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

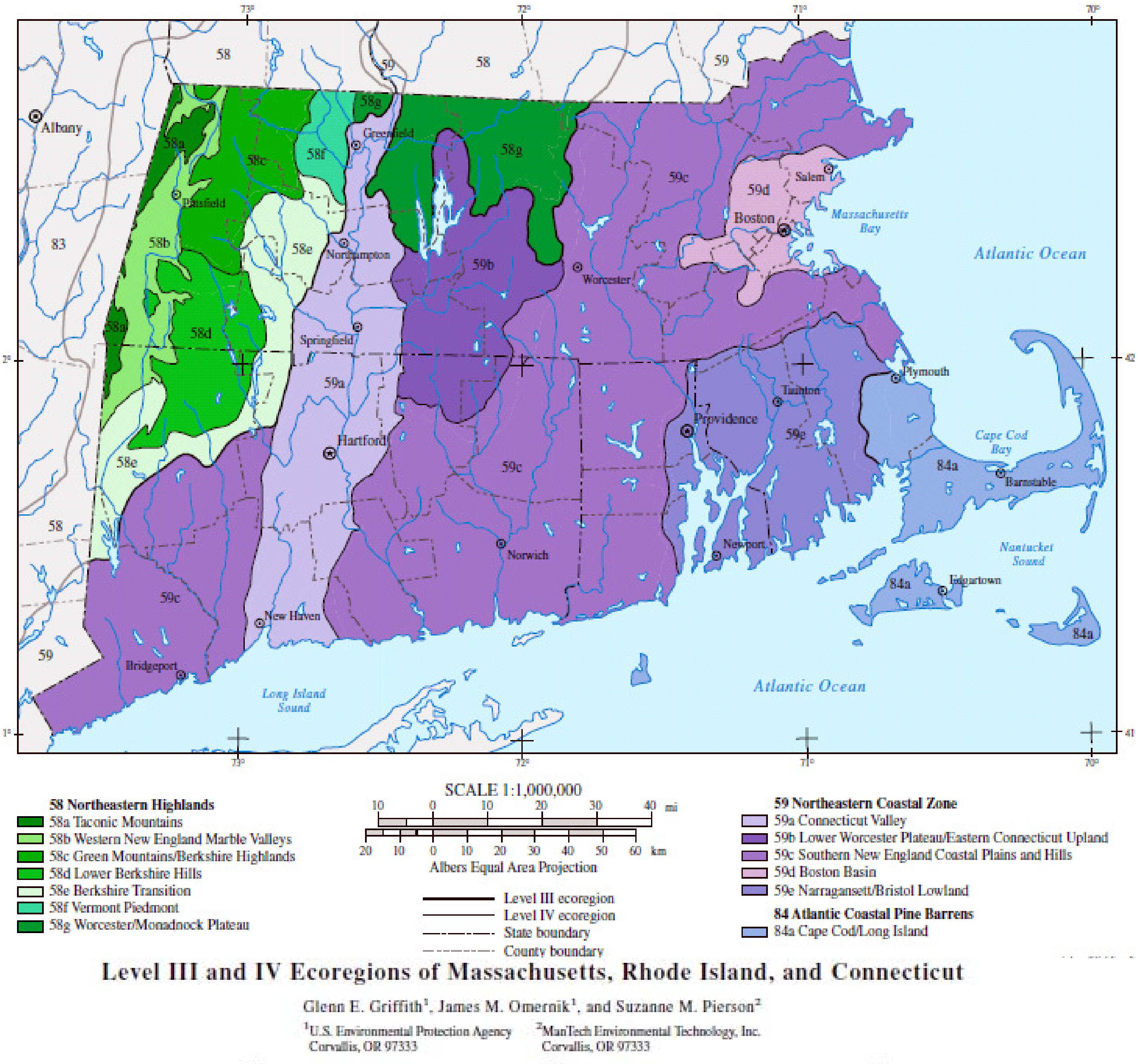

Figure 3. Level III and IV Ecoregions of Massachusetts, Rhode Island, and Connecticut.

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.

