Exploring Suitable Eelgrass Habitat on Cape Cod, Massachusetts

Final Report to The Nature Conservancy

Prepared by Cape Cod Cooperative Extension Marine Program
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Executive Summary

Eelgrass test transplants were performed to evaluate potential sites for full-scale eelgrass restoration on Cape Cod. From a set of twelve potential sites, three (Phinney's Harbor in Bourne, Nauset Inlet in Orleans, and Cape Cod Bay in Truro) were chosen for test plantings. Plantings were performed using two methods: the clump transplant method and the horizontal rhizome method. Survival varied over time between sites and overall success was limited in all three test plots. Reasons for limited success included excessive bioturbation at Nauset, sediment instability at Truro, and marginal water quality at Phinney's Harbor.

Introduction

In fall 2009 The Nature Conservancy (TNC) contracted with the Barnstable County Cooperative Extension Marine Program to explore potential sites for eelgrass restoration on Cape Cod. The project included identification of potential restoration sites, evaluation of those sites for suitability, performing transplant trials at three sites, and monitoring for one year post-planting. This report describes the project methods and results. The ultimate aim of the project was to identify sites on Cape Cod where full-scale eelgrass restoration might be viable. Therefore a set of recommendations regarding larger-scale restoration prospects on the Cape is provided.

Task 1. Site Selection

The project entailed a thorough site selection process to ensure appropriate sites were available prior to performing any test transplants. The process followed generally that recommended in Short et al (2002), amended for our purposes based on site-specific information that was deemed relevant to the evaluation of sites. Potential restoration sites were identified in a stepwise process described below.

First-tier Site Selection – Elimination of Unsuitable Sites

In the first phase of site selection, as recommended in Short et al. (2002), a preliminary evaluation was done to eliminate areas from consideration if they were clearly not conducive to eelgrass growth. All coastal areas on Cape Cod were evaluated with respect to readily measured parameters that would exclude them from consideration. Parameters included existing eelgrass beds (where restoration is unnecessary); depth (exclude areas >30' deep), human use areas (exclude areas characterized by infrastructure including mooring fields, navigation channels, or heavy public use areas such as marinas, commercial or recreational shellfishing); sediment type (exclude high organic, silt/clay areas); and storm/wave exposure (exclude east side of Cape Cod National Seashore and embayments directly open to northeast exposure).

Preliminary Site Selection (12 sites)

A number of potential sites were selected after eliminating non-viable sites based on the criteria above. Twelve sites (Figure 1) were considered potentially viable based on the criteria noted above (see Appendix A). The 12 sites were:

1. Buttermilk Bay/Bourne
2. Phinney's Harbor/Bourne
3. Toby's Island/Bourne
4. Bourne's Pond/Falmouth
5. Waquoit Bay/Mashpee
6. Popponesset Bay/Mashpee
7. Cotuit Bay/Barnstable
8. Cape Cod Bay/Brewster
9. Pleasant Bay/Orleans
10. Hopkins Island/Orleans
11. Cape Cod Bay/Wellfleet
12. Cape Cod Bay/Truro

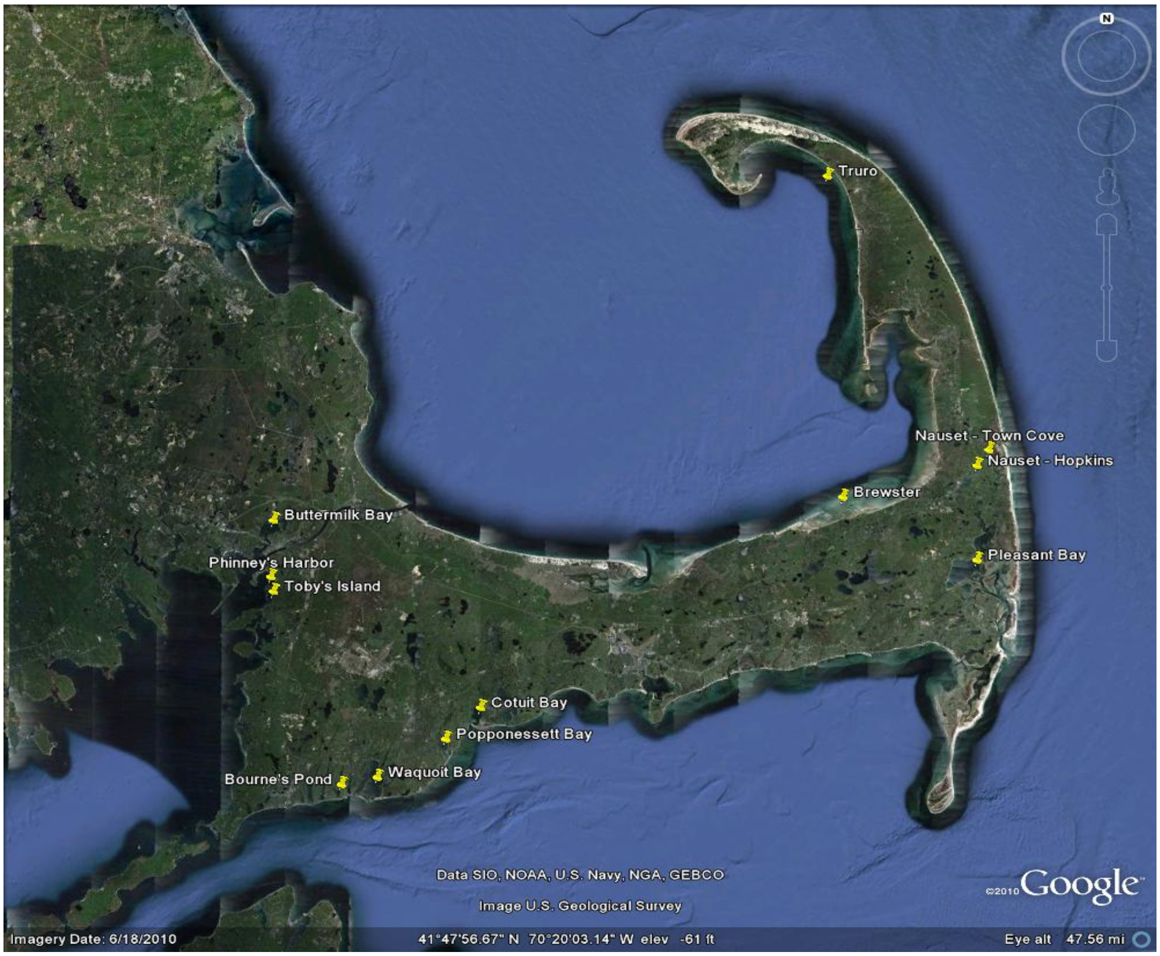


Figure 1. Twelve Potential Eelgrass Restoration Sites on Cape Cod.

To further narrow this list of sites, comments were solicited from the project technical review team[1], and from town shellfish wardens who have expertise with eelgrass management and familiarity with the sites of interest.

Secondary Site Selection (5 sites)

With comments from town shellfish wardens and the technical review team, which requested we pull the Wellfleet site and all Pleasant Bay sites, the list of 12 sites was narrowed to 5.

The 5 potential sites included

1. Phinney's Harbor/Bourne,
2. Toby's Island/Bourne,
3. Cape Cod Bay/Truro,
4. Cape Cod Bay/Brewster, and
5. Nauset-Town Cove/Orleans (Figure 2).

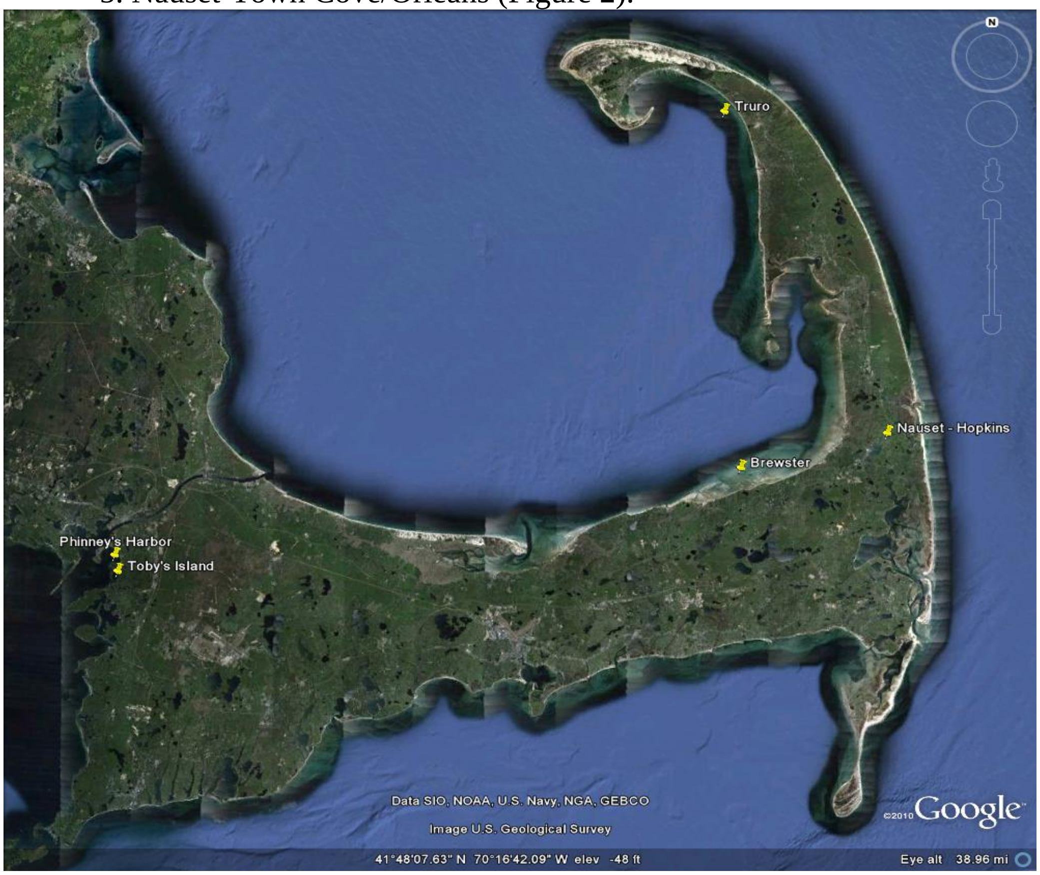


Figure 2. Five Potential Eelgrass Restoration Sites on Cape Cod.

[1] The technical review team included eelgrass restoration specialists from MA DMF, USEPA, WBNERR, NOAA, DEP, Mass Bays Program, CZM, and CCNS.

