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EELGRASS HABITAT CREATION IN NANTUCKET HARBOR, MASSACHUSETTS

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Executive Summary

In response to eelgrass habitat losses associated with development and marine activities in and around Nantucket Harbor, the Nantucket Land Council became interested in restoring eelgrass. One approach was to establish a meadow by transplanting eelgrass to previously vegetated areas. An experimental eelgrass planting was conducted in June and July, 2010 in Nantucket Harbor following a site selection process that included surveys and light measurements. Areas where eelgrass had thrived in the past, but now appeared to be absent based on aerial photographs and local accounts, were surveyed in early spring 2010 with assistance from Harbormaster Dave Fronzutto and town biologist Tara Riley. Our surveys confirmed that most of the sites appeared to have abundant eelgrass seedlings at that time, and so were eliminated from consideration for subsequent experimental planting. Three potential sites were further examined, including a comparison of bottom type, relative current speed and light availability. After review of the data, one site was selected for planting due to its low to moderate tidal current and highest light availability (18.1% of ambient). The planting site is located about 1,000 meters southwest of the inlet to Polpis Harbor, just offshore of the bluff at the border of Quaise and Polpis, in slightly deeper waters than existing eelgrass beds.

The planting area was populated with local eelgrass shoots, sustainably harvested from an extensive bed within the Harbor with assistance from trained volunteers. Over 6,000 eelgrass shoots were collected from this donor site, located just west of First Point and near the inlet to Nantucket Sound. Four weeks following collection, impacts from our collection were shown by a 24% decline in shoot density, but live eelgrass cover did not decline significantly. After 12 weeks, no effects of collecting could be measured at the donor site for shoot density or cover, a result supported in the literature by others using donor beds for eelgrass restoration in our region. We returned to the site after 13 months and again found no collection effect.

Plants had difficulty establishing within the restoration area due in part to extensive phytoplankton and macroalgal blooms that dramatically shaded the transplants for the initial three months following transplanting. After the first growing season, few of the 6,000 plants had survived, but those plants that survived became well established and grew through the second growing season in 2011. The significance of the macroalgae was documented through estimates of percentage cover, whereas light measurements showed the decline in water clarity from phytoplankton blooms to less than 10% ambient. Combined with our planting and monitoring results, our observations suggest that reestablishment of eelgrass beds in Nantucket Harbor is not limited by the distribution of seedlings, but by shading from phytoplankton and macroalgal blooms that resulted in levels of light too low to support eelgrass establishment during the summer months in 2010.

Eelgrass Habitat Creation

in Nantucket Harbor, Massachusetts

Introduction

Eelgrass, *Zostera marina*, is a rooted vascular plant of subtidal habitats that is known to support many valuable ecosystem functions, from essential fish habitat such as bay scallops to improvement of water quality (Thayer et al. 1984). Nantucket Harbor supports extensive eelgrass beds and has one of the few remaining bay scallop fisheries in Massachusetts. However, eelgrass beds in some areas of Nantucket have begun to decline and other areas have been impacted by development and marine activities. To investigate the possibility of increasing eelgrass habitat, The Nantucket Land Council (NLC) has engaged restoration scientists from the University of New Hampshire Jackson Estuarine Laboratory (JEL).

As a first step, we have examined the feasibility of using transplants to reestablish eelgrass where it had thrived in the past. Creation of eelgrass beds is difficult and there are more failures than successes described in the literature, so site selection is important (Thom 1990, Fonseca et al. 1998, Short et al. 2002). However, success rates appear to be improving in estuaries where water quality is improving (Boston Harbor: Leschen et al. 2008; Narragansett Bay: SaveTheBay 2009). Working with NLC and the Town of Nantucket we surveyed areas shown to have lost eelgrass in the past throughout the Harbor to choose a planting site. A moderately shallow area off of Polpis, shown to have fairly good light conditions in April 2010, was chosen as the best site that did not already have eelgrass seedlings. In June and July of 2010 we worked with the NLC and volunteers from the UMASS field station to collect and transplant approximately 6,000 eelgrass shoots using two frame methods. The team planted approximately 6,000 square feet of marine bottom with 120 planting frames totaling over 6,000 eelgrass plants in 2010. Impacts to the donor site and transplant success were assessed in 2010 and 2011 and are reported herein.

Methods

Planting Site Selection

Rigorous evaluation of potential sites is critical to site selection and ultimate restoration success (Thom 1990, Short et al. 2002). We based our initial review of potential restoration sites upon comparison or the latest aerial imagery (MassGIS, 2001, 2003, 2005) and the most up-to-date mapped areas of eelgrass resources (MassDEP 2006) that were generated in 1995 and 2001. On site observations were conducted with the help of harbormaster David Fronzuto on March 25, 2010 and led us to narrow the search to three potential locations for eelgrass habitat creation (Figure 1). At each potential restoration site we deployed light sensing data loggers (Hobo^{TM} pendants) to evaluate available light within the water column. Light is critical to eelgrass bed success (Short et al. 2002) and we compared proposed sites for light data collected from mid-March to mid-April.

Eelgrass donor site and collection

Several areas within the Harbor were evaluated for their potential to serve as donor beds. Donor site harvesting is an accepted approach for use in seagrass restoration that has been successfully employed at many locations throughout the northeast by a variety of groups, each demonstrating no long-term impacts to the donor bed (Davis and Short 1997, Leschen et al. 2007). The key to sustainable use of donor sites lies in careful site selection and adherence to several critical selection criteria and collection protocols, as outlined below. The donor site chosen was located in the outer harbor on the western shore of the First Point along Coatue, opposite from Brant Point (Figure 1). The bed had an eelgrass cover averaging over 80%, with a stem density averaging 490 shoots per square meter. Prior observations of the bed from surveys conducted in 1995 and 2001 (MassDEP 2006) suggest eelgrass coverage has been persistent at this location. Therefore, with more than 50% cover and documented persistence, it was deemed acceptable for use as a donor bed following new state recommendations (Evans and Leschen 2009). Following assessment of cover and stem density, plants were harvested directly for transplanting.

Figure 1. Potential areas for eelgrass creation sites (green) and donor bed (open circle). One reference site was established adjacent to the donor site, while another was established adjacent to the planting site.

