IDENTIFYING LOCATIONS FOR EELGRASS HABITAT RESTORATION IN THE ANNISQUAM RIVER

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ABSTRACT

In the summer of 2007, test plots of eelgrass (*Zostera marina* L.) were planted in areas of the Annisquam River that were identified as potentially suitable for restoration. A restoration site-selection tool, along with additional information such as fine-scale site characteristics, extent of human uses, and historic and current anecdotal knowledge, were used to identify potential restoration areas. As the Annisquam River is a busy, developed waterway, the combination of empirical and anecdotal information was critical to improve our understanding of human influences and trends in historical and existing eelgrass habitat and to better locate test transplant sites. Test transplant survival was low (6% for sites combined), with survival ranging from <1% to 11%. The transplant experiment, however, provided insight into potential causes for low survival of transplants and the lack of natural recovery. Given the results of the site selection process, parts of Goose Cove, the Annisquam River outside of Goose Cove, and the mouth of the Little River appeared suitable for further testing and/or larger-scale transplanting efforts. Results of this study improved the understanding of probable causes of eelgrass habitat degradation and the potential to restore eelgrass habitat in the Annisquam River. This study also provides the foundation for the Massachusetts Office of Coastal Zone Management and the City of Gloucester to develop a plan to restore eelgrass habitat in the Annisquam River.

INTRODUCTION

The Massachusetts Office of Coastal Zone Management (CZM) developed a wetlands restoration plan for the Great Marsh on the North Shore of Massachusetts. As part of this plan, eelgrass habitat was identified as a valuable coastal habitat that warranted investigation. CZM initiated a study of the suitability of eelgrass habitat restoration in the Annisquam River, which is part of the Great Marsh complex, to assess the viability of restoration efforts and support future planning for eelgrass restoration and conservation in the region.

Eelgrass (*Zostera marina* L.) is an underwater plant that forms valuable shallow water habitat in coastal Massachusetts. In the 1930s, a wasting disease, caused by the slime mold *Labyrinthula zosterae*, decimated eelgrass populations throughout the North Atlantic Ocean, including Massachusetts (Milne and Milne 1951). This catastrophe substantially altered coastal food webs and processes (e.g., current and sediment transport patterns), severely diminished populations of waterfowl and bay scallops, and caused the extinction of a marine snail (Carlton et al. 1991), and demonstrating the ecological and economic value of eelgrass (reviewed by Thayer 1984). Although site-specific information on recovery is rare (e.g., Dexter 1985), sporadic observations through time indicate eelgrass generally recovered throughout its range from this epidemic by the 1950s-60s. Some areas, however, did not recover, and/or more recent (1980s to present) anthropogenic threats have extensively depressed eelgrass distribution from historic levels (see Duarte 2002). Contemporary global losses in seagrass distribution, including eelgrass along the eastern United States, is considered a crisis in coastal waters (Orth et al. 2006).

The abundance of eelgrass is greatly diminished from historic levels in northern Massachusetts (e.g., Dexter 1985). The record of eelgrass presence in the Annisquam River is supported by monitoring and anecdotal evidence. Addy and Alyward (1944) documented the presence of eelgrass in the Annisquam River in 1943, and Dexter (1985) monitored eelgrass around Cape Ann from 1933 to 1984. These accounts indicate that eelgrass recovered from the wasting blight after the 1930s and was broadly distributed throughout the Annisquam River (Figure 1).

Eelgrass maps created from aerial photography taken in 1995 and 2001 by the Massachusetts Department of Environmental Protection (MassDEP) show small areas of eelgrass north of the Annisquam River (MassGIS 2006; Figure 1). The areas mapped in 1995 and 2001 represent a dramatic decline in eelgrass within the Annisquam River since the 1970s and early 1980s (Dexter 1985). Eelgrass initially disappeared in the southern sections of the Annisquam River and gradually declined in the northern waters between the mid-1980s to early-1990s (Buchsbaum personal communication).

Determining the causes of decline in eelgrass has received extensive study. Indirect human impacts, such as eutrophication, stormwater run-off, and coastal development, and direct perturbations (e.g., mooring fields, docks, and shellfishing) in shallow waters are ubiquitous in coastal Massachusetts. These many influences degrade eelgrass habitat. While degradation of the water column light environment, typically as a result from eutrophication, is the largest threat to eelgrass in watersheds of Buzzards Bay and southern Cape Cod (Short and Burdick 1996; Howes et al. 1999), evidence suggests that factors other than nutrient loading reduced eelgrass populations in coastal areas of northern Massachusetts (Chandler et al. 1996; Lent et al. 1998).

We hypothesize that either another outbreak of wasting disease occurred in the Annisquam River after 1984, as an outbreak of wasting disease was reported in coastal New Hampshire in the 1980s (Short et al. 1986; Short 1987). The disease possibly extended south to Massachusetts. However, monitoring data for eelgrass in coastal Massachusetts are scant and there were no reports of the disease in the Annisquam River at that time. Another likely cause for decline is contemporary anthropogenic degradation, such as increased suspended sediments in the water column. Questions remain on why eelgrass has not recovered in the Annisquam River, given the apparent suitability of environmental conditions for eelgrass. Potential reasons for the lack of recovery include a lack of an adequate propagule source and/or continued, persistent human insults to eelgrass habitat.

This study investigated the potential to restore eelgrass and possible causes of eelgrass decline in the Annisquam River. The long-term goal of the initiative is to expand the distribution of eelgrass in the Annisquam River. The study is systematically collecting quantitative information that will inform future eelgrass conservation and restoration efforts. While protecting existing eelgrass beds remains the most effective management strategy and natural recovery of eelgrass habitat is preferred, active transplant or seeding may re-establish eelgrass habitat decades before natural recovery (Short et al. MS). This study will assist with potentially quickening the recovery of this valuable habitat to the Annisquam River.

The four fundamental steps of Short et al. (2002a) are followed for this study: (1) use available information to provide a preliminary assessment of restoration suitability; (2) collect field measurements, as needed, to improve the preliminary assessment and identify sites for test transplants; (3) plant test plots and monitor survival and growth of test transplants; and (4) recommend the most suitable areas for restoration. The phased approach is an effective planning tool as it does not dedicate substantial resources to a large-scale restoration effort before better determining the likelihood of success.

Phase 1 was completed for the Annisquam River and Gloucester Harbor in 2005-2006 (Short and Novak 2006). Preliminary results from phase 1 identified potential restoration sites, but the study also determined that the lack of data, particularly water quality, compromised model results (Short and Novak 2006). Shellfish contamination information (i.e., Massachusetts Division of Marine Fisheries 2000) was used as a proxy for water quality in the Annisquam River but was deemed inadequate in terms of spatial resolution or correctness in relation to eelgrass habitat (Short and Novak 2006).

Among the factors that influence the distribution and abundance of eelgrass, such as physical (e.g., substrate type and water depth) and biological features (e.g., abundance of bioturbating decapod crustaceans), water quality – specifically water clarity and/or the light environment in the water column –

greatly determines the distribution of eelgrass (e.g., Dennison and Alberte 1985). Water clarity is mediated by nutrient concentration, phytoplankton abundance, and/or suspended sediments (summarized by Carruthers et al. 2001). Fecal contamination information used for shellfish management was not an appropriate surrogate for water clarity.

Phase 2 included a five-month study to describe geographic and temporal characteristics of water clarity and chemistry in the Annisquam River (Wilbur 2007). Results demonstrated a gradient of relatively higher water quality in northern waters to comparatively depressed water quality in southern waters of the Annisquam River, with the poorest water clarity, highest temperature, and lowest dissolved oxygen observed in the Little River. Phase 2 results were used to refine the identification of potential restoration sites.

The objective of this study (Phases 3 and 4) was to identify potential eelgrass habitat restoration sites, transplant test plots of eelgrass at the potential sites, determine success of test transplants, and recommend sites for full-scale restoration and/or additional research required to better understand suitability of restoration. Results from this study will be used to guide the development of an eelgrass habitat restoration plan for the Annisquam River. The restoration plan will be used by the City of Gloucester to guide efforts to increase the distribution and abundance of eelgrass habitat in the Annisquam River.

MATERIALS AND METHODS

Study Area

The Annisquam River is located in northern Massachusetts Bay and connects Gloucester Harbor to Ipswich Bay. Eelgrass was mapped by the MassDEP along the north shore of Massachusetts in 1995 and 2001 (MassGIS 2006; Figure 1). There are also records of the historic presence of eelgrass in the Annisquam River available from 1951 aerial photography (Costello personal communication), an eelgrass monitoring study from 1933-1984 around Cape Ann (Dexter 1985), and “GRS” marks – meaning grass and interpreted as submerged vegetation – on NOAA Nautical Chart 13279. Mapping data and anecdotal information provided an indication of the current and historic occurrence of eelgrass (Figure 1).

Identifying Test Plots

Locating areas for test plantings of eelgrass involved a combination of quantitative and qualitative examinations of resources in the Annisquam River. This study used a systematic approach to identify potential restoration areas that included modeling environmental requirements of eelgrass, studying water quality, evaluating human uses and conflicting resources, and incorporating local knowledge.

Preliminary Transplant Suitability Index

The preliminary transplant suitability index (PTSI) is a multiplicative equation that uses the historic and current distribution of eelgrass, proximity to current eelgrass, sediment type, wave exposure, water depth, and water quality to prioritize locations for transplant or seedling restoration of eelgrass habitat (Table 1; see Short et al. 2002a). Short and Burdick (2005) adapted the PTSI to run in a geographic information system (GIS). Existing data for current eelgrass, sediment type, wave exposure, and water depth were compiled by Short and Novak (2006). Historic eelgrass relied on an estimate of eelgrass in 1951 (Costello personal communication).

Secchi disk depth and water chemistry were studied in the Annisquam River and Gloucester Harbor from June to October 2006 (Appendix A; Wilbur 2007). Mean Secchi disk depth for the study were displayed in the Annisquam River and Gloucester Harbor by inverse distance weighted (IDW) interpolation (Figure 2a). IDW interpolation showed the spatial characteristics of water clarity and provided a foundation for classifying and creating spatial categories (i.e., polygons) of water quality in the Annisquam River (see Wilbur 2007 for details of water quality study and IDW interpolation).

Two water quality classes (i.e., good and fair) were assigned to the Annisquam River (Figure 2b). Mean Secchi disk depth greater or equal to 3 meters was classified as good (rank=2), and Secchi depth less than 3 meters was classified as fair (rank=1). The water quality classes were combined with the other parameters in the PTSI to identify potential sites for test transplants.

Site Assessment

The PTSI is a desk-top exercise that uses the site selection software (i.e., Short and Burdick 2005) and a GIS to locate potential areas for eelgrass restoration. The PTSI does not include human dimensions, such as the presence and location of dredged navigation channels. The presence of potential human uses and other perturbations are important to identify before planning a test transplant.

Navigation channel boundaries, utility corridors (sewer, pipelines, and cables), anchorages, and public boat launch sites were delineated in the Annisquam River (Moda 2007). Potential disturbances within the surrounding watershed were also reviewed and digitized in GIS (Wilbur 2004). These water-based and watershed influences were compiled into a geodatabase. PTSI results were compared to these human uses and potential disturbances in a GIS to further examine possible locations of test sites for transplanting eelgrass.

As stated above, sediment type is required for the PTSI. Based on personal observations of the predominant grain size of seafloor sediments, sediment type was assumed to be uniform, cobble free with <70% silt/clay in the study area. This classification of sediment type received the highest PTSI rating (2) in the initial application of the PTSI in the Annisquam River. To better characterize grain size composition at potential restoration sites, sediment grabs were located in areas that received favorable PTSI rankings (US EPA 2007). Divers collected multiple sediment core samples at each site. Samples were transported on ice to a laboratory for processing. Grain size analysis was completed by sieving samples into different size fractions. The differing size fractions were dried and weighed to determine relative contributions.