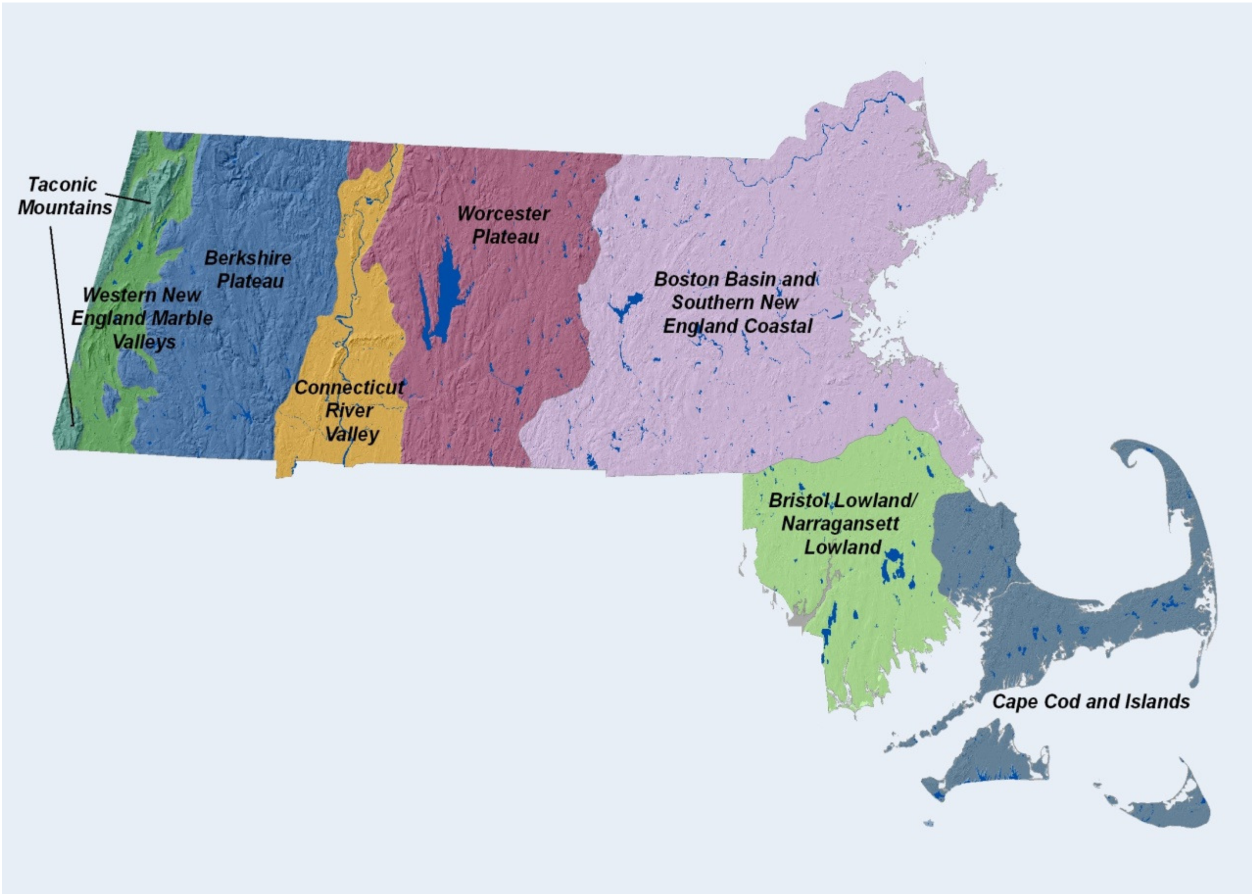

Figure 4. The eight ecoregions used to stratify and select ecosystems in *BioMap2*.

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.

