CREATING THE BASIS FOR A SUCCESSFUL RESTORATION: TEST-TRANSPLANTING MULTIPLE EELGRASS DONOR POPULATIONS AND CHARACTERIZING THE EUROPEAN GREEN CRAB POPULATION TO INFORM RESTORATION INITIATIVES IN THE GREAT MARSH, MASSACHUSETTS

Applicant Town of Essex

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Overview

Eelgrass beds are an ecologically and economically valuable resource and have become the focus of management initiatives in Massachusetts. Great Marsh, which includes the water bodies of Plum Island Sound and Essex Bay, once contained acres of lush, thriving eelgrass beds that were wiped out by the mid-1900s. With funding from the Massachusetts Bays National Estuary Program (MassBays) in 2012 and 2013, our research team developed a model for Plum Island Sound that identified areas with good potential for the re-establishment and growth of eelgrass and we began test-transplanting eelgrass at the most suitable sites. In 2014, we expanded upon our prior work and began transplanting eelgrass in Essex Bay where a new self-established bed has been identified. In addition, we began collecting information on the population structure of the hyper-abundant European green crab population in Great Marsh in an effort to determine its potential impacts on our restoration initiatives. Eelgrass successfully transplanted into multiple sites in Essex Bay while transplants failed in Plum Island Sound. Green crab populations were found to be hyper-abundant throughout the Great Marsh system. Based on our results, we recommend conducting a large-scale restoration at select sites in Essex Bay using multiple donor sources while continuing test-transplanting efforts in Plum Island Sound. All transplant sites should be monitored and managed for green crabs through trapping. Moreover, baseline information on the population structure of the green crab should continue to be collected in both Plum Island Sound and Essex Bay and used to implement a depletion program for this invasive species before it thwarts efforts to restore and enhance the overall resiliency of this system.

Introduction

Eelgrass (*Zostera marina* L.) is a temperate marine angiosperm that grows in the intertidal zone to approximately 10 m below mean low water in Massachusetts. Eelgrass beds 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, coastal development has led to increased nutrient loadings within watersheds and has caused significant declines in eelgrass populations in Massachusetts (Valiela et al., 1992; Short and Burdick, 1996). Because eelgrass beds are both ecologically and economically valuable, they have become a 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 for management.

Great Marsh, located in northeastern Massachusetts, includes the water bodies of Plum Island Sound and Essex Bay (Figure 1). The area once contained acres of lush, thriving eelgrass beds that were destroyed by multiple stressors during the early-to-mid 1900s (Addy and Aylward, 1944; MassGIS, 2001; Costello and Kenworthy, 2011). Although the environmental conditions appear suitable for growth, the waters of Great Marsh are still devoid of eelgrass except for a small bed (<0.25 acres) that was recently identified near the mouth of Essex Bay (Colarusso pers. com.; Phippen, Walker and Novak, pers. observ.). Both the vast size of the area and the lack of nearby propagules make it unlikely that eelgrass could fully re-establish itself on its own and the Massachusetts Division of Marine Fisheries (DMF), the Environmental Protection Agency (EPA) - Region 1, and the U.S. Fish and Wildlife Service (USFWS) at the Parker River National Wildlife Refuge on Plum Island have jointly recommended that eelgrass be restored to waters of the Great Marsh.

In 2012, as part of the MassBays Research and Planning Grants, our research team developed an Eelgrass Habitat Suitability Model (adapted from Short et al., 2002) in Geographic Information Systems (GIS) that input biological, chemical, and physical parameters to identify and prioritize specific locations within Plum Island Sound (Essex Bay was not included in the analyses) for eelgrass transplantation. The parameters incorporated by the model included: geographic boundaries of the area of interest, bathymetry, sediment type, water quality and clarity, wave exposure, and the location of tidal flats and mooring fields. 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); Novak and Short, 2012; Figure 2).

