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.

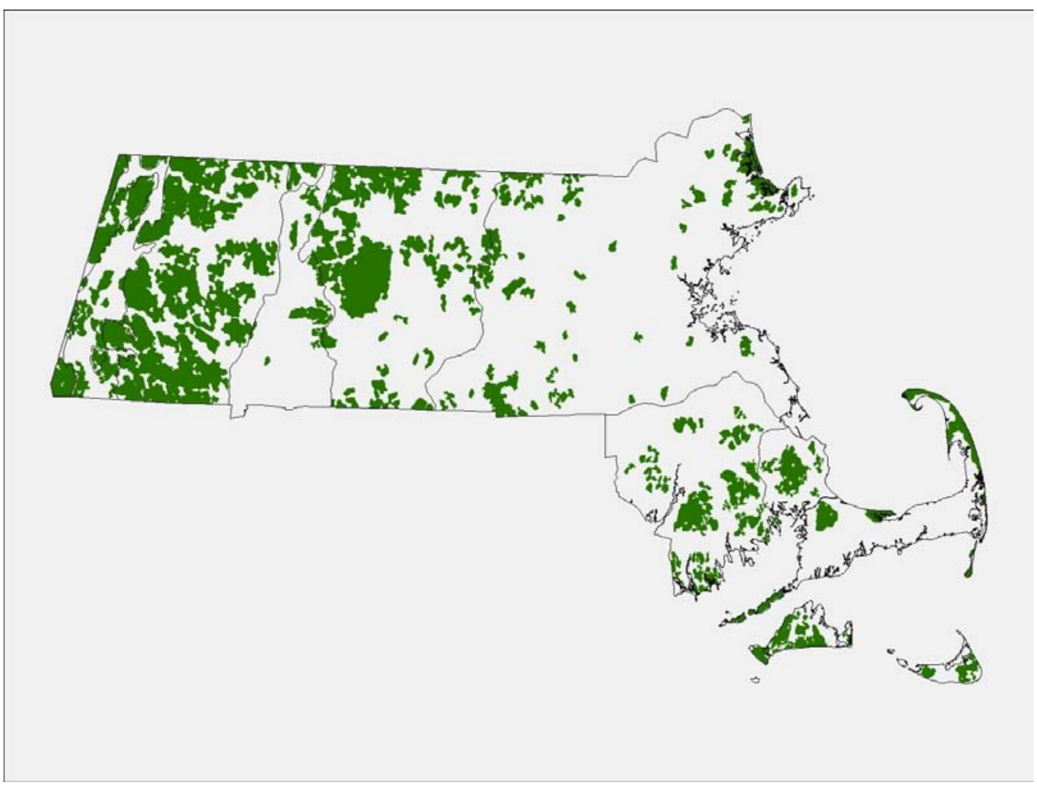

Figure 24. Landscape Blocks showing ecoregional boundaries.

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).

