is a major consideration in evaluation of rare species reports;

2. Documentation obtained and submitted in support of the observation; thorough and complete observation report including but not limited to well documented location of sighting; clear photographs and or voucher specimens as appropriate;

3. Ease of species identification. How distinctive is the species? Can it be confused with other species;

4. Appropriateness of the habitat for that species. Are the observations in a type of habitat that is normally utilized by the species in question;

5. Known range of the species in Massachusetts, including its historical distribution; and

6. Phenology. Does the observation date coincide with a time of year when the species is present or conspicuous because of breeding activity, migration, flowering period, etc.

Each submitted report is reviewed on a case-by-case basis considering the criteria listed above. Based on these criteria, reports are either rejected or accepted and incorporated into the NHESP database for use in the Program's biological conservation work. When possible, staff biologists will go into the field to verify insufficiently documented but likely reports. If a field visit is not possible and there is any uncertainty about the accuracy or precision of the report, then the observation is not incorporated into the NHESP's occurrence database. When updating and revising Priority Habitat boundaries, NHESP staff undertake further evaluation of each database record for its suitability for inclusion within Priority Habitat (pursuant to 321 CMR 10:12), for example, to exclude records older than 25 years and exclude certain records where it is determined that the local population has a low probability of persistence.

December 2009

Appendix L. Road Buffer Polygon Layer

The depiction of roads in the 2005 Land Use Land Cover is not adequate. Only large roads/highways, and some railroad corridors are shown as a land use polygon. There were several points during the project when we needed to see how roads fragmented habitat polygons. In order to identify these areas, we created a roads polygon layer using the following buffer assumptions:

Class of Road from EOTROADS Layer	**Buffer width**
Class 1 and 2	60 feet
Class 3 and 4	30 feet
Class 5 and 6	20 feet

These road width estimates were chosen "by eye" by selecting several different examples of highways, medium-sized roads, and smaller roads.

Appendix M. NHESP Priority Natural Communities by Ecosystem Type

Coastal Ecosystem Priority Natural Communities.

Community	Number of polygons	Acres
Coastal interdunal marsh/swale	4	652
Estuarine intertidal: brackish tidal marsh	7	877
Estuarine intertidal: coastal salt pond marsh	2	66
Estuarine intertidal: fresh/brackish tidal swamp	1	88
Estuarine intertidal: freshwater tidal marsh	5	811
Estuarine intertidal: saline/brackish flats	2	556
Estuarine intertidal: salt marsh	6	21,611
Estuarine subtidal: coastal salt pond	11	3,195
Marine subtidal: flats	3	2,129
Maritime beach strand community	4	1,112
Maritime dune community	8	7,459
Maritime juniper woodland/shrubland	4	458
Maritime pitch pine on dunes	1	428
Maritime rock cliff community	1	0
Maritime shrubland community	5	58
Marine intertidal: flats	2	2,133
Marine intertidal: rocky shore	2	26
TOTAL		**41,661**

Forest Priority Natural Communities.

Community	Number of polygons	Acres
Black oak - scarlet oak forest/woodland	2	145
Calcareous forest seep community	1	4
Coastal forest/woodland	11	427
Dry, rich acidic oak forest	2	49
Forest seep community	12	38
Hemlock ravine community	4	96
Hickory - hop hornbeam forest/woodland	16	163
High elevation spruce - fir forest/woodland	2	268
Mixed oak forest	3	1,357
Northern hardwoods - hemlock - white pine forest	11	4,512
Oak - hemlock - white pine forest	1	83
Oak - hickory forest	5	528

Community	Number of polygons	Acres
Oak - Holly Forest / Woodland	4	227
Red oak - sugar maple transition forest	2	71
Rich, mesic forest community	37	1,063
Spruce - fir - northern hardwoods forest	5	649
Yellow oak dry calcareous forest	5	20
Oak - Tulip Tree Forest	2	21
TOTAL		**9,720**

Riverine Priority Natural Communities.

