Final Report

Field Assessment and Simulation of Shading from Alternative Dock Construction Materials

Dr. Clark Alexander
Skidaway Institute of Oceanography
10 Ocean Science Circle
Savannah, GA 31411
clark.alexander@skio.usg.edu

18 March 2012

This report was prepared by Clark Alexander under grant award #NA08NOS4190461 from the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration. The statements, findings, conclusions and recommendations are those of the author and do not necessarily reflect the views of OCRM or NOAA.

Executive Summary

Shading from dock walkways has been shown to have a significant negative impact on the productivity of the salt marsh ecosystem in Georgia, other southeastern states and along the East Coast (Kearney, Segal, and Lefor, 1983; Burdick and Short, 1999; Sanger and Holland, 2002; Kelty and Blivens, 2003; Alexander and Robinson, 2004, 2006). Docks shade a habitat that naturally receives full sun, resulting in lower production rates in *Spartina alterniflora*, Georgia's dominant marsh plant, and the most important primary producer for saltmarsh ecosystems along the east coast (Pomeroy et al., 1981). Studies have shown that some alterable parameters of dock construction (i.e., orientation of dock, height above marsh surface, walkway width) can significantly change how strongly shading effects are felt (Burdick and Short, 1999; Shafer, 1999).

Reducing shading and its impacts on the salt marsh ecosystem of Georgia requires new approaches to dock and walkway construction. New materials, with the potential to reduce shading impacts, have become available over the past decades. Early investigations of alternative decking materials concluded that open grated material showed some promise (Schaefer, 1999; Schaefer and Robinson, 2001; Kelty and Blivens, 2003). New materials, such as stronger, more durable fiberglass gratings, metal and plastic gratings with a variety of shape and size openings, and innovative dock access designs have appeared on the market as shading effects have become more widely recognized and the desire to reduce those effects more prevalent in the management community. However, the realized efficacy of these materials has not been tested in real world settings.

This project evaluated the effects of new dock walkway construction materials and techniques on marsh shading along two parallel paths: 1) by collecting light-level data (i.e., photosynthetically active radiation (PAR) intensity) at various seasons, orientations and heights with sensors above and below walkway sections ("mock docks" five-feet high), constructed of alternative materials on the upland; and 2) by collecting field data (i.e., stem density, biomass, chlorophyll *a*, organic carbon, salinity, grain size) under and adjacent to new docks, constructed with traditional and alternative materials, prior to construction and annually thereafter. Three mock docks were constructed using alternative materials and methods (i.e., ThruFlow fiberglass-impregnated grating, Gator Dock fibergrate grating and a DockRider Sundock) and a traditional wood-planked walkway was constructed as a control**.**

Mock Dock Simulation Experiment

In the mock dock studies, we examined how different dock walkway structures affected shadow duration, daily PAR loss, and PAR loss above a 0% biomass loss threshold (0% BLT) under docks, at different orientations and heights. The 0% BLT is that light level above which we do not expect to see any biomass loss because of shading. During the orientation experiment, docks were oriented at 0º, 45º, 90º and 135º. Docks oriented at 90º and 135º during winter and fall and oriented at 0º and 45º during spring and summer created the shortest shadow periods and the least overall PAR loss. Typically, the traditional, ThruFlow, and Fibergrate docks exhibited similar characteristics during the experiments. The SunDock system had a smaller impact at all orientations and seasons. **Because spring and summer are the major growth seasons for *S. alterniflora,* these orientation results demonstrate that docks that provide the most light penetration during these seasons, those oriented N-S, have a much smaller shading impact on the marsh than those oriented E-W.** The height study examined shadow durations and PAR loss associated with docks at 4, 5, 6, 7 and 8 feet heights with docks oriented at 0º. In general, the data show that shadow duration and PAR loss under the docks decrease as height increases, although the Sundock exhibited PAR losses that were about half those of the decked walkways. **The height study demonstrates that docks should be built as high as possible above the marsh surface to minimize shading effects.**

For both the orientation and height experiments, PAR loss above the 0% BLT follows the results of the orientation and height shadow duration and PAR loss studies. In the orientation study, traditional planked dock structures effectively block 100% of the PAR above the 0%, 25% and 50% BLTs in some seasons and orientations (summer, 90º and winter, 0º). At these same seasons and orientations, alternative decking materials increase the amount of PAR present under the dock by less than 10% at the same BLTs, thus also effectively blocking most of the incident PAR. No matter their orientation, decked structures during spring and summer block 80-100% of the PAR above the 0% BLT. Under these same conditions, the SunDock blocks 20-40% of incident PAR above the 0% BLT. Similar results are noted in the height study, where the traditional dock (and other decked structures) during winter and fall exhibited PAR losses of 86-100% above the 0% BLT at 4 feet and 69-77% losses at 8 feet. Spring and summer data show decreases in daily PAR loss above the 0% BLT for all heights, with losses of 74-87% of PAR above the 0% BLT at 4 feet and 45-60% losses at 8 feet. As with other datasets in this study, the SunDock had a smaller PAR loss, ranging between 23-62% loss of PAR above the 0% BLT in the fall and winter, and a 15-40% loss of PAR in the spring and summer. **These results show that all docks significantly reduce the amount of PAR above the 0% BLT received below the dock in all seasons, although the Dockrider system has a smaller impact. Similar results were found for the 25% and 50% BLTs.**