Data Collection at Candidate Sites and Donor Beds

Field data were collected at the five potentially viable sites in order to evaluate habitat conditions and rank the sites with respect to habitat quality for eelgrass. In summer 2010 these sites were monitored to determine which would provide the most suitable habitat conditions for eelgrass test plantings. The following parameters were measured at transplant sites and at the corresponding donor bed:

- *Light attenuation* – HOBO Pendant Data Loggers were mounted on cement blocks and set on the sediment at potential transplant sites, at donor beds, and at the water surface (on land, as close as possible to the transplant site) to measure light attenuation at each site. Secchi depth was also monitored at these same sites.
- *Water quality* – salinity, dissolved oxygen, temperature[2], turbidity, pH, and chlorophyll were measured using YSI 6600 multiparameter sondes. In-situ measurements were made at times when these parameters are expected to be most extreme (that is, efforts were made to sample during early morning hours during high summer, when biological activity is high and dissolved oxygen levels are lowest). In addition, inorganic nitrogen (NO_x) samples were collected monthly at each site. Nitrogen (NO_x) was measured as nitrite and nitrate, with analyses performed by Groundwater Analytical laboratory in Buzzards Bay, MA.
- *Water depth* – water depths were measured, and depths of about 1 - 4m were sought to facilitate ease of planting and monitoring.
- *Sediment Characteristics*
  - Grain size – sandy sediments with a low silt/clay fraction were sought.
  - Organic matter – sediments were analyzed for organic carbon content for a further indication of sediment health. Low organic carbon content was sought as mucky sediments are not considered optimal for transplanting.
  - Oxygenation – oxygen levels in water were evaluated qualitatively by examining samples and looking for dark, sulfidic sediments with an odor of hydrogen sulfide, indicating low oxygen conditions. Areas of poor sediment quality were avoided.
- *Historical eelgrass distribution at the site* – historic distribution of eelgrass was evaluated using available information from local and State eelgrass records.
- *Current distribution at the site* – current distribution of eelgrass beds at the site was evaluated in the field by transiting the site and nearby areas by boat at low tide.
- *Proximity to natural eelgrass bed(s)* – proximity to existing eelgrass beds was estimated to insure a nearby donor bed was available and also to insure that the chosen site was at least 100m from an existing bed, where natural recolonization would be possible even without restoration efforts.

[2] A reviewer of this report noted that temperature is important in conjunction with light levels. It was noted that 25 C is the temperature at which gains due to photosynthesis equal the losses due to respiration for eelgrass. Further, the reviewer noted that in most of our coastal waters these days light is compromised so that compensation point occurs at even lower temperatures. In future studies, site selection criteria could include not just a maximum temperature threshold, but analysis of the number of hours above the compensation point.

- *Wave exposure* – wave exposure was initially evaluated in the field and later evaluated quantitatively using estimates of fetch from NOAA charts and/or Google Earth images.

Donor Bed Monitoring

At the same time the potential transplant site investigations were conducted, nearby eelgrass donor beds were assessed. Donor bed proximity to transplant site was noted, and the following parameters were measured in the selected donor beds:

- Shoot density
- Aboveground biomass
- Canopy height
- Leaf Area Index (LAI, the area of leaves multiplied by density).
- Percent cover of eelgrass vs. macroalgae and sessile invertebrates.

Donor bed measures were used to ensure that a healthy donor bed was available proximal to the transplant site, and to perform baseline assessments for before-and-after monitoring to ensure that removing plants for transplanting did not harm the donor beds.

Site ranking based on field measures at candidate sites.

Ranking was done in a manner similar to that of Short et al. (2002), but modified due to local conditions and available data. Data used in the site rankings are provided in tables 1 and 2.

Table 1. Donor Bed and Transplant Site Characteristics.

	Donor Bed %Coverage/m²	Donor Bed Mean Canopy Height/m² (in.)	Donor Bed Mean %Cover Macroalgae	Donor Bed Sediment %Silt/Clay	Donor Bed Sediment %OM	Donor Bed Sediment %TOC	Transplant Site Sediment %Silt/Clay	Transplant Site Sediment %OM	Transplant Site Sediment %TOC
Bourne/ Phinneys	99.6	42.5	37	2.9	0.47%	0.23%	3.8%	0.52%	0.26%
Bourne/ Tobys	99.6	42.5	37	2.9	0.47%	0.23%	7.6%	1.67%	0.83%
Brewster/ Cape Cod Bay	57.5	17.5	45.5	1.5	0.41%	0.21%	1.5%	0.50%	0.25%
Nauset/ Hopkins Island	67.7	32.7	0	45	2.70%	1.37%	10.5%	0.46%	0.23%
Truro/ Cape Cod Bay	92.9	24.6	0.2	1.9	0.50%	0.25%	1.3%	0.43%	0.21%

Table 2. Percent Available Surface Light at Donor and Transplant Sites. (average value from one week deployments)

Site	Date	% Available Surface Light at Donor Bed	% Available Surface Light at Transplant Site (shallow)	Date	% Available Surface Light at Donor Bed	% Available Surface Light at Transplant Site (shallow)
Bourne/Phinneys	6/12-6/18/10	17.86%	14.45%	7/21-7/27/10	10.19%	9.07%
Bourne/Tobys	6/12-6/18/10	16.21%	14.18%	7/21-7/27/10	10.07%	13.16%
Brewster/Cape Cod Bay	6/10-6/16/10	24.85%	17.52%	7/23-7/30/10	N/A	N/A
Nauset/Hopkins Island	6/5-6/11/10	25.50%	24.95%	7/20-7/25/10	17.69%	20.08%
Truro/Cape Cod Bay	6/16-6/21/10	16.05%	18.80%	7/20-7/26/10	7.06%	13.31%

Using these field measures, candidate sites were ranked using a matrix similar to that developed by Short et al. (2002), showing local factor suitability (sediment quality, light availability, water quality, historic and current eelgrass presence, wave exposure, water depth). Suitability of each factor was described with a numerical scale with 0 = 'low', 1 = 'moderate', and 2 = 'high' for each factor. Suitability scores were calculated as the sum of the score for each factor. This ranking scheme suggested that all the sites were similar in terms of the ability to support eelgrass. All sites scored 13 or 14 out of a possible 22 points (Table 3).

Table 3. Transplant Site Scores (0-2 lowest – highest)

	Bourne Phinneys	Bourne Tobys	Brewster	Nauset	Truro
Water Depth (MLW) 0 = <1.25m, >3.25m 1 = 1.25m to 3.25m	1	1	1	1	1
Sediment 0 = rock/cobble 1 = <70% silt/clay 2 = <30% silt/clay	2	2	2	2	2
Secchi Depth 0 = <1m 1 = 1 to 2m	2	1	2	1	2
Water Temperature 0 = >27.1C 1 = <27.1C	1	1	1	1	1
Current Eelgrass 0 = currently vegetated 1 = unvegetated	1	1	1	1	1
Proximity to Eelgrass 0 = < 100m 1 = > 100m	1	1	1	1	1
Historic Eelgrass 1 = previously unvegetated 2 = previously vegetated	2	2	2	2	2
Fetch Qualitative - limits not established 1 = moderate wind/wave activity 2 = low wind/wave activity	1	2	1	2	1
Bioturbators 0 = abundant 1 = present 2 = absent/not observed	1	1	1	1	1
Donor Bed 0 = not reasonably proximate 1 = proximate	1	1	1	1	1
Human Activity 0 = mooring field/channel/shellfishing 1 = moderate human usage 2 = minimal human disturbance	1	0	1	0	1
Final Score	**14**	**13**	**14**	**13**	**14**

Because the scores were generally the same for all sites based on the generalized site ranking, it seemed prudent to further compare sites and numerically rank them (1 – 5) on a finer scale using actual parameter measurements from our field work (Table 4).

Table 4. Finer scale transplant site rankings (1-5, lowest – highest)

Parameter	Measure	Bourne Phinney's	Bourne Toby's	Brewster	Nauset	Truro
Sediment	% silt/clay	3	2	4	1	5
	% OM	2	1	3	4	5
	% TOC	2	1	3	4	5
Inorganic N	nitrite mg/l	5	5	5	5	5
	nitrate mg/l	5	5	5	5	5
Light Data	% surface light @ transplant site/June	2	1	4	3	5
	% surface light @ transplant site/July	1	4	3	2	5
Donor Bed	proximity	5	5	5	4	5
Human Activity		3	1	4	2	5
Bioturbators		4	4	4	4	4
Water Quality	avg. temperature	3	2	5	1	4
	turbidity (NTU)	3	2	5	1	4
	Secchi	3	2	4	1	5
Depth	~MLW	5	2	4	1	3
	Scores	**46**	**37**	**58**	**38**	**65**

Overall differences between sites became greater at this level of comparison. Truro became the highest ranking transplant site followed by Brewster, Phinney's Harbor, Nauset, and Toby's Island.

Final site selection (3 sites)

In making a final decision on the sites, the Brewster site was eliminated because small patches of eelgrass were observed in the general vicinity of the transplant area, suggesting natural recolonization of the beds may be underway. In addition, the Brewster site was very similar to Truro in terms of physical environment (north side of Cape Cod, extensive sand bar, tidal range >10 ft, somewhat similar exposure to winds and wave action).

Therefore the three sites selected for transplanting were Cape Cod Bay in Truro, the Town Cove area of Nauset Harbor in Orleans, and Phinney's Harbor in Bourne. This set of sites afforded a wide range of environments in which to evaluate transplant success in that these three sites represent the Buzzard's Bay side, the Cape Cod Bay side, and an embayment on the Atlantic Ocean side of Cape Cod. In addition, the physical characteristics of these three sites were quite different: Truro is open to the west and southwest, and lies on an extensive sand bar. Phinney's Harbor is in Buzzard's Bay and is exposed to southwest winds which dominate in summer, but has some protection from Mashnee Island - a point of land extending along the north and west sides of the site. Nauset is a protected inlet characterized by marshy areas and shallow water but is flushed with water from the Atlantic. In each of these areas a healthy donor bed exists in the waterbody so handling and transport time was minimized.

While pre-planting site selection was being completed, TNC staff carried out the permit application process with the towns in which the transplants were anticipated. Permits were granted in all areas where permits were sought. Although some town Conservation Commissions required full Notices of Intent and issued Orders of Conditions for the work, other towns required only a Request for Determination. In addition, was permitted by the Army Corps of Engineers under Category 1, Appendix C.

Task 2. Trial Plantings

Once the final set of sites was selected, trial plantings were carried out in September 2010. The original study plan was to use the clump method, wherein clumps of approximately 3-10 eelgrass shoots and intact rhizomes are removed from the donor bed and replanted at the test site. However in the pre-planting phase of the project MA Division of Marine Fisheries (DMF) suggested the project include a comparison between the clump method and the horizontal rhizome (HR) method (Davis and Short, 1997), wherein individual shoots with rhizomes are harvested from the donor bed, and planted by twos with shoots and rhizomes facing opposite direction, secured with a small bamboo skewer. DMF suggested this method because it may cause less damage to donor beds. To accommodate this request for the planting method comparison, one of the 3 replicates at each site was planted in this manner and 2 were planted using the clump method.

Planting was done using a 2m x 2m checkerboard grid pattern in each of the 3 replicates within a site. Within each grid, plant- and no-plant quadrats were arranged alternately every .25m^2 (Figure 3). Shaded squares in the figure represent one .25m^2 planting.

Each grid of 8 shaded squares was planted with 50 shoots for a total of 400 shoots/grid using either the clump or the HR method. At each site a total of 1,200 shoots were transplanted. This magnitude of shoot removal from the large donor beds near the planting sites was not expected to result in measurable impact.