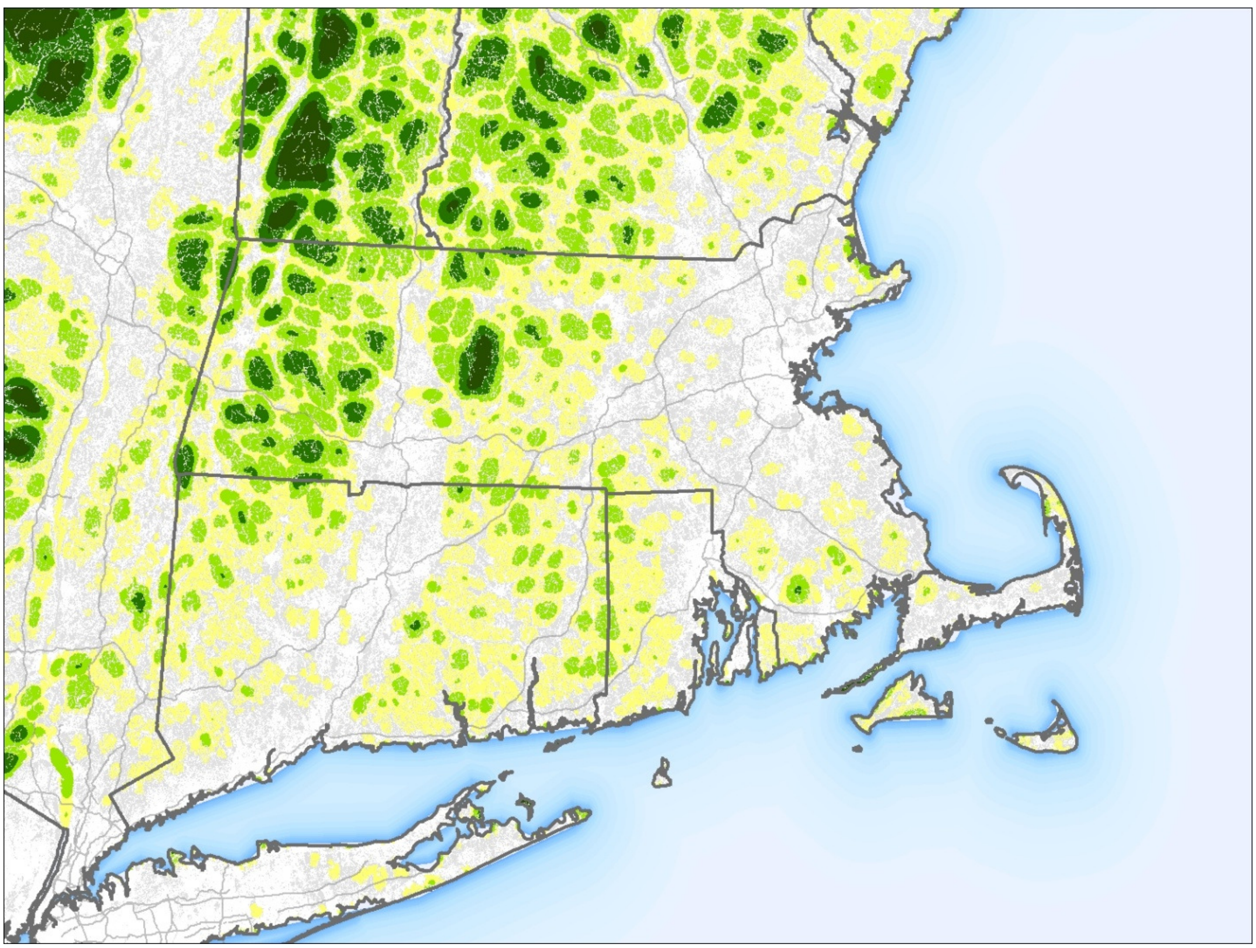

Figure 25. Regional connectedness
showing areas of highest local connectivity in dark green.