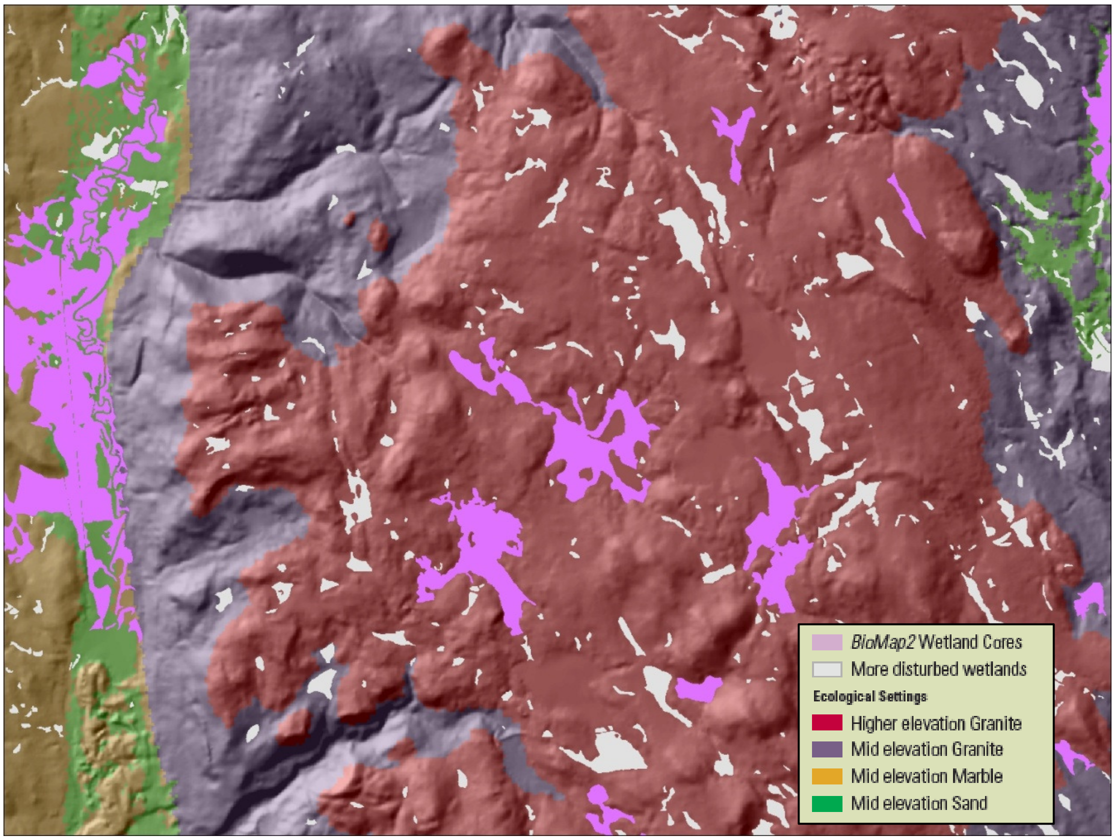

Figure 5. *BioMap2* wetlands on various physical settings.

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.

