Draft Final Report

Shading Impacts of Small Docks and Piers on Salt Marsh Vegetation in Massachusetts Estuaries

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Introduction

The proliferation of small docks and piers in coastal states has led to concerns about cumulative environmental impacts [1]. Potential impacts to coastal and estuarine ecosystems include direct loss of habitat to support structures, release of heavy metals from pressure treated wood [2], turbidity from float grounding and prop dredging [3], and shading of underlying intertidal and subtidal vegetation [4,5]. In New England, this latter effect relates mainly to eelgrass (*Zostera marina*) in subtidal habitat and salt marsh vegetation (mainly smooth cordgrass (*Spartina alterniflora*) and salt marsh hay (*Spartina patens*)) in intertidal habitat. Eelgrass and salt marsh vegetation both provide a variety of ecosystem services, including habitat and energy sources for many fish and invertebrate species [6,7,8,9,10]. Burdick and Short (1999) [4] quantified dock shading impacts to eelgrass in a Massachusetts estuary (Waquoit Bay) and provided recommendations on dock height requirements to minimize such impacts to this important habitat. Dock shading effects on salt marsh vegetation have also been studied previously [5,11], but not in a manner that provided specific guidelines on dock height.

Previous studies have shown reductions in marsh density under docks relative to unshaded areas, presumably due to light limitation [5,11,12,13]. These previous studies were largely focused on more southern coastal areas from the mid-Atlantic to southeast U.S. In Georgia and South Carolina, marsh stem density was shown to be significantly lower under docks than in adjacent unshaded areas [5,12]. Similarly, a recent field study of docks in Maryland [11] found vegetation effects under docks and found that this effect was significantly correlated with dock width, but not with other measured variables (height, deck spacing, orientation). A historical study conducted in Connecticut [13] also found a stem density effect under docks and found dock height to be the only significant explanatory variable.

The New England District of the Army Corps of Engineers recommends a 1:1 height to width ratio for docks overlying marsh [3], although a specific height requirement is not currently mandated under the Wetlands Protection Act. While previous studies [5,11,12,13] have demonstrated a shading effect through opportunistic sampling of existing docks, no one has tested whether a 1:1 ratio will effectively limit shading impacts. Since a variety of dock characteristics could affect marsh vegetation (e.g., dock orientation, height, width, length, deck spacing), existing study designs have not allowed for more detailed assessments of individual variables that would be needed for managers to recommend best management practices. Consequently, new docks being built over salt marsh that adhere to permitting agency recommendations could still be altering salt marsh. Given the proliferation of docks along the Massachusetts coast, cumulative impacts to marsh vegetation could be substantial. For example, the Division of Marine Fisheries (*MarineFisheries*) environmental review program responded to over 70 individual dock and pier permit applications over salt marsh in the south coast region of Massachusetts (Hull to Rhode Island border) in 2011 and 2012. In all cases, a 1:1 height to width ratio was recommended as the main modification to minimize impacts to salt marsh.

Funding for this project was awarded to the Massachusetts Division of Marine Fisheries (*MarineFisheries*) by the Mass Bays Program (MBP) to provide 1) quantitative measurements of dock shading impacts on salt marsh in relation to dock height 2) cumulative impact assessments for a representative coastal town or estuarine system, and 3) a threshold height recommendation to minimize dock shading impacts for coastal resource agencies to use in permitting activities. Objectives 1) and 3) were addressed through the installation of a matrix of experimental docks set at varying heights above the marsh platform and subsequent monitoring of underlying marsh vegetation characteristics. Objective 2) was addressed with a Google Earth survey of existing dock-marsh interactions in the North and South River system of southern Massachusetts.

Methods

Dock Matrix Study

Study Site

The dock matrix study was conducted at the English Salt Marsh on the North and South River system in Marshfield, Massachusetts (Fig. 1). The English Marsh is a 179 acre parcel of salt marsh habitat managed by the Massachusetts Division of Fisheries and Wildlife. The marsh site is bisected by a dirt and gravel road that connects the mainland to a series of islands terminating at Trouants Island. The islands are bordered by higher elevation marsh dominated by *Spartina patens*, with patches of *Distichlis spicata* also present. The remaining area of the English Marsh is low elevation with *Spartina alterniflora* as the dominant species.

Figure 1. Map of the Dock Matrix site in Marshfield, Massachusetts. The Dock Matrix was installed to the west of Trouants Island off of Macombers Way (within the Locus box).

A total of 24 docks were installed over the marsh platform from April 17 to 24, 2013 (Table 1). Half of the docks were installed over the *Spartina alterniflora*-dominated low marsh and the remaining half were installed over the *Spartina patens*-dominated high marsh. Docks were arranged according to a randomized complete block design (RCBD) with each block containing a single two, four, and six foot dock as well as a control plot of the same dimensions that contained no dock. For both high and low marsh locations, two blocks were located on each

side of the dividing road, with A3, A4, P3, and P4 set to the north of the road and A1, A2, P1, and P2 set to the south side (Fig. 2).

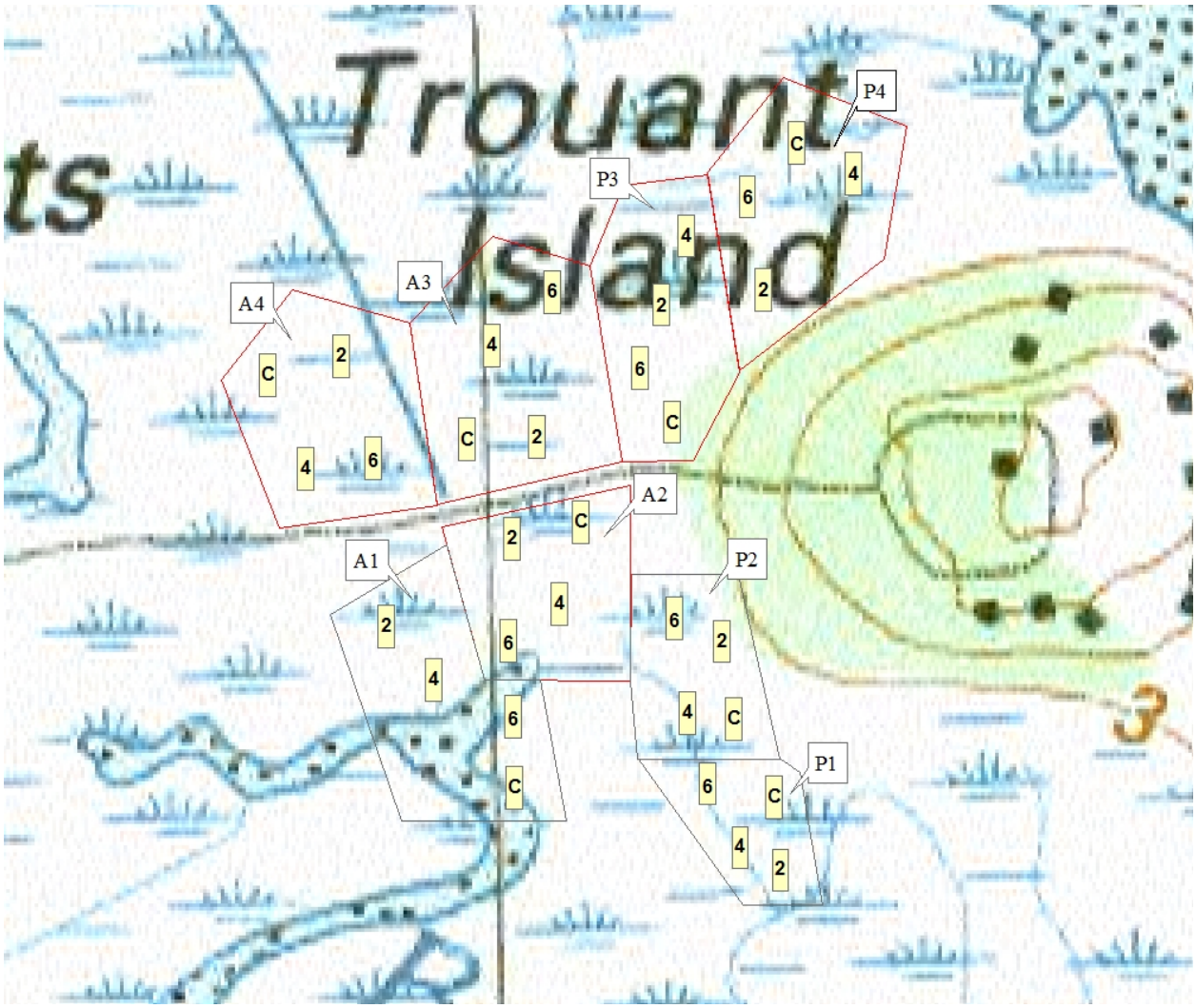

Figure 2. Map of the general Dock Matrix array layout following a randomized complete block design. The “P” high marsh blocks (P1, P2, P3, P4) were installed adjacent to Trouants Island while the “A” low marsh blocks (A1, A2, A3, A4) were installed in the lower elevation marsh to the west.

Within each block, docks were placed in a random sequence with 25 foot separation among docks. Docks were all installed with a north-south orientation. Small sections of lobster trap coated wire mesh were placed under each dock support to minimize subsidence into the marsh platform. Docks were further stabilized and secured through an anchoring system that consisted of four lengths of rope connecting the dock corners to the marsh platform at an approximate 45 degree angle to 18 inch wooden stakes that were inserted in the platform surface (Fig. 3).

Figure 3. North facing view of the Dock Matrix field site in Marshfield, Massachusetts. The foreground contains a two foot dock (P12) set over *Spartina patens* in the high marsh. The corresponding four (P14) and six (P16) foot docks are visible to the left and behind the two foot dock.

All docks were twelve feet long and four feet wide. Decking consisted of six inch wide, 5/4 inch thick cedar planking that was set with ¾ inch spacing between planks. Four inch by four inch pine supports were attached at the four dock corners, and six inch wide cross bracings were installed at the two dock ends for additional structural support. A 5/4 inch X six inch cedar board was installed as a horizontal stringer along the outer length of both sides of each dock. Supports were set to hold the docks at heights of two, four, and six feet measured from the ground to the base of the support stringers, resulting in decking heights above ground of approximately 2.5, 4.5, and 6.5 feet.

HOBO light and temperature loggers were installed under the center of a subset of twelve dock and control sites and programmed to collect measurements at two-minute intervals. The loggers were mounted to wooden stakes set one foot above the marsh platform to minimize shading effects from vegetation (Fig. 4). Four loggers were placed under the "P2" array for the duration of the study. The remaining loggers were rotated among the other arrays on weekly

or biweekly intervals throughout the study to allow for temperature and light level comparisons among replicates (e.g., two foot docks at P2 and P1).