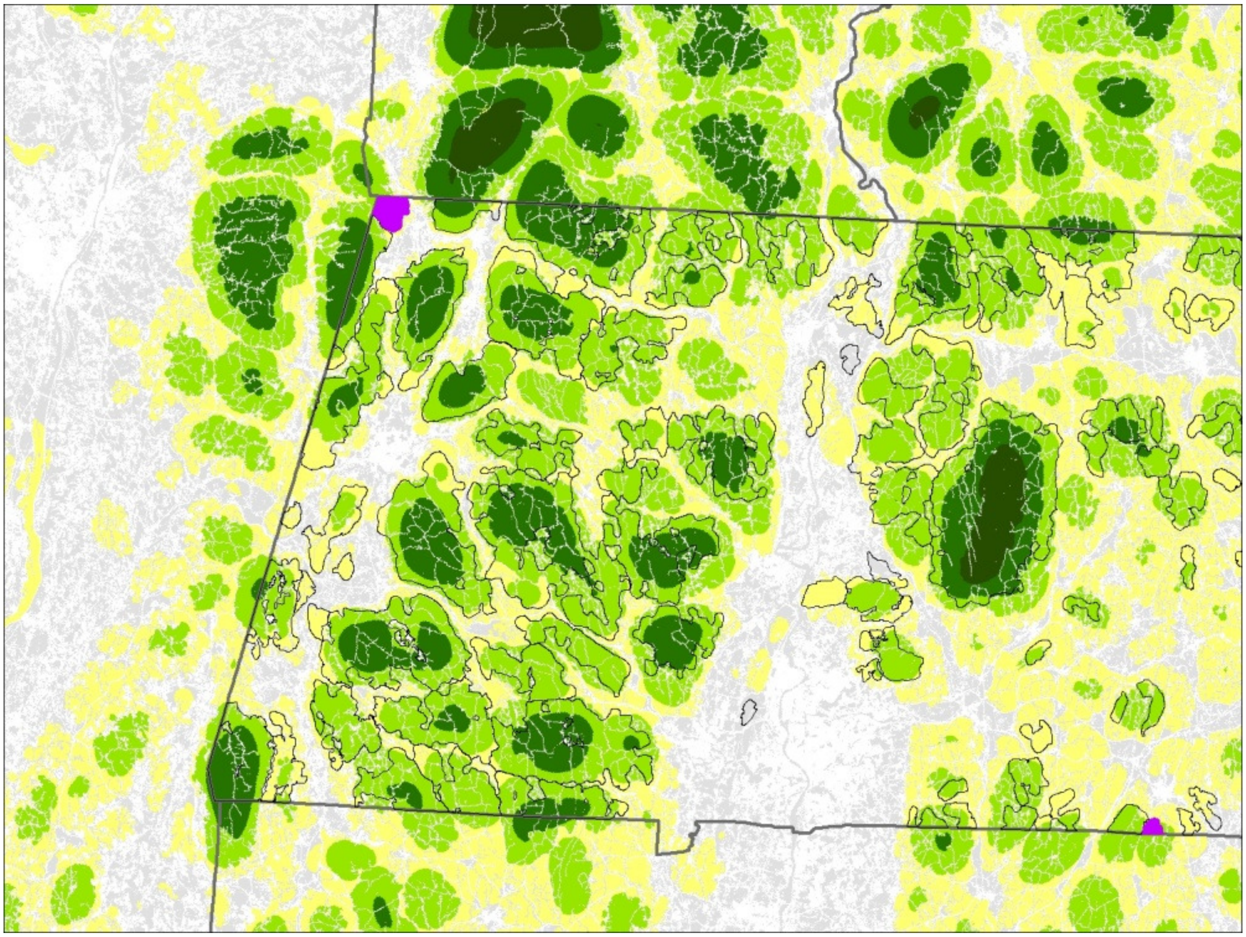

Figure 26. Landscape Blocks that were added as a result of this review are shown here in purple.