Areas with favorable PTSI ranks were visited to identify potential conflicts to eelgrass habitat restoration and further characterize the potential transplant sites. Locations (latitude and longitude) were loaded into a geographic positioning system (Garmin GPSMAP 76; see Appendix B). The vessel navigated to each site at low tide and observations were recorded.

Local knowledge on potential restoration sites and other areas was sought to help understand resources and potential conflicts in the Annisquam River. Local support for restoration activities is essential to achieve project goals. Location of test plots was reviewed by the Shellfish Constable, Harbormaster, City Engineer, and Conservation Agent for the City of Gloucester. Several coastal residents also offered insight that supported locating test plots.

Final Site Selection of Test Plots

The combination of PTSI results, mapping of in-water disturbances, site characteristics observations, and personal knowledge was used to identify locations for test plots. The final location of test transplants required review and approval by the Gloucester Conservation Commission, Gloucester Waterways Board, Massachusetts Board of Underwater Archeological Resources (BUAR), and Massachusetts Historical Commission. A letter describing the study, including the location of the test sites, was sent to each agency for review and comment. Written correspondence was required by the BUAR and Historic Commission. The Gloucester Conservation Commission provided a letter permit for the test transplants, and the Waterways Board emailed approval for the test transplants.

Deploying and Monitoring Test Plots

After the locations of test plots were determined, eelgrass was transplanted from a donor bed to potential restoration areas and monitored to assess the success of the transplants. Niles Beach, located on the eastern shoreline of Gloucester Harbor, was used as the donor bed. The eelgrass bed at Niles Beach is stable, as evidenced by aerial photography mapping in 1995 and 2001 (Figure 1), and was deemed capable of sustaining a minor harvest to support the test transplanting.

Approximately 1,200 shoots were collected on 31 July 2007. Divers entered the water from shore, swam into the middle of the eelgrass bed, and haphazardly began collecting mature terminal (vegetative) shoots in areas covered by relatively dense eelgrass. Collection was spatially dispersed in the middle of the eelgrass bed (not on the edge of the bed) to minimize impacts. The diver followed individual shoots to the substrate, uprooted approximately 3-5 cm of the rhizome, and snapped the rhizome to remove the plant. Harvested eelgrass was immediately stored in a cooler with seawater to prevent desiccation. Previous studies demonstrate eelgrass remains viable for transplant at least 72 hours if properly stored (e.g., Davis and Short 1997).

Monitoring was not conducted at Niles Beach after the harvest because of the small number of shoots collected from the eelgrass bed. If or when a larger transplanting effort occurs, monitoring should be conducted at the donor bed.

Test transplants were deployed using TERFS (Transplanting Eelgrass Remotely with Frame Systems). TERFS are wire frames that are 60 cm x 60 cm, with four 60 cm x 15 cm sides, two 25 cm x 55 cm pieces for brick baskets, and four clay bricks (Short et al. 2002b). The TERFS are referred to as frames throughout the report. The frames were populated with eelgrass at staging areas adjacent to transplant areas. Staging areas were identified prior to the transplant dates at each location. Transplanting occurred at low tide to allow easier deployment of frames in shallow water.

Each wire frame was populated with 25 pairs of shoots (50 shoots total per frame) using the TERFS method (Short et al. 2002b). Two shoots were aligned with rhizomes in opposite directions and attached to the bottom of the frame with biodegradable ties (dissolving paper). Shoots were evenly spaced on the frame. While tying eelgrass to the frames, frames were turned upside down and suspended over a tray of seawater so shoots were suspended in the water to prohibit desiccation.

Nineteen frames were deployed from 31 July to 2 August. Frames were gently lowered to the seafloor and checked with snorkeling gear to make sure the frames rested flat on the bottom. Frames were generally placed one meter apart at each site and marked with an orange float and fiberglass rod. Frames were numbered (1-4) at each site.

Test Plot Monitoring

Each site was visited on 2 August for general observations and subsequently checked approximately every other week from August to October. Shoot counts and other observations (e.g., presence of crabs and lobsters) were made for each frame using snorkel gear, except SCUBA was used on the 23 August. Shoot counts through the study are described to assess test transplant survival. At the end of the study (October), the frames were removed from each site. We attempted to leave the surviving eelgrass while retrieving the frames.

RESULTS

Locating Test Transplant Locations

Preliminary Transplant Suitability Index

The PTSI (Short et al. 2002a) was used to prioritize locations for test transplants of eelgrass. Although water quality seemed relatively degraded in the upper reaches of the Little River, with mean Secchi depth below 2.5 meters (Figure 2a), compared to other areas in the Annisquam River, water quality was classified as fair, which receives a rank of one (1). Water quality classified as poor receives a rank of zero (0) in the PTSI, and since the index is multiplicative, a zero rank for any parameter would eliminate an area from consideration. The fair classification allowed the identification of potential locations for eelgrass restoration in the Little River. However, current water quality conditions in the upper portions of the Little River should be improved before substantial efforts are made to transplant or seed eelgrass in the area. No test sites were located in the upper reaches of the Little River for this study.

The water quality ratings were combined with the ratings for the other parameters (historic and current eelgrass distribution, sediment type, water depth, and wave exposure) that were determined by a preliminary assessment of the PTSI in the Annisquam River (Short and Novak 2006). Areas within the estimated eelgrass distribution from 1951 received a rating of two (2) for historic eelgrass distribution, and all other areas in the study received a rating of one (1). Current eelgrass distribution was determined by the combination of 1995 and 2001 mapping data (MassGIS 2006), with areas currently mapped and a buffer of 100 m receiving a zero rating (areas with eelgrass do not require restoration) and all other areas were rated one (1). Based on personal observations, sediment grain size was assumed to be cobble free with ≤70% silt-clay throughout the study area and was rated two (2). Grain size information was supplemented by cores collected in summer 2007 (see below). A bathymetric map was created by contouring soundings from NOAA Nautical Chart 13279. The PTSI model assessed the range of water depth values in relation to the extent of historic eelgrass distribution and rated sites that are deeper and shallower than current distribution of eelgrass as zero (0), sites similar to the deep and shallow edge as one (1), and sites near the average depth as two (2). Wave exposure is a relative index generated in the PTSI based on exposure and fetch. Waters in the study area are largely protected from substantial waves and fetch, so the entire study area received a rating of one (1).

PTSI scores were higher in the northern sections of the study area, particularly in Ipswich Bay, in and around Goose Cove, and the northern section of the Mill River, and scores were lower in the Jones River and southern waters (e.g., Little River) of the Annisquam River (Figure 3). The most favorable conditions (PTSI=16) were found within and adjacent to Goose Cove. Favorable conditions (PTSI=4 to 8) were also identified adjacent to Coffins Beach (i.e., Ipswich Bay), within and surrounding Lobster Cove, and the northern sections of Mill River (Figure 3). Much of the Little River had a PTSI rank of four. Model results also demonstrated favorable PTSI rankings (PTSI=4 to 8) in Gloucester Harbor, including the western harbor (adjacent to Stage Head and Freshwater Cove) and around Tenpound Island (Figure 3).

Site Observations

The Annisquam River is a busy waterbody that is used by commercial vessels, recreational boats, and shellfishermen – among other uses. As the PTSI does not include potential conflicting uses or human disturbances, the location and distribution of navigation channels, mooring fields, docks and piers, marinas, and boat launches were mapped in a GIS (Moda 2007; C. Slinko personal communication; Figure 4) and compared to the PTSI results. Navigation channels, which obviously congregate boating activity and require periodic dredging to maintain safe and navigable waters, are located throughout the Annisquam River, and mooring fields are widely distributed through the study area, particularly around Lobster Cove and the Little River. Potential restoration sites identified by the PTSI were moved to accommodate the presence of these potential in-water disturbances.

Ten sediment cores were collected in areas that received favorable PTSI rankings to improve the understanding of grain size composition (Table 2; USEPA 2007). Cores demonstrated that the areas with favorable PTSI rankings were dominated by sand (≥0.075 mm), with the exception of Lobster Cove, which was characterized by a high silt composition (<0.075 mm) and total organic carbon.

Based on PTSI results and human uses, 12 sites were identified as potential locations for test transplants (Figure 5). Each site was visited to further assess potential anthropogenic disturbances or other natural resources (Table 3). A substantial abundance of eelgrass was distributed throughout Ipswich Bay in early summer 2007 in areas that were not mapped in 1995 or 2001 (MassGIS 2006). The presence of eelgrass eliminated TP-1 and TP-2 from consideration for test transplants. Abundant lobster fishing gear was observed at stations TP-6 and TP-7. The lobster gear presented a conflicting use and potential direct disturbance to transplants, removing TP-6 and TP-7 from consideration. The other sites were slightly moved, as needed, to minimize potential conflicts.

Incorporating local knowledge was an important step for finalizing the location of test transplants. In addition to the formal requirements from the City of Gloucester (i.e., letter permit from the Conservation Commission and Waterways Board to allow test transplants), the Shellfish Constable, Harbormaster, and Conservation Agent reviewed the location of the original 12 test plots. Knowledge gathered from these municipal employees helped determine the exact location of the sites. Sites were slightly moved to eliminate potential impact with shellfishing and navigation areas. The historic knowledge of eelgrass and shellfish presented by the Shellfish Constable was particularly useful in understanding the loss of eelgrass habitat in the Annisquam River and locating test plots in areas that historically supported eelgrass.

Final Locations of Test Transplants

The final number of test plots was determined based on field observations and available resources (e.g., time and equipment) to plant and monitor the test transplants. We decided to focus efforts of this study on the Annisquam River, eliminating the sites in Gloucester Harbor (i.e., TP-10, TP-11, and TP-12). Five areas were identified for test plots: Lobster Cove (TP-3), Goose Cove (TP-4), outside of Goose Cove (TP-5), Mill River (TP-8), and the mouth of the Little River (TP-9; Figure 6).

The Annisquam River is a heavily developed, busy waterway, complicating the identification of suitable sites for test transplants. Lobster Cove received a favorable PTSI (8) but was the site believed to be least suitable for restoration because of shoreline development, distribution of moorings, and high percentage of fine-grain sediments. Goose Cove and outside of Goose Cove received the most favorable PTSI (16). Historic knowledge of Goose Cove indicated an expanse of eelgrass in the area (e.g., Purdy personal communication). While outside Goose Cove was surrounded by a mooring field and public launch, sufficient area adjacent to the mooring field was available to conduct test transplants. The Mill River received a favorable PTSI (8) and appeared suitable for eelgrass restoration. Although the Little River site received the lowest PTSI ranking (4) of the final potential sites, a location in the southern section of the Annisquam River, at the mouth of the Little River, was identified to examine survival of test transplants throughout the Annisquam River. This site was favorable due to the historic presence of eelgrass (Sargent personal observation) and the relatively low level of shoreline development and low density of moorings, possibly presenting fewer impacts to the test transplants.

Transplant Experiments and Monitoring

Test Plot Monitoring

A precipitous decline in shoots was observed at all sites, with extensive mortality and/or loss (e.g., shoots dislodged from frames) between the day of transplanting and the first monitoring date (Figure 7). Shoot counts were collected from 23 August to 2 October. Each site was visited on four dates, except Mill River, which was only monitored on three days. The largest decline in shoots was observed between transplant date (31 July to 2 August) and the first monitoring date (23 August and 30 August).