Figure 4. View of a HOBO temperature/light logger installed under a two foot dock. The logger is mounted to a wooden stake set 12" above the marsh platform and installed under the center of the dock.

Field Sampling and Surveys

Visual surveys and presence-absence surveys at fixed quadrat stations were performed three times during the growing season. Visual surveys consisted of approximate estimates of percent cover of each vegetation type using the Braun-Blanquet cover-abundance scale [14]. Following a visual survey of the entire area under each dock and control site, each species present was assigned a percent cover estimate of <1-5%, 6-25%, 26-50%, 51-75%, or 76-100%. A complementary non-destructive quadrat survey was also performed during the same time intervals. Vegetation diversity and abundance were quantified for each station by placing three adjacent 1/4 m^2 quadrats at the center region of each station and noting presence/absence information for 64 sub-quadrats within this region (Table 1).

Clip plot samples were collected at the end of the growing season (mid-September) as the main means of comparing marsh vegetation among dock height treatments and between docks and control plots. Prior to sampling the dock sites, test clip plot samples were collected (July 2013) from high and low marsh areas near the dock matrix. A total of 16 ¼ m^2 quadrat clip plots were taken from random locations within each marsh zone area. Each ¼ m^2 sample was sub-divided into four separate 1/16 m^2 samples. One 1/16 m^2 sample was randomly selected from each larger quadrat to represent this smaller quadrat size. Each sample was then separated between live and dead stems. Live stems were divided by vegetation type and each individual stem was measured and counted to provide median stem length and stem number per quadrat.

For the September clip plot sampling, eight foot by two foot grids were created for each replicate site. For dock sites, this grid was centered under the dock such that sampling would occur from an area separated from the ends of the dock by at least two feet and from the edge of the dock by at least one foot. This area was selected to avoid any potential edge effects. This twelve by two foot region was then divided into a numbered grid set at a 1/16 m^2 scale. Eight sampling locations from within each replicate site were determined using a random number generator. This system ensured randomization of sampling locations and also will allow new areas to be sampled in the following field season. For the P3 and P4 high marsh blocks, the marsh surface was hummocky and contained depressions with no vegetation present. Since these depressions lacked vegetation uniformly across sites, they were not included in clip plot sampling. Instead, when random number assignments landed within a depression, a sample was taken from the nearest bordering quadrat to the right of the depression. For each sample, all of the aboveground biomass within a quadrat was clipped at the sediment surface. Only stems originating within the quadrat surface were sampled. Overhanging vegetation with stems outside of the quadrat was not sampled. Samples were labeled, bagged, and transferred to frozen storage until later analysis.

Relative elevation estimates were made for all dock locations on September 20′ 2013 during a full moon high tide using tide sticks [15]. This method consisted of coating peeled *Phragmites* stems with a mixture of non-toxic water soluble glue and red dye. The coated stems were then placed in the marsh platform at the center of each dock site during low tide. When the tide rose over the stems, the red coating dissolved up to the high water mark, leaving a clear indication of tidal elevation (Fig. 5). After the tide had risen and fallen, elevation was measured at each site as the vertical distance from the marsh platform to the “red line” separating the dissolved and existing glue/dye sections of each stick. These results provided relative elevation data across stations.

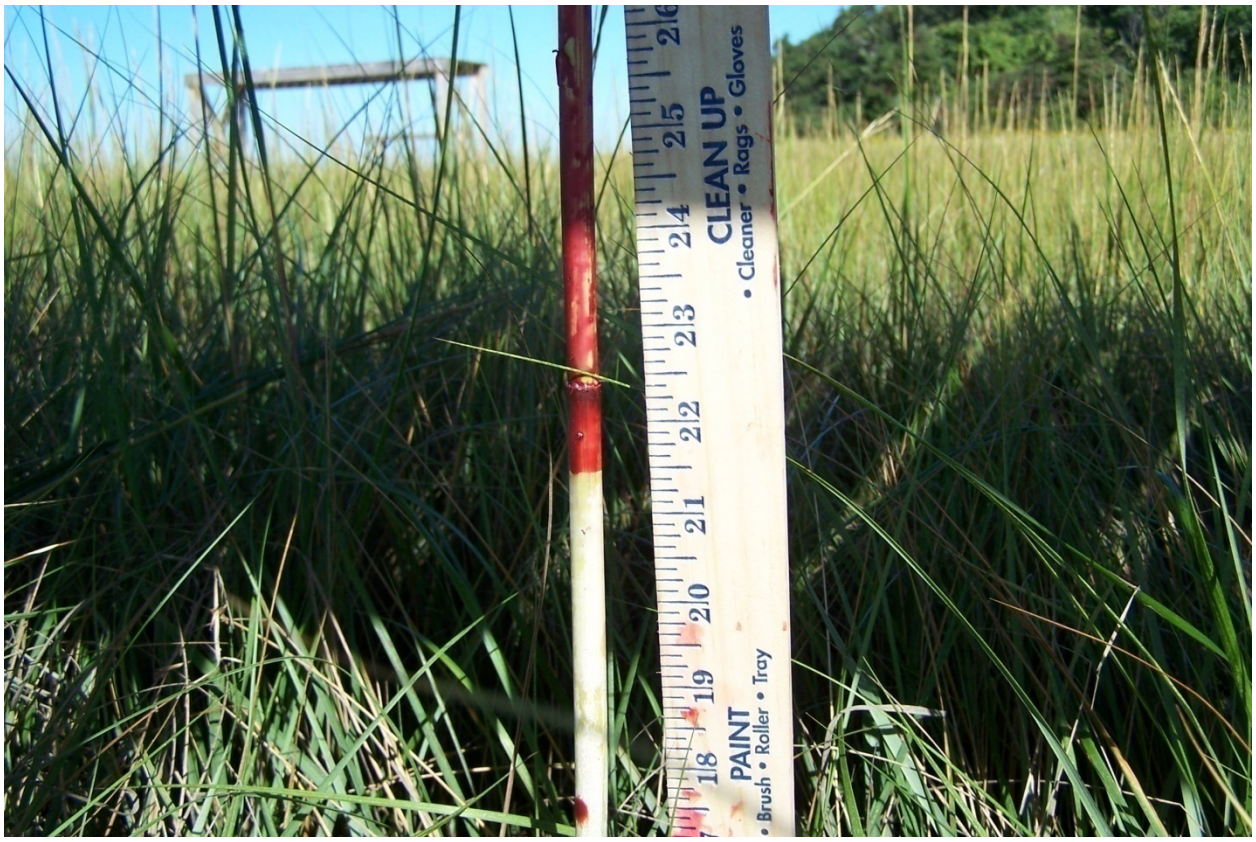

Figure 5. Example of a tide stick after rise and fall of high tide. The maximum water height is clearly marked by the end of the red dye coating.

All dock structures were removed from the marsh during the first week of October. Small metal stakes were inserted into the marsh platform at the southern corners of each site to mark the exact locations. Docks will be reassembled and installed in the marsh in spring 2014 in these exact same locations to shade the same plots for a second field season.

Lab Analyses

Clip plot samples were later thawed, and rinsed to remove detritus at the University of Massachusetts School for Marine Science and Technology (SMAST). For each sample, dead stems were removed and set aside for dry weight measurements. Live stems were counted and separated by species, and each stem was measured for total length (± 0.1 mm) using an electronic measuring board linked to a lap top computer (Fig. 6).

Figure 6. Electronic measuring board and laptop used for stem measurements and counts. Individual stems were measured to the nearest 0.1 mm and values were automatically uploaded to a text file.

Measured stems were then bundled together with bundles separated between dead and live stems and live stems further sub-divided by species (Fig. 7).

Figure 7. An example (P22) of a full set of clip plot samples post-measuring and pre-drying. Each bundle represents an individual clip plot sub-sample and includes separate bundles of dead and live stem material.

Stems (both live and dead) were then wrapped in tin foil and dried in a drying oven set at 50°C for at least 48 hours. All dead stems and live stems separated by species were then weighed (± 0.01 g) separately (Fig. 8).

Figure 8. An example of a dried sub-sample being weighed to compare aboveground biomass.

All dried, live *Spartina alterniflora* sub-samples from the low marsh sites (A1-A14) for each individual plot were pooled and homogenized using a blender. For the high marsh sites (P1-P4), all live *Spartina patens* were pooled for each plot and homogenized. An aliquot of the dried homogenized material (~ 4-5 mg) from each dock station was then packed into tin capsules and analyzed for % carbon (C) and % nitrogen (N) using a CHN elemental analyzer at the Ecosystems Center of the Marine Biological Laboratory (MBL) in Woods Hole, Massachusetts. Sample % carbon and nitrogen were calculated relative to an aspartic acid standard. A full six-sample standard curve of aspartic acid was run at the start of the analysis with weights ranging from approximately 0.25 mg to 6 mg. A check standard of aspartic acid and a blank were also run after each set of ten marsh samples. A duplicate marsh sample was also included after each set of ten samples for a total of four duplicates. The standard curve had an r^2 value of 0.9999 for both % carbon and % nitrogen. The mean standard deviation of duplicate samples for % carbon and nitrogen was 0.58% C and 0.07% N, respectively.

Statistical Analyses

To determine appropriate sample sizes and scales for the end-of-season clip plot survey, a bootstrapping analysis was performed on the July clip plot samples in which increasing sample sizes (n=2 to n=16) were randomly sampled 1,000 times from each dataset (1/4 and 1/16 m^2). These data were then used to generate mean and 95 % confidence intervals for each metric (median stem height, stem density, stem dry weight) and for each sample size (Fig. 9 and 10).