Shoot collections were led by JEL scientists and aided by NLC staff and volunteers from the UMASS Field Station that received on-site training. Harvesting of plants was conducted entirely by hand and resulted in no greater than 20% of shoots removed from the bed. The collection process was methodical, with all participants harvesting plants distributed across the entire bed surface to minimize localized harvesting impacts. To obtain viable shoots for transplanting, selected plants were separated from the rhizome by hand after a small clump of 3-5 shoots was pulled from the sediment. Each shoot was snapped off the rhizome about two internodes below the youngest root node. This provides a viable shoot with minimal disturbance to the sediment. Plants were collected from the donor site and bound in sets of fifty plants. Plants were tied to frames and installed on the bottom on the same day or the day following collection.

In order to characterize the collection impacts to the donor bed, eelgrass was monitored for cover and shoot density (Table 1). The boundaries of the donor and reference areas (each 7 by 20 meters) were established using WAAS-corrected GPS and marked in the field with PVC stakes. Twelve randomly chosen locations in the donor bed were assessed at four intervals: before collections (June 2010), 4 weeks following collections (mid-August), at the close of the growing season (mid-October), and once again in mid-August, 2011. For percentage cover, 1 m^2 quadrats were placed on the bottom and visual estimates of eelgrass and algae were made. A smaller 0.1 m^2 quadrat was placed at the center of the larger quadrat and shoot density was counted. Similar monitoring was performed on the same dates from an adjacent reference bed where no eelgrass was collected for transplanting.

Table 1. Sampling associated with experimental eelgrass planting in Nantucket Harbor. Twelve replicates (1m^2) were collected for the donor/reference site (9.2% of area) and 20 were collected for the planting/reference sites (3.5% of area).

Sample Area	**Existing Conditions**	**4 weeks (mid-Aug. 2010)**	**12 weeks (mid-Oct. 2010)**	**Year 2 (mid-Aug. 2011)**
Donor Site	Cover/Shoots	Cover/Shoots	Cover/Shoots	Cover/Shoots
Donor Reference	Cover/Shoots	Cover/Shoots	Cover/Shoots	Cover/Shoots
Planting Site	Cover	Cover	Cover	Cover
Planting Reference	Cover	Cover	Cover	Cover

Eelgrass planting and monitoring

There have been many techniques for planting eelgrass developed over the past 20 years. Each technique possesses unique benefits and drawbacks such that no one method suits all sites or conditions equally. After careful consideration of our site conditions and specific project goals, we elected to employ two different frame-based planting methods described below.

Review of various transplanting methodologies shows that shoots are often planted too deep in the sediment or too shallow so they are loosened and lost through typical wave action. When planted in clumps, the sediment often becomes anoxic after re-planting and impacts survival. An alternative method involves tying pairs of rhizomes to coated wire frames, known as TERFS ™ (Short et al. 2006). This approach allows very shallow planting depths to minimize exposure to anoxic sediment conditions, yet protects the plants from becoming dislodged by waves or bioturbation (Short et al. 2006). In this method, crepe paper is twisted tightly to form rapidly biodegradable 'string' that holds rhizomes to the frame, while the frame itself is brought into close contact with the sediment using retrievable metal wire staples (Figure 2).

Eelgrass planting and reference sites were assessed for cover of plants at four intervals: before planting, and one, three and thirteen months following transplanting. A 30 by 30 m grid was used to choose 20 random 1 by 1 meter locations prior to transplanting. Following transplanting a 22 by 30 m grid was used (the size of the actual transplanted area) to generate 20 random sampling locations. At each location the percentage cover of eelgrass and different types of dominant macroalgae were estimated and recorded, as well as any obvious invertebrates (e.g., scallops).

Figure 2. Original TERF™ unit deployed with attached eelgrass in Bellamy River, NH.

TERFS™ were originally constructed from plastic-coated wire mesh (typically used for lobster and crab traps; Short et al. 2006) with bricks along two edges to hold the structure to the marine bottom. Depending upon site conditions, a modified frame can be employed which lack the sides shown in Figure 2. These modified TERFS™ are simply coated wire frames held in place with bent wire staples. In either case, transplanted eelgrass plants will establish within six to eight weeks. Rooted plants have rooted in the sediment and the crepe is dissolved, so the frames and staples can be carefully removed and used again, leaving no permanent materials behind at the site.

In Boston Harbor, TERFS™ were modified using biodegradable jute mat fastened to a frame of PVC pipe (Figure 3) and stapled to the sediment (Leschen et al. 2007). In this new adaptation, the jute is released from the frame and only the frame and staples are removed once plants become established after several weeks. This allows the jute to remain and continue protecting the plants until it slowly degrades. We used two types of frames that held 50 shoots each: the flat, coated wire frames and the newly developed PVC with jute frames.

Figure 3. Planting frame developed by Leschen and colleagues (2007).

Typically, 50 plants are attached to each frame that is affixed at the center of an area that is 50 square feet. In our application, 120 frames were used over a 6,000 square foot area (one planting frame every 50 square feet). Following planting, the successful eelgrass transplants are distributed in small patches that will coalesce over a period of one to several growing seasons, dependant upon local conditions (Short et al. 2006, Leschen et al. 2007).

Statistical Analyses

Data were input to excel spreadsheets and imported to JMP for statistical analysis using monitoring area and period as fixed effects in a two-way Analysis of Variance (ANOVA) of dependent variables (eelgrass and algal cover, shoot and scallop density). Effects were deemed statistically significant using an alpha of 0.05. Residuals were examined for outliers, normal distribution and evenness of variance to assure assumptions of parametric statistics were met. For analyses of the eelgrass donor sites, algae and bare sediment cover were square root transformed; other variables met assumptions. For analyses of planting sites, eelgrass cover was ranked; scallop density, cover of *Codium* and cover of *Gracilaria* were log transformed; and *Lyngbya* and total algae cover were square root transformed. Post hoc differences between means were tested using Tukey's when main and interactive effects were significant in ANOVA.

Results

Planting Site Selection

To increase the likelihood of success, we carefully reviewed general site information and light data collected from the three potential planting sites. Our field survey on March 25, 2010 found abundant eelgrass plants throughout the majority of the potential planting sites we visited (some sites appeared to be re-colonizing from seedlings), leaving only three potentially suitable sites for transplanting as shown in Figure 1.