Highest survival of transplants (11%) was observed at Little River (TP-9). The edges of the frames at the Little River were scoured, which seemed to dislodge plants. While the frames at Little River were quickly covered by epiphytes, plants remained relatively clean. Transplants in the Mill River (TP-8) completely died, except one shoot, by 18 September (<1% survival). Each frame in the Mill River was scoured around the edges from currents and/or burrowing by crabs. A few shoots survived at Lobster Cove (TP-3) during the length of the study (3% survival). Remaining shoots at Lobster Cove appeared stressed by epiphytes and sediment loading. Transplants at Goose Cove (TP-4) and outside of Goose Cove (TP-5) demonstrated a rapid decline during the first few weeks of the study and then a relatively stable number of shoots until October, 7% and 8% survival respectively.

Initial observations at each site on 3 August showed that creatures were immediately attracted to all plots. Bioturbating crustaceans, particularly green crabs at plots outside of Goose Cove, were observed in and around the frames soon after deployment. Bioturbation (the disturbance of the plant by fauna) was apparently a substantial source of mortality. The first monitoring day revealed that leaves appeared clipped at outside of Goose Cove and Goose Cove. Decapod crustaceans, including green crab, rock crab, and American lobster, burrowed under many of the frames in Lobster Cove, outside of Goose Cove, and Goose Cove. American lobsters burrowed under three of four frames in Goose Cove. Burrowing activity dislodged plants from the frames, and the apparent predation of plants reduced the abundance of shoots.

While test transplants did not fare well, plants remaining after the initial die-off appeared healthy and new lateral shoots were observed in September and October at Goose Cove, outside of Goose Cove, and the mouth of the Little River. Naturally occurring eelgrass was also found in Goose Cove and outside Goose Cove during the monitoring. These discovered patches remained through the length of the study, indicating Goose Cove and outside Goose Cove are suitable for eelgrass growth.

DISCUSSION

The abundance of eelgrass habitat is severely diminished from historical levels, and management measures, including protection of existing beds and restoration of degraded habitat, are required for comprehensive ecosystem-based management of coastal resources. Results from this study are an important component of understanding the potential to restore eelgrass habitat in the Annisquam River, while also providing the foundation to develop an eelgrass habitat restoration plan. The restoration plan will be used by the City of Gloucester to guide eelgrass habitat restoration efforts in the Annisquam River. This study and the developing restoration plan will also be incorporated into the wetlands restoration efforts for the Great Marsh on the North Shore of Massachusetts. In addition, the eelgrass habitat restoration plan will serve as a guide for further restoration efforts throughout Massachusetts.

This study tested the application of an eelgrass habitat restoration site-selection tool, which was supplemented with additional information such as fine-scale site characteristics, extent of human uses, and historical and current anecdotal knowledge, and investigated survival of eelgrass test transplants. Results improved the understanding of probable causes of eelgrass habitat degradation and the potential to restore eelgrass habitat in the Annisquam River. While the historical distribution and characteristics of eelgrass in the Annisquam River is relatively well documented (e.g., Dexter 1985), recent assessment of eelgrass is limited to a statewide eelgrass mapping dataset, and the last site-specific examination of eelgrass in the Annisquam River occurred in the late 1980s (Buchsbaum personal communication).

The statewide mapping data were created from aerial photography collected in 1995 and 2001. While comprehensive, these data are not effective at mapping small beds, as the minimum mapping unit is 20 m (MassGIS 2006). Furthermore, fine-scale observations of eelgrass distribution in the Annisquam River are nearly two decades old, and observations from this study identified eelgrass that was not mapped by the statewide survey and elucidated potential causes for eelgrass decline. This study resumed the assessment of fine-scale (<1 m) characteristics of eelgrass habitat, while investigating the potential to restore eelgrass habitat and possible causes of degradation in the Annisquam River.

Moreover, test transplanting was successful at further narrowing the locations for potential eelgrass habitat restoration, and the discovery of small extant eelgrass patches strengthened the case for fine-scale monitoring and further examination of restoration in the Annisquam River. While the precise causes for the decline and lack of recovery of eelgrass in the Annisquam River remain uncertain, test plots results demonstrated that the successful sites could support eelgrass based on the physical parameters (sediment type, water quality, etc.). This supports our theory that the lack of a seed source may contribute to the lack of eelgrass recovery in the Annisquam River and demonstrates the importance of active planting and/or seeding to actively restore eelgrass habitat.

Effectiveness of Site-Selection Tool

Eelgrass restoration is a relatively new and expensive management strategy in New England. However, transplanting eelgrass in appropriate locations has proved successful (Davis and Short 1997; Short et al. 2002a; Leschen et al. 2007) and warrants additional study and consideration for comprehensive, ecosystem-based restoration of the coastal environment. Site-selection is integral to the success of restoration (Fonseca et al. 1998). The site-selection model (i.e., PTSI; Short et al. 2002a and Short and Burdick 2005) was useful at identifying potential locations for eelgrass test transplants. Locations identified by favorable PTSI scores were largely corroborated by historic and anecdotal knowledge of the distribution of eelgrass in the Annisquam River.

While the PTSI is a valuable tool to identify potential restoration sites, this study also demonstrated the value of mapping human uses, conducting field visits, and incorporating local knowledge, in combination with the PTSI, to determine final sites for test transplants. Mapping human uses in the Annisquam River (Moda 2007; Slinko personal communication) and comparing human uses and PTSI results in a GIS was particularly valuable to better understand limitations and/or conflicts with restoration. Anecdotal knowledge of resources in the Annisquam River, although not empirical, was also important to identify the final test plot locations. The anecdotal knowledge confirmed that there was a dramatic decline in eelgrass habitat throughout the Annisquam River and that all test plots were located in areas that once supported eelgrass. Supplementing PTSI results with this additional information was an effective approach to refine the location and number of potential restoration sites in an area that is heavily influenced by human activities.

During field observations of potential restoration sites (identified by the PTSI), widely distributed patches of eelgrass were discovered in the shallow waters of eastern Ipswich Bay. In addition, small patches of eelgrass were found within and outside of Goose Cove during the study. These eelgrass patches were not indicated on the MassGIS eelgrass data, which are interpreted from 1995 and 2001 aerial photography. While aerial photography is the most effective method to map large areas of eelgrass, small patches and areas of low density are often not visible in the imagery. Moreover, imagery is only episodically gathered, and the abundance and distribution of eelgrass frequently changes.

Data available from MassGIS are typically the only eelgrass data available for review of projects that potentially impact eelgrass habitat. This study not only demonstrates the value of the site-selection tool for restoration but also as a predictor of eelgrass habitat. This has implications for the review of development projects and could provide another layer of scrutiny in areas that are potentially suitable for eelgrass. The model could also be used to guide the development of a monitoring effort, with groundtruthing of eelgrass maps and the collection of site-specific environmental characteristics in areas of “potential eelgrass habitat” that are not shown in the current statewide data.

Test Transplants and Observations

The overall survival rate of test transplants was 6%. Contributing to low survival rates was the loss of shoots during and shortly after deployment due plants becoming dislodged from frames and substantial bioturbation in the first few weeks of the transplanting experiment. Following the initial loss of shoots, shoot density seemed to stabilize at all sites except Mill River. Survival ranged from less than 1% at Mill River (TP-8) to 11% at Little River (TP-9). Of note, there was a substantial die-off of shoots at Little River between the end of September and October. Survival rate at Little River excluding October (August to September) was 19%.

While poor test transplant survival does not support advancing plans for large-scale restoration, monitoring results and observations provided insight on possible causes of poor survival and approaches to mitigate threats to transplants. Specifically, testing other planting techniques and investigating optimal planting period may improve survival.

A few shoots were likely dislodged from the frames during or shortly after deployment. Given the relatively few shoots transplanted to each area, a few lost shoots due to not being tightly secured to the frame and/or seafloor substantially influences survival rate. Future work should consider alternative methods to plant shoots in the seafloor or greater diligence in attaching shoots to the frame.

Most likely, a bigger influence on survival was bioturbation. Bioturbation by decapod crustaceans, including burrowing under transplants and clipping shoots, was an apparent impact to transplanted shoots at all sites. The abundance of green crabs, rock crabs, and American lobster in the Annisquam River is potentially a factor in the natural recovery and survival of eelgrass. It is possible that increased abundance of crustaceans in the relatively recent past is limiting the recovery of eelgrass. The change in long-term abundance of decapod crustaceans could be influenced by a number of factors, such as trophic alteration due to overfishing (e.g., Jackson et al. 2001) and/or invasion by non-native species (Williams 2007). Options to lessen the impact of crabs and lobsters should be considered in future plantings.

Transplant techniques using frames may attract bioturbating crustaceans and limit the success of transplants. Structure – both natural (rocks) and human debris (e.g., buckets, discarded lobster traps, boots, etc.) – attract crabs and lobsters. There is a substantial abundance of decapods in northern Massachusetts, which require suitable cover. The addition of wire frames apparently provided structure for these crustaceans. Future eelgrass planting in the Annisquam River should consider using hand planting techniques, such as the horizontal rhizome method (Davis and Short 1997), to eliminate the addition of structure to the seafloor, which may attract crabs and exacerbate bioturbation. Further discussion of bioturbation, as a natural influence, is presented below.

Monitoring results and observations improve the understanding of eelgrass habitat throughout the Annisquam River and Ipswich Bay. Study results suggest that Goose Cove (TP-4), outside of Goose Cove (TP-5), and the mouth of the Little River (TP-9) warrant future consideration for restoration. Limited to no success of transplants at Lobster Cove (TP-3) and Mill River (TP-8), along with environmental and human use characteristics at these two sites, indicate limited possibility to restore eelgrass in these areas. Observations of test plots indicate a variety of potential factors that influence transplant survival and/or limit the recovery of eelgrass in the Annisquam River.

Organic-rich, fine-grain sediments are predominant in Lobster Cove (US EPA 2007) and are likely to be frequently resuspended by boat traffic and mooring chains. The shoreline of Lobster Cove is lined with docks and piers, and a mooring field is distributed through the majority of the subtidal environment, leaving little space for eelgrass to grow. The few shoots that survived in Lobster Cove test plots suggest that with less development, restoration of eelgrass habitat may be possible. Eelgrass historically persisted in the area (Dexter 1950; Dexter 1985; Sargent personal observation), but it seems that environmental conditions (e.g., sedimentation) and human development have altered Lobster Cove to the point that it is unlikely to support restoration or natural recovery of eelgrass.

It is unlikely that there will be a reduction in moorings and/or shoreline development in Lobster Cove. Conversion of antiquated moorings to mooring systems with less impact on the seafloor (e.g., helical anchors and flexible rods) may improve water quality conditions. With an improvement in water quality, the area could be considered for future transplants. However, even with the conversion to environmentally sensitive moorings, there is little space that is not armored by seawalls or covered by docks or boats, making eelgrass recovery in the area highly unlikely.

The cause of virtually no survival of test transplants in the Mill River is uncertain. Eelgrass was transplanted on a shallow subtidal flat that received a favorable PTSI rating, and field observations indicated that the area was suitable for eelgrass. The flat was adjacent to a slightly deeper channel that is lined with a few moorings, and the channel is used by recreational boats and a commercial lobster vessel. Recreational boaters were observed traveling over the test plots and cutting the float marking the test transplants (Zwemke personal communication). The current within the channel and over the adjacent subtidal flat is also quite strong and likely created the scour observed under and around the frames. It is probable that the Mill River is moderately suitable for eelgrass, but the heavy boating activity in the area diminishes environmental conditions for eelgrass. Transplanting shoots in the Mill River using methods developed for high energy environments in Long Island Sound (Pickerell et al. 2007) could possibly improve success and limit interaction with boaters.