The results presented above are for the total integrated PAR received throughout the day. The purpose for using alternative materials is to enhance the penetration of light during the time when the dock shadow is under the dock, so we separately examined PAR levels above and below the dock during this period. When the sun's elevation is low (in fall and winter), light does not penetrate the alternative decking materials, and the PAR loss is similar among the traditional, Thruflow and Fibergrate docks (41-47% loss), whereas the Sundock exhibits an average 26% loss. When the sun's elevation is higher (in spring, but dominantly in summer), light is able to penetrate the grated materials. During these seasons, the traditional planked dock PAR loss remains at 41%, but the alternative material PAR losses decrease to 34% because of light penetration through the materials. When compared to a traditional planked walkway, only the Sundock receives more PAR under the dock throughout the year, receiving 13% and 22% more in fall and winter, respectively, and 39% more PAR during spring and summer. Other alternative docks only receive more PAR than the traditional planked dock during spring and summer, although the increase in PAR is less than 10% during both seasons. If we look just at the 2 hour period around maximum insolation, grated materials allow less than 10% additional PAR in the spring and between 20-35% more PAR in the summer, compared to a traditional planked dock. However, this 2-hour period is only a portion of the time during which the shadow is under the dock, so the increased PAR has little effect**.** The dock height data illustrate that as docks get higher off the marsh surface, there is less advantage to using alternative materials. As height increases, the shading impact of traditional planked docks decreases and the small amount of additional PAR provided by alternative materials becomes relatively less important on a percentage basis. Given that the height study showed that docks should be built as high above the marsh as possible to decrease shading impacts, there is again less need to use alternative materials for walkway decking.

These results show that, for the latitude of Skidaway Institute (31º 56' N) where the experiments were carried out, alternative decking materials do not ameliorate the impacts of dock shading, given that most of the PAR above the 0%, 25% and 50% BLT thresholds is effectively blocked from reaching below the docks. The elevation of the sun is only high enough to allow sunlight to penetrate through grated materials during spring, when penetration is relatively limited, and during summer, when penetration is at its greatest. Even at this time, grated materials provide less than 10% additional PAR under docks when compared to a traditional planked walkway. Because the elevation of the sun is related to latitude, our results are applicable from Skidaway Island north along the US east coast. Penetration of PAR through alternative materials will increase toward the south, decreasing the impact of marsh (and sea grass) shading, as the sun's elevation in the sky increases toward lower latitudes.

Field Assessment of Alternative Materials and Construction Methods

Three separate field sites along the Georgia coast were examined to determine the effects of alternative dock materials and construction methods on the marsh environment on yearly timescales. Pairs of sample stations, consisting of one dock station, located directly underneath the dock, and one control station, located parallel with, and 5 meters away from the dock, were occupied beginning at the upland-marsh boundary, and advancing at 20 meter intervals into the marsh. At each station, dock and control samples were collected to quantify the changes that dock construction, dock presence, and presence of alternative construction techniques exert on the marsh environment. At the two alternative material and construction docks, Turners Creek (ThruFlow) and Shell Point Cove (Dockrider), we were able to sample along the corridor used to install the docks prior to dock construction; a traditional planked dock at Betz Creek was also included to provide a control for traditional dock building techniques and any dock-induced effects on the marsh.

Post-construction stem density data show a substantial decrease in stem density beneath all docks for all years, ranging from a 44% to an 80% decrease year over year, compared to control sites. Biomass shows decreases beneath the docks at all three sites as well. The ThruFlow dock exhibited the greatest biomass loss of the three field sites (63%). The dockrider system also showed a significant decrease in biomass under the dock (40%). In addition, several dock-associated impacts were observed, including transitions from vegetated marshes to persistent denuded muflats in areas of piling-associated marsh wrack accumulation and from *J. roemerianus* to *S. alterniflora* because of lowered surface elevations along dock-construction walking paths. Organic carbon content was similar at all three sites, and typical for salt marsh sites in Georgia (3-6%). In many cases, dock samples had consistently lower organic carbon values, reflecting the loss of vegetation and input of plant material. Apparently, benthic algae are not able to fill that gap, even with less vegetation to block light, given the increased shading from the dock. Chl *a* values in the sparse grass below docks, which reflect the productivity of the benthic algae community, were low compared to unvegetated mudflats, but were similar to those observed in vegetated salt marshes in Georgia. A drop in Chl *a* pigments at under-dock sampling sites was observed at both the Dockrider and ThruFlow sites in the year following dock construction, perhaps indicating a temporary disruption of the benthic algal productivity. No consistent pre-and post-construction patterns were observed in salinity or grain size at any of the sites.

The results from the field assessments of docks built using alternative construction materials and methods reinforce the conclusions from the mock dock simulation study that neither current alternative materials nor construction

methods effectively negate the effects of dock shading in our region. Both docks built using these approaches exhibited significant reductions in stem density, Chl *a*, organic carbon and biomass under the docks; however, the Thruflow dock exhibited a greater biomass loss than did the SunDock.

This study only examined the impact of dock shading on the productivity of the marsh. Several other impacts, most notably marsh wrack accumulation around dock and walkway pilings, can also negatively impact the marsh. Wrack accumulation has been implicated in killing aboveground and belowground biomass, thus lowering the marsh surface elevation and turning marshes into mudflats. Although the Sundock provided less reduction in PAR in all cases, this type of access walkway must be constructed with pilings spaced 10 feet apart, whereas other construction methods can space pilings between 12 and 20 feet apart. This closer spacing may trap more wrack than more traditional docks with a wider piling spacing. Studies are currently underway to more precisely determine the distribution and impact of wrack in the salt marshes of Georgia.

Other Factors Affecting PAR Availability in Georgia Salt Marshes

Two parameters further affect the light plants receive for photosynthesis in a salt marsh: the canopy density and inundation by turbid waters by the tides. A short study was conducted near Skidaway Island to better understand the effects of these parameters on the quality, extent and duration of light encountered by *S. alterniflora*. Over the four hours around solar noon, 25-78%, 20-61% and 7-23% of incident PAR reaches the sediment surface in low, medium and high density canopy, respectively, illustrating that self-shading and decreases in benthic algae production can be significant in marshes. Turbidity in the water column also can significantly alter light availability to salt marsh grasses, with only 0.5 m of water overlying plants needed to reduce the incident PAR by 50-70%. These effects would be less severe in winter, when our waters are clearer. These data serve as a first examination of these issues in Georgia saltmarshes.