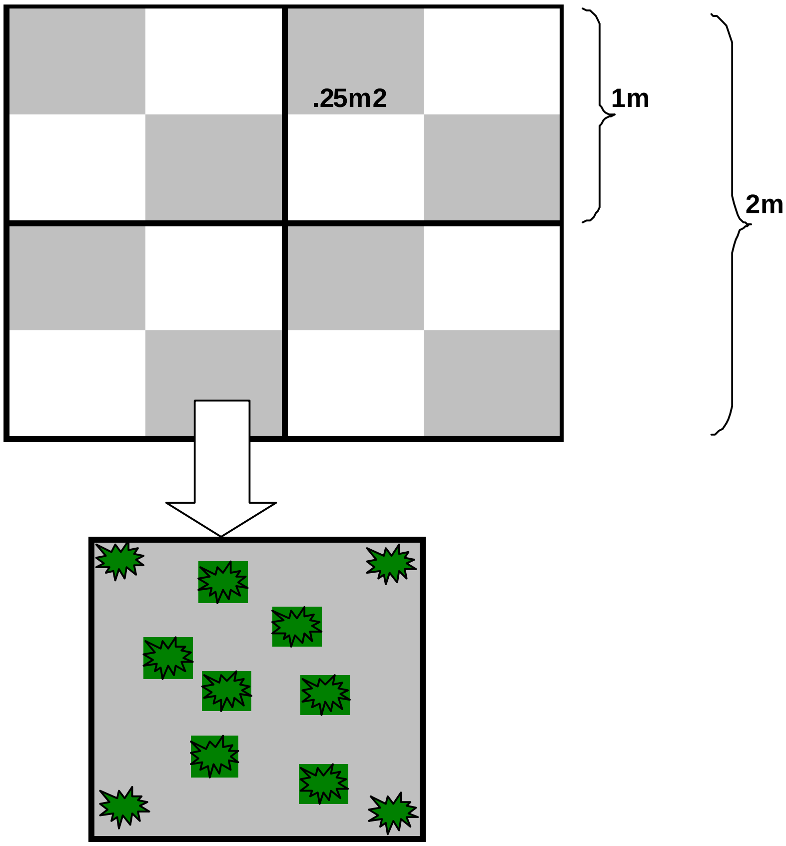


Figure 3. Planting grids.

On planting days divers assembled at the donor bed and reviewed harvest protocols before proceeding. Small garden trowels were used to carefully remove plants with intact rhizomes. Harvested shoots were placed in mesh dive bags and relayed to the surface where they were placed into seawater-filled 29 gallon plastic totes. Non-diver staff carefully separated shoots and packaged them into bundles of 50 secured with a soft cotton string. All plants remained wet throughout processing to avoid desiccation. Larger clumps were used for the clump method grids; single shoots were used for the HR method plantings.

At the transplant site divers secured a 2m x 2m PVC and string template on the bottom to delineate planting grids. This template was left in place until the first post-transplant counting was performed. Divers planted the quadrat's four corners first – later filling in the quad in random fashion. When all 8 quadrats within a grid were planted, a large marker buoy was attached to the upper left-hand corner of the grid and a smaller buoy was used at the farthest lower right hand corner. The larger buoy indicated permit number and other pertinent information. Grid corners were recorded with a GPS.

Monitoring

Monitoring was conducted at four different times: 2 weeks post-planting in October 2010 (to double-check planting density and evaluate short-term survival), 8 months post-planting in May 2011 (to evaluate winter survival); 10 months post-planting in July 2011 (to evaluate survival and growth over the early part of the growing season); and one year post-planting in September 2011 (to evaluate survival over the first full growing season). Donor beds were monitored in August 2010, July 2011, and September 2011 to evaluate any effect of removing plants for transplanting, and to compare donor bed plants with the transplants.

During the October 2010 transplant monitoring, the following parameters were measured:

- Presence/absence
- Shoot density
- Predator/bioturbator survey
- Light levels
- In-situ water quality measures

In May 2011 and September 2011 the following parameters were measured:

- Presence/absence
- Shoot density
- Canopy height
- Light levels
- In-situ water quality measures

In July 2011 the full suite of measures were made at both the transplant sites and donor beds. The following parameters were measured:

- Presence/absence
- Shoot density
- Aboveground biomass
- Canopy height
- 2-sided Leaf area index (LAI, the area of leaves multiplied by density)
- Percent cover of eelgrass vs. macroalgae and sessile invertebrates
- Epiphyte cover
- Light levels
- In-situ water quality measures

Photographs were taken during field visits when visibility was adequate.

Results

Donor Beds: Pre-transplant Assessment

Healthy donor beds were available at each of the sites. Donor bed percent cover was approximately 85-90% and the number of shoots per quarter meter quadrat was 50-117 prior to harvest (see table 6 below). Figures 4, 5, and 6 show the donor bed transects. Donor beds were located within the same waterbody as the transplant sites, approximately ½ to 1 mile from the transplant sites. This facilitated the harvest and planting work, as the transplants were quickly moved from the donor bed to the transplant area.

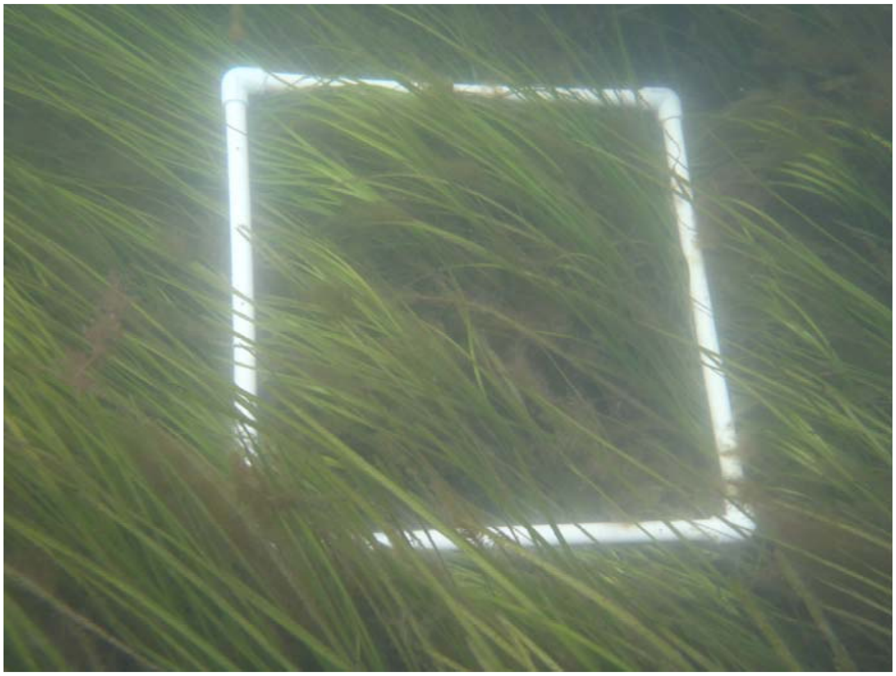


Figure 4. Bourne (Phinney's Harbor) donor bed

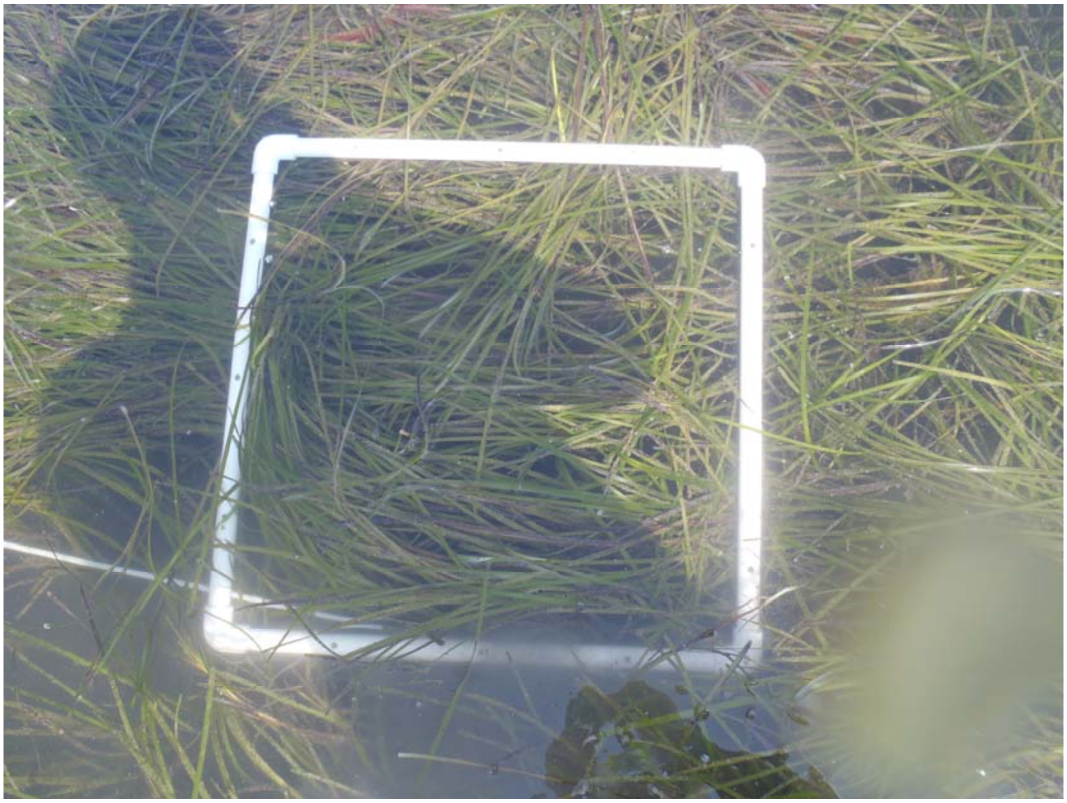


Figure 5. Nauset donor bed

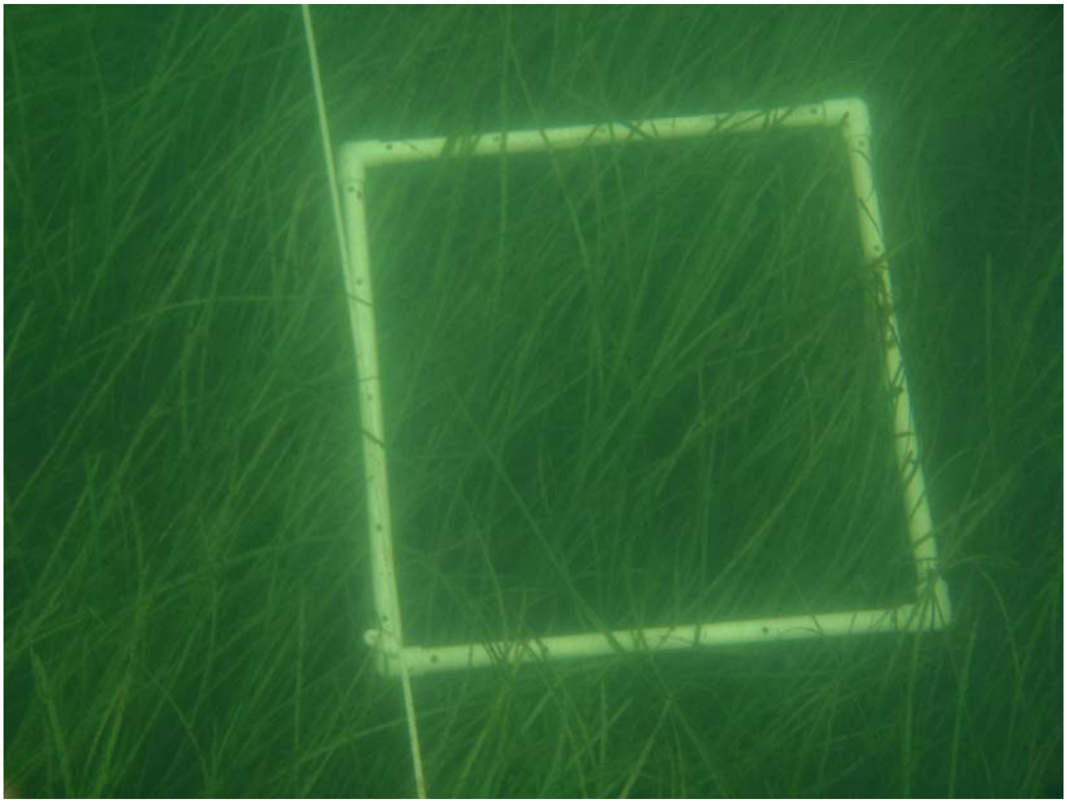


Figure 6. Truro donor bed

Transplant Survival

Transplant success at the test sites was variable until the end of the study, when all three sites had almost no surviving plants. Initial survival rates varied, however at Phinney's Harbor and Truro, initial survival (2 weeks post-transplant) was almost 100%. In contrast, almost no plants survived at the Nauset site, likely due to bioturbation[3]. Short et al. (2002) report the type and magnitude of bioturbation can be difficult to quantify. Bioturbator activity at the Nauset site, likely by crabs such as *Limulus polyphemus*, was not detected during early pre-transplant surveys, yet may have contributed significant disturbance just after the transplanting in 2010.