The major influence on shoot survival in Goose Cove and outside Goose Cove appeared to be bioturbation. Even with the substantial impact of predation and burrowing, eelgrass survived – with new lateral shoots growing at the end of the study (September and October). While the frames were developed to both protect eelgrass transplants from uprooting and reduce bioturbation (Short et al. MS), the wire frames seemed to attract decapod crustaceans, especially green crabs outside Goose Cove and lobsters in Goose Cove. Planting shoots without a frame and instead using the horizontal rhizome method (Davis and Short 1997) may limit the impact of burrowing crustaceans and may improve the success of transplants in the area. The observation of small patches of eelgrass within and outside Goose Cove also suggest these areas are suitable eelgrass habitat.

Little River test plots were planted between a large tidal flat and a navigation channel. The test plots were located in an area with less shoreline development and moorings compared to other test areas. The frames appeared slightly scoured around the edges, presumably due to the current. The scour likely dislodged eelgrass on the perimeter of the frames. Eelgrass in the center of the frames appeared healthy throughout the study, until October. After the initial loss or die-off of eelgrass in the beginning of the study, shoot counts stabilized and then declined between 18 September and 2 October. The decline late in the study may indicate that conditions were barely suitable for eelgrass at the site, and as day length decreased, the plants could not obtain sufficient light to survive. This area warrants additional investigation, including transplanting techniques described by Davis and Short (1997) and/or Pickerell et al. (2007) to limit the influence of scouring.

This study and the supporting water quality study (Wilbur 2007) did not capture environmental conditions in spring and early summer. Environmental conditions during this period may influence the long-term survival of eelgrass, as relatively short-term stress, particularly water quality conditions, can substantially influence eelgrass populations (Moore et al. 1996). Transplanting eelgrass in spring or early summer may also improve survival of transplants. Earlier transplanting may reduce stress to the plants and allow longer acclimation time to new environmental conditions before day length shortens and water temperature cools in the fall. It is critical for transplants to develop the root-rhizome system shortly after transplant. Eelgrass uses substantial energy to produce seeds, which occurs in the middle of the summer in northern Massachusetts. To minimize stress to transplanted shoots, planting may be more appropriate before reproduction. Results of this study could be complemented with further test transplants using alternative methods, particularly at Little River, outside of Goose Cove, and Goose Cove, and examination of water column light attenuation in the spring and early summer to better understand the suitability of areas to support eelgrass habitat restoration.

Environmental and Anthropogenic Influences

While survival of test transplants was low, observations before, during, and after transplanting improved the understanding of potential natural and human disturbances of eelgrass habitat. The Annisquam River is a busy waterway, especially during the eelgrass growing season (spring to early fall). Boating activity is a substantial direct and indirect threat to eelgrass habitat due to mechanical damage from prop scarring and increased turbidity due to the disturbance of the bottom and shoreline from boat wakes. Infrastructure to support commercial and recreational boating, such as mooring fields and docks, is found throughout the Annisquam River and also represents another threat to eelgrass habitat. Docks and boats on moorings shade eelgrass, prohibiting growth and survival. Furthermore, moorings in the Annisquam River are predominantly block and chain, which directly disturb the benthos and suspend sediments into the water column. The effects of recreational boating seemingly impacted transplants in Lobster Cove and Mill River and may be a factor in the natural recovery of eelgrass.

Many other human activities directly and indirectly impact eelgrass in the study area (see Duarte 2002 for review). The Annisquam River shoreline and adjacent watershed are heavily developed, which increases impervious surface, alters hydrology, and exacerbates sedimentation and turbidity in coastal waters. Shellfishing also represents a potential direct impact to eelgrass from harvesting techniques (e.g., digging) and indirect impact from suspending sediments. Effects of climate change, including rising sea level and warming water temperature (e.g., Short and Neckles 1999), and changing trophic structure associated with fisheries (e.g., Jackson et al. 2001; Thrush and Dayton 2002; Heath 2005) and invasive species (Williams 2007) also likely influence eelgrass habitat and the resiliency of areas to naturally recover.

Natural threats also influence eelgrass habitat. Low levels of wasting disease are commonly found on eelgrass, and occasional epidemics can substantially impact eelgrass beds (e.g., Short et al. 1986). It is unknown if wasting disease contributed to the decline of eelgrass in the Annisquam River during the past two decades. As efforts to restore eelgrass progress, wasting disease should be monitored at transplant sites and natural beds to evaluate if disease is persistent in the Annisquam River. Ice scour can also impact shallow waters, possibly uprooting shoots.

Bioturbation can limit the distribution and recovery of seagrasses (reviewed by Davis et al. 1998). Bioturbation was an obvious impact to the survival of eelgrass in this study, particularly within and outside of Goose Cove. Davis and Short (1997) also observed impacts from green crabs in a transplant effort in the Great Bay Estuary, New Hampshire. Davis et al. (1998) observed green crabs cutting eelgrass shoots through foraging and burrowing behavior at natural and restored eelgrass beds.

Extensive green crab damage was observed immediately after transplant in New Hampshire (Davis et al. 1998), which corroborates with observations of transplants in the Annisquam River. The highest mortality of transplants was witnessed between planting and the first monitoring date. Green crabs were particularly abundant outside of Goose Cove. Disturbance shortly after transplanting reduces the development of the root-rhizome system, hindering transplant success.

American lobster were also responsible for bioturbation, by creating extensive burrows under frames in Goose Cove. Lobster seek refuge in complex habitat, which frequently include human debris such as discarded lobster traps. The wire frames used for transplants are similar in structure to lobster traps. The frames provided structure for lobster in locations with low seafloor complexity.

The abundance of decapod crustaceans in coastal Massachusetts may be higher than historic levels due to the proliferation of the invasive green crab and changing trophic structure (e.g., diminished populations of predators). The relationship between changes in the community and abundance of decapod crustaceans and eelgrass habitat is unknown. However, observations of direct impacts of crabs and lobster in this and other studies demonstrate the influence of these species on eelgrass habitat. Approaches to transplant eelgrass that minimize bioturbation are required in the Annisquam River.

The variety of anthropogenic and natural impacts, while substantial, are not insurmountable to eelgrass habitat restoration (Table 4). While this study does not suggest changes to the uses of the Annisquam River, acknowledging the limitations to restore eelgrass in a busy and intensely developed waterway is critical to develop an eelgrass habitat restoration plan. Eelgrass habitat restoration – and conservation – requires accommodating multiple uses in coastal Massachusetts. The Annisquam River specifically, and coastal Massachusetts in general, support many recreational and commercial activities, along with a substantial resident and tourist population. Designing, implementing, and protecting eelgrass habitat restoration sites would benefit from increased awareness and diligence of citizens, along with creative approaches to manage competing uses. For restoration to succeed in the Annisquam River, grass root efforts are required to maintain vigilant watch on restored and existing eelgrass beds.

Natural Recovery or Active Restoration

Eelgrass was historically found throughout the Annisquam River but is now largely absent and limited to waters north of the Annisquam River (Figure 1). Eelgrass beds north of the Annisquam River appear stable, and the discovery of eelgrass throughout the shallow waters of Ipswich Bay indicate that a source of viable seeds and fragmented reproductive shoots should be available to the Annisquam River. While fragmented reproductive shoots can contain and disperse viable seeds over long distances (Harwell and Orth 2002), seeds released within beds quickly sink to the seafloor (Orth et al. 1994). Eelgrass has not recovered in the Annisquam River and it is unknown if seeds or fragmented reproductive shoots are sufficiently abundant and transported from these northern waters to locations that are suitable for survival and growth in the Annisquam River.

Eelgrass found within and outside Goose Cove indicate natural recovery, and these patches may provide an additional source of eelgrass to stimulate recovery. The patches were, however, small (approximately 1 m^2), especially in relation to the historic distribution of eelgrass habitat. While it is possible that eelgrass is beginning to recolonize Goose Cove, the relatively depressed abundance and distribution of eelgrass may limit or prolong full recovery. The low abundance and limited distribution of discovered eelgrass also provides little resiliency against natural or human-induced impacts. Without an abundance of seeds, beds will expand through vegetative growth under optimal conditions. The small existing beds will take an excessive amount of time to grow throughout available habitat. The Washington Street causeway also severely restricts and isolates Goose Cove from the Annisquam River, presenting challenges for propagules to settle in areas that potentially support eelgrass.

Recovery of eelgrass in southern waters, including the mouth of the Little River, is inhibited by the lack of a close source of propagules (seeds or reproductive shoots). The mouth of the Little River is geographically isolated from existing eelgrass located north of the Annisquam River and in Gloucester Harbor. Active planting in and outside of Goose Cove and the mouth of the Little River may quicken recovery of eelgrass in the Annisquam River. If successful, restored eelgrass habitat in these locations could provide a larger and closer source of eelgrass in northern and southern sections of the Annisquam River, stimulating natural recovery throughout the tidal river.

Suggested Future Study and Recommendations

While this study improved the understanding of environmental conditions and possible human impacts to eelgrass, it also raised questions for future study and suggested options to stimulate recovery of eelgrass habitat in the Annisquam River. Additional study of site characteristics, planting techniques, and approaches to protect transplants from bioturbation would improve the final selection of locations for full-scale restoration. There are other issues, such as considering human uses in site-selection, identifying a suitable source population for full-scale restoration (e.g., donor bed(s)), and monitoring requirements for restoration sites and donor beds, that warrant consideration in future efforts and/or as this initiative advances.

Restoration Site Selection

- The PTSI does not consider human influences (Short et al. 2002a). Human use of coastal waters is a major direct and indirect disturbance to eelgrass habitat and consequently limits restoration success in Massachusetts. The addition of anthropogenic resources into the site-selection model would improve the applicability of this tool. At a minimum, future studies of eelgrass habitat restoration in areas with obvious anthropogenic conflicts should identify and map potential human uses prior to locating eelgrass test transplants, similar to the process used for this study.

  PTSI model results should also be verified before planning test transplants. Field visits during this study revealed characteristics, such as the presence of eelgrass and an abundance of lobster gear, that eliminated sites from consideration for test transplants. While the PTSI is an empirical model, anecdotal knowledge of resources and potential conflicts (which is largely not quantifiable) is important information to consider when planning restoration and can supplement PTSI results. Where possible, anecdotal information should be mapped in a GIS to facilitate incorporating this knowledge into the siting process.

Transplant Site Assessment

- Viable shoots that survived test transplanting were left at the sites when frames were removed in October. Each location, particularly Goose Cove, outside of Goose Cove, and the mouth of the Little River, should be visited in the spring to see if any shoots survived the winter. The presence of shoots would be a good indication that the location is suitable for larger-scale transplanting. The location of remaining shoots should be marked or recorded in a GPS to assist with subsequent observations.

  Patches of eelgrass discovered within and outside of Goose Cove in 2007 should also be located, mapped, and monitored in 2008. The depth distribution of the discovered eelgrass in Goose Cove should be determined to evaluate the optimal depth range for transplanting eelgrass. The depth distribution of existing eelgrass in Goose Cove can also be used to predict the approximate extent of potential restoration in the area, which will be useful to plan a full-scale restoration effort.

- Currents may have dislodged plants from the wire frames at test plots, especially in the Little River and Mill River. A study in Long Island Sound described favorable site characteristics for transplanting in high energy environments with moderate currents (15-35 cm/sec; Pickerell et al. 2007), and studies in Washington indicate that eelgrass was capable of withstanding velocities up to 80 cm/sec (Thom et al. 2001). Evaluating current strength and approaches to secure the plants to the seafloor without attracting crabs and lobsters may be warranted (e.g., Davis and Short 1997; Pickerell et al. 2007).

- While eelgrass historically grew on intertidal flats in the Annisquam River (Dexter 1985; Sargent personal observation), eelgrass planting in the intertidal environment is not recommended because of low success of previous intertidal transplanting in New England (Davis and Short 1997) and potential conflicts with shellfishing. Furthermore, herbivory by waterfowl in shallow waters and intertidal flats is a notable threat to transplants and seedlings. Investigating eelgrass restoration on tidal flats may be warranted, however, if subtidal transplanting is successful.