Further examination of site conditions revealed that two of these three would ultimately be unsuitable. The Head of the Harbor Site (planting site #3, just west of Wauwinet) had fairly poor water quality as demonstrated by the light logger data (12.3% of ambient) and was therefore removed from consideration. Planting site #2, at Pocomo Head, had better water quality (17.4% of ambient light), but was continually subject to strong water currents. In the past, we have found strong currents hinder transplant establishment by undercutting and eroding the sediment from beneath the sampling frames. Currents could also exacerbate problems with drift algae and debris becoming caught on the planted eelgrass and frames. Therefore, this site was also removed as a potential planting site.

Planting site #1 had the best water quality during the pre-planting monitoring period (April 2010) with 18.1% of ambient light. Yet this location also demonstrated potential limitations to success. We were concerned that invasive macroalgae (primarily *Codium fragile*) could interfere with planting and expand into planted plots, hindering eelgrass survival and growth. Nevertheless, this location represented the best overall site conditions and met all other restoration area requirements (i.e., total area, water depth, etc.) based on existing conditions within the harbor in 2010. The selected planting site and a reference area 200 meters to the west were marked using temporary stakes and existing conditions were assessed. Resulting data were summarized and provided to the Nantucket Conservation Commission and Marine Department for review and comment prior to planting. Light meters were also deployed in June and show the relative light environment at the planting site and its reference (Table 2). Light levels had declined in summer and were much lower at the planting site compared to its reference, despite being so close to one another and occurring at similar depth.

Table 2. Comparative light environment 20 cm above the marine bottom for potential and selected eelgrass planting sites in Nantucket Harbor. Light intensity is reported as average lumens/ft^2 from 10 AM to 2 PM on days with low tides occurring during the mid-day period relative to control sensors placed out of the water, reduced by 20% to correct for light scatter (Carruthers et al. 2001).

April 2010	Intensity (lum/ft^2)	Light (% of Control)
Site 1	1,950	18.1%
Site 2	1,870	17.4%
Site 3	1,324	12.3%
Control	10,790	
June-July 2010		
Planting Site 1	1,287	9.4%
Planting Reference	2,335	17.0%
Control	13,698	

Harvesting and Planting

We received invaluable volunteer assistance from the NLC as well as volunteers organized and provided by the UMASS field station in harvesting, planting and monitoring the donor and planting sites (Figure 4). In total, 6,050 plants were collected and 120 frames were set with plants and installed at the planting site using two types of frames (Table 3). The majority of frames were removed on August 12th (seven weeks or more after installation) with the help of Chris Fuller, a local diver. However, several frames were left for later retrieval in early fall 2010 to allow more time for transplants to better root and establish. By mid-October, all frames deployed had been removed from the Harbor.

Figure 4. Volunteers learning how to tie eelgrass shoots to frames.

Table 3. Plant collection and planting schedule

Date Deployed	# Shoots Collected	# Frames Deployed	
		Jute	Wire
6/16/10	300	6	0
6/22/10	2100	2	8
6/23/10	1850	21	19
6/24/10	0	13	15
7/15/10	1800	14	22
Total	6050	56	64

Donor Site Assessment

The donor site and adjacent reference site were each assessed for eelgrass cover and density as well as algal cover at 12 randomly selected locations in June, August and October 2010 and again in August 2011. Eelgrass was the dominant cover for both sites and most sample dates (Figure 5). In June 2010, live eelgrass was mixed with minor amounts of dead eelgrass and bare sediments in both donor and reference locations (Figure 5, Table 4). In August following eelgrass collections, the cover of live eelgrass declined about 6% and drift macroalgae increased 20% in the donor area. However, similar changes were noted in the donor reference area (eelgrass cover fell 16% and algae increased 15%; Figure 5), likely the result of seasonal water quality decline throughout Nantucket Harbor. Sampling took place again in October, approximately three months following the final donor plant collection. As the season progressed, macroalgae increased and reached similar percentage of cover compared to eelgrass (Figure 5, Table 4). Cover of live and dead eelgrass, algae and bare sediment were very similar between donor and reference sites in October 2010. In August 2011, we observed more bare sand and less macroalgae, but similar amounts of eelgrass coverage in comparison to August 2010. Despite noted changes in species composition and cover types over the observation period, no effects of donor collections were found for any of the measures of cover from August 2010 to 2011 (Figure 6). In fact, the live eelgrass cover 13 months following the collections appeared to be greater than its reference, but the difference was not statistically significant.

Figure 5. Cover of eelgrass and algae in the donor and reference areas before (June 15) and after (August 18 2010, October 13 2010, and August 18 2011) eelgrass collections.

Table 4. Eelgrass cover and stem counts in the donor and donor reference sites. Each mean represents 12 randomly located replicates within a 7 by 20 meter area; Quadrat size for % cover and invertebrates was 1 m^2; Quadrat size for stem # was 0.1 m^2.

Collection Station	Date (2010)	Live Eelgrass	Dead Eelgrass	Algae	Bare	Shoots (# / 0.1 m^2)	Scallops (# / m^2)
Donor Site							
Mean	June 15	**81.7**	**8.8**	**2.2**	**7.3**	**49.1**	**0.8**
St Dev	2010	5.4	4.5	1.4	3.3	12.0	1.0
Donor Ref							
Mean	June 15	**92.9**	**3.8**	**1.2**	**2.2**	**35.5**	**0.8**
St Dev	2010	2.6	1.7	1.4	1.9	8.6	1.1
Donor Site							
Mean	August 18	**69.6**	**1.7**	**22.9**	**5.8**	**36.9**	**3.3**
St Dev	2010	6.6	2.5	8.1	3.6	5.8	6.5
Donor Ref							
Mean	August 18	**77.1**	**2.5**	**16.7**	**3.8**	**38.3**	**1.8**
St Dev	2010	8.9	2.6	8.3	3.1	5.5	3.9
Donor Site							
Mean	October 13	**44.4**	**4.8**	**46.4**	**4.3**	**29.1**	**1.2**
St Dev	2010	7.2	3.6	8.5	6.4	9.8	0.7
Donor Ref							
Mean	October 13	**41.3**	**8.5**	**48.9**	**1.3**	**25.2**	**1.6**
St Dev	2010	6.2	6.3	5.1	2.6	6.7	2.1
Donor Site							
Mean	August 18	**75.4**	**2.7**	**3.2**	**18.8**	**64.3**	**0.6**
St Dev	2011	9.2	2.0	3.3	9.9	13.0	0.7
Donor Ref						3.8	
Mean	August 18	**69.8**	**2.9**	**4.7**	**22.2**	**66.7**	**0.3**
St Dev	2011	12.3	2.7	4.4	10.5	12.8	0.7

