A “Climate-Smart” Model for the Optimization of Tidal Salt Marsh Conservation

a thesis submitted by

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Abstract

Tidal salt marsh ecosystems are vital to the health and protection of northeast United States coastlines. This ecosystem is often the buffer between the ocean and shoreline development, and provides many ecosystem services such as water filtration, habitat for commercially harvested species, and recreational enjoyment. Sea level rise is a threat to salt marshes; as water levels rise, salt marshes will either drown in-place or migrate landward. Marsh migration can only occur into upland areas without development, so it is imperative that these areas are conserved to ensure the future persistence of tidal salt marsh. One of the most effective tools for the protection of this resource is the conservation easement. This study offers a new methodology for the prioritization of conservation investments through use of both socio-environmental as well as resiliency metrics, including metrics for marsh migration, to aid in the identification of sites with the highest conservation value.

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Chapter 1

Introduction

Large parts of our region, our country, are thriving areas of high biodiversity due to the work of land managers and planners from generations before us. Parks we played in as children are still there for the enjoyment of today's youth, the trails we walk today have been walked by many thousands of other people before us. It is the naturalists goal, that the work we do to protect and restore important environmental areas over the course of our careers remain intact for the enjoyment of generations to come. However, we are now experiencing a time of rapidly increasing global temperatures, changing weather patterns, and shifting species ranges. This means today's land managers and planners must consider not only which spaces are important to conserve for society and the environment, but also which spaces will remain resilient to the pressures of climate change and continue to support biodiversity into the future.

Conservation practices have historically focused on conserving existing biodiversity, with the assumption those land areas will continue to be biodiversity hotspots into the future (Lawler et al., 2015). More modern practices attempting to address the problem of a changing climate have focused on "connectivity conservation," which promotes the building and maintenance of connected environments, allowing species to move freely with the climate (Hodgson et al., 2009). Lawler et al. (2015) suggest instead examining abiotic conditions and conserving areas that offer a diversity of abiotic conditions and high biodiversity today, with the theory that these abiotic “stages” will continue to support high biodiversity into the future (though, the composition of that biodiverse area may change dramatically into the future). Of course, different theories must be employed depending on the management objective (Hodgson et al., 2009). Large-landscape acquisitions by the Department of the Interior or The Nature Conservancy should be examined through a regional lens and prioritize the protection of resilient bio-geographical land cores and corridors (OSI and NALCC, 2016). Management at the local or species level requires a very different set of finer-grain site considerations.

There will be winners and losers on the ecological game board as climate change continues to intensify. Some species and ecosystems may benefit, but others will become degraded and vulnerable, especially as climactic impacts are coupled with an increasing global population and increased development pressure. One of these particularly embattled systems is the tidal salt marsh. Tidal salt marshes – wetland areas along coasts in mid-to high latitudes, subject to flooding twice per day – provide many services, and thus economic benefits, to society. These services include provisioning services such as raw materials, food, and water purification; regulating services such as regulation of storms and floods, drought, land degradation, and disease; supporting services such as fish and wildlife habitat, soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious, and other nonmaterial benefits (Barbier et al., 2011). This important ecosystem is most prevalent along the Atlantic coast of the

United States and has experienced a rapid rate of loss with the intensification of development along the shoreline for the last two centuries.

This study aims to provide a decision-support framework for the inclusion of future land-use and land-type scenarios and outlines a new methodology for the optimization of tidal salt marsh habitat conservation with the inclusion of both regional and local socio-environmental and resiliency metrics for land acquisition prioritization. Chapter 2 presents the data and methods used for the development of a land conservation prioritization model, as well as a presentation of model analysis using the Massachusetts Conservation Land Tax Credit Program as a sample study area. Chapter 3 provides a literature review of the value of tidal salt marshes as evidenced by regulatory protections and academic studies of ecosystem services valuation to support the argument for inclusion and heavy weighting of marsh metrics in conservation valuation for prioritization. Chapters 4 and 5 discuss regulatory and non-regulatory tools for the protection of tidal salt marshes that extend beyond the conservation easement or acquisition concept. Chapter 6 reviews major themes and take-aways from the thesis and provides recommendations to further refine the decision-support process as public and private entities continue to work towards tidal salt marsh conservation into the future.

Chapter 2

Conservation in a Changing Climate

Some conservation decisions, such as those made by private landowners to secure their lands against development into the future through private servitudes (see footnote 3, pg.58) or deed restrictions (see footnote 4 pg. 59), are intrinsically motivated actions made because the landowner believes as much land as possible should be set aside for future generations or because the land has enough aesthetic and recreational value to warrant protection. However, many decisions to enter into some sort of conservation sale or agreement are monetarily incentivized. When a landowner donates an easement to a land trust or public agency, she or he is giving away some of the rights associated with the land. The easement permanently limits uses of the donated parcel in order to protect its conservation values, as specified in the Internal Revenue Code (IRC) 170(h). These donations qualify the landowner for a charitable tax deduction on their federal income tax. The easement also lowers the value of the property, and so property tax liability is also reduced. Additionally, some states, including Massachusetts, offer income tax credits for conservation land donations. Collectively, this is a fair amount of resources dedicated to the protection of ecologically-important high resource areas, and should be allocated strategically to ensure lands of the highest value to both local species and regional connectivity are prioritized for investment.

Selection of lands for conservation investment must be informed not only by species locations today or on their predicted responses to climate change, but must also be considered through the complimentary lens of land characteristics that are likely to support diversity and resilience into the future (Anderson et al., 2012). Landscape complexity [a measure of the number of microhabitats and climactic gradients available within a given area, including elevation range and wetland density] and landscape permeability [the number of barriers and degree of fragmentation within a landscape] are critical factors to consider in climate-smart conservation planning (Anderson et al., 2012). Through the identification of these characteristics, the most resilient places within a planning area may be identified. The term "resilience" is used to refer to the capacity of a site to adapt to climate change while still maintaining function and diversity (OSI and NALCC, 2016; Anderson et al., 2012). A highly permeable and complex landscape may promote resilience by facilitating range shifts and community reorganization as species move through connected and diverse landforms with the changing climate. Development such as roads, dams, and buildings interrupt and redirect movement, and therefore, lower permeability.

Many datasets and tools exist to aid land planners in land conservation decision-making. Given the limited resources available for the preservation of physically and biologically important lands, it is imperative that the best available data and decision-making frameworks are applied in this process. It is important not only that data used are technically accurate but are also at a fine enough grain for the planning area and consider climate change factors. Data and tools have been created and made publicly available for conservation planning purposes. This proposed model integrates several local and regional resiliency measures, social and environmental factors, marsh migration potential, and development stress through the combination of data from these resources. The goal of the study is to increase tidal salt marsh conservation in a climate-smart manner through the application of this proposed model.

Optimization of tidal salt marsh protection

As defined by the Ramsar Convention on Wetlands, wetlands are "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres." These include inland wetlands (such as swamps, marshes, lakes, rivers, peatlands, and underground water habitats); coastal and near-shore marine wetlands (such as mangroves, seagrass beds, and marshes); and human-made wetlands (such as rice fields, dams, reservoirs, and fish ponds) (Ramsar Wetlands Convention, 2017b). This study is concerned with the fate of coastal and estuarine tidal salt marshes, which can be found along protected coastlines in middle to high latitudes worldwide. This type of wetland ecosystem is most prevalent in the United States along the eastern coast from Maine to Florida, continuing westward along the Gulf Coast to Louisiana and Texas (US EPA, 2015). This review and discussion will focus on tidal salt marshes in the northeast.

Tidal salt marshes in the northeast United States are generally classified into two distinct zones: the lower, or intertidal, marsh and the upper, or high, marsh areas (Figure 1). A belt of cordgrass (or *Spartina alterniflora)* usually grows along the edges of the creeks and ditches within the marsh system. This area (the low or intertidal marsh) is the only elevation that supports this type of marsh grass, and is flooded daily by the tides (US EPA, 2015; Waterview Consulting, 2015). The boundary of the low marsh is demarcated by the mean high water line. The rest of the marsh, at higher elevations (upper or high marsh), contains shorter grasses such as the saltmeadow grass (or *Spartina patens*) and herbaceous plants. While the difference in elevation between these two parts of the marsh system may seem small and inconsequential, it actually has profound effects on plant life. Tidal salt marsh plants are individually suited to differing levels of salinity and water content in the substrate. Even a slight change in elevation can cause big changes in the marsh ecosystem.

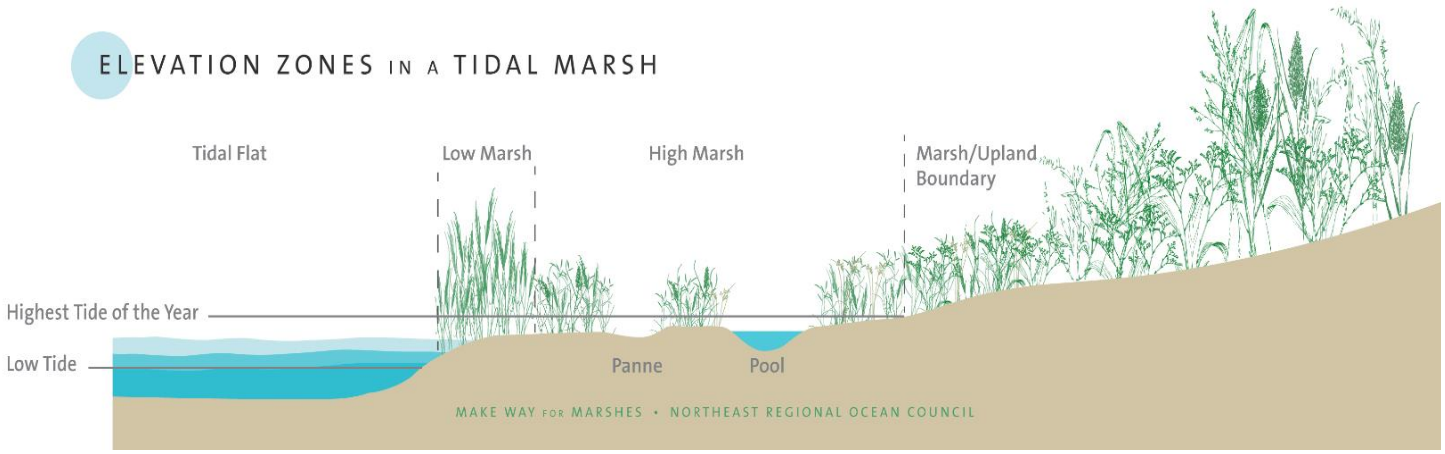


Figure 1: Elevation zones in a tidal salt marsh. A cross-section illustration of tidal salt marsh ecomorphology. Source: Waterview Consulting 2015

When sea levels rise (or land subsides), the frequency and duration of tidal flooding increases over marsh areas. Tidal salt marshes can adapt to this change in two ways: 1) the marsh grasses can grow taller to stay above the tidewaters, which in turn aids in the accumulation of peat at the marsh surface, effectively raising the surface elevation of the marsh; or 2) the entire marsh area can migrate to higher ground(Flournoy & Fischman, 2013; Waterview Consulting, 2015). If the sea rises faster than peat can accumulate at the marsh surface or the system can migrate, the increased flooding can cause plant death and the breakdown of peat, resulting in the loss of marsh area (Flournoy & Fischman, 2013; Waterview Consulting, 2015). This loss due to increased flooding associated with sea level rise has already been documented in some places (Flournoy and Fischman 2013).

When tidal flooding increases over the marsh area, this tidal influence reaches further uphill onto formerly dry land. This causes changes in soil salinity and water content, enabling marsh vegetation to grow and persist at this higher elevation (Waterview Consulting 2015). The lowest areas of saltmarsh cordgrass in the intertidal marsh, now more frequently or permanently inundated, may die off completely, leaving behind a tidal flat. The boundary between low and high marsh areas will shift as well, causing cordgrass to replace some low-lying areas of saltmeadow grass. Further upland, this cascade of tidal habitat areas continues; as flooding increases at higher elevations, tidal marsh vegetation can creep further uphill, replacing upland plants and shrubs. This ecological phenomenon is called marsh migration. This landward movement can only happen where rocky cliffs, roadways, seawalls, parking lots, and other hard structures do not block the substrate available for the establishment of marsh vegetation (Lopez 2015; Flournoy and Fischman 2013). Areas where these hard structures are in place close to shore trap salt marsh habitats between rising sea levels and human development, causing a loss of transitional habitat between land and sea (Lopez 2015). This phenomenon is called coastal squeeze.

Due to their high value for people and nature, many of our coastal marshes are already protected by public or private conservation. Unfortunately, land immediately surrounding the marsh is often unprotected, or already developed, leaving nowhere for the marsh to migrate as sea levels rise. By prioritizing land conservation based on each site's migration space – land that could convert and support coastal habitats into the future as seas continue to rise – we can provide a stage on which future habitats can adapt and thrive (Anderson and Barnett, 2017). Experts in natural resource management believe an important strategy for the preservation of tidal salt marsh habitat is to make way for the marshes to move into present-day upland areas in the future (Waterview Consulting, 2015). This will require the identification of parcels most likely to support marsh migration in the next several decades and the identification of marsh areas most likely to migrate and sustain their ecological value so resource managers can determine appropriate policies and practices to implement in support this migration (Waterview Consulting, 2015). This proposed model will allow land planners to examine the relative resilience of parcels within the planning area, as well as identify and prioritize for conservation the parcels that are most likely to become host to, or continue to host, tidal salt marshes into the future.

Dataset description

This dataset was developed for the state of Massachusetts, however, a number of the data sources used in this model are regional in relevance and may be applied in other states using commensurate data sources for state-specific metrics. Several composite datasets were used to derive metrics for the estimation of local and regional resiliency, marsh migration potential, and development stressors. The sub-components of these metrics are described in detail below, and further technical documentation is provided in the references for this chapter. Social and environmental metrics are measured by a set of characteristics defined by the Massachusetts Conservation Land Tax Credit Program selection criteria (Appendix 1). Descriptions of all datasets and links to data sources and descriptions can be found in Appendix 2.