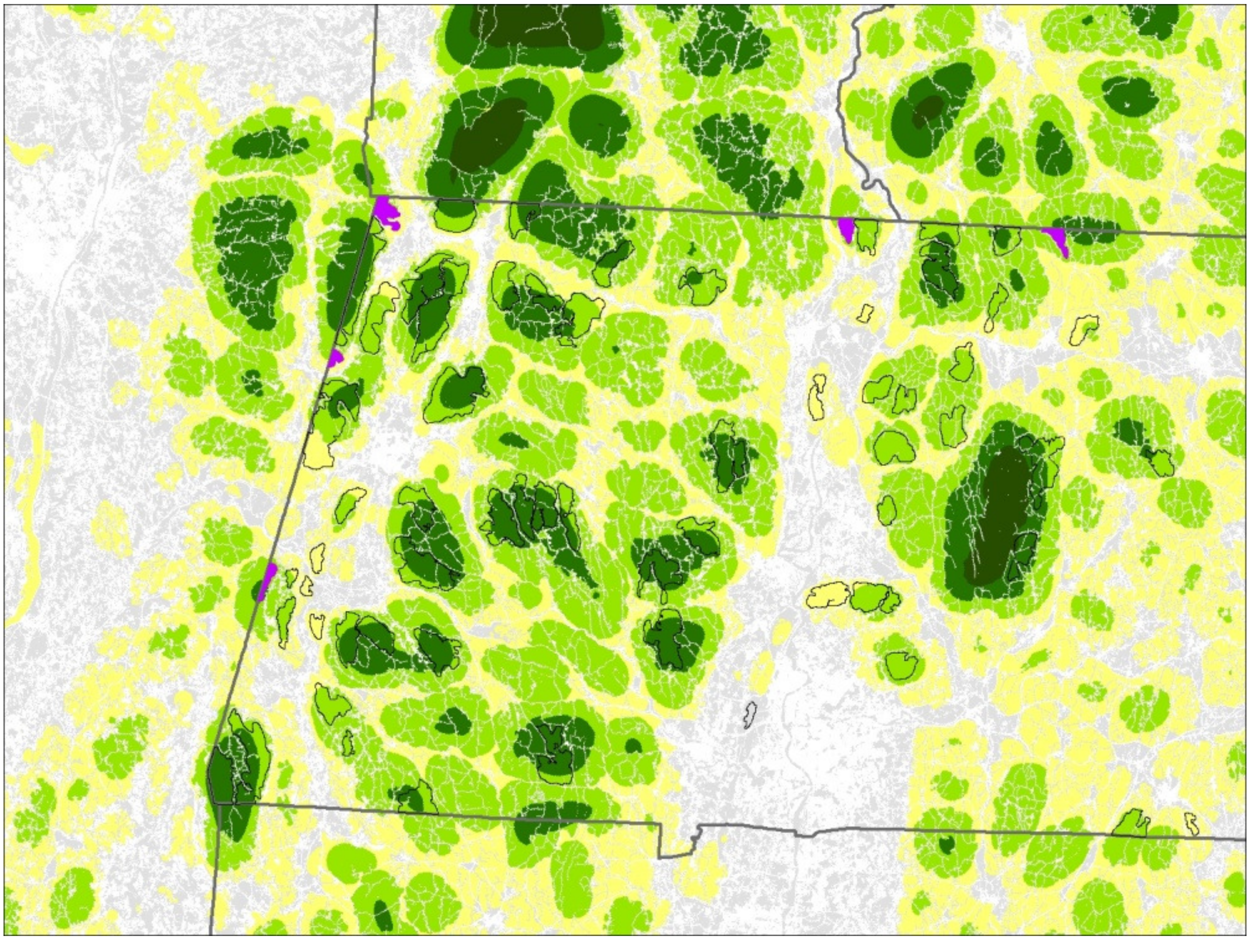

Figure 27. Forest Cores that were added
as a result of this review are shown here in purple.

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.