- This study used a relative measure of water clarity based on Secchi disk depth. Further investigation of the light environment, such as studying photosynthetically active radiation (PAR) and light extinction, may be warranted to better establish the suitability of habitat for eelgrass and/or determine if light limits survival and growth of eelgrass at test sites in the Annisquam River (see Gallegos 1994 and Carruthers et al. 2001). Additional studies should occur from April to October to capture environmental conditions during the eelgrass growing season.

- Niles Beach was used as the donor site for the test transplants and is the planned donor site for supplying the required planting at Pavilion Beach (Metcalf and Eddy 2007). While Niles Beach supports an apparently stable eelgrass bed, additional donor beds may be required to ensure no impact to Niles Beach. Moreover, genetic variability in transplants is an important but relatively unknown consideration in eelgrass restoration (Williams and Davis 1996), and the genetic variability in populations of eelgrass north and south of Cape Ann are unknown. Transplanting eelgrass from Niles Beach, in combination with eelgrass from north of the Annisquam River (e.g., Pigeon Cove), would help reduce potential negative consequences from overharvesting at Niles Beach and reduced genetic variability at restoration sites.

  Viable shoots washed to shore may also offer a source for test or small-scale transplants. Shoots can be collected along local beaches and stored for several days to determine viability (Pickerell personal communication). Once it is determined if shoots are healthy and appropriate for transplant, eelgrass can be planted at restoration sites.

Planting Techniques and Bioturbation

- The wire frames used to attach and deploy transplanted eelgrass attracted decapod crustaceans. Crabs and lobsters burrowed under the frames, which dislodged attached shoots, and green crabs apparently clipped transplanted shoots. Alternative methods that do not use structures to transplant shoots, such as anchoring shoots with bamboo staples as in Davis and Short (1997), should be investigated to potentially minimize the impact of bioturbating crustaceans on transplants.

  Transplant plot configuration and density should be assessed to determine if planting density and/or size could lessen the impact of crab disturbance to shoots. Higher density planting may deter crabs from entering a test plot, or the higher density planting may provide a greater chance for a portion of the shoots to survive.

- Trends in the abundance of green crabs are largely unknown for Massachusetts. These and other bioturbating crustaceans may hinder the natural recovery of eelgrass and disrupt restoration activities. Short et al. (2002a) assigned a poor rating within the transplant suitability index for crab density greater than 4.0 m^2. Assessing the relative abundance and distribution of green crabs and other bioturbating crustaceans in the Annisquam River would improve the understanding of potential effects of bioturbation. However, studying the population of decapod crustaceans in the Annisquam River would require a relatively long-term study, and temporal dynamics of the green crab population would remain hard to predict. Given the few areas available to restore eelgrass habitat in the Annisquam River, efforts to mitigate the effects of green crabs should be considered for future transplanting efforts.

  Efforts to minimize the abundance of crabs around transplants and/or protect transplanted shoots may help success. Crab pots or fish traps could be deployed near transplants to lessen the local abundance of crabs at restoration sites. Temporarily harvesting crabs at the restoration sites may allow the root-rhizome complex to develop, which would help long-term survival of transplants. Traps could be retrieved and emptied twice per week for one month after transplanting. Crabs could be transported to a site appropriately distanced from the transplant areas that does not support eelgrass (e.g., inner Gloucester Harbor).

  Exclusion cages and/or nets may protect transplants from bioturbating crabs and lobsters. Constructing and deploying cages/nets require materials for the exclusion device and adds structure to the areas that may attract fouling organisms and additional bioturbators. Exclusion devices will also require periodic maintenance. If exclusion devices are used, traps could be deployed inside the area to harvest and remove crabs around the transplants (Davis et al. 1998).

- Clam worms (*Neanthes virens*) are also a potential bioturbator (Davis and Short 1997) and may warrant assessment (e.g., benthic cores at final sites, sieved through a 1 mm mesh, Short et al. 2002a), if impacts from clam worms are observed at transplant sites. Impacts from clam worms are typically observed by leaves of transplants pulled into worm burrows. The transplant then lays on the sediment and dies. Future planting and subsequent monitoring efforts should be aware of this potential impact.

- Invasive colonial tunicates (e.g., *Bottyloroides* spp.) are a relatively new threat to eelgrass. Eelgrass patches collapsed under the biomass of invasive colonial tunicates in Salem Harbor (personal observation). Given the apparent impact on eelgrass, restoration efforts should avoid transplanting eelgrass with attached invasive species. Divers harvesting eelgrass from a donor bed should be aware of the presence of colonial tunicates.

- Wire frames appeared eroded around the edges at sites in the Little River and Mill River, and slightly eroded outside Goose Cove. If additional test planting is desired for these areas, attempting to secure shoots to the bottom with cobbles (Pickerell et al. 2007) and/or bamboo shoots (Davis and Short 1997) may limit erosion around the transplants.

- Seeding may facilitate eelgrass recovery and help stabilize populations of transplanted eelgrass. Dispersing seeds at potential restoration sites is relatively low cost and may provide an additional stimulant to quicken eelgrass recovery. Seeds may be dispersed by collecting mature reproductive shoots in mesh bags, and then suspending the mesh bags in the water column at potential restoration sites to allow the natural release of seeds (Pickerell et al. 2005 and 2006). This method of dispersing seeds could facilitate natural recovery and active restoration of eelgrass (Pickerell et al. 2005).

- Herbivory by waterfowl, particularly swans and Canada geese, can substantially degrade eelgrass habitat (reviewed by Williams 2007). It is difficult to eliminate impacts from waterfowl. However, managing human activities that may attract swans and geese to areas should be considered in outreach material (see below).

- This study and the study of water quality in 2006 used to guide site-selection occurred in the summer to early fall. Survival of eelgrass transplants may be influenced by environmental conditions, particularly water quality, in the spring and early summer. Furthermore, the optimal time to transplant eelgrass is during the period that rhizome energy reserves are greatest, which would occur before reproduction in summer. Additional examination of transplant survival should be studied in the spring and early summer.

Monitoring

- A monitoring plan, similar to protocols for monitoring at Pavilion Beach (Leschen et al. 2007; Metcalf and Eddy 2007) or research methods as outlined by Short and Coles (2001), for the restoration area(s) and donor bed is required before full-scale transplanting. Monitoring should occur for a minimum of one year at the donor bed(s) and 3-5 years at transplant sites. Longer term monitoring (>5 years) of presence-absence, percent cover, and disturbance (e.g., wasting disease, bioturbation, etc.) at restoration sites would further help determine success and/or failure (along with potential causes).

  Mapping the extent of the donor bed (e.g., Niles Beach), Pavilion Beach, and transplant sites using aerial photography would help assess and document changes in eelgrass bed characteristics. Aerial photography could occur – as resources allow – yearly for three years, following established protocols used by the Massachusetts Department of Environmental Protection (MassGIS 2006).

Protecting Restoration Areas

- Transplants and seedlings are susceptible to disturbance and warrant proactive protection. The Annisquam River is heavily used by recreational and commercial vessels. Increasing awareness of the citizens and visitors of Gloucester, particularly recreational boaters and shellfishermen, is critical to ensure protection of restoration sites and existing eelgrass beds. Outreach efforts should include posting interpretive signs at strategic locations along the Annisquam River and appropriately marking of restoration areas. Fact sheets, such as the CZM publication found at http://www.mass.gov/czm/docs/pdf/eelgrass.pdf, could be widely distributed to the citizens and stakeholders that surround the Annisquam River.

  It is important for the outreach material to describe ecological values of eelgrass habitat and impacts to this valuable shallow water habitat. Among notable disturbances to eelgrass habitat is herbivory by waterfowl. A flock of pet swans inhabited Goose Cove in the 1980s (D. Sargent personal observation) and possibly contributed to the disappearance of eelgrass in Goose Cove. Pet swans – or other domesticated and nuisance waterfowl – have potentially detrimental impacts to shallow water habitat, including eelgrass. Outreach material should explain the detrimental influence of nuisance species such as swans. Feeding waterfowl should be discouraged, especially in close proximity to the restoration sites and natural eelgrass beds.

  Without appropriate protection and adequate awareness of eelgrass habitat, existing and restored eelgrass will continue to be disturbed, presenting enduring challenges to the conservation and restoration of this valuable shallow water habitat.

ACKNOWLEDGMENTS

A portion of this study was supported by a grant/cooperative agreement of the National Oceanic and Atmospheric Administration (NOAA) Award #NA03NOS4190087. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies, as well as the US EPA. Many partners and volunteers helped this study. Chris Slinko (CZM) created a GIS for the Annisquam River and helped examine site-selection results. Kathryn Glenn (CZM) organized several meetings and facilitated communication with city and state permitting agencies. Kathleen Purdy (Gloucester citizen) provided insight on historical and current conditions of eelgrass in Goose Cove. Bill Zwemke and Charles and Susan Kelly (Gloucester citizens) provided shoreside access to study sites and insight on local resources. Fred Short (University of New Hampshire) donated the wire frames used to transplant eelgrass. Paul Somerville (DMF) instructed on use and assisted with launching a boat used for field work. Eric Nelson, Erik Beck, Tim Bridges, Dave McDonald, Dan Boudreau, and Nathan Raines III (all from US EPA) collected and processed sediment samples. Jean Brochii (US EPA) helped harvest eelgrass used for test transplants. Chris Garby (CZM), Brad Washburn (CZM), Jen Thomson (DMF), Regina Lyons (US EPA), and Christian Krahforst (Mass Bays National Estuaries Program) helped deploy test transplants. Vin Malkoski (DMF) assisted with monitoring. Robert Buchsbaum (Mass Audubon) provided insight on the historical and current status of eelgrass in the Annisquam River.

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Table 1. Input parameters and confidence ranking for the preliminary transplant site index (PTSI; Short et al. 2002a).

PARAMETER	PTSI RATING
Historical eelgrass distribution[1]	1 for previously unvegetated 2 for previously vegetated
Current eelgrass distribution	0 for currently vegetated 1 for currently unvegetated
Proximity to existing eelgrass	0 for <100 m 1 for ≥100 m
Seafloor sediments	0 for rocks/cobble (consolidated bottom) 1 for >70% silt/clay 2 for cobble free with <70% silt/clay
Wave exposure[2]	Relative exposure index based on wind direction, fetch, and location of existing eelgrass beds
Water depth	0 for too shallow or too deep 1 for shallow edge of reference bed 1 for deep edge of reference bed 2 for average of reference bed
Water quality[3]	0 for poor (≤ 2.5 m mean Secchi depth) 1 for fair (3.0-2.5 m mean Secchi depth) 2 for good (> 3.0 m mean Secchi depth)
Basemap	no rating – data frame for model results

[1] Measurement of distance from existing eelgrass not given a confidence rank.
[2] Wave exposure calculated within model using existing wind data of GOMOOS buoy #A0102 from July 2001 to March 2007.
[3] Water quality rating based on interpretation of water clarity (Secchi disk depth) and water quality data collected in 2006; the location of particular ratings are based on inverse distance weighting contours (Wilbur 2007).

Table 2. Annisquam River sediment grain size and total organic carbon (TOC) analysis (US EPA 2007).