1.0 Introduction

Shading from dock walkways has been shown to have a significant negative impact on the productivity of the salt marsh ecosystem in Georgia, other southeastern states and along the East Coast (Kearney, Segal, and Lefor, 1983; Burdick and Short, 1999; Sanger and Holland, 2002; Kelty and Blivens, 2003; Alexander and Robinson, 2004, 2006). Docks shade a habitat that naturally receives full sun, resulting in lower production rates in photosynthetic communities. These shading impacts have been shown to be similar for sea grasses and *Spartina alterniflora*, Georgia's dominant marsh plant, and the most important primary producer for saltmarsh ecosystems along the east coast (Pomeroy et al., 1981). Studies have shown that some alterable parameters of dock construction (i.e., orientation of dock, height above marsh surface, walkway width) can significantly change how strongly shading effects are felt (Burdick and Short, 1999; Shafer, 1999). Other secondary factors affecting marsh habitat are impacts from initial construction of the dock, which temporarily destroys the marsh in and around the structure, and the presence of dock pilings, which can disrupt channels and affect water flow, trap marsh wrack that leads to marsh degradation, and leach toxic chemicals into the environment (Warner and Solomon 1990; Alexander and Robinson, 2007; Weis and Weis, 2006).

Most marsh shading in Georgia is associated with private recreational docks. Alexander and Robinson (2004, 2006) have shown that these structures create a ~50% decrease in vegetation stem density beneath docks when compared to areas adjacent to docks. On average, 87% of the biomass in the marsh grass was contained within the living, tall stems, so a decrease in stem density represents a decrease in carbon production within the marsh. This decrease is between 21-37% of biomass and carbon produced per meter square under a dock structure. Using State-wide data for dock numbers and sizes, these reductions suggest that private recreational docks are reducing organic carbon input between 10-17 million g Carbon per year, leading to a loss of potential nekton production (e.g., juvenile shrimp, crabs) of 0.6-1.2 million g nekton (wet weight) State-wide. Thus, their shading impact can be significant to State resources and any methodologies that minimize this shading effect should be evaluated.

This concern for the salt marsh habitat in Georgia has produced a need for alternative materials and construction techniques to help reduce the impact of docks on marsh ecosystems. This project focused on the impact of shading from docks on salt marsh vegetation, and investigates the potential amelioration of negative effects that can be gained through the use of newer dock building materials and technologies. Early investigations of alternative decking materials concluded that open grated material showed some promise (Schaefer, 1999; Schaefer and Robinson, 2001; Kelty and Blivens, 2003). New materials, such as stronger, more durable fiberglass gratings, metal (dominantly aluminum and steel) gratings with a wider variety of shape and size openings, and innovative dock access designs have begun to be prevalent as the shading effects have become more widely characterized and the desire to reduce those effects more prevalent in the management community.

This project pursued the issues described above along two parallel pathways: 1) by collecting simulated environmental data (i.e., readings of above–dock and under-dock photosynthetically active radiation (PAR) intensity at various seasons, orientations and heights) from walkway sections ("mock docks") constructed of alternative materials on the upland; and 2) by collecting field data (i.e., stem density, biomass, chlorophyll *a*, organic carbon, salinity, grain size) under and adjacent to new docks, constructed with traditional and alternative materials, prior to construction and annually thereafter.

2.0 Methods

2.1 Dock Simulations

Four types of "Mock Docks" were constructed to assess the shading effects on salt marshes from several alternative dock materials and construction techniques. The docks we constructed on land at the Skidaway Institute of Oceanography campus to allow easy manipulation of dock height and orientation. Several dock construction partners assisted us with this study, providing materials and labor as in-kind support. Dockrider Systems, LLC and Green Heron Docks in Jacksonville, FL (contact: Ben Wilder), provided a pre-constructed section of a SunDock. The Georgia Department of Natural Resources (contact: Spud Woodward) provided a section of Gator Dock fibergrate decking identical to that used for public docks that DNR constructs. Dock Supply, Inc. in Midway, GA (contact: Mindi Ansley) provided alternative and traditional decking materials to construct the ThruFlow and traditional mock dock sections, and advice on dock construction using these materials (e.g., number of stringers required, pile spacing, etc. in a real-world setting). AMC Marine, Inc. in Midway, GA (contact: Aaron Tompkins) constructed Thru-Flow and traditional mock docks in consultation with Dock Supply, Inc. Each mock dock was constructed as it would be in the real world, to bear typical loads, so that the light penetration could be assessed within a realistic framework.

Four types of mock docks with different decking and construction were used in this study. Each of the materials and techniques assessed are commonly in use in coastal Georgia. See Appendix 2 for material dimensions and specifications.

1) A traditional dock, 5 feet wide (the average dock width in Georgia) by 20 feet long, consisting of contiguous wooden planks (4 inches wide). This mock dock consisted of the upper wooden deck, three supporting stringers and four pilings with a standard pile spacing of 12 feet.

2) A ThruFlow™ grated material dock, made from fiberglass-impregnated plastic, measuring 5 feet wide by 20 feet long. This mock dock consisted of the upper plastic deck, five supporting stringers and four pilings with a standard pile spacing of 12 feet.

3) An aluminum-framed, Fibergrate™ fiberglass grated material dock, measuring 6 feet wide by 13 feet long. This decking panel is identical to those used by the Georgia Department of Natural Resources when they build public-access facilities along the cost of Georgia. This mock dock consisted of the fiberglass upper deck, one supporting

aluminum stringer down the middle of the dock, three large, aluminum u-channel cross members equally spaced under the dock and four pilings with a pile spacing of 13 feet dictated by the decking panel length. Pile spacing with this type of decking material can be up to 20 feet, if cement piles are used.

4) A SunDock™, measuring 20.8 feet long with two 5.5-inch rails spaced 3 feet apart. The SunDock™ does not have a traditional upper deck, utilizing instead a powered cart that runs along the dual-rail track connecting the upland to the terminal platform. The mock SunDock™ consisted of the two top rails, rail cross supports and four pilings with a pile spacing of 10 feet. This 2-foot shorter distance between pilings is one of the required SunDock™ design parameters.

