Creating the Basis for Successful Restoration: An Eelgrass Habitat Suitability Model in GIS for Plum Island Sound, Massachusetts

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Project Summary

Eelgrass meadows are both ecologically and economically valuable to coastal waters and have become the focus of resource management initiatives in Massachusetts and elsewhere. Plum Island Sound, located in the Upper North Shore region of Massachusetts, presently lacks eelgrass although historically it grew there. We developed an Eelgrass Habitat Suitability Model in Geographic Information Systems (GIS) based on the scientific parameters that most influence eelgrass establishment and growth. Each parameter was weighted according to its degree of influence on eelgrass success and combined in a multiplicative rating to identify areas suitable for eelgrass reestablishment within Plum Island Sound. The model identified a number of sites with good eelgrass habitat suitability, having scores of 8 (total area of 314 ha (776 ac)) and 16 (total area of 246 ha (608 ac)). The model also identified sites with fair suitability having a score of 4 (total area of 75 ha (185 ac)) and sites with poor suitability having scores of 2 and 0 (total area of 20 ha (49 ac)). Our product, a user-friendly map and GIS data layer, shows the rankings of all areas on a scale of eelgrass restoration suitability and is a valuable tool for guiding future eelgrass transplanting efforts in the Sound.

Introduction

Eelgrass (*Zostera marina* L.) is a temperate marine angiosperm that grows throughout the North Atlantic and is found in the intertidal zone to approximately 10 m below mean low water in Massachusetts. Eelgrass meadows are highly productive communities and contribute to the coastal environment by stabilizing and enriching sediments, trapping and cycling nutrients, maintaining water quality and clarity, and providing habitat for microbes, invertebrates, and vertebrates (Heck et al., 1995; Short and Coles, 2001). In recent decades, eutrophication caused by increased nutrient loading associated with development of coastal watersheds has resulted in significant declines in eelgrass populations in Massachusetts (Valiela et al., 1992; Short and Burdick, 1996). Because eelgrass meadows are both ecologically and economically valuable they have become the focus of resource management initiatives in the state, with the Massachusetts Department of Environmental Protection (MassDEP) mapping the distribution of eelgrass on a three-year cycle and several government and academic groups participating in monitoring programs (e.g., SeagrassNet, see Short et al., 2006) to assess eelgrass habitat quality.

Transplanting to restore eelgrass populations and mitigate loss has been used in many regions of the North Atlantic, achieving mixed success largely because of poor site selection (Cunha et. al, 2012; Short et. al, 2002). Site selection has been identified as the single-most important factor in eelgrass restoration success (Fonseca, 1998). To improve the outcomes of costly transplant efforts, Short and colleagues (2002, 2005) developed a quantitative site-selection model based on scientific data from thriving eelgrass beds and a literature review of the parameters that most influence eelgrass establishment and growth (Short et al., 2002; Short and Burdick, 2005). The parameters are weighted according to their degree of influence on eelgrass success and combined in a multiplicative rating that incorporates the various factors within a common index such that the degree of suitability is reflected in the quantitative assessment. Certain elements that are detrimental to eelgrass cause a site to be eliminated from consideration. The overall rating is compiled in GIS format and mapped to allow a quick overview of an area's potential for successful eelgrass growth. Field assessments and test-transplanting are then conducted at high priority sites to confirm site suitability prior to conducting a large-scale restoration (Short et al., 2002; Short and Burdick, 2005).

The eelgrass model was first beta-tested during an eelgrass restoration project in New Bedford Harbor, Massachusetts in 1999. Transplanting at high-priority locations identified by the model resulted in 62% transplant success, a distinct improvement over previous restoration attempts which averaged 25% success (Short et al., 2002; Short and Burdick, 2005). In addition, eelgrass at the restored sites was indistinguishable from natural healthy eelgrass meadows after four years. The model has since been successfully applied to restorations in Great Bay Estuary, NH and Annisquam River, MA as well as in Rhode Island (Narragansett Bay and Ninigret Pond). In the recent Logan Airport eelgrass restoration mitigation project, a preliminary site selection model was applied, but the entire site selection process recommended by Short and colleagues (2002, 2005) was not followed and the near total failure of these transplant efforts demonstrates the importance of following the complete protocol prior to a large-scale restoration. There is also some question whether adequate transplant expertise was used in the effort.

Plum Island Sound Estuary consists of a coupled watershed and estuary in northeastern Massachusetts (Figure 1). There is no eelgrass in the Sound although populations once existed (Belding, 1909; Addy and Aylward, 1944; MassGIS, 2003; Costello and Kenworthy, 2011). In the early 1900's, ten acres of eelgrass grew in the area encompassing Ipswich River, Plum Island, Green's Creek and Roger's Island, and Essex River Flats. The eelgrass was abundant and encroaching beds on clam flats were often kept back by digging (Commissioners of Fisheries and Game, 1908; Belding, 1909). In the mid-1900's eelgrass was reported to be abundant near the mouths of the Parker and Ipswich Rivers and across from the mouth of the Rowley River. Eelgrass was also successfully transplanted to the mouth of the Plum Island River after the massive 1930's die-off known as the wasting disease (Addy and Aylward, 1944). In 1995, MassDEP conducted aerial surveys of the region and showed that Plum Island Sound was devoid of eelgrass (MassGIS, 2003). The reasons for the disappearance of eelgrass from the Sound remain unclear. It is possible that multiple factors contributed to the decline including: the wasting disease of the 1930's, digging back for clamming, and watershed development that increased storm water runoff into the estuary (Buchsbaum et al., 2000). There is currently no evidence to suggest that eelgrass cannot thrive again in this system.