In May 2011, the Phinney's Harbor plantings appeared to have become established, as average plant density was slightly greater than the original planting density (shown on graph as >100). In contrast, the Truro site showed poor survival over the winter, and only about 8% of the original number of plants were living in May 2011.

In July 2011, the situation changed again. The Phinney's Harbor plantings were reduced to <40% of original planting density, and clumps of macroalgae were observed throughout the test transplants. However, some of the plants in the test plots were large and healthy, and divers observed flowering shoots among the transplants. The Truro plantings increased slightly to >12% of original planting density. In Nauset 8 plants were observed in July, though some of the bamboo stakes used in planting were noted by divers. The 8 surviving (but small and weak) shoots were noted within only one of the transplant grids.

In September 2011, no plants were left at the Phinney's Harbor site. The plants had all died over the summer, likely due to lack of light (see discussion below). At Truro, one of the planting grids still had about 10% survival, but overall survival was reduced to about 3%. At Nauset no living plants were observed in September.

[3] During the October 2010 monitoring at Nauset a large number of bioturbators including hermit crabs, green crabs, and horseshoe crabs were observed. Many planting skewers were exposed or were missing, and the few remaining plants were unhealthy or dead.

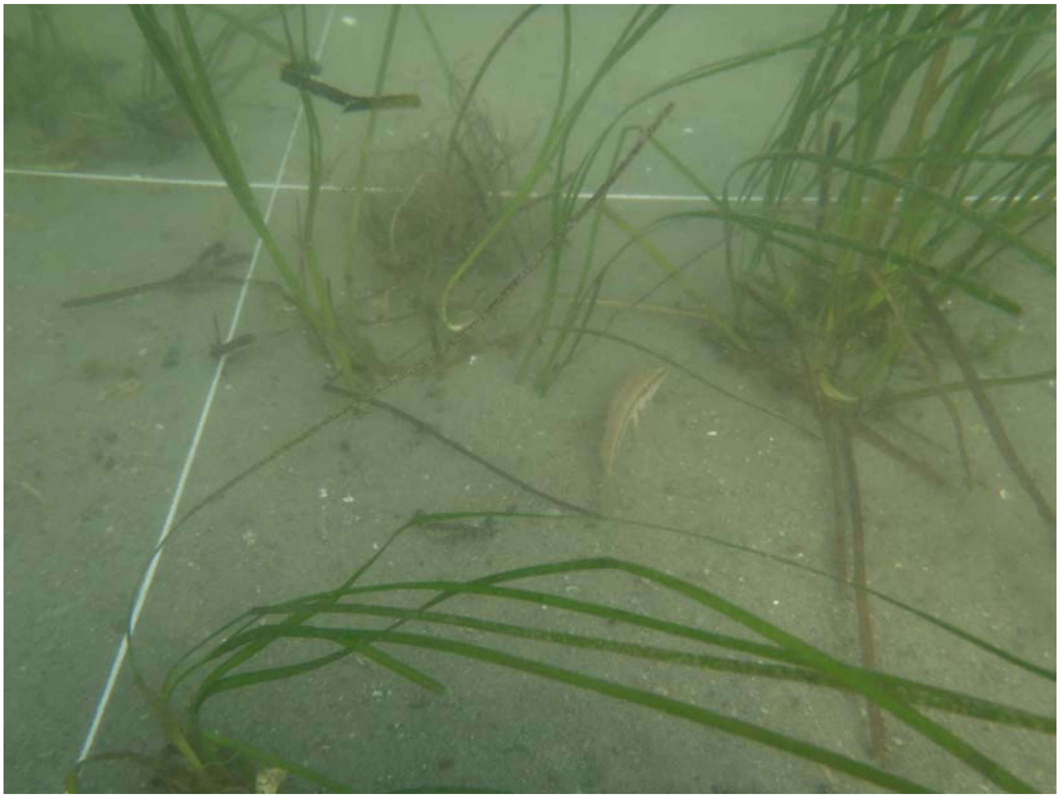


Figure 7. Transplants at Bourne, October 2010 (juvenile black sea bass in center).

Figure 8. Transplants and bioturbators (green crab) at Nauset, October 2010.

Figure 9. Transplants at Truro, October 2010.

Figures 10 and 11 below show eelgrass survival (% of initial planting density) by site and time period. Figure 10 provides a bar graph with each site compared over time. Figure 11 shows the trend over time with each site as a separate ‘series’ on the graph. Both are provided as the first shows the within-site changes over time, while the second shows the overall trend.

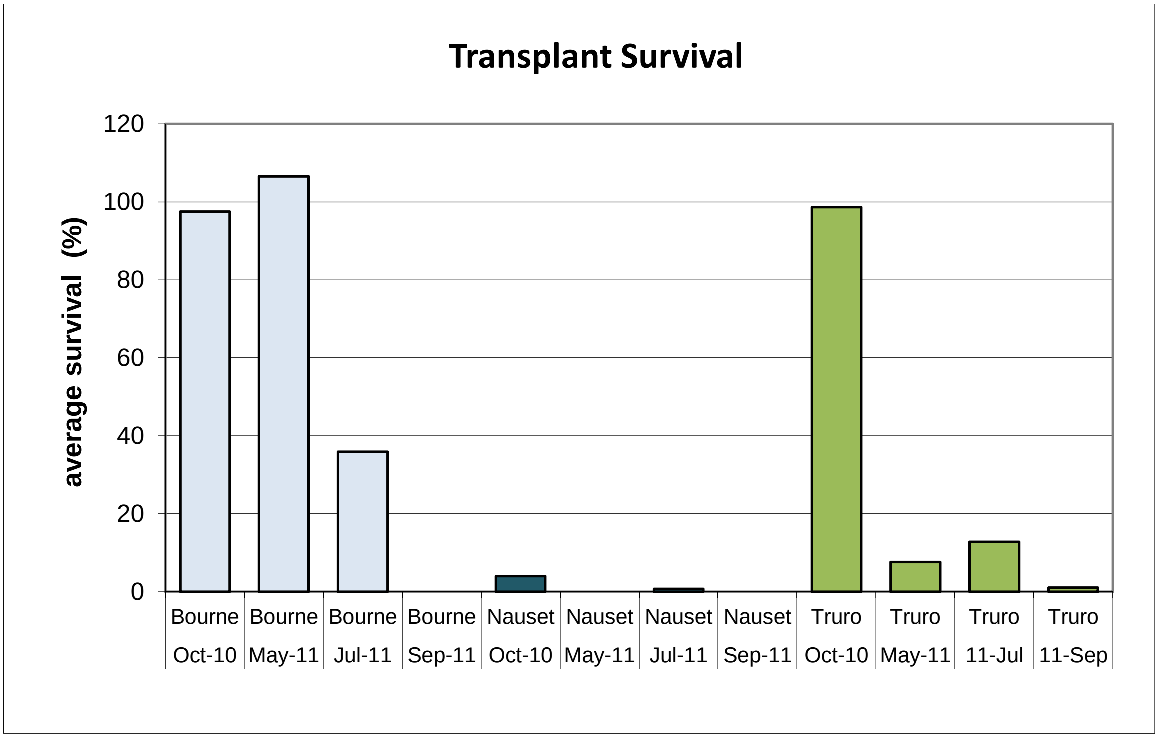


Figure 10. Test plant survival by site and sampling date.

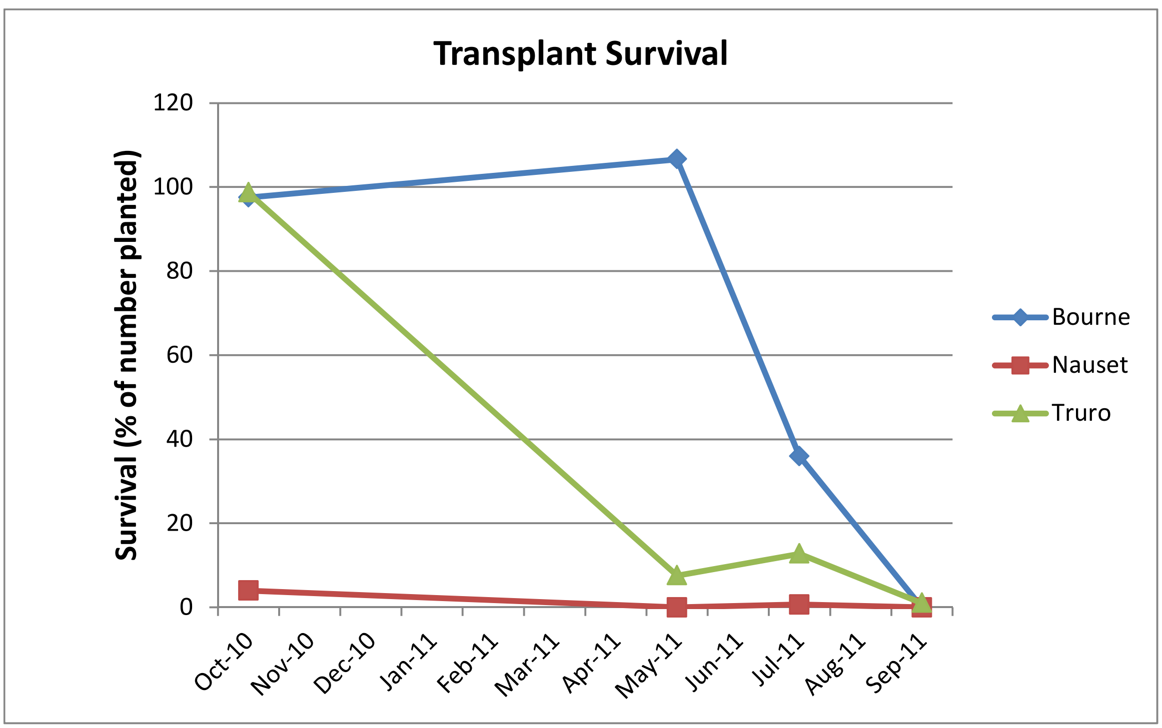


Figure 11. Test plant survival by site and sampling date. Alternate graph format shows initial differences as well as final survival.