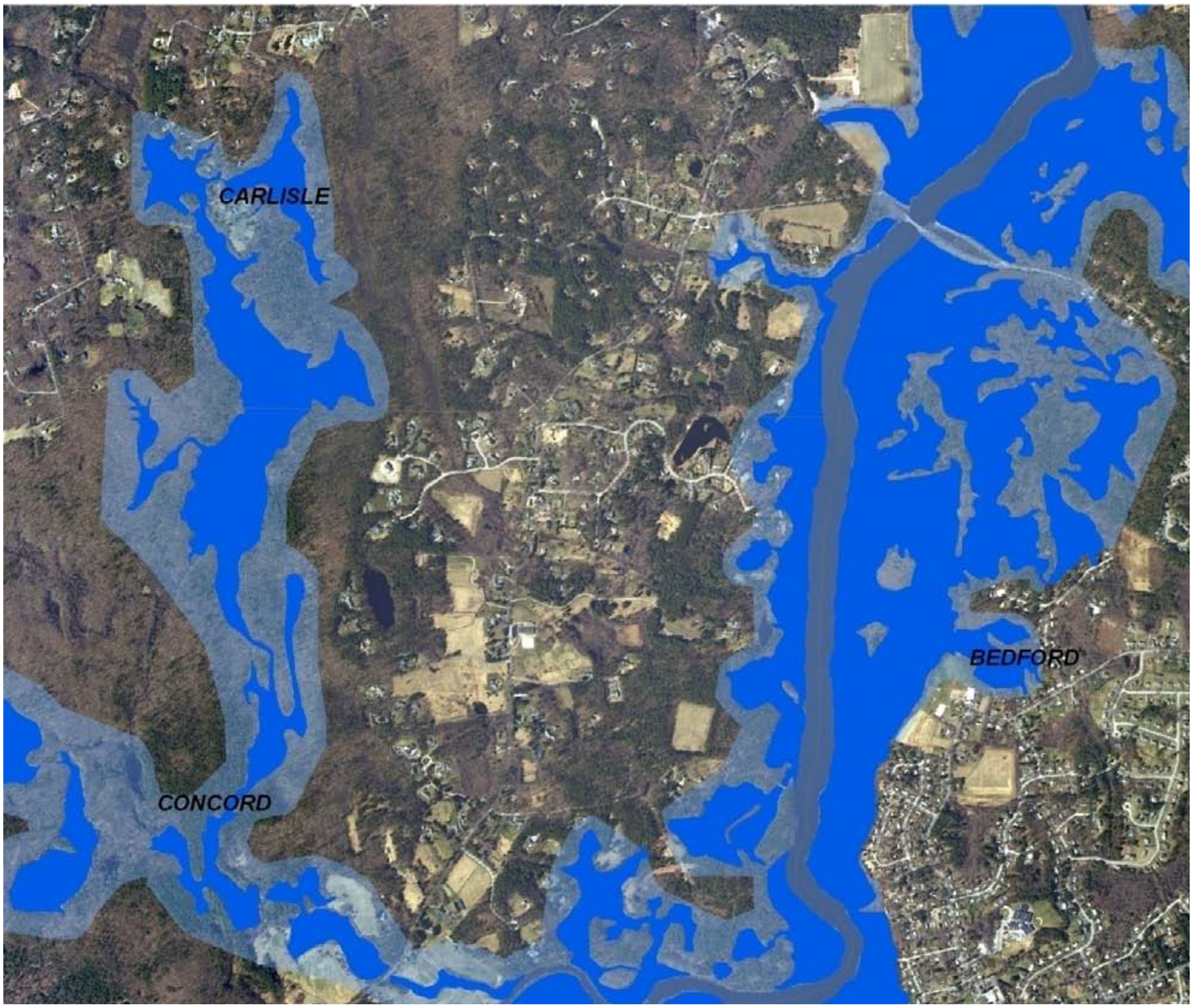

Figure 28. Example of the buffer created by the buffer tool surrounding a Wetland Core.

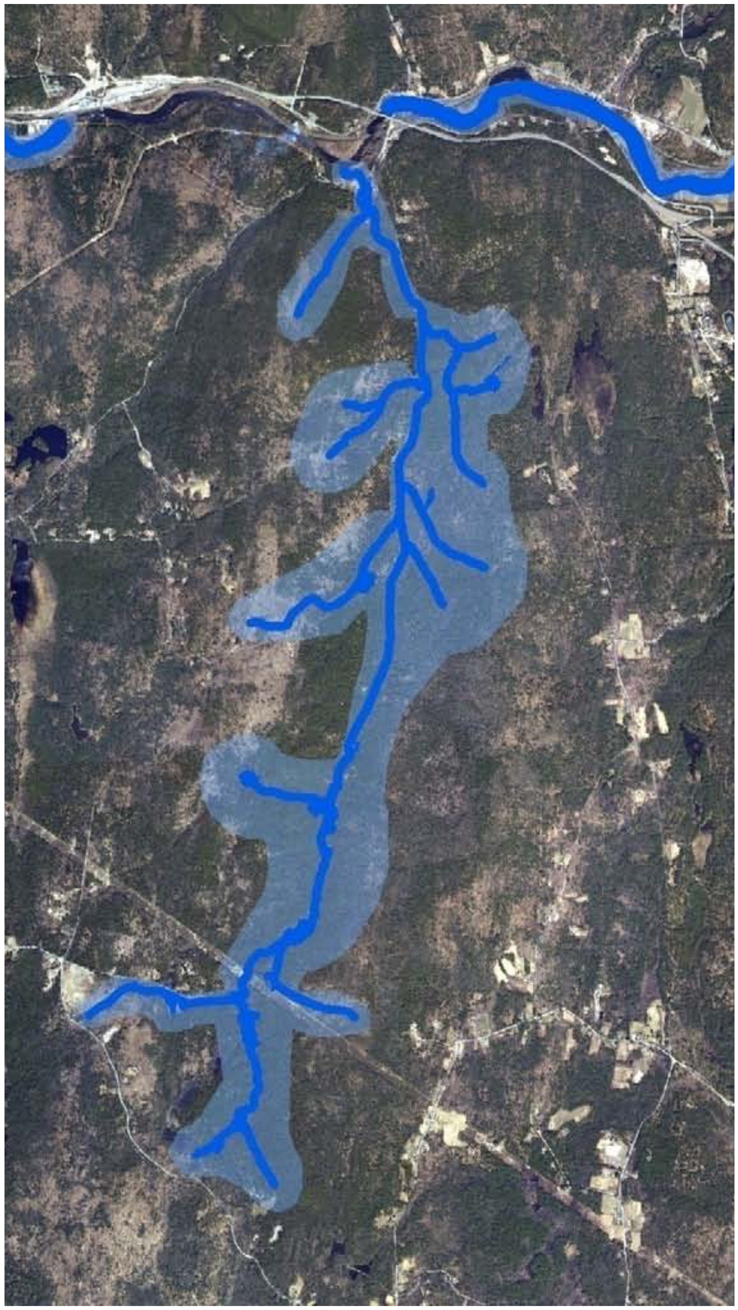

Figure 29. Example of the buffer created by the buffer tool surrounding an Aquatic Core.