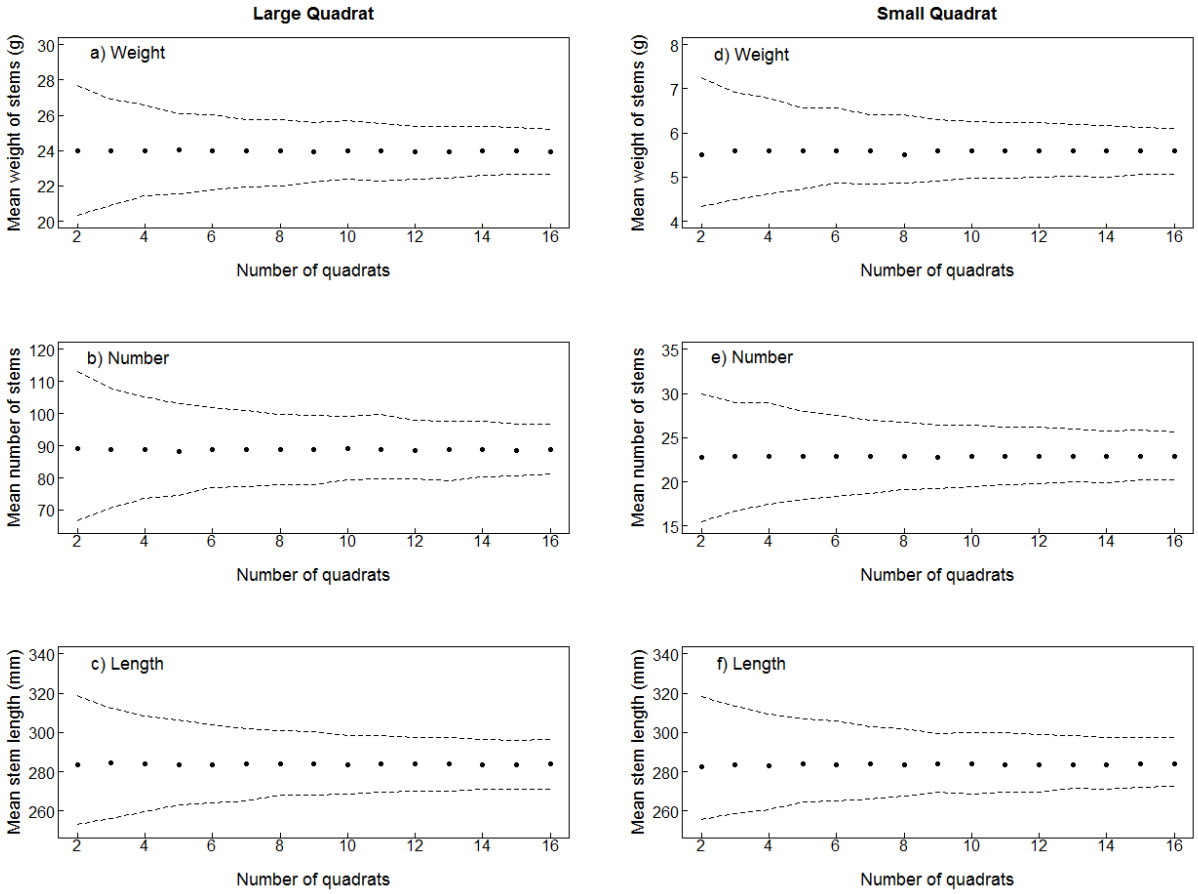

Figure 9. Test plot data for *Spartina alterniflora* collected on July 11, 2013. Sub-plots show estimates of mean stem weight (a,d), number (b,e), and length (c,f) based on bootstrapping of sixteen large (1/4 m^2) and small (1/16 m^2) quadrat test plots. Points represent mean estimates while dotted lines reflect the upper and lower 95% confidence intervals for estimates for sample sizes of 2-16.

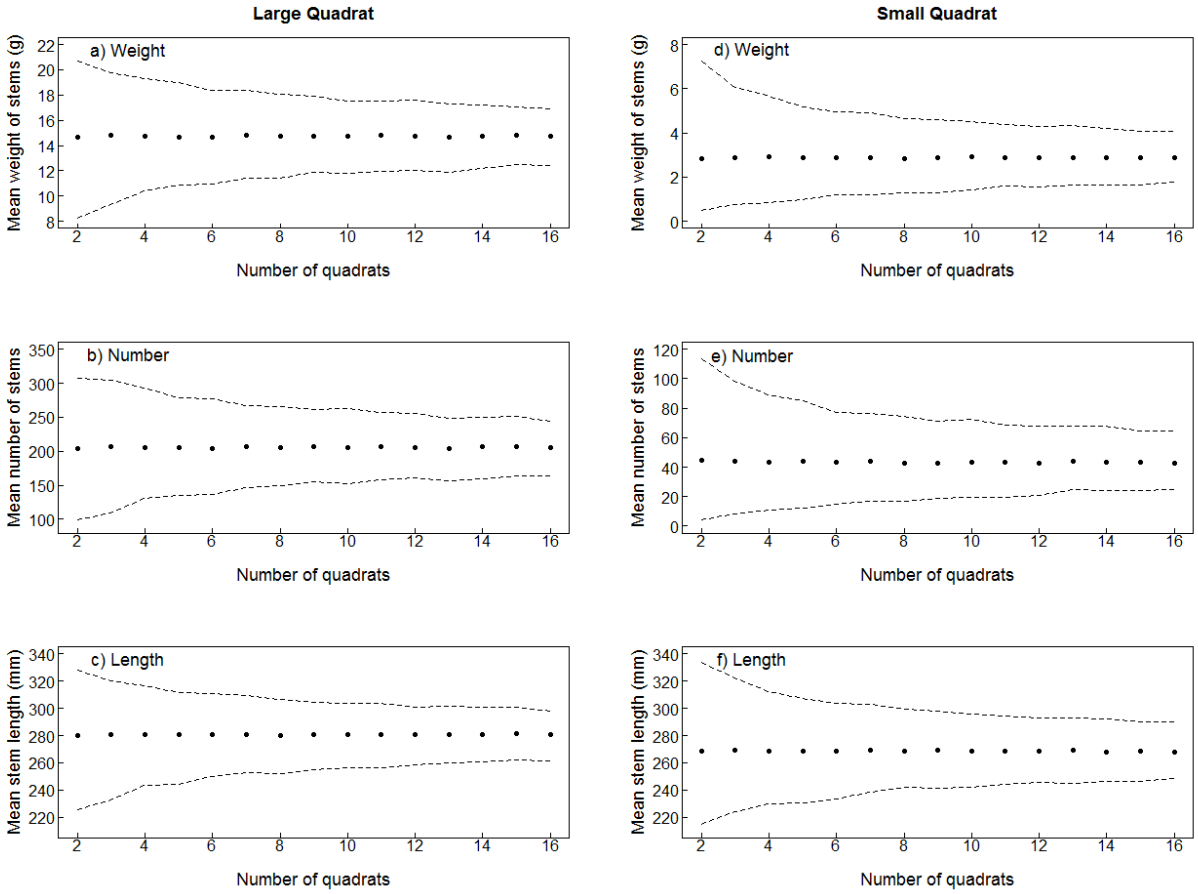

Figure 10. Test plot data for *Spartina patens* collected on July 11, 2013. Sub-plots show estimates of mean stem weight (a,d), number (b,e), and length (c,f) based on bootstrapping of sixteen large (1/4 m^2) and small (1/16 m^2) quadrat test plots. Points represent mean estimates while dotted lines reflect the upper and lower 95% confidence intervals for estimates for sample sizes of 2-16.

For the end-of-season survey, median stem height, stem density, and live stem dry weight were compared among dock treatments using a linear mixed effects model. Each of these three response variables was assessed using block and treatment (control, 2', 4', and 6' docks) as fixed effects in the model and sub-sample as a random effect. Significant effects were then further assessed using a post-hoc Tukey's Honest Significant Difference (HSD) test. These analyses were performed in R using the "nlme" and "multcomp" packages, respectively [16]. Since % carbon, % nitrogen, and C:N ratios were based on pooled samples rather than individual sub-samples, statistical comparisons of these characteristics were based on an analysis of variance (ANOVA) for a randomized complete block design. Post-hoc comparisons were made using Tukey's HSD test.

Table 1. 2013 Field Sampling Activity Summary

Activity	Date(s)
Dock Installation	April 17-24
Temp/Light Logger Monitoring	May 2-October 3
Visual and Presence-Absence Survey	June 27, August 2 and 9, September 13
Test Clip Plot Sampling	July 11
Matrix Clip Plot Sampling	September 4-6
Elevation Survey	September 20
Dock Removal	October 3, 4, 7

Cumulative Impact Survey

DEP permit files and Google Earth imagery were used to quantify the area of impact of docks and piers on salt marsh in the North and South River system in which the Dock Matrix field site was located. Using measuring tools in Google Earth, polygon outlines were made over dock sections overlying salt marsh throughout the North and South River system. These data were then used to quantify dock characteristics over salt marsh. Specifically, dock width and length for the sections over salt marsh were measured. These data were then used to generate an estimate of the total area of marsh shading for this estuarine system. Using GIS, the total marsh area was quantified using the DEP salt marsh habitat layer. All polygons coded "salt marsh" were selected in the 2009 DEP Wetlands Polygon layer for the North-South River salt marsh. The area of all selected polygons was then summed to generate an estimate of total marsh area for this system. The wetlands are interpreted from 1:12,000 scale, stereo color-infrared (CIR) photography by staff at the University of Massachusetts – Amherst. The photography was captured in 1990, 1991, 1992, 1993, 1999, and 2000 and verified in the field by DEP. Metadata are available at: http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/depwetlands112000.html. The total dock shading area was then combined with the total area of marsh to estimate the portion of this habitat that is currently impacted by dock structures.

Results

Dock Matrix Study

Light and Temperature Data

For the complete field season (May-October), control plots had higher average temperatures and light availability than the dock treatments. For block P2, which had temperature and light monitoring throughout the study, average temperature increased with dock height (Fig. 11; Table 2).

Table 2 Average light and temperature data for block P2. This block was monitored throughout the field season (May-October) for light and temperature.

Treatment	Average Temperature (˚C)	Average Light (lux)	Percent of Control Light (%)
Two Foot Dock (P22)	20.7	9,007	21
Four Foot Dock (P24)	21.7	24,336	56
Six Foot Dock (P26)	22.6	37,548	86
Control (P2C)	22.7	43,807	100