The mock docks were deployed in adjacent open areas at Skidaway Institute of Oceanography in Savannah, GA, where they would receive unobstructed sunlight throughout the day. The docks were used in two 1-year simulation studies to document the separate effects of dock orientation and dock height on light penetration through alternative dock construction materials. Docks were oriented to several pre-determined cardinal directions using a compass while the dock was suspended above the ground with a backhoe or forklift. All mock docks were constructed so that the dock height above the ground could be altered by adding or subtracting leg sections to the dock pilings. To decrease the working weight of the mock docks, dock pilings were simulated by 10.75 inch diameter, heavy-walled PVC pipe, spray painted to mimic the low reflectivity of standard wood pilings.

2.1.1 Measurement of Photosynthetically Active Radiation (PAR)

2.1.1.1 Orientation Data

The one-year orientation experiment, to evaluate the effect of dock orientation on shading, started in Fall 2008. The docks were deployed at a height of 5 feet above the ground (the average height for docks in Georgia; Alexander and Robinson, 2004, 2006), and data were collected quarterly to evaluate the further effect of sun angle during fall, winter, spring and summer. During these quarterly deployments, mock docks were oriented to the compass directions of 0°, 45°, 90°, and 135° for a full day of light collection. Quantum light sensors (Li-Cor Biosciences, model LI-190) were used to measure Photosynthetic Active Radiation (in µmol $m^{-2}s^{-1}$) above and below each dock. Eight sensors were cross-calibrated, and a pair of sensors was deployed per dock: one sensor was installed on top of the decking and one was installed at ground level at the center point of each dock. The "above sensor" was attached on top of the decking to quantify the amount of PAR that plants would receive if no dock was present, whereas the "under sensor" recorded the shading created by each dock material. Each pair of sensors was connected to a single Campbell datalogger (Model CR800), which was programmed to take PAR measurements at one minute intervals from sunrise to sunset. Throughout each sampling day, pictures were taken every three minutes by a video camera to record shadow variations and atmospheric conditions.

Some seasonal variation in collection protocols occurred due to unavoidable weather and sun angle considerations. We sought to collect data on consecutive days in each seasonal collection period. A typical data collection period spanned 7 days. However, at times inclement weather precluded collecting a full day of clear-sky data, particularly during the summer thunderstorm season, leading to a small amount of variability in sun angle and intensity between data collection days. Some amount of variability is inherent in a data collection of this sort, as no two days have identical atmospheric conditions. In addition, the sampling protocol was slightly modified starting in Spring 2009 to better characterize light parameters at the below dock sensors in the early and late times of the day when sun angle is low. At certain orientations, low-angle sunlight would reach under the docks because they were short (13-20 feet long) compared to docks installed in the field (100-2000 feet long). We overcame this issue by installing plywood extensions at the ends of the mocks docks, identical in width, to give them a longer effective length. However, the light at these times is dim and does not provide much PAR to the daily total. Comparison between our pre- and post-extension data shows similar patterns and intensities in PAR.

2.1.1.2 Height Data

Beginning in spring 2010, the second year of mock dock data collection examined the effects of dock height on shading effects. Using data from the earlier orientation experiment, the mock docks were oriented at 0 degrees, the orientation that allowed the most light to pass through the decking materials and which provided the clearest pattern of shadow migration. Dock height effects on dock shading were quantified at 1 foot increments from 8 to 4 feet, by removing 1-foot sections from dock pilings. Data were collected during fall, winter, spring and summer. PAR was recorded above and below each of the docks, at each height, using the same methods described in the orientation experiment. Dock extensions were not required in this orientation.

2.1.1.3 Data Analysis

Raw PAR sensor data from the dataloggers was converted to PAR (µmol $m^{-2}s^{-1}$) using pre-established calibration multipliers. In rare instances, when scattered clouds were unavoidable in the Summer data, the drop in light intensity was removed from the PAR curves in *both* above and below sensors to provide a more representative daily PAR value, but only if the signal was within the flanks of the PAR curve. No data were removed when shadows were present under the docks, because the effect of clouds cannot be separated from the rapidly changing signal of light penetration through the materials. However, summer has the highest light intensity and strongest signal of light penetration through alternative materials, so the effect of these small alterations should be minimal.

For each day data were collected, a daily PAR curve was created to compare and contrast above and below sensor data. The integrated area under the above and below curves was quantified using TableCurve 2D® computer software (Systat, Inc.). The above and under sensor's integrated area was compared to determine the percentage of PAR lost/gained under the dock using alternative dock materials at different seasons, compass orientations and heights (Figure 1). These integrated areas were further partitioned into areas of shadow (Area A), representing the loss of PAR from the presence of the dock structure, area beneath the shadow (Area B), representing indirect PAR received during time of shadow with a non-transmissive dock in place, and area of light penetration (area C), representing the amount of additional PAR received under the dock because of the alternative materials (see Figure 14).