The Nature Conservancy's Resilient Terrestrial Landscapes data approach is based on observations that species diversity is highly correlated with geophysical diversity in the Northeast and the Mid-Atlantic United States (Anderson et al., 2012 citing Anderson and Ferree, 2010), that species take advantage of the micro-climates available in complex landscapes, and that species can move to adjust to climatic changes if the area is permeable. Therefore, the characteristics of landscape complexity (landform variety, elevation range, and moisture gradients) and landscape permeability (local connectedness and regional flow patterns) are characterized by the data. Data is at a 30-meter resolution; all metrics are analyzed in 100-acre circles around each 30-m cell on the landscape. Landscape complexity and permeability metrics are combined to yield a terrestrial resilience score for each cell. This terrestrial resilience score is used in an estimation of local resiliency in the conservation prioritization model (see pg. 29). In the combined index for landscape complexity, landform variety is weighted twice as much as the other two factors, due to the importance of this feature in creating well defined microclimates. Landscape permeability is defined by two separate analytical models in this study: local connectedness, which examines resistance to ecological flow patterns in all directions from each cell's local neighborhood and regional flow patterns, which is measured by broad east-west and north-south flow patterns across the entire region that determine how flow patterns may become slowed, redirected, or channeled into concentration areas due to spatial arrangement of cities, farms, roads, and natural land. However, regional flow patterns were not given consideration in the estimation of site resilience. This layer was included separately in the estimation of regional resiliency in the conservation prioritization model (see pg. 33). See Anderson et al., 2010, for a full technical review of terrestrial resilience and regional flow patterns assessment methodology.

Scientists from The Nature Conservancy also evaluated coastal sites in the northeast and mid-Atlantic for their capacity to sustain biodiversity and natural services under increasing inundation from sea level rise. Each site received a relative resilience score based on the likelihood that its coastal habitats can and will migrate to adjacent lowlands under six feet of sea level rise (also analyzed at a 30-meter grid resolution). This score was also used as an estimation of local resiliency in the conservation prioritization model (see pg. 29). For each site, the amount of migration space available under six feet of level rise was examined and the amount of buffer area surrounding the tidal complex was identified. These areas were used to measure marsh migration metrics in the model (see pg. 33). Sites vary widely in the amount and suitability of migration space they provide. This is determined by the physical structure of the site and the intactness of processes that facilitate migration. A marsh hemmed in by rocky cliffs will eventually convert to open water, whereas a marsh bordered by low lying floodplain with ample migration space and a sufficient sediment supply will have the option of moving inland (Anderson and Barnett, 2017). As existing tidal marshes are encroached by rising sea levels, the amount of available high-quality migration space becomes an indicator of a site's potential to support estuarine habitats in the future. For tidal complexes, the physical factors assessed included the size and tidal zone diversity of the migration space, the size and shoreline intricacy of the existing tidal complex, and the amount of shared edge between the tidal complex and its migration space. Condition factors included the amount of hardened shoreline, as well as the magnitude of nitrogen inputs, and the quantity of sediment and freshwater inputs. For the buffer area, the size and variety of compatible landforms and soils, the connectedness of its wetlands, and the amount of natural cover were all assessed. A score was calculated for each site based 80% on the tidal complex factors and 20% on the buffer factors, with equal weight given to physical and condition characteristics. For a full technical review of coastal site resilience scoring methodology, see Anderson and Barnett, 2017.

The North Atlantic Landscape Conservation Cooperative (NALCC) and the Northeast Association of Fish and Wildlife Agencies (NEAFWA) coordinated a team of partners from 13 states, the U.S. Fish and Wildlife Service, nongovernmental organizations, and universities, who worked for more than a year to develop a regional conservation design that provides a foundation for unified conservation action from Maine to Virginia. “Nature’s Network Conservation Design” depicts an interconnected network of lands and waters that, if protected, will support a diversity of fish, wildlife, and natural resources that the people of the Northeast and Mid-Atlantic region depend upon. The Conservation Design represents a combination of three Nature’s Network products: 1) the terrestrial core-connector network, 2) aquatic core areas, and 3) core habitat for imperiled species. These core areas were used to measure regional resiliency metrics in the conservation prioritization model (see pg. 33). The terrestrial core-connector network is made up of two components: 1) terrestrial and wetland core areas, and 2) connectors. Terrestrial and wetland core areas are intact, well-connected places that have the potential to support wildlife and plants that occur in terrestrial settings (such as upland forests) or in wetlands (such as marshes). Core areas contain widespread ecosystems (such as hardwood forests), rare natural communities (such as bogs), and important habitat for a variety of fish, wildlife, and plants. Core areas are linked together by a network of connectors. If protected, the connectors will foster the movement of animals and plants between core areas and across the landscape into the future. Aquatic core areas are intact, well-connected stream reaches, lakes, and ponds in the Northeast and Mid-Atlantic region that, if protected as part of stream networks and watersheds, will support a broad diversity of aquatic species and the ecosystems on which they depend. They feature intact, resilient examples of every major aquatic ecosystem in the region and also are designed to incorporate habitat for important species such as brook trout, American shad and Atlantic salmon. Core habitat for imperiled species are relatively intact areas that contain habitats likely to support high levels of imperiled terrestrial and aquatic species. This product represents a regional network of habitats critical for sustaining populations of imperiled species, based on over 600 Species of Greatest Conservation Need. Core habitat for imperiled species is intended to complement aquatic core areas and terrestrial and wetland core areas by highlighting ecosystem types where they are closely associated with high numbers of imperiled species. These data products are also provided at a 30-meter resolution; technical documentation for all three data products are available online at the NALCC's Data Basin (NALCC, 2017).

A team of natural resource professionals, led by the Harvard Forest research center, developed four land-use scenarios for the Massachusetts landscape: (1) Recent Trends, (2) Opportunistic Growth, (3) Regional Self-Reliance, and (4) Forests as Infrastructure (see Thompson et al., 2014, Table 2 pg.3). The scenarios represent four plausible alternatives to current trends, built around two drivers of landscape change that are considered highly uncertain and high-impact: natural resource planning & innovation (high or low) and socio-economic connectedness (global or local). The scenarios project started with data that quantified land-use and conservation trends during the period from 1999 to 2005.This information included the amount, intensity, and location of all new development, harvesting, land protection, and farmland expansion in the state. With these patterns as a baseline, the team of natural resource professionals then brainstormed how these patterns might change over the next fifty years. The team developed a set of specific prescriptions for the amount, distribution, and intensity of different land uses that would occur within each scenario. The scientists then used a modified version of landscape-model LANDIS-II to simulate how the landscape would change over the next 50 years under each scenario, together with average increases in temperature and precipitation associated with climate change. The modeled 2060 development scenarios (at a 50-meter resolution) are used to estimate development pressure in this model, except for the Forests as Infrastructure scenario, which was omitted due to data issues. It should be noted these development scenarios project futures that are unrealistic given current land use policies and regulations, and significant change in management practices would be required to realize these projections. They are, however, a good proxy for future development outcomes with which to examine development pressure across sites.

These datasets were chosen for this study because they are recently published comprehensive considerations of future land-use and land-type. The Nature Conservancy (TNC), publisher of both the Resilient Sites for Terrestrial Conservation and Resilient Coastal Sites for Conservation and a contributor to the Natures Network Conservation Design, is a leader in land conservation and a reputable source of information. TNC datasets were produced and reviewed by either internal or external expert partners and represent a thorough review of relevant parameters. These datasets are the only regionally consistent assessment of land resilience and marsh migration potential. State or location-specific estimates of tidal salt marsh migration, gain, and loss require the use of complex models by technical experts; this publicly available dataset provides enough detail for conservation planning purposes. The Natures Network Conservation Design was also a collaborative process involving the NALCC, U.S. Fish and Wildlife Service, members of state fish and wildlife departments, academic partners, and other conservation organizations. The Conservation Design data layers represent a complex of land areas that project partners agree are high-priority for protection. All land planners should be considering this data when determining where to invest in conservation.

Despite the relative newness of these data sources, there are examples of their use in the literature. For example, the North Quabbin Regional Landscape Partnership used the TNC Terrestrial Resilience data to inform their strategic conservation planning process (OSI and NALCC, 2016). The Atlantic Coast Joint Venture used information from Nature's Network Conservation Design as part of a pilot project to identify priority areas for three bird species that depend on saltmarsh habitat by looking for parcels that may be eligible for funding through Natural Resources Conservation Service (NRCS) programs to support conservation on working lands. The U.S. Army Corps of Engineers developed a comprehensive and integrated restoration plan with a roadmap for habitat restoration and conservation in the 64,000 square-mile Chesapeake Bay watershed using the Conservation Design. The imperiled species layer offered spatially explicit information about the location of the most important habitat for fish and wildlife species, and the connectivity analysis helped them understand how to ensure that habitat could be fully utilized as part of functioning network. Other testimonials to the use of the Conservation Design can be found on the NALCC's Natures Network webpage. What is unique about this study compared to these other examples is the integration of all these datasets into one model for conservation planning purposes.

Integrated Valuation of Socio-Environmental and Resiliency Metrics

This study uses the Massachusetts Conservation Land Tax Credit program applicant sites as a sample of parcels for analysis and prioritization. This first-come-first-served program currently uses a 3-tier assessment process to determine if applicant sites are of acceptable quality for state investment through a tax credit. This assessment system does not include any climate change considerations; however, it still results in the majority of applicant sites being accepted into the program. This has resulted in more credits being committed each year than the $2 million program cap; the state will promise credits from the next fiscal cycle, resulting in a long backlog of landowners waiting to receive a tax credit and finalize the conservation donation. Making “climate-smart” investments requires not only the identification of high conservation value parcels that are likely to remain resilient into the future, but also the prioritization of these parcels for investment within given budgetary constraints. The use of this model by the program would require a switch from the first-come-first-served method currently used for the dispersion of funds to a method that includes an application period and bulk review of applicant sites. Use of the following method will allow land planners to see which sites have the highest conservation value; sites that have high social and environmental value today and are projected to remain resilient to changing climactic conditions and out of the way of development pressure. Those sites with the highest conservation value can be invested in first, working down the list until the budget for that fiscal year has been exhausted.

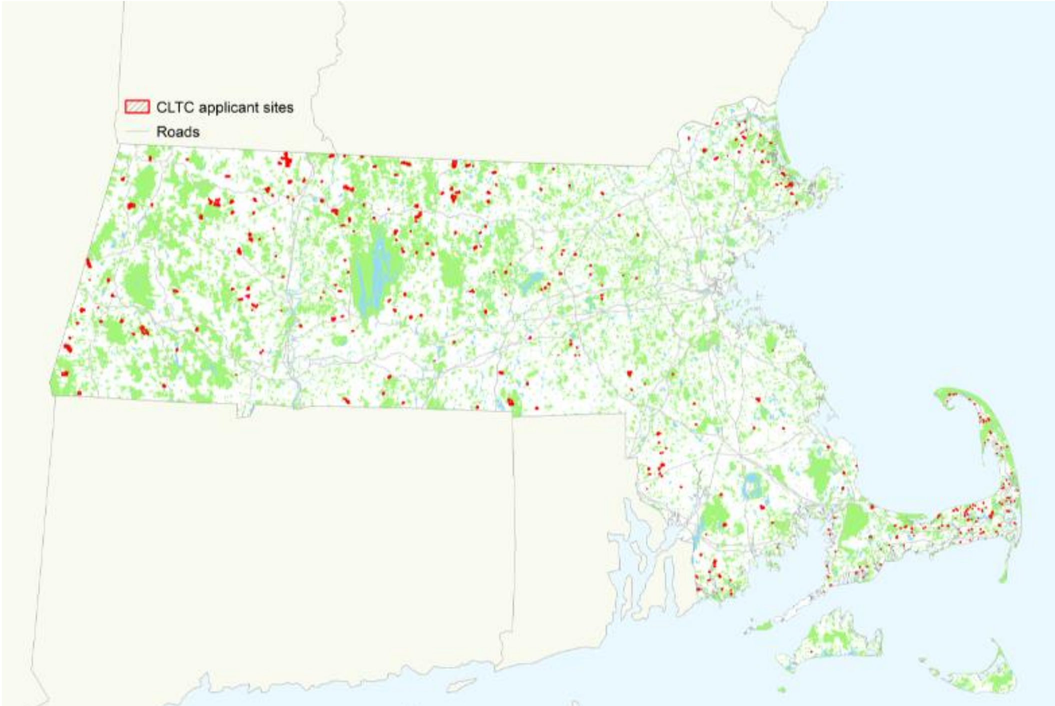
The key spatial question being addressed by this study is – where are the sites that have high value today and are expected to remain high value into the future? This value is measured by 6 bins of metrics: stressors, local resiliency, regional resiliency, environmental, social, and marsh migration potential. A "successful" outcome – one that would validate the proposed model – is a statistically significant ($p >= 0.05$) difference in the number of current tidal wetlands or projected marsh migration space conserved between current practices and the proposed model. The Marsh Model outcome will be tested against the No Future Considerations Model (Table 1, pg. 34), which is representative of the metrics used for the MA CLTC program analysis.

Methods:

1) Data Collection

Most of the data used in this study is open access (links provided in Appendix 2). The CLTC applicant sites were readily available following a phone call to the program office. I would recommend repeating this study with a different set of sites to compare outcomes and test the success of the model.

Figure 2: Massachusetts Conservation Land Tax Credit Program applicant sites



Source: author

2) Data Preparation

a) Regional datasets (Resiliency metrics) clipped to the MA outline and projected to the MA State Plane FIPs Mainland (meters).

b) Harvard Forest land cover projections for 2060 raster layers had to be reclassified and named for analysis as well as mapping. An excel file is included in the download package with the codes for land-cover type associated with each raster cell value.

c) Create a quarter mile buffer of CLTC sites for analysis of adjacent wetland and open space acres

d) Create 200 ft buffer of MA DEP Hydro and Scenic Byways layers for analysis

e) High and medium aquifer areas are combined into one dataset. Use "Select by Attribute" in the Aquifers layer to select TYPE="HIGH." Export Data to create a new shapefile called "AquiferHigh." Repeat with TYPE="MEDIUM."