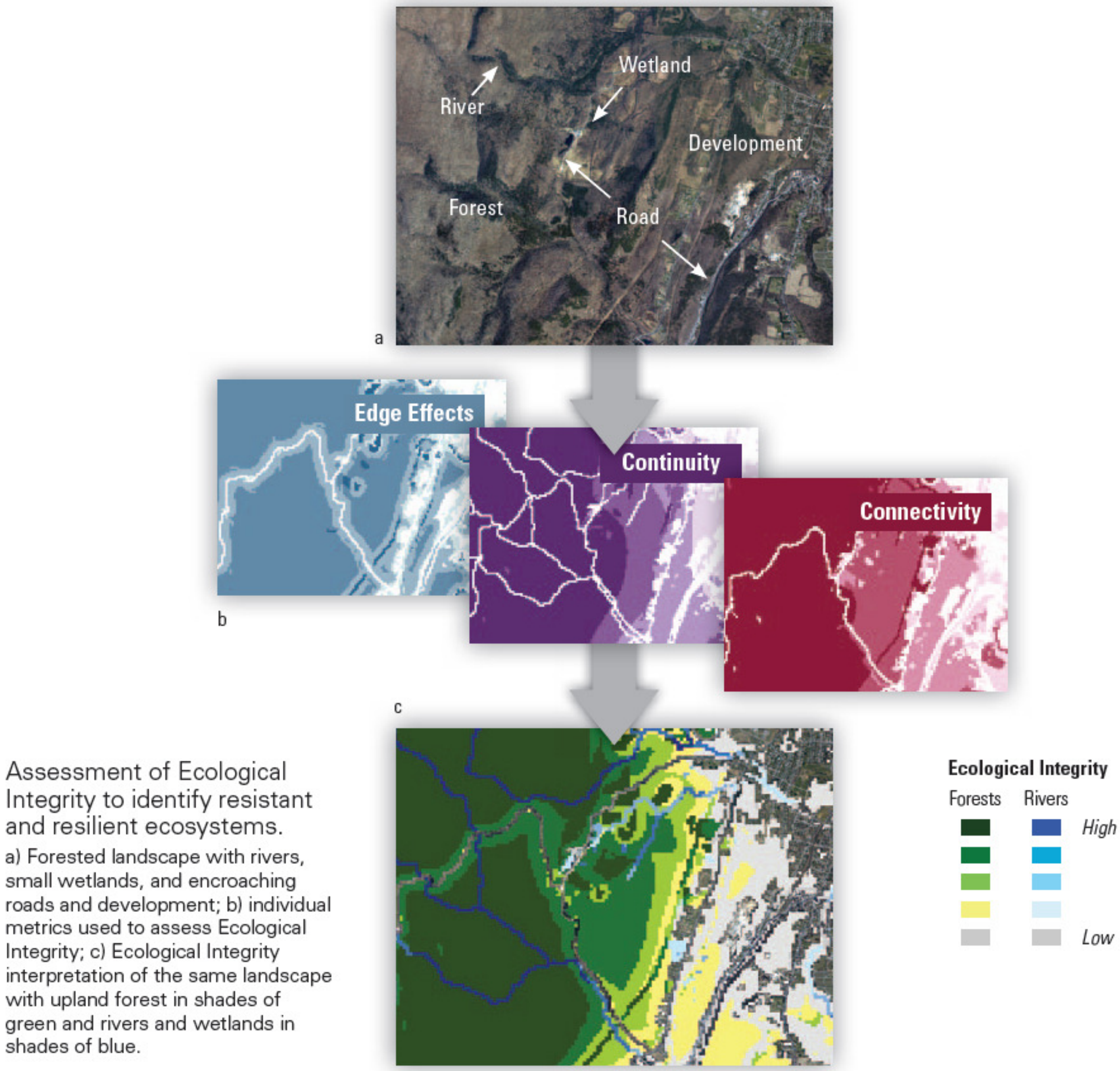

Figure 6. Building the IEI.

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*.