Community	Number of polygons	Acres
Cobble bar forest	2	16
Dry riverside bluff	1	2
High-energy riverbank	15	78
High-terrace floodplain forest	16	134
Low-energy riverbank	4	20
Major-river floodplain forest	21	682
Riverine pointbar and beach	2	7
Riverside rock outcrop community	4	13
Riverside seep	3	15
Transitional floodplain forest	8	206
Small-river floodplain forest	11	351
TOTAL		**1,523**

Shrublands/Grasslands/Barrens Priority Natural Communities.

Community	Number of polygons	Acres
Pitch pine - scrub oak community	6	18,665
Sandplain grassland	6	629
Sandplain heathland	6	745
Scrub oak shrubland	2	14
TOTAL		**20,053**

Talus/Ridge-top/Cliff Priority Natural Communities.

Community	Number of polygons	Acres
Acidic rocky summit/rock outcrop community	14	103
Acidic talus forest/woodland	5	50

Community	Number of polygons	Acres
Calcareous rock cliff community	7	22
Calcareous rocky summit/rock outcrop community	5	29
Calcareous talus forest/woodland	8	120
Circumneutral rock cliff community	3	19
Circumneutral rocky summit/rock outcrop community	7	85
Circumneutral talus forest/woodland	24	326
Ridgetop chestnut oak forest/woodland	3	108
Ridgetop pitch pine - scrub oak community	13	163
Acidic rock cliff community	3	33
TOTAL		**1,058**

Wetlands Priority Natural Communities.

Community	Number of polygons	Acres
Acidic graminoid fen	22	256
Acidic shrub fen	21	664
Alluvial atlantic white cedar swamp	7	162
Alluvial Hardwood Flat	3	21
Alluvial red maple swamp	17	1,153
Atlantic white cedar bog	10	189
Black ash swamp	4	10
Black ash-red maple-tamarack calcareous seepage swamp	17	637
Black gum swamp	7	65
Black gum-pin oak-swamp white oak "perched" swamp	7	2,098
Calcareous basin fen	3	74
Calcareous pondshore/lakeshore	1	6
Calcareous seepage marsh	3	34
Calcareous sloping fen	9	23
Coastal atlantic white cedar swamp	13	4,298
Coastal plain pondshore	95	423
Deep emergent marsh	5	754
Hemlock-hardwood swamp	10	400
Highbush blueberry thicket	2	56
Inland acidic pondshore/lakeshore	1	3
Inland atlantic white cedar swamp	16	1,455
Kettlehole level bog	25	91
Kettlehole wet meadow	5	12
Level bog	37	847

Community	Number of polygons	Acres
Northern atlantic white cedar swamp	1	118
Red maple swamp	3	1,521
Sea-Level Fen	3	8
Shallow emergent marsh	4	98
Shrub swamp	6	263
Spruce-fir swamp	19	405
Spruce-tamarack bog	10	321
Wet meadow	3	49
Red Maple - Black Ash - Bur Oak Swamp	1	7
TOTAL		**16,519**

Appendix N. Aquatic MESA-listed species that were included in Aquatic Core and buffered by 30 meters.