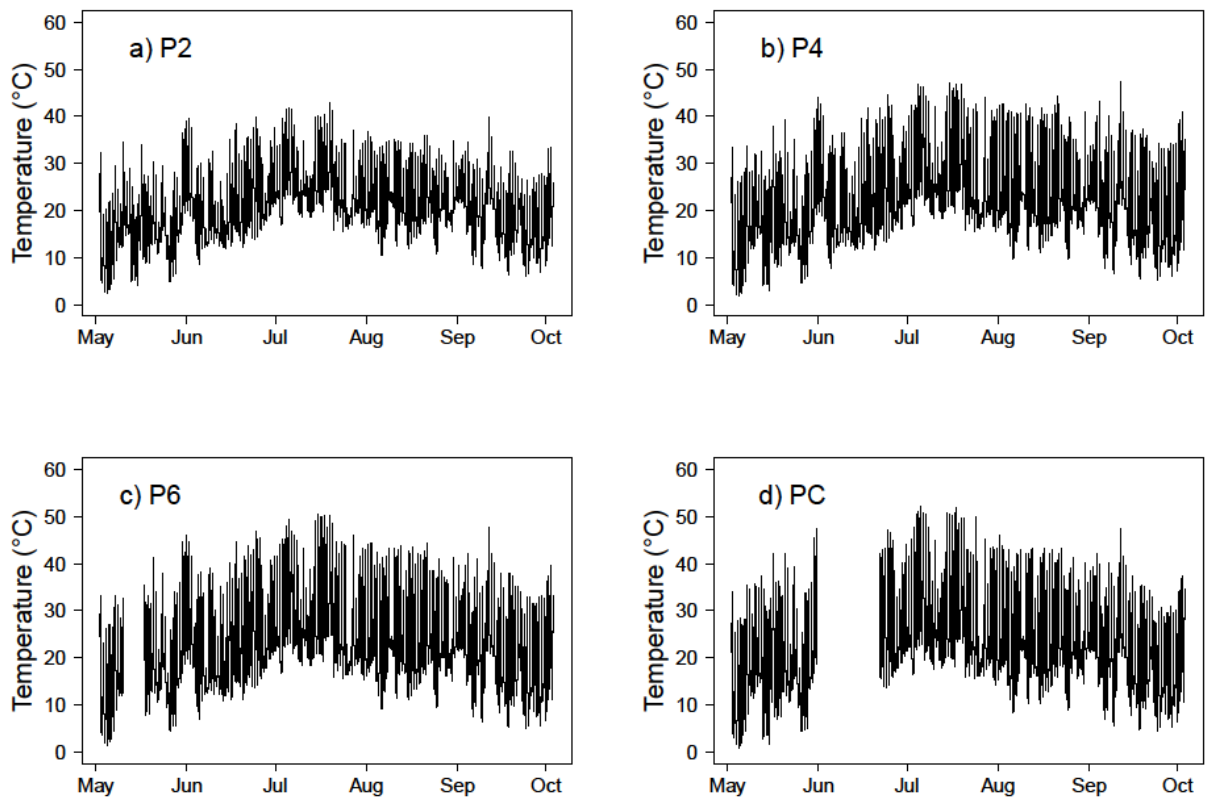

Figure 11. Temperature data for the "P2" array collected at two-minute intervals from May to October, 2013. Data are presented for a) two foot dock, b) four foot dock, c) six foot dock, and d) control plot. Gaps in data (e.g., early June PC) reflect periods of logger error. Temperature decreases overall from the control plot (PC) to docks of decreasing height (P6>P4>P2).

Average light levels increased with dock height, with two foot, four foot, and six foot docks having 21%, 56%, and 86% of the light observed at the control site, respectively (Table 2; Fig. 12). Two foot docks were distinct from the taller docks and control plots in that they received only short pulses of full light (Fig. 12a).

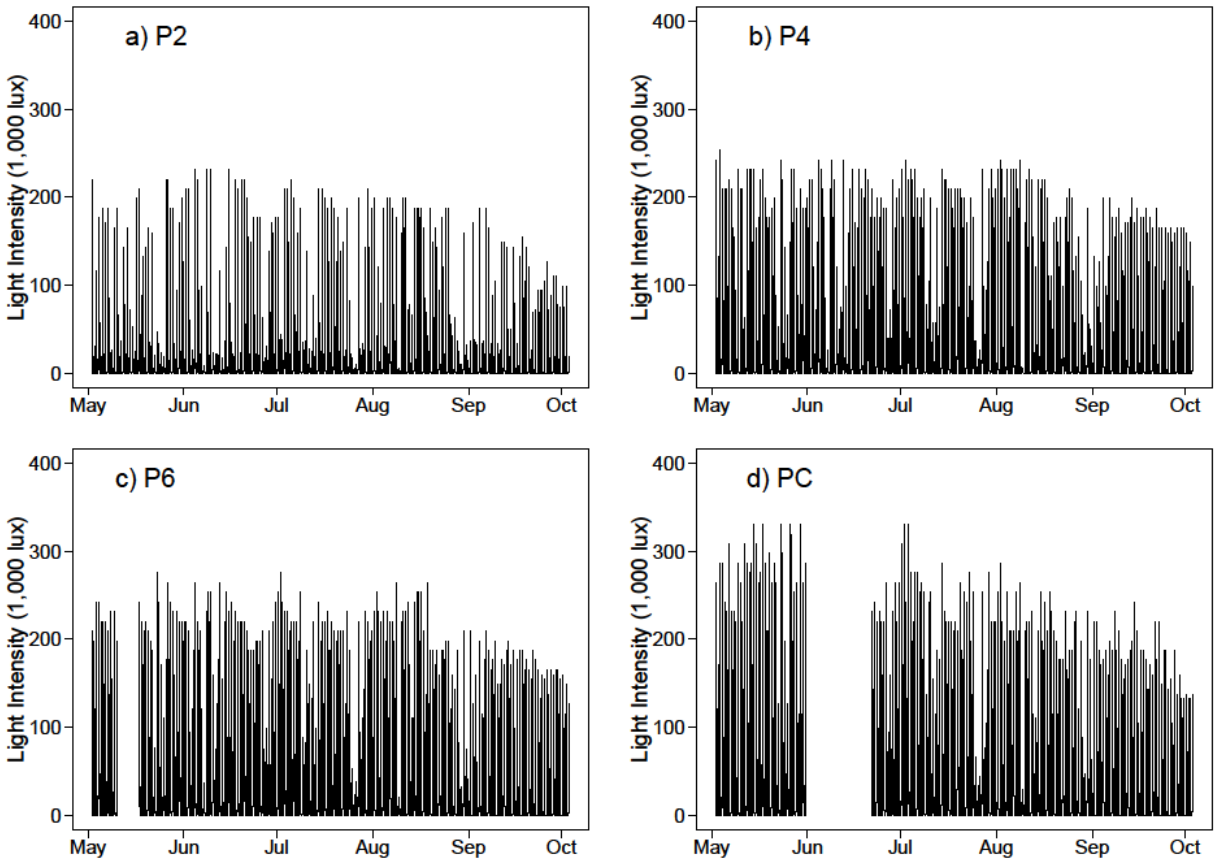

Figure 12. Light data across the duration of the field study for block "P2". Gaps in data (e.g., early June PC) reflect periods of logger error. Light levels decrease overall from the control plot (PC) to docks of decreasing height (P6>P4>P2).

Visual and Fixed Quadrat Surveys

All low marsh ("A Block") sites were mainly composed of *Spartina alterniflora* while high marsh ("P Block") sites mostly contained *Spartina patens* (Fig. 13). Among A Block sites, the percentage of empty space increased monthly under two foot docks (Fig. 13 a,c,e). Among P Block sites, proportions of vegetation and empty space were relatively constant across sampling months, and *Distichlis spicata* was the main secondary vegetation type for P2, P6, and PC but not P4 (Fig. 13 b,d,f). This pattern is not due to any apparent shading effect, but rather to random placement of docks within the P2 block. The P2 section contained patches of *D. spicata* at the P22, P26, and control (P2C) locations but not at the P24 location. For sites containing *D. spicata*, there were no apparent changes in percent cover for this species across months.

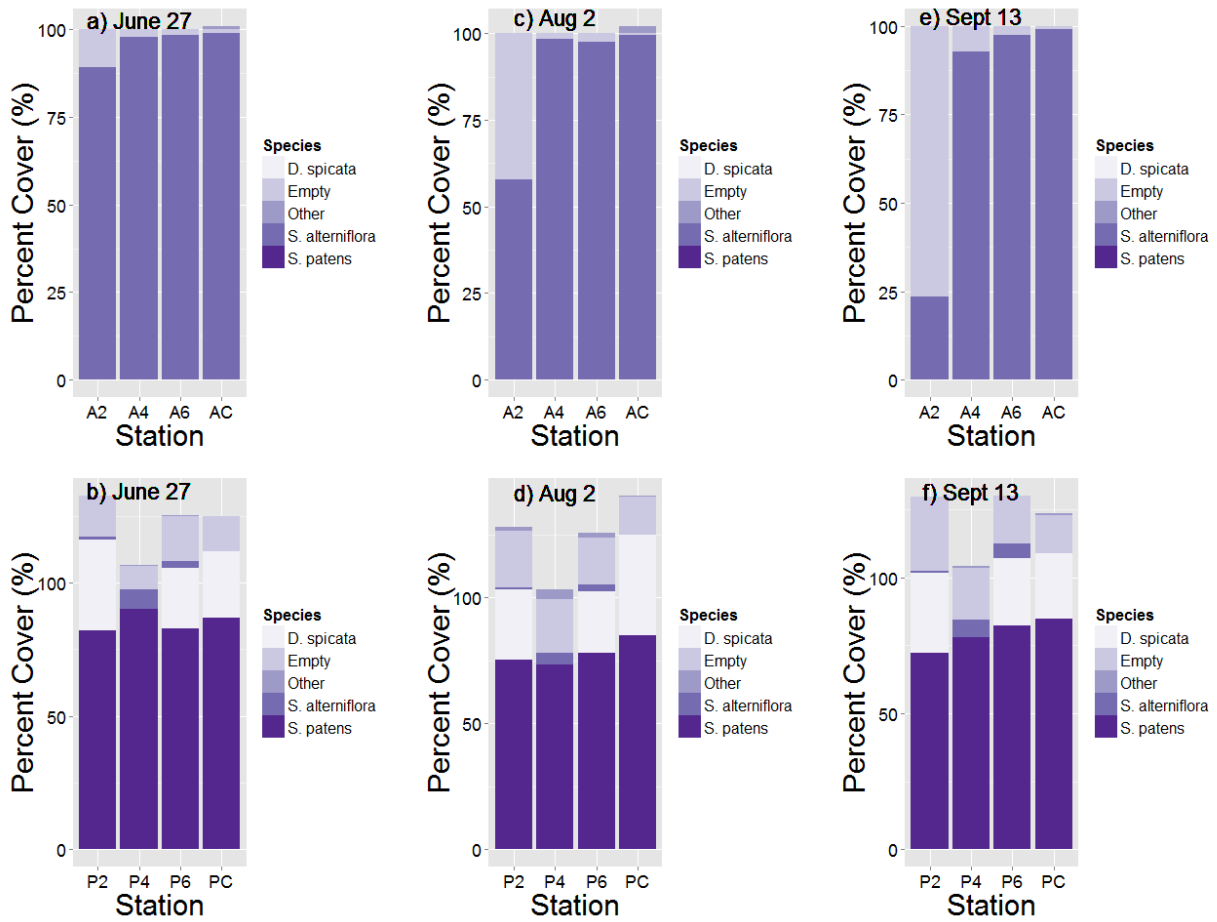

Figure 13. Percent cover estimates for surveys performed on a,b) June 27, c,d) August 2, and e,f) September 13. Percent cover is based on average values among four replicate blocks and reflects the percentage of blocks in which a given vegetation type was observed. Percentages can total to > 100% in cases where multiple species were observed in the same block.

Results from the visual survey largely followed the same patterns observed in the quadrat survey (Table 3).

Table 3. Visual estimates of vegetation percent cover. Surveys were performed on June 21, August 2 and 9, and September 13, 2013. For each survey, visible percent cover was estimated for the full station footprint using the Braun-Blanquet cover-abundance scale (<1-5%, 6-25%, 26-50%, 51-75%, or 76-100%). In cases where abundance estimates varied among replicates for a given sampling month and treatment, the most common estimate is presented.