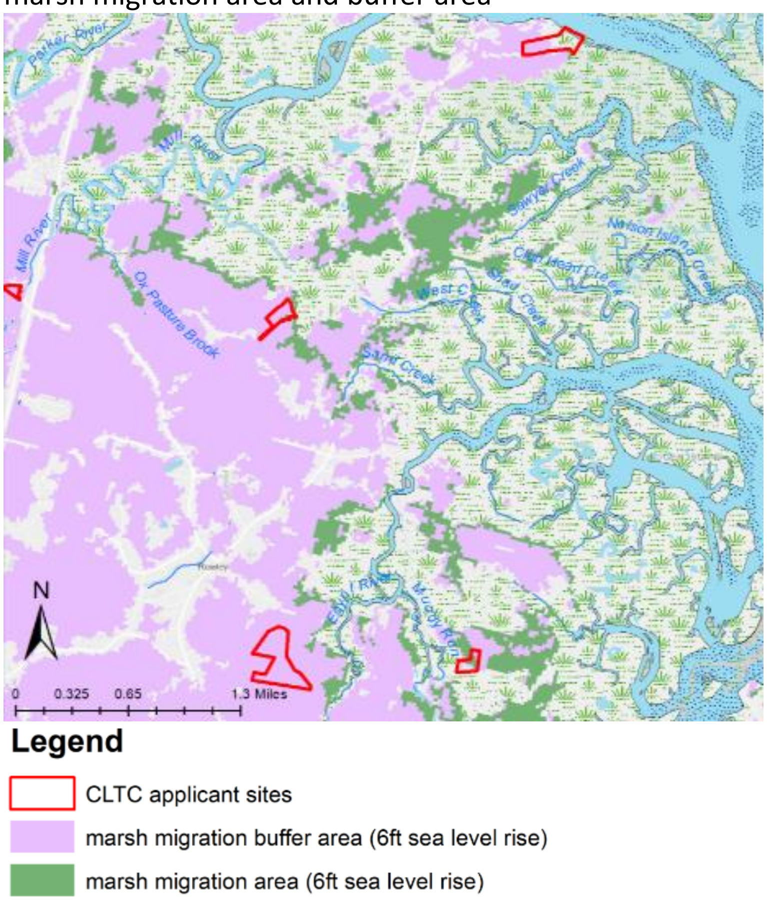
f) Prime Forest Land includes “Non-Forested Land” as a mapped category and needs to be removed. Use “Select by Attribute” to remove “PRIME=NON-FOREST” from the Selection of the entire Prime Forest Lands layer. Export the new layer for use in analysis.

3) Data Analysis

a) All <u>Regional Resiliency</u>, <u>Marsh Migration</u>, <u>Social</u> and <u>Environmental</u> metrics (vector datasets) were measured using the Intersect tool. Areas where these metric areas overlapped with CLTC applicant sites* were extracted.

*The quarter mile buffer of CLTC sites layer was used to measure the number of acres of wetlands and permanently protected open space contained within each site + buffer area.

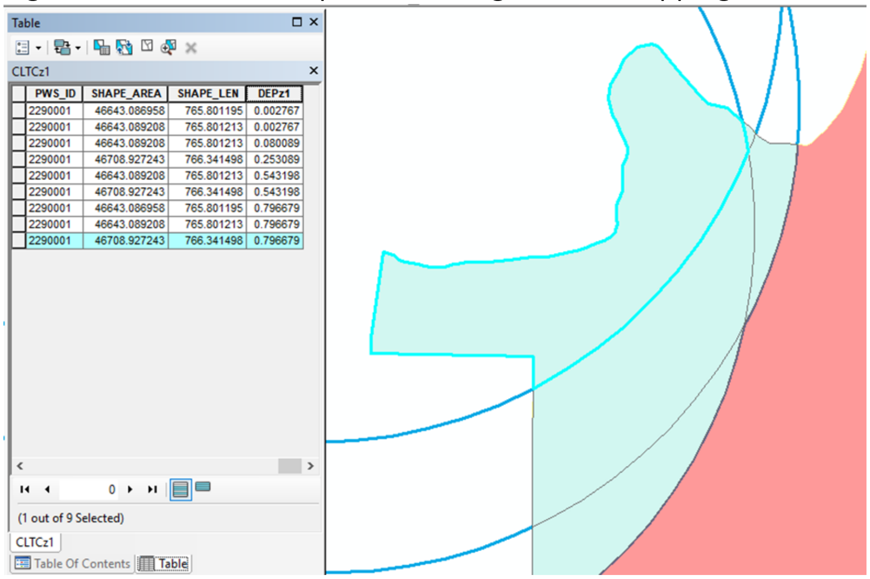
Figure 3: Intersect of CLTC sites and 6ft sea level rise marsh migration area and buffer area



Source: author

Some sites have multiple areas of intersection, or even multiple overlapping areas of intersection. For example, Wellhead Protection Area Zone 1 resulted in 6 areas of intersection on 1 CLTC site:

Figure 4: Methods example for dealing with overlapping metric areas

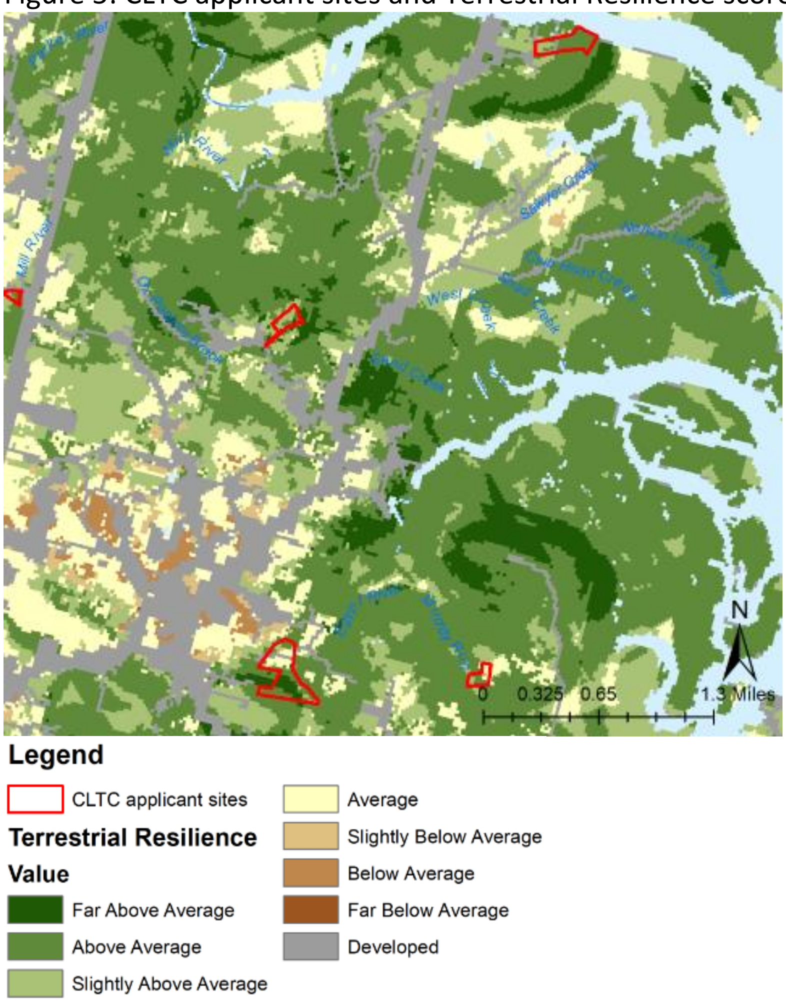


Source: author

In this case, the 5 independent areas of intersection are summed, omitting a 6th area of overlapping intersection. All instances for other metrics were dealt with in the same manner. Total land area relevant to a metric was counted, but no land area was double counted. This was accomplished using the “Dissolve” (Data Management) tool, dissolving the metric layer based on the SiteID. Once the dissolved intersection was created for each site, a field was added to the attribute table, where “Calculate Geometry” was used to find the total dissolved intersection area in acres for each site. These attribute tables were exported and saved as Excel workbooks to be joined back to the CLTC sites layer by SiteID. All metrics are measured and reported as number of acres of the metric that cover each site.

b) <u>Local Resiliency</u> was measured by the resilience scores assigned by The Nature Conservancy's Resilient and Connected Terrestrial Landscapes and Resilient Coastal Landscapes datasets. The mean resilience score for each site was extracted using "Zonal Statistics by Table"; SiteID was used to designate Zones. This process was repeated for both resiliency score layers and joined back to the CLTC sites layer by SiteID.

Figure 5: CLTC applicant sites and Terrestrial Resilience score



Source: author

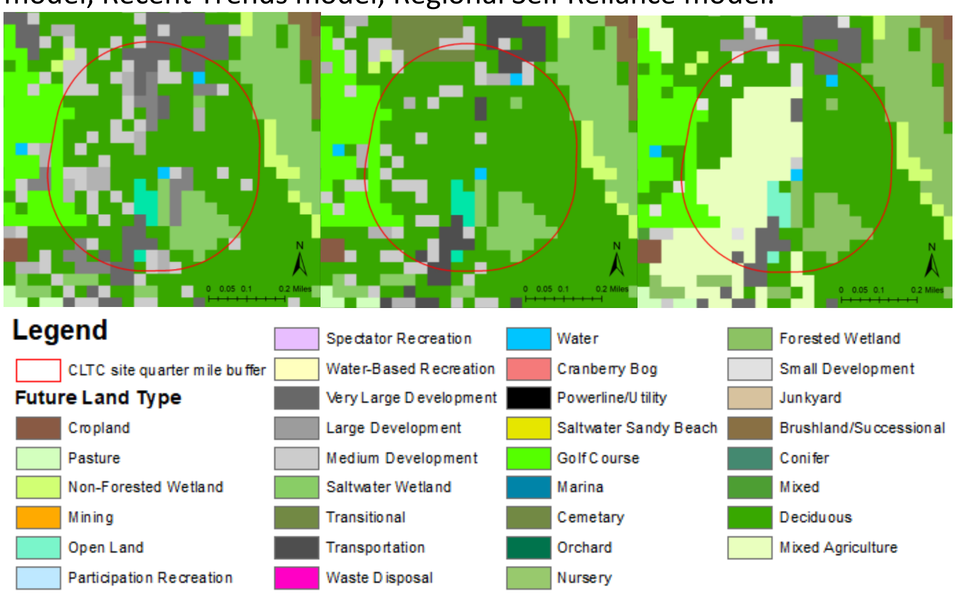
These scores ranged from -3 (Far Below Average Resilience) to 4(Far Above Average Resilience). Some sites have both Coastal and Terrestrial resilience scores. In these cases, the average of the two scores was taken and assigned to the site. To avoid a “0” value for the Average Resilience Score, all values >=0 were increased by 1. The metric “Site Resilience Acres” (to be applied in a later step) is calculated by taking the product of the Average Resilience Score and the CLTC site total acres.

Site size is an important factor in site resilience; larger land areas are more beneficial, however, to balance both future and current benefits the long-term resilience of the land area must also be considered (Hodgson et al., 2009). The above formula counts sites with an “Average” resilience score as the total acres contained in that site. Sites with Above Average resilience receive a multiplier of 2 to 5 to the site acres. Conversely, sites with Below Average resilience scores receive a multiplier of -1 to -3 to the site acres

c) <u>Stressors</u> were measured using the Harvard Forest 2060 Development Scenarios. Four scenarios were developed in the study, but due to issues with the data for one scenario (Forests as Infrastructure) only three were used for analysis.

Using the CLTC quarter mile buffer layer, “Tabulate Area” was used for each development scenario raster. There are 31 values on the layers that correspond to land cover types. To find the percent of this area that was projected to be developed under each scenario, I summed the areas for all values (assumed unitless), then summed the area for development values (Small, Medium, Large, and Very Large Development; LUcodes 38, 12, 11, and 10, respectively) and found the percent of the area projected to be developed (sum of development LUcode areas/sum of all LUcode areas x 100).

Figure 6: Harvard Forest 2060 development scenarios with CLTC site quarter mile buffer area. Pictured from left to right: Opportunistic Growth model, Recent Trends model, Regional Self Reliance model.



Source: author

The percent of developed area for each scenario was averaged to find the mean estimate for percent of development predicted to be within the site and quarter mile buffer area in the future. This average development estimate was used to assign a Development Pressure Score: 0-20%

developed = “1,” 21-40% developed = “2,” 41-60% developed = “3,” 61-80% developed = “4,” 81-100% developed = “5.”

The average percent developed metric was also used to calculate estimated 2060 Developed Area on each CLTC site + quarter mile buffer by applying the average percentage to the site’s total acreage.

Development Stress (“{Stressors}”) is calculated by the product of 2060 Developed Area and Development Pressure Score.

4) The key spatial question being addressed by this study – where are the sites that have high value today and are expected to remain high value into the future – is answered by the sorting of applicant sites by calculated conservation value. This value is measured by the 6 bins of metrics described above (stressors, local resiliency, regional resiliency, environmental, social, and marsh migration potential). These metrics are applied to the calculation of a conservation value for each site using the following general equation:

0.XX{Environment}+0.XX{Social}+0.XX{Resiliency}+0.XX{Marsh Migration} - 0.XX{Stressors}

{Environment} = quarter mi. buffer wetland acres + Watershed Protection Act acres (200ft buffer of MA DEP Hydro) + Areas of Critical Environmental Concern acres + BioMap2 Critical Natural Landscapes acres + BioMap2 Core acres + NHESP Estimated Habitats of Rare Wildlife acres + quarter mi. buffer permanently protected open space acres

{Social}= EJ Area acres + MA Historical Commission Area acres + Scenic Byways (200ft buffer) Area acres + Scenic Inventory acres + Prime Forest acres + Drinking Water Area acres + Prime Agriculture acres

{Resiliency} is calculated as a function of {local resiliency} and {regional resiliency}. Formula used for this study was 0.7{local resiliency} + 0.3{regional resiliency}. Users are encouraged to alter these weights according to their own priorities.