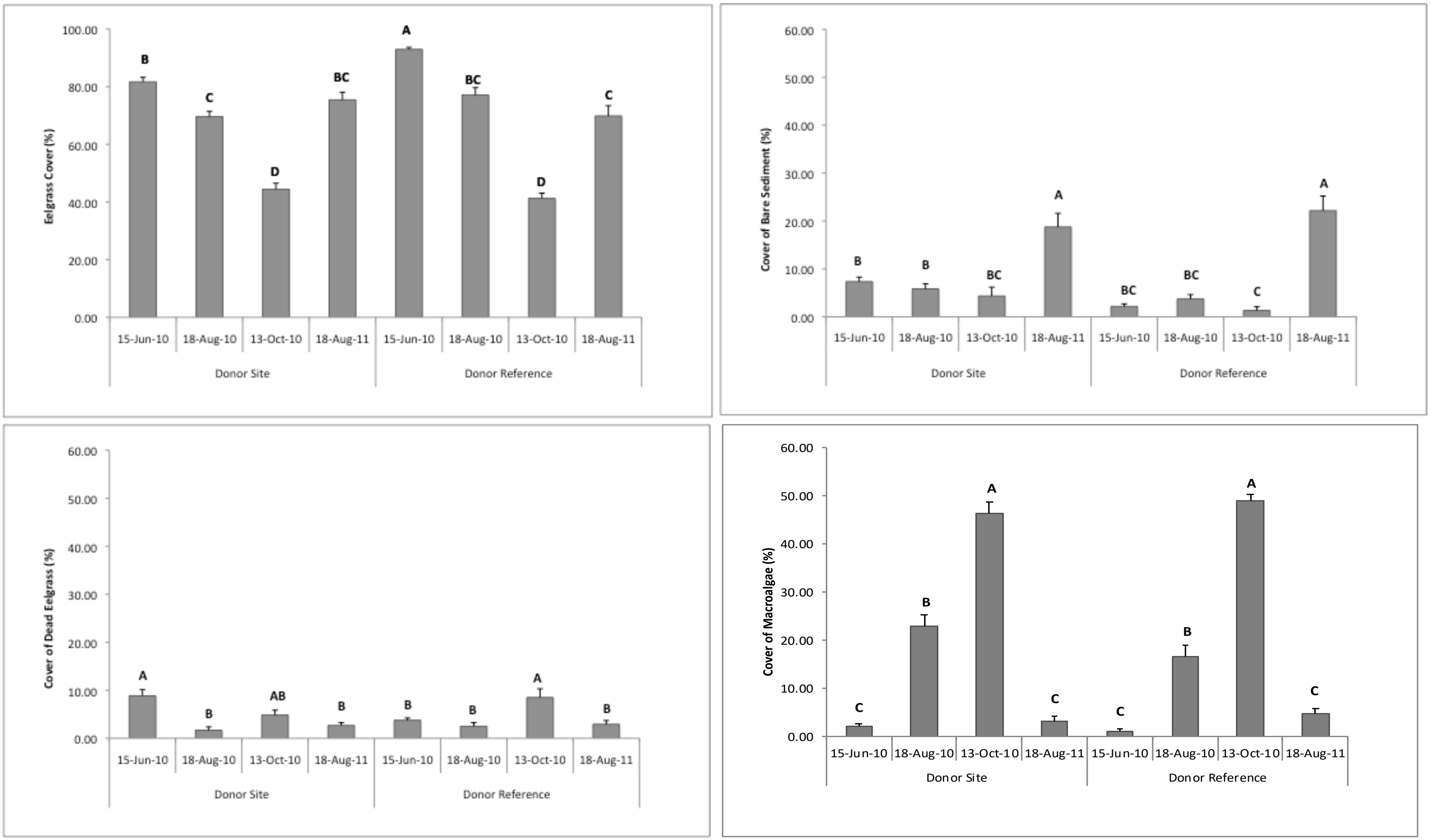

Figure 6. Live and dead eelgrass, algae and bare sediment cover at the Donor and associated Reference site. Bars with different letters denote significant differences using Tukey's post hoc test following a two-way ANOVA where the site by date interaction term was significant (except for bare sediment cover; p=0.0736).

As one might expect, a short-term decrease in eelgrass shoot density was observed in sample plots immediately following donor plant harvest (Figure 7, Table 4). Average shoot number in the reference area was similar on the first two dates, while shoot number in the donor area declined following collection of approximately 6,050 shoots. The donor area encompassed 140 m^2 and we estimate it originally had 68,600 shoots; after collection the second assessment was used to estimate 51,800 shoots (24% decline). While variability in data collection may be responsible for some of the decline in shoot number (we extrapolated from 0.1m^2 quadrats using twelve plots), many lateral shoots were discarded or not counted with the 6,050 shoots used for planting. This is because only terminal shoots are counted for planting whereas terminals and laterals cannot be distinguished and are both counted in when counting stem density in underwater plots. We were able to measure an immediate effect of the collection in a two-way Analysis of Variance (i.e., probability of no interaction effect was low: P= 0.0065). However after three months of re-growth and recovery, no differences were found between donor and reference sites (13 October; Figure 7). Monitoring continued in mid-August 2011 and documented a strong rebound in shoot density at both areas, illustrating no long-term impacts to the donor bed following harvest.