Due to the lack of any proximal source of eelgrass seeds or propagules, Plum Island Sound is unlikely to be naturally re-populated with eelgrass. The Massachusetts Division a Marine Fisheries (DMF), the Environmental Protection Agency (EPA) - Region 1, and the U.S. Fish and Wildlife Service at the Parker River National Wildlife Refuge on Plum Island have jointly recommended that eelgrass be restored to the Sound. In this study, we used the formulation of Short and colleagues (2002, 2005) to develop an eelgrass habitat suitability model for Plum Island Sound. The results of our study are the first step toward identifying and prioritizing sites for future restoration efforts.

Study Area

Plum Island Sound Estuary, located in northeastern Massachusetts, supports a diversity of fish and wildlife and is the largest wetland-dominated estuary in New England (Figure 1). The estuary is formed by Plum Island Sound, the Parker, Plum Island, Rowley, Eagle Hill, and Ipswich Rivers, as well as a vast network of tidal creeks that meander through 3500 hectares (8649 acres) of salt marsh. Plum Island Sound is relatively shallow with an average depth from 3 m (MHW) to 1.6 m (MLW) and a tidal amplitude ranging from 2.6 m to 3.6 m during the neap-spring cycle. The large amount of tidal flushing between tides makes Plum Island Sound less impacted by nitrogen loading than other estuaries in Massachusetts where eutrophication has been well documented (Buchsbaum et al., 2000).

Methods

Model Parameters

For this study, we used ArcMap 10.0 to develop an eelgrass habitat suitability model for Plum Island Sound based on the site selection formulation (Short et al., 2002; Short and Burdick, 2005). The scientific parameters used in the model included a map of the area of interest, information on bathymetry, sediment type, water quality and clarity, as well as the location of tidal flats, and wave exposure. Each parameter was weighted according to its degree of influence on eelgrass success and combined in a multiplicative rating to determine the degree of suitability. A description of each parameter and the criteria used to evaluate it is discussed below.

Base Map: A base map grid of the aquatic area in Plum Island Sound was created using the Mass GIS statewide shoreline map. To establish the area of interest, the map water areas received a value of 1 while areas of land were classified as No Data (Figure 2).

Bathymetry: Information on depth in Plum Island Sound and the connecting water bodies was provided by Joseph Vallino from the Marine Biological Laboratory in Woods Hole. The bathymetry data was obtained from LIDAR, NOAA NGDC surveys, and by pairing a kinematic GPS survey to a depth sounder (ref to NADV88). The original data was a point data set in MA State Plane with depth in meters and ±10 cm accuracy. For the model, we created a bathymetric surface map from the point data by using the inverse distance weighting function (IDW) in ArcMap 10.0 (Figure 3). The data was then reclassified and ranked using information on eelgrass depth ranges (Dennison, 1998; Short et al., 2002) and the tidal amplitude in the Sound (2.9 m average; 2.6 to 3.6 m neap-spring cycle; Figure 4) as follows:

1) 0 to 1.8 m (No Data; Exposed at MLW and/or neap-spring cycle)
2) 1.8 to 2 (1; Depths similar to the shallow edge of eelgrass; Fair conditions)
3) 2 to 3 (2; Good conditions for eelgrass establishment and growth)
4) 3 to 4 m (1; Depths similar to the deep edge of eelgrass; Fair conditions)
5) >4 m (No Data; Exceeds average depth limit of deep edge of eelgrass)

Sediment: Information on sediment type and grain size for Plum Island Sound and the connecting water bodies was provided by Sergio Fagherazzi. The data is based on 38 sampling points from 2011 that were collected within the Sound and the Parker and Rowley Rivers (Figure 5). The sediment type and grain size data suggest that the entire Sound has substrate that is suitable for eelgrass growth since it is <70% silt/clay and is sandy (Short, 1987; Short et al., 2002). The entire Sound and the connecting water bodies received a rating of 2 (good) for sediment suitability (Figure 6).

Water quality: Information on total dissolved nitrogen (TDN), suspended solids (SS), Chl *a*, and salinity was obtained from Plum Island Estuary (PIE) Long-term Ecological Research Network (LTER) (ecosystems.mbl.edu/PIE/data/EST/EST-PR-NUT.html). The datasets are based on 15 years of information taken from 25 sampling points located in Plum Island Sound, as well as the Parker, Rowley and Ipswich Rivers. Each dataset was averaged at each sampling point for the 15-year time period and National Estuarine Eutrophication Assessment standards were used to define areas with poor, fair, and good conditions relating to concentrations of TDN, SS, and Chl *a*. Salinity information was also used to define relative boundaries of freshwater inputs and areas with salinities unfavorable for eelgrass (<10 psu). The information from each dataset was then combined in a multiplicative rating to create one water quality data set showing areas with poor (0), fair (1), and good (2) water quality (Figure 7).

Water Clarity: Light information was obtained from PIE- LTER (ecosystems.mbl.edu/PIE/data/EST/EST-PR-NUT.html) to assess water clarity. The dataset is based on 15 years of information taken from 25 sampling points located in Plum Island Sound, as well as the Parker, Rowley and Ipswich Rivers. Light extinction coefficients at each sampling point were averaged over the 15 year time period and used to identify and rank areas with light limited (> 2.0; rating = 0), fair (1.0-2.0; rating= 1) and good (<1.0; rating= 2) conditions for eelgrass growth, with value ranges derived from eelgrass light requirement information presented in Dennison (1987), Short et al. (1995) and Ochieng et al. (2010; Figure 8).

Intertidal Flats: Information on the location of intertidal flats was obtained from MassGIS (2009), Google Earth, and field observations. The intertidal flats dataset was needed because the bathymetry dataset did not identify all areas that could be potentially exposed during low tides and the neap-spring cycle. Intertidal flats are not suitable habitat for transplanting eelgrass and were eliminated from consideration (Figure 9).

Exposure: Wave exposure was determined from wind direction and velocity information (obtained from NOAA Climatic Data Archives) using the method of Murphey and Fonseca (1995). Areas greater than ±2 SD from the mean were considered unsuitable for eelgrass growth and were eliminated from consideration since wave energy can break eelgrass leaves and uproot plants (Kopp, 1999; Figure 10).