{local resiliency} = Site Resilience acres (pg. 30)

{regional resiliency} = Terrestrial Core-Connector Network acres +Aquatic Lentic Core acres + Core Habitat for Imperiled Species acres + Regional Flow acres

{Marsh Migration} = 6ft SLR Marsh Migration Area acres+6ft SLR Marsh Migration Buffer Area acres

{Stressors} = Development Stress (pg. 30-32)

5) The effectiveness of the model was tested by running the model for different management priorities – Balanced across all metrics, weighted heavily for Marsh Migration metrics, weighted heavily for Social metrics,

and with No Future Considerations – and analyzing resultant habitat metrics for the top 10% of sites (n=41) for each model run.

Table 1: Model runs results comparison

Model	Conservation Value Equation	Total Acres Conserved	Tidal Wetland Acres Conserved	6ft SLR Marsh Migration Area Acres Conserved	6ft SLR Marsh Migration Buffer Area Acres Conserved
Balanced Model	-0.1 Stressors, 0.2 Marsh Migration, 0.2 Resiliency, 0.3 Social, 0.2 Environmental	7160.828356	176.5914511	21.35397719	698.8647683
Marsh Model	-0.1 Stressors, 0.5 Marsh Migration, 0.2 Resiliency, 0.1 Environment, 0.1 Social	6855.339129	184.5619405	21.36089165	838.2391453
Social Model	-0.1 Stressors, 0.1 Marsh Migration, 0.1 Resilience, 0.2 Environment, 0.5 Social	7408.142181	148.0468297	13.24359471	543.0963387
No Future Considerations Model	0.5 Environment, 0.5 Social	6599.765226	150.7957402	16.71454741	579.0386059

Despite an insignificant difference in current tidal wetland acres and projected marsh migration area conserved across the different models, the approach does appear to work as designed. Just 8.82% of the 408 sample sites (n=36) actually contain tidal salt marshes, so the sample size used to test this model may not be large enough to detect differences in outcomes. The Marsh model does select the highest number of tidal marsh and marsh migration buffer area acres for conservation of all model runs. In the Social model, 2 of the top

10% sites (n=41) contain tidal salt marsh; in the Marsh model, 4 of the top 10% sites contain tidal salt marsh. This is a 50% increase in the number of sites with tidal salt marsh that appear in the top 10% of the land conservation prioritization result. Repeating this study with a different set of sites, more of them with tidal salt marsh acreage, would give better insight as to the effectiveness of this model.

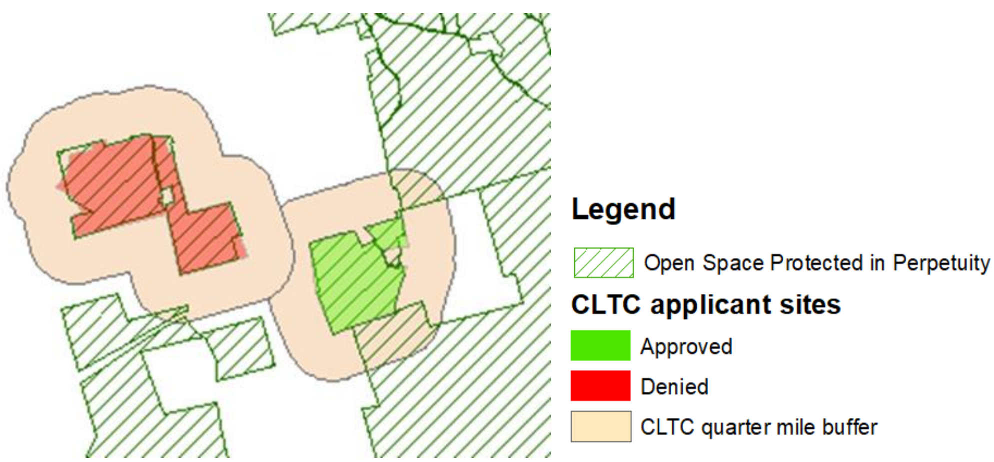
Data considerations for future studies

Data extraction and management could be greatly improved through the use of a geodatabase and the Model Builder tool. Data extraction was performed manually due to lack of experience with the ArcGIS software at the start of the project. However, each data preparation and analysis step could be entered and saved as a model in ArcMap Model Builder to avoid having to execute the model manually. A geodatabase is the preferred file type for the management of large, complex datasets, and is compatible with Microsoft Access for site analysis and prioritization.

Accounting for site resilience using the common unit of acres proved difficult. This study combines site area and resilience score to yield a positive or negative value (high or low resilience, respectively) to contribute to the overall conservation value of the site. When calculated in this manner, large land areas with a negative resilience score take a big hit to the calculated conservation value, though the large land area of the site should be accounted for positively. It may be useful to explore how to control for site size and site resilience separately in the model.

The MassGIS permanently protected open space layer analysis may have some accuracy issues. The layer is frequently updated and now likely contains areas that have been protected by CLTC program agreements in the dataset that have already been acquired by the State. So, many of these sites will reflect a higher percentage of permanently protected open space in a quarter mile radius of the site than was the case at the time the original analysis was conducted. Some CLTC sites that were denied for conservation and a tax credit do contain open space protected in perpetuity. This could be because the landowners found another venue to donate the land. Permanently Protected Open Space layer was left intact for analysis.

Figure 7: Data inaccuracy demonstration: permanently protected open space



Source: author

An additional component of the model that should be developed in the future is an estimation of applicant parcel land value to conduct budget scenarios analysis. The Messer et al. (2013) study used an existing hedonic analysis from their study area originally formulated to estimate agricultural easement values (pp.4-5, Table 1). A similar guide exists from MA Department of Revenue for value per land type/use for an agricultural conservation tax program that could be used as a rough estimate for land value in this model[1].

[1] http://www.mass.gov/dor/docs/dls/bla/farmland/fy15/chapterlandvaluesfy15.pdf (Accessed 11 May 2018)

Chapter 3

The value of tidal salt marshes

Valuation of Tidal Salt Marsh Ecosystem Services in Academic Studies

Tidal salt marshes provide important ecosystem services to human society, and thus provide economic value. Ecosystem services are the benefits that people obtain from ecosystems (Flournoy & Fischman, 2013; Millennium Ecosystem Assessment, 2005). These services include provisioning services such as raw materials, food, and water purification; regulating services such as regulation of storms and floods, drought, land degradation, and disease; supporting services such as fish and wildlife habitat, soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious, and other nonmaterial benefits (Barbier, 2012; García-Llorente et al., 2011; Millennium Ecosystem Assessment, 2005). The concept of total economic value of ecosystem services has been widely used as a framework for quantifying the contribution of the ecosystem to human well-being. This quantification allows for wetlands to be considered as economically productive systems when compared to other possible uses of land, resources, and funds (Flournoy & Fischman, 2013; McKinney et al., 2010). It provides an analytical basis for considering trade-offs and making management decisions that better support overall public welfare.

A wide range of methods that move beyond the use of direct market prices are available and are increasingly used for valuing wetlands. These include approaches that elicit valuations directly (such as through contingent valuation methods) as well as those that use indirect methods to infer valuation from actions taken to purchase provisioning-related services - for example, through purchase of salt-hay for cattle feed (García-Llorente et al., 2011; Millennium Ecosystem Assessment, 2005). Most studies conduct or assess a valuation study for 1-8 ecosystem services (Table 1), however(Liquete et al., 2013) extracted 476 different marine and coastal ecosystem service indicators from a review of 145 papers – suggesting approximately 3 unique indicators of value are evaluated in each study.

Table 2: Ecosystem service valuations in literature reviewed. The 10 services listed are the services most frequently cited and discussed. These 10 services are lumped by service type. An “x” indicates qualitative or theoretical discussion of the service. Numbers are presented for studies that quantified specific values; values without explanation depict willingness to pay derived from contingent valuation studies.

Ecosystem Services	aesthetics	educational and cultural values	recreation and tourism	fish and wildlife values	water supply, storage and conservation	carbon sequestration	erosion control	coastal protection	water quality improvements	food and fiber production
	cultural			supporting		regulating			provisioning	
Source:										
Pendleton et al. (2013)			x	x		x	x	$8,236 per hectare per year in reduced damages (citing Costanza et al., 2008)	x	
Shepard et al. (2011)			x	x	x	x	x	x	x	x
Garcia-Llorente et al. (2011)	$3.97 per year			$4.65 per year						$4.05 per year
Barbier et al. (2011)			$42.72 per person for habitat creation and $1.58 per person for bird protection	$6471 per acre capitalized value for recreational fishing		$30.50 per hectare per year	x	$8,236 per hectare per year in reduced damages (citing Costanza et al., 2008)	$785-$15000 per acre capitalized cost savings over traditional waste treatment	$20.17 per hectare per year net income from livestock grazing
Geden et al. (2011)								just under $5000 per hectare in storm protection value		
Spalding et al. (2014)							x	x		
Luisetti et al. (2014)			x	x		x				

Source: author

The uniqueness of each study makes comparison across studies and specific ecosystem services difficult. There does not appear to be a “standard” value for any ecosystem service provided by coastal wetlands. The studies reviewed exhibited an array of valuation methods, resulting in a range of values for tidal salt marsh ecosystem services. All of the studies contained some qualitative and theoretical discussion of the services examined. A subset of these studies provided quantitative valuations of these services. There is a distinct difference of value across the ecosystem services and valuation methodologies. Willingness-to-pay methods yield lower values for ecosystem services compared to purchase-related or production-related services valuation (Table 1). Purchase and production valuation infers a value for a unit of marsh area given the equivalent cost to purchase or produce that resource. For example, Barbier et al. (2011) found that farmers capitalize more than $20 per hectare of marsh per year by allowing livestock to graze on the marsh and avoiding the cost of feed. Similarly, the cost of rebuilding roadways and other coastal infrastructure after a major coastal storm event is much diminished if the salt marsh ecosystem can dissipate storm energy before it reaches the coast; Costanza et al., (2008) calculated that this regulating service is worth over $8000 per hectare of marsh per year.

It is also clear that coastal protection, fish and wildlife support and water quality improvements are services more highly valued than others (Table 1). Disparate valuation makes it difficult to accurately consider and account for the value of ecosystem services in policy and regulation. Different studies and values may need to be considered depending on the intent of the policy or regulation in design. Decision-makers intending to support coastal protection should consider using storm damage assessments across communities protected and unprotected by marshes to ascertain the value of avoided costs of reconstruction as a proxy for wetland value rather than using willingness-to-pay (WTP) studies to illustrate the value of the community's natural resource. Garcia-Llorente et al. (2011) found that, when ecosystem service benefiters were polled for their willingness-to-pay for ecosystem services, direct use values, such as cultural and provisioning services (Table 1), were associated with a higher WTP than indirect use values such as storm protection. This makes sense, because ecosystem service benefiters may not always be aware of the indirect services provided by tidal salt marshes; cultural and aesthetic values are much more obvious. It may be more appropriate to use WTP studies to value marshes in policies related to recreational or other cultural services. Policies intending to support fish and wildlife services should use a more objective valuation method than WTP; using production-related service valuation may be most appropriate to try to quantify the value of habitat to the production of economically-important fisheries species. This could be done by using the cost of aquaculture production as a proxy for the value of fishery habitat provide by the marsh.

Tidal Salt Marsh Valuation in Policy and Regulation

A review of international, United States federal, and the State of Massachusetts policies and regulations related to tidal salt marshes yielded a wide variety of protections for this ecosystem. A striking observation from this review was finding protection for these services in all three branches of government; Supreme Court cases, Executive Orders, as well as Congressional and state government legislative action. The Federal policies operate through top-down regulation of activity and can be challenging to enforce. State and local protections were instituted by State government but are enforced at the local level. The international treaties are very aspirational in their goals and require international cooperation to implement.

Some policies and regulations were explicit in their definition of wetland ecosystem services (see Table 2) and which ones fell within the protection of their regulatory jurisdiction. Other policies and regulations stated that tidal salt marshes provide ecosystem services which must be protected, but did not explicitly define these services or specify which services were to be protected. None of these policies explicitly value the habitat or provide a structure for payments for ecosystem services. Fish and wildlife habitat was the only service mentioned in all of the policies and regulations that specifically define which ecosystem services are to be protected (Table 2). Coastal protection and food and fiber production each appeared in all but one policy or regulation (Table 2). Education and culture is the service least frequently protected by legislation

(Table 2). With a strong regulatory structure in place for the protection of these services, efforts should be focused next on creating mechanisms for payments for these services. For example, property taxes could be raised and levied against coastal homeowners for the funding of a salt marsh restoration project that will offset storm damages and provide protection for multiple land parcels.

Table 3: Policies and regulations describing ecosystem services provided by tidal salt marshes. The 10 services listed are the services most frequently cited and discussed in the literature. These 10 services are lumped by service type: cultural, supporting, regulating, and provisioning.