Station	Date	*Spartina patens*	*Spartina alterniflora*	Empty	*Distichlis spicata*	Other
P2	June	26-100	<1-5		26-75	
	August	26-100	<1-5		6-50	<1-5*
	September	26-100	<1-5		6-50	<1-5 *+
P4	June	76-100	<1-50			
	August	51-100	<1-50			
	September	51-100	<1-50			<1-5 *
P6	June	26-100			51-75	
	August	26-100	6-25		51-75	
	September	26-100	6-25		26-50	<1-5 *
PC	June	26-100			26-50	
	August	26-100			26-50	
	September	26-100			26-75	<1-5 *
A2	June		76-100			
	August		76-100			
	September		26-75	26-50		
A4	June		76-100			
	August		76-100			
	September		76-100			
A6	June		76-100			
	August		76-100			
	September		76-100			
AC	June		76-100			
	August		76-100			
	September		76-100			

*Pickleweed (*Salicornia europeae*)
+ Sea lavender (*Limonium carolinianum*)

Test clip plot sampling showed a decrease in confidence intervals with increasing quadrat sample size to an approximate sample size of eight, at which point the confidence interval stabilized (Fig. 9 and 10). This pattern was consistent across all three metrics and both quadrat sizes.

Clip Plot Sampling

Among low marsh plots, live dry stem weight was significantly lower for A2 docks than A4, A6, and Control plots (P<0.05 for all comparisons) but no other pairs were significantly different (Fig. 14). A2 stem density was also significantly lower than the remaining dock and control treatments (P<0.05). Control stem density was significantly higher than all three dock treatments (P<0.05) while A4 and A6 did not significantly differ from each other (Fig. 15). Control median stem height was significantly lower than all three dock treatments (P<0.05) while no differences were detected among the different dock heights (Fig. 16). There were no significant differences among treatments for percent carbon. Percent nitrogen and C:N ratios were significantly higher in A2 docks than remaining treatments (P<0.05). These values were also significantly lower for Control docks relative to A4 docks (P<0.05), but no differences were detected between A4 and A6 or A6 and Controls (Fig. 17).

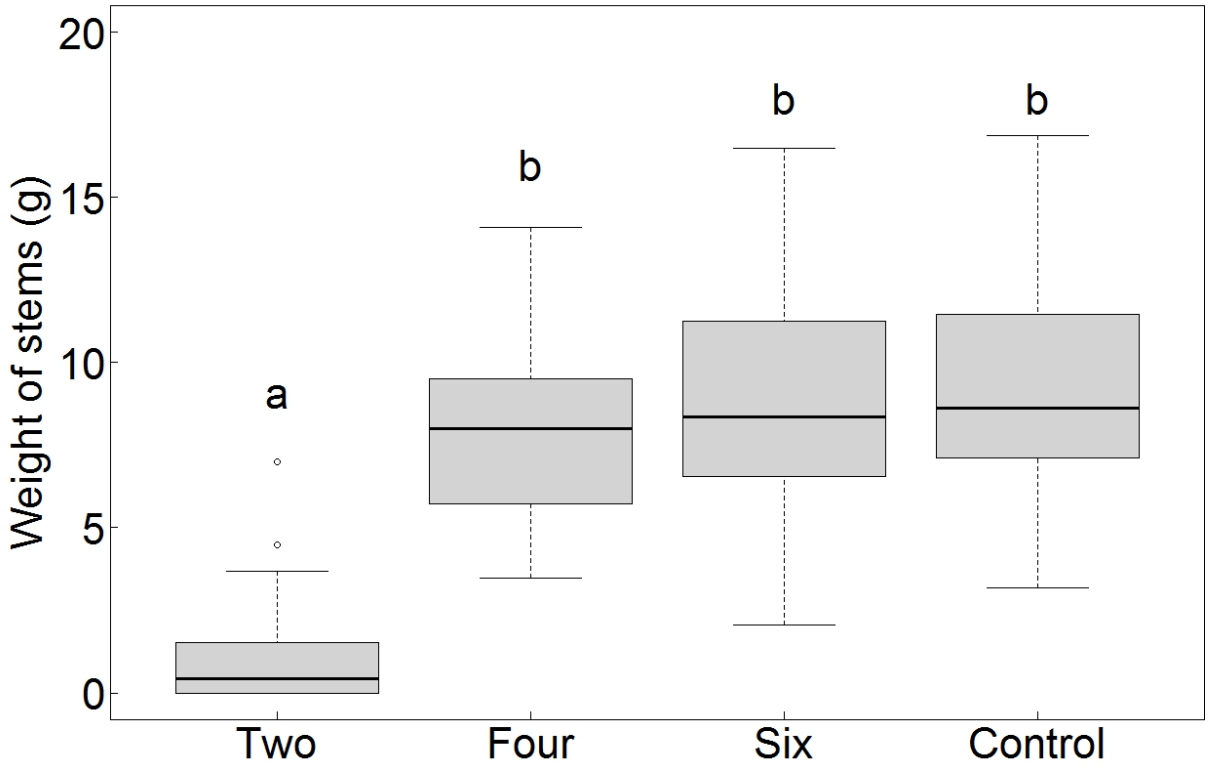

Figure 14. Boxplots of low marsh live stem dry weight (g) for two, four, and six foot docks as well as control, unshaded plots. Plots with different letter labels are significantly different (P<0.05). The black horizontal line in each boxplot identifies the median value while the shaded box contains the 25th and 75th percentiles. The dashed lines ("whiskers") show values up to 1.5 X the interquartile range. Outlier values that are more than 1.5 X the interquartile range are displayed as individual points.

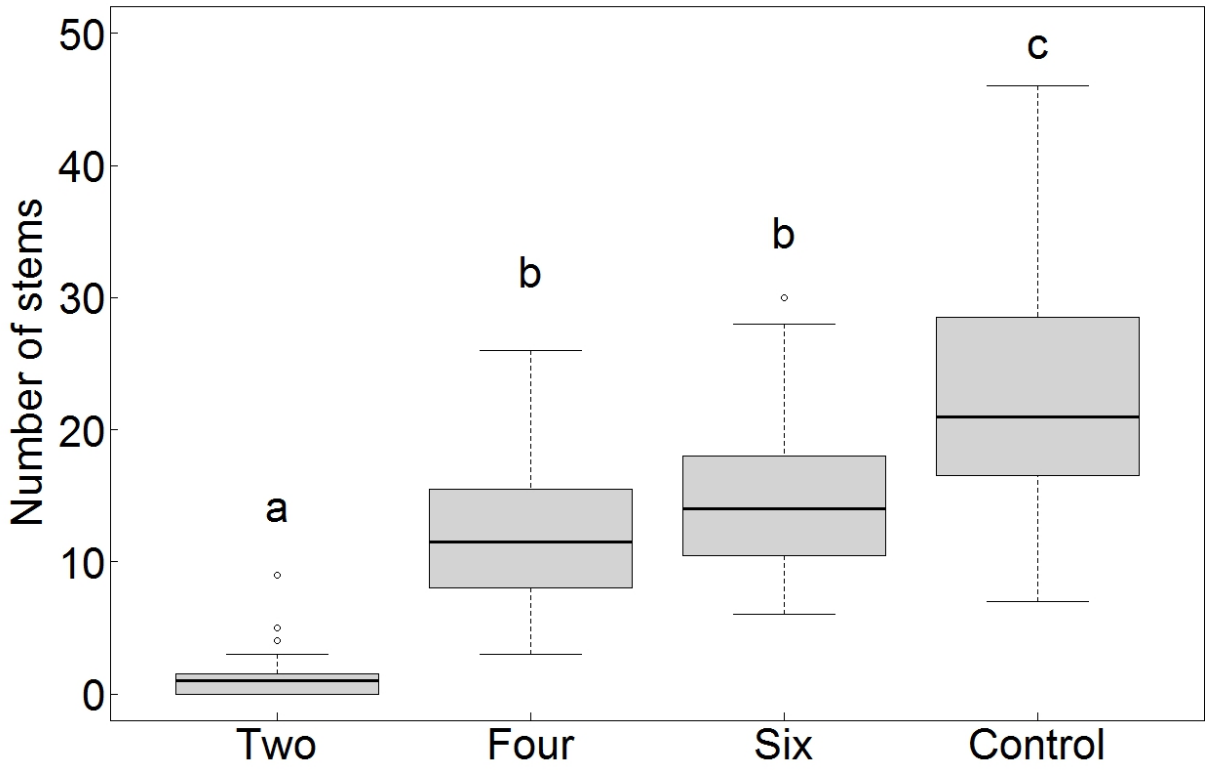

Figure 15. Boxplots of low marsh live stem density for two, four, and six foot docks as well as control, unshaded plots. Plots with different letter labels are significantly different (P<0.05). The black horizontal line in each boxplot identifies the median value while the shaded box contains the 25th and 75th percentiles. The dashed lines ("whiskers") show values up to 1.5 X the interquartile range. Outlier values that are more than 1.5 X the interquartile range are displayed as individual points.

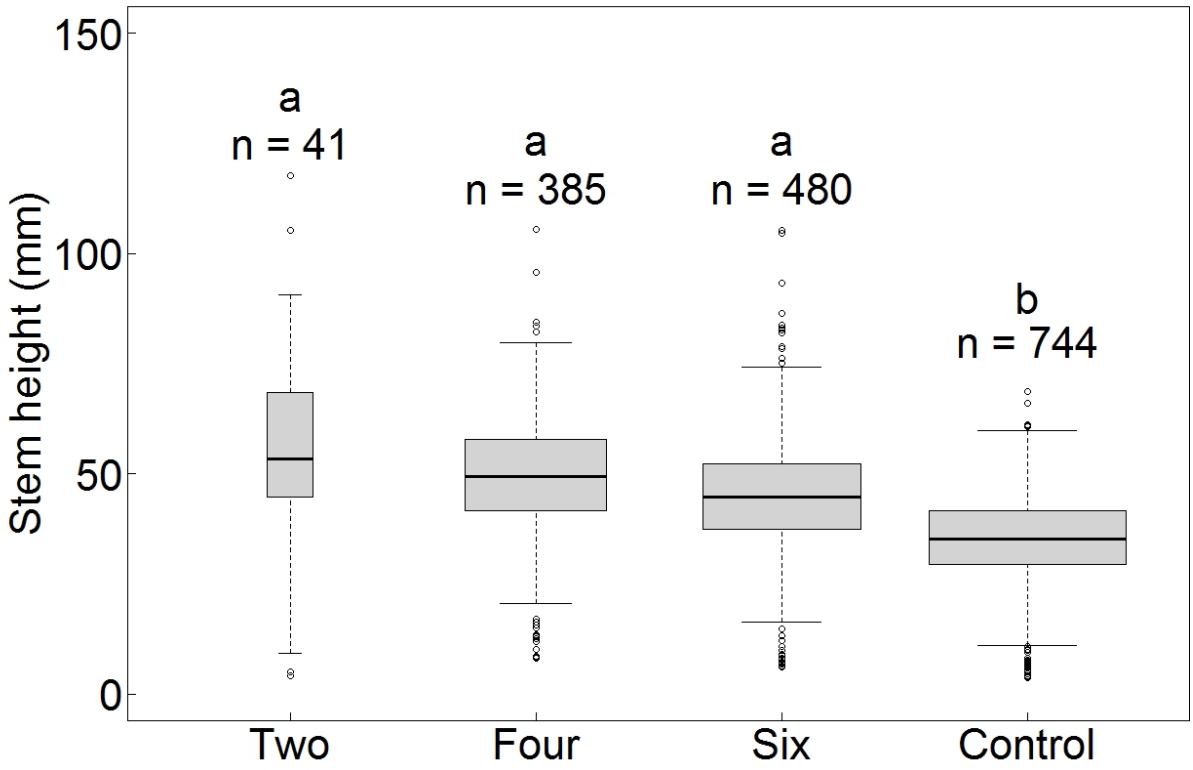

Figure 16. Boxplots of low marsh live stem height (mm) for two, four, and six foot docks as well as control, unshaded plots. Plots with different letter labels are significantly different (P<0.05). The black horizontal line in each boxplot identifies the median value while the shaded box contains the 25th and 75th percentiles. The dashed lines ("whiskers") show values up to 1.5 X the interquartile range. Outlier values that are more than 1.5 X the interquartile range are displayed as individual points.