Survival and Planting Method

Regarding planting method, there appeared to be no difference between planting methods for the most part. When survival was good (at Bourne and Truro initially), both methods yielded approximately the same number of surviving plants. When survival was low, there was no clear pattern (Figure 12). In Nauset the 8 small surviving shoots found in July 2011 were in the horizontal rhizome planting grid. In contrast, at Truro the shoots that survived over the winter were those in the clump plantings. This may be due to their having intact rhizomes that help stabilize the plants in the highly dynamic sediments at that site. At Bourne, survival was almost identical for the clump and horizontal rhizome plots.

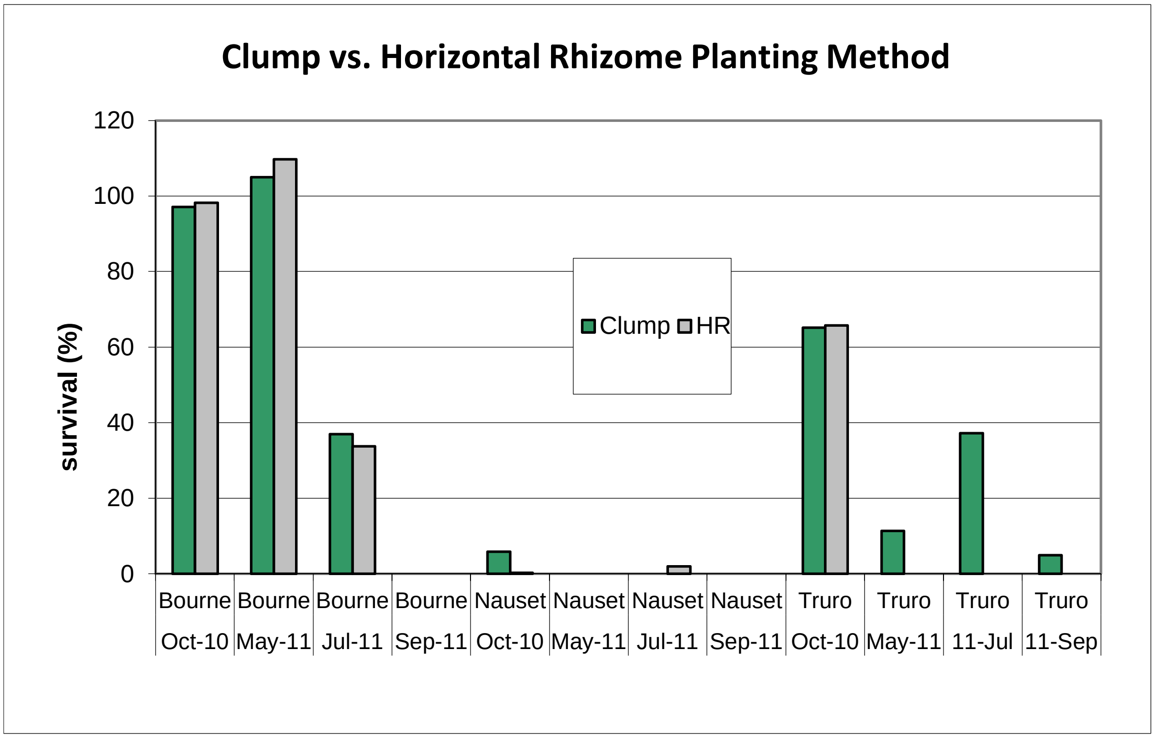


Figure 12. Test Plant Survival by Site and Planting Method

Biomass

Aboveground biomass of the transplants[4] was lower than donor bed biomass throughout the study both when evaluated on a per-shoot basis and in terms of biomass per unit area of sediment. Biomass per shoot in the surviving transplants was on average about half of that in the donor bed plants (Figure 13). In contrast, biomass per unit area was dramatically lower in transplant areas than in donor beds (Figure 14).

[4] Because of low survival rates at most of the transplant sites, test plant biomass was measured by harvesting just one shoot from each quadrat in which there were surviving plants, and multiplying the mass of the shoot by the number of shoots in a planting grid. This is in contrast to other studies that have harvested all aboveground plant material and dried and weighed it directly (e.g. Leschen et al. 2010).

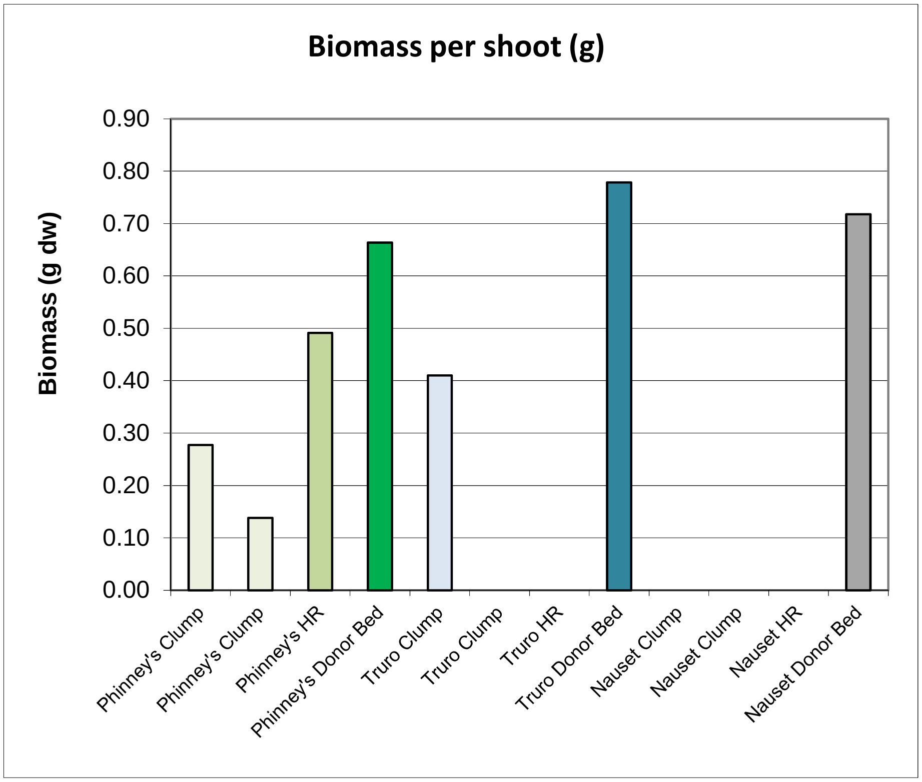


Figure 13. Biomass per shoot in transplant grids.

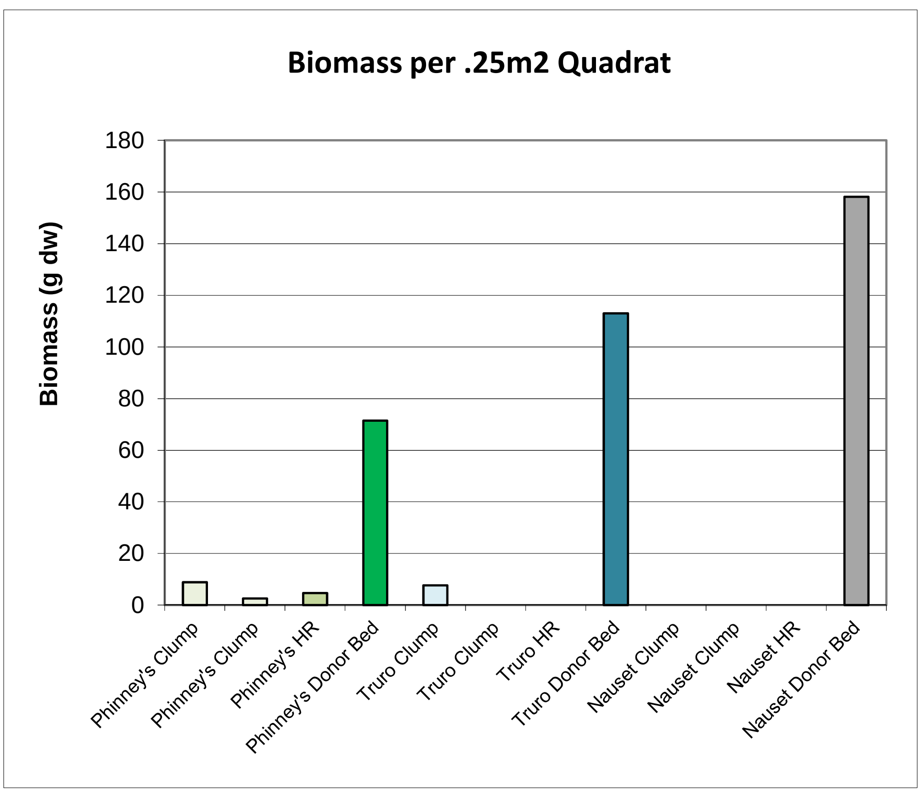


Figure 14. Biomass per quadrat in transplant grids.

Plant Height, Leaf Area Index, and Macroalgal Cover

Monitoring included additional measures of plant health which included height, 2-sided leaf area index[5], macroalgal cover, and epiphytes. All of these parameters were measured at transplant sites in July 2011. In September 2011 plant height and macroalgal cover were measured, but leaf area index was not.

Plant Heights

The surviving transplants were on average about 25 cm in height. At Bourne the average transplant height was approximately 27 cm, and at Truro the surviving plants were on average about 20 cm tall. Table 5 shows plant heights in each of the planted grids. The 8 surviving shoots found in Nauset in July were measured at approximately 12.5 cm.

Leaf Area Index

Leaf area index is defined in silviculture as one-sided leaf area per unit ground surface. It can be used to predict photosynthetic condition or to measure crop growth (Asner et al., 2003). For this study we measured 2-sided LAI, consistent with other eelgrass studies (Leschen et al. 2010) Table 5 shows 2-sided LAI. Note that two of the Truro grids and all of the Nauset plantings had no shoots or a minimal number (8 shoots in total at Nauset), so none were harvested for LAI measures and the LAI reported value is 0 for these planting grids.

Table 5. Transplant Leaf Area Index and Height.

Site	Quadrat	Planting Method	LAI (July 2011)	Ave Height (mm)
Bourne	1	Clump	0.22	184
Bourne	2	Horizontal Rhizome	0.63	288
Bourne	3	Clump	0.86	332
Ave Phinney's	**1, 2, and 3**	**Both**	**0.57**	268
Truro	1	Horizontal Rhizome	0.00	0
Truro	2	Clump	0.51	198
Truro	3	Clump	0.00	0
Ave Truro	**1, 2, and 3**	**Both**	**0.17**	50
Nauset	1	Clump	0	0
Nauset	2	Horizontal Rhizome	*	125**
Nauset	3	Clump	0	0
Ave Nauset	**1, 2, and 3**	**Both**	*****	0
* only 8 surviving shoots in this planting grid so none were harvested for LAI.				
** measured in-situ by divers; not harvested and measured				

Leaf area index in the surviving test plots was much lower than that reported in large-scale transplant areas in Boston Harbor (DMF, 2006) where LAI ranged from about 1-2.5

[5] Leaf area indices are often used to estimate eelgrass plant productivity and to estimate the amount of habitat available for colonization by epifauna. LAI is calculated as mean shoot length * mean shoot width * mean density of shoots (/m2). LAI is thought to be a measure more sensitive to environmental stress since it integrates both plant density and area (Neckles, 1994).

m^2/m^2). However, our transplants were small test plots whereas the Boston Harbor projects included full-scale transplants. It may be that the small, exposed transplants in our area are more vulnerable to stress than a larger-scale planting would be.