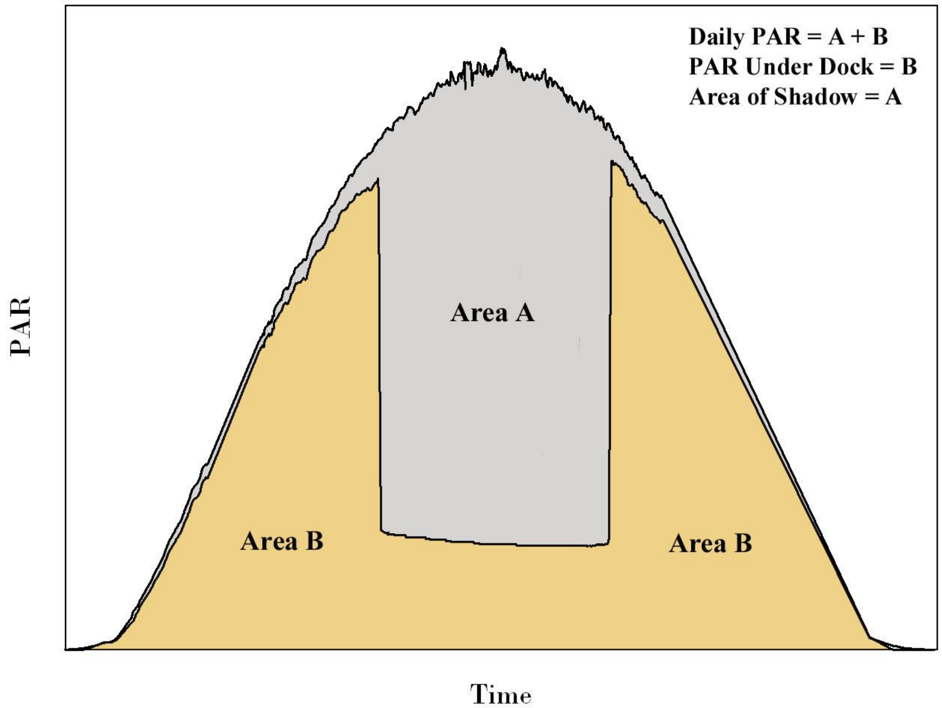


Figure 1. Example of light sensor data produced by the Traditional dock.

To determine estimates of biomass loss due to dock shading, biomass loss thresholds with respect to shading were established using new, unpublished shade treatment experimental data for *S. alterniflora* from Sapelo Island, GA (Steve Pennings, University of Houston; unpublished data). The data were collected as part of the NSF-funded Georgia Coastal Ecosystems – Long Term Ecosystems Research (GCE-LTER) project, a large, ongoing project studying salt marsh ecosystems.

Shade treatment data were collected using mesh fabric shades approximating 0%, 30%, 40%, 60%, and 80% PAR loss. Multiple replicate *S. alterniflora* plants were placed in an experimental enclosure at the University of Georgia Marine Institute on Sapelo Island under these shade treatments. PAR measurements were collected both beneath the shaded plots and outside of the shaded area. These measurements were used to calculate the light transmittance for each shade treatment. Over the course of a summer, biomass loss beneath the different shade treatments was quantified.

To determine our BLTs, a curve was created correlating the biomass reported losses and the percent shade for each treatment. A polynomial was fit to the data to produce an equation relating % shading to % biomass loss (Figure 2). From this equation, we were able to predict biomass loss at 0%, 25% and 50% shading (Table 1). PAR measurements taken inside and outside the experimental enclosures were used to determine an equation to describe the relationship between PAR and % Shade (Figure 3). We then used this equation to determine critical PAR levels for 0%, 25% and 50% biomass loss (Table 2).

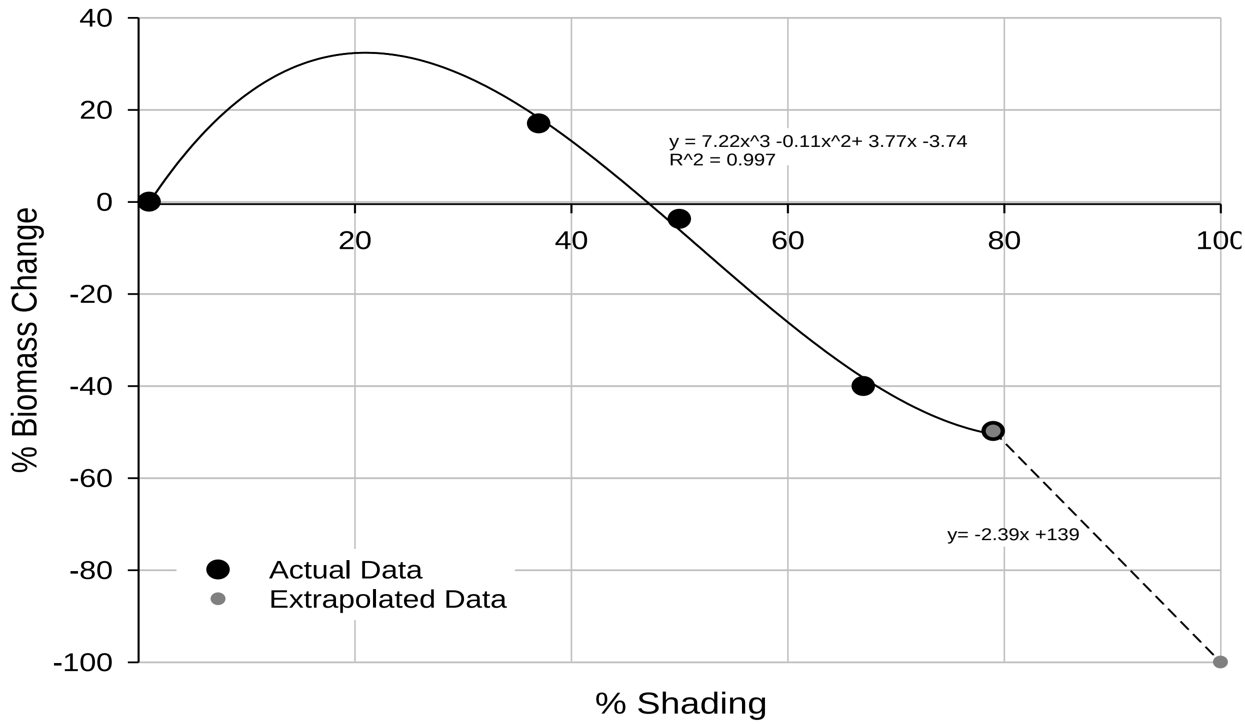


Figure 2. Change in biomass with increased shading in greenhouse experiments on Sapelo Island, GA. The polynomial curve was not fit beyond the experimental data, but extrapolated linearly from 80% shading to 100% shading, assuming that at 100% shade, there would be 100% biomass loss. Note enhanced biomass production centered on 20% shading, suggesting inhibition of photosynthesis in *S. alterniflora* at higher ambient light levels.

Table 1. Biomass Loss Thresholds from shading calculated from equation based on *S. alterniflora* field experimental data in Figure 2.

