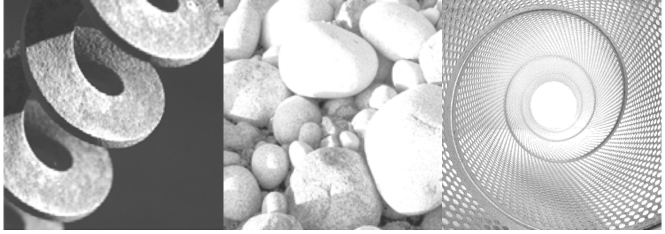

Consulting
Engineers and
Scientists

Final Report to the National Wildlife Federation

MAST Modeling for the Great Marsh in Coastal Massachusetts

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Project 1510490

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Executive Summary

As part of a larger coastal resiliency initiative funded by the Department of Interior, the National Wildlife Federation is providing a suite of community engagement services to help develop robust strategies to respond to sea level rise in the Great Marsh in northeastern coastal Massachusetts. Among these services is use of the Marsh Adaptation Strategy Tool (MAST) to help inform coastal land prioritization decisions in an era of marsh migration. Stakeholders using the tool, recruited from the community of practicing state and local land conservation professionals, ranked 11 high-priority coastal parcels in an auction process according to ecosystem services that they value. The software then gradually inundated each parcel according to identified sea level rise scenarios. Through topographic analysis in each year, in each of three sea level rise scenarios through 2100, and in reference to 13 benefit creation functions, the software then calculated cumulative ecosystem services that may be expected to emerge on each parcel over time.

Across parcels, flood damage prevention and habitat connectivity received the largest number of initial ecosystem service value allocations. Whether comparing wetland benefits on the wet portions of the parcels as they became wet or comparing both dryland and wetland benefits over time, the modeling exercise indicated that according to the stated values of the selected group of participants, and adjusting for size differences between parcels, parcel 9 appeared to be the most valuable parcel under all sea level rise scenarios.

The study shines light on issues of prioritization and gradual landscape change that could be considered both in conducting a regional vulnerability assessment and in creating an adaptation plan that takes marsh migration into account. Specifically, it could help land conservation organizations evaluate conservation priorities and opportunities among these or similarly-situated Great Marsh parcels.

1. Background

GEI Consultants, Inc. (GEI) was contracted in 2015 by the National Wildlife Federation (NWF) to provide services regarding ecosystem services benefits from marsh migration and real estate losses from sea level rise and storm surge. The effort was part of a larger project funded by the Hurricane Sandy Resiliency Grant Program administered by the National Fish and Wildlife Foundation and funded by the Department of the Interior. The grant is aimed at reducing risk to coastal communities along the Great Marsh of Massachusetts by increasing the resiliency of the natural systems that these communities so often depend upon.

The larger NWF project includes many categories of work outside the scope of this effort, including sand movement modeling, analysis of economic issues related to sea level rise, and others in the study towns. This project is in support of the “community resiliency” category, where adaptation planning efforts are intended to help community members, nonprofits, state agencies, and others think through adaptation planning steps and possible actions these communities may need to take and support in response to the combined threats of sea level rise and storm surge.

The impetus for this project was recognition that rising sea levels are changing our wetlands and the ecosystems and services that depend on them. Some marshes will struggle to keep up with the rate of sea level rise, and the ones that do will often be in competition for available land as our communities grow and develop. Without a viable path to migrate, marshes can become pinched between the ocean and impermeable surfaces like roads, parking lots and buildings – and can eventually disappear, along with the systems that rely on them.

As a result, any groups interested in restoring wetlands and saltwater marshes may need to become more strategic in planning for the future of these resources. Specifically, areas for future marsh migration may need to be acquired and habitats may need to be restored in advance of the migration and before development restricts their path or ability to thrive. Candidate parcels also need to be compared so that funds are allocated to the land that could provide the greatest public benefits over time. Prioritization efforts of this type can help land managers be more proactive and make significant contributions to strategic land conservation in an era of marsh migration (Arkema et al. 2015, Merrill et al. 2008).

Among other geotechnical, engineering, and other service categories, GEI helps ecological, land protection, and habitat restoration organizations identify strategic actions based on different sea level rise scenarios and a portfolio of wetland benefits the candidate parcels could provide. This type of analysis is primarily accomplished using the Marsh Adaptation Strategy Tool (MAST) software, in collaboration with local stakeholders. Designed using input from wetland and marsh specialists and well-tested in several marsh acquisition projects, MAST has received recognition from the Northeast Regional Ocean Council as a top model for marsh migration analysis and is profiled in their guidance document Make Way for Marshes.

The main principle behind MAST is that as dry parcels become inundated by rising sea levels, some will convert to wetlands. Those parcels may begin to create benefits or "ecosystem services" for society including carbon storage, wildlife habitat, flood prevention, nutrient export, recreational opportunity, and many others. The software uses a depth-benefit function for each of these services, and then for each parcel under consideration it calculates cumulative benefits over specified periods and sea level rise scenarios – benefits that can then be compared between parcels to help identify the best option for acquisition, restoration, or development.

In this project GEI provided a complete iteration of the MAST tool for 11 parcels selected by NWF, the Ipswich River Watershed Association, and project team members; details are provided in this report. An additional component of the community resiliency efforts reflects NWF's concern about potential real estate losses in the six Great Marsh communities. Under this category GEI was also enlisted to help evaluate risks to vulnerable assets from the combined threats of sea level rise and storm surge for one of these communities. Using the COAST software (Coastal Adaptation to Sea level rise Tool), GEI provided a complete no-action analysis for vulnerable real estate in Newburyport. Details on these related modeling efforts are provided in a separate report.

2. Methods

2.1 Site Selection

In collaboration with Task Force members, NWF staff, and local land conservation experts, staff at Ipswich River Watershed Association identified 43 candidate sites for the MAST initiative from among the combined coastlines of the six-town Great Marsh project area. Based on general assessments of which of these sites might contribute more to various local land management and protection initiatives, 11 of these parcels were selected to be modeled and ranked via the MAST process and software. Selection criteria included proximity to tidal wetlands, relatively flat topography (providing general expectation that gradual inundation was likely with rising sea levels), and in some cases there was some indication from representatives of the local conservation community that some of the 11 parcels were of potential conservation interest. An additional search goal was to provide geographic representation from throughout the six-town study area, allowing two parcels in each of the six towns. Site descriptions and overview maps are provided in Figs. 1 through 11 and a regional reference map showing locations of all 11 parcels is in Fig. 12.

2.2 Geographic Inputs

Digital Elevation Models (DEMs) were created for parcel locations by combining multiple DEM files from MASSGIS. The elevations within the DEMs were reported in NAVD88 (feet).

NOAA's VDATUM tool was used to calculate the difference between Mean Lower Low Water (MLLW) and NAVD88. Once this correction factor was calculated, the Highest Annual Tide (HAT) estimations for the eleven (11) parcels were converted from heights referenced in MLLW to heights referenced in NAVD88. The DEMs were then lowered by the HAT estimations so that sea level rise was starting from the HAT boundary.

Three sea level rise curves were used to evaluate the change in wetland benefits over time by 2100. These curves were developed by the Massachusetts Office of Coastal Zone Management (2013) and were designed to be used as guidance for various long-term planning exercises in coastal Massachusetts. Table 1, taken from this report, shows the three sea level rise scenarios used for analysis in the Great Marsh: "Highest," "Intermediate High," and "Intermediate Low."

2.3 Ecosystem Services Inputs

Because the MAST software is used to assess values of parcels relative to one another, not relative to an absolute standard, a pseudo-monetary unit was used (the "wetland benefit unit," or WBU). The WBU permits a valuation process that can reflect basic economic principles of valuation in the assessment of wetlands without having to rely on inherently difficult comparisons with market-based values. That is, it allows people to focus on the relative valuation problem within a constrained choice framework, avoiding the distractions of whether dollar estimates would be "realistic," either to participants in the process or users of the results (Merrill, 2015).

Participants in the Great Marsh MAST project were self-selected as a subset of a larger Task Force that had already been meeting to address goals of the NWF's Community Resiliency project. They included local residents and representatives from state agencies, land trusts, and other organizations in the region with an interest in adapting to a changing climate (Appendix A).

Participants were informed about how the model would operate, how the online survey would transpire, which ecosystem services would be used to weight each parcel, and what the benefit creation functions were for each included ecosystem service. This occurred in a meeting at the Ipswich River Watershed Association on July 28 2015. They were given a budget of 1,100 WBUs according to the methodology in Merrill (2015). The online survey program Qualtrix was used to host the survey. The following background text was used to orient participants:

> The National Wildlife Federation (NWF) Northeast Regional Office has identified 11 parcels of potential future coastal marsh that they would like to evaluate and compare using MAST. To estimate future ecosystem services values of these parcels, we must first estimate their current values. Here's where your help is needed.
>
> In this survey you are asked to assess current day values of 13 ecosystem services for each of 11 parcels. To accomplish this you now have a budget of 1,100 Wetland Benefit Units (WBUs) to distribute across all parcels. WBUs are like currency, used to represent the relative value you place on the parcels you are considering. You may then distribute the WBUs across the different ecosystem services for each parcel in any way you feel is appropriate. You may spend as much or as little time on the survey as you think is appropriate.
>
> You can spend less than a total of 1,100 units among all the parcels you are considering, but you cannot spend more than 1,100 in total. The survey program keeps track of the totals you enter for each site, but not of the totals for all sites. You may use the back button to return to previous questions. You will also be given the opportunity to change your estimates once you have completed the estimation section.
>
> Step 1: Divide the 1,100 units among the parcels. The primary question to ask yourself is: Based on the information available from handouts given to you at meeting on 7/28 and your local knowledge and experience about the parcels, which of these parcels is most valuable to you - for beauty, recreation, wildlife habitat, or other benefits you think you or society at large derive from it? This step can be completed on paper and before you even begin clicking through the remaining screens, using the handout received on 7/28 or the .pdf version of it circulated with the email link to this survey.
>
> Step 2: In the questions that follow, allocate the number of units across the ecosystem service categories for each parcel. If in Step 1 you allocated 150 units for Parcel 1, you would then divide those 150 units among the 13 ecosystem services for Parcel 1, and do the same each subsequent parcel. Here is a clarifying question for this Step: Does it appear that some services are particularly more available than others today on this parcel? For example:
>
> - If a parcel seems to have excellent views of a wetland today, perhaps you'd allocate more points to "aesthetics";

- If you think a parcel may be densely vegetated often, perhaps you'd allocate more points to "carbon sequestration"; and importantly,

- If you don't know about a particular ecosystem service in that location or don't value it highly, you'd allocate fewer or no points to that service.

The results of this survey will then be used by the MAST tool to estimate future ecosystem service values as they are created when sea level rises.

For each parcel participants then conducted their allocations in response to questions similar to this one:

Please enter your allocation of Wetlands Benefits Units to Parcel 1 under existing conditions for each of the following services. In evaluating the allocations you may consider all available data that you wish, including published data, expert opinion, and local knowledge. You may come back to change your estimates after you enter the WBU values for the other sites.