LOCATION	APPROXIMATE TEST PLOT	TOTAL SAND ≥ 0.075 mm	TOTAL SILT & CLAY < 0.075 mm	TOC CONCENTRATION mg/Kg	RL* mg/Kg
Ipswich Bay	TP-1	100.0	0.0	646	321
Ipswich Bay	TP-2	100.0	0.0	717	305
Lobster Cove	TP-3	21.5	78.5	24600	356
Outside Goose Cove	TP-5	85.3	14.7	8290	302
Goose Cove	TP-4	88.9	11.1	1420	285
Goose Cove	TP-4	87.7	12.3	2250	346
Mill River	TP-8	100.0	0.0	1520	315
Main Channel	TP-6/TP-7	100.0	0.0	1640	310
Mouth of Little River	TP-9	87.2	12.8	6530	330
Pavilion Beach		87.5	12.5	1920	322

* RL = Reporting Limit for TOC, which is the lowest concentration that the lab feels they could quantify a result for each sample.

Table 3. Preliminary locations of test plots for eelgrass transplant in Ipswich Bay, the Annisquam River, and Gloucester Harbor. See Appendix B for latitude and longitude coordinates of each site.

SITE NUMBER	LOCATION	PTSI SCORE	SITE OBSERVATIONS & LOCAL INPUT
TP-1	Ipswich Bay	8	Eelgrass discovered throughout area
TP-2	Ipswich Bay	8	Eelgrass discovered throughout area
TP-3	Lobster Cove	8	Substantial shoreline development and mooring field
TP-4	Goose Cove	16	Historically high abundance of eelgrass; Patches of eelgrass discovered in 2007
TP-5	Outside Goose Cove	16	Adjacent to public landing and mooring field; Patch of eelgrass (< 1 m^2) discovered in 2007
TP-6	Northern main channel	8-16	Abundant lobster gear and adjacent to mooring field
TP-7	Northern main channel	8-16	Abundant lobster gear and adjacent to mooring field
TP-8	Mill River	8	Broad mud flat and narrow channel; heavily used by recreational boats
TP-9	Mouth of Little River	4	Broad mud-sand flat adjacent to navigation channel
TP-10	Stage Fort Park	8	Gloucester Harbor, close proximity to mapped eelgrass
TP-11	Freshwater Cove	8	Gloucester Harbor
TP-12	Freshwater Cove	4	Gloucester Harbor

Table 4. Impediments to eelgrass restoration and options to improve restoration success.

IMPEDIMENT TO RESTORATION	OPTIONS
Decapod crustacean burrowing	• Bare-root planting without frame
Crab clipping	• Bare-root planting without frame • Exclusion device/structure • Baited crab traps to locally reduce abundance of crabs
Currents	• Pickerell et al. (2007) approach for planting in high energy environment
Boating	• Increase awareness of eelgrass habitat • Limit interaction between boats and transplants • Designate no anchorage zones to protect transplants and promote natural recovery
Mooring fields	• Conversion of moorings to environmentally sensitive systems • Reduce overlap of mooring fields with eelgrass beds
Shellfishing	• Reduce overlap of shellfishing with eelgrass habitat • Designate no shellfishing areas to protect transplants and promote natural recovery
Stormwater	• Institute best management practices to minimize sediment discharge and turbidity in shallow waters

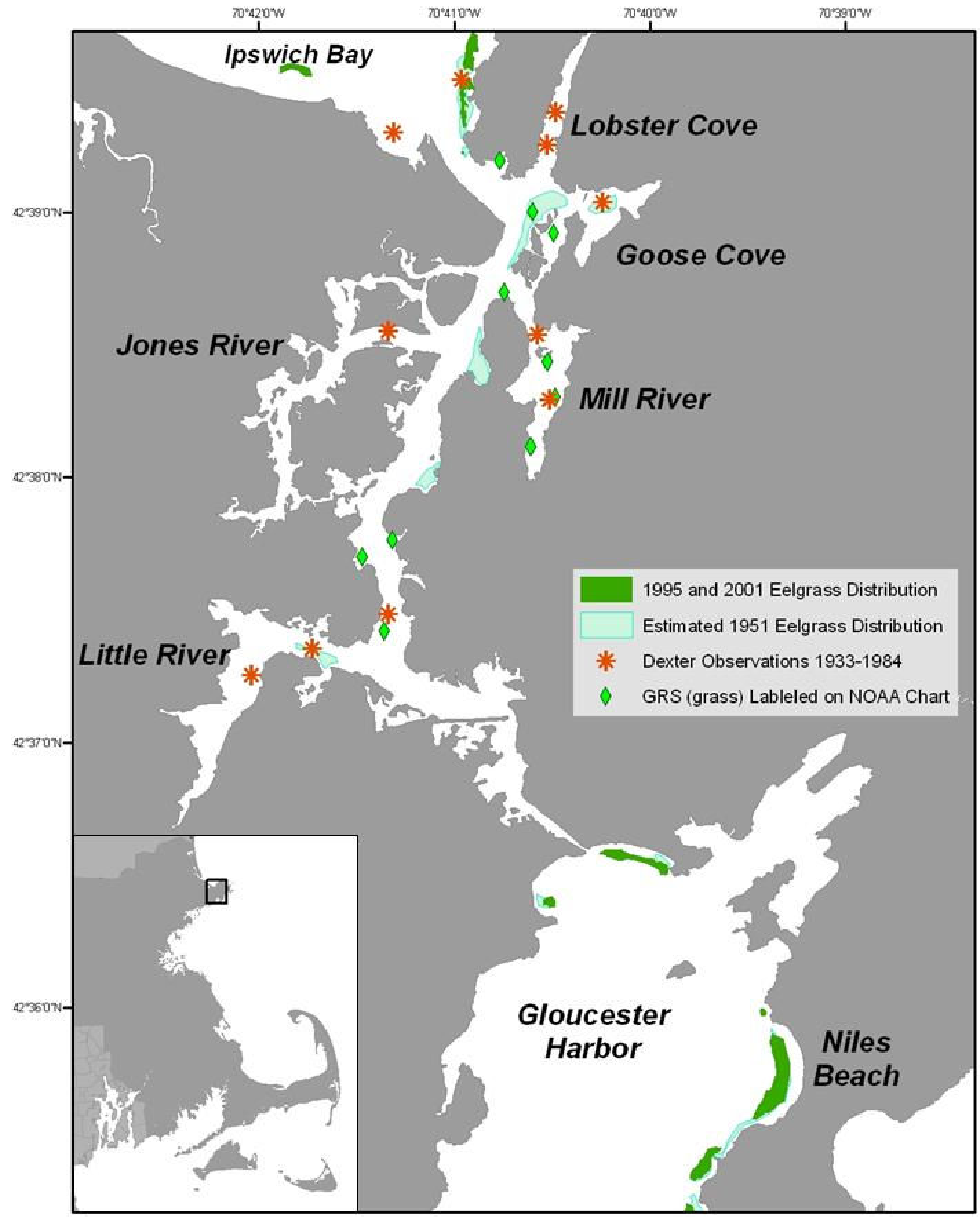

Figure 1. Study area map, showing the current distribution of eelgrass in 1995 and 2001 mapped from aerial photography (MassGIS 2006), estimate of presence of eelgrass in 1951 mapped from historical aerial imagery (light blue polygon; Costello personal communication), observations from 1933-1984 (Dexter 1985), and NOAA nautical chart GRS labels.

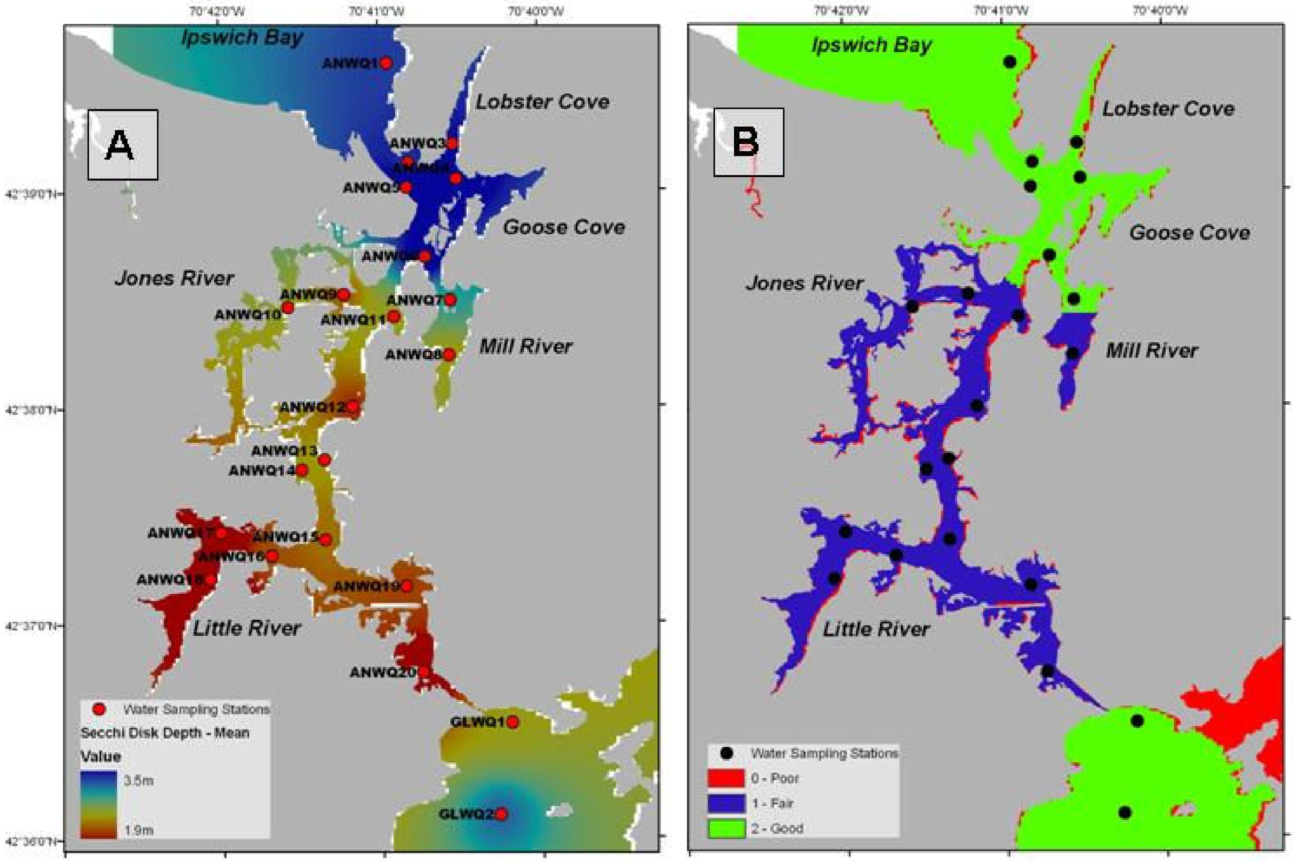

Figure 2. A) Inverse distance weighting (IDW) interpretation of mean Secchi disk depth and B) water quality classes used in the preliminary transplant suitability index (PTSI) for Annisquam River. See Wilbur (2007) for full description of water clarity study in the Annisquam River.