BLTs as a Function of % Shade
0% Biomass Loss = 46% Shade
25% Biomass Loss = 61% Shade
50% Biomass Loss = 79% Shade
Regression Equation
$y = 7.22x^3 - 0.11x^2 - 3.77x - 3.74$

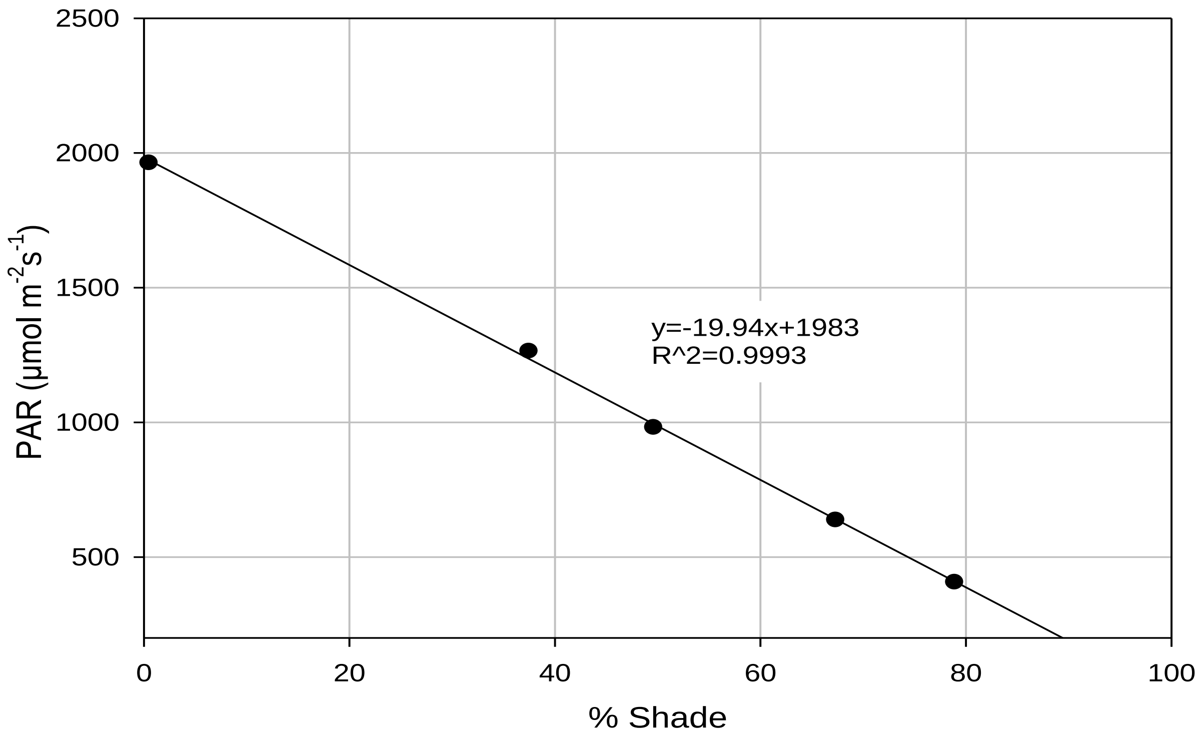


Figure 3. Incident PAR received in relation to shading in greenhouse experiments on Sapelo Island, GA.

Table 2. Critical biomass Loss Thresholds related to PAR requirement. Calculated from data in Table 1 and equation based on *S. alterniflora* field experimental data in Figure 3.

BLTs as a Function of Incident PAR Values
0% biomass loss = 46% shade = 1072 µmol $m^{-2}s^{-1}$
25% biomass loss = 61% shade = 767 µmol m^{-2} s^{-1}
50% biomass loss = 79% shade = 407 µmol m^{-2} s^{-1}
Regression Equation
y = -19.94x + 1983

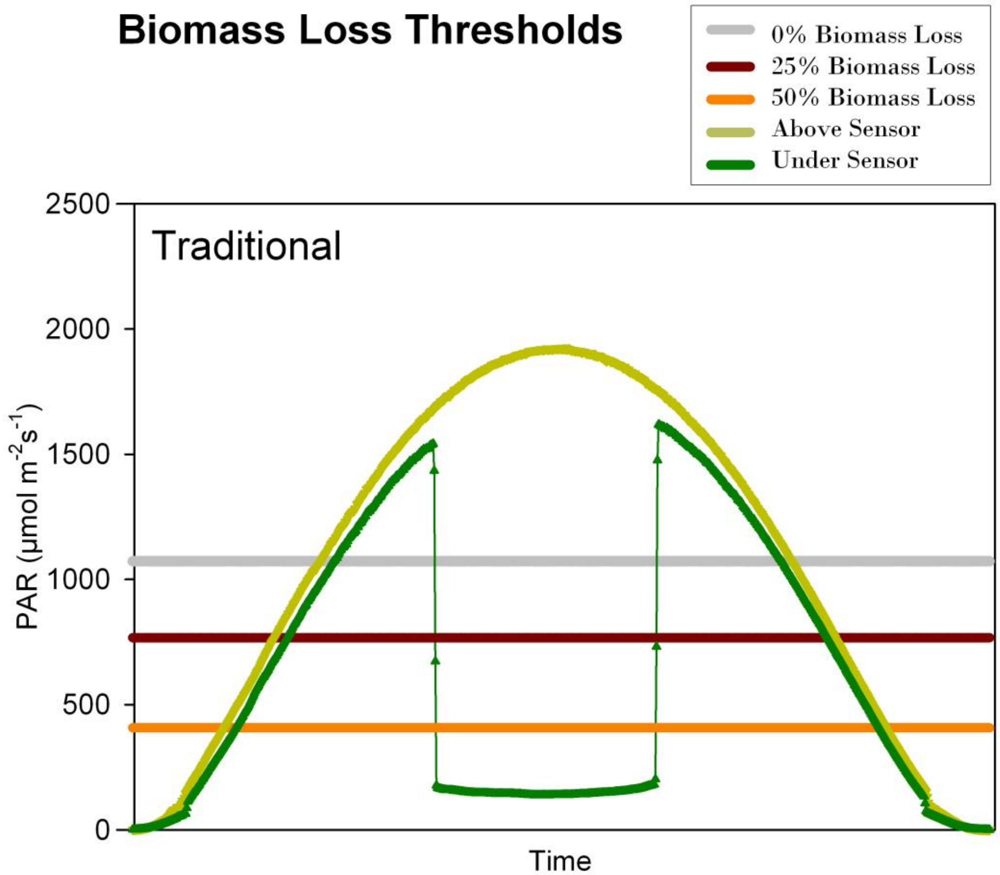


Figure 4. Example of PAR data from the "above" and "below" sensors for the Traditional Dock at 5 feet and 0 degrees.