In 2013, our team used the results of the model and began test-transplanting in Plum Island Sound at sites with the highest scores (8 and 16) as survival of test-transplants is highly indicative of how well a large-scale transplanting effort will succeed at a given site (Figure 3; Short et al., 2002, 2005). Multiple donor sources were used to identify the best sources for this system and to build a genetically diverse population with potentially enhanced resilience to multiple stressors, including climate change (Figure 3; Short et al., 2012). It was during test-transplanting efforts that we became aware of a hyper-abundant European green crab population in Plum Island Sound and Essex Bay with a catch per unit effort (CPUE) greater than 40 crabs per trap in a 24 hour period. While European green crabs have been present along the Northeast Atlantic coast since the early 1800s, a recent explosion of the green crab population in Nova Scotia and Maine has caused significant declines in eelgrass and shellfish populations (Say, 1817; Roman, 2006; Neckles et al. 2009; McCarthy and Neckles pers. com.). Parks Canada has been actively managing the green crabs in Nova Scotia for the past five years and has found that CPUEs <15 crabs per trap within a 24 hour period are needed for eelgrass restoration attempts to be successful (McCarthy, 2013).

In 2014, our team continued test-transplanting using different eelgrass donor sources at the most suitable sites selected by the model in Plum Island Sound and expanded test-transplanting efforts to Essex Bay. Information on the population structure (sex, size, reproductive condition) of the hyper-abundant European green crab population in Plum Island Sound and Essex Bay was also collected in an effort to better understand its potential impacts on our restoration initiatives. The results of our 2014 test-transplanting and trapping efforts are discussed in this report and should be used to inform future eelgrass restoration initiatives in Great Marsh.

Methods

<u>Site Description</u>

Great Marsh is located in the Upper North Shore of Massachusetts. The area is the largest wetland-dominated estuary in New England, supporting a diversity of flora and fauna. Plum Island Sound and Essex Bay are relatively shallow embayments with an average depth from 3 m (MHW) to 1.6 m (MLW) and 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 Great Marsh less sensitive to nitrogen than other estuaries in Massachusetts where eutrophication has been well documented (Buchsbaum et al., 2000).

<u>Eelgrass</u>

Harvesting

Approximately 2,000 shoots were haphazardly collected from each of five donor sites (i.e., Wellfleet, Orleans, Nahant, Chatham and Manchester) between April 1 and September 30 and transplanted in Plum Island Sound/Ipswich River and Essex Bay (Figure 1). Collection of shoots at donor sites was spatially dispersed in the middle of the eelgrass beds to minimize impacts (~2m MLW). Shoots were removed by uprooting 3-5 cm of the rhizome and snapping the rhizome at the base of plants. Harvested eelgrass was cleaned of epiphytes and immediately stored in a cooler with seawater and two aerators for less than 24 hours before being transplanted at test-sites (Davis and Short, 1997).

Test-Transplanting

Test-transplanting in Plum Island Sound/Ipswich River and Essex Bay was performed at a total of eighteen sites between April and September (Figure 1). The selection of sites was based on the results of our model (i.e., suitable sites with scores of 8 or 16 in Plum Island Sound), the presence of historical/current eelgrass beds, areas with stable substrate (no sand waves), and good water quality conditions at the time of planting (Novak and Short, 2013). All shoots were transplanted at the same depth as donor source sites (~ 1m MLW).

a. Biodegradeable Frames

A modified version of Kidder et al. (2013) biodegradable wooden frames was used to test-transplant eelgrass in Plum Island Sound/Ipswich River and Essex Bay. The method consists of tying mature eelgrass shoots with biodegradable ties to the cross-hairs of a frame. Each frame is 66 cm X 66 cm and contains 32 planting units (PU; 2 shoots per cross hair; 74 shoots). In June and July, our collaborators and over 20 volunteers from the local community and organizations participated in test-transplanting efforts. Donor populations were tied in monoculture (one donor source per frame) to forty frames and were deployed among sites (Figure 4).

b. Horizontal Rhizome Method

The horizontal rhizome method consists of anchoring two mature eelgrass shoots (planting units (PU)) with a biodegradable staple. The rhizomes are aligned parallel, pointing in opposite directions, and are pressed horizontally into the top 2 cm of the sediment, and held in place with the staple (Davis and Short, 1997). The horizontal rhizome method was used to transplant shoots into plots (1m x 1m) at five test-transplant sites in Essex Bay between August and September 30 (Figure 4). Each plot contained 25 PUs (50 shoots) and contained shoots from one donor population. The horizontal rhizome method was selected over the biodegradable frame method for all test-transplanting efforts after August 1 because the biodegradeable frames were difficult to secure to the bottom due to the dynamic nature of the bedload substrate.