The overall eelgrass habitat suitability score for Plum Island Sound (we also included the connecting water bodies) was calculated in ArcMap 10.0 by multiplying the ratings of each parameter listed above in Map Calculator (in Arc). Higher scores indicate greater eelgrass habitat suitability, as well as a better likelihood of eelgrass transplant success. The maximum possible rating is 16. Areas in the output layer with the highest values are considered the "Most Suitable" for undertaking eelgrass restoration. Areas with high-to-moderate values are considered "Very Suitable" and areas with moderate-to-low values are considered "Suitable." Areas with the lowest values are rated "Unsuitable" for eelgrass restoration.

Additional Scientific Information

The following parameters were not included in the model, but are considered to be important when selecting potential locations for an eelgrass restoration in Plum Island Sound.

Historical eelgrass: Information on the approximate location of historical eelgrass sites in Plum Island Sound and the surrounding water bodies was acquired from Addy and Aylward (1944), as well as from local fisherman (pers. comm. Geoff Walker; Figure 11). We also contacted N. Tay Evans at the Department of Marine Fisheries (DMF) and visited special collections at the State Library in Boston to review historical maps from 1600 to 1940. DMF was unable to provide us with any additional information and suggested that notes on eelgrass in Plum Island Sound may have been lost in a fire some years ago. Maps at the State Library provided no additional information.

Mooring fields: Information on the location of moorings was obtained from MassGIS (2009) and from field observations. Mooring fields are considered unsuitable habitat for transplanting eelgrass since boat mooring chains can uproot transplants (Figure 12).

The following parameters were considered, but were not included in the model or the final habitat suitability map because they are unlikely to affect the establishment and growth of eelgrass in this system at this time.

Current eelgrass: Information on current eelgrass locations in Massachusetts was obtained from MassGIS.gov. No eelgrass beds currently exist in Plum Island Sound or the connecting water bodies. If there was eelgrass in the system we would recommend transplanting in areas outside of the range of natural re-vegetation potential (distances >100 meters from each bed; Orth et al., 1994).

Conflicting Uses: Ground-truthing determined there are no additional conflicting uses that need to be considered for the model or this study.

1) Boating Activity: heavy boating appeared to be confined to mooring fields and channels, areas that will not be recommended for transplanting.
2) Lobster pots: pots are present in the system, but not in quantities believed to be detrimental to transplanting efforts.
3) Bioturbation: crabs were seen in low numbers and a local fisherman confirmed that bioturbation is not a serious threat in the system (pers. comm. Geoff Walker).
4) Clamming: shell fishing appeared to be confined to tidal flats, areas that were eliminated from the model by our intertidal flat data layer.

Results and Discussion

In this study, we developed a model using the formulation of Short et al., (2002) to identify and prioritize sites in Plum Island Sound that could support eelgrass habitat. The model identified a number of sites with good eelgrass habitat suitability, having scores of 8 (total area of 314 ha (776 ac)) and 16 (total area 246 ha (608 ac)). The model also identified sites with fair suitability having a score of 4 (total area of 75 ha (185 ac)), and sites with poor suitability having scores of 2 and 0 (total area of 20 ha (49 ac); Figure 13). Most areas with good eelgrass habitat suitability were found toward the center of the Sound, near the Rowley and Ipswich Rivers. Areas with fair and unsuitable eelgrass habitat potential were primarily confined to northern section of the Sound near the mouths of the Parker and Plum Island Rivers (Figure 13). For eelgrass restoration purposes, sites with scores of 8 and 16 have the best potential for successful restoration. Sites with a score of 4 could be considered for restoration, and sites with a rating of 2 or 0 should not be selected. Hence, there is a total area of 655 ha (1618 ac) in the Sound and the connecting water bodies that are suitable for restoration.

There was an adequate amount of information available for the development of our model. Plum Island Sound Estuary has been part of the LTER network since 1998 and has collected fine-scale bathymetry data, sediment data, and water quality and clarity data that we were able to use for this study. In addition, we used MassGIS, Google Earth, and our field observations to identify additional areas and conflicting uses (intertidal flats and mooring fields) that may influence eelgrass transplant success. Although detailed information on the distribution and abundance of historical eelgrass in Plum Island Sound was lacking, we do not believe it is an important predictor of eelgrass suitability and transplant success in this system, as eelgrass beds disappeared decades ago and conditions at these sites may have changed. The relative locations of beds should still be noted and considered when determining eelgrass habitat suitability and selecting potential locations for transplanting eelgrass during future restoration efforts in the Sound.

Once the habitat suitability scores have been calculated for a given area within a system, we strongly recommend continuing to “Phase II” of the site selection process as described in Short et al. (2002). Phase II involves evaluating sites with high scores by conducting a test transplanting effort. The survival of test transplants is highly indicative of eelgrass habitat suitability and provides the best indication of how well a large-scale transplanting effort will succeed at a given site. For Plum Island Sound, we recommend test-transplanting at multiple sites with scores of 8 and 16 to evaluate eelgrass habitat suitability. Sites within mooring fields should be avoided and sites with a high score (8 or 16) and a history of eelgrass should be given preference.

Conclusion

We developed a GIS-based Eelgrass Habitat Suitability Model using the formulation of Short et al., (2002) to create a map that ranks all areas in Plum Island Sound on a scale of eelgrass restoration suitability. Our analysis of the scientific parameters that affect the establishment and growth of eelgrass indicate that the Sound contains multiple sites suitable for eelgrass. Our product, a map and GIS data layer, creates the capacity to prioritize sites for future eelgrass restoration efforts in the Sound. We now recommend using the results of our study as a guide for scientific test-transplanting.