Besides descriptions of the ecosystem services at the July 28 2015 meeting, participants also received the following reference definitions:

1) Prevention of flood damages. *Coastal marshes are known to provide flood-buffering protection to adjacent real estate, through absorption and distribution of wave energy in water surging through them.*

2) Increase in land values. *Coastal marshes often dramatically increase property values of adjacent real estate.*

3) Effects on water quality through filtration of pollutants. *Runoff from adjacent uplands and entire watersheds often passes through coastal marshes. Pollutants in this water can be filtered through activity of microorganisms and complex chemical and nutrient pathways found in marshes.*

4) Drinking water supply. *Coastal marshes are a significant source of groundwater recharge.*

5) Recreation. *Coastal marshes provide numerous recreational opportunities such as boating, sightseeing, hiking and bird watching.*

6) Aesthetics. *Many people place high value on the aesthetic qualities of marshes – tranquility, beauty, etc.*

7) Carbon storage. *Carbon is stored as plant and animal biomass and helps mitigate climate change, among other benefits. Wetlands are known to represent substantial carbon storage activity.*

8) Habitat connectivity. *Some parcels are very connected to similar habitat or other natural resources, while other parcels are more isolated. Highly connected parcels may be more valuable for species migration, nutrient flow, and other processes.*

9) Habitat for any life stage of <u>commercial</u> species. *Some shellfish species spend their whole lives in coastal marshes while others depend on marshes only during crucial life stages (e.g., as fish nurseries).*

10) Habitat for any life stage of species <u>important to biodiversity</u>. *Biodiversity itself has value. For example, ecosystems with more diversity can often better withstand temperature extremes. Some components of marsh biodiversity may rely upon the marsh for only part of their life cycles.*

11) Nutrient export for commercial species. *Coastal marshes produce large volumes of nutrients important to many commercial species; loss of these nutrients would compromise the health and productivity of these populations.*

12) Nutrient export for biodiversity. *Coastal marshes produce large volumes of nutrients important to many species critical to biodiversity; loss of these nutrients would compromise the health and productivity of these populations.*

13) Research value. *Coastal marshes serve as living laboratories for exploration and research about how marshes function, the services they provide, and how human activities influence them.*

Because the survey process was an auction, the highest allocation stated for each ecosystem service on each parcel is the number of WBUs used as the actual "value" for that service, according to this group of participants (Table 2). In general, the process is socially driven, allowing for individual and values-based differences and perceptions of both monetary and non-monetary benefits to be adequately incorporated in a single metric. It is also a process in careful reference to best available science, via benefit creation functions revised in each location where MAST modeling occurs (functions shown in Appendix B). At the beginning of this project benefit creation functions to be used in the study were revised from those used in earlier MAST efforts (in Maine), tailoring them to the range of wetland types and tidal extents more typical in northeastern Massachusetts.

2.4 Software Operation

Once all data inputs were incorporated and made available to the model, cumulative simulations were run for each sea level rise scenario. The software created flooding layers for each year in each scenario, inundating parcels gradually over time and tallying benefits that accrued on wet portions of each parcel according to the benefit creation functions for each ecosystem service. Benefits were also tallied on the dry portions of each parcel in the same manner, in reference to a zero-depth value from the benefit creation function for each ecosystem service. For a generic 100-acre parcel, Fig. 13 illustrates portions of each parcel that would be subjected to the wet-benefit curves at the appropriate depth and what portions would be subjected to zero-depth levels from the same curves, with three different amounts of sea level rise having occurred.

Project team discussing MAST results

3. Results

3.1 Survey Outcomes

Online survey results for the 11 parcels are in Table 2. These initial allocations represent the relative values placed on each ecosystem service by the participants. They also establish a starting condition for how benefits will accrue on the parcels over time under the different sea level rise scenarios and given variations in topography between parcels. From the bottom of the table reading up: Low allocations were confirmed by the group for the ecosystem service values "Research" and "Nutrient Export." There were moderate allocations for the several categories of "Habitat" value, and relatively high allocations for "Habitat connectivity," especially on parcel 9, the largest of the 11. Moderate allocations were confirmed for carbon storage, aesthetics, and recreation, except on parcel 9 for recreation. Relatively low allocations were confirmed for water quality benefits and impacts on land values, except for parcels 9 and 3 that received allocations of 100 WBUs each for water quality benefits. There were high allocations for flood damage prevention on parcels 9, 6, and 3. Across parcels, flood damage prevention and habitat connectivity received the largest number of initial WBU allocations.

3.2 Cumulative Benefits over Time

Cumulative ecosystem services benefit tallies over the three sea level rise scenarios are in Fig. 14, clearly indicating parcel 9 accumulated the largest number of WBUs in all three scenarios. Observers may suspect this result is entirely due to parcel 9 being much larger than the others. This is partially true. That is, participants were aware of differences in size between the parcels and therefore had the opportunity to weight parcels based on their size. This is reflected in the allocations in Table 2: although parcel 9 was 2.7 – 22.6 times larger than the other 10 parcels, allocated WBUs indicate a much smaller variability, with WBUs for parcel 9 only ranging 1.8 – 6.6 times larger than the other 10 parcels. This is a reflection of area-standardization that occurred through the WBU allocation process, before the MAST software was run.

Also notable is that cumulative benefits for parcel 9 are at least several times larger than those for the other parcels, whereas initial allocations for the next highest-scoring tier of parcels (parcels 3, 4, and 6; Table 2), were only half as much as those for parcel 9. This indicates that while observers may suspect the results are driven by area effects, which is partially correct, other factors are clearly involved in determining the difference in cumulative benefits over time between parcel 9 and the others. These include topography at the site of each parcel, shape of individual benefit creation functions, distribution of their initial allocations across parcels, and interaction of each of these over time in the different sea level rise scenarios. Software like MAST is required to identify how these different factors influence ecosystem services that may accrue over time.

After the modeling was complete, Parcel 9 again scored highest for these cumulative dry benefits but this effect was lessened on account of local topography: at some point after 1.9' of sea level rise the parcel became mostly inundated by high tide every day. The result for was that while dry benefits were large for the 1.9' sea level scenario, in the 4.2' and 6.8' sea level rise scenarios the high tide line had moved far across the parcel (Fig. 9) and these dry benefits dropped of precipitously (Figs. 15a, b). This is in contrast with parcels 8 and 10, for example, for which inundation extents did not change much between 1.9' and 6.8' of sea level rise by 2100 (Figs. 8 and 10), and cumulative dry benefits continued to build in these scenarios (Figs. 15a, b). Similar comparisons can be made for other pairs in the collection of 11 parcels.

4. Discussion

It is now well recognized that land conservation can be a constructive component of sea level rise adaptation planning efforts. Examples include work demonstrating the utility of incorporating ecosystem services valuations into coastal planning and prioritization efforts (Arkema et al. 2015), showing beneficial connections between coastal land conservation and community planning efforts (Benedict et al. 2006, Lucius et al. 2011) and quantifying benefits to businesses of coastal habitat protection in an era of marsh migration (Reddy et al. in press). Results from this study should therefore provide a useful reference in efforts to develop sea level rise adaptation strategies for the Great Marsh.

Whether comparing wetland benefits on the wet portions of the parcels as they became wet or comparing both dryland and wetland benefits over time, the modeling exercise indicated that according to the stated values of the selected group of participants, and adjusting for size differences between parcels, parcel 9 appears to be the most valuable parcel under all sea level rise scenarios (Figs. 14 through 16). The second-highest cumulative score was for parcel 6, also in all sea level rise scenarios and in both wet and combined wet and dry classifications (Figs. 14 through 16). The third-highest cumulative score was nearly equivalent between parcels 3 and 4, under both wet and combined wet and dry cumulative tallies (Figs. 14 and 16). In general, the study shines light on issues of prioritization and gradual landscape change that could be considered both in conducting a regional vulnerability assessment and in creating an adaptation plan that takes marsh migration into account. Specifically, it could help land conservation organizations evaluate conservation priorities and opportunities among these or similarly-situated Great Marsh parcels.

With these intents understood, it is equally important to understand what the study does *not* do. It is not a definitive statement about how the modeled coastal areas will change over time or more specifically, where exactly wetlands are likely to emerge or what specific ecosystem services will emerge in which locations. The scientific modeling on these points has substantial limits including relying on relationships between depth and ecosystem services, whereas many other factors are likely to be strong drivers including land use change over time and changes in habitat connectivity at local or regional scales. And although the depth relationships relied on wetland experts and literature review and were somewhat customized for tidal ranges and broad types of wetlands in Massachusetts, there may have been either more or less variability among the 11 parcels than is reflected in the benefit functions used. Also not considered are transverse or horizontal effects of current; varying sedimentation rates or salinity curves between parcels; and diverse influences from adjacent land use types or development contexts. Further, important assumptions about the future were made including that wet portions of a parcel would in fact convert to wetlands and that roads required to access a parcel would be maintained and/or elevated under high sea level rise scenarios.

Similarly, although a significant component of the work is values-driven and based on participant opinion survey, the study is also not a definitive statement about the values of a diverse or representative group of stakeholders in the six Great Marsh communities. That is, initial WBU allocations were largely a result of who participated in the survey. Participation by representatives from different stakeholder groups would certainly have produced dramatically different results.

Nevertheless, the above caveats need to be understood in light of the goals of the study, which did *not* include predicting the future of wetland extents with extreme precision or conducting a comprehensive survey of stakeholder values. The single goal was to examine the relationship between: 1) broad categories of physical changes that might be expected in these coastal wetlands when sea levels rise; and 2) changes in the economic uses of these wetlands, as reflected by value allocations of the land conservation-oriented participants recruited for the project. Regarding this goal, and because land conservation is now understood to be a critical component of meaningful coastal adaptation plans, details about interactions between these two sets of changes can help inform these planning efforts.

Note that whereas the present results may help inform land prioritization questions from a conservation perspective, a more diverse set of participants could shine light on strategic adaptation planning questions more broadly. If a similar survey were to be conducted in the Great Marsh, it could also be beneficial to include local government representatives, active recreational users of the candidate parcels, real estate professionals, those who rely on the wetlands for extractive uses to support their livelihoods, and many others. Results in the initial WBU allocations and in the final cumulative WBU rankings would be expected to differ significantly from those in this study.

With this or another group of participants, it could also be beneficial to take the additional step of identifying which parcel(s) would likely provide the greatest levels of particular ecosystem services under the modeled scenarios. This could help evaluate, for example, which parcel could provide greater flood buffering capacity when it is gradually inundated. However the current version of the software does not allow breaking out individual contributions of each ecosystem service from the cumulative tallies for each parcel. The desired goal could be reached by scoping a project to either: 1) re-run the set of simulations with individual ecosystem services for each parcel (11 parcels x 13 services = 143 simulations or a selected subset); or 2) upgrading the software to incorporate this functionality and re-running the scenarios once.

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Tables

Table 1. Relative sea level rise estimates for Boston, MA (MA CZM, 2013).

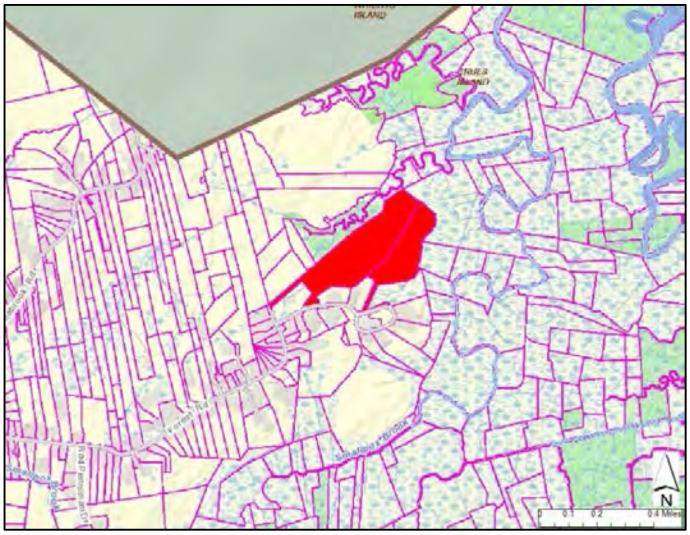
Scenario	2025		2038		2050		2063		2075		2088		2100	
	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m
Highest	0.49	0.15	1.08	0.33	1.81	0.55	2.80	0.85	3.92	1.19	5.33	1.63	6.83	2.08
Intermediate High	0.36	0.11	0.73	0.22	1.19	0.36	1.80	0.55	2.47	0.75	3.32	1.01	4.20	1.28
Intermediate Low	0.24	0.07	0.43	0.13	0.65	0.20	0.92	0.28	1.21	0.37	1.55	0.47	1.91	0.58
Lowest (Historic Trend)	0.18	0.06	0.29	0.09	0.39	0.12	0.50	0.15	0.60	0.18	0.71	0.22	0.81	0.25
Range	0.31	0.09	0.79	0.24	1.42	0.43	2.30	0.70	3.32	1.01	4.62	1.41	6.02	1.83

Table 2. Online survey results for the 11 study parcels.