Dock shading impact was further appraised by looking at shadow durations. Shadow durations were quantified to understand the amount of time plants experience reduced light levels each day. The length of time that the shadow was beneath the dock was determined by looking at the "under" dock sensor data. Durations were also applied to the biomass loss thresholds. Unlike the daily shadow durations, the thresholds took into consideration the various material properties. During the time above the threshold, each minute that dropped below the established PAR for that threshold was counted as a minute of shadow and each time the light rose above a given threshold, it was counted as time above the threshold (see Figure 8). This technique takes into consideration when grated materials allowed for PAR to rise and fall above a given threshold.

2.2 Field Data Collection

2.2.1 Site Descriptions

As a complement to our mock dock studies and to assess vegetation response to alternative material use, field studies were carried out on three docks using the materials and construction methods we investigated with the mock docks. Field collections were conducted from 2007 to 2010 to assess biomass, stem density, stem height, chlorophyll a, phaeophytin, sediment organic carbon, pore water salinity and sediment grain size associated with a traditional dock, a Thru-Flow-decked dock and a Dockrider-style system. Field samples were taken in October to capture maximum biomass conditions, which is the end of the growing season for *S. alterniflora*. Pre-dock data was collected as determined by the dock construction schedule. Although the original plan was to document only large, community facilities, and to have pre-construction data for every field site, plans for pre-dock sampling and the types of docks documented had to be modified because of a cessation in community dock-building activity with the continuing economic downturn, which began shortly after this grant was funded.

The first field site was located at Shell Point Cove (SPC) at Pine Harbor, a subdivision in McIntosh County, Georgia. This is a community facility that consisted of a Dockrider Systems SunDock™, although it was not built by Dockrider, LLC. Field sampling began at this site before dock construction in 2007 and continued post-construction annually in 2008, 2009 and 2010. The dock at this site trends 115°, is 1743 feet long and ranges from 1.2 to 6.5 feet above the marsh surface. The dual rail system consists of rails 5.5 inches wide. The rails run parallel to each other 2.67 feet apart. Pilings are approximately 7.5 inches in diameter and have a pile spacing of 9.5 feet. The SPC dock traverses several terrains. The station nearest the land (SPC, Site 1) consists of sandy muds with *Juncus roemerianus*. Sites 2-13 consist predominantly of muds occupied by *Spartina alterniflora,* with a creek bisecting the dock at site 6. Between sites 13 and 24, the sediments become sandier and are well-drained during low tide. At the start of this study, this area was dominated by *J. roemerianus*, with some *Salicornia europaea* and *Distichlis spicata*. As the dock nears the channel and the terminal platform, sediments become muddy again, and *S. alterniflora* dominates.

The second field site is a private recreational dock located on Turners Creek (TC), in Chatham County, Georgia. Field sampling began at this site before dock construction in 2008 and continued post-construction annually in 2009 and 2010. The dock is constructed of Thru-Flow fiberglass impregnated plastic decking. This dock at this site trends 116º, is 674 feet long, 5 feet wide and has a pile spacing of 9.5 feet. It is the tallest dock in our study, ranging from 8.7 to 9.5 feet above the marsh surface. This dock has a 3 foot railing and crosses a muddy *S. alterniflora* marsh with numerous bifurcating tidal creeks that pass under the dock.

The third field site is a private recreational dock located on Betz Creek (BC) in Chatham County, Georgia. This dock is constructed of traditional wood planking and functions as a control for our alternative-material dock assessments. This dock, built in 1998, is 442 feet long, 6 feet wide and has a pile spacing of 13.5 feet. It ranges from 3.5 to 5.8 feet above the marsh. Stations 1, 2 and 3 trend 0º, station 4 is located where the dock changes orientation and stations 5, 6, and 7 trend 60°, so this dock captures the signatures of two dock orientations. This muddy site exhibits a few small drainage creeks and is dominated by *S. alterniflora*. Pre-construction sampling was not possible at this dock, but it was sampled in both 2009 and 2010.

2.2.2 Field Dock Data Collection

Sampling at each field dock was carried out following the same protocol. Each station represents a pair of sampling sites, one placed below the dock (the "dock" sample) and one placed 5 meters perpendicular to the dock sampling site (the "control" sample), starting at the marsh/upland boundary and extending out along the dock at 20-m spacing. Stations are numbered, with station 1 at the marsh/upland boundary, and dock and control sites designated Station 1D and Station 1C, respectively. Each sample site was located with a Trimble sub-meter Geo-XT GPS and a 0.25 m^2 quadrat was placed on the marsh at the site location. Adjacent to the quadrat, surficial sediment samples were collected in a whirl-pak bag for grain size and organic carbon and placed in a cooler. Chlorophyll samples were collected directly into acetone pre-rinsed, pre-weighed, polypropylene falcon tubes and also placed in the cooler. Stem density counts were made within the quadrat at ground level. Biomass samples were collected by clipping at ground level all dead and live *S. alterniflora* within each quadrat. Pictures were taken during each sampling effort; during the final 2010 sampling, before and after images of all clip plots were captured.

In the lab, *S. alterniflora* stems were cleaned and divided into live and dead categories. The live stems were measured for height. Dry weights for both the live and dead stems were determined by placing them in individual, pre-weighed aluminum foil pouches and oven drying them at 80º C for 48 hours (Cramer et al., 1981; Gross et al., 1991; Kirby and Gosseling, 1976).