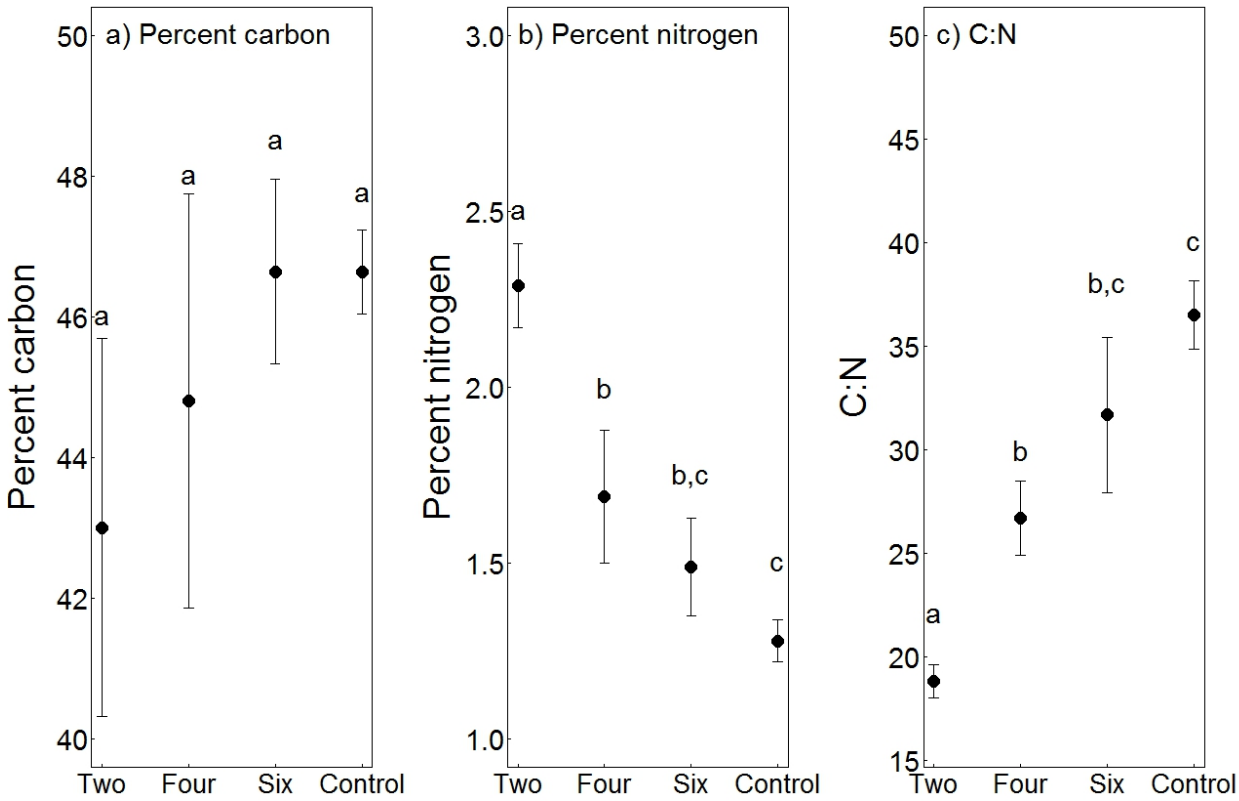

Figure 17. Mean (± SD) a) percent carbon, b) percent nitrogen, and c) C:N ratio of dried live *Spartina alterniflora* from low marsh plots. Values with different letters are significantly different (P<0.05).

Among high marsh plots, combined aboveground biomass of *Spartina patens* and *Distichlis spicata* was significantly higher (P<0.05) for P6 than P2 while no other treatments differed significantly (Fig. 18). Stem density was significantly higher for P6 docks than all other treatments (P<0.05), but no other treatments differed significantly from each other (Fig. 19). Median stem height was significantly lower for control and six foot docks relative to four and two foot docks (P<0.05), with no significant differences between each respective pair (Fig. 20). *S. patens* percent carbon did not significantly differ among treatments (Fig. 21). Percent nitrogen and C:N ratios were significantly higher for two foot docks than four foot and control docks (P<0.05), but did not significantly differ from six foot docks. Four foot, six foot, and control docks were not significantly different from each other (Fig. 21).

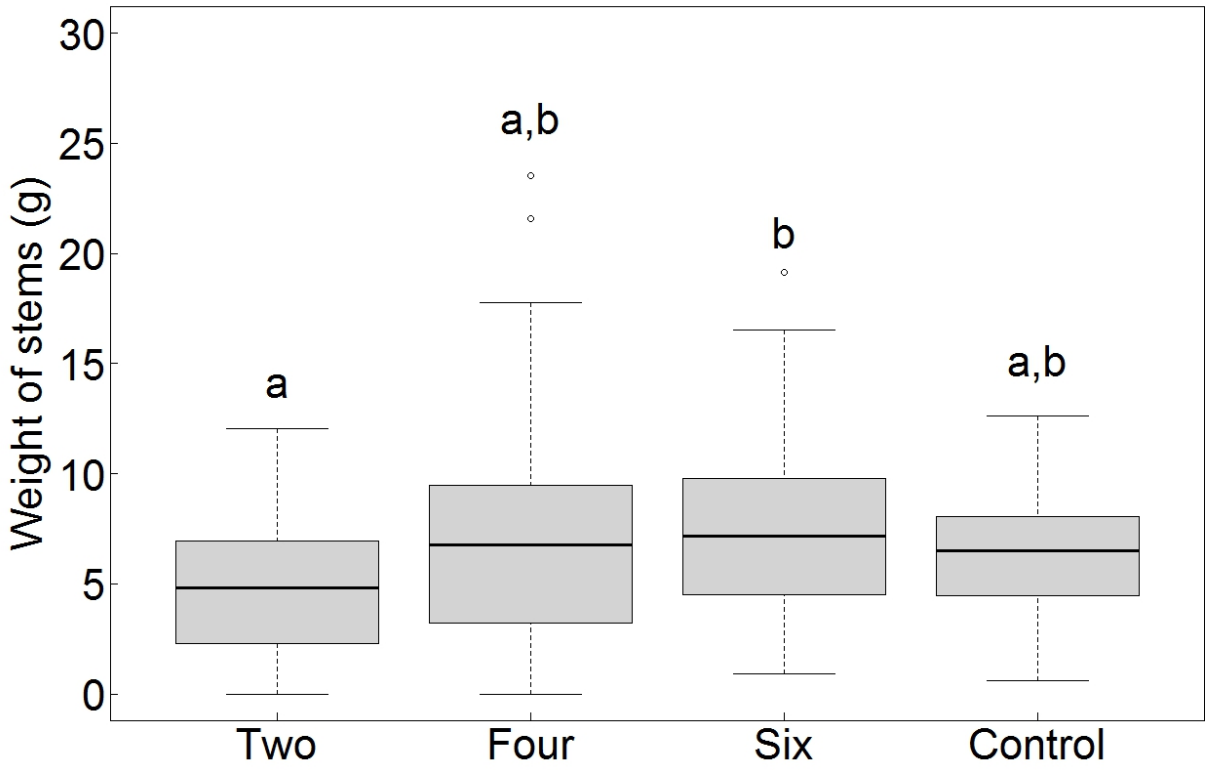

Figure 18. Boxplots of high marsh (*Spartina patens* and *Distichlis spicata*) live stem dry weight (g) for two, four, and six foot docks as well as control, unshaded plots. Plots with different letter labels are significantly different (P<0.05). The black horizontal line in each boxplot identifies the median value while the shaded box contains the 25th and 75th percentiles. The dashed lines ("whiskers") show values up to 1.5 X the interquartile range. Outlier values that are more than 1.5 X the interquartile range are displayed as individual points.