Scientific Name	Common Name	MESA Status (as of 2010)
Alasmidonta heterodon	Dwarf Wedgemussel	E
Alasmidonta undulata	Triangle Floater	SC
Alasmidonta varicosa	Brook Floater	E
Amphicarpum amphicarpon	Annual Peanut-grass	E
Arethusa bulbosa	Arethusa	T
Betula pumila	Swamp Birch	E
Bidens eatonii	Eaton's Beggar-ticks	E
Bidens hyperborea	Estuary Beggar-ticks	E
Bolboschoenus fluviatilis	River Bulrush	SC
Botaurus lentiginosus	American Bittern	E
Cardamine longii	Long's Bitter-cress	E
Cardamine pratensis var. *palustris*	Fen Cuckoo Flower	T
Carex castanea	Chestnut-colored Sedge	E
Carex chordorrhiza	Creeping Sedge	E
Carex davisii	Davis's Sedge	E
Carex grayi	Gray's Sedge	T
Carex lenticularis	Shore Sedge	T
Carex lupuliformis	False Hop-sedge	E
Carex michauxiana	Michaux's Sedge	E
Carex mitchelliana	Mitchell's Sedge	T
Carex oligosperma	Few-fruited Sedge	E
Carex pauciflora	Few-flowered Sedge	E
Carex schweinitzii	Schweinitz's Sedge	E
Carex sterilis	Dioecious Sedge	T
Carex striata	Walter's Sedge	E
Carex tetanica	Fen Sedge	SC
Carex trichocarpa	Hairy-fruited Sedge	T
Carex tuckermanii	Tuckerman's Sedge	E
Carex typhina	Cat-tail Sedge	T
Cicindela duodecimguttata	Twelve-spotted Tiger Beetle	SC
Cicindela limbalis	Bank Tiger Beetle	SC
Cicindela marginipennis	Cobblestone Tiger Beetle	E
Cicindela puritana	Puritan Tiger Beetle	E
Cyperus engelmannii	Engelmann's Umbrella-sedge	T
Cypripedium parviflorum var. *makasin*	Small Yellow Lady's-slipper	E
Cypripedium reginae	Showy Lady's-slipper	SC
Dichanthelium wrightianum	Wright's Panic-grass	SC
Elatine americana	American Waterwort	E
Eleocharis intermedia	Intermediate Spike-sedge	T
Eleocharis ovata	Ovate Spike-sedge	E

Scientific Name	Common Name	MESA Status (as of 2010)
Eleocharis quinqueflora	Few-flowered Spike-sedge	E
Eleocharis tricostata	Three-angled Spike-sedge	E
Eriocaulon parkeri	Parker's Pipewort	E
Eriophorum gracile	Slender Cottongrass	T
Eubranchipus intricatus	Intricate Fairy Shrimp	SC
Eulimnadia agassizii	Agassiz's Clam Shrimp	E
Eupatorium novae-angliae	New England Boneset	E
Ferrissia walkeri	Walker's Limpet	SC
Floridobia winkleyi	New England Siltsnail	SC
Galium labradoricum	Labrador Bedstraw	T
Gallinula chloropus	Common Moorhen	SC
Gammarus pseudolimnaeus	Northern Spring Amphipod	SC
Gavia immer	Common Loon	SC
Gentiana andrewsii	Andrews' Bottle Gentian	E
Hydrocotyle verticillata	Saltpond Pennywort	T
Hypericum adpressum	Creeping St. John's-wort	T
Isoetes acadiensis	Acadian Quillwort	E
Isoetes lacustris	Lake Quillwort	E
Ixobrychus exilis	Least Bittern	SC
Juncus filiformis	Thread Rush	E
Lachnanthes caroliana	Redroot	SC
Lampsilis cariosa	Yellow Lampmussel	E
Leptochloa fusca ssp. *fascicularis*	Saltpond Grass	T
Leptodea ochracea	Tidewater Mucket	E
Ligumia nasuta	Eastern Pondmussel	SC
Limnadia lenticularis	American Clam Shrimp	SC
Lipocarpha micrantha	Dwarf Bulrush	T
Listera cordata	Heartleaf Twayblade	E
Littoridinops tenuipes	Coastal Marsh Snail	SC
Ludwigia polycarpa	Many-fruited False-loosestrife	E
Ludwigia sphaerocarpa	Round-fruited False-loosestrife	E
Lycopodiella alopecuroides	Foxtail Clubmoss	E
Lycopus rubellus	Gypsywort	E
Malaxis monophyllos var. *brachypoda*	White Adder's-mouth	E
Marstonia lustrica	Boreal Marstonia	E
Mimulus alatus	Winged Monkey-flower	E
Mimulus moschatus	Muskflower	E
Myriophyllum alterniflorum	Alternate-flowered Water-milfoil	E
Myriophyllum farwellii	Farwell's Water-milfoil	E
Myriophyllum pinnatum	Pinnate Water-milfoil	SC
Myriophyllum verticillatum	Comb Water-milfoil	E
Nuphar microphylla	Tiny Cow-lily	E
Orontium aquaticum	Golden Club	E
Panicum philadelphicum ssp. philadelphicum	Philadelphia Panic-grass	SC
Panicum rigidulum ssp. *pubescens*	Long-leaved Panic-grass	T
Pedicularis lanceolata	Swamp Lousewort	E
Persicaria setacea	Strigose Knotweed	T