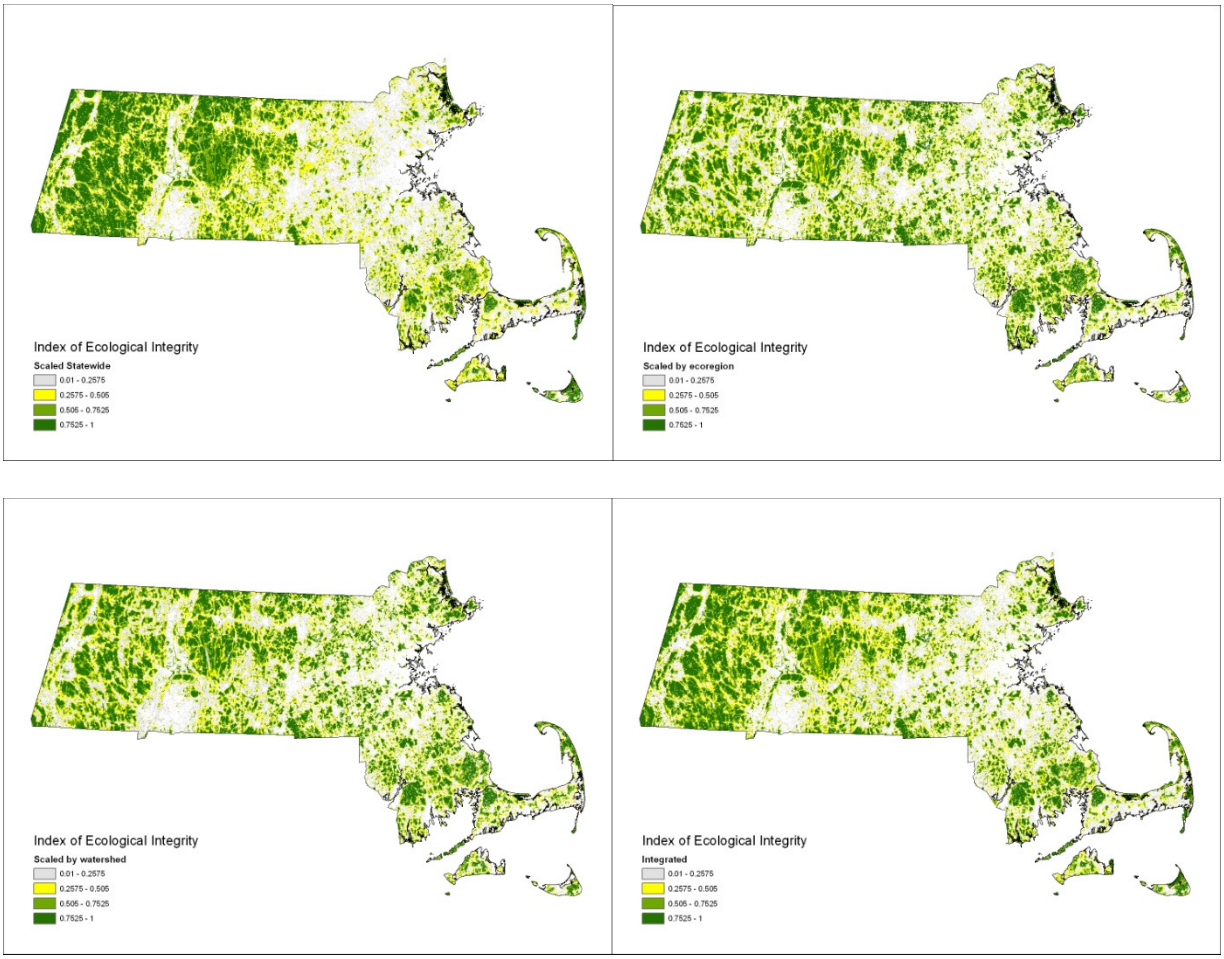

Figure 7. IEI scaled by 4 different extents (statewide, ecoregion, watershed, and integrated)

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).

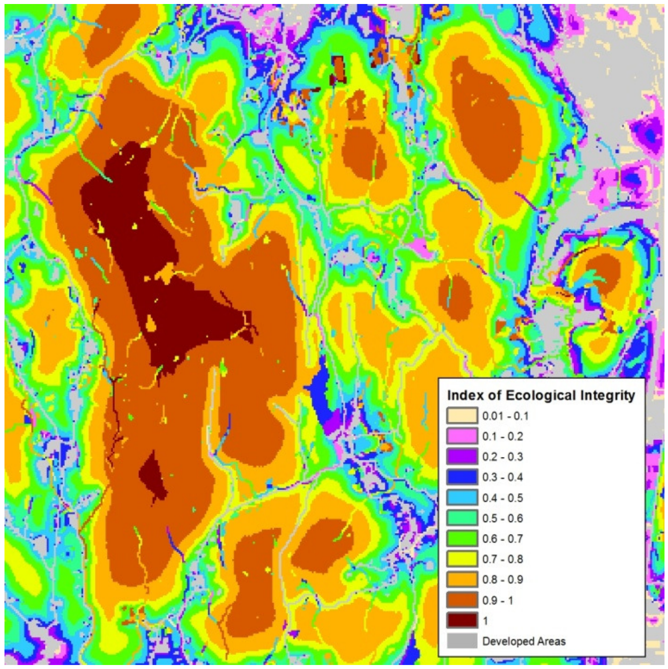

Figure 8. CAPS IEI for ecological communities.

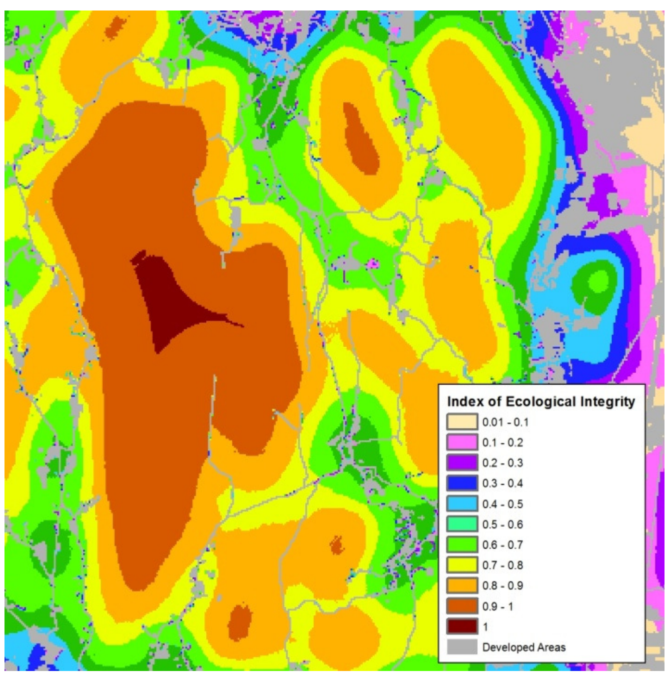

Figure 9. CAPS IEI for natural cover.

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.