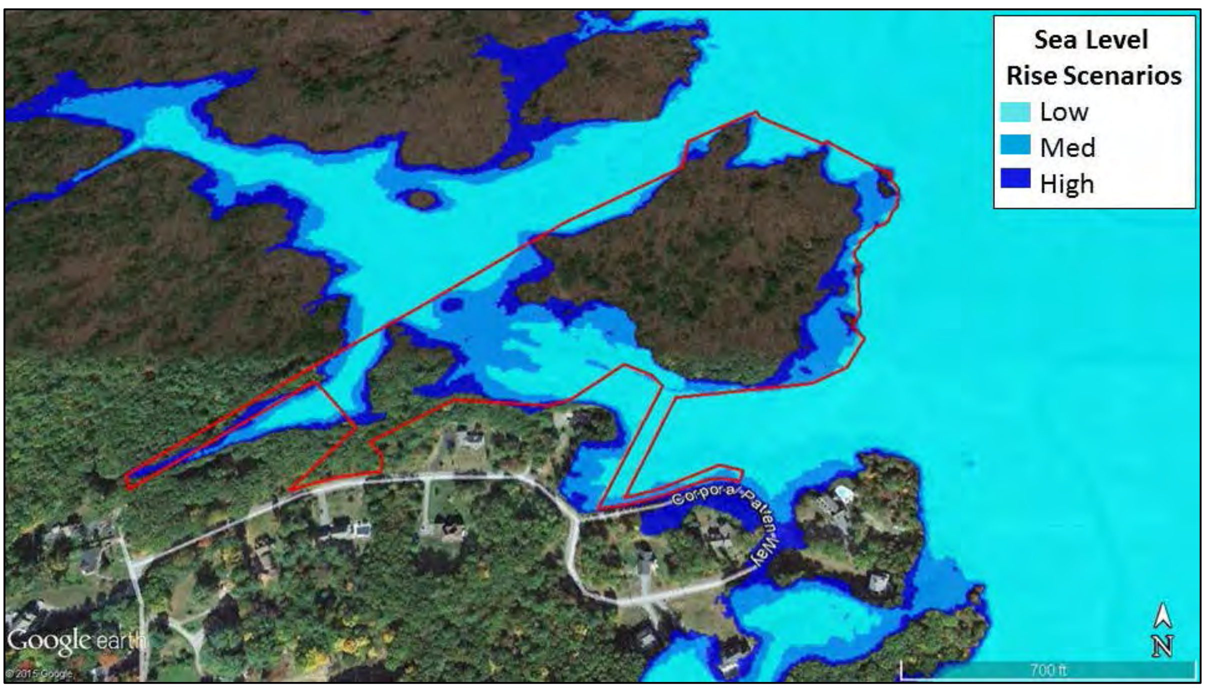
		Parcels											
	Services	1	2	3	4	5	6	7	8	9	10	11	**Totals**
1	Prevention of flood damages	50	30	100	75	6	100	30	75	100	25	20	611
2	Increased land values	20	50	18	10	16	20	10	16	40	10	10	220
3	Water quality	10	10	100	30	10	20	20	30	100	10	20	360
4	Drinking water supply	10	10	10	10	10	10	20	10	30	10	15	145
5	Recreation	10	25	20	50	10	50	25	40	100	15	10	355
6	Aesthetics	10	10	30	50	10	25	20	40	50	10	10	265
7	Carbon storage	20	25	20	20	10	30	25	10	50	10	40	260
8	Habitat connectivity	50	25	90	50	15	50	30	50	200	10	20	590
9	Habitat for commercial sp.	50	10	20	75	10	75	10	50	70	10	10	390
10	Habitat for biodiversity	25	15	15	75	20	50	25	50	50	10	20	355
11	Nutrient export for commercial sp.	8	25	20	10	10	15	10	10	30	5	10	153
12	Nutrient export for biodiversity	5	6	30	20	20	30	25	10	50	6	20	222
13	Research value	9	5	20	10	5	10	5	8	30	5	8	115
	(acres)	*33*	*46*	*146*	*134*	*23*	*148*	*191*	*125*	*571*	*27*	*130*	
	Totals	277	246	493	485	152	485	255	399	900	136	213	

Figures

Fig. 1. Location map, parcel description, and sea level rise inundation maps for Parcel 1, Little River Area, Salisbury (32.7 acres).

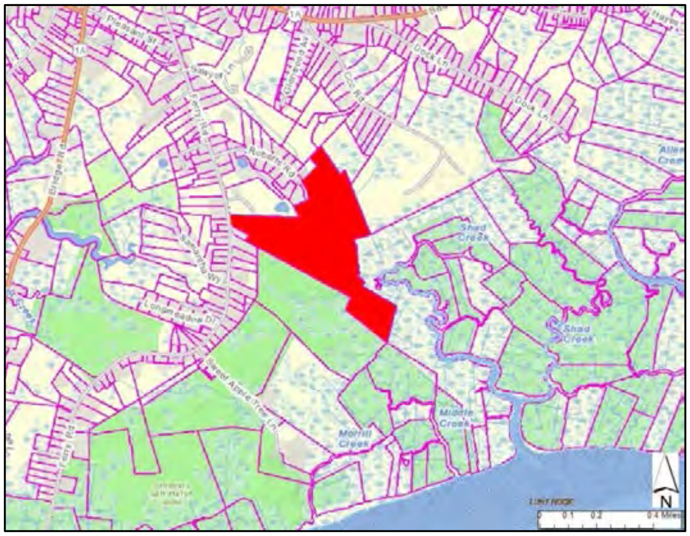


Parcel 1 is located in northern Salisbury off of Forest Road, just north of Corporal Patten Way, south of the MA/NH border, and west of Dead Creek and Rt. 1A. Its 32.70 acres are mostly comprised of forested areas that abut residential properties. Corporal Patten Way is a cul-de-sac and the properties on this road have wetlands to the south and east. The Commonwealth of Massachusetts owns a 6-acre property abutting this parcel on the north called Carr's Cove. The town often receives inquiries about developing this whole area, connecting Forest Road and Seabrook Road. This property is comprised of two tax parcels owned by different landowners.

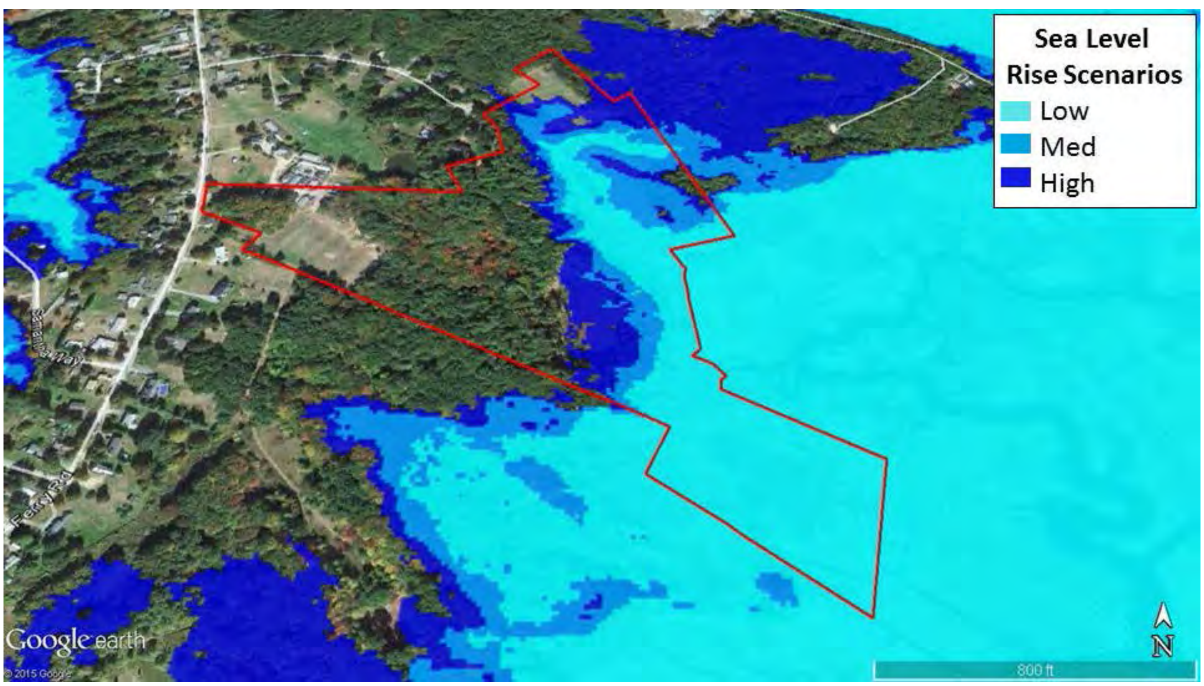


*Note: Graphical representation of flood inundation for each sea level rise scenario is based on steady state hydraulic modeling of water surface elevations. The map shows approximate inundation areas for given water surface elevations and should not be used for navigation, permitting, or other legal purposes, but for general reference purposes only."

Fig 2. Location map, parcel description, and sea level rise inundation maps for Parcel 2, Shad Creek area, Salisbury (46.42 acres).

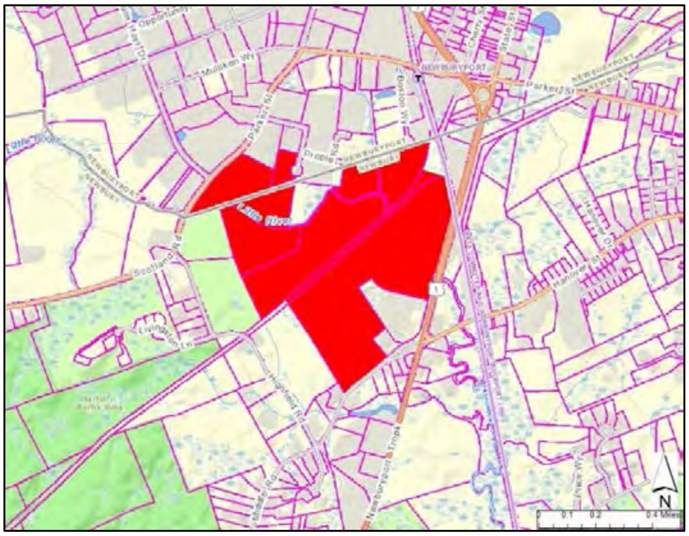


Parcel 2 is located in southern Salisbury off of Ferry Road. It is located north of the Merrimack River, east of Route 1, west of Shad Creek, and south of Beach Road/Route 1A. The Pettengill Flower Farm and the Pines Camping Area abut the parcel. South of the parcel is land owned by the State as a wildlife management area.