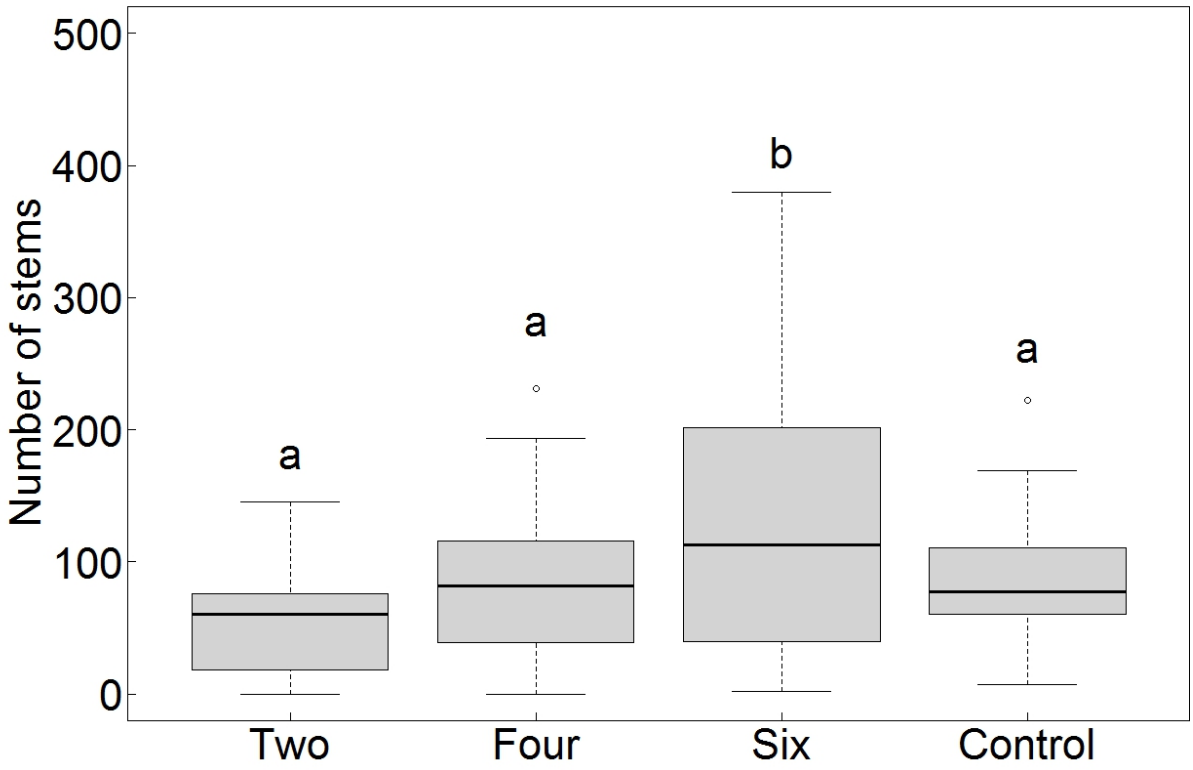

Figure 19. Boxplots of high marsh (*Spartina patens* and *Distichlis spicata*) live stem density for two, four, and six foot docks as well as control, unshaded plots. Plots with different letter labels are significantly different (P<0.05). The black horizontal line in each boxplot identifies the median value while the shaded box contains the 25th and 75th percentiles. The dashed lines ("whiskers") show values up to 1.5 X the interquartile range. Outlier values that are more than 1.5 X the interquartile range are displayed as individual points.

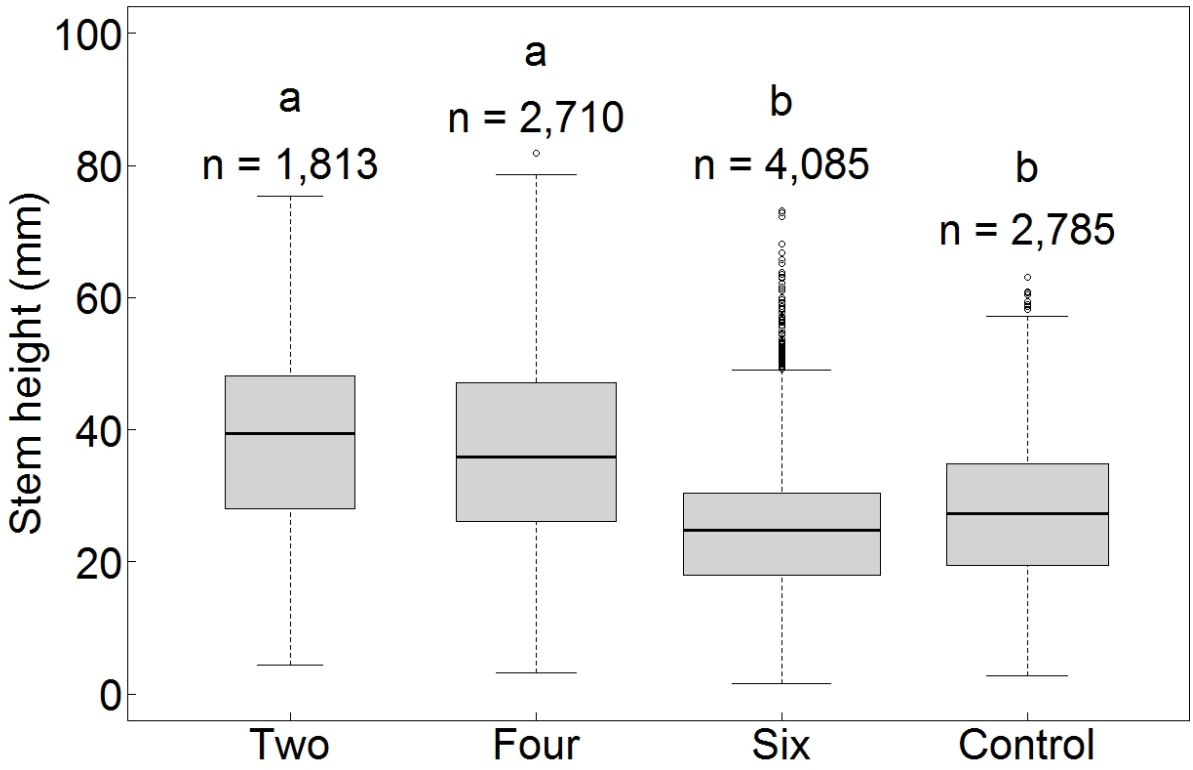

Figure 20. Boxplots of high marsh (*Spartina patens* and *Distichlis spicata*) live stem height (g) for two, four, and six foot docks as well as control, unshaded plots. Plots with different letter labels are significantly different (P<0.05). The black horizontal line in each boxplot identifies the median value while the shaded box contains the 25th and 75th percentiles. The dashed lines ("whiskers") show values up to 1.5 X the interquartile range. Outlier values that are more than 1.5 X the interquartile range are displayed as individual points.

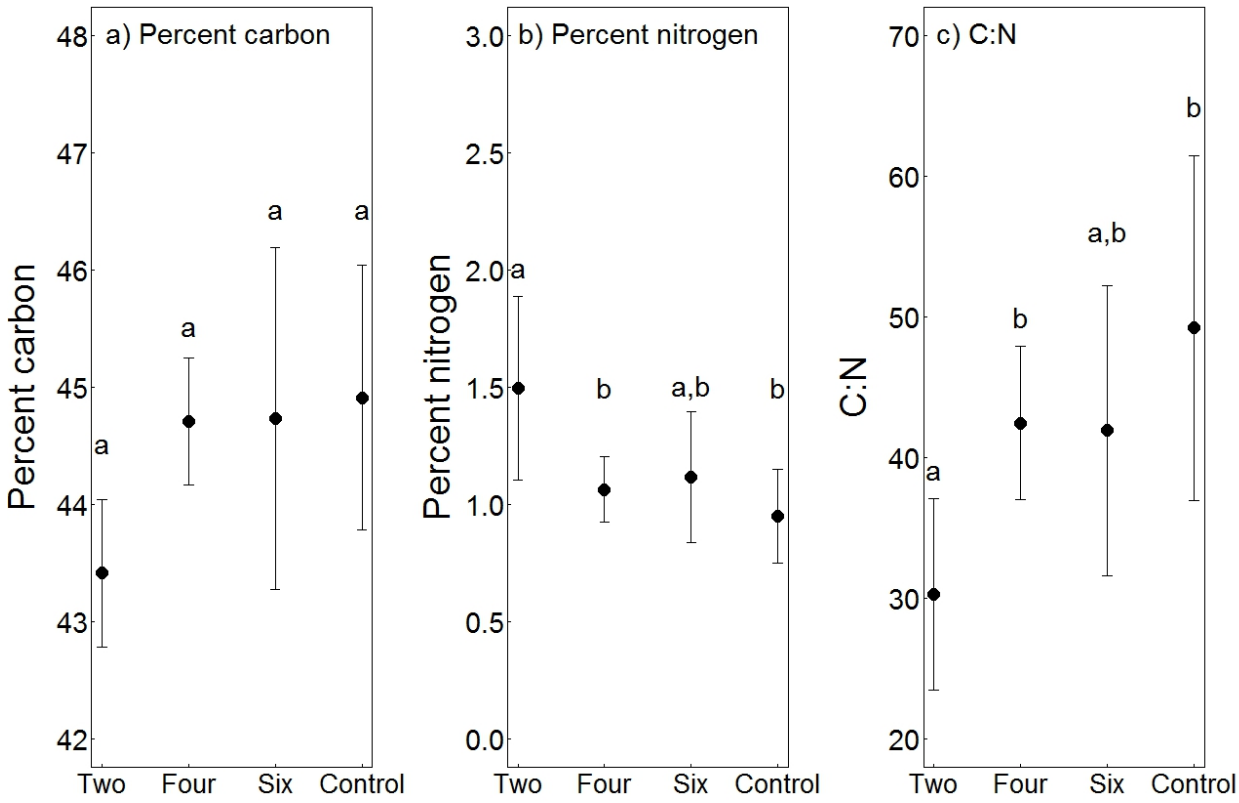

Figure 21. Mean (± SD) a) percent carbon, b) percent nitrogen, and c) C:N ratio of dried live *Spartina patens* from high marsh plots. Values with different letters are significantly different (P<0.05).

Elevation

Plot elevations were highly similar within each marsh zone (Table 4). In the low marsh, docks generally averaged a relative height of 48 cm (water level at extreme high tide) while high marsh plots were set at approximately 33 cm (16 cm height above low marsh). A single dock (A42) was at an elevation 19 cm below remaining low marsh plots (65.1 cm water height vs. average among remaining low marsh docks of 46.0 ± 5.0 cm). A single control plot (A2C) was set 16 cm above remaining low marsh plots (32.1 cm vs. 48.1 ± 5.6 cm). No anomalous elevations were observed among high marsh plots, which had a group mean elevation of 33.4 ± 2.3 cm.

Table 4 Estimates of relative dock elevation. Estimates based on tide stick method and reported as maximum water height above marsh platform during full moon high tide.

Station	Water height at high tide (cm: mean ± SD)
PC	32.7 ± 2.0
P2	32.0 ± 3.4
P4	34.3 ± 2.0
P6	34.3 ± 1.6
AC	42.9 ± 7.3
A2	50.2 ± 10.6
A4	48.4 ± 4.9
A6	48.2 ± 1.7

Cumulative Impact Survey

Based on a review of DEP permit files and Google Earth imagery, a total of 53 docks were identified over salt marsh vegetation in the North and South River system. The sections of docks overlying salt marsh had a median width of four feet, length of 80.5 feet, and area of 310.6 square feet (Fig. 22).