Green Crab Monitoring

Spring

Twenty sites (14 in Plum Island Sound and 6 in Essex Bay) were sampled in April 2014. Twelve sites were located at the same depth of eelgrass test-transplant sites (~1 m MLW) and 6 sites were located at depths >1 MLW; Figure 5). To sample crabs we used Russell traps baited with haddock wrack. Traps were deployed for a 24 hr. period. To assess population structure, crabs caught were counted and examined for sex, size (carapace width at widest point), and reproductive condition (McCarthy, 2013).

Summer and Fall

Twenty-six sites (11 in Plum Island Sound/Ipswich River and 15 in Essex Bay) were sampled in July and November 2014. All sites were located adjacent to current/past (2013) eelgrass test-transplant sites (~1 m MLW; Figures 6,7). To sample crabs we used Russell traps baited with haddock wrack. Traps were deployed for a 24 hr. period. Volunteers from the New England Aquarium Live Blue Ambassadors Program and MassBays participated in monitoring efforts and counted and examined crabs for sex, size (carapace width), and reproductive condition (Figures 8, 9,10).

Results

Eelgrass

Eelgrass from our spring and summer transplants did not survive at any test-transplant site in Plum Island Sound/Ipswich River. Eighty percent survival was observed in December at the three sites near the natural eelgrass bed and ten percent survival was observed at two additional sites in Essex Bay (Figure 1). The natural eelgrass bed in Essex Bay appeared to be smaller and patchier than the previous year and we observed clammers digging up planted eelgrass on the clam flats on multiple occasions (Figure 11).

Green Crab Monitoring

Spring

A total of 1384 crabs were caught in Plum Island Sound and Essex Bay during our April sampling efforts. Catch per unit efforts (CPUE) ranged from 0 to 215 at sampling sites. Only one trap of fourteen deployed in Plum Island Sound (Roger's Island) had a CPUE that was below the limit recommended for eelgrass growth and survival (<15 crabs per trap) while four traps of six deployed in Essex Bay were below (Figure 5). Twice as many females were caught compared to males ($p < 0.05$) and the majority of all crabs caught had a carapace width less than 2 inches ($p < 0.001$). Four female crabs, all with a carapace width between 1.5 and 2 inches, were producing eggs.

Summer

A total 4762 crabs were caught in Plum Island Sound/Ipswich and Essex Bay during our July sampling efforts. Catch per unit efforts (CPUE) ranged from 34 to 572 at sampling sites and exceeded the limit suitable for eelgrass growth and survival at all sites (Figure 6). Three and a half times as many females were caught compared to males ($p < 0.001$) and the majority of all crabs caught had a carapace width less than 2.5 inches ($p < 0.001$). Twenty-five female crabs, all with a carapace width between 1.5 and 2 inches, were producing eggs. Forty-two rock crabs were caught as by-catch.

Fall

A total 1720 crabs were caught in Plum Island Sound/Ipswich and Essex Bay during our November sampling efforts. Catch per unit efforts (CPUE) ranged from 15 to 226 at sampling sites and exceeded the limit suitable for eelgrass growth and survival at all sites except one (Figure 7). Overall, there were as many females caught compared to males ($p > 0.05$) and the majority of all crabs caught had a carapace width less than 2.5 inches ($p<0.001$). No gravid females were observed and fifteen rock crabs were caught as by-catch.

Discussion

In 2014, eelgrass was test-transplanted at eight sites in Plum Island Sound and ten sites in Essex Bay using multiple donor sources from Massachusetts (Figure 1). Eighty-percent of the shoots transplanted at three sites in Essex Bay survived while no transplants survived in Plum Island Sound (Figure 1). The shoots that survived in Essex Bay were from Wellfleet, Orleans, Nahant, Chatham and Manchester. Based on our results, we recommend performing a large-scale restoration (~ 2 acres) in Essex Bay using multiple donor sources and continuing test-transplanting efforts in Plum Island Sound and Essex Bay.