Ecosystem Services	aesthetics	educational and cultural values	recreation and tourism	fish and wildlife habitat	water supply, storage, and conservation	carbon sequestration	erosion control	coastal protection	water quality improvements	food and fiber production
	cultural			supporting		regulating			provisioning	
Source:										
Ramsar Convention on Wetlands treaty		x	x	x	x	x	x	x	x	x
33 CFR 320.4	x		x	x	x		x	x	x	x
40 CFR 230	x		x	x			x			x
Principles and Guidelines for Water and Related Land Resources Implementation Studies; Water Resources Development Act	x	x	x	x	x	x	x	x	x	x
131 MGL 40; 310 CMR 10				x	x			x	x	
MA Office for Coastal Zone Management Policy Guide				x			x	x		x

Source: author

Chapter 4

Legal and regulatory protections

International treaties

The Ramsar *Convention on Wetlands of International Importance especially as Waterfowl Habitat* is an international treaty for the conservation and sustainable use of wetlands (History of the Ramsar Convention, 2017). It is the oldest of the modern global intergovernmental environmental agreements, and the only global environmental treaty to deal with one particular ecosystem (Ramsar Wetlands Convention, 2017a). The unique attention this ecosystem has received by this international intergovernmental body is indicative of the high value of wetlands to global society. The treaty was negotiated through the 1960s by countries and non - governmental organizations concerned about the increasing loss and degradation of wetland habitat for migratory waterbirds. It was adopted in the Iranian city of Ramsar in 1971 and was entered into force in 1975. There are currently 169 Contracting Parties to the treaty, a number greatly increased from the 18 original Contracting Parties in 1971. The Convention's Mission is "the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world" (Millennium Ecosystem Assessment, 2005; Ramsar Wetlands Convention, 2017b). Under the "three pillars" of the Convention, the Contracting Parties commit to: a) work towards the wise use of their wetlands; b) designate suitable wetlands for the list of Wetlands of International Importance; and c) cooperate internationally on transboundary wetlands, shared wetland systems and shared species (Ramsar Wetlands Convention, 2017b). The United States Departments of State, Fish and Wildlife Service, and Bureau of Oceans, along with the International Environmental and Scientific Affairs are responsible for overseeing the protection of the 38 Ramar Site(s) covering 1,860,879 ha of wetlands in the United States.

The Bonn *Convention on Migratory Species*, adopted in 1979 and entered into force in 1983, aims to build and strengthen global conservation efforts for migratory species in the air, on land, and in the seas ("Convention on Migratory Species," 2017). This international and intergovernmental treaty supported by the U.N. Environmental Programme has 116 Contracting Parties working together to protect migratory species and their habitats throughout their entire ranges and across governing borders (UNEP/CMS Secretariat, 2017). This is the only international treaty specializing in migratory species, their habitats, and migration routes. The Convention Text defines habitat as any area in the range of a migratory species which contains suitable living conditions for that species and states that, where appropriate and feasible, each Agreement entered into under this treaty should provide for (among other things) "conservation and, where required and feasible, restoration of the habitats of importance …the protection of such habitats from disturbance…[and] maintenance of a network of suitable habitat appropriately disposed in relation to the migration routes." This treaty is directly related to the value of marshes due to the importance of tidal salt marsh habitat for many migratory bird species, indicating this is one type of habitat that the United States has agreed it should be protecting. There are not currently any existing agreements, special species initiatives or memoranda of understanding involving the United States for the protection of marsh-dependent migratory species, but the framework for this protection exists under The Bonn Convention and could be utilized in the future.

U.S. Federal policies and regulations

The Clean Water Act (CWA), enacted in 1948 and significantly expanded in 1972, is designed to “restore and maintain the chemical, physical, and biological integrity of the Nation’s waters” by placing stringent regulations on activities which may impact these important resources. Sections 303 (Water Quality Standards and Implementation Plans), 319 (Nonpoint Source Management Programs), and 402 (National Pollutant Discharge Elimination System) aid in the valuation and protection of wetlands, but section 404 (Dredge or Fill Permit Program) of the CWA really provides the principal protection for wetlands in the United States. Section 404 states that no one can discharge dredged or fill materials into a wetland without first obtaining a permit from the U.S. Army Corps of Engineers (ACOE). On the surface, section 404 may appear to regulate simply the filling of wetlands and not other potentially damaging activities such as draining or dredging – however, the ACOE has stretched its jurisdiction of section 404 to include regulation of any redeposit of dredged material (Salzman & Thompson, 2013). This means any excavation activities which may result in sediments falling back into the marsh surface also require section 404 permits from the ACOE. Significant value of marsh habitat is indicated by this command and control structure that greatly diminishes the ability of landowners to fill, dredge, or develop within important and sensitive wetland habitat.

For every authorized (permitted) discharge into wetlands, the adverse impacts to the ecosystem must be avoided and minimized to the extent practicable (CWA 404(b)); for unavoidable impacts, compensatory mitigation is required to replace the loss of wetland and aquatic resource functions within the watershed area (Flournoy & Fischman, 2013; US EPA, 2017a). Compensatory mitigation is a critical tool in helping the federal government meet the longstanding national goal of "no net loss" of wetland acreage and function. In 2008, the Environmental Protection Agency and the Army Corps of Engineers (ACOE) jointly promulgated regulations revising and clarifying compensatory mitigation requirements under the CWA section 404 program. These regulations define compensatory mitigation as restoration, establishment, enhancement, and/or preservation of wetlands for the purposes of offsetting unavoidable adverse impacts from federally permitted projects (US EPA, 2017b). Under these regulations, there are three mechanisms to provide compensatory mitigation: through mitigation banks, in-lieu fee programs, and permittee-responsible mitigation (US EPA, 2017b).

Mitigation banks are a site, or suite of sites, where wetland resources are restored, established, enhanced, and/or preserved for the purpose of offsetting impacts to wetlands authorized by the ACOE. Generally, a mitigation bank sells mitigation “credits” to permittees whose obligation is to provide mitigation is then transferred to the mitigation bank. The in-lieu fee program is similar to the mitigation bank in that it sells mitigation credits to permittees, whose responsibility to provide mitigation is then transferred to the in-lieu fee sponsor. However, these fees go to governmental or non-profit natural resource programs involving the restoration, establishment, enhancement, and/or preservation of aquatic resources rather than to a mitigation bank. The third option for offsetting unavoidable impacts to wetlands is through permittee-responsible mitigation, where and aquatic resource restoration, establishment, enhancement and/or preservation is undertaken by the permittee (or authorized agent or contractor). This section 404(b) of the CWA is most direct in its valuation of tidal salt marsh habitat by asserting the requirement of mitigation for wetland habitat degradation or loss through direct habitat interventions.

The United States Supreme Court confirmed wetlands fall under the jurisdiction of CWA protections – and therefore, ACOE and EPA regulations – by the opinion and decision delivered in *Rapanos v. US*, 547 US 715 (2006). Justice Kennedy concluded that, for a wetland to be considered within the jurisdiction of CWA section 404, wetlands that are not adjacent to a traditionally navigable water must have a "significant nexus" with one. This requirement is satisfied if the wetland has a significant effect on the water quality of navigable waters. “Wetlands possess the requisite nexus, and thus come within the statutory phrase ‘navigable waters,’ if the wetlands, either alone or in combination with similarly situated lands in the region, significantly affect the chemical, physical, and biological integrity of other covered waters more readily understood as ‘navigable’” (*Rapanos v. US*, 2006). This decision by the Supreme Court is the most significant case ruled in favor of protecting wetland value through regulation. Later Supreme Court cases regarding the reach and jurisdiction of the CWA have resulted in rulings stating compliance orders issued and decisions rendered regarding wetland regulation by the Environmental Protection Agency and Army Corps of Engineers are subject to judicial review under the Administrative Procedures Act, *Sackett v. EPA*, 566 U. S. ____ (2012) and *ACOE v. Hawkes*, 578 U.S. ____ (2016). These decisions detract from the ability for EPA and ACOE to act autonomously in wetland protection enforcement by requiring public buy-in for federal wetland protection action, given the nature of the Administrative Procedures Act. This may be interpreted as a judicial roll-back on Common Law interpretation of the value of wetlands to society.

While the Clean Water Act is most direct in its protection and valuation of tidal salt marsh habitat, there are many other examples of Federal policies and regulations aimed at the protection and restoration of this habitat as well. The Endangered Species Act, while not written with the express purpose of wetland protection, is equally effective for this purpose. The Endangered Species Act is intended to provide a program for the conservation of endangered and threatened species, and requires that all Federal departments and agencies shall seek to conserve endangered and threatened species by acting to conserve the ecosystems upon which endangered and threatened species may depend upon to survive (Lopez, 2015; Salzman & Thompson, 2013). President Obama issued Executive Order 13563 in January of 2011 and a Presidential Memo in February of 2012 to direct the Fish and Wildlife Service to consider the costs and benefits of designating critical habitats of endangered species while developing designations of such habitats needed to ensure species survival and recovery. Both the Presidential Executive Order and Memo urge that actions taken for habitat protection maximize potential net benefits and are imposed in a manner least burdensome to society.

Tidal salt marshes in the northeastern United States support a suite of avian salt marsh habitat "specialists," such as the Saltmarsh Sparrow, which use this ecosystem exclusively for breeding, nesting, and foraging purposes (Correll et al., 2017). These species are extremely threatened by coastal squeeze (see pg. 15). Studies have shown that the Saltmarsh Sparrow in particular is at risk of being squeezed out, in fact, the species may be extinct within the next 50 years (Correll et al., 2017). This species builds nests on the ground just above the mean high water mark; these nests are often flooded and destroyed by extreme high tides and storm events. While this species is not currently listed as "endangered" under the Endangered Species Act, the Fish and Wildlife Service is currently undertaking a status review to determine whether the species should be listed. Should this species end up on the ESA list, passive assisted migration techniques, such as those employed at Sapowet Marsh in Tiverton, RI (Kuffner, 2016), can be employed to encourage the preservation of critical tidal salt marsh habitat for this and other salt marsh habitat specialists. At Sapowet Point, a public parking area was relocated and stretch of gravel road was removed from the landward border of the marsh area and a nearby agricultural field was replanted with native warm season grasses, which will eventually give away to salt marsh species as the system migrates. Protecting existing habitat migration corridors and reserves will help species as they retreat landward due to sea level rise (Lopez, 2015). Natural resource managers can utilize passive assisted migration techniques for the protection of salt marsh species that are threatened by rising seas by encouraging and assisting in tidal salt marsh conservation and migration projects.

Other federal policies that require the protection or consideration of marshes and ecosystem services include: Natural Resources Damage Assessments, required under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), which aim to determine and remediate or mitigate the loss natural resources or services associated with project impacts compared to baseline conditions; the National Environmental Policy Act, which requires all federal agencies to analyze the impacts of their actions on the environment and encourages public involvement in the decision-making process; the Coastal Zone Management Act, which requires states to develop coastal zone management plans in order to accept NOAA coastal zone management funds; the Swampbuster provision of the 1985 Food Security Act which states that farmers who fill in wetland to create cropland will be ineligible to receive federal farm program benefits; and the revised (2013) Principles and Guidelines for Water and Related Land Resources Implementation Studies called for in the Water Resources Development Act require consideration of ecosystems services when determining the economic benefits associated with coastal habitat potentially impacted by water resource projects.

While this appears to be a long list of cross-jurisdictional opportunities for federal agencies to oversee the protection of wetland areas, some studies do question the effectiveness of these policies in reaching the goal of no-net loss of wetlands and protection of wetland ecosystem services. Pendleton et al., 2013, provide a thorough overview of the lack of ability for federal statutes and policies to protect carbon sequestration services provided by wetlands. Flournoy and Fischman (2013) provide a review of studies that call into question the effectiveness of the Clean Water Act in the protection of wetlands, specifically due to: lack of ability to enforce the Act across the extensive U.S. wetland system; failure by permittees to undertake promised mitigation requirements; failed efforts at wetland creation or restoration; and the lack of functional value equivalence between the wetlands destroyed and those created or restored as compensation. This same study also makes the important point that section 404 of the CWA seeks to preserve wetlands where they exist today, however, as has already been discussed, wetlands will not stay in place as climate changes and sea levels continue to rise. To provide comprehensive protection for wetland ecosystems now and into the future, all the policies and regulations discussed in this section will need to be leveraged.

State and local policies and regulations

Every state has completed a comprehensive wildlife action plan as charged by Congress in order to be eligible to receive funds through the Wildlife Conservation and Restoration Program and the State Wildlife Grants Program. As the product of public-private partnerships, these plans articulate practical measures to protect and restore important lands and waters, curb invasive species, and address issues related to habitat corridors and connectivity. Many action plans emphasize both the need to inform decisions with the best available scientific information and the use of market-based incentives and collaboration rather than regulation (McKinney et al., 2010). These plans exemplify the importance Congress and the states place on the use of ecosystem service valuation in land-use decision-making.

The Commonwealth of Massachusetts Office of Coastal Zone Management (CZM) is the lead policy, planning, and technical assistance agency on coastal and ocean issues within the Executive Office of Energy and Environmental Affairs, and implements the state's coastal program under the aforementioned federal Coastal Zone Management Act. The CZM Policy Guide calls specific attention to the threat of sea level rise outpacing vertical accretion and landward migration of coastal wetland resources and recommends that the need for these resource areas to migrate landward in response to sea level rise be addressed through the design, placement, and elevation of structures, as well as for other activities in the coastal floodplain. CZM has applied the Sea Level Affecting Marsh Migration (SLAMM) model to its coastal areas to aid in the management of this important resource. These model results have been interpreted to make land management decisions at the local level, such as in Chelsea, MA.

A 2017 report by the City of Chelsea and MA Office of Coastal Zone Management, *Designing Coastal Community Infrastructure for Climate Change*, identifies vulnerable areas of the City at risk of coastal flooding, under both present day and projected future climate change conditions. SLAMM results illustrated the limited areas within the City available for resource migration, such as undeveloped or less developed areas that will likely experience significant changes in land cover and wetland type. For example, the Mill Creek Corridor was identified as an area that will experience minimal changes in the relative near term but, with the penetration of salt laden water further upstream leading to eventual regular flooding, the majority of the creek system is anticipated to transition to tidal salt marsh and estuarine flooded water. No immediate adaptations are required in this situation, but the report does recommend proactive shoreline restoration and infrastructure protection to buffer the effects of inevitable increased overbank flooding. Also recommended are living shoreline applications and targeted thin layer deposition projects that would involve the placement of clean, compatible sediment in thin layers on existing salt marsh areas to assist marsh accretion pace match that of relative sea level rise.