Macroalgal Cover and Epiphytes

Macroalgal cover is of special interest because it can interfere with eelgrass growth (Hauxwell et al. 2001). Macroalgae were observed in all embayments prior to planting, with the donor beds in Truro and Nauset showing minimal amounts of *Ectocarpus* spp.

The Bourne site had much heavier epiphytic macroalgal growth (identified as *Polysiphonia spp*.), particularly in August 2009, when the percent cover of epiphytic macroalgae was measured at almost 40% (average 37% in donor bed quadrats). At this time in late summer, the eelgrass plants appeared to be weighed down by the macroalgae toward the apex of the leaves, and were found to be bent over almost horizontally during low tide sampling. In September 2010, when transplanting took place, the eelgrass leaves in Bourne had sloughed off the dead part of the leaf that was covered in macroalgae, and the canopy height was reduced by about one third to one half. This made transplanting easier, as the plants were more compact and no epiphytes or dead material had to be removed, but it does suggest these beds are under stress related to increased nutrient loading and macroalgal growth in the embayment. The prevalence of macroalgae on the eelgrass in this area may be a recent phenomenon, as neither the Massachusetts Estuaries Project TMDL report for Phinney's Harbor (MEP, 2006), nor an online report regarding the reasons for loss of eelgrass in Phinney's Harbor (Costa, 2004) mentions the epiphytic macroalage as a stressor on the eelgrass.

In Truro there was some bryozoan (*Bugula neritina*) biomass associated with the existing eelgrass beds (0.2 – 1.5% cover) but it did not appear to be interfering with plant growth.

Light and Temperature

Light

Light levels as measured by the Hobo dataloggers are shown as the percent of available surface light. To account for twilight variability and fouling on dataloggers, we used only data from 10 am through 4 pm for the first week of deployment. Light levels varied by season and by site, ranging from about 9 – 25% of surface light, with mid-summer light levels being lower due to biological activity in the water column. In Bourne the light levels were consistently lower than the other sites, and the transplant site light was lower than that of the donor bed. This may have been a factor in the summer decline in the transplanted eelgrass at this site. Table 6 shows light levels as percent of surface light, and percent difference in light levels at the transplant site vs. the donor bed. Figure 15 shows the percent of light at the transplant site as a percentage of donor bed area light levels. This shows that the Bourne transplant site had consistently lower light than the donor bed, whereas the Nauset transplant site had higher light than its corresponding donor bed, and Truro was more variable.

Table 6. Light levels at donor beds and transplant sites.

Site	Date	Donor Bed (% of surface light level)	Transplant Site (% of surface light level)	Difference (T-D)
Bourne	June-10	17.86%	14.45%	-3.40%
Bourne	August-10	10.19%	9.07%	-1.12%
Bourne	September-10	11.98%	8.39%	-3.59%
Bourne	June-11	18.82%	14.08%	-4.74%
Bourne	July-11	16.44%	8.00%	-8.44%
Bourne	September-11	15.11%	10.39%	-4.72%
Nauset	June-10	25.50%	24.95%	-0.55%
Nauset	August-10	17.69%	20.08%	2.39%
Nauset	September-10	9.76%	23.60%	13.84%
Nauset	July-11	7.84%	14.60%	6.75%
Nauset	September-11	16.60%	23.95%	7.34%
Truro	June-10	16.05%	18.80%	2.75%
Truro	August-10	7.06%	13.31%	6.25%
Truro	September-10	9.13%	7.77%	-1.37%
Truro	June-11	10.66%	10.13%	-0.53%
Truro	July-11	10.79%	13.51%	2.73%
Truro	September-11	19.60%	10.37%	-9.23%

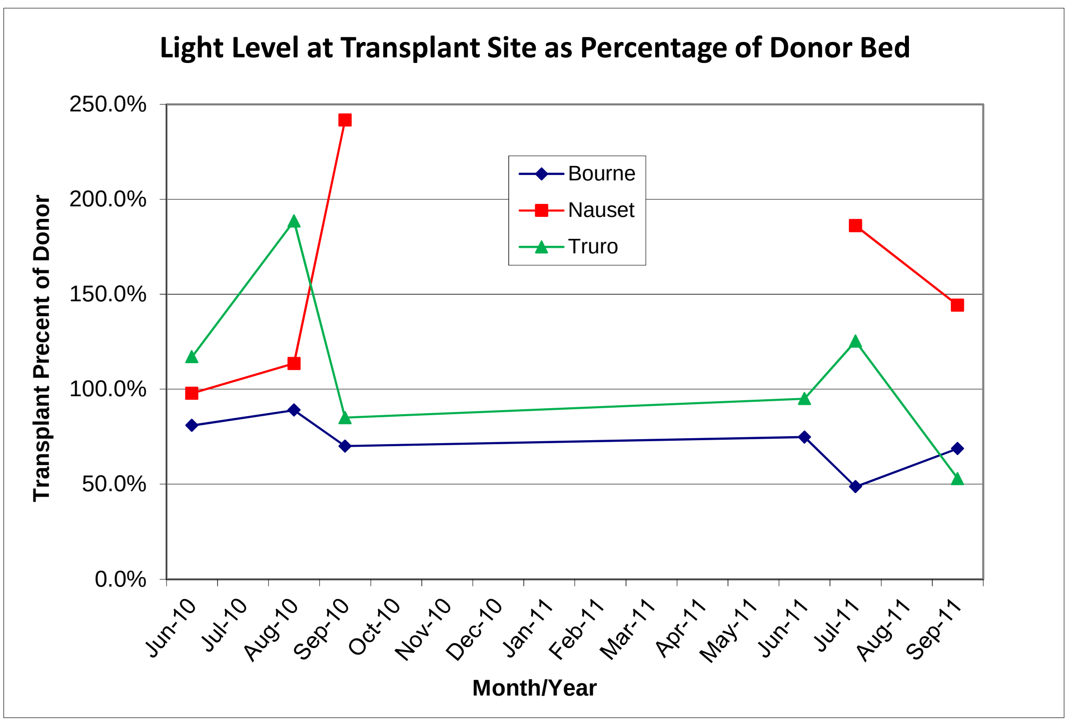


Figure 15. Light levels at transplant sites, as a percentage of light at the donor bed.

Water Temperature

Water temperatures at the transplant sites were similar until summer 2011, when the Truro site was somewhat cooler than the other sites. This is not unexpected, as Truro is a north side shoreline with a more extreme tidal range, so the site is well-mixed with cooler waters on the north side of the Cape. The other two sites are shallower, more enclosed, and mixed with warmer water. Figure 16 shows water temperature at the three sites.

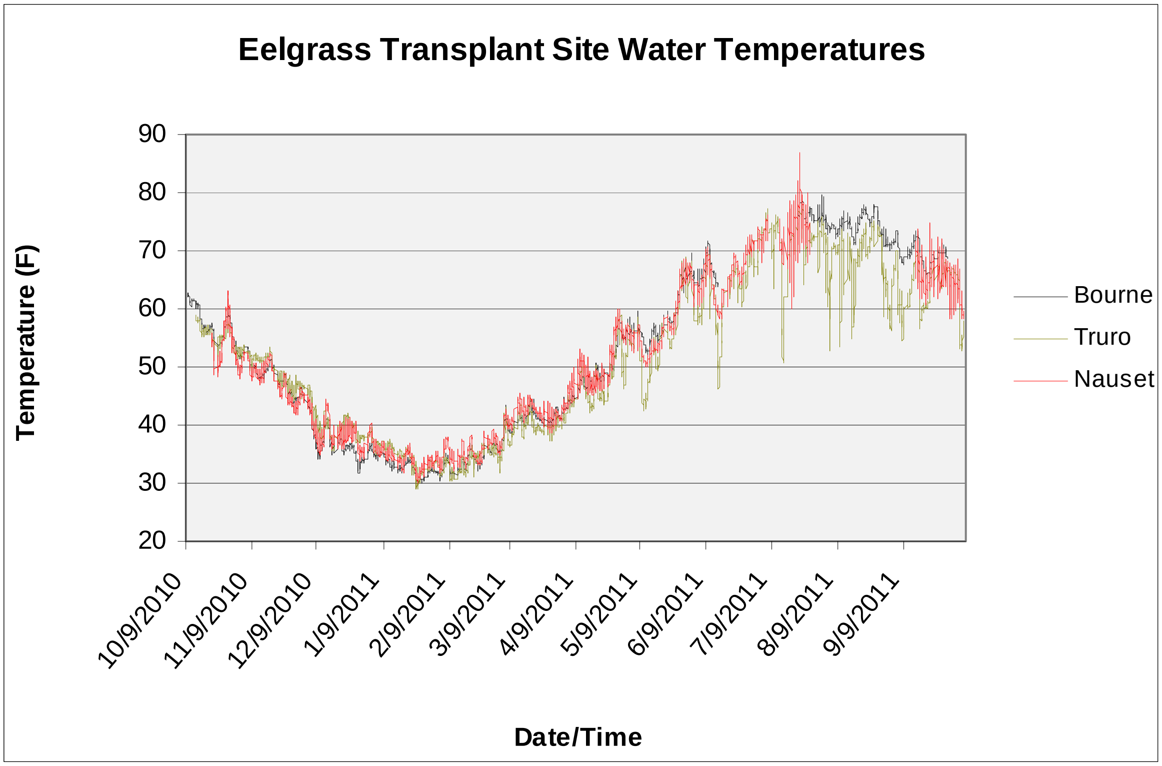


Figure 16. Water temperature at transplant sites.

Precipitation

Interannual variation in rainfall may play a role in water quality and should be considered in site selection. When assessing site suitability based on a single season or year's data there's always a risk of monitoring a 'good' condition year only to have the subsequent year present different results. Higher rainfall amounts can contribute to decreased water clarity and quality due to increases in N, resuspension of sediments, etc. Figure 17 compares precipitation between 2010 and 2011.

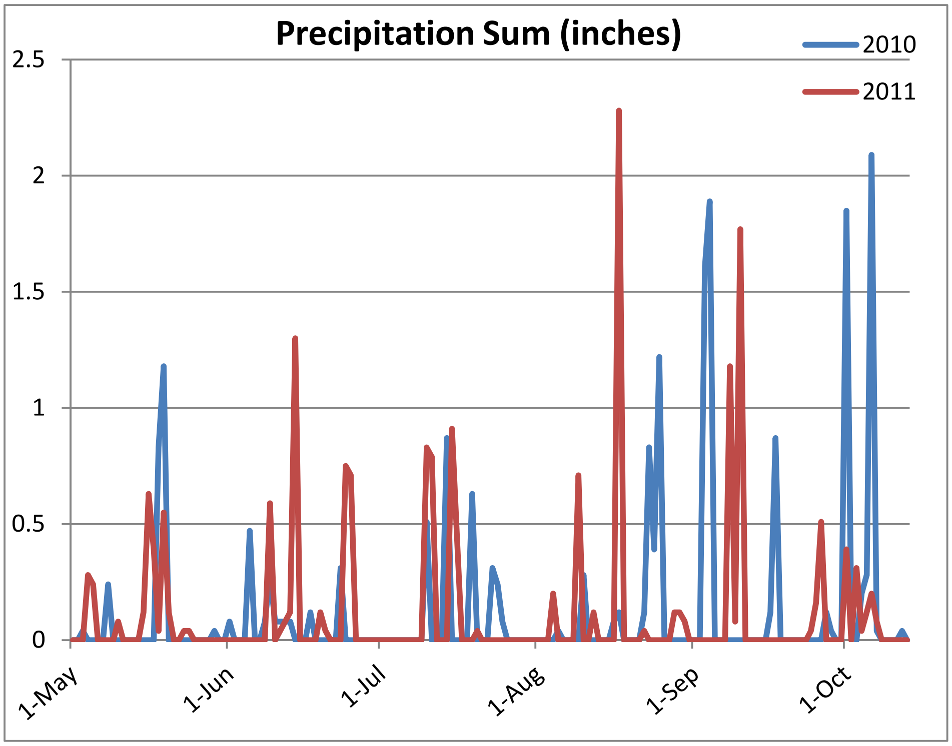


Figure 17. Precipitation records for Barnstable County, MA.