Large-scale transplanting efforts in Essex Bay should initially focus on sites where eelgrass test-transplanting efforts have been successful. Three potential sites for restoration efforts are located adjacent to the natural bed near the mouth of the Essex River (Figure 1). Over the winter of 2013-2014, the natural bed in this area dramatically decreased in size for unknown reasons, however, we were able to reestablish and expand the bed via transplanting five thousand shoots from various donor sources. In addition to performing a large-scale restoration in Essex Bay, test-transplanting efforts should be continued to identify additional restoration sites because environmental conditions appear suitable for eelgrass in other un-tested areas. One potential site for consideration is the area located at the mouth of Essex Bay (Figure 1). This site has green crab CPUE's similar to the area adjacent to the natural eelgrass bed, is well-flushed, and eelgrass shoots were observed while pulling crab traps (Figures 5,6, 7; Novak, Phippen and Fitzgerald pers. obser.). Before proceeding with a large-scale restoration and/or future test-transplanting efforts in Essex Bay, restoration initiatives must be communicated to clammers to avoid potential conflicts. In addition, we recommend collecting habitat quality measurements to monitor environmental conditions and trapping/harvesting green crabs near eelgrass transplant sites to reduce the numbers to 15< CPUE's and to ensure that restoration efforts are successful.

Continuing test-transplanting efforts in Plum Island Sound to identify sites for a large-scale restoration is recommended. Previous test-transplanting efforts in this area were unsuccessful most likely due to bioturbation by green crabs. Catch per unit efforts (CPUEs) of green crabs were magnitudes greater than suggested management levels at all sites except Roger's Island (Figures 5,6,7; McCarthy, 2013). Other factors that may be contributing to the inability of eelgrass to establish itself in Plum Island Sound including high rates of bedload sediment transport and low light levels caused by suspended solids (Novak, Phippen and Fitzgerald pers. observ.). Next year, our team will continue to trap and monitor green crabs near transplant sites and collect additional information on water quality and clarity in the system (e.g., PAR, suspended solids). In addition, we will be working closely with colleagues to develop hydrodynamic and sediment transport models. The information derived from the models will be used refine our Eelgrass Site Suitability Model we developed in 2013 and to increase our understanding of the processes governing the establishment and growth of eelgrass in the Sound, especially at sites where eelgrass historically grew.

Our green crab monitoring efforts confirmed the assertion that this invasive species is a serious threat to eelgrass restoration initiatives. CPUE's were higher than recommended management levels at almost all Plum Island Sound and Essex Bay sites, with >500 crabs per trap in a 24 hr period at some sites during the summer months. In addition, seasonal variations in the abundance and proportion of males/females were observed, with data suggesting that intensive trapping efforts to manage this species may be most effective during the summer months when crabs are the most abundant and females are more prevalent. In August, the Town of Ipswich issued a bounty on green crabs and more than 60,000 pounds were caught within two weeks in the Ipswich River (Lapointe, pers. com.). Continuing intensive trapping efforts throughout the Great Marsh should reduce the population size to levels that are less threatening to eelgrass restoration initiatives and to the systems natural resources.

Based on our results, we recommend conducting a large-scale restoration at select sites (Figure 1) in Essex Bay using multiple donor sources and continuing test-transplanting/habitat quality measurements in Plum Island Sound and Essex Bay. All transplant sites should be monitored and managed for green crabs through trapping to ensure that transplanting efforts are successful. Moreover, baseline information on the population structure of the green crab should continue to be collected in both Plum Island Sound and Essex Bay and used to advise the implementation of a depletion program before this invasive thwarts eelgrass restoration initiatives. A summary of our recommendations as we move forward with our efforts to enhance the ecology, economy, and overall resiliency of Great Marsh are as follows:

Summary of Recommendations:

- Conduct a large-scale eelgrass restoration in Essex Bay (2 acres);
- Measure/monitor environmental and habitat conditions in Essex Bay transplant sites: sediment conditions, light, temperature, and nutrient concentrations;
- Use eelgrass plants from multiple donor sources in order to identify the best-adapted eelgrass populations;
- Conduct additional test transplanting in Plum Island Sound and Essex Bay to identify new optimal sites;
- Measure environmental and habitat conditions (as above) at test sites;
- Use data from the hydrodynamic and sediment transport models to refine the eelgrass site selection model for Plum Island Sound;
- Notify clammers of eelgrass restoration efforts and discourage/restrict digging at transplant sites;
- Control green crab populations through routine trapping at transplant sites and other areas in the Great Marsh; and
- Monitor and assess the population status of green crabs in both Plum Island Sound and Essex Bay for comparison to the invasive green crab monitoring programs underway in Maine and Canada.