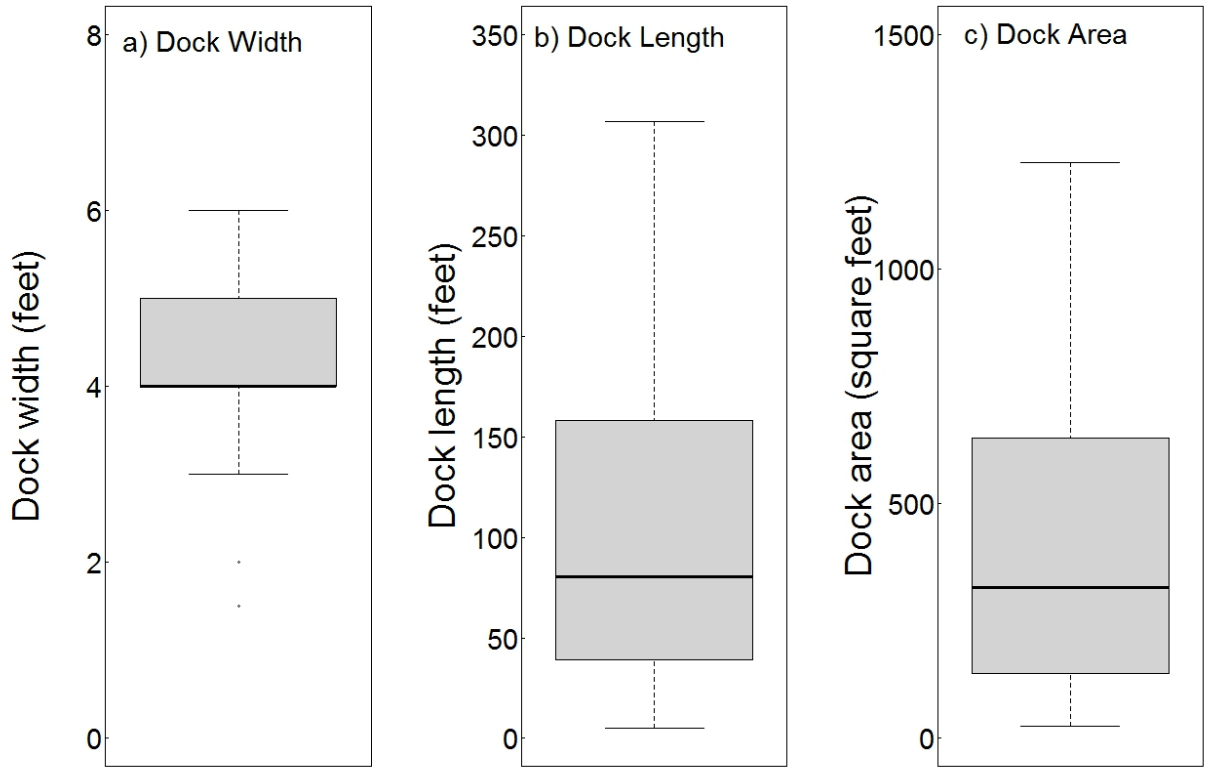

Figure 22. Boxplots of a) width, b) length, and c) area of docks (n = 53) observed over salt marsh in the North and South River system. The black horizontal line in each boxplot identifies the median value while the shaded box contains the 25th and 75th percentiles. The dashed lines ("whiskers") show values up to 1.5 X the interquartile range. Outlier values that are more than 1.5 X the interquartile range are displayed as individual points.

The total estimated area of dock surface overlying salt marsh was 23,548.4 square feet. The total estimated area of salt marsh in the North-South River system was estimated to be 102,758,040 square feet. Total dock area of marsh as a percentage of all marsh habitat was < 1 percent.

Discussion

The broadest range of effects were observed for the two foot docks installed over *S. alterniflora* in the low marsh. Reductions in biomass and stem density were visually apparent by early August, and these docks were unique in that large areas of the dock footprint were completely lacking vegetation by the end of the growing season. Two foot docks in the high marsh affected stem height, but did not alter biomass or stem density, suggesting that *S. patens* and *D. spicata* are less affected by dock impacts than *S. alterniflora*, at least under relatively short time scales. The large reduction in vegetative cover under these short low marsh docks potentially makes these areas vulnerable to erosion and habitat alteration. Since docks were otherwise constructed and installed in a manner that maximizes light penetration, equivalent or greater effects would be expected for docks set over low marsh habitat with different characteristics (e.g., east-west orientation, ½" deck spacing).

Stem density was highest for control and six foot docks for low and high marsh zones, respectively. In the low marsh, docks meeting or exceeding the 1:1 height to width ratio had a reduction in stem density relative to control plots of 20 to 34% while the two foot docks had a reduction of nearly 95%. Since biomass did not differ among control, four, and six foot docks, overall marsh production was not affected in the first field season of shading for height-compliant docks. However, the observed reduction in stem density suggests a shading impact, which may result in a decline in subsequent sampling years if plants are unable to continue to compensate for reduced density with increased height. The reduced stem density could also result in increased erosion and a reduced ability to trap organic matter. In the high marsh, the greater stem density observed at six foot docks could simply be a spurious result. While the docks were set in a randomized pattern, the six foot dock locations could have randomly been installed in areas that promoted higher stem density due to conditions unrelated to dock shading. Alternatively, for *S. patens*, the six foot docks may have actually created environmental conditions more suitable to growth than ambient, unshaded conditions. The six foot docks allowed approximately 86% of ambient light penetration. The slightly cooler conditions and reduced light under these dock structures may have maintained sufficient light for growth while also reducing heat stress and associated energetic costs.

Unshaded stems were shorter than those occurring under docks, a pattern that has been observed previously for docks in South Carolina [17], Maryland [11], and Connecticut [13].

Etiolation, the process in which plants elongate more rapidly under reduced light conditions, has been proposed as a likely explanation for this phenomenon [11,13]. Under this scenario, marsh plants growing under docks would grow taller in search of available light and consequently would have weaker, less robust stems. An alternative explanation for this pattern is that plants growing under docks are exposed to elevated fertilization as a result of birds feeding and perching on dock platforms [17]. In our study, herring gulls (*Larus argentatus*) and osprey (*Pandion haliaetus*) were observed perching on the docks. Green crab (*Carcinus maenas*) carapaces and other food remains as well as bird faeces were also frequently present on docks. While not significant, the median stem height was inversely correlated with light intensity for *S. alterniflora*, with lowest median height in unshaded plots and greatest under two foot docks. For *S. patens*, the six foot docks actually had equivalent stem heights to unshaded plots while the higher stem heights were only observed for the shorter two and four foot docks. These results are more consistent with etiolation than fertilization as height appears to be related to light availability. Nitrogen content and C:N ratios also differed with vegetation under the two foot docks, a pattern that has been observed for *Spartina* in relation to latitude [18]. In both cases, these shifts in elemental composition could be related to reduced growth or differences in stem structural components, which would also be consistent with the etiolation hypothesis.

Cumulative impacts from dock shading to the North and South River system at current levels of development were relatively minor, with docks covering < 1 percent of all marsh area. This system is relatively unique in that it contains a high proportion of marsh habitat that is protected from development. The Commonwealth of Massachusetts owns a 179 acre parcel near the confluence of the North and South rivers, the site of the dock matrix study. The Marine Biological Laboratory (MBL) owns two nearby parcels of marsh that jointly represents approximately 100 acres of habitat. These large protected parcels represent approximately 12 percent of the total marsh area in this system (Fig. 23).

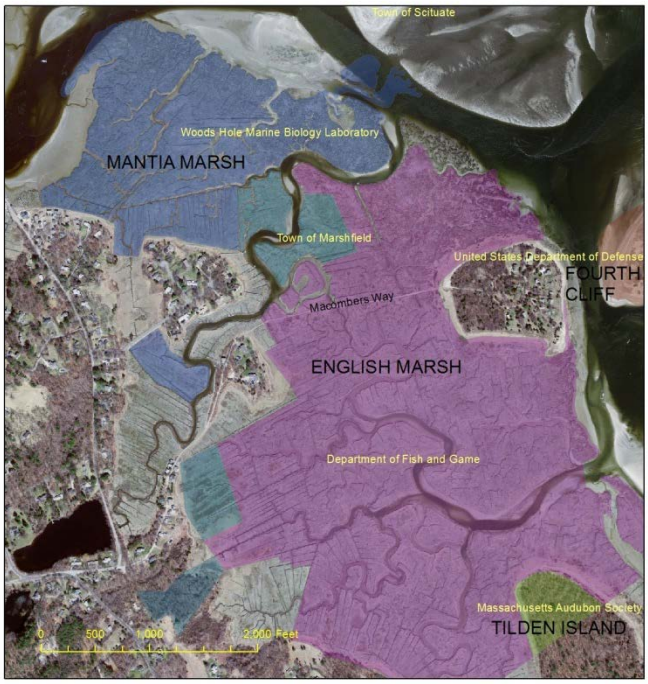

Figure 23. Map of North and South River system showing large parcels of protected salt marsh. The Mantia Marsh property, highlighted in blue, is owned by the Marine Biological Laboratory while the English Marsh, highlighted in purple, is owned by the Commonwealth of Massachusetts. The large and small Mantia Marsh properties are 5.6 and 94.4 acres in area, respectively while the English Marsh is 179 acres.

Conclusions and Recommendations

Year one results of the dock matrix field study should be viewed with relative caution. Aside from dock height, the experimental docks were constructed in a manner consistent with DEP-advocated best management practices [3]. Specifically, all docks were aligned in a north-south orientation, which should maximize light penetration to underlying vegetation along the sides of the dock. Deck spacing was set at ¾ inch, which should further facilitate light penetration through the decking surface [3]. Consequently, this design provides more of a "best case scenario" and shading impacts would be expected to only increase for docks with characteristics that are less conducive to light penetration. Shading impacts are also likely compounded over time, as an energy debt builds with each year of reduced lighting and consequently reduced production and belowground storage. After year one, docks following the 1:1 height to width standard showed no detectable signs of reduced aboveground production (biomass) relative to unshaded areas, but effects may simply require multiple seasons of shading. After a single season, the near elimination of vegetation under low marsh two foot docks indicates the need to maintain at least a 1:1 height to width ratio. Shading impacts were evident after only four months of shading as the percentage of bare surface increased substantially by early August in these two foot dock footprints. Given that other dock features were designed to maximize light penetration, results suggest that standard four foot

width docks with traditional decking set over low marsh vegetation at less than a 1:1 ratio would significantly reduce marsh vegetation under all dock orientations. Since results were observed within a short, single season timescale, long term effects should be equivalent or more severe. Thus, preliminary experimental results provide cautious support for the 1:1 height to width minimum, but further monitoring will be required to apply a more rigorous test to the existing guidelines. Significant declines in both stem density and biomass for docks under the 1:1 minimum provides support for requiring at least a 1:1 separation for docks over marsh vegetation.

Future Research

The dock matrix will be re-installed in the same locations for a second field season of shading and monitoring in spring 2014. Light and temperature loggers will again be installed and both visual and clip plot sampling will be repeated. To avoid potential confounding effects of marsh elevation, two outlier stations will be relocated for the 2014 field season. Pending 2014 results, a third field season may be conducted to provide a full three-year shading study. This short term experimental matrix would also benefit from similar clip plot sampling under existing private docks and piers, as such sampling would allow shading effects to be assessed over a longer timescale and across a range of dock characteristics.

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