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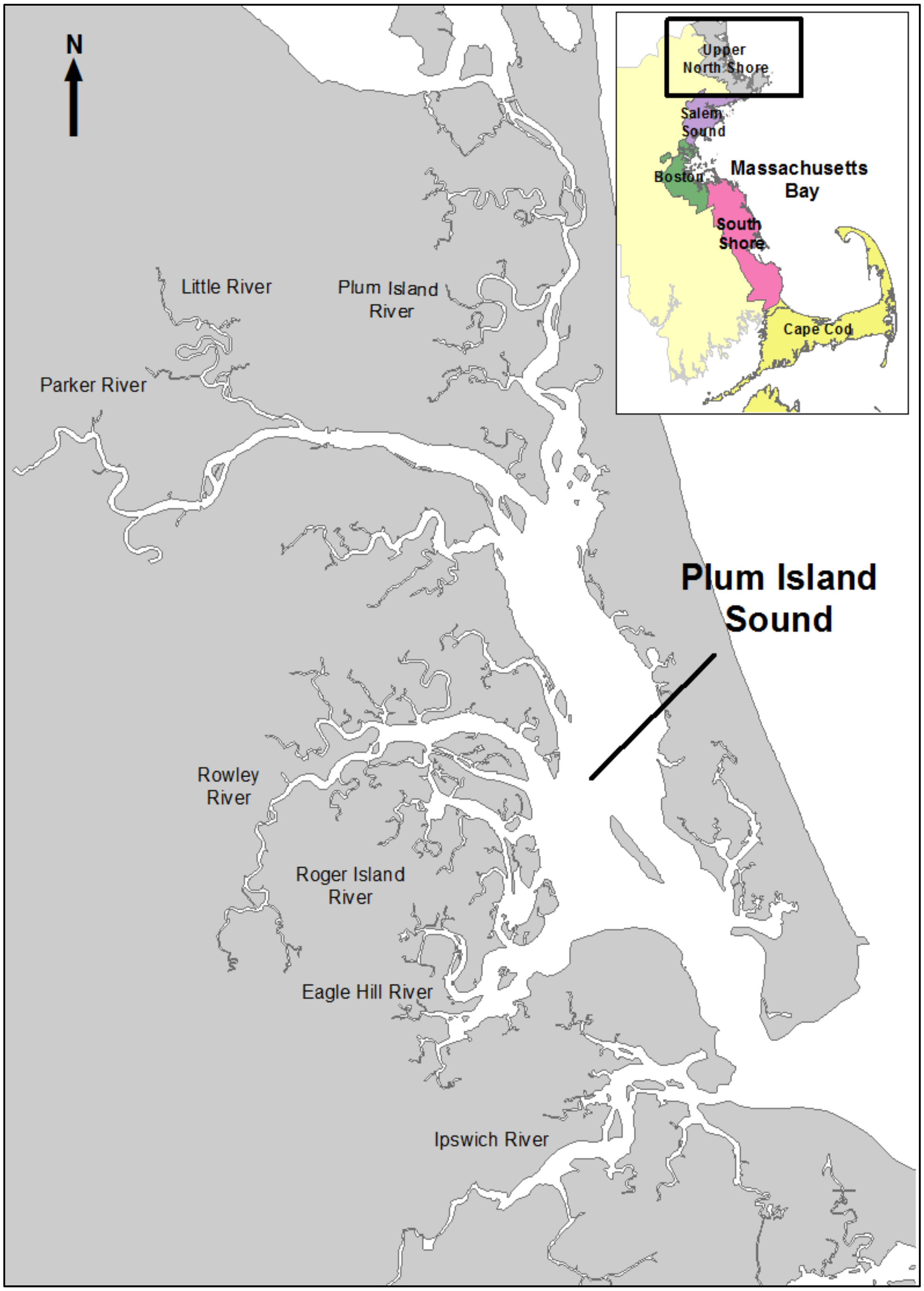

Figure 1. Plum Island Sound is located in northeastern Massachusetts in the Upper North Shore region (inset) of the Massachusetts Bays program (MBP) planning area. There is no eelgrass within the Sound.

Figure 2. Map defining the area of interest (in blue) for the Plum Island Sound Eelgrass Habitat Suitability Model.