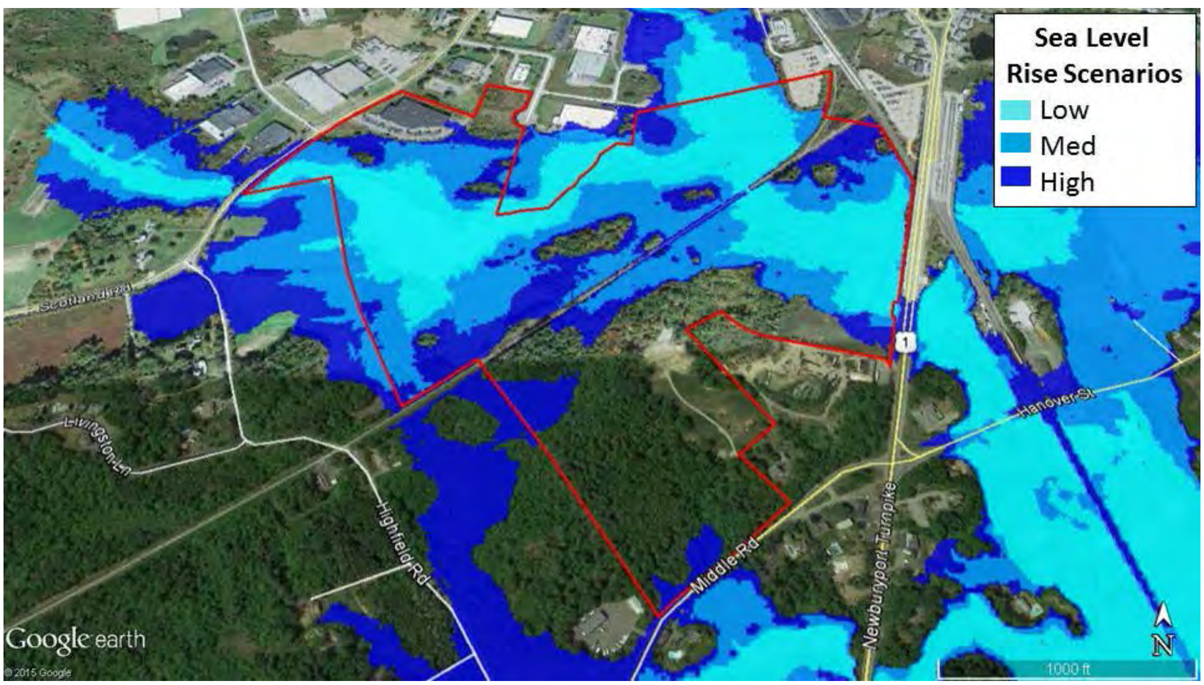


*Note: Graphical representation of flood inundation for each sea level rise scenario is based on steady state hydraulic modeling of water surface elevations. The map shows approximate inundation areas for given water surface elevations and should not be used for navigation, permitting, or other legal purposes, but for general reference purposes only."

Fig 3. Location map, parcel description, and sea level rise inundation maps for Parcel 3, Little River area, Newburyport and Newbury (145.66 acres).

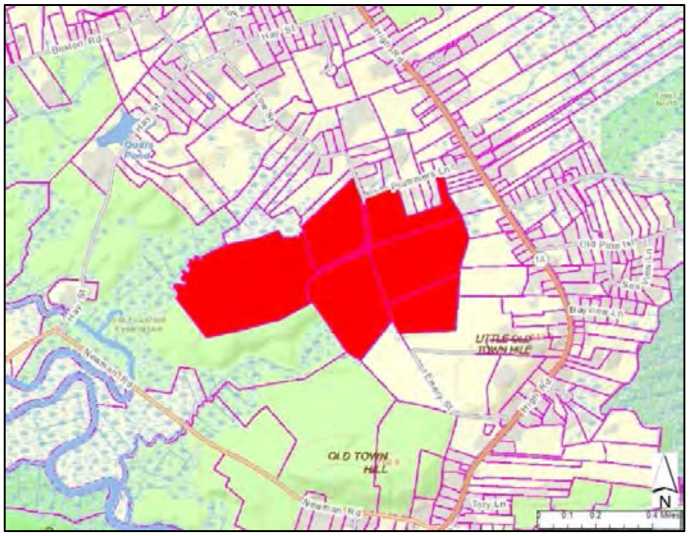


Parcel 3 includes land in both Newburyport and Newbury, and is located between Scotland Road, Middle Road, Route 1, and the Newburyport Industrial Park. The parcel's 145 acres are comprised of forested areas with some wetland in the northeast and some small cleared areas. A portion of the Little River runs through the property, and it abuts agricultural conservation land, including the Common Pasture, to the west. A 10-acre portion of the lot has been permitted for a large ground-mounted solar array.

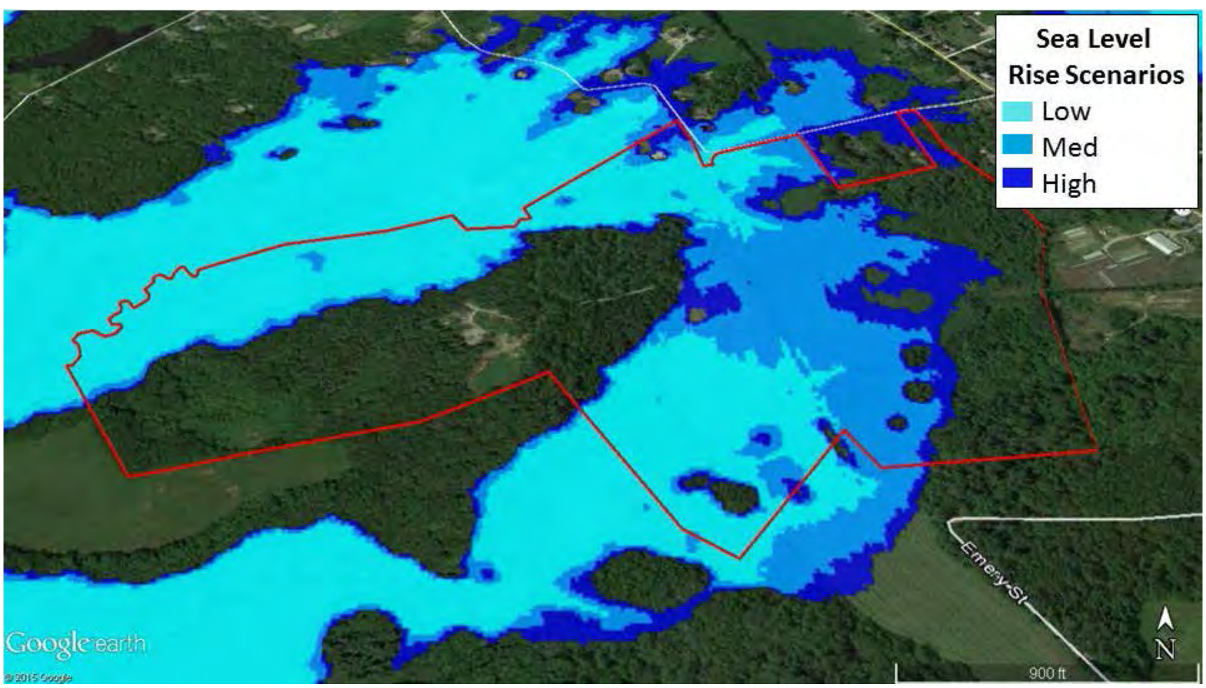


*Note: Graphical representation of flood inundation for each sea level rise scenario is based on steady state hydraulic modeling of water surface elevations. The map shows approximate inundation areas for given water surface elevations and should not be used for navigation, permitting, or other legal purposes, but for general reference purposes only."

Fig 4. Location map, parcel description, and sea level rise inundation maps for Parcel 4, Old Town Hill Area, Newbury (133.67 acres).



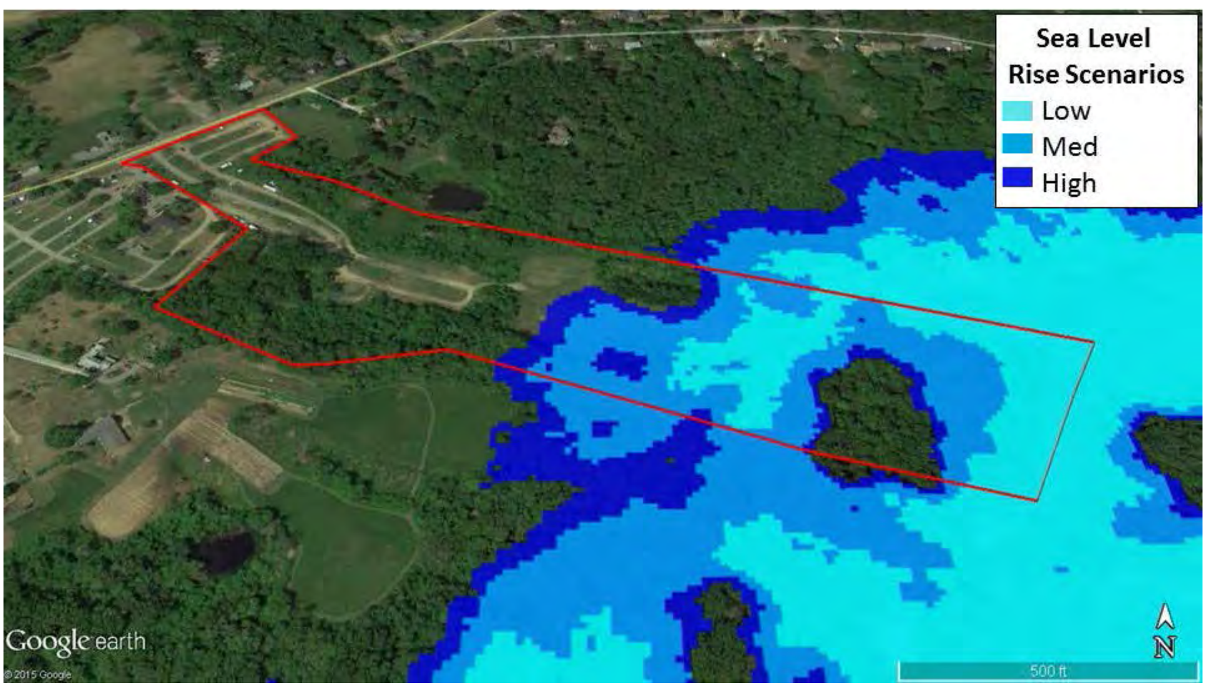
Parcel 4 is located in located in Newbury, north of Newman Road, east of Hay Street, and southwest of Route 1A. Its 133 acres are comprised of forested areas and farmland, with wetlands abutting. West and south of this area is Old Town Hill, a 531-acre conservation area owned by the Trustees of Reservations, bordering the Parker River, which includes well-used recreational trails and a portion of the Bay Circuit Trail. North of the parcel are residential lots.



*Note: Graphical representation of flood inundation for each sea level rise scenario is based on steady state hydraulic modeling of water surface elevations. The map shows approximate inundation areas for given water surface elevations and should not be used for navigation, permitting, or other legal purposes, but for general reference purposes only."