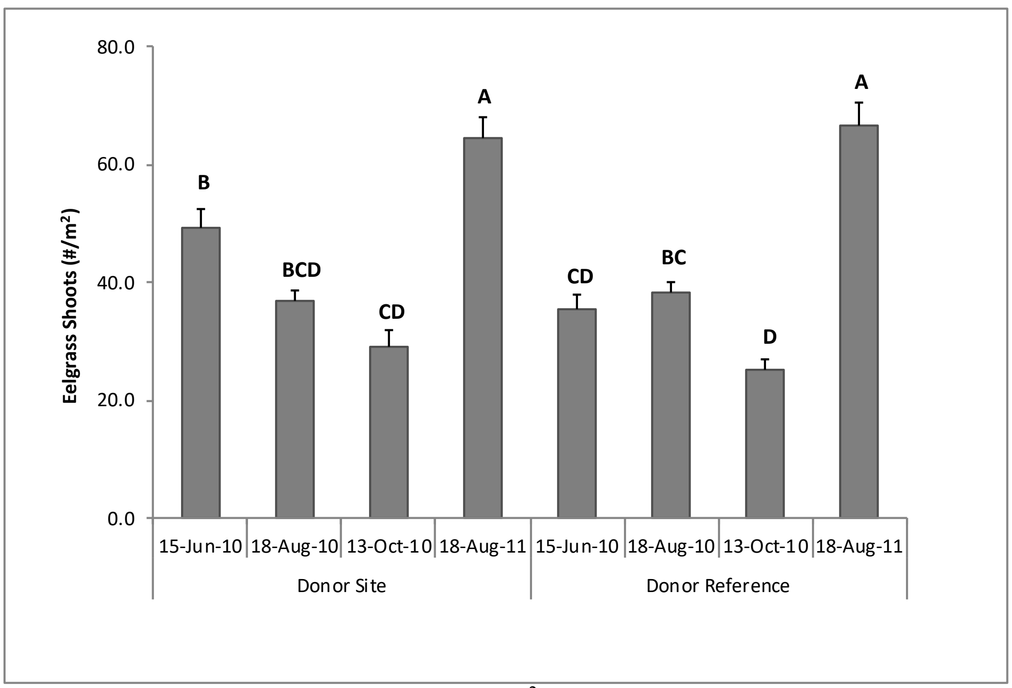

Figure 7. Number of eelgrass shoots in 0.1 m^2 quadrats collected at donor and adjacent reference areas before (June 15) and after (August 18 2010, October 13 2010, and August 18 2011) eelgrass collections. Mean values +/- SE; different letters over bars denote shoot density was significantly different, based on Tukey's post hoc means test.

Planting Site Assessment

Eelgrass and algal cover were assessed at the planting and reference sites before (June 2010) and after planting (August and October 2010, August 2011) to assess the planting effort (Figure 8). In August 2010, one month following planting, eelgrass cover increased from 0.1 to 0.4% at the planting site, but the increase was not statistically significant (Table 5a and b). Eelgrass cover at the reference site varied from 43 to 59% by date, but this variation was not significant based on Tukey's post hoc test (Figure 9). The only difference found was clear: the planted site averaged significantly less eelgrass than the reference site (0.3 vs. 51%, Figure 9). The shallower edge of the planted bed was observed to have better planting success: 10 adjacent $1m^2$ plots contained an average of 1.9% eelgrass cover in August 2011.

Because algae compete with eelgrass for light and growing space, we also assessed the cover of algae. The two-way ANOVA found that the cover of total algae varied significantly by site, date and their interaction, meaning that changes in algal cover over time differed between the planted and reference areas. When surveyed in June prior to planting, the proposed planting site had about 16% cover of *Codium* and other algae while the reference site had 7% algae (Table 5a). At the planted site, *Codium fragile*, an exotic green alga which covered 14% of the seafloor in June, expanded to 19% cover in August and was joined by the exotic red alga *Gracilaria tikvahiae* (7% cover) and a blue green alga, *Lyngbya* spp. (25% cover; Table 5b). The blue green presented significant problems for eelgrass survival because it formed a mat over the live plants, completely covering many of them and leading to high mortality within weeks of planting. Although lowest in actual percentage cover, *Gracillaria* also presented a significant challenge to planting units because it rolled along the marine bottom like tumbleweed and collected on anything fixed (i.e., eelgrass frames as well as the plants themselves). By October, the cover of total algae had continued to increase, with almost 70% cover at the planting site (Table 5b, Figure 9).

Cover of live eelgrass at the planting reference site averaged 47% in June with only 7% cover of macroalgae (Figure 8, Table 5). By August, macroalgae increased to over 40% cover, with most of the algae being *Lyngbya*. By mid-October, live eelgrass cover had rebounded to 59% and algal cover fell to 23% at the reference bed (Figure 9). It is not clear why macroalgae declined in cover by October or why the light levels were so much higher at the reference bed. However, the rebound of eelgrass in October might have been related to greater light levels reaching the plants (i.e., less shade from algae). Cover of all algae likely declined in winter, and when the sites were sampled again in August 2011, differences in algae cover between planting and reference sites continued (54% in planting but only 13% in reference area; Figure 9).

In addition to macroalgal competition, eelgrass must compete for light with phytoplankton. We found that water clarity was severely reduced by phytoplankton soon after planting. Light data from June and July demonstrated a significant decline in light penetration to the sea floor when compared with April data, falling by half to well under 10%, (representing the lower limit for eelgrass (Duarte 1991, Short et al. 1995). Phytoplankton blooms noted in July appeared to worsen at the planting site in August, darkening waters from orange-yellow to rusty-red and reducing visibility to less than three feet. In June, light meters were deployed at our planting reference bed and found light levels about twice as high compared to the planting site, even though the two light meters were only 200 m apart (Table 2). Both macroalgae and phytoplankton appear to have had significant negative impacts on light resources and eelgrass survival at the planting site.