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.

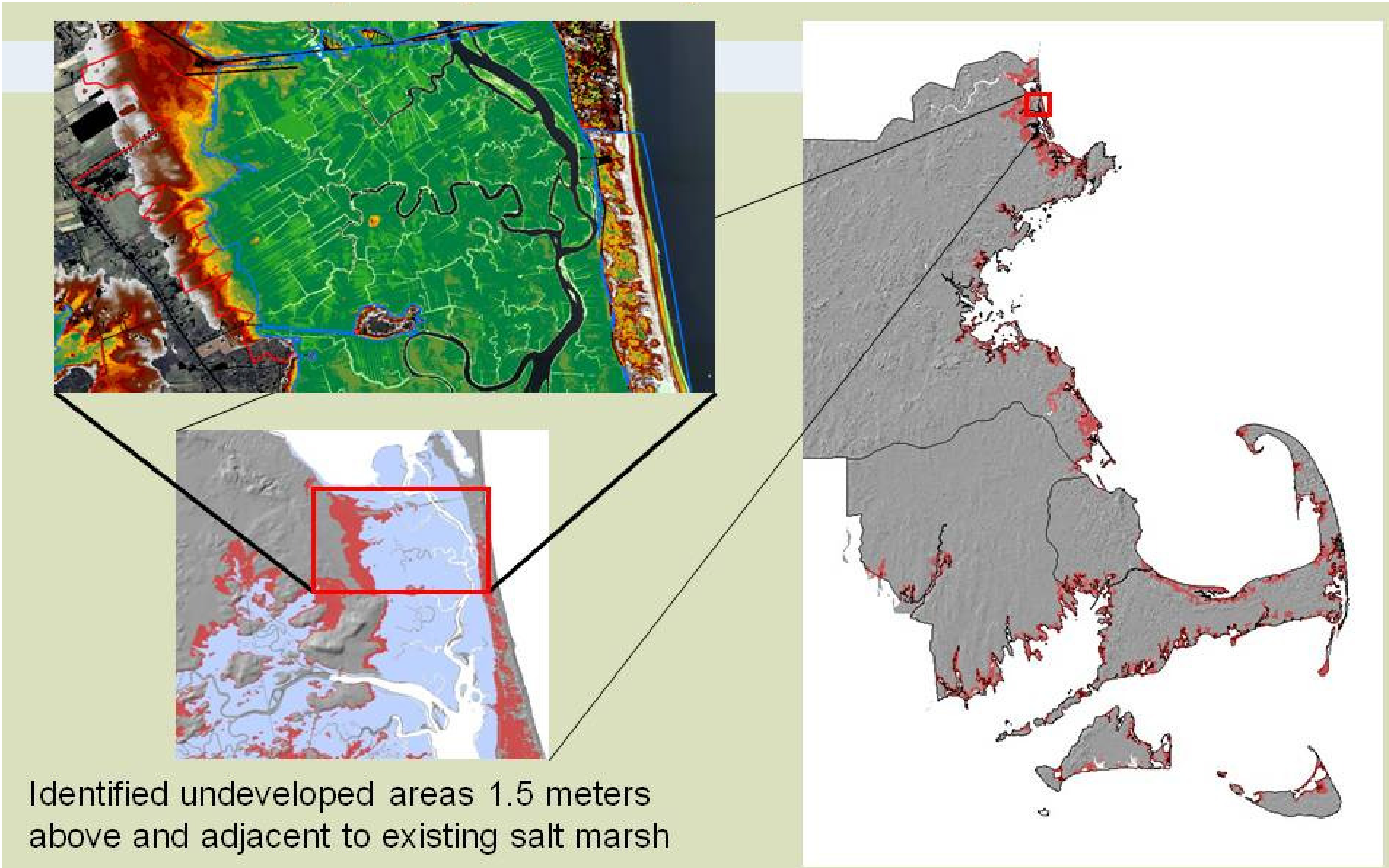

Figure 30. Identifying Coastal Adapation Uplands.