Wetlands enjoy regulatory protection in addition to their consideration in wildlife and habitat plans, policy guides, and shoreline models. Massachusetts adopted the Wetlands Protection Act (310 CMR 10, promulgated pursuant to MGL c. 131, § 40) with the purpose to protect the following interests: private and public water supplies, groundwater supply, flood control, storm damage prevention, pollution prevention, shellfish areas, fisheries, and wildlife habitat. The areas subject to this protection include any bank, freshwater wetland, coastal wetland, beach, dune, flat, marsh, or swamp bordering on the ocean or any estuary, creek, river, stream, pond, or lake (in Massachusetts). This protection also extends the land under any of these waterbodies, land subject to tidal action, land subject to coastal storm flowage, land subject to flooding, and any riverfront area; a 100 ft buffer zone for these land areas is also protected. When a proposed project involves the dredging, filling, removing or altering of a salt marsh, the [permitting] authority shall presume that such area is significant to the interests specified above; these activities must file a Notice of Intent for review by local conservation commissions. These commissions are 3-7 members, appointed by the leadership of the jurisdiction. Commission members oversee the promotion and development of natural resources and the protection of watershed resources within their jurisdiction (MGL c.40, § 8c). Conservation commissions, especially those in coastal areas, should consider the promotion of, or even requirement for, conservation subdivision design[2] of large residential development projects near natural resource areas. This type of project design clusters the housing units on a lot away from the resource area, while still building the maximum number of units allowable according to lot size and zoning law.

[2] Conservation subdivisions (CSDs) are residential or mixed-use subdivisions designed to minimize site disturbance and to protect ecologically significant areas of a development site (Carter, 2009). This form of land protection is only useful and successful if the ecological features and functions of the site are established and considered early on in the development planning process. The decision to create this type of development can be motivated purely by the developer of the site but may also be motivated by a group of interested landowners willing to pay for the development of a subdivision that meets their ecological and conservation interests.

CSDs typically require the use of a conservation easement for protection of open space on the site. These easements, as described below, may be held by land trusts with ownership of the property given to the homeowner's association. Not only does this place permanent protection on the open space and allow for enforcement of the conservation restrictions, but it also allows for a reduction in cost of the development. Once an easement is placed on the property, the same tax deductions as outlined below are applicable to CSD parcels.

Chapter 5

Non-regulatory tools

A study conducted in 2003 estimates that approximately 153 million people (53% of the nation's population) lived in the 673 coastal counties of the U.S. (Crosset, 2005). This number has likely increased in the almost 15 years since the study was conducted. This means that a large amount of land in the coastal zone is held privately. So, efforts by state coastal zone managers can only go so far in the protection of marshes in their current places and in the facilitation of marsh migration. Private landowners currently hosting marshland on their property - and those with land in the projected marsh migration zone - can also take action to preserve and protect this ecosystem. These conservation options range from purely non-regulatory tools, such as private servitudes[3] and deed

[3] A conservation servitude is a negative restriction on land which prohibits the landowner from acting in a way that would alter the existing natural, open, scenic, or ecological condition of the land (Korngold, 1984). They address conservation concerns by allowing restrictions on alteration of natural land without transferring possessory or access rights (Korngold, 1984). These contracts may exist between two adjacent parcel holders, or many appurtenant parcels along the shore. Provisions aimed at the protection of tidal wetlands may include a prohibition on shoreline armoring or the elevation of land.

Restrictive covenants are somewhat limited in their effectiveness, as they often do not protect the land in perpetuity and may dissolve upon the sale of the land (Carter 2009). If they are linked to a homeowner's association, the covenant can be changed with a unanimous vote of the members (Carter, 2009). There is also, typically, no party responsible for the monitoring of the protected land under a restrictive covenant, and makes enforcement of violations difficult, if there is any identified recourse for violation at all (Carter, 2009). If the goal is to prevent current and all future owners of the land from holding back the rising sea, then the property right to erect shoreline structures must be transferred to a third party with no interest in the development of shoreline armoring (Kwasniak, 1993; Titus, 2011). See "Conservation easements" (pg. 59), "Rolling easements" (pg.62), "Defeasible estates" (footnote 4), and "Transferred development rights" (pg. 64) for information on how to integrate conservation restrictions with deed restrictions.

restrictions[4], to voluntary conservation programs such as rolling easements and transferred development rights, which do require regulation to implement but are individually-motivated agreements. These tools can be used alone or in combination to achieve the desired conservation outcome.

Conservation easements

A conservation easement is a legally binding agreement between the owner of the land encumbered by the easement and the holder of the easement that restricts the development and use of the land to achieve certain conservation goals, such as the preservation of open space, wildlife habitat, or agricultural land (McLaughlin, 2015). These agreements "run with the land," which means that even if the land is sold or passed on to heirs, the documented restrictions still apply to all landowners (Brandywine Conservancy, 2008). These agreements also give the easement holder the right and obligation to enforce the specified restrictions of the easement (Brandywine Conservancy, 2008). Most often, the holder of a conservation easement is a local land trust or a government agency. The purchase of conservation easements allows for efficient land conservation action; organizations can reach their preservation goals at a lessor

[4] Private landowners with a present interest in land can convey their land while retaining a future interest in the property; this method of land conveyance allows the property to be conveyed back to the original land owner, or a third party, contingent upon a stated event (this event is stated in the deed agreement). For example, a parcel deed could contain a stipulation that states the landowner may not erect additional structures on the property or conduct activities that infringe on the health and extent of fragile shoreline ecosystems, at risk of the ownership of the land reverting to a named third party, such as a local land trust, in the event the deed restriction is breached. These forms of conveyance create a fee simple defeasible estate. There are three forms of defeasible estates: estate in fee-simple determinable, estate in fee simple subject to a condition subsequent, and estate in fee simple subject to an executory limitation. See Restatement (Third) of Prop.: Property §153, 154, 24, 25, 44-46.

cost without having to acquire a fee interest, and individual private landowners can also fulfill their conservation interests while maintaining fee interest (ownership) of their land. These agreements are motivated outside of the regulatory system and are usually driven by a mutual interest in the preservation of ecological land value and ecosystem services. However, these agreements are not solely intrinsically motivated and benefit the grantor as well as the grantee.

Since 1980, a landowner who donates a qualifying conservation easement to a government agency or charitable conservation organization has been eligible for a charitable income tax deduction generally equal to the value of the easement – or to the reduced value of the property – under Code § 170(h) (Korngold, 2009; McLaughlin, 2015). A landowner who donates a qualifying conservation easement also removes the value of the easement from his or her estate free of transfer tax under Code § 2522(d) and, since 1997, may potentially exclude up to an additional 40% of the value of land encumbered by the easement from the estate for estate tax purposes under Code § 2031(c) (McLaughlin, 2015). A landowner who donates a conservation easement will be eligible for a charitable income tax deduction under Code § 170(h) only if, among other things, the easement is donated for one or more of the following qualified conservation purposes: a) the preservation of land areas for outdoor recreation by, or the education of, the general public; b) the protection of a relatively natural habitat of fish, wildlife, or plants, or similar ecosystem; the preservation of an historically important land area or a certified historic structure; or c) the preservation of open space (including farmland and forest land) where such preservation is either for the scenic enjoyment of the general public and will yield a significant public benefit or pursuant to a clearly delineated federal, state, or local governmental conservation policy and will yield a significant public benefit (McLaughlin, 2015). An option for landholders who are "land rich but cash poor," with a low tax liability, is the bargain sale, where, for example, 75% of the value of the easement is paid to the landowner in cash by the grantee, and the remaining value of the easement is deducted from the landowner's tax liability.

The National Conservation Easement Database indicates 25,692,063 acres of land are currently protected by 146,236 different conservation easement agreements. The value of this land is determined in one of two ways: 1) If there is a substantial record of sales of easements comparable to the donated easement (such as purchases pursuant to a governmental program), the fair market value of the donated easement is based on the sales prices of such comparable easements; or 2) the fair market value of the easement is equal to the difference between the fair market value of the property before the easement and the fair market value of the property after the easement. This equates the value of the conserved land with that of the value of the real property or that of the development rights associated with said property. Conservation easements are a critical tool for the protection of ecologically important habitat absent relevant or effective policies and regulations.

A case decided by the Supreme Judicial Court of Maine, *Windham Land Trust v. Jeffords*, 967 A.2d 690 (2009), demonstrates how judicial validation of conservation easements could lead to their increased use. Common Law precedent holds that when interpreting land restrictions, conflicts should be resolved in favor of permitting freer use of the land rather than greater limitations on the owner's use. The court could have relied on this concept to find that the ambiguity in the conservation easement in question should result in the permitting of the proposed commercial uses. The court instead protected the conservation easement to the fullest. The significance of the Windham Land Trust decision lies in its support for conservation over commercial development and the willingness of at least this court to enforce conservation interests to the fullest. This case is an important milestone in the recognition and validation of the value of conservation easements and may in the future lead to a greater number of judicial rulings in favor of land conservation (Korngold 2009).

Transferred development rights

Transfer of development rights (TDR) is way to convey the development rights of one property to a different property (Brandywine Conservancy, 2008). Any landowner in possession of a parcel that has not been developed to its fullest potential may sell that development potential to a different landowner, provided a regulatory mechanism for this transfer has been established. If a community wants to permanently protect marshland and promote development and growth within an urban growth area, the municipality must first add a TDR program to its zoning ordinance (Brandywine Conservancy, 2008). The ordinance must identify a "sending area," where the land is to be protected, and a "receiving area" where growth is encouraged. This gives landowners in the sending area the legal ability to sever and sell development rights to a parcel in the receiving area (Brandywine Conservancy, 2008). The sending area is generally a high natural resource area, for example, the Great Marsh and Wingaersheek Beach in Gloucester, Massachusetts. Gloucester is also a historic port City, and one of Massachusetts' Designated Port Areas (DPA) ("Designated Port Area Planning and Implementation," 2017). These areas require a comprehensive planning approach through DPA Master Plans. The DPA Master Plan must comply with standards which include measures to preserve and enhance the capacity of DPA to accommodate water-dependent industrial use and measures to prevent substantial exclusion of such use by any other use eligible for licensing in a DPA ("Designated Port Area Planning and Implementation," 2017). Gloucester might consider creating a sending area along the coast to include its portion of the Great Marsh and Wingaearsheek beach, and create a receiving area behind the Designated Port Area in the more highly developed downtown. This would allow landowners within the important high natural resource area sending district to sell their development rights to landowners in the downtown receiving area, where development is already being encouraged.

When a landowner sells the right to develop their property, the landowner receives a cash payment for those rights but retains all other rights and responsibilities of owning land, such as paying property taxes (Brandywine Conservancy, 2008). By selling the right to develop on the property, the landowner will likely see a reduction in property value, and therefore have less tax liability on that property. The cash value for the TDR is sensitive to the local real estate market and the program established in the municipal agreement. To achieve the most desirable price to encourage use of this program, the sending area should be large enough to generate a sufficient number of TDRs, as a limited supply of them will drive up the price per unit, making it unlikely the rights will be sold. Conversely, too many TDRs may depress their market value which may de-incentivize landowners interest in choosing the TDR option. In addition to enabling the severance and sale of development rights, the municipal ordinance must also establish a procedure to ensure the permanent preservation of the land once the TDRs have been sold. This may be accomplished through a conservation easement held by the municipality or a land trust.

Rolling easements

A rolling easement allows for the facilitation of wetland, beach, and open water migration onto areas that are dry land today. No effort is made to restrict land use, but it does prevent shoreline armoring either through regulation or by transferring any right to hold back the sea from owners who may be inclined to do so to organizations that would not (Titus, 2011). The biggest difference between rolling easements and the other tools discussed in this paper is that, rather than protect land in perpetuity from development, the easement is a means to an end until the protections are no longer needed, i.e., until sea level rise is allowed to naturally reclaim previously developed areas (Titus, 2011). There are a number of regulatory approaches to the implementation of rolling easements, including zoning and permitting requirements, but those will not be examined in this paper. Instead, various property rights approaches will be discussed. However, it should be noted that these approaches are not mutually exclusive. A land trust or other qualified organization could acquire a rolling easement on lands where there are regulations in place to prohibit shoreline armoring to ensure that future changes in public policy do not put ecosystem migration in jeopardy (Titus, 2011). The property rights approaches combine many of the tools discussed throughout this paper, but with the addition of "rolling" land protections as the sea continues to rise and ecosystems attempt to migrate landward.

A rolling easement is a legally enforceable expectation that the shoreline can migrate inland instead of being subjected to coastal squeeze between rising sea levels and a physical structure or property line (Titus, 2011). It is essentially a legally bound plan to retreat from the shoreline as sea levels rise. While the initial reaction by landowners to this approach is to not retreat or allow their property to shrink in size and lose value as land subsides or erodes – preferring instead to implement shoreline armoring, so long as the cost is less than the value of the property – the actual implication of the rolling easement is a very slight decrease in property value, as the eventual submergence of land will happen so far in the future (Titus, 2011). The rolling easement holder can be a person, land trust, or governmental organization who obtains the property rights subject to the easement; these rolling easements are obtained from property owners. For the purposes of this discussion, a rolling easement is a property right to ensure that wetlands move landward with the natural retreat of the shoreline due to sea level rise. For wetland migration, it is not only important to prohibit the armoring of the shoreline, but also to prohibit the elevation of the grade of the property; tidal salt marshes require a low-grade slope in order to migrate landward. Property rights approaches to rolling easements include conservation easements, restrictive covenants, future interests, and transferable development rights. The rest of this section will provide examples of how to apply rolling easements to these approaches.

A rolling easement implemented as a conservation easement may prohibit shoreline protection or land elevation along the shore, but otherwise does not restrict the use of dry land. The boundary of the easement will continue to move landward as sea levels rise overtime, and eventually the sea may reclaim the entire property (Titus, 2011). Until this time, landowners may continue to enjoy their land and unrestricted use of the dry portions of the property. This varies from the concept of the conservation easement only in that as land is lost, the easement is not lost along with it; the easement “rolls” landward as sea level rises incrementally.