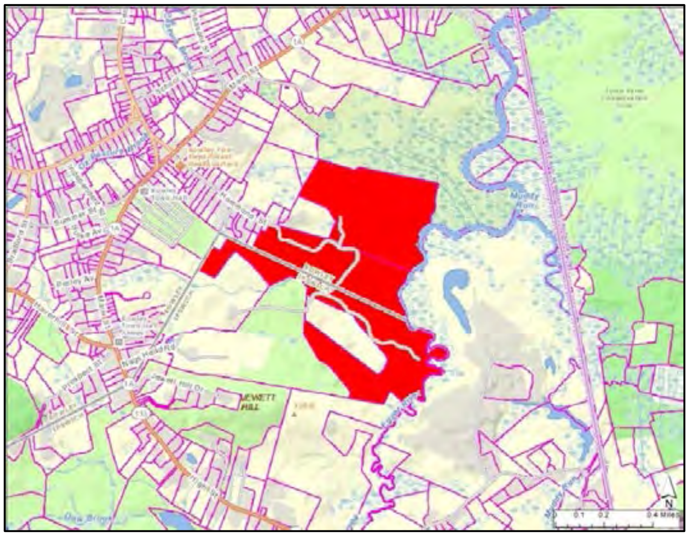
Fig 5. Location map, parcel description, and sea level rise inundation maps for Parcel 5, 283 Main Street, Rowley (22.57 acres).

Parcel 5 is located on Route 1A just north of the Bradstreet Farm Conservation Area and the center of Rowley. It is west of the Rowley River and wetlands, including the Town of Ipswich's Town Farm Conservation Area. It is just south of 26 acres of conservation land owned by the Town of Rowley.

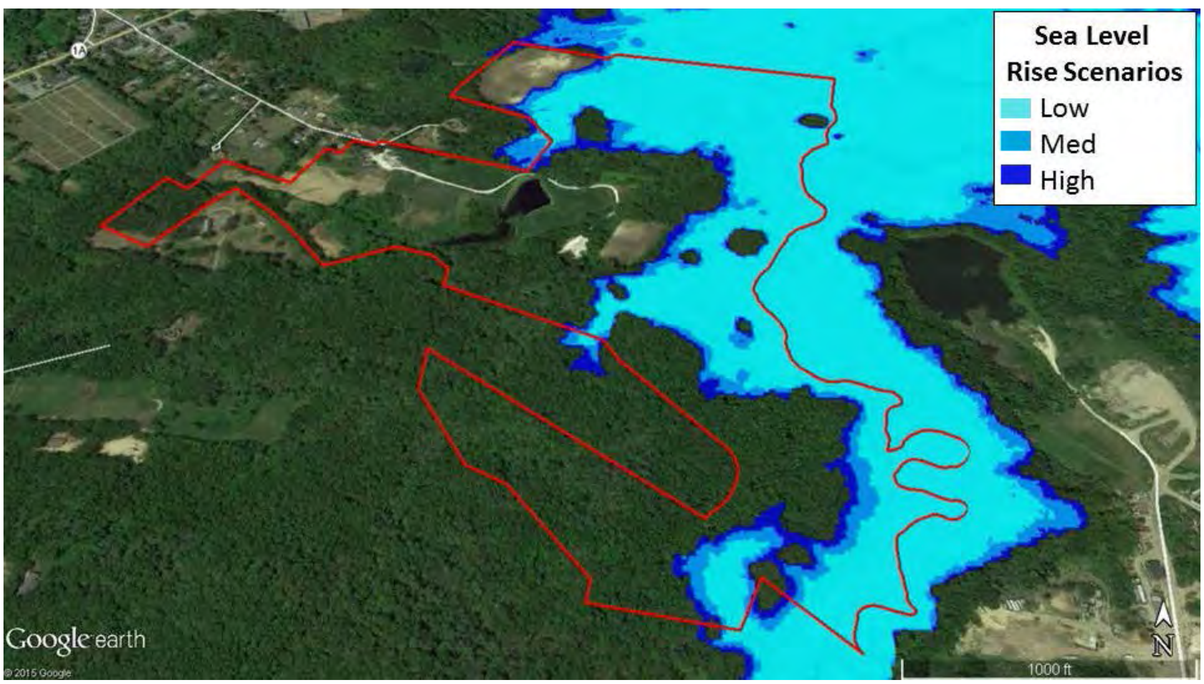


*Note: Graphical representation of flood inundation for each sea level rise scenario is based on steady state hydraulic modeling of water surface elevations. The map shows approximate inundation areas for given water surface elevations and should not be used for navigation, permitting, or other legal purposes, but for general reference purposes only."

Fig 6. Location map, parcel description, and sea level rise inundation maps for Parcel 6, Hammond Street area, Rowley and Ipswich (147.64 acres).

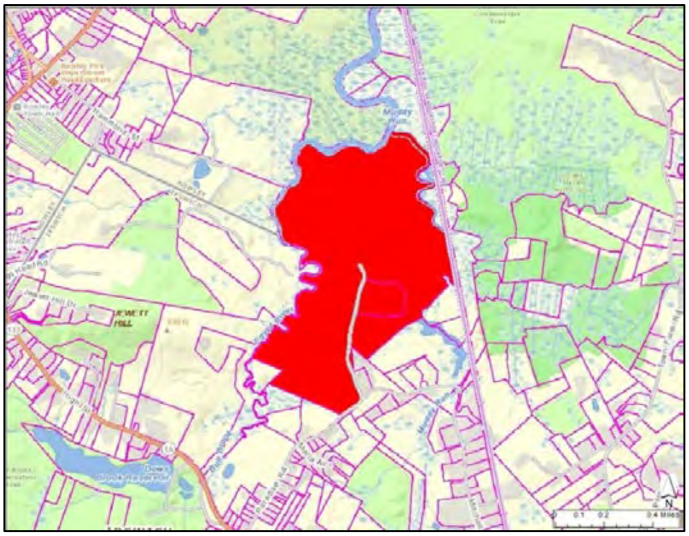


Parcel 6 is located in Rowley and Ipswich, east of Rt. 1A and directly west of Muddy Run and the Rowley River. Its 147 acres are comprised of forested areas, tidal wetlands, and farmland. North of the parcel is the 103-acre Bradstreet Farm Conservation Area. South of the parcel is Jewett Hill which has private land recently conserved with the Essex County Greenbelt Association. The Bay Circuit Trails Association has long envisioned an extension of their long distance hiking trail traversing this land.

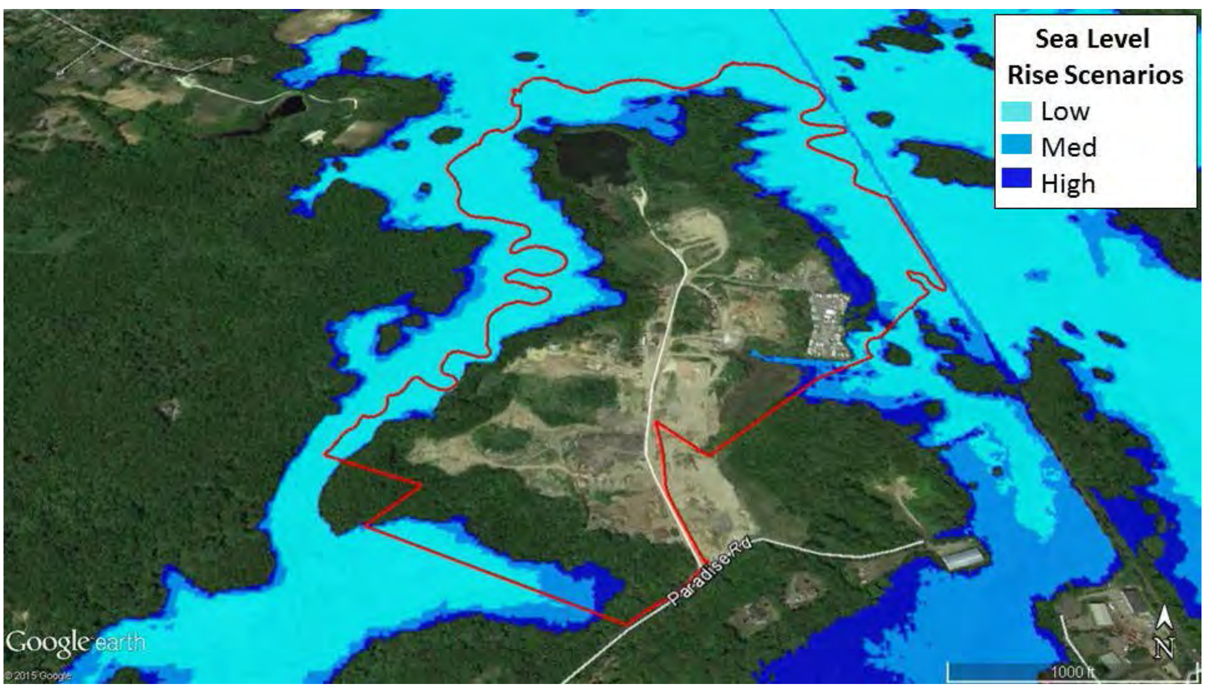


*Note: Graphical representation of flood inundation for each sea level rise scenario is based on steady state hydraulic modeling of water surface elevations. The map shows approximate inundation areas for given water surface elevations and should not be used for navigation, permitting, or other legal purposes, but for general reference purposes only."

Fig 7. Location map, parcel description, and sea level rise inundation maps for Parcel 7, Miles River area (191.06 acres).

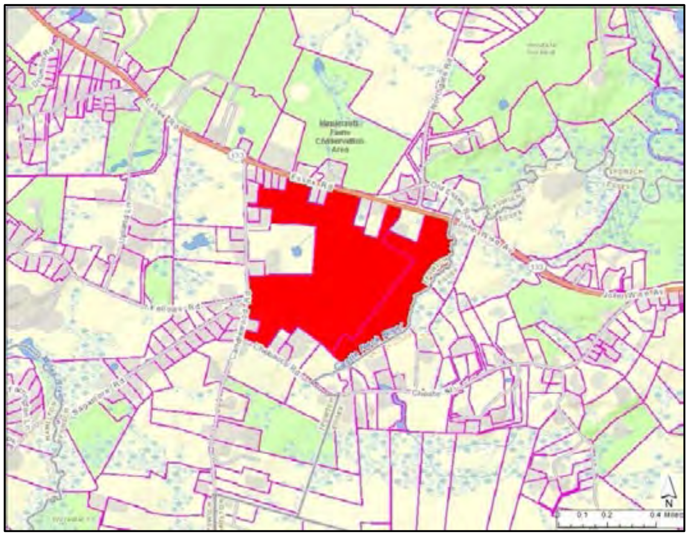


Parcel 7 is located in Ipswich, north of Paradise Road, east of the Egypt River, and west of Muddy Run, the railroad tracks, and the town of Ipswich's Town Farm Conservation Area. Its 191 acres are comprised of forested and wetland areas. In the center of the parcel there is a large cleared area used for industrial purposes, with multiple gravel pits throughout, a small pond, and a boat storage area.



*Note: Graphical representation of flood inundation for each sea level rise scenario is based on steady state hydraulic modeling of water surface elevations. The map shows approximate inundation areas for given water surface elevations and should not be used for navigation, permitting, or other legal purposes, but for general reference purposes only."