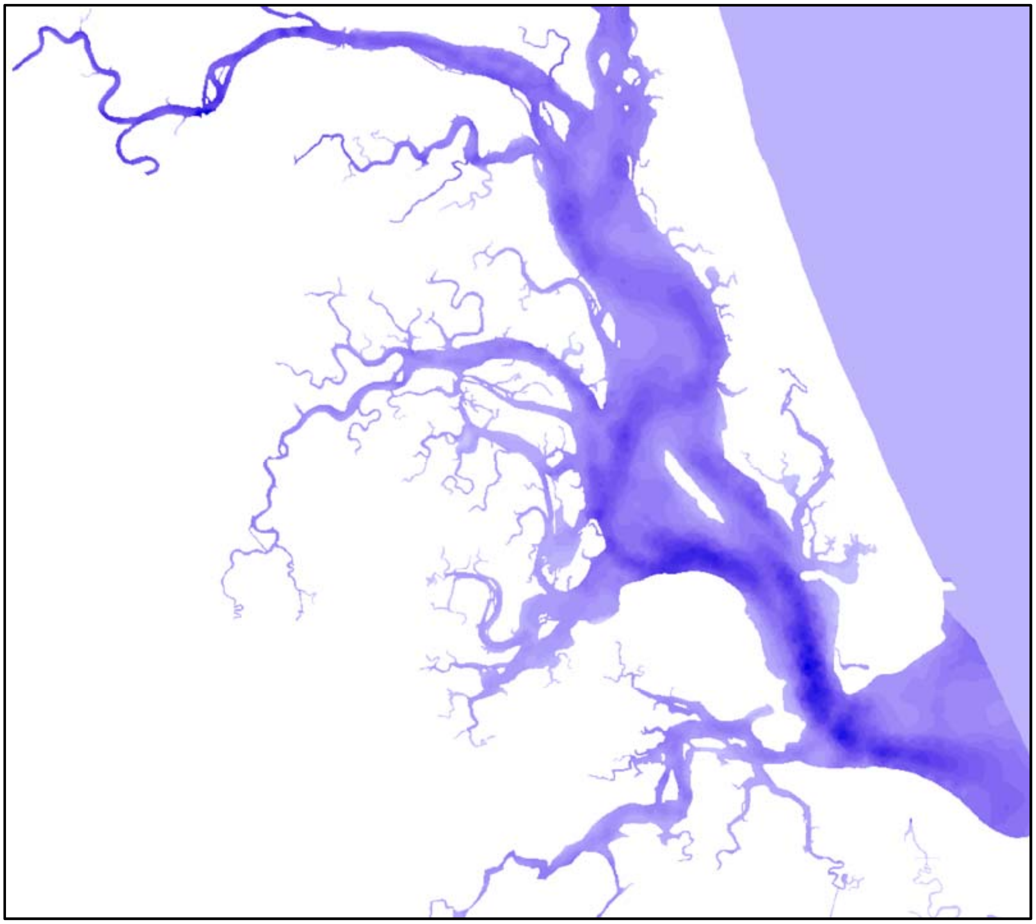

Figure 3. Bathymetry map for Plum Island Sound and the connecting water bodies. Darker areas are deeper.

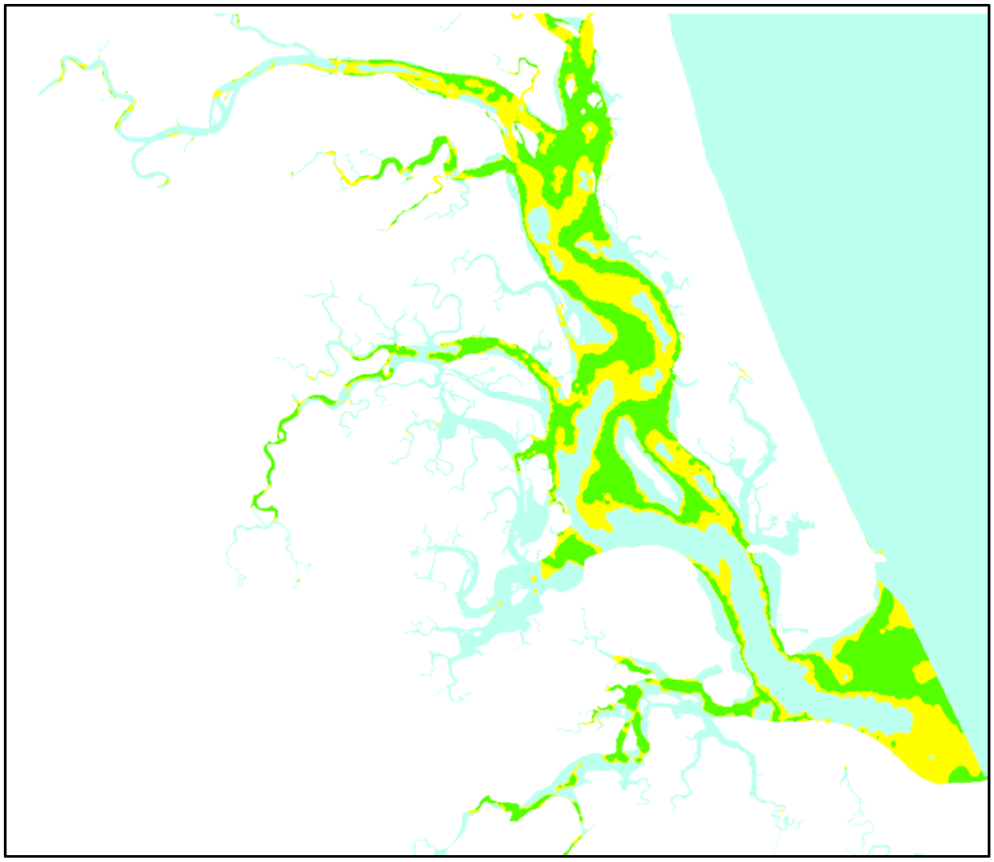

Figure 4. Reclassified bathymetry map for Plum Island Sound and the connecting water bodies. The map shows areas with fair (yellow) and good (green) depths for transplanting eelgrass, as well as areas outside the range suitable for transplanting (blue).

Figure 5. Location of sediment sampling sites. Map provided by Sergio Fagherazzi at Boston University.