Restrictive covenants, or private servitudes (see footnote 3), are another way to preserve natural shorelines and allow them to migrate landward in areas where neither conservation organizations nor government agencies are able or willing to own and manage conservation easements. Landowners with large lots may be willing to tolerate gradual land loss along the shoreline rather than invest a great amount of money on a revetment [a coastal stabilization technique using hard, grey infrastructure such as concrete to overlay the shoreline; SAGE, 2015] that may also destroy their beach, but only if they are assured that their neighbors are also not going to build revetments (Titus, 2011). A developer of a site may also decide that the neighborhood would be best served with a prohibition on shoreline armoring, and may include those restrictions on the deeds conveyed to residents (Titus, 2011). Covenants that run with the land are a common way to bind landowners to a set of restrictions with reciprocal advantage to all. Rather than simply an agreement to not armor the shoreline, the agreement includes a provision to allow that shoreline to naturally migrate landward, which must require a no-development “buffer zone” along the migration corridor.

A different way to ensure that wetlands can migrate landward, as discussed in footnote 4, is through defeasible estates and future interests in land. The examples provided denote reversion of land ownership contingent upon development activities or disturbance to the shoreline; an alternative approach may be to denote a reversion of land ownership contingent upon sea level. For example, “A” owns a parcel of land 4 ft above sea level in the marsh migration zone in fee simple absolute (owned “free and clear” of debt or interest to others), and conveys a future interest “to B once the sea level rises 4 ft.” In this case (an estate in fee simple determinable), B is likely a municipality or land trust who has the means to manage and protect this land as natural wetlands into the future. Other parcels at different elevations could transfer land ownership when the sea reaches a different height (Titus, 2011). The prospect of land reverting to B also inherently limits any incentive to armor the shoreline, as the owner will lose the land eventually anyways (Titus, 2011). This method can be used in any form of defeasible estate. Providing for land titles to transfer upon a specific event (i.e., sea level rise), has several advantages over a shoreline migration conservation easement. The holder of the future interest in land, “B” – a municipality or land trust – does not have any responsibility to monitor possible efforts by landowners to extend their tenure by adding fill or otherwise preventing landward wetland migration, because the property ownership reverts regardless once the agreed upon level of sea level rise has occurred (Titus, 2011). The future interest holder also does not have a duty to manage the property until the stated event occurs and they take ownership of the land, unlike with a conservation easement which may require costly land management (Titus, 2011).

Finally, transferred development rights can also be implemented using the rolling easement framework. The sending district for development rights would still be along the waterfront in a low to moderately developed area within the marsh migration zone where a municipality would like to plan for retreat. Rather than designating the receiving district in a downtown urban growth area, the receiving area would instead be in an undeveloped area further upland of the marsh migration area, encouraging new development away from the shoreline (Titus, 2011), which could be implemented using a conservation subdivision development technique. Alternatively, the sending district could literally “roll” landward as sea level rises, with the receiving district still being a downtown urban growth area.

Conclusions

There are many tools available to private landowners to voluntarily participate in positive conservation behaviors. Depending on the nature of the conservation behavior, and the parties involved in the conservation agreement, some of these tools are more situationally appropriate than others. Land management goals that are only relevant to or affected by one property may be best addressed through deed restrictions. Land management that requires cooperation amongst many property owners would likely be better achieved through the use of easements or transferred development rights. Some of these techniques do require regulatory bounds to function within, and therefore require the support of government, and others can happen without any regulation. In areas without the necessary regulatory structure or governmental support for tidal salt marsh conservation, private landowners can still employ deed restrictions as a means for restricting development in a resource area.

Standing alone, these are all important tools for the conservation of critical ecosystems such as tidal salt marshes. Often, these tools are more effective and longer lasting when used in tandem. Both conservation restrictions and deed restrictions should be utilized to ensure the restrictions "run with the land" and last in perpetuity. Since any of these tools can be applied using the rolling easement framework, it is also important that this framework is applied where ecosystems are particularly vulnerable to rising sea levels. No tidal salt marsh is safe from this threat, so the argument can be made that rolling easements should be implemented for any conservation activity targeting this habitat[5].

[5] Private land owners risk losing, at worst, their land to the sea and at best their right to develop a portion of their and exclude others from it (Zilgme, 2012). A significant issue surrounding rolling easements is whether or not they constitute a governmental regulatory taking, which occurs if the government's actual or effective acquisition of private property occurs without just compensation to the landowner (U.S. Const. amend. V.). The examination of this issue is outside of the scope of this thesis but is noted as an important area for future research. See also Novack, E. 2016. Resurrecting the Public Trust Doctrine: How Rolling Easements Can Adapt to Seal Level Rise and Preserve the United States Coastline. 43 *B.C. Envtl. Aff. L. Rev*. 575 and Higgins, M. 2008. Legal and Policy Impacts of Sea Level Rise to Beaches and Coastal Property. *Sea Grant Law and Policy Journal* 1(1)43-64.

Chapter 6

Conclusions and Recommendations

There is no “best” method to protect land for future generations, increase the extent and health of tidal salt marshes, or prioritize land conservation efforts. Data and models that work for a large regional jurisdiction are often not at a fine enough grain for local considerations, and statewide datasets may be inconsistent for use at the regional level. Site-specific or municipality-specific data is often at the finest granularity and is the best-available for that area, but is expensive to create and is inconsistently available for use in a larger planning area (i.e., data is missing or produced differently in some parts of the shoreline, state, or region). This has necessarily led to disparate methodologies for the assessment and prioritization of parcels for conservation across jurisdictions. While each of these methods is unique, a review of the literature revealed some common themes in efforts to address the issue of conservation in a changing climate:

1) Areas of biodiversity today may not remain areas of biodiversity into the future, and to make the most effective conservation decisions future condition must be considered
2) Abiotic site factors contribute greatly to resilience; sites with greater landform diversity have a higher chance of supporting a diversity of life into the future
3) Marsh migration model data can be used to identify areas that are likely to support tidal salt marshes under increased sea levels, and conservation efforts should be focused on the preservation of these sites
4) There are many tools for the conservation of land, through both regulatory and voluntary mechanisms. These tools have the most impact when employed together.

This thesis was written to exemplify the possibility and importance of the integration of these themes in conservation planning. The conservation prioritization model draws together the most important themes from each study: local connectedness and landform diversity to increase terrestrial resilience, terrestrial and aquatic core connector networks important to the support of regional flow of species, consensus priority conservation areas informed by a regional committee, local social and environmental metrics, and development scenario analysis. Furthermore, conservation options are offered that do not require investment by a land trust or government organization but still increase protections for tidal salt marsh and allow for ecosystem migration. In addition to the tools discussed and promoted throughout this document, the following recommendations are offered:

- Community outreach and educational events should be planned and advertised in coastal areas with significant coastal resources to educate coastal landowners on their options for voluntary conservation actions. Tax incentives for entering into these agreements must be explained; an additional incentive that might be offered by a community is free legal advice and services to establish conservation agreements.
- Leverage the recently passed Massachusetts Environmental Bond Bill, which authorized over $1.4 billion in capital allocations for investments in safeguarding residents, municipalities, and businesses from the impacts of climate change, protecting environmental resources, and investing in communities. This bond includes $30 million set aside exclusively for the acquisition of land and interests in land by the Executive Office of Energy and Environmental Affairs, including the capitalization of the Transfer of Development Rights Revolving Fund. An additional $125 million was set-aside for grant programs for land resource conservation, protection, and acquisition.

Beneficiaries should also continue to advocate for renewals and increased funding levels.

- Increase the tax credit cap for the Massachusetts Conservation Land Tax Credit Program. This program is capped at $2 million per year, which is vastly less than the $20 million allowance for the Low-Income Housing Tax Credit program or the whopping $50 million allowance for the Historic Rehabilitation Tax Credit program.
- Incentivize payments for ecosystem services. A 2006 study found that conservation subdivisions with land preservation around stream corridors and high infiltration areas had decreased reliance on structural stormwater management control practices and resulted in a developed watershed that more closely resembled and mimicked predevelopment hydrologic conditions than traditional developments (Carter 2009, citing Williams and Wise, 2006). A municipality might encourage more of this type of development by waiving stormwater system user fees for parcels or developments that reduce the burden on the stormwater system using natural stormwater controls (Carter, 2009).
- Expand the dataset used for this model to include additional datasets, especially data relating to the biological condition of sites. While the abiotic stage is the more important consideration than where focal species exist today, biological condition of the site is still an important factor to consider in terms of site resilience (OSI and NALCC, 2016). A site that is in a degraded state is much more likely to continue to degrade due to increased pollution and changing weather and climate pattern than a site that is currently highly productive and intact. The Index of Ecological Integrity, developed by the Designing Sustainable Landscapes project at University of Massachusetts Amherst and the North Atlantic Landscape Conservation Cooperative, is a regional dataset which is a measure of relative intactness (i.e., freedom from adverse human modifications and disturbance) and resiliency to environmental change (i.e., capacity to recover from or adapt to changing environmental conditions driven by human land use and climate change). It is a composite index derived from up to 21 different landscape metrics, each measuring a different aspect of intactness (e.g., road traffic intensity, percent impervious) and/or resiliency (e.g., ecological similarity, connectedness) and applied to each 30-meter cell.

- Given the limitations of the Harvard Forest Future Development Scenarios study, planning jurisdictions using this tool should consider undergoing their own build-out scenarios development process. These build-out scenarios should be ones that are feasible within existing regulations and priorities, or feasible within desired regulatory and management priority changes. Scenarios are not predictions of the future or a set of land-use recommendations. They are set of “what ifs…” that represent contrasting visions for the future of the landscape. As such, scenarios make it possible to evaluate the potential consequences of different land-use choices.

These recommendations, if implemented, will broaden both the level of resources and use of climate-relevant data for land conservation. Application of this proposed conservation prioritization model may increase the amount of tidal salt marsh conserved and conservation of areas projected to host tidal salt marsh into the future. While this model did not meet the stated outcome for success, it certainly lays the groundwork for consideration of climate resiliency and salt marsh migration metrics in conservation prioritization. Due to the extremely high value of salt marsh ecosystems to society, it is in our best interest to strive to provide the best protections possible to them. Using this guide, land managers in Massachusetts, the northeast, and around the country should consider how they might better support tidal salt marsh resilience through their programs.

Appendices

1:

Conservation Land Tax Credit Program
General Selection Criteria

Generally, land that has:

- more than 50% coverage or more than 5 acres, of 1 or more Tier I environmental assets and 1 – 5 below; or
- more than 50% coverage each of two of the Tier 2 environmental assets, (each Tier 2 acreages must exceed 50% of coverage.) Or, more than 5 acres of combined Tier 2 environmental assets and 1 – 5 below; or
- land that has at least 2 of the Tier 3 interest at 50% coverage each plus; one of the Tier 1 with at least 25% coverage or one of Tier 2 with at least 25% coverage, and 1 – 5 below;

1) that substantially contributes to the conservation values,
2) the land is of uniformly good condition and sufficient size to maintain the conservation purposes,
3) the uses will be consistent with the conservation purposes,
4) the surrounding land uses are not incompatible or do not materially impair the conservation values,
5) the recipient is a governmental entity or private conservation corporation whose purposes include the conservation of land or water areas and has sufficient resources and commitment, as well as a plan, to provide stewardship to ensure continued viability of the conservation purposes.

Conservation purposes are prioritized as follows:

Tier 1

1. Zone I and II and Zone A and B and high and medium yield aquifer drinking water maps. Appl. (a); Reg. 14.05 (1) (a) & (2) (a)

2. Areas specifically identified in State, regional and local Public Water Supply Protection Plans. Appl. (h); Reg. 14.05 (1) (b), (f)

3. BioMap 2 Core or Priority Habitat delineated by the Department of Fish and Game (DFG) pursuant to M.G.L. c. 131A. Appl. (b); Reg. 14.05 (1), (d), (e); or Estimated Habitat. Reg. 14.05 (1), (d)

4. Prime or state important agricultural and forest soils. Appl. (d); Reg. 14.05 (1), (g)

5. BioMap2 Critical Natural Landscape or any succeeding versions, including those shown in various state upland and aquatic resource maps. Appl. (b); Reg. 14.05 (1), (d)

6. Other regional plans for water quality protection of rivers, streams, lakes, and significant wetlands, including reduction of erosion, especially for land contributing directly to the protection of public drinking water supplies. Appl. (i); Reg. 14.05 (1), (f) & (2) (a), (b)

Tier 2

1. Prime agricultural and forestry lands and lands of sufficient size for viable agricultural and forestry production including Chapter 61 and 61A lands; working landscapes that are or will be in compliance with a Farm Conservation Plan or a Forestry Plan by a licensed forester that protects the natural resource values of the land. Appl. (c); Reg. 14.05 (1), (h) & (2) (d), (e)

2. Significantly contributes to various focus areas for EEA and federal natural resource agencies. Appl. (g); Reg. 14.05 (1), (j)

3. Protection of riparian buffers and wildlife corridors for native plant and animal species, especially species listed by DFG as “species of special conservation concern” in the Massachusetts Statewide Wildlife Action Plan and the BioMap2 or other state wildlife policy or plans. Appl. (b); Reg. 14.05 (1) (c), (d), (e), (f); (2) (a), (b), (c) & (2) (c), (f)

4. Protection of substantial areas or those that significantly contribute to cultural sites, state heritage corridors, and archaeological and historic resources including those listed by the Massachusetts Historical Commission; in specific areas mapped by the Massachusetts Historic Commission as important for cultural resource protection. (i.e., [substantially] a large undeveloped area that is the “backdrop” for a historic site or landmark, or [significantly] the historic site or landmark itself). Appl. (j), (m); Reg. 14.05 (1), (o) & (2) (g)

5. Priority areas in the Department of Conservation and Recreation’s state forest assessment and strategy. Reg. 14.05 (1), (i)

6. Substantially or significantly contributes to federal, state or local natural resource designated areas such as Areas of Critical Environmental Concern or habitat reserves. (i.e., a very large intact area within the designated area, or one or more particular features significant to the designation). Appl. (e); Reg. 14.05 (1), (n)

7. Areas that substantially contribute to state and regional scenic plans designating the land as of statewide or regional significance including lands listed in DCR’s scenic inventory documents or state or regional natural resource, Greenway or park priority plans. Reg. 14.05 (1) (l), (m) & (2) (h)

8. River protection Act buffers (0- 200 feet) and lands containing within 200 feet of mapped rivers, streams, lakes, ponds and coastal or freshwater wetlands, marshes or water areas. (River protection act buffers are already regulatorily protected, but going beyond the buffers is important)

Tier 3

1. Land within Chapter 61B being permanently protected.

2. Land that significantly (highly contributes) or substantially (large areas) contributes to federal, state or local resource designated areas such as federal Scenic Byways or National Heritage corridors; or specific priority resources in local Open Space and Recreation Plans that are consistent with and substantially advance statewide or regional policies or plans. Reg. 14.05 (1), (p)

3. Specific priority resources in the Statewide Comprehensive Outdoor Recreation Plan or lands with high recreational value that provide significant passive recreation via non-motorized activities consistent with the protection of conservation values including land in and near environmental justice neighborhoods or in state or regional natural resource, greenway or park priority plans. Appl. (k); Reg. 14.05 (1), (k) & (2) (i)

4. Property in an environmental justice area, or a similar densely populated area with a significant lack of adequate open space and protected land that are heavily populated and underserved by open space, availability of passive recreational opportunities, urban gardens, habitat areas unique within the community or needed buffer areas, particularly to protect water quality, or other protected lands. Reg. 14.05 (1), (r) & (2) (j)

5. Parcels with more than 30% of the land within ¼ of a mile of its boundaries are permanently protected.

6. Parcels with more than 30% of the land within ¼ of a mile of its boundaries in wetlands.

Marginal or ineligible:

Sites of too minimal size or condition to maintain conservation values, or values likely to be severely compromised, including by abutting property.