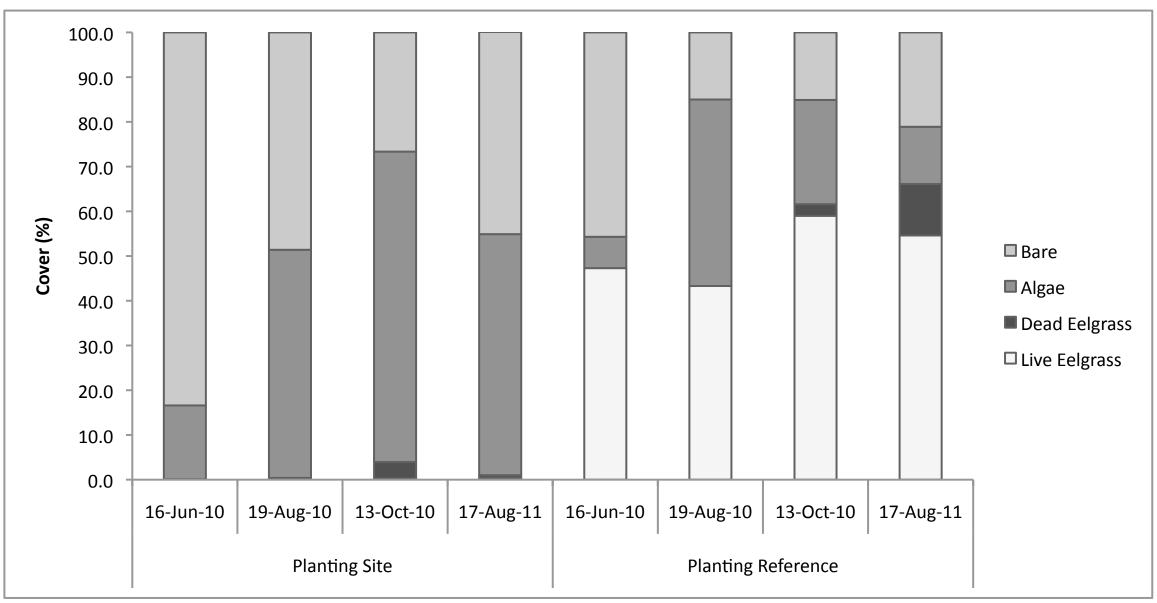

Figure 8. Cover of eelgrass and algae in the planting site and reference bed from before (June 16) to after planting (4 weeks: August 19; 12 weeks: October 13; and 13 months: August 17 2011).

Table 5a. Eelgrass and algae cover in planting and reference sites before planting*.

Planting Sites	Date (2010)	Live *Z. marina*	Dead *Z. marina*	Other Algae	*Codium*	Scallops (#/m^2)	Comments
Planting Site #1	(30 x 30 m)						
Mean	June 16	**0.1**	**0.0**	**2.3**	**14.2**	**0.0**	Many slipper shells *(Crepidula*)
St Dev		0.3	0.0	3.9	16.5	0.0	
Planting Reference Site							
Mean	June 16	**47.3**	**11.2**	**5.2**	**1.8**	**0.2**	*Bittium* snails common;
St Dev		20.7	9.7	8.1	5.4	0.5	A few slipper shells

*Each mean represents the average of 20 randomly located replicate quadrats of $1m^2$ in size

Table 5b. Eelgrass and algae cover in planting and reference sites after planting*.

		Live *Z. marina*	Dead *Z. marina*	*Codium*	*Lyngbya*	*Gracillaria*	Bare	Scallops (#/m^2)	Comments
Planting Site #1	(22 x 30 m)								
Mean	Aug. 19 2010	**0.4**	**0.0**	**19.2**	**24.7**	**7.1**	**48.7**	**0.1**	Many slipper shells
St Dev		0.9	0.0	21.4	20.7	12.7	32.1	0.2	
Planting Reference Site									
Mean	Aug. 19 2010	**43.3**	**	**2.2**	**38.8**	**0.7**	**15.5**	**0.9**	A few slipper shells
St Dev		13.6		4.7	9.4	1.6	12.0	1.0	
Planting Site #1	(22 x 30 m)								
Mean	Oct. 13 2010	**0.3**	**3.7**	**23.8**	**45.6**	**0.0**	**26.7**	**0.0**	Many slipper shells
St Dev		0.6	4.6	12.0	27.9	0.0	28.9	0.0	*Lyngbya* still dominant
Planting Reference Site									
Mean	Oct. 13 2010	**59.0**	**2.6**	**0.7**	**22.3**	**0.3**	**15.5**	**0.7**	A few slipper shells
St Dev		15.1	2.5	1.6	10.4	1.1	12.0	1.0	
Planting Site #1	(22 x 30 m)								
Mean	Aug. 17 2011	**0.4**	**0.6**	**31.5**	**1.8**	**20.6**	**45.2**	**0.0**	Many slipper shells
St Dev		0.9	0.8	20.1	3.7	22.9	27.8	0.0	More algae in deeper part of bed
Planting Reference Site									
Mean	Aug. 17 2011	**54.6**	**11.5**	**0.0**	**1.3**	**11.5**	**21.2**	**0.6**	Slipper shells common
St Dev		19.0	9.3	0.0	4.6	8.8	20.9	0.7	

*Each mean represents the average of 20 randomly located replicate quadrats of $1m^2$ in size
**Cover of dead eelgrass was included with the estimates of live cover for this date