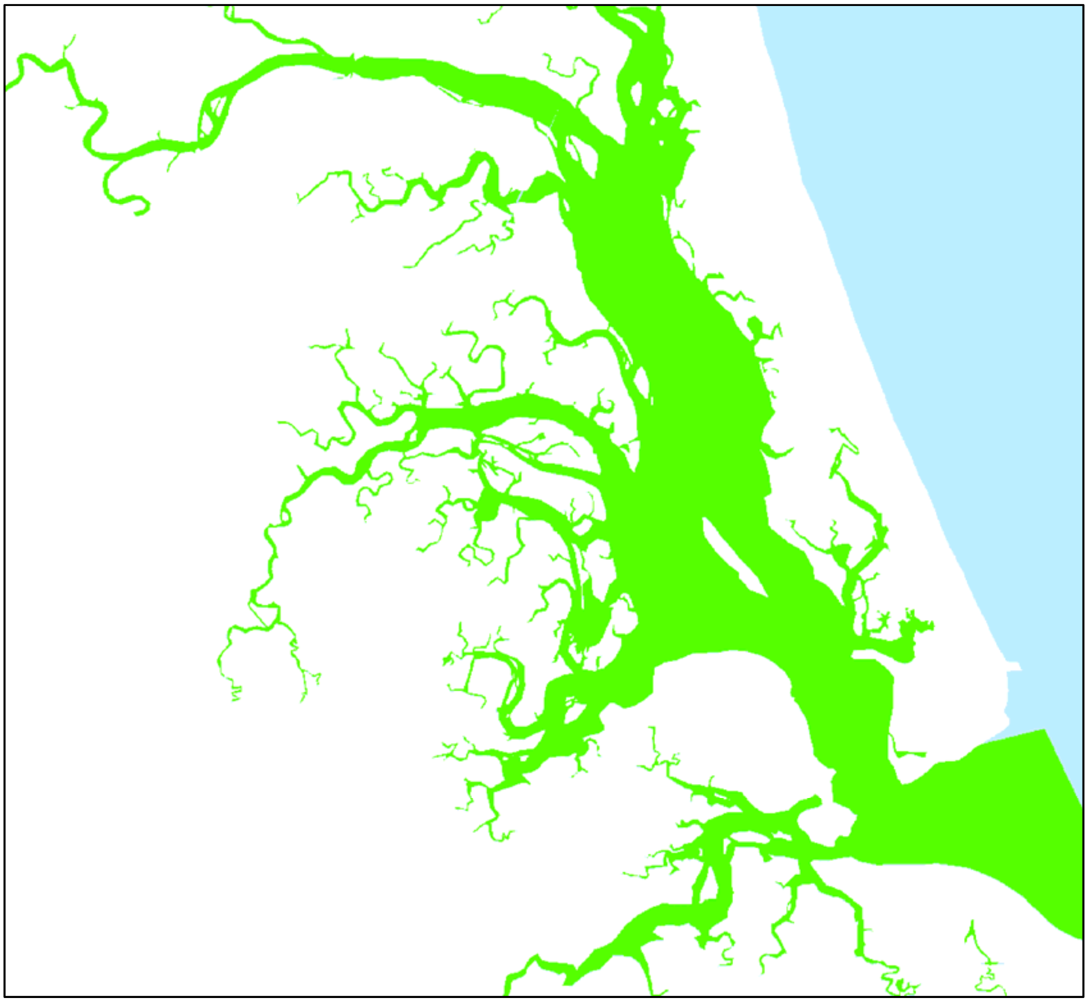

Figure 6. Sediment map for Plum Island Sound and the connecting water bodies. The map shows that the entire Sound has substrate that is suitable for transplanting eelgrass (green). Please note that sediment samples were only collected for the Sound and the Parker and Rowley Rivers and suitability for other rivers and tidal creeks may not be accurate.

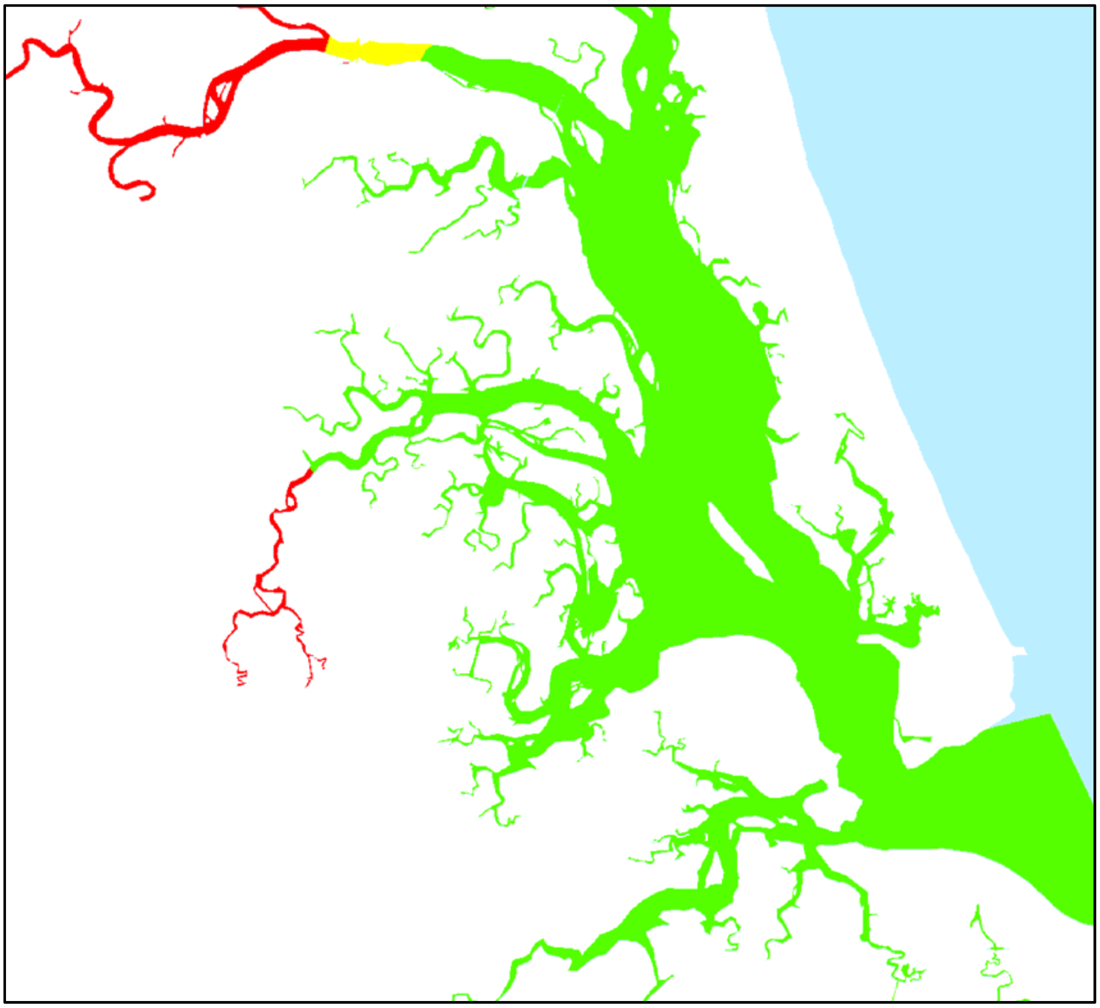

Figure 7. Water quality information for Plum Island Sound and the connecting water bodies. The map is based on TDN, SS, Chl *a* and salinity data and shows areas with poor (red), fair (yellow) and good (green) water quality.