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.

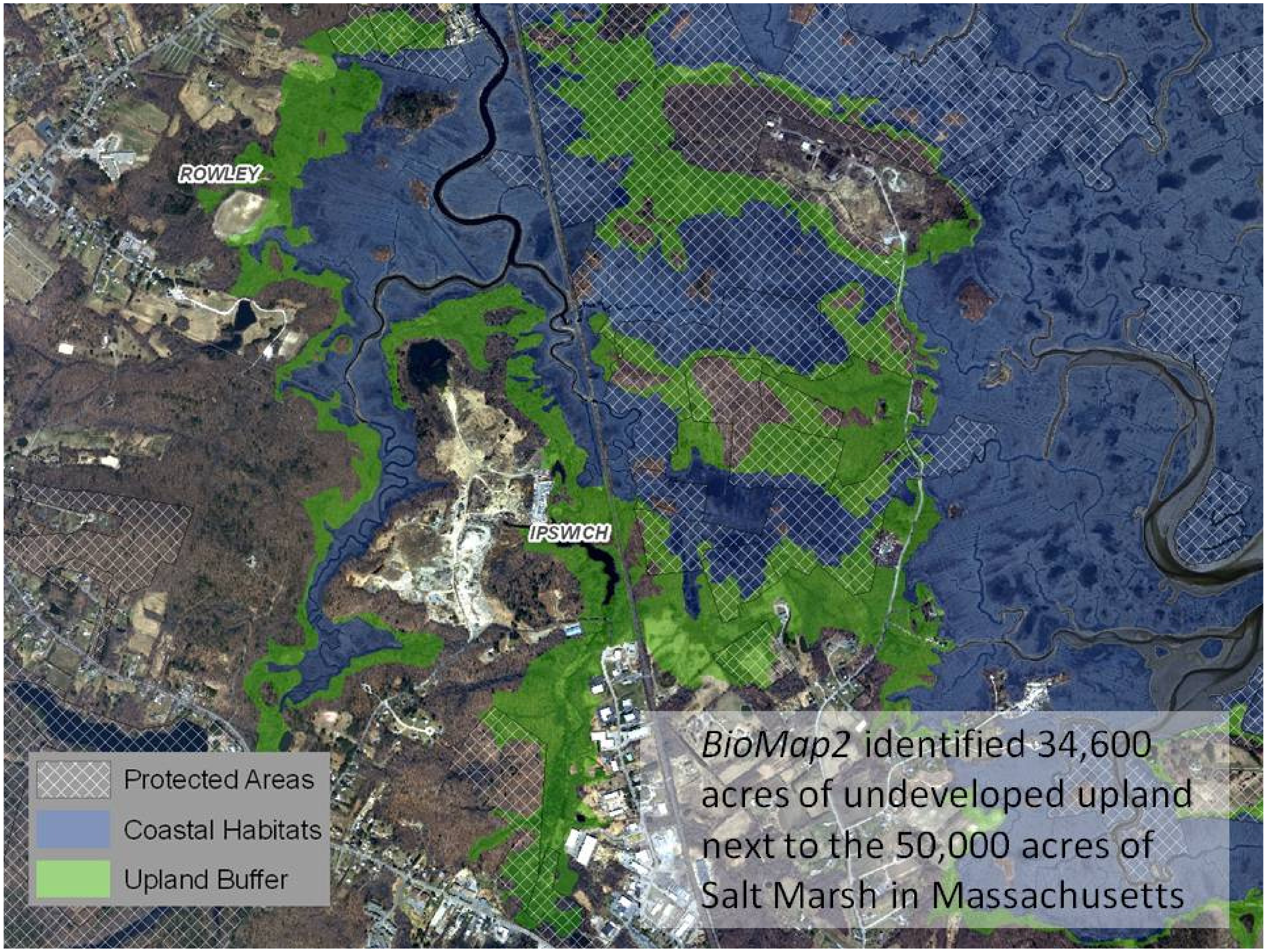

Figure 31. Example in Ipswich and Rowley.
This shows the unprotected land (not hatched) that falls in the coastal adaptation zone (green).

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.

<u>Arctic, Common, and Roseate Terns</u>
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.

<u>Least Tern</u>
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.