Donor Beds: Post-transplant Assessment

Donor beds were monitored to ensure that there were no adverse effects from harvesting transplant shoots (Table 7). Results suggest no change in percent cover after harvesting from the donor beds, whereas the plant density appeared to increase (approximately doubling at all sites) after transplanting in all cases. This suggests that the removal of plants for transplanting did not have an adverse effect on the donor beds.

The donor beds at Bourne appeared more stressed than those at the other two sites. As mentioned above, an epiphytic macroalga (*Polysiphonia spp*.) was found at relatively high density throughout the donor beds. The eelgrass may have adapted to the stress by sloughing off dead leaves and epiphytes each fall (see further discussion in next section).

Table 7. Donor Bed Monitoring

Site	Date	% Cover Eelgrass	Density (Shoots / .25 m2)	Ave Shoot Length (mm)	Shoot Width (mm)	2-sided LAI (m^2/m^2)	Biomass (g dw / shoot)	Biomass (g dw / .25m^2)	Biomass of fouling (g dw / shoot)	% cover macroalgae
Bourne	Pre-Transplant (Aug 2010)	86	50	686	4.3	1.24	0.8	39.01	1.0	37.0
Bourne	Post-Transplant (July 2011)	73	108	444	5.1	2.11	0.7	71.46	0.0	7.5
Bourne	Post-Transplant (Sept 2011)	69	139	38	3.7	LAI & biomass were not measured in Sept. 2011				10.0
Nauset	Pre-Transplant (Aug 2010)	90	117	831	4.3	2.43	0.6	68.62	0.0	0.0
Nauset	Post-Transplant (July 2011)	97	220	462	4.1	1.68	0.7	158.07	0.0	0.0
Nauset	Post-Transplant (Sept 2011)	72	93	22	5.7	LAI & biomass were not measured in Sept. 2011				7.0
Truro	Pre-Transplant (Aug 2010)	90	63	140	3.6	0.93	0.6	35.60	0.0	0.0
Truro	Post-Transplant (July 2011)	90	117	1022	5.3	3.31	1.2	143.33	0.0	0.0
Truro	Post-Transplant (Sept 2011)	93	144	34	4.4	LAI & biomass were not measured in Sept. 2011				2.5

Discussion

Survival

Transplant survival at the end of summer 2011 was relatively low in all three transplant areas. Survival rates varied greatly at first, however, with the Bourne site showing promise until the last monitoring event, while the Nauset site experienced early failure at least in part due to bioturbator activity. Survival at each site is described in the following paragraphs.

The Bourne site showed the best survival over the first 8 months of the project. Monitoring indicated 100% survival after one month. At the 8-month sampling event (May, 2011) shoot density was >100% of original planting density, indicating the plants were taking hold and spreading. By July 2011 however, transplant density had decreased to less than 40% of the original planting, and in September 2011 no surviving plants were found.

The loss of transplants during summer is likely due to water quality in general, and light availability in particular. Light levels during the summer were lower in the transplant area than the donor beds. In addition, during 3 of the 5 sampling events light levels were less than 10% of surface irradiance (see Table 6). This was noted in 2010 before transplanting, but because the transplant area light level was very close to that seen in the donor bed, it was thought this would not be a major issue. Light levels at the transplant site appeared to be sufficient during the fall, winter and spring months but during summer they became a limiting factor.

In addition to the low light levels, macroalgae were prevalent at the site. At the transplant site, all quadrats had at least as high a percent cover of free-floating macroalgae interspersed with the eelgrass (generally around 10-30% macroalgal cover in July 2011 and 5-10% in September 2011), indicating competition for light and other resources. Divers also noted poor visibility at the transplant area in July 2011, relative to the donor bed area. Because of the importance of light in seagrass survival (Short et al. 2002; Kemp et al. 2004; CCE, 2010), it appears that the low light levels at the transplant site may have been a major factor in the loss of transplants during summer 2011.

The Truro transplants showed good survival initially, but all three planting grids showed a steep decline over the winter. The sediment at this site was found to be highly dynamic in that the PVC stakes used to mark the corners were either buried more deeply or scoured out and exposed throughout monitoring visits. In addition, one of the screw anchors used to mark the grids pulled free during the first two weeks after planting, suggesting substantial sediment movement at this site. Sediment dynamics were not a specific part of the site screening (though fetch, northeast exposure, and other factors related to sediment movement were). Future projects in this region might consider sediment dynamics in addition to the other factors used to screen sites.

At Nauset the transplants were unsuccessful initially, likely due to activity by the large numbers of bioturbators (*Limulus polyphemus* in particular) observed at the 2 week monitoring event. Although summer 2010 monitoring included a field survey, the number of bioturbators observed during summer monitoring did not indicate a major problem. However at the 2 week post-transplant survey a large number of juvenile and adult *Limulus polyphemus* (commonly known as horseshoe crabs) appear to have molted in the area, as tens or hundreds of molts were observed both in the water and on a small sandspit island adjacent to the transplant site. In addition, crab species observed during post-transplant surveys included *Carcinus maenus*, *Libinia emarginata*, and *Pagurus spp*. As structure in the marine environment seems to provide an attractant, the newly planted eelgrass likely provided sought-after structure to a diverse assemblage of biota, including the many crabs that were moving through the area during the post-transplant period. *Ampelisca spp*. (tube-building amphipods) also infiltrated the site and covered a good portion of sediment during the 2011 surveys.

Planting Method

Though the sample size was small and results limited, there appeared to be no major difference between the clump method of planting and the horizontal rhizome method during this project. However, it was noted that the clump method was less labor intensive.

Recommendations

Based on results of this study eelgrass restoration at these sites would be challenging. All three sites are characterized by certain factors that make transplant success somewhat less likely.

Phinney's Harbor, Bourne

Water quality, and in particular light levels during the summer months appear to be lower than optimal for eelgrass growth in Phinney's Harbor. In addition, the embayment has abundant macroalgae, and this may have been a factor in the reduced success of the transplants. If nutrient loads are reduced in the embayment, consistent with recommendations from the TMDL report for Phinney's Harbor (MEP, 2006), then there will be good potential for eelgrass restoration in this embayment. The Massachusetts Estuaries Project (MEP) report for Phinney's Harbor suggests there are 70-80 acres of eelgrass habitat are available in Phinney's Harbor, if nutrient loads are reduced below the TMDL (MEP, 2006 page 107). The report further suggests restoration should take place first in the lower part of the main basin that flushes faster and has lower nitrogen concentrations, and that the other areas of the harbor historically characterized by eelgrass could be restored later, as nutrient loads are further reduced. In the event that nutrient reduction is achieved Bourne appears to be a good candidate site for eelgrass restoration. At present however, water clarity may not be adequate to support new transplants. Anecdotally, brief conversations with several local fisherman at Phinney's Harbor indicated that they had noticed changes in water clarity over the years along with reductions in eelgrass and bay scallops.

Cape Cod Bay, Truro

Regarding the Truro site, the sediment appears to be highly dynamic, such that new transplants are quickly dislodged by scour or burial. This is a challenge to the viability of the site, despite favorable conditions in terms of water quality, macroalgal biomass, and bioturbators. Controlling sediment movement is virtually impossible in the marine environment. However, it may be possible to choose a site in the lee of existing eelgrass beds, which could provide sediment stability if this site is pursued. The survival of a few plants suggests the plants can live in the area, as long as they can become established.

Nauset Inlet, Orleans

The Nauset transplants appear to have failed due to excessive numbers of bioturbators in fall 2010 that were not present during the bioturbator survey in August 2010. This doesn't necessarily mean the embayment is not suitable for eelgrass restoration, but it does suggest careful attention to bioturbators. One option would be to do additional plantings either earlier in the season (spring-early summer) or later in the season (October), when bioturbator numbers might be lower.

Nauset is an interesting site, as the eelgrass beds in the outer harbor appear to be healthy and spreading. Water clarity seems to improve the closer the area is to the Atlantic Ocean inlet, so that there were noticeable differences between the transplant site in the Town Cove area (further inside Nauset Harbor) and the donor area further toward the ocean in Nauset Harbor. That the area is well protected and allowed for transplants in shallower water where light penetration is still very good. Sediment was muddy in a number of areas of Nauset Harbor including the donor bed area though the plants seem to do well there. In the event that further test plantings are an option, Nauset could potentially be planted in different areas, and plantings could be planned around bioturbator activity.

Size of Test Plots

It is recommended that slightly larger test plantings be done in future, as the small size of our plantings rendered the plants vulnerable to edge effects. That is, our grids were 4x4 quarter-meter planting grids, with alternating patches planted, so there were no large 'interior' patches in our grids that would be buffered from currents, bioturbators, and scouring more than the exterior patches. Larger sized test plantings would trigger a more rigorous permitting process which should be considered when planning future projects.

References

Asner, G.P., Scurlock, J.M.O. & Hicke, J.A. (2003). Global synthesis of leaf area index observations: implications for ecological and remote sensing studies. Global Ecology and Biogeography, 12, 191–205.

Cornell Cooperative Extension, 2010. Light and Seagrasses. Cornell Cooperative Extension Seagrass Restoration online information available at http://counties.cce.cornell.edu/suffolk/habitat_restoration/seagrassli/ec

Costa, 2004. Causes of eelgrass degradation and jet-clamming issues. Presentation to the Bourne Shellfish Advisory Committee. Available online at *http://www.buzzardsbay.org/eelgrass/eelgrass-jetclamming-issues.pdf*

Davis, RC and FT Short (1997). Restoring eelgrass, *Zostera marina* L. habitat using a new transplanting technique: the horizontal rhizome method. Aquatic Botany 59:1-15.

DMF, 2006. Eelgrass Restoration Project Update 10/16/2006. Boston Harbor eelgrass restoration report. Available online at *http://www.mass.gov/dfwele/dmf/programsandprojects/hubline/eelgrass_update_101606.pdf*

Hauxwell, J, J Cebrian, C Furlong, and I Valiela. 2001. Macroalgal canopies contribute to eelgrass (*Zostera marina*) decline in temperate estuarine ecosystems. Ecology 82(4):1007-1022.

Kemp, WC, R Batiuk, R Bartleson, P Bergstrom, V Carter, CL Gallegos, W Hunley, L Karrh, EM Koch, JM Landwehr, KA Moore, L Murray, M Naylor, NB Rybicki, JC Stevenson, and DJ Wilcox. 2004. Habitat requirements for submerged aquatic vegetation in Chesapeake Bay: water quality, light regime, and physical-chemical factors. Estuaries 27(3): 363-377.