Acknowledgements

We would like to thank our robust team of collaborators who have dedicated a total of 300 hours during the 2014 field season:

Peter Phippen, Pam Dibona, Prassede Vella, Lisa Engler, and Sarah Stanley (Mass Bays); Geoff Walker (Great Marsh Task Force); New England Aquarium Live Blue Ambassadors Program (24 volunteers); Lisa O'Donnell (Town of Essex); Holly Bayley and Megan Tyrell (National Park Service); Duncan Fitzgerald (Boston University); Tim Simmons (Division of Fisheries and Wildlife); Gregg Moore and Fred Short (University of New Hampshire).

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Figure 1. Location of eelgrass test-transplanting sites in Plum Island Sound/Ipswich River and Essex Bay in 2014. Yellow/yellow with a green outline circles denote sites where eelgrass is growing successfully. Yellow circles with a green outline denote potential sites for a large-scale restoration. The black circle denotes a potential restoration site that should be further assessed.

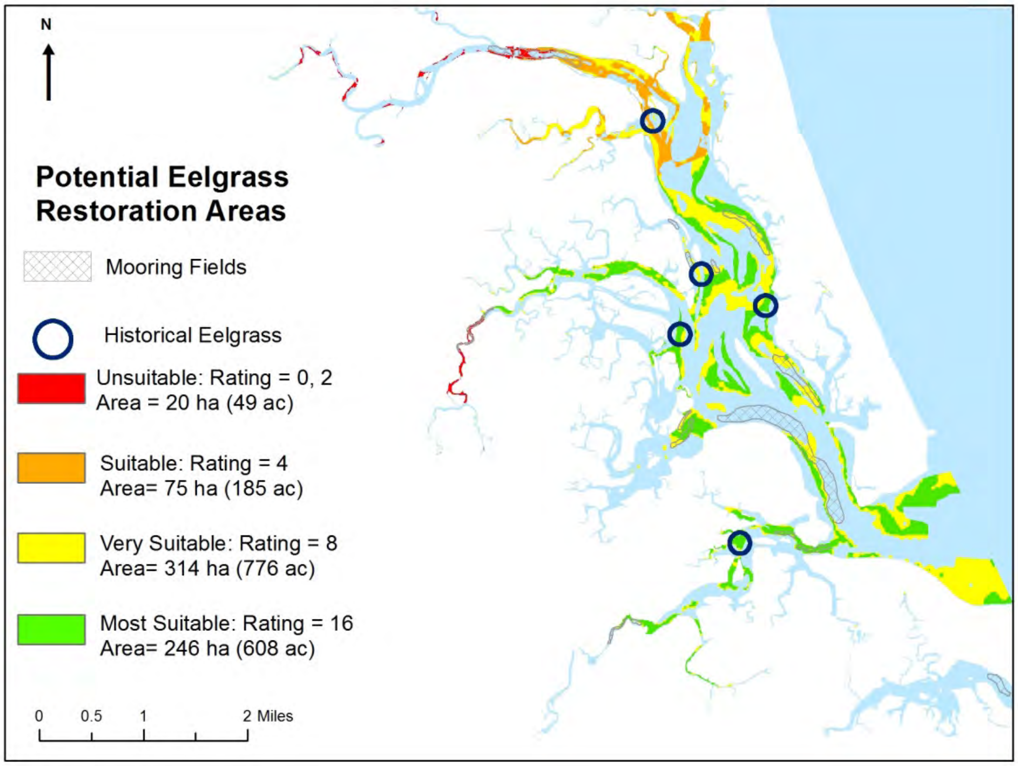

Figure 2. Map showing potential eelgrass restoration areas in Plum Island Sound identified by the model. The parameters of bathymetry, sediment type, water quality and clarity, wave exposure, and the location of tidal flats were used in a model to produce this map. Mooring fields and approximate locations of historical eelgrass beds are also shown.