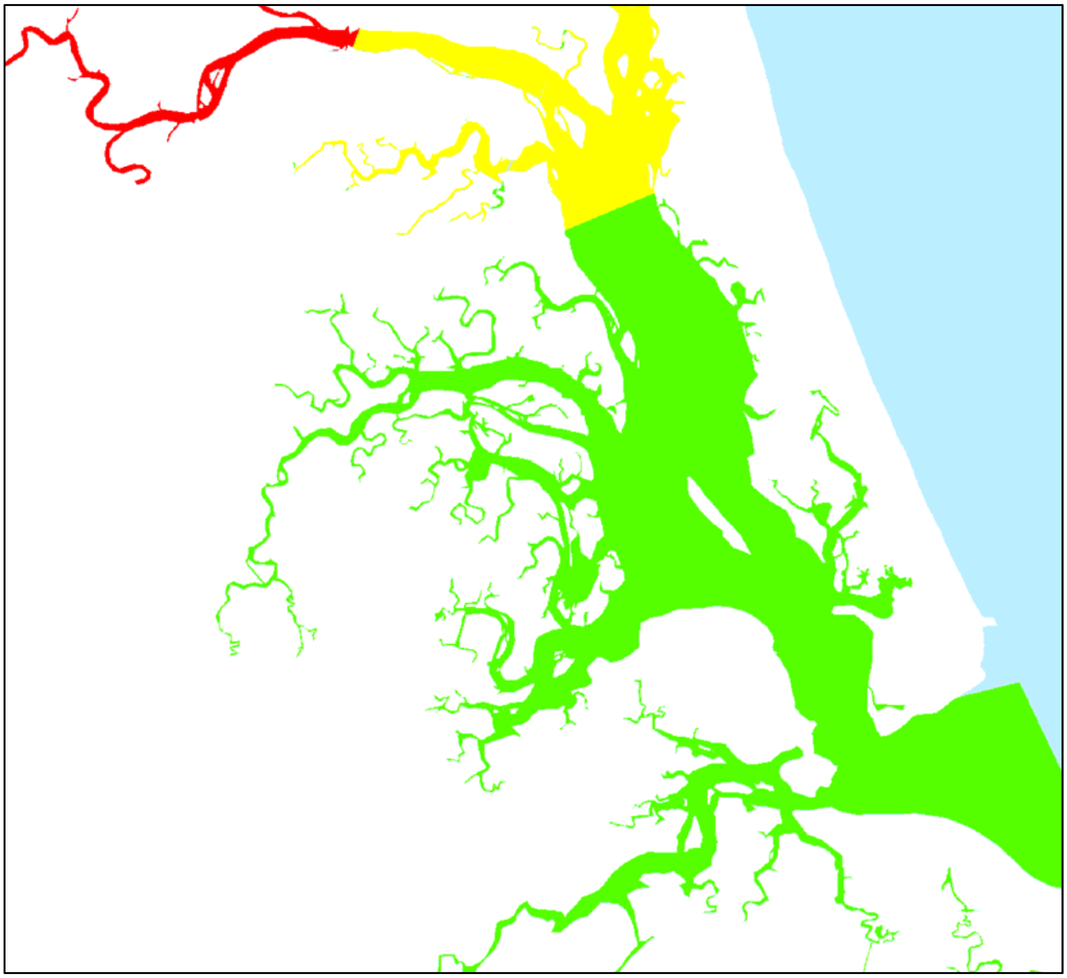

Figure 8. Water clarity information derived from light data for Plum Island Sound and the connecting water bodies. The map shows relative boundaries of areas with poor (red), fair (yellow) and good (green) water clarity.

Figure 9. Location of intertidal flats in Plum Island Sound and the connecting water bodies (black). Intertidal flats are unsuitable locations for transplanting eelgrass and were eliminated from consideration.