Leschen, AS, KH Ford, and NT Evans. 2010. Successful eelgrass (*Zostera marina*) restoration in a formerly eutrophic estuary (Boston Harbor) supports the use of a multifaceted watershed approach to mitigating eelgrass loss. Estuaries and Coasts 33(6):1340-1354.

MEP, 2006. Linked Watershed-Embayment Model to Determine Critical Nitrogen Thresholds for the Phinney's Harbor, Eel Pond, and Back River System, Bourne, Massachusetts. Final Report.

Neckles, H.A. (ed.) 1994. Indicator development: Seagrass monitoring and research in the Gulf of Mexico. U.S.E.P.A.

Short, FT, RC Davis, BS Koop, CA Short, and DM Burdick. 2002. Site-selection model for optimal transplantation of eelgrass *Zostera marina* in the northeastern US. Marine Ecology Progress Series 227: 253-267.

Appendix A

Potential Site Selection Criteria Scoring

Scoring criteria was adapted from Short's model in addition to other eelgrass restoration information such as reports published by the MA Division of Marine Fisheries, MA Estuaries Project, and the Coalition for Buzzards Bay. The scores would be multiplied eliminating any sites with very poor qualifying criteria.

Depth (at mean low tide)
0 – less than 1 m, greater than 3.25 m
1 – 1 to 3 m

Sediment
0 – Mud/silt/clay or macroalgae
1 – Less than 70% silt/clay
2 – Less than 30% silt/clay

Secchi Reading and/or Hobo measured light penetration
0 – Less than 1 m
1 – 1 to 2 m
2 – Greater than 2 m

Water Quality (from our measurements, and/or existing data)
0 – Poor
1 – Fair
2 – Good
Bioturbators (visual surveys and trapping)
0 – Abundant
1 – Present
2 – None

Existing Eelgrass
0 – Less than 100 m away (too close)
1 – Greater than 100 m away

Donor Bed Proximity
0 – None in reasonable proximity
1 – Donor bed in water body or connecting water body

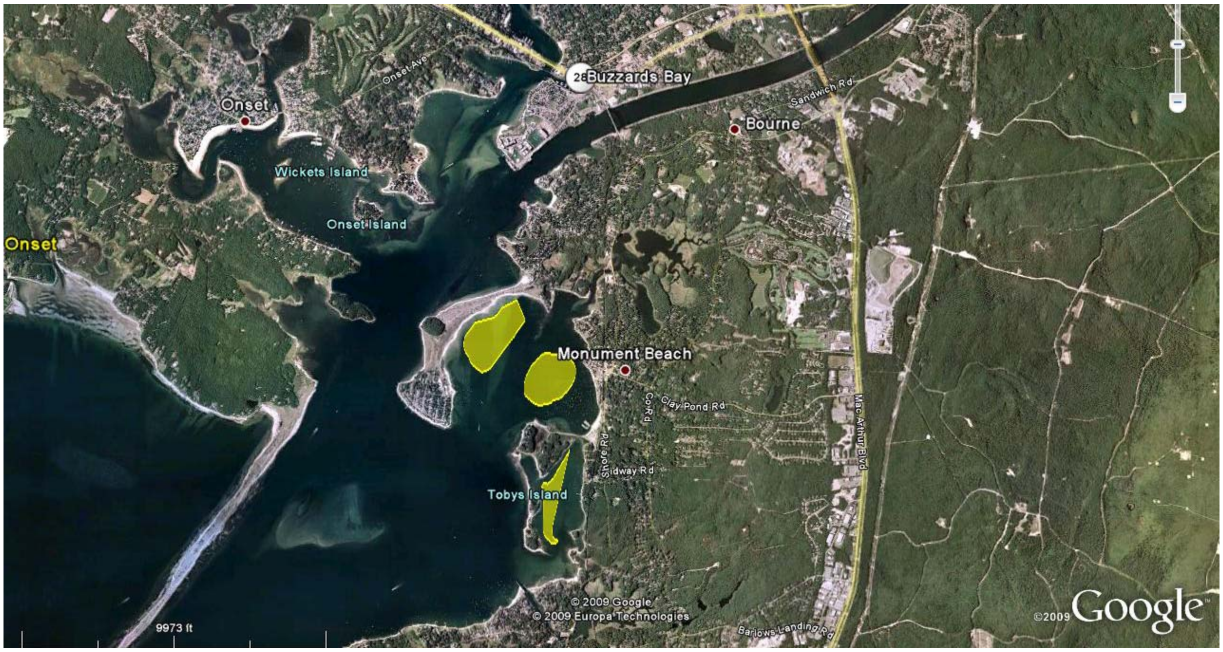
Exposure to Wind and Waves
0 – Large Northeasterly fetch
1 – Moderate wind/wave activity
2 – Low wind/wave activity expected

Human Activity

0 **–** Mooring field, boat channel, shellfishing area
1 **–** Moderate human usage
2 **–** Little to no human disturbance

Maps with potential sites highlighted in yellow:

Regions of Interest in Bourne: Phinneys Harbor, Tobys Island



Regions of Interest in Barnstable: Cotuit Bay - Outer

Regions of Interest in Brewster: Cape Cod Bay Crosby to Skaket

Regions of Interest in Orleans: Namequoit River, SW edge Sipson Island

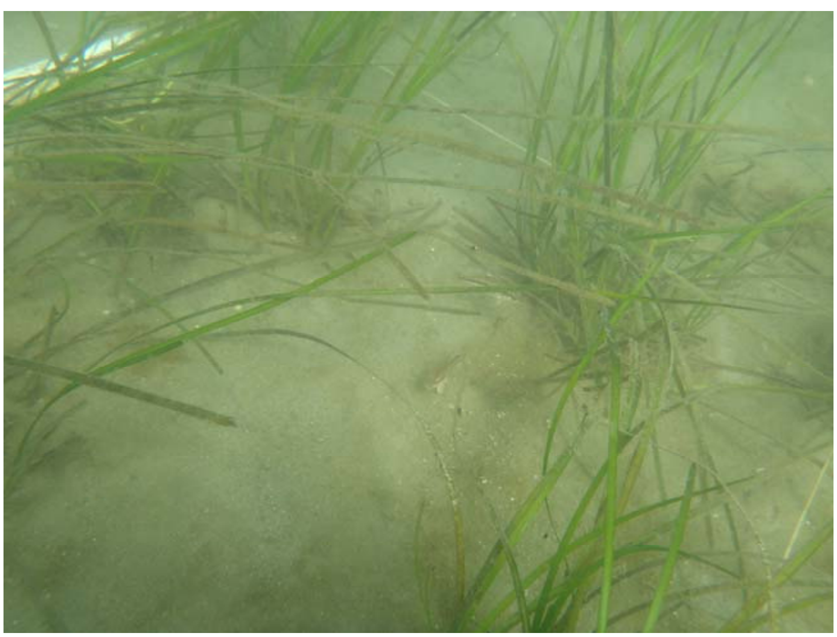
Regions of Interest in Eastham/Orleans: Town Cove/S edge Hopkins Island, Stony Island, Snow Point, Weeset Point

Region of Interest in Wellfleet: SW Griffin Island/Cape Cod Bay

Region of Interest in Truro: SE East Harbor/Cape Cod Bay

Appendix B

Bourne post-transplant assessment on 10-08-2010 with bay scallop.



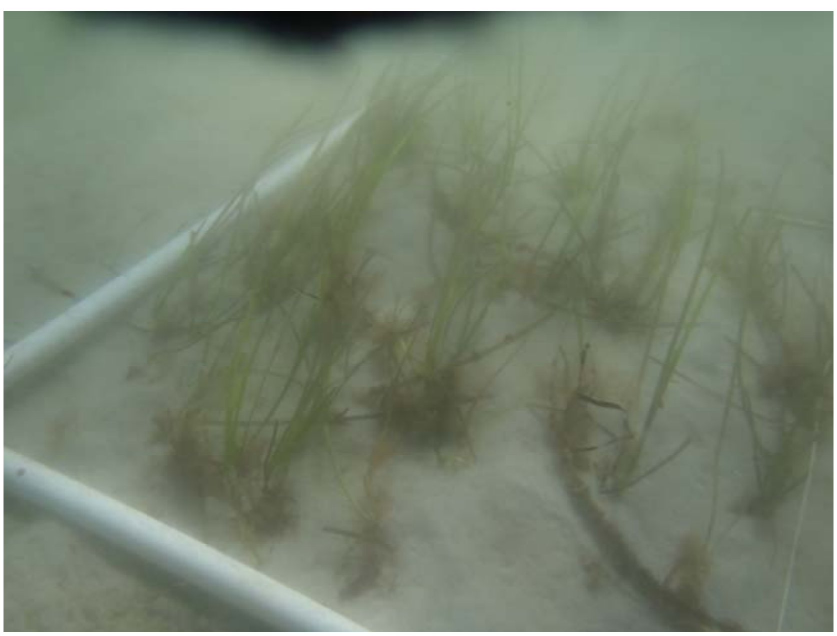
Bourne transplants 10-08-2010


Bourne transplants 10-08-2010.

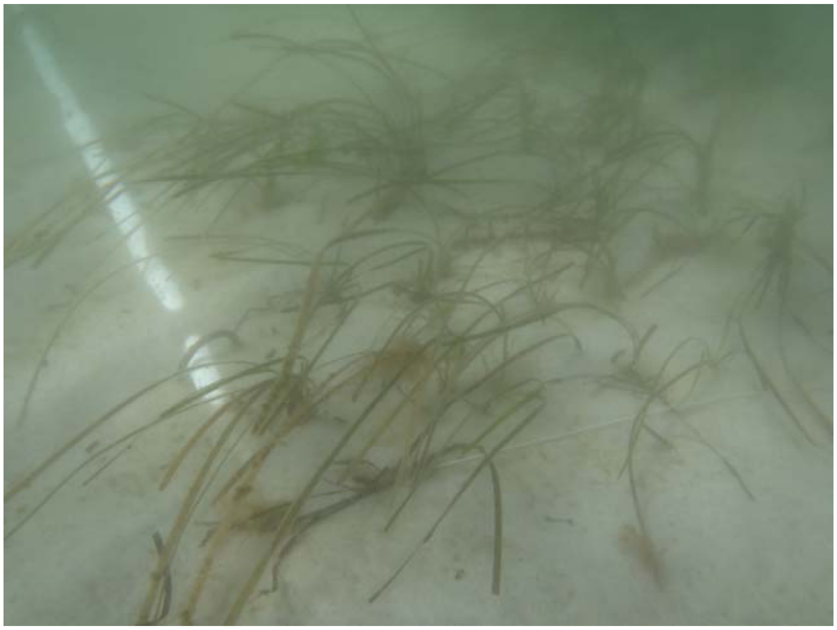

Bourne transplants 5-25-2011.

Bourne transplants July 2011.

Truro planting in September, 2010.



Truro post-transplant assessment on 10-13-2010.



Truro transplants showing sediment movement 10-13-2010.

Truro transplants 5-31-2011.


Truro transplant assessment on 7-19-2011.


Nauset – showing green crab occupying newly transplanted eelgrass on 9-21-2010.


Nauset – small patch of remnant transplants 7-13-2011.