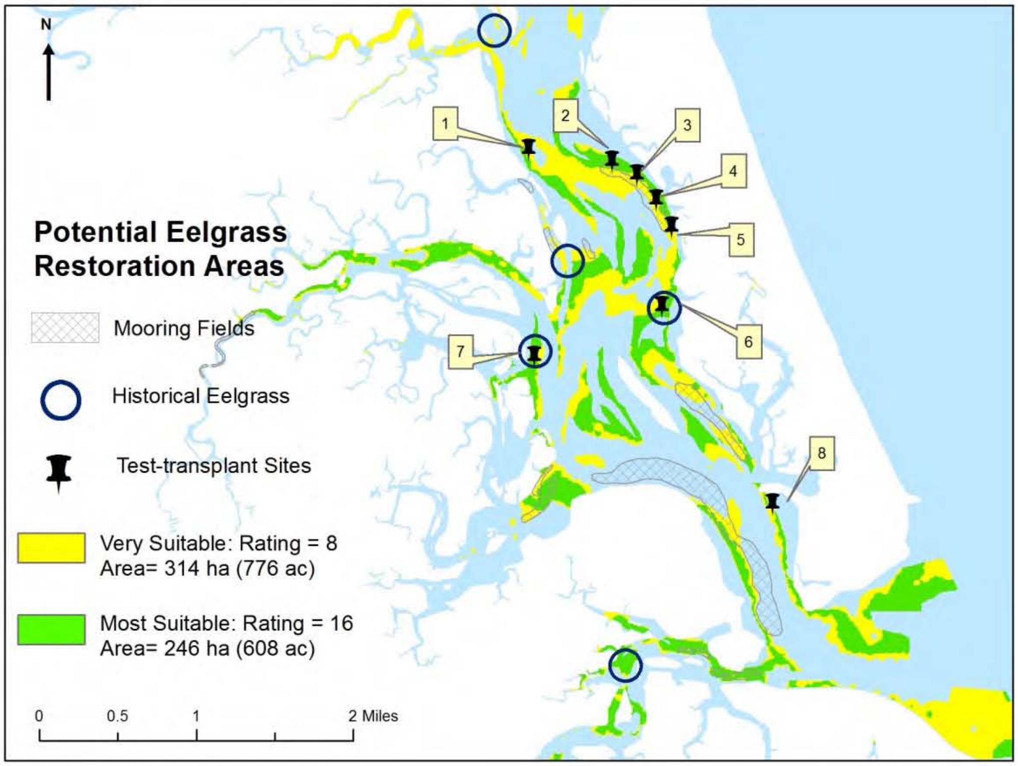

Figure 3. Map showing the location of eelgrass test-transplant sites (black push-pin) in 2013. All test-transplant sites were in areas identified by the model as very suitable (yellow areas; rating= 8) or most suitable (green areas; rating=16). Mooring fields and approximate locations of historical eelgrass beds are also shown.

Figure 4. Photos of eelgrass frames and monitoring efforts.

Figure 5. Location of European green crab sampling sites in April. CPUE's were less than 15 crabs per trab in a 24 hour period at one site in Plum Island Sound and four sites in Essex Bay.