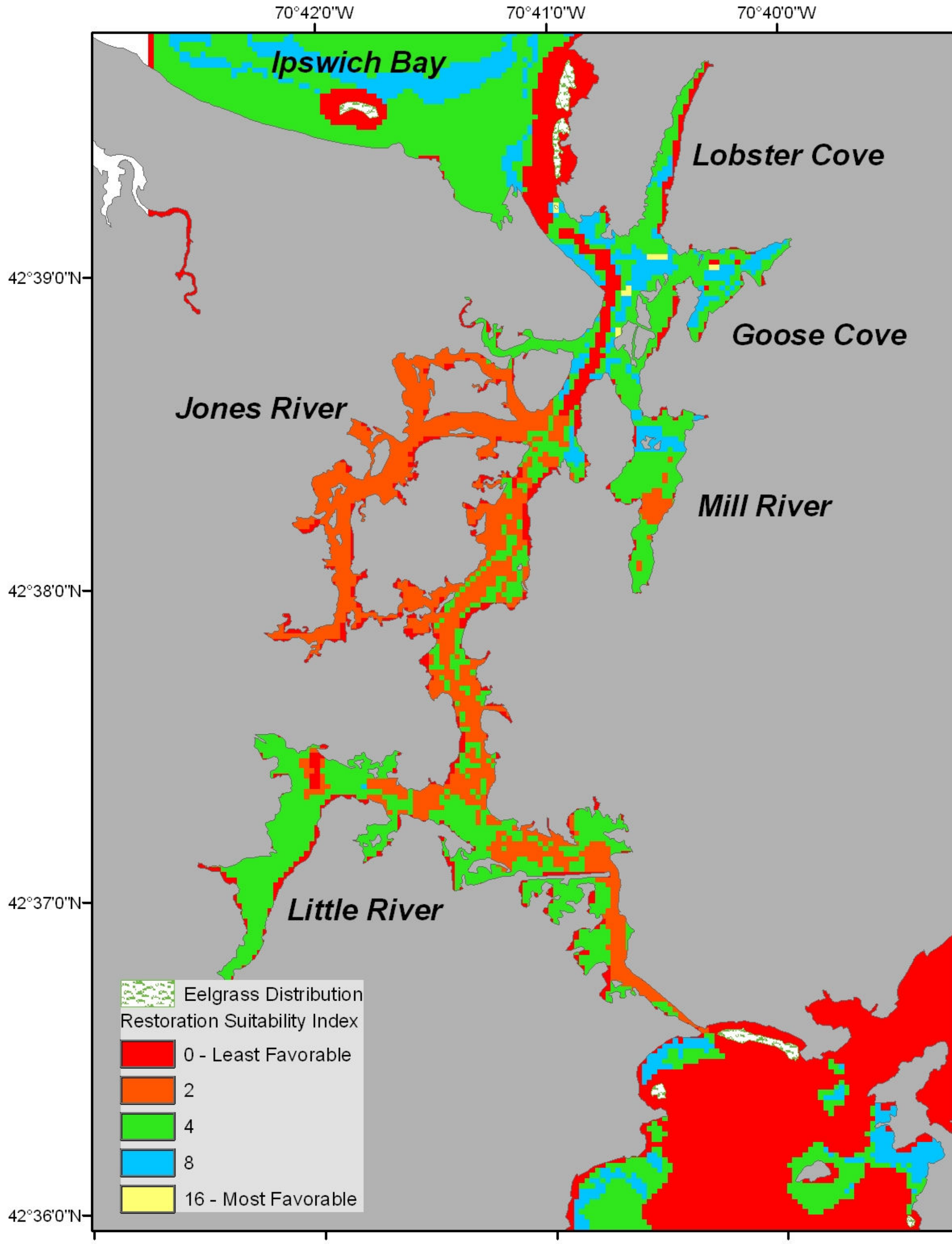

Figure 3. Preliminary transplant suitability index (PTSI) results for the Annisquam River. PTSI rankings range from 0 (red; least favorable) to 16 (yellow; most favorable).

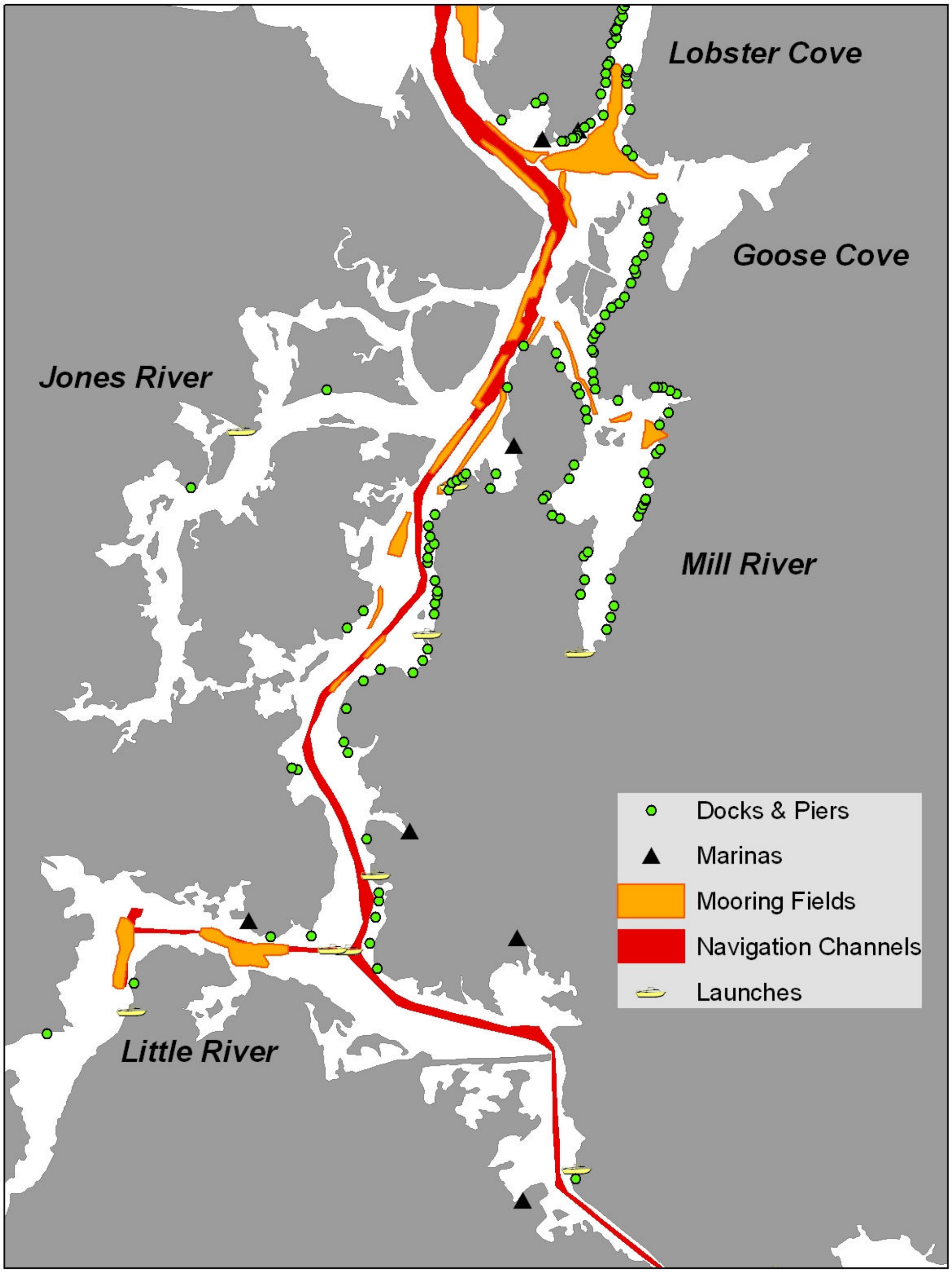

Figure 4. Map showing the location and extent of boat launches, navigation channels, mooring fields, marinas, and docks and piers in the Annisquam River.

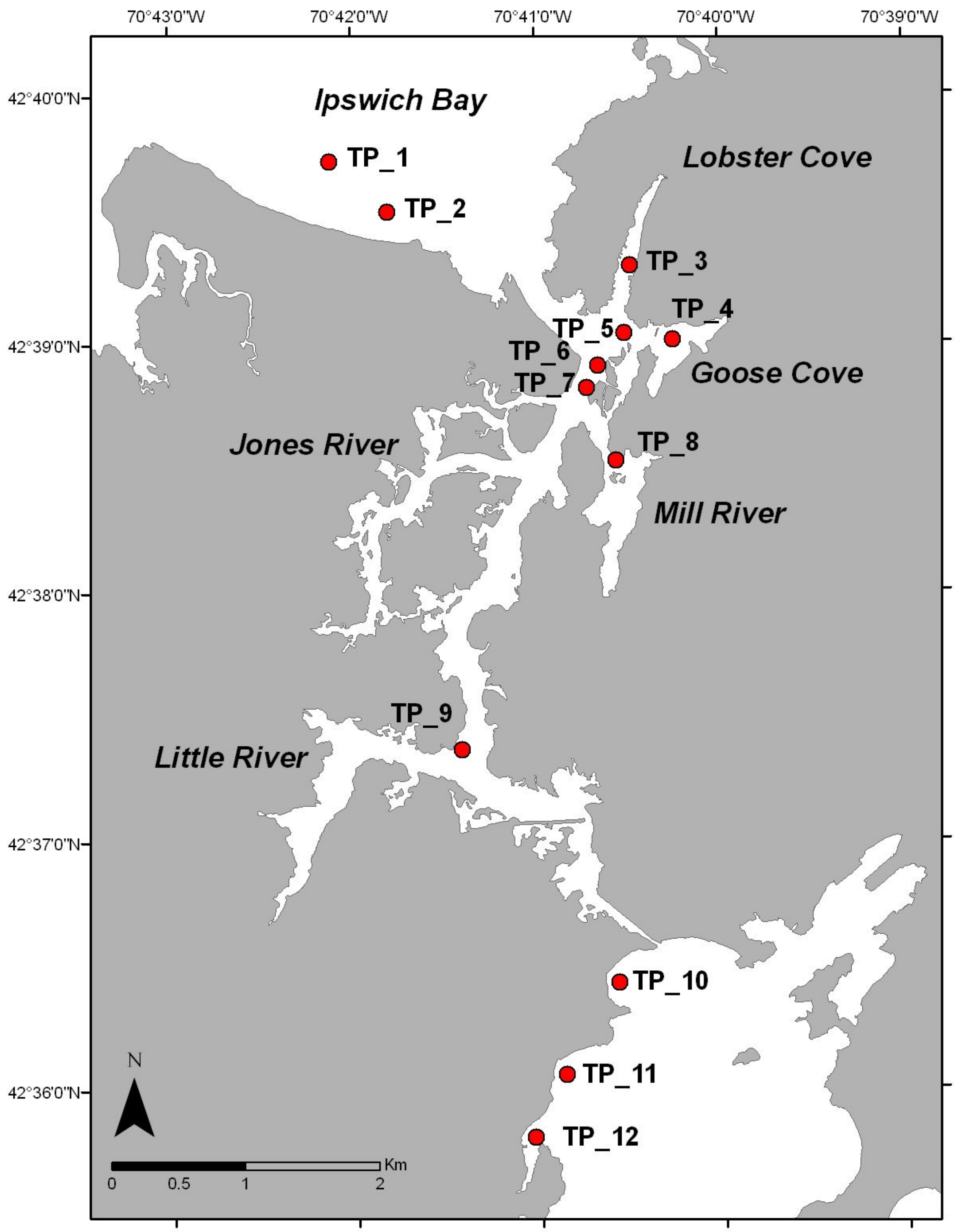

Figure 5. Preliminary locations of test plots that were visited for field observations (see Appendix B for coordinates of sites).