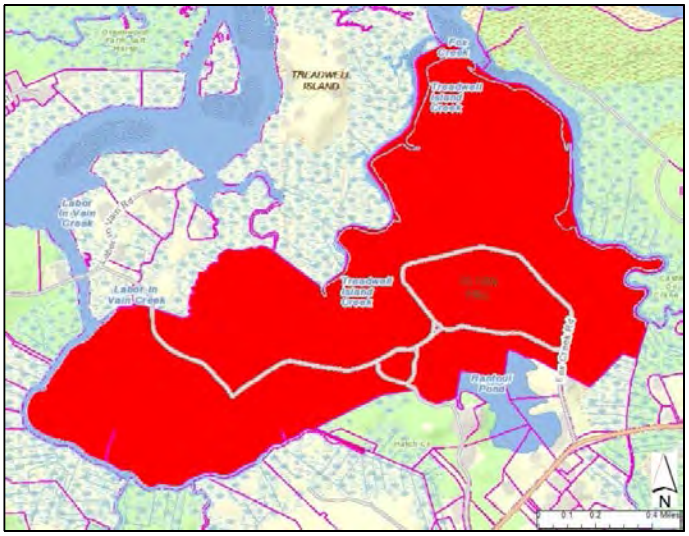
Fig 8. Location map, parcel description, and sea level rise inundation maps for Parcel 8, Castle Neck headwaters, Ipswich (124.96 acres).



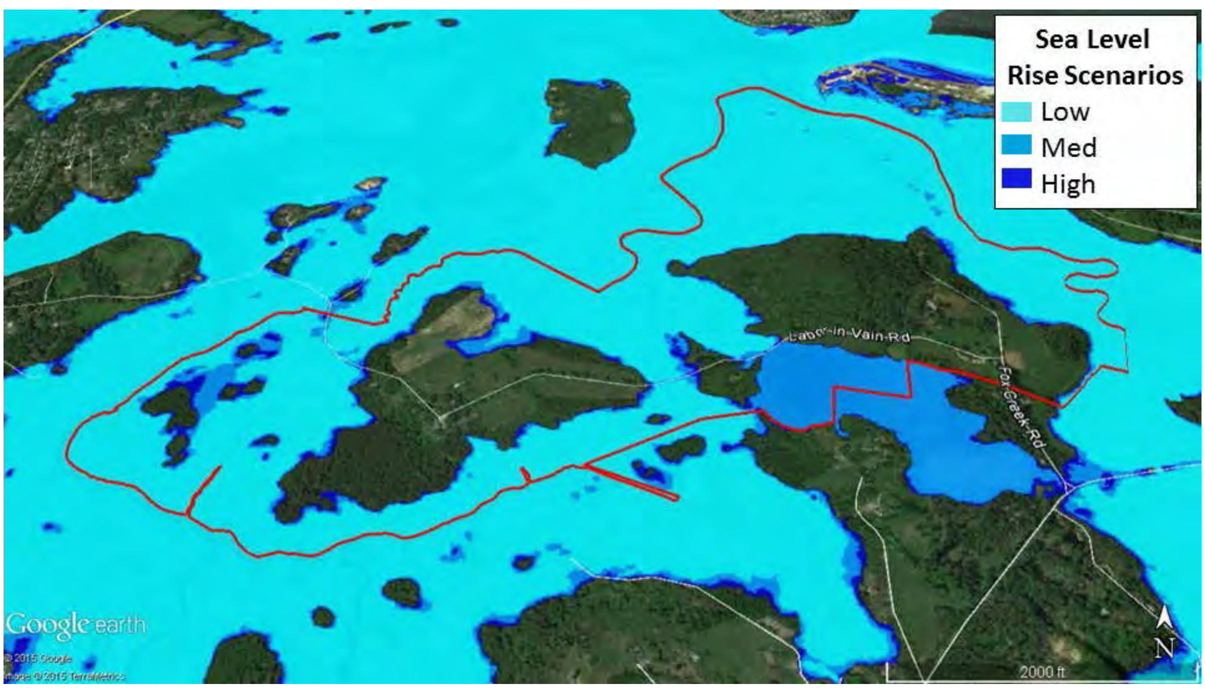
Parcel 8 is located in Ipswich, south of Route 133, east of Candlewood Road, and north of Chebacco Road. Its 125 acres are comprised mostly of cleared land with fields that service a polo horse farm. There are some forested areas in the western section that abut a tidal wetland and the headwaters of the Castle Neck River. There are some residential properties along Rt. 133 and Chebacco Road, and the conserved Maplecroft Farm is located on the north side of Route 133.

*Note: Graphical representation of flood inundation for each sea level rise scenario is based on steady state hydraulic modeling of water surface elevations. The map shows approximate inundation areas for given water surface elevations and should not be used for navigation, permitting, or other legal purposes, but for general reference purposes only."

Fig 9. Location map, parcel description, and sea level rise inundation maps for Parcel 9, Labor in Vain/Fox Creek area, Ipswich (525.10 acres).

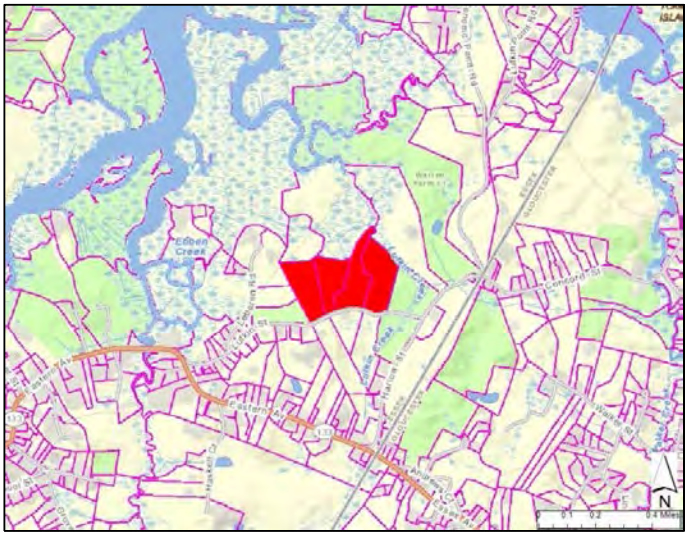


Parcel 9 is located in Ipswich, northwest of Argilla Road, west of The Trustees of Reservation's Crane Estate and Castle Hill, and east of Labor-in-Vain Road. Its 525 acres are comprised mostly of tidal wetland areas associated with Fox Creek and Labor-in-Vain Creek, with some upland forested areas and cleared land surrounding a road that runs through the center of the parcel.



*Note: Graphical representation of flood inundation for each sea level rise scenario is based on steady state hydraulic modeling of water surface elevations. The map shows approximate inundation areas for given water surface elevations and should not be used for navigation, permitting, or other legal purposes, but for general reference purposes only."

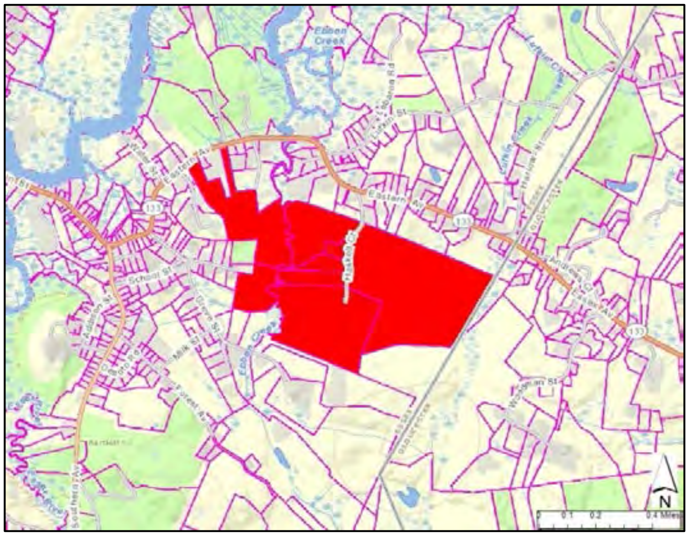
Fig 10. Location map, parcel description, and sea level rise inundation maps for Parcel 10, Lufkin Creek area, Essex (26.74 acres).



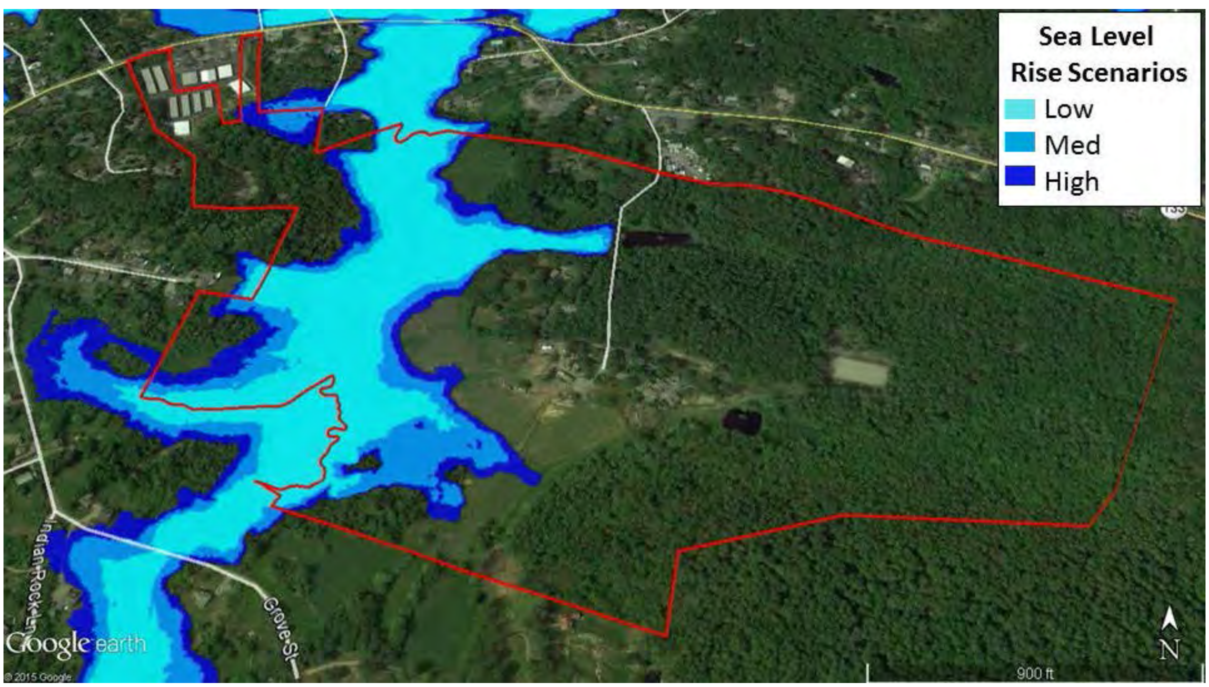
Parcel 10 is located in Essex, north of Lufkin Street, and west of Lufkin Creek and Conomo Point Road. Its 26 acres are comprised of forested and agricultural areas, with a large tidal wetland to the north. There are multiple residences to the south as well as nearby conservation land.

*Note: Graphical representation of flood inundation for each sea level rise scenario is based on steady state hydraulic modeling of water surface elevations. The map shows approximate inundation areas for given water surface elevations and should not be used for navigation, permitting, or other legal purposes, but for general reference purposes only."

Fig 11. Location map, parcel description, and sea level rise inundation maps for Parcel 11, Ebben Creek area, Essex (129.79 acres).



Parcel 11 is located in Essex, south of Rt. 133 and east of Grove Street and Southern Avenue. Its 130 acres are mostly forested with cleared land and wetlands in the center. This area includes the headwaters of Ebben Creek which flows north to Essex Bay. There is conservation land to the southeast along Southern Ave and to the southwest where Gloucester's watershed protection lands are located.



*Note: Graphical representation of flood inundation for each sea level rise scenario is based on steady state hydraulic modeling of water surface elevations. The map shows approximate inundation areas for given water surface elevations and should not be used for navigation, permitting, or other legal purposes, but for general reference purposes only."