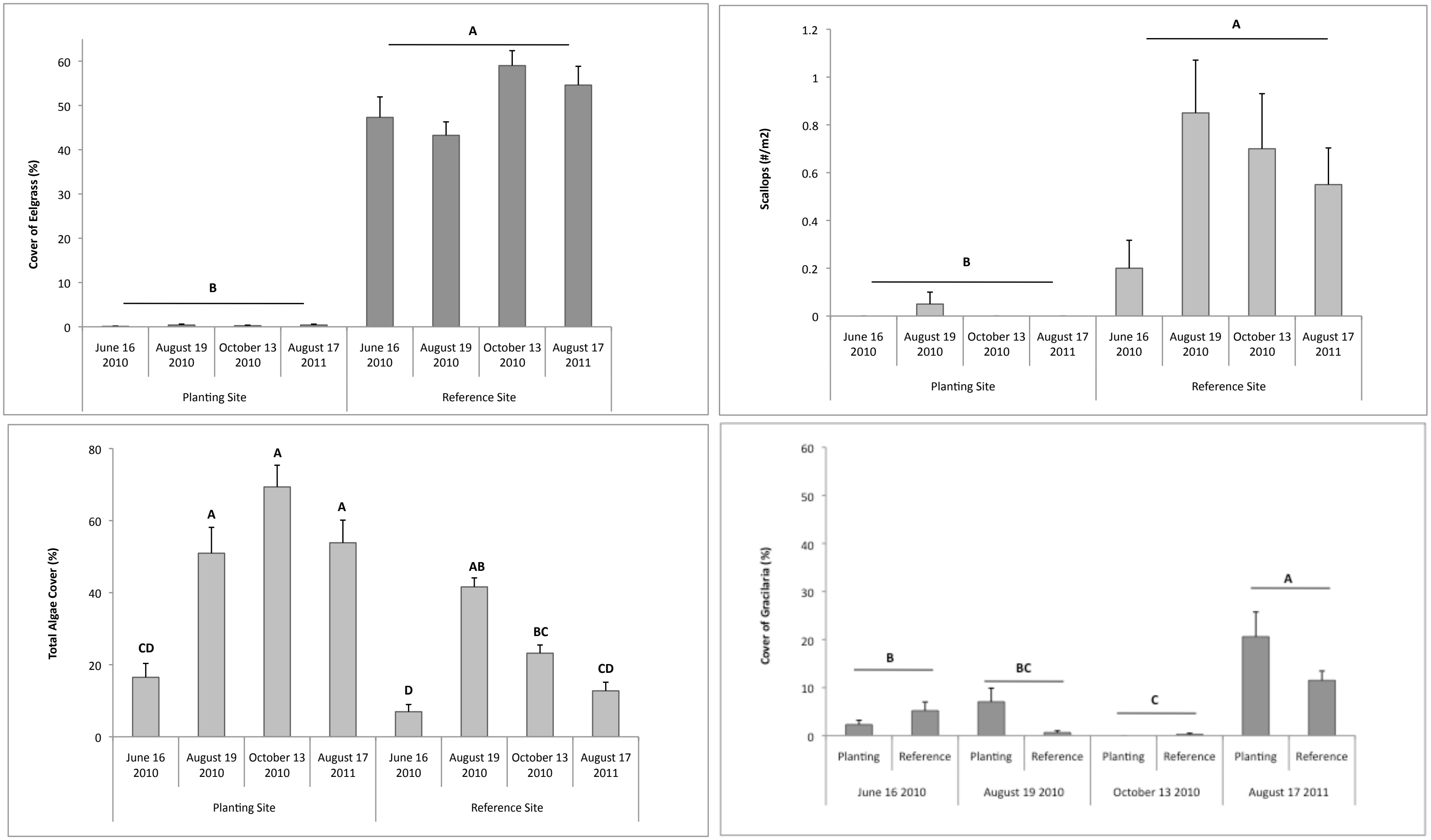

Figure 9. Cover of eelgrass and algae and scallop densities in planted and reference areas before (June 2010) and two months (August 2010), four months (October, 2010) and thirteen months after planting (August 2011). Bars with different letters indicate significantly different means following a two –way ANOVA and Tukey's post hoc test.

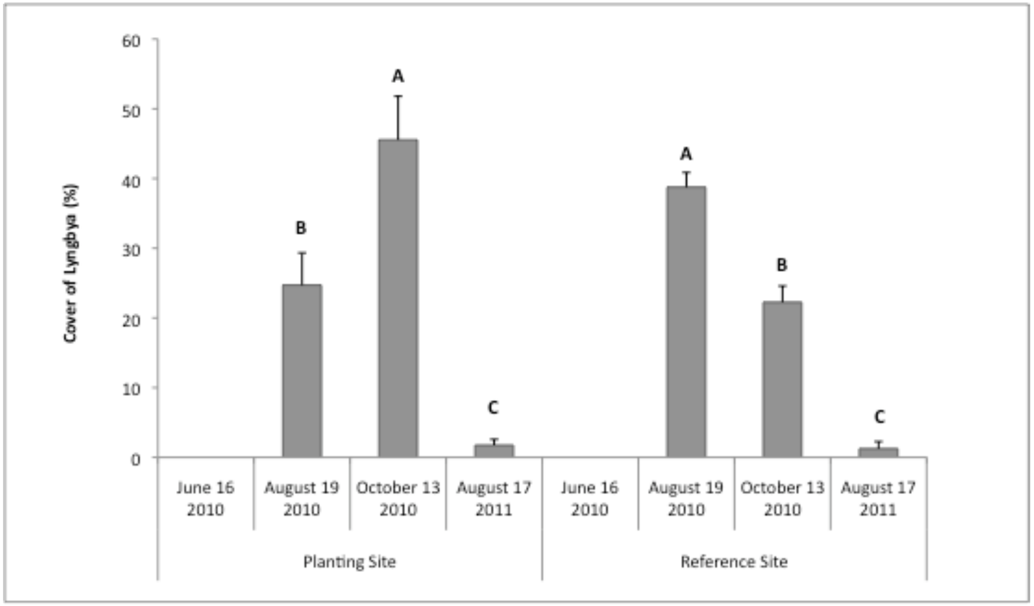

Figure 10. Cover of different alga genera in planted and reference areas before (June 2010) and two months (August 2010), four months (October, 2010) and thirteen months after planting (August 2011). In June, we noted 'other algae' besides *Codium* and these were primarily *Gracilaria*. Bars with different letters indicate significantly different means following a two–way ANOVA and Tukey's post hoc test.

Discussion

An experimental eelgrass planting was conducted in June and July, 2010 in Nantucket Harbor following a site selection process that included field surveys, light measurements and observations of bottom type, bathymetry and water current. Areas of recent eelgrass loss were examined, but most of the sites appeared to have abundant eelgrass seedlings and so were eliminated from consideration. Light is often limiting for eelgrass (Dennison et al. 1993), so Planting Site 1, which had the most light (18.1% of ambient), was selected as the planting site.

In order to provide plants for the experimental transplanting, over 6,000 eelgrass shoots were selectively harvested from a 140 m^2 area within an extensive bed in Nantucket Harbor, located just west of the First Point of Coatue, near the inlet to Nantucket Sound. Four weeks following the final collection, impacts from our collection were shown by a 24% decline in shoot density, but live eelgrass cover did not decline significantly. After 12 weeks, no effects of collecting could be measured at the donor site for shoot density or cover, a result supported in the literature by others using donor beds for eelgrass restoration in our region (Davis and Short 1997, Leschen et al. 2007). We returned to the site after 13 months and again found no collection effect.

Two planting techniques were used, divided approximately equally across the site, using metal wire frames (western half) and PVC pipe frames with jute (eastern half). Overall, 120 frames were deployed with 6,000 plants over an area of 7,200 square feet, about 70% of the 10,000 square foot area proposed. Plants had difficulty establishing, with intense phytoplankton and macroalgal blooms shading the transplants the initial three months following transplanting. After the first growing season, few of the 6,000 plants had survived. Many of the frames had only one or two surviving plants, but several had a half-dozen or more shoots that became established. The poor survival of the plants prevented us from using statistical methods for comparing success between the two frame types (jute versus metal) but no differences were noted.