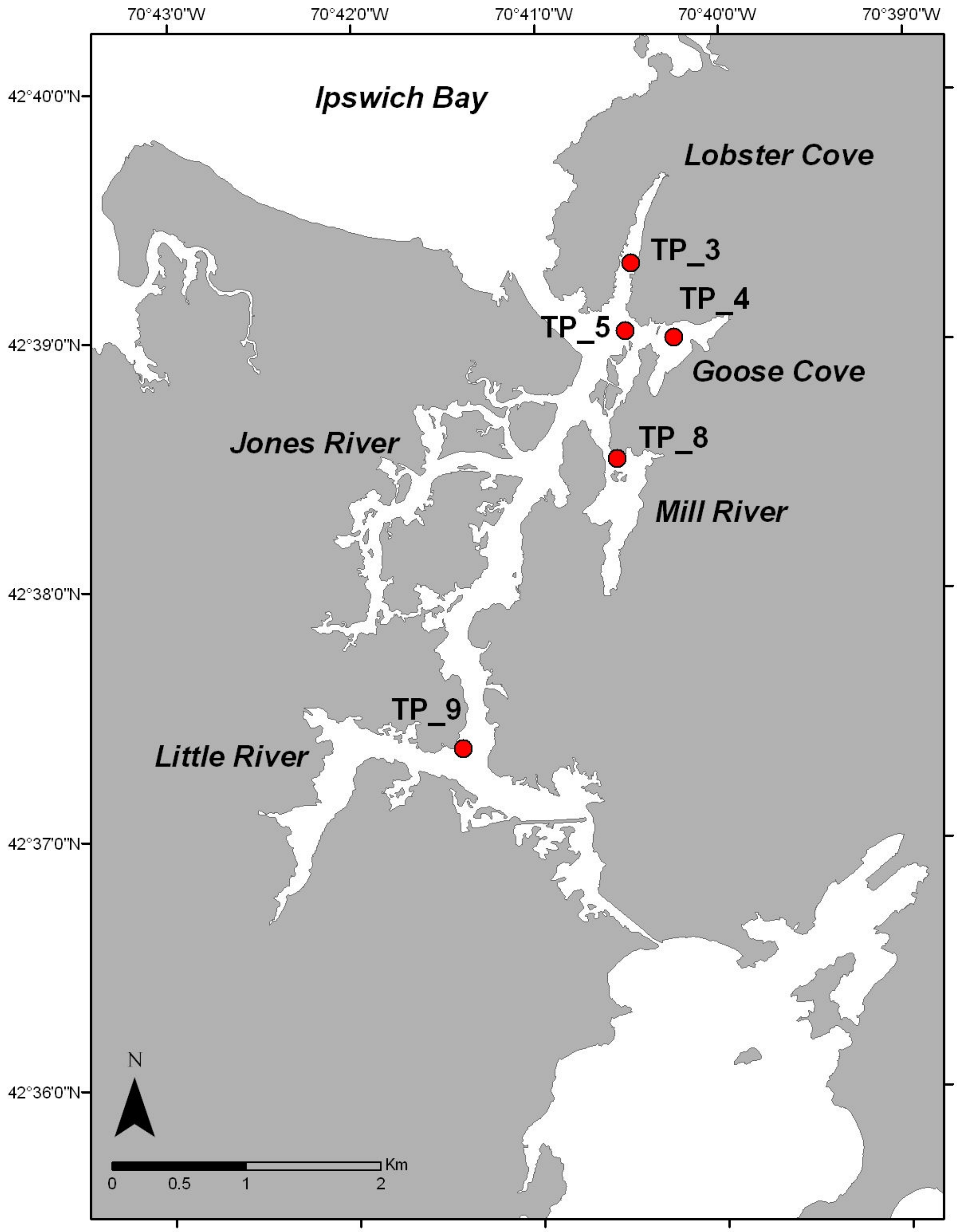

Figure 6. Final location of test plots: Lobster Cove (TP-3), Goose Cove (TP-4), outside of Goose Cove (TP-5), Mill River (TP-8), and the mouth of the Little River (TP-9).

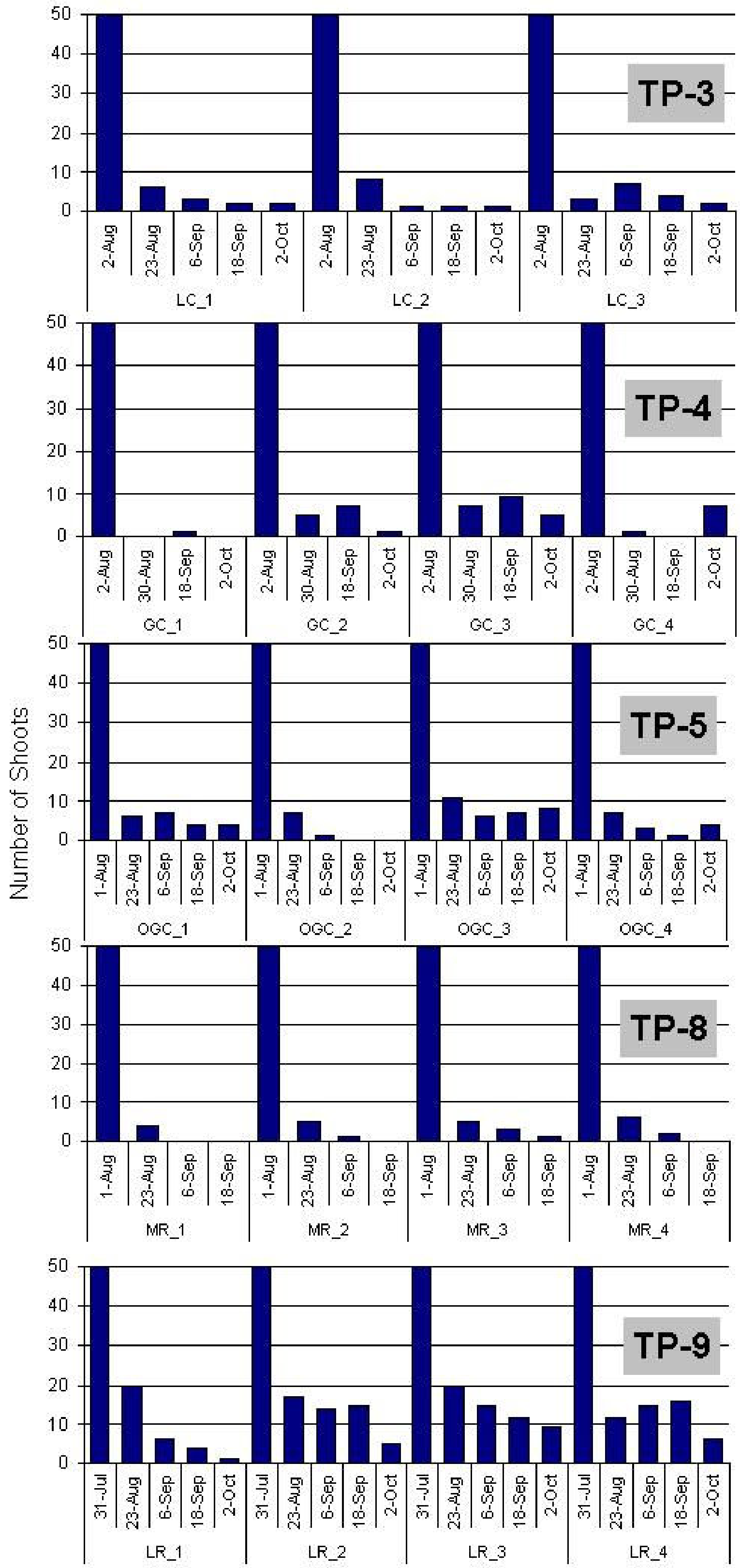

Figure 7. Shoot counts of test transplants at Lobster Cove (TP-3), Goose Cove (TP-4), outside of Goose Cove (TP-5), Mill River (TP-8), and the mouth of the Little River (TP-9).

APPENDIX A. Secchi disk depth measurements for the Annisquam River and Gloucester Harbor, June to October 2006. "+" means that the Secchi disk was resting on the bottom; these data were not used to calculate station or sample date mean ± standard deviation. See Wilbur (2007) for full report.

STATION	23-Jun	7-Jul	24-Jul	7-Aug	21-Aug	7-Sep	20-Sep	4-Oct	19-Oct	Station Mean ± SD
ANWQ1	5.6+	4.1+	3.7	4.7+	3.1	3.0	3.4	2.9	4.4+	3.2±0.3
ANWQ2	3.3+	4.3	3.1+	2.6+	2.8	2.8	3.0+	3.0	3.6+	3.2±0.7
ANWQ3	3.3	4.2	3.0	3.0	3.4	2.4	3.6	3.2	3.7	3.3±0.5
ANWQ4	5.4+	4.5	3.8	3.3	3.5+	3.0	3.5	3.2	3.3+	3.6±0.5
ANWQ5	5.0	4.1+	3.3	3.3	3.5	2.7	3.5	2.9	4.2	3.6±0.7
ANWQ6	4.5	4.6	2.7	3.0	3.1	3.0	3.7	3.2	3.9	3.5±0.7
ANWQ7	3.6	3.3	3.1	2.6	2.8	2.3	3.2	2.1+	2.2+	3.0±0.4
ANWQ8	3.2+	2.7+	2.7	2.7+	2.8+	2.5	2.9+	2.8	3.0+	2.7±0.2
ANWQ9	2.2+	1.4+	2.0+	1.7+	2.1+	2.5	2.2+	2.6+	2.1+	NA
ANWQ11	3.2+	3.3+	2.1	2.7	2.6	2.6	3.3	2.7	3.3+	2.7±0.4
ANWQ12	2.1+	1.3+	1.9+	1.7+	2.1+	2.4+	1.7+	1.3+	1.7+	NA
ANWQ13	3.1	2.5+	2.3+	2.1	2.5	2.5	3.2	3.0+	2.5+	2.7±0.5
ANWQ14	2.4+	3.3	2.0	2.4+	3.1+	2.5	1.9+	2.9	3.7+	2.7±0.6
ANWQ15	2.8	2.3	2.1+	2.6+	2.3+	2.2	3.0	1.8+	2.1+	2.6±0.4
ANWQ16	2.5	2.0	1.9	2.0	2.6	2.4	3.6	2.5	3.0	2.5±0.5
ANWQ17	2.1	1.9	2.1	1.6	2.3	2.2	2.9	2.1	2.4	2.2±0.3
ANWQ18	2.2	2.5+	1.7	1.7	2.1+	2.2	1.9+	1.4+	2.0+	2.0±0.3
ANWQ19	2.6	2.3	1.4+	1.3+	1.4+	2.3+	1.2+	1.3+	1.5+	2.5±0.2
ANWQ20	1.5+	1.4+	2.1+	1.6+	2.5	2.6+	1.8	2.0+	1.4+	2.2±0.5
GLWQ1	2.9	4.1+	3.2+	3.0+	2.5	2.3	3.3	2.5	3.3+	2.7±0.4
GLWQ2	3.2	3.0	3.6	3.3	2.6	NA	3.5	2.7	NA	3.1±0.4
Sample Date Mean ± SD	3.2±0.9	3.2±1.0	2.7±0.7	2.6±0.6	2.8±0.4	2.5±0.3	3.2±0.5	2.8±0.3	3.4±0.7	2.9±0.7

APPENDIX B. Preliminary locations of test plots for eelgrass transplanting in Ipswich Bay, the Annisquam River, and Gloucester Harbor.

SITE NUMBER	LOCATION	LATITUDE (ºNorth)	LONGITUDE (ºWest)	COMMENT
TP-1	Ipswich Bay	42.66227	70.70200	Investigate current eelgrass
TP-2	Ipswich Bay	42.65889	70.69680	Investigate current eelgrass
TP-3	Lobster Cove	42.65521	70.67474	Potentially poor sediments
TP-4	Goose Cove	42.65017	70.67095	High priority
TP-5	Outside Goose Cove	42.65063	70.67530	Moderate-high priority
TP-6	Northern main channel	42.64846	70.67777	Moderate-high priority
TP-7	Northern main channel	42.64696	70.67876	Moderate-high priority
TP-8	Mill River	42.64210	70.67613	High priority
TP-9	Mouth of Little River	42.62277	70.69039	High priority
TP-10	Stage Fort Park	42.60708	70.67627	Gloucester Harbor
TP-11	Freshwater Cove	42.60095	70.68109	Gloucester Harbor
TP-12	Freshwater Cove	42.59673	70.68398	Gloucester Harbor

CZM