Fig. 12. Reference map showing locations and relative size of all 11 parcels.

Fig. 13. Schematic illustrating dry benefits versus wet benefits that accrue and are recorded by the software on modeled parcels under the three selected sea level rise scenarios.

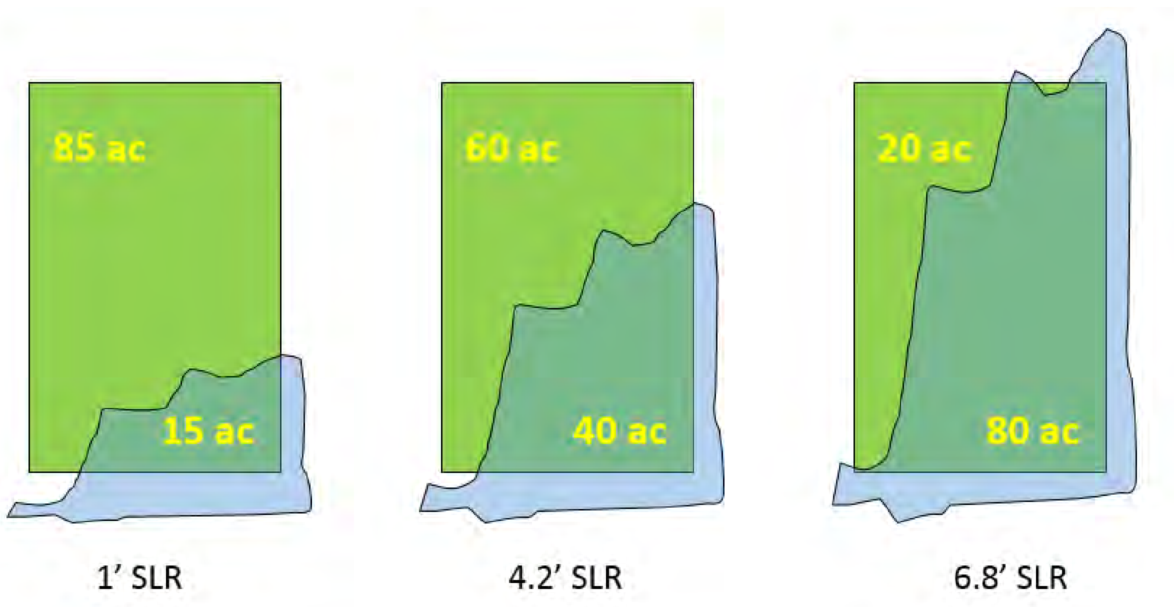


Fig. 14. Cumulative wetland benefits in three sea level rise scenarios.

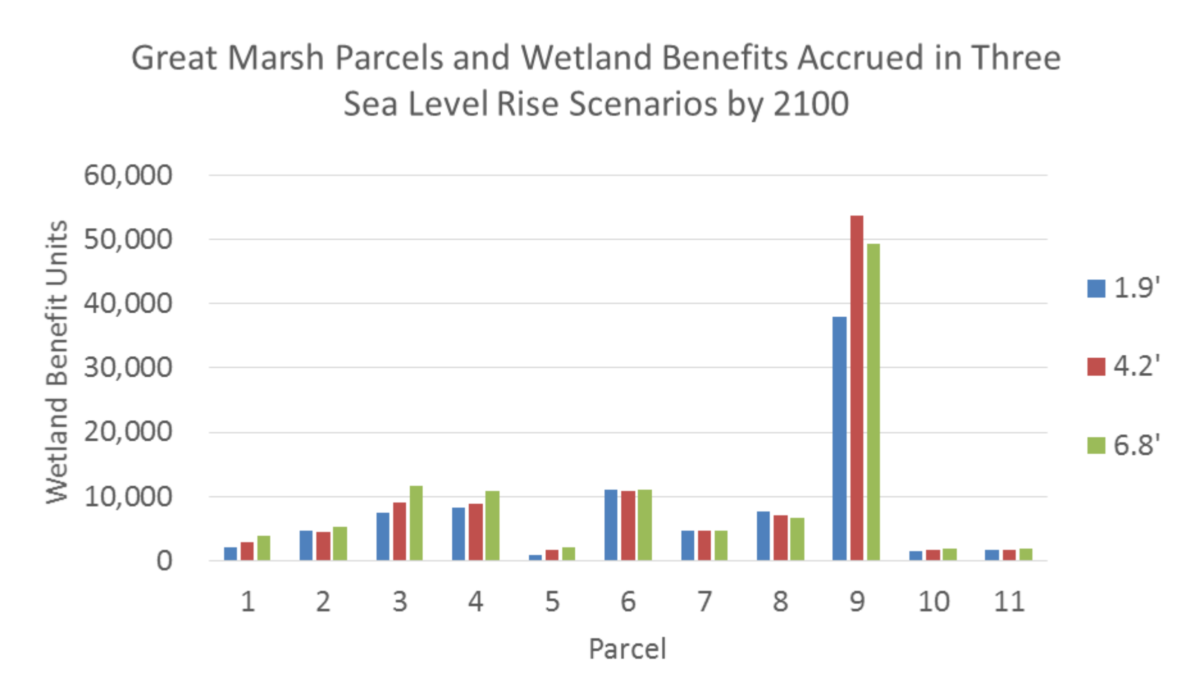


Fig. 15a. Cumulative dryland benefits in three sea level rise scenarios.

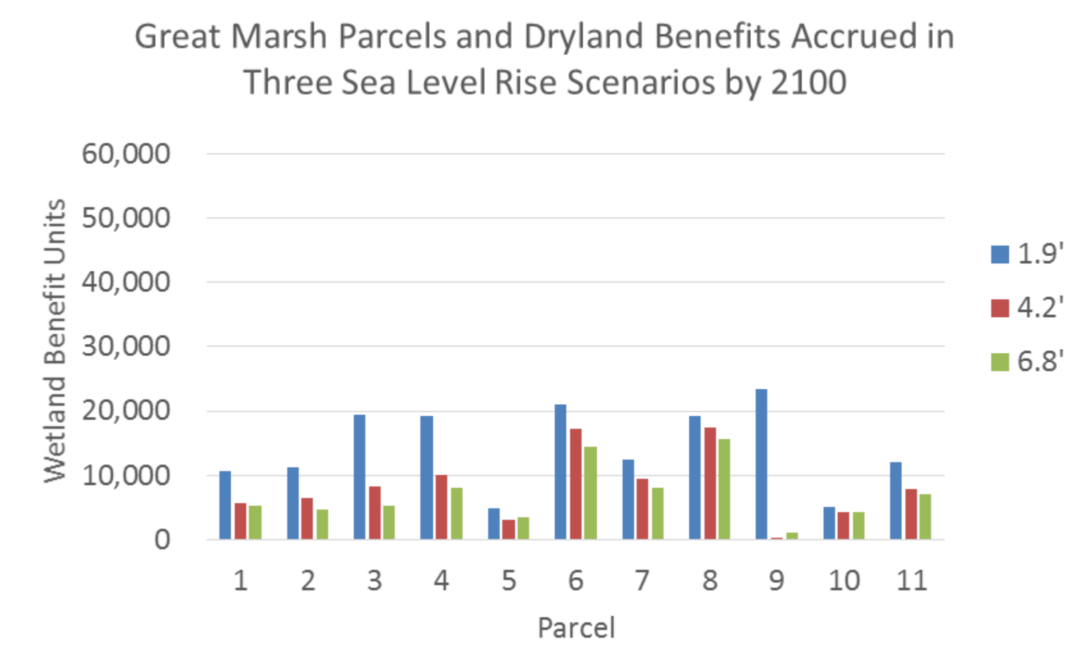


Fig. 15b. Cumulative dryland benefits in three sea level rise scenarios.

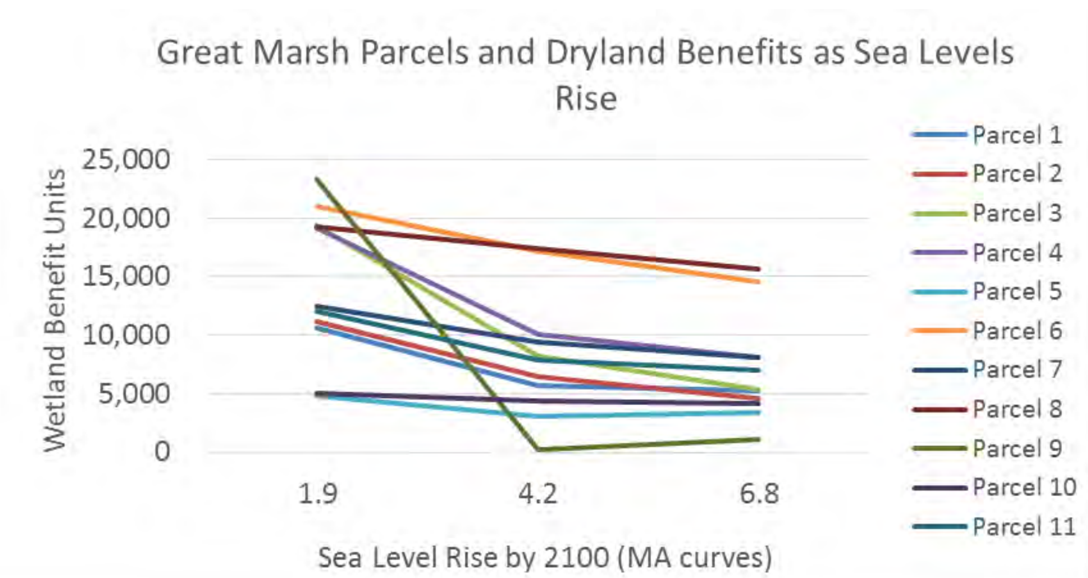
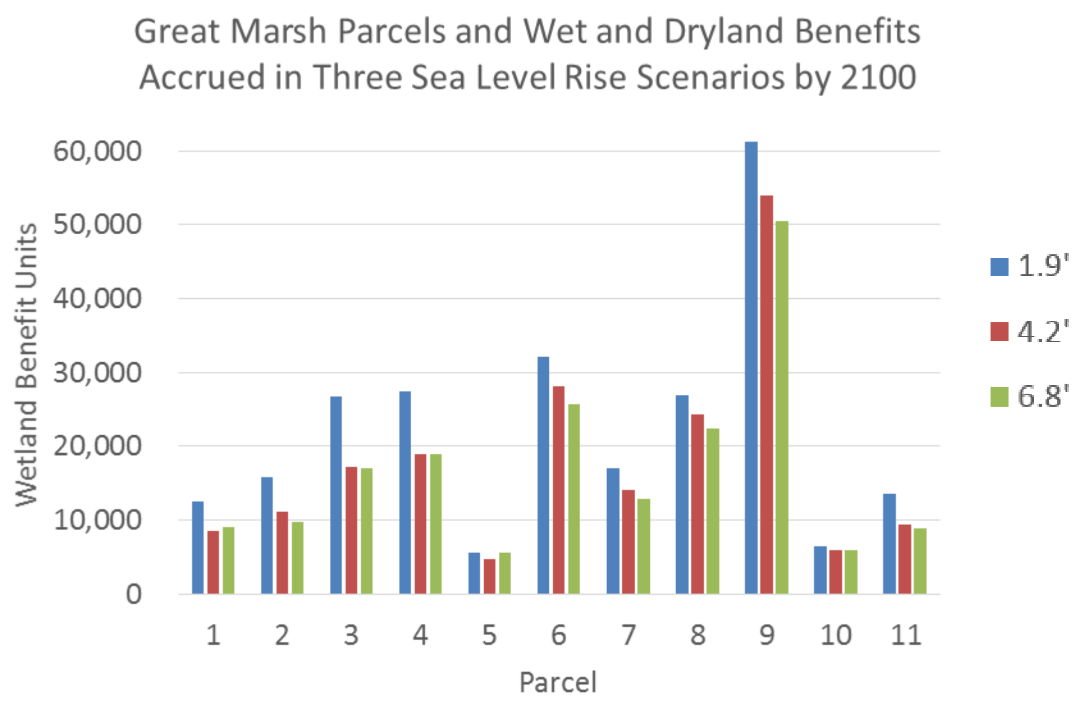


Fig. 16. Cumulative wetland and dryland benefits in three sea level rise scenarios.