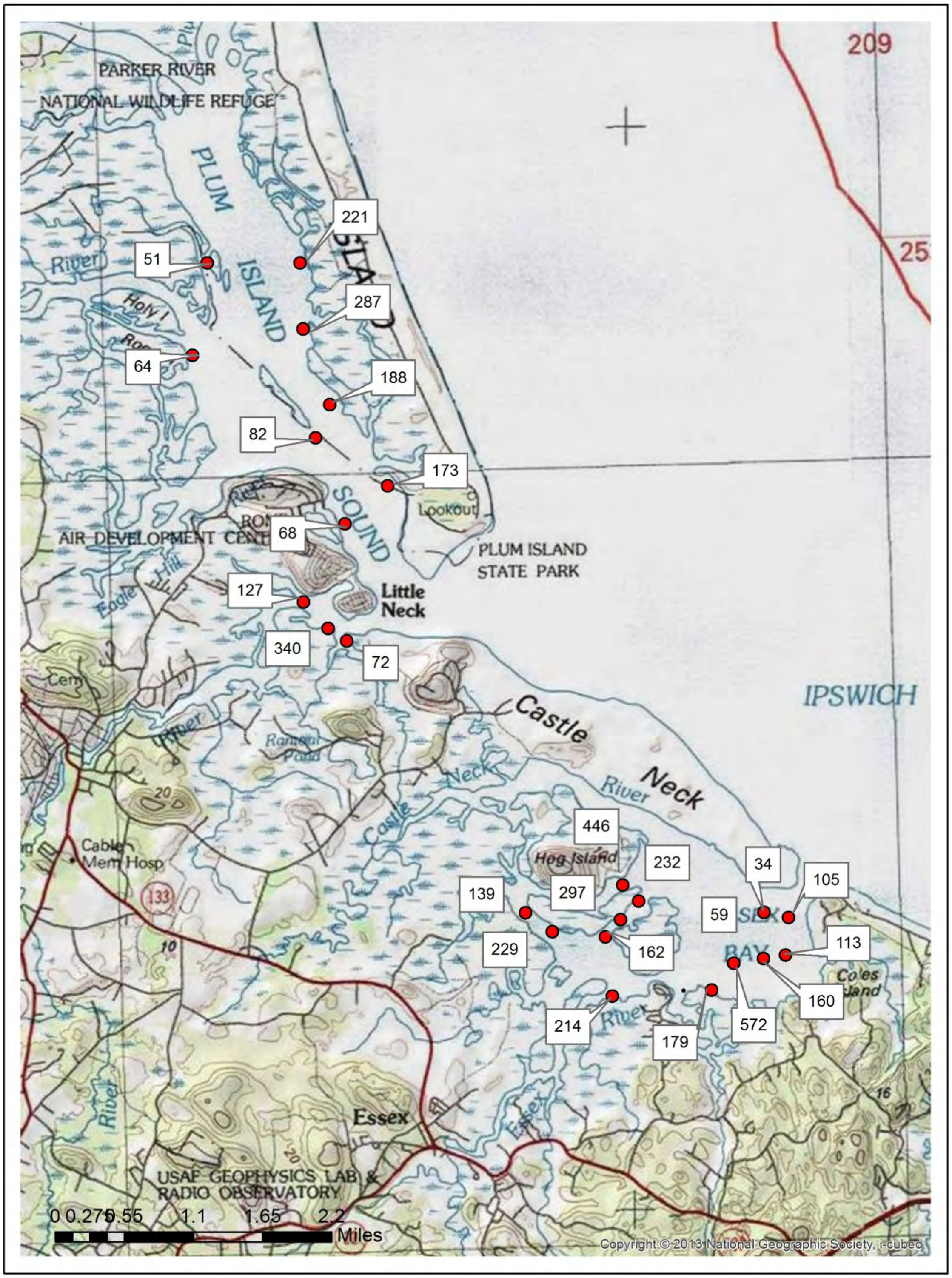

Figure 6. Location of European green crab sampling sites in July. CPUE's (denote in call-out box) were greater than 15 crabs per trap in a 24 hour period at all sites.