Too many reserved rights or planned uses, including subdivision or development, inconsistent with conservation purposes.

In highly sensitive areas, activities that are not pursuant to a Farm Conservation Plan, Forest Management Plan approved by the Massachusetts Department of Conservation and Recreation, or that do not require consultation with the relevant state agency; i.e., Natural Heritage and Endangered Species Program, Department of Environmental Protection Drinking Water Program, Conservation District, etc.

Buildings or building envelopes with structures that have few or no historic or other conservati on values.

Insufficient, unacceptable or non-existent management plans or restriction, or Grantee's inability or insufficient resources likely to compromise the site's conservation values.

Recreational or other uses inconsistent with or incompatible with long-term maintenance of conservation purposes.

Surrounding land uses compromised or incompatible or threaten conservation or integrity.

Previously restricted through development set-aside agreements, open space set asides, regulations.

Public recreation but access questionable, or remote area with no parking, etc.

2: Data sources for land conservation prioritization model

Layer Name	Description	Source Agency and URL	Key attributes	Data format and year represented
Conservation Land Tax Credit program applicant sites	Shapefile depicting outline of applicant parcels to MA CLTC program. File will be used as the study area for site environmental quality analysis and prioritization exercise.	MA EEA, N/A (received via email, personal communication)	Site area and location	Vector, current through January 2018
Social metrics				
Aquifer areas	The USGS 1:48,000 hydrologic atlas series on groundwater favorability was produced for all of Massachusetts. The basemaps for these were photographically reduced and spliced together from 1:24,000 USGS quadrangles.	MassGIS, https://docs.digital.mass.gov/dataset/massgis-data-aquifers	High and medium yield aquifer areas	Vector, 2011
Wellhead protection areas	As stated in 310 CMR 22.02, Zone I is the protective radius required around a public water supply well or wellfield. Zone II is th area of an aquifer which contributes water to a well under the most severe pumping and recharge conditions that can be realistically anticipated (180 days of pumping at safe yield, with no recharge from precipitation).	MA DEP, https://docs.digital.mass.gov/dataset/massgis-data-massdep-wellhead-protection-areas-zone-ii-zone-i-iwpa	Zones 1 and 2 areas	Vector, 2017
Surface water supply protection areas	These Surface Water Supply Protection Areas delineate those areas included in 310 CMR 22.00, the Massachusetts Drinking Water Regulations, as Surface Water Supply Protection Zones.	MA DEP, https://docs.digital.mass.gov/dataset/massgis-data-surface-water-supply-protection-areas-zone-b-c	Zones A and B areas	Vector, 2017
Prime forest land	These layers were created using primarily the NRCS/MassGIS Soils data; the basic procedure was to classify potentially forested land into nine different categories based on potential average timber productivity.	NRCS/MassGIS, https://docs.digital.mass.gov/dataset/massgis-data-prime-forest-land	Prime or state important forest area	Vector, 2013
Prime farmland soils	This layer combines agricultural land uses from the 2005 MA Land Use data layer and an	NRCS, https://www.ncmhtd.com/arcgis/re	Prime or state important	ArcGIS online service;

	unpublished “LCLU 2013” dataset. The 2005 land uses included are cropland, pasture land, nurseries, orchards and cranberry bog. The 2005 data are included in this layer because visual inspection showed that the 2013 data was incomplete.	st/services/NRCS/NRCS_SoilData/MapServer/3	agricultural soils area	Vector, 2013/2005
Scenic Landscape Inventory	The Scenic Landscapes datalayer may be used as a state-wide overview of scenic areas as identified in the Massachusetts Landscape Inventory Project, 1982.	MA DCR, https://docs.digital.mass.gov/dataset/massgis-data-scenic-landscape-inventory	Designated landscapes areas	Vector, 1982
MA Historical Commission Inventory	This public layer consists of points and polygons representing information from the Massachusetts Cultural Resource Information System database and related records on file at the MHC, including the Inventory of Historic Assets of the Commonwealth, National Register of Historic Places nomination forms, local historic district study reports, local landmark reports, and other materials.	MA Historical Commission, MassGIS; https://docs.digital.mass.gov/dataset/massgis-data-mhc-historic-inventory	Inventory areas	Vector, 2017
Scenic Byways	This data layer contains the name and location of roads that the Federal Highway Administration has designated as Scenic Byways within the Commonwealth of Massachusetts. The Scenic Byways program supports roads that have outstanding scenic, historic, cultural, natural, recreational, and archaeological qualities.	MA DOT, https://geo-massdot.opendata.arcgis.com/datasets/scenic-byways	Designated byways line length	ArcGIS web service; Vector, 2018
Environmental Justice areas	MassGIS has processed a portion of the U.S. Census Bureau's 2010 data release for Massachusetts in order to assist GIS users who may need access to these demographic-related datasets. The Block Group boundaries were used to create the	MassGIS, https://docs.digital.mass.gov/dataset/massgis-data-datalayers-2010-us-census	Environmental Justice areas	Vector, 2010

	Environmental Justice 2010 Populations data.			
Environmental metrics				
BioMap2	The Massachusetts Natural Heritage & Endangered Species Program and The Nature Conservancy's Massachusetts Program developed BioMap2 in 2010 as a conservation plan to protect the state's biodiversity. Bio Map2 is designed to guide strategic biodiversity conservation in Massachusetts over the next decade by focusing land protection and stewardship on the areas that are most critical for ensuring the long-term persistence of rare and other native species and their habitats, exemplary natural communities, and a diversity of ecosystems.	MA DFW and TNC, https://docs.digital.mass.gov/dataset/massgis-data-biomap2	Core Habitat area, Critical Natural Landscape area	Vector, 2010
Natural Heritage and Endangered Species Program priority habitats of rare species	The Priority Habitats of Rare Species datalayer contains polygons representing the geographic extent of Habitat of state-listed rare species in Massachusetts based on observations documented within the last 25 years in the database of the Natural Heritage & Endangered Species Program (NHESP).	MA DFW, https://docs.digital.mass.gov/dataset/massgis-data-nhesp-priority-habitats-rare-species	Area	Vector, 2017
Natural Heritage and Endangered Species Program estimated habitats of rare wildlife	Estimated Habitats are for use with the Wetlands Protection Act regulations (310 CMR 10.00). The Estimated Habitats of Rare Wildlife datalayer contains polygons that are a subset of the Priority Habitats of Rare Species. They are based on occurrences of rare wetland wildlife observed within the last 25 years and documented in the NHESP database. They do not include those areas delineated as Priority Habitat for rare plants or for rare wildlife with strictly upland habitat requirements.	MA DFW, https://docs.digital.mass.gov/dataset/massgis-data-nhesp-estimated-habitats-rare-wildlife	Area	Vector, 2017

Areas of Critical Environmental Concern	ACECs are places in Massachusetts that receive special recognition because of the quality, uniqueness and significance of their natural and cultural resources. These areas are identified and nominated at the community level and are reviewed and designated by the state's EEA Secretary.	MA DCR, https://docs.digital.mass.gov/dataset/massgis-data-areas-critical-environmental-concern	Area	Vector, 2013
Wetlands	The original MassDEP wetlands mapping project was based on the photo-interpretation of 1:12,000 stereo color-infrared (CIR) photography, captured between 1990 and 2000, and included field verification by the MassDEP Wetlands Conservancy Program (WCP). In 2007 the MassDEP WCP began a statewide effort to assess and, where necessary, update the original wetlands data.	MA DEP, https://docs.digital.mass.gov/dataset/massgis-data-massdep-wetlands-2005	Wetland type, areas	Vector, 2005
Protected and recreational open space	The associated database contains relevant information about each parcel, including ownership, level of protection, public accessibility, assessor's map and lot numbers, and related legal interests held on the land, including conservation restrictions. Protected OpenSpace symbolized all green Conservation and outdoor recreational facilities owned by federal, state, county, municipal, and nonprofit enterprises are included in this datalayer. Not all lands in this layer are protected in perpetuity, though nearly all have at least some level of protection.	MassGIS, https://docs.digital.mass.gov/dataset/massgis-data-protected-and-recreational-openspace	Level of protection, area of protected spaces	Vector, 2018
MassDEP Hydrography	The MassDEP Hydrography layer is an enhanced version of the older U.S. Geological survey 1:25,000 Hydrography datalayer. It represents hydrographic (water-related) features, including surface water (lakes,	USGS/MA DEP, https://docs.digital.mass.gov/dataset/massgis-data-massdep-hydrography-125000	Lands within 200ft of mapped rivers, streams, lakes, ponds, and coastal	Vector, 2017

	ponds, and reservoirs), wetlands, bogs, flats, rivers, streams, and others		or freshwater wetlands, marshes or water areas	
Regional Resiliency metrics				
Natures Network Conservation Design	Nature's Network Conservation Design depicts an interconnected network of lands and waters that, if protected, will support a diversity of fish, wildlife, and natural resources that the people of the Northeast and Mid-Atlantic region depend upon. The Conservation Design represents a combination of three Nature's Network products: 1) the terrestrial core-connector network, 2) aquatic core areas, and 3) core habitat for imperiled species.	North Atlantic LCC, https://databasin.org/datasets/3d670fad4c924e7ba2ae02f04a128256	Terrestrial core-connector network, aquatic core areas, core habitat for imperiled species	Vector, 2017
Regional Connectivity (Flow)	Flow refers to the gradual movement of plant and animal populations in response to changes in the climate. Types of Flow: *Climate Corridors* occur where high amounts of flow become concentrated in relatively small channels or pinch points. Climate Corridors often correspond to natural ridgelines (terrestrial corridors) or relatively intact riparian and floodplain areas (riparian climate corridors) embedded in a matrix of development and agriculture. Climate Corridors may connect climate flow zones or areas of confirmed biodiversity. *Climate Flow Zones* occur in intact natural areas where high amounts of flow can spread-out and expand in many directions. These areas correspond to the least fragmented parts of the region.	The Nature Conservancy and North Atlantic LCC; https://databasin.org/datasets/e6c7374107624643be052c44d29ad246	Areas of regional flow	Website describes the datalayer as a raster file, but .zip download includes feature layer files (used for analysis), 2017

	Blocked Flow occurs where flow hits a hard barrier or encounters strong resistance that dampers and decreases the overall amount of movement in an area			
Local Resiliency and Marsh Migration metrics				
Resilient Coastal Landscapes	Scientists from The Nature Conservancy evaluated over 10,000 coastal sites in the Northeast and Mid-Atlantic for their capacity to sustain biodiversity and natural services under increasing inundation from sea level rise. Each site received a resilience "score" based on the likelihood that its coastal habitats can and will migrate to adjacent lowlands.	TNC, https://conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/climate/CoastalResilience/Pages/default.aspx	Projected marsh migration area under 6ft sea level rise; marsh migration buffer area for 6ft sea level rise; resilience score	Vector, 2017
Resilient and Connected Landscapes for Terrestrial Conservation	This dataset brings together resilience, permeability, and landscape diversity to develop a connected network of sites that both represents the full suite of geophysical settings and has the connections necessary to support the continued rearrangement of species in response to change.	TNC, http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/resilience/Pages/Downloads.aspx	resilience score	Raster, 2016
Stressor metrics				
Land Cover Models	A team of natural resource professionals developed four plausible land-use scenarios for the Massachusetts landscape: (1) Recent Trends, (2) Opportunistic Growth, (3) Regional Self-Reliance, and (4) Forests as Infrastructure. The scientists then used several computer models to simulate how the landscape would change over the next 50 years under each scenario, together with average increases in temperature and precipitation associated with climate change. The consequences of these changes were quantified for a set	Harvard Forest	http://harvardforest.fas.harvard.edu:8080/exist/apps/datasets/showData.html?id=hf290	Raster, development scenarios for the years 2010, 2030, and 2060

	of nine forest benefits and measures of environmental quality and water quality; and habitat conservation, habitat quality, and forest fragmentation.			

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33 CFR 320.4

40 CFR 230

310 CMR 10

131 MGL 40

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