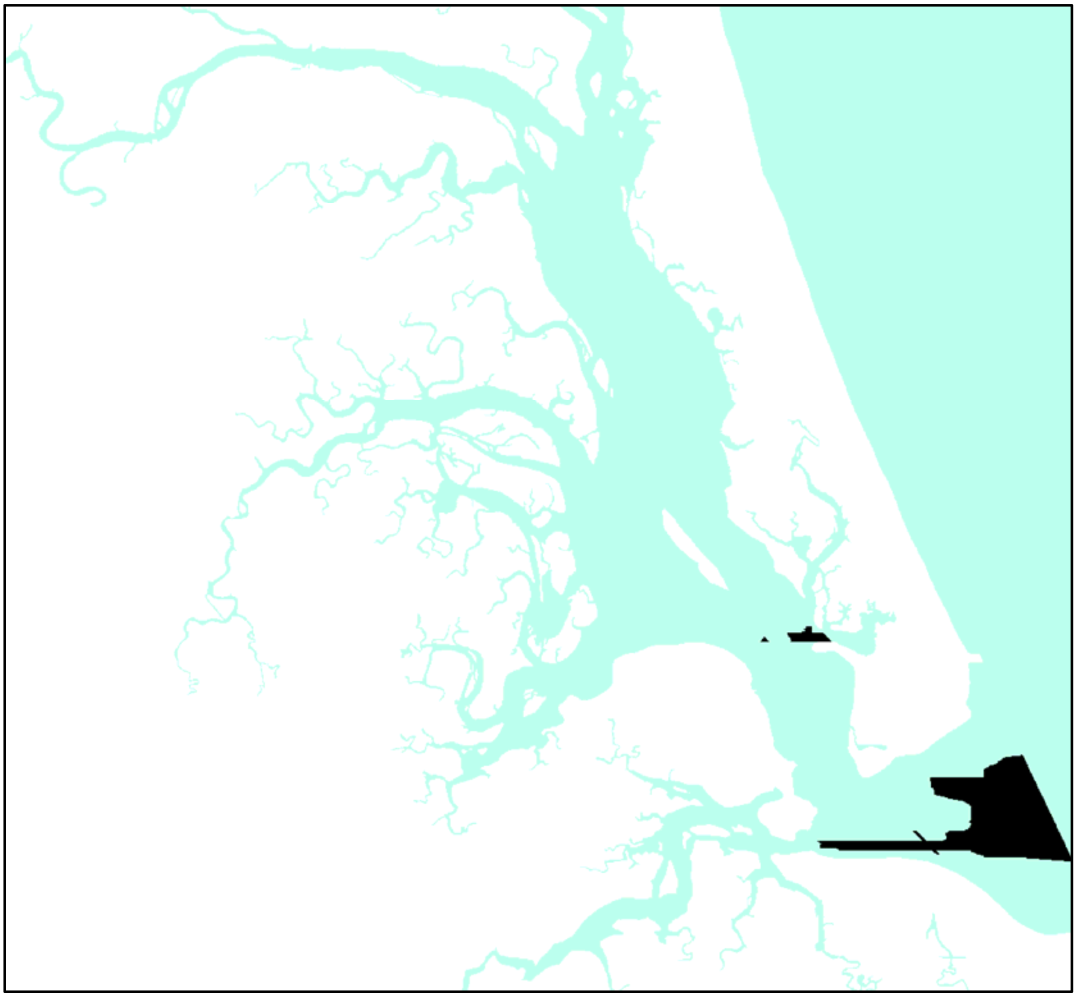

Figure 10. Areas with high wave exposure (± 2SD) are unsuitable for eelgrass establishment and growth and were eliminated from consideration (black).

Figure 11. Approximate locations of historical eelgrass beds in Plum Island Sound and the connecting water bodies (blue circles) based on Addy and Aylward (1944) and personal communication with a local fisherman (Geoff Walker).

Figure 12. Locations of mooring fields in Plum Island Sound and the connecting water bodies (gray). Transplanting eelgrass in areas with moorings is not recommended since mooring chains can uproot plants.

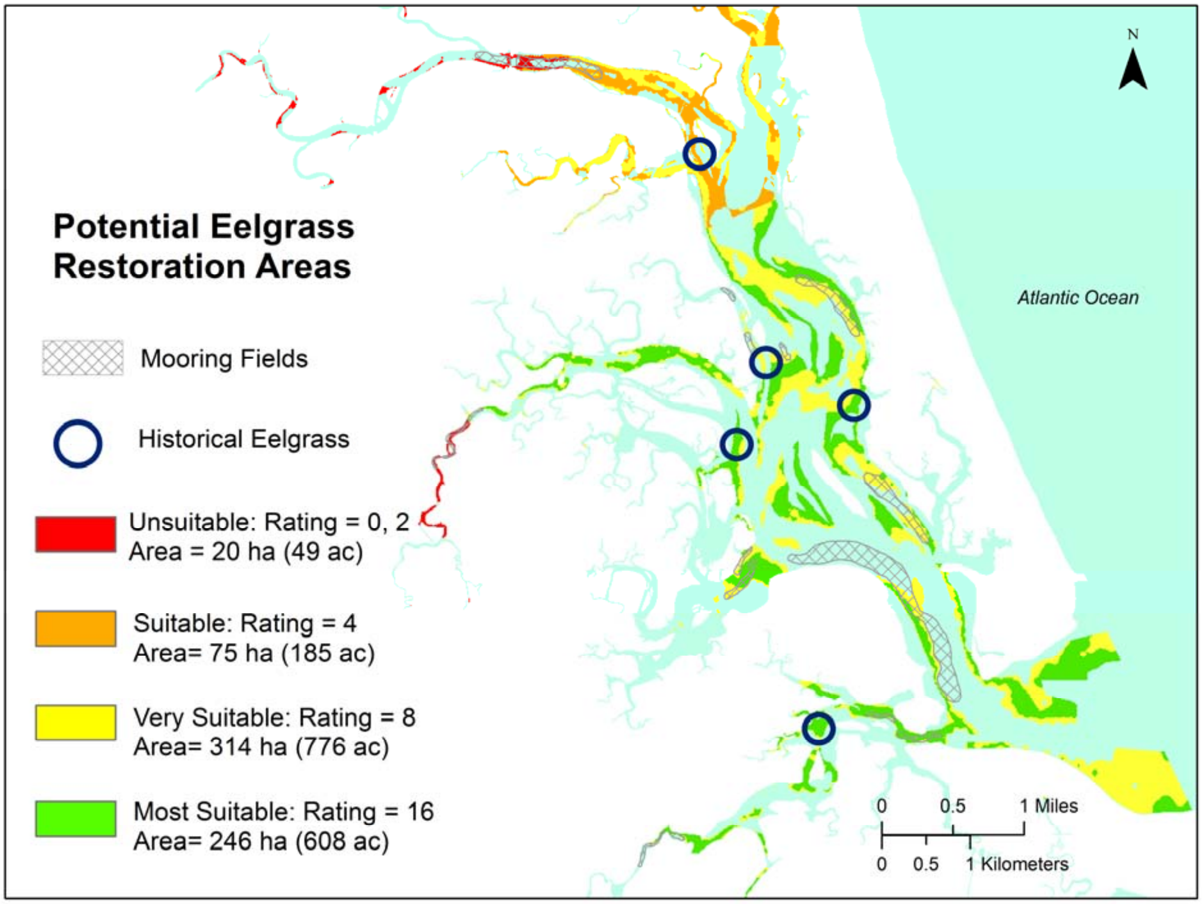

Figure 13. Eelgrass Habitat Suitability Map for Plum Island Sound and the connecting water bodies. Areas in green are the most suitable sites for the establishment and growth of eelgrass and should be the focus of test transplanting efforts and ultimately of eelgrass restoration.