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The significance of the macroalgae was documented through estimates of percentage cover, whereas light measurements showed the decline in water clarity from phytoplankton blooms to less than 10% ambient. Our pre-restoration monitoring indicated light intensity was sufficient at this site to support eelgrass transplants. However, by mid-summer light levels declined and macroalgae began to foul the plants, creating poor conditions for eelgrass establishment and resulting in high mortality. In August, *Codium* increased to 19% cover, and *Gracilaria* grew to 7% cover, but the worst impact was from a filamentous-forming blue-green bacterium of the genus *Lyngbya*.

Lyngbya appears as dark green strands growing on the bottom and attached to seagrass. It is known locally as witch's hair (personal communication with Chris Fuller), and can easily be misidentified as a macroalgae. When we returned in August following planting, *Lyngbya* covered 25% of the planting area, increasing to 46% cover in October and forming complete mats over the planted eelgrass, smothering it. *Lyngbya* blooms appear to be infrequent in marine environments, with a much-studied bloom of *Lyngbya majuscula* in Moreton Bay, Australia that smothered seagrass beds and posed human health risks and tourism impacts (Watkinson et al. 2005). Florida has harbored *Lyngbya* blooms on both coasts, affecting seagrass beds in Sanibel and Captiva Island embayments (Paerl et al. 2008), and covering coral reefs along the southeastern coast (Paul et al. 2005).

The following summer, *Lyngbya* was present, but we did not observe the thick coverings on our planted eelgrass or on eelgrass at the reference meadow. Instead we found over 20% cover of *Gracilaria* in August 2011 at the planting site (Table 5b). This seaweed presents a different challenge since it moves along the bottom and fouls anything fixed, such as rooted seagrass. A variety of studies have shown *Gracilaria* blooms fueled by discharge of groundwater nutrients compete with eelgrass for light and is associated with eelgrass declines in the region (Short and Burdick 1996, Hauxwell et al. 2003, Short et al. 2006, Fox et al. 2008).

In the case of Nantucket Harbor, it appears that a combination of macroalgae (*Codium* and *Gracilaria*), blue-green bacteria (*Lyngbya*) and phytoplankton blooms have severely impacted eelgrass transplants at Site 1 and may be responsible for general eelgrass declines in the Harbor. The rapid blooms in macroalgae and phytoplankton are likely the result of nutrient additions to the Harbor through groundwater. Although no specific change analysis was made for Nantucket Harbor in a recent report by Costello and Kenworthy (2010), they found a general decline in eelgrass cover throughout Massachusetts bays, except where nutrient loading was decreased. Sites in Boston Harbor and Gloucester expanded in eelgrass coverage (Costello and Kenworthy 2010), and in Boston, planted eelgrass restorations were successful (Leschen et al. 2010).

In March 2010, we made observations of eelgrass seedlings throughout the Harbor, including many areas thought not to contain eelgrass (based on aerial photographs, MASS GIS eelgrass distributions, and local knowledge). Combined with our planting and monitoring results, our observations suggest that reestablishment of eelgrass beds in Nantucket Harbor is not limited by the distribution of seedlings, but by shading from phytoplankton and macroalgal blooms that resulted in levels of light too low to support eelgrass establishment during the summer months in 2010. Further trials to establish eelgrass could focus on planting early in the season (mid-spring) ahead of algal blooms. However over the long term, eelgrass may continue to decline in the Harbor from phytoplankton and macroalgal competitors that bloom in response to nutrient enrichment. To prevent further losses, we recommend: 1) prevention of physical damage to beds from development and marine activities such as losses from mooring chains; and 2) assessment of nutrients entering the Harbor through groundwater and other sources followed by development of a long-term program to reduce nutrient loads to the Harbor.

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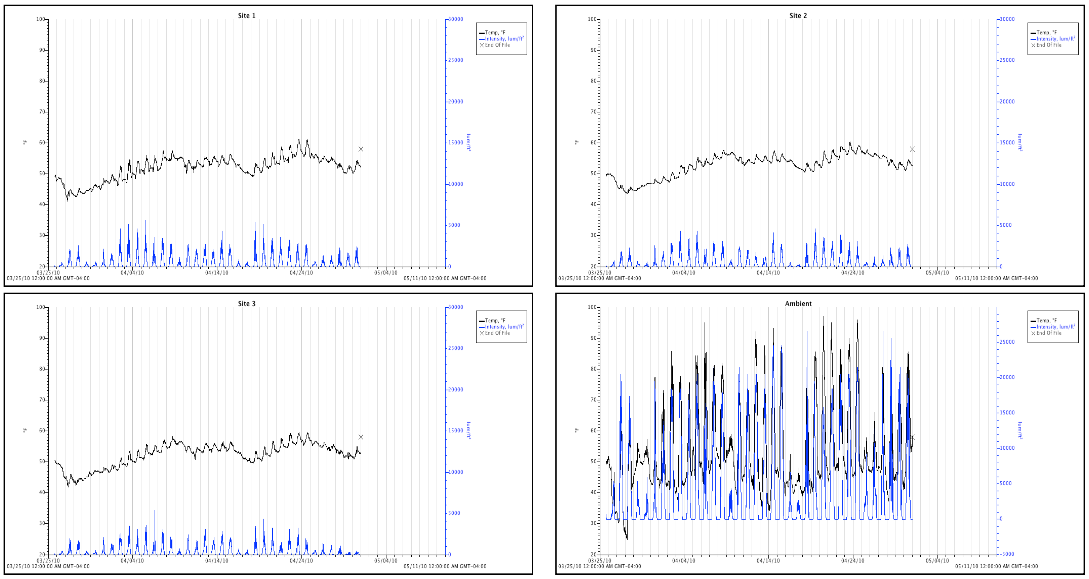
Appendix 1. Raw light and temperature data from Hobo™ light meters and loggers from a) April; and b) June/July deployments in 2010. Note that ambient daytime temperatures are high, due to being in direct sunlight.

a) April 2010



b) June-July 2010