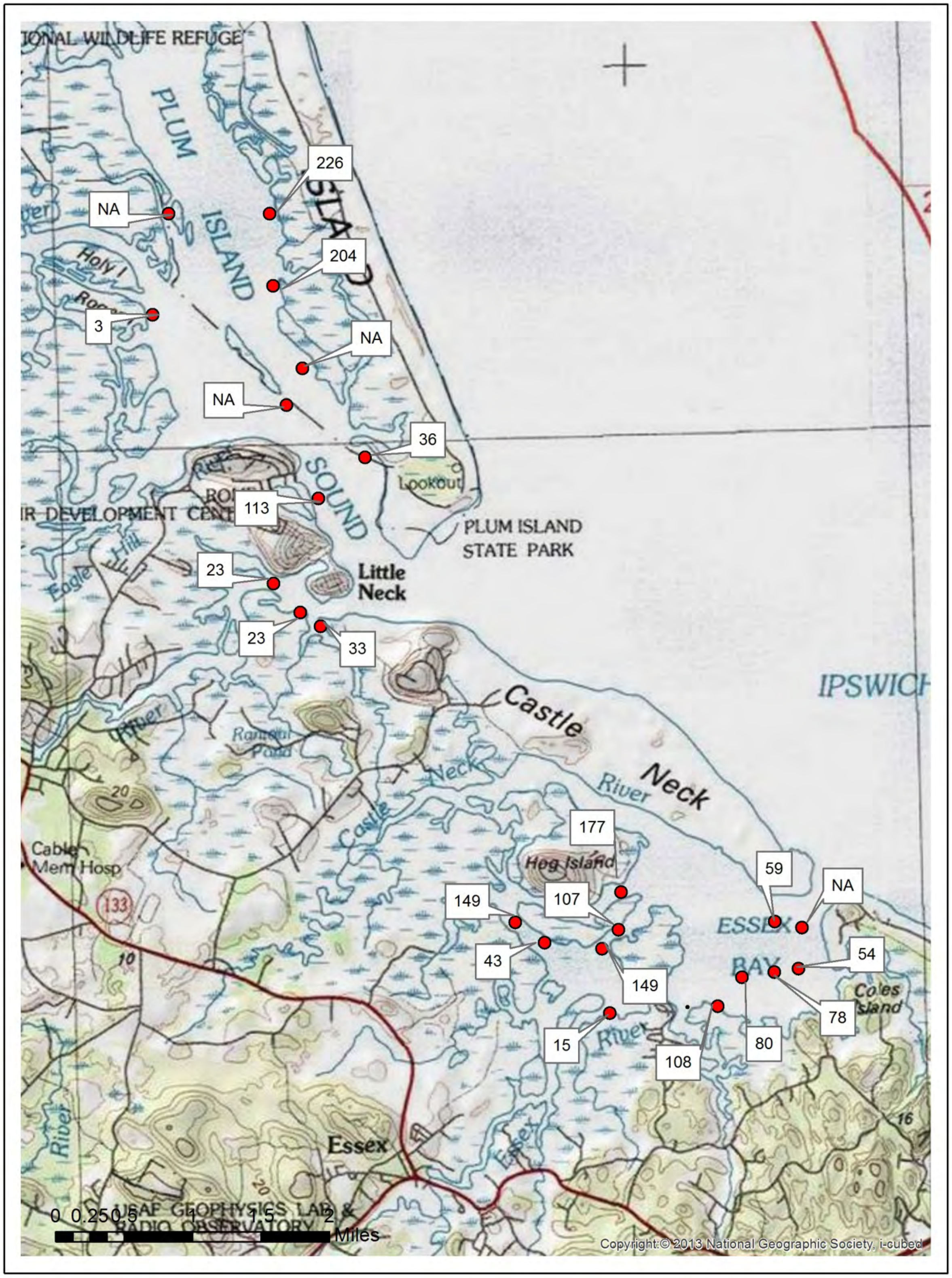

Figure 7. Location of European green crab sampling sites in November. CPUE's (denote in call-out box) were greater than 15 crabs per trap in a 24 hour period at all sites except one.

Figure 8.   Photo of a green crab.

Figure 9. Male green crab.

Figure 10. Female green crab with eggs.

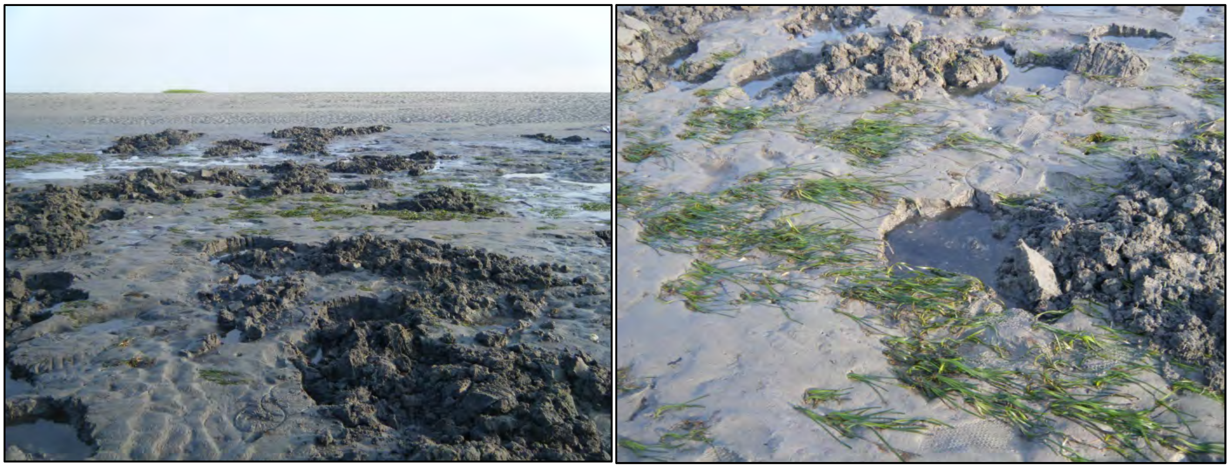

Figure 11. Pictures of holes created by clammers digging at eelgrass transplant sites for clams
The sites are only exposed during spring tides.