Scientific Name	Common Name	MESA Status (as of 2010)
Petasites frigidus var. *palmatus*	Sweet Coltsfoot	E
Platanthera cristata	Crested Fringed Orchis	E
Platanthera dilatata	Leafy White Orchis	T
Platanthera flava var. *herbiola*	Pale Green Orchis	T
Podilymbus podiceps	Pied-billed Grebe	E
Podostemum ceratophyllum	Threadfoot	SC
Polycelis remota	Sunderland Spring Planarian	E
Polygonum puritanorum	Pondshore Knotweed	SC
Pomatiopsis lapidaria	Slender Walker	E
Potamogeton confervoides	Algae-like Pondweed	T
Potamogeton friesii	Fries' Pondweed	E
Potamogeton hillii	Hill's Pondweed	SC
Potamogeton ogdenii	Ogden's Pondweed	E
Potamogeton strictifolius	Straight-leaved Pondweed	E
Potamogeton vaseyi	Vasey's Pondweed	E
Rallus elegans	King Rail	T
Ranunculus pensylvanicus	Bristly Buttercup	SC
Rhexia mariana	Maryland Meadow Beauty	E
Rhododendron maximum	Great Laurel	T
Rhynchospora capillacea	Capillary Beak-sedge	E
Rhynchospora inundata	Inundated Horned-sedge	T
Rhynchospora nitens	Short-beaked Bald-sedge	T
Rhynchospora scirpoides	Long-beaked Bald-sedge	SC
Rhynchospora torreyana	Torrey's Beak-sedge	E
Rotala ramosior	Toothcup	E
Rumex verticillatus	Swamp Dock	T
Sabatia campanulata	Slender Marsh Pink	E
Sabatia kennedyana	Plymouth Gentian	SC
Sabatia stellaris	Sea Pink	E
Sagittaria cuneata	Wapato	T
Sagittaria montevidensis ssp. *spongiosa*	Estuary Arrowhead	E
Sagittaria teres	Terete Arrowhead	SC
Scheuchzeria palustris	Pod-grass	E
Scirpus ancistrochaetus	Northeastern Bulrush	E
Scirpus longii	Long's Bulrush	T
Sclerolepis uniflora	Sclerolepis	E
Sparganium natans	Small Bur-reed	E
Spartina cynosuroides	Salt Reedgrass	T
Sphenopholis pensylvanica	Swamp Oats	T
Spiranthes romanzoffiana	Hooded Ladies'-tresses	E
Spongilla aspinosa	Smooth Branched Sponge	SC
Strophitus undulatus	Creeper	SC
Stygobromus tenuis tenuis	Piedmont Groundwater Amphipod	SC
Symphyotrichum prenanthoides	Crooked-stem Aster	T
Synurella chamberlaini	Coastal Swamp Amphipod	SC
Thuja occidentalis	Arborvitae	E
Tillaea aquatica	Pygmyweed	T

Scientific Name	Common Name	MESA Status (as of 2010)
Tripsacum dactyloides	Northern Gama-grass	E
Utricularia resupinata	Resupinate Bladderwort	T
Utricularia subulata	Subulate Bladderwort	SC
Veronica catenata	Sessile Water-speedwell	E
Viola brittoniana	Britton's Violet	T