Appendix A

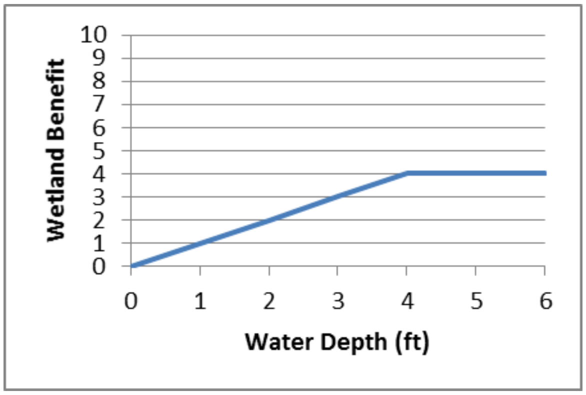
MAST Survey Participants

Name	**Affiliation**
Christine Berry	MA Department of Conservation and Recreation
Wayne Castonguay	Ipswich River Watershed Association
Liz Duff	MA Audubon
Anne Gagnon	MA Department of Fish and Game
Kristen Grubbs	Ipswich River Watershed Association
Russel Hopping	Trustees of Reservations
Christopher LaPointe	Essex County Greenbelt Association
Jessica Locke	High school student, town of Rowley
Alyssa Novak	Boston University
Peter Phippen	Merrimack Valley Planning Commission
Michelle Rowden	Salisbury Conservation Agent
David Santomenna	Trustees of Reservations
David Standley	Ipswich Conservation Commission
Joe Teixeira	Newbury Conservation Commission
Jennifer Troisi	Salisbury Conservation Commission
Geoff Walker	Newbury Selectman

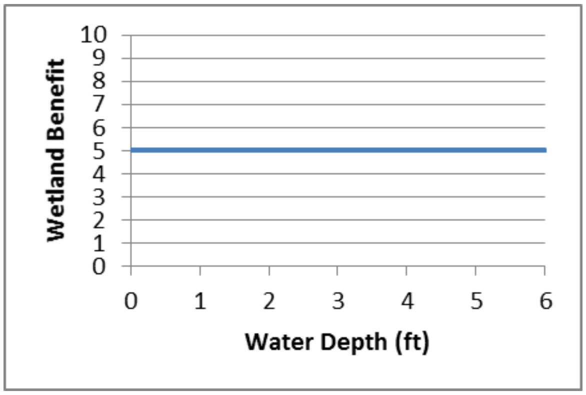
Appendix B

Benefit Creation Functions

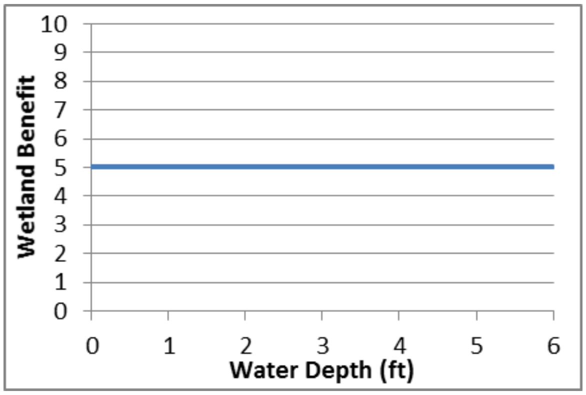
1. Prevention of flood damages.



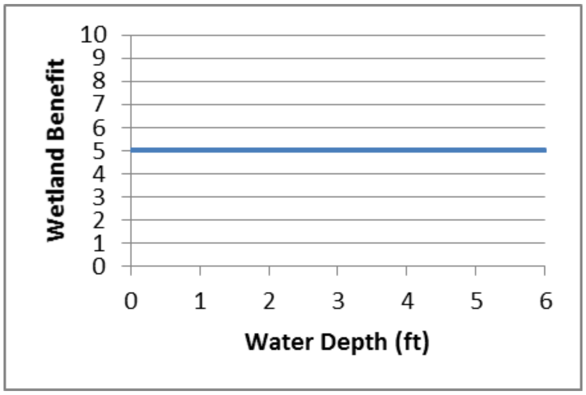
2. Increase in land values.



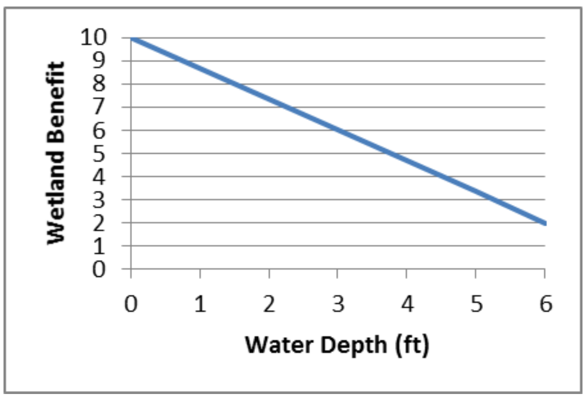
3. Effects on water quality through filtration of pollutants.



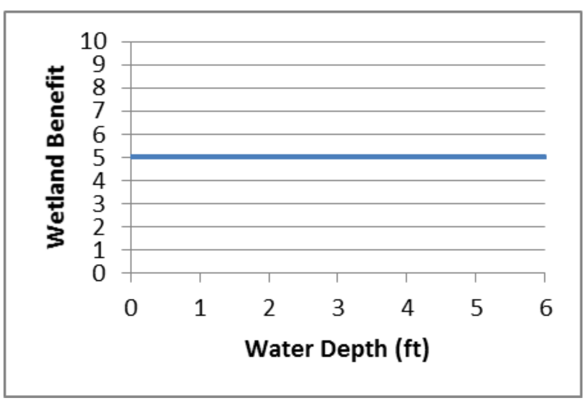
4. Drinking water supply.



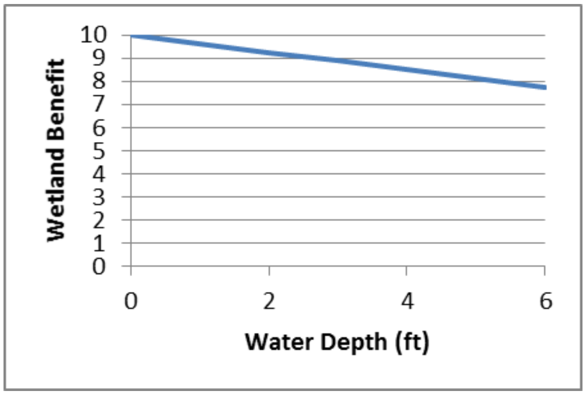
5. Recreation.



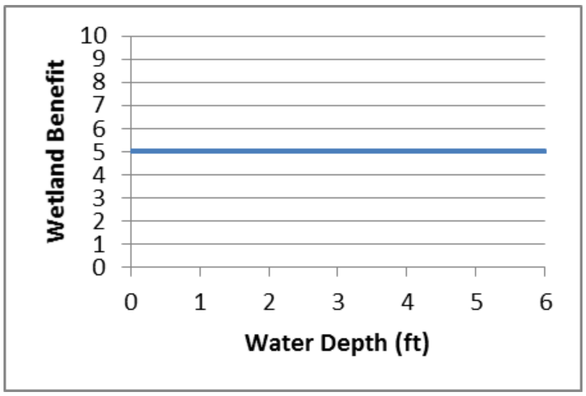
6. Aesthetics.



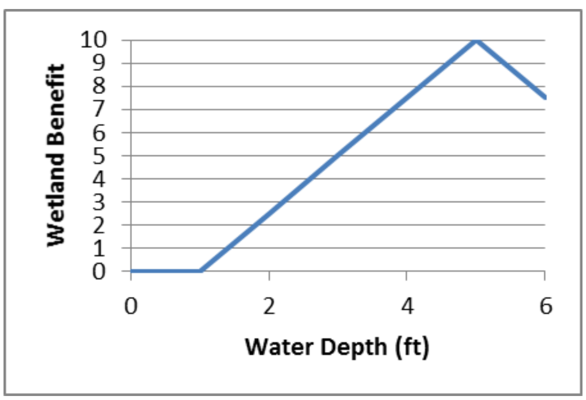
7. Carbon storage.



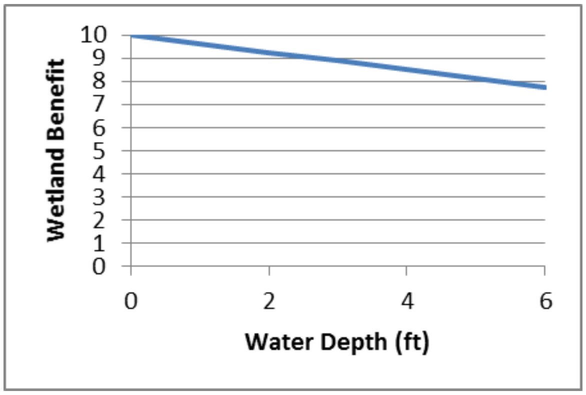
8. Habitat connectivity.



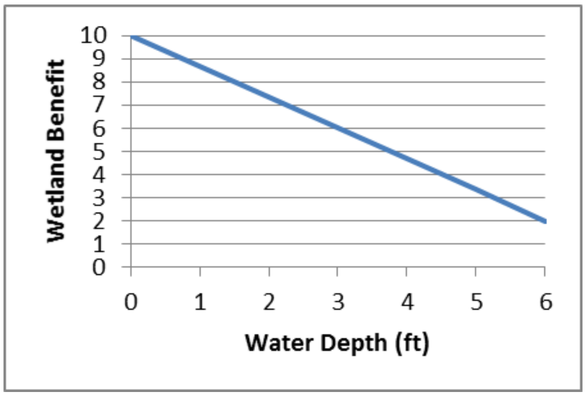
9. Habitat for any life stage of commercial species.



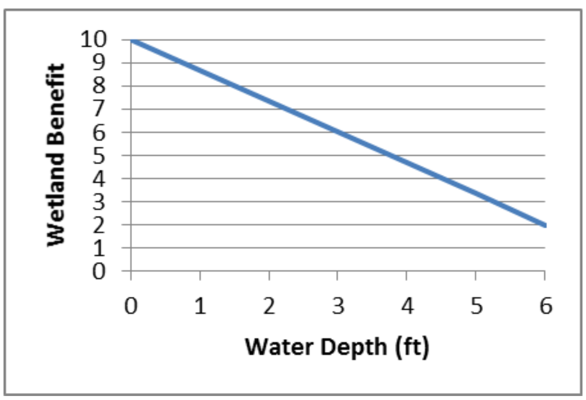
10. Habitat for any life stage of species important to biodiversity.



11. Nutrient export for commercial species.



12. Nutrient export for biodiversity.



13. Research value.