Organic carbon samples were kept frozen until analyzed, then dried and ground with a mortar and pestle. Dried samples were placed into precombusted scintillation vials and one sample fraction was run through a Carlo-Erba CHN analyzer to determine total carbon content. A second sample fraction was weighed, digested 3 times using 5% HCl, then rinsed 3 times with double deionizer water. Samples were then dried at 102º C for 2 days and then reweighed to determine carbonate content by difference. The amount of carbonate carbon in each sample was used to derive the amount of organic carbon in the sample by difference from the total carbon measured earlier.

Chlorophyll samples were returned to the lab the day of collection and placed in a dark freezer to avoid degradation. Within two weeks, pigments were extracted using 90% acetone and allowed to sit in the freezer for 24 hours. Chlorophyll-*a* and Phaeophytin were quantified using spectrophotometric techniques. After extraction, the remaining sample material was dried and weighed to ascertain the amount of chlorophyll per gram of sample.

Salinity samples were weighed wet, then dried for 4 days at 50ºC. They were then reweighed to determine water content. A known amount of deionized water was added and the resulting supernatant was measured for salinity using a refractometer.

Grain size was determined using ¼-phi interval sieves for the sand fraction (0ϕ to 4ϕ; 2 mm to 63 um). The silt and clay fractions (4ϕ to 12ϕ; 63 um to 0.25 um) were quantified by settling velocity using a Sedigraph 5100 (Alexander et al., 1991).

2.3 Field Light Transmittance Study

Two parameters further affect the light plants receive for photosynthesis in a salt marsh: the canopy density and inundation by turbid waters by the tides. A short study was conducted on Skidaway Island in the fall of 2010 to better understand the effects of these parameters on the quality, extent and duration of light encountered by *S. alterniflora*. These data serve as a first examination of these issues in Georgia.

2.3.1 Canopy

A 1-m long, Line Quantum Light Sensor (Li-Cor Biosciences, model LI-191) was placed in a *S. alterniflora* marsh near Skidaway Institute of Oceanography to determine the effect of varying canopy densities on light delivery to the marsh surface. The line sensor was installed 10 cm above the marsh surface, in a N-S orientation, during low tide in the middle of the day. The sensor was placed in low, medium and high density stands of *S. alterniflora* on three consecutive days to best characterize canopy light penetration. Stem density and plant height were quantified in a $0.25m^2$ quadrat. A point quantum sensor (Li-Cor Biosciences, model LI-190), identical to those used for the mock dock study, was placed on a nearby dock to determine incident PAR to the site. Data from the line and point sensors were used to calculate light transmittance through the canopy to the marsh surface.

2.3.2 Water Column Turbidity

Light transmittance through the water column during a tidal cycle was measured using a Spherical Quantum Sensor (Li-Cor Biosciences, model LI-193). This parameter was determined over a tidal cycle in a major tidal channel (the Skidaway River) and on a marsh platform near the Skidaway Institute. The sensor was placed at low tide in an unvegetated area such that the spherical sensor would be inundated during high tide in the middle of the day. A Hydrolab MiniSonde Model 4a was placed next to (and below) the sensor to record water temperature and depth. Light transmittance over the tidal cycle was calculated and plotted alongside tidal height to illustrate trends in light penetration through the water column during a tidal cycle.

3.0. Results

The mock dock study took place over two years from 2008 to 2010. The results from this study are presented here in graphical form along with a text discussion for easier interpretation. Data for Figures 5-35 are presented in Tables 3-22 in Appendix 1.

3.1 Orientation

3.1.1 Shadow Duration

Shadow durations under the mock docks were examined at dock orientations of 0º, 45º, 90º and 135º to determine the amount of time vegetation beneath the docks spent at reduced light levels. Durations were determined to the minute from seasonally collected light data. Dock orientation produced consistent responses in shading that were dependent on the sun's angle relative to season of data collection.

During the fall and winter experiments, the sun's angle of declination was negative and the angle of altitude was low (approximately 35º to 45º) and shadow durations were short: 1 to 4 hours. Docks oriented at 90º and 135º produced the shortest shadow durations beneath the docks. Because the traditional, ThruFlow and Fibergrate docks exhibited similar behavior, results for the traditional dock will be discussed as illustrative of all three. The 90º orientation produced shadow durations for the traditional dock of only 0.70 hours in fall and 0.75 hours in winter, at 135º the traditional dock produces 2.13 hours of shade during fall and 2.68 hours during winter. The 0º and 45º orientations created longer durations ranging from 2.77 hours (fall at 0º) and 3.42 hours (fall at 45º) (Figure 5, Table 3).

In contrast, during the spring and summer experiments when the sun's angle of declination was positive and angle of altitude was high (approximately 65º to 80º), the shortest shadow durations beneath the docks occurred when they were oriented at 0º and 45º, and the most shade was produced beneath the dock at orientations of 90º and 135º. Shadow durations were longer as well: 4 to 10 hours. These results occur because the shadows at 90º and 135º were cast north of the dock footprint in the fall and winter when the sun angle was low, but were cast under the dock footprint in the spring and summer when the sun angle was high. When oriented at 90º, the traditional dock received 6.76 hours of shade in spring and 10.12 hours during summer. The orientations of 0º and 45º produce between 3.46 hours (spring 0º) and 4.17 hours (summer 45º) of shade (Figure 5**)**.

The SunDock system had much lower shadow durations in all orientations and seasons, except for 90º and 135º in the fall, when results were similar to that of the other docks. Of the three decked walkways, the traditional and ThruFlow decking typically exhibited similar shadow durations, followed by the Fibergrate decking. Other factors being equal, the Fibergrate decking should provide the longest shadow duration because the decking was 1 foot wider than the traditional or ThruFlow walkway. Mock dock data measure when the shadow was present under the middle of the dock at the point sensor. Our estimates of shadow duration are conservative estimates, as part of the shadow is present under the dock prior to and after passing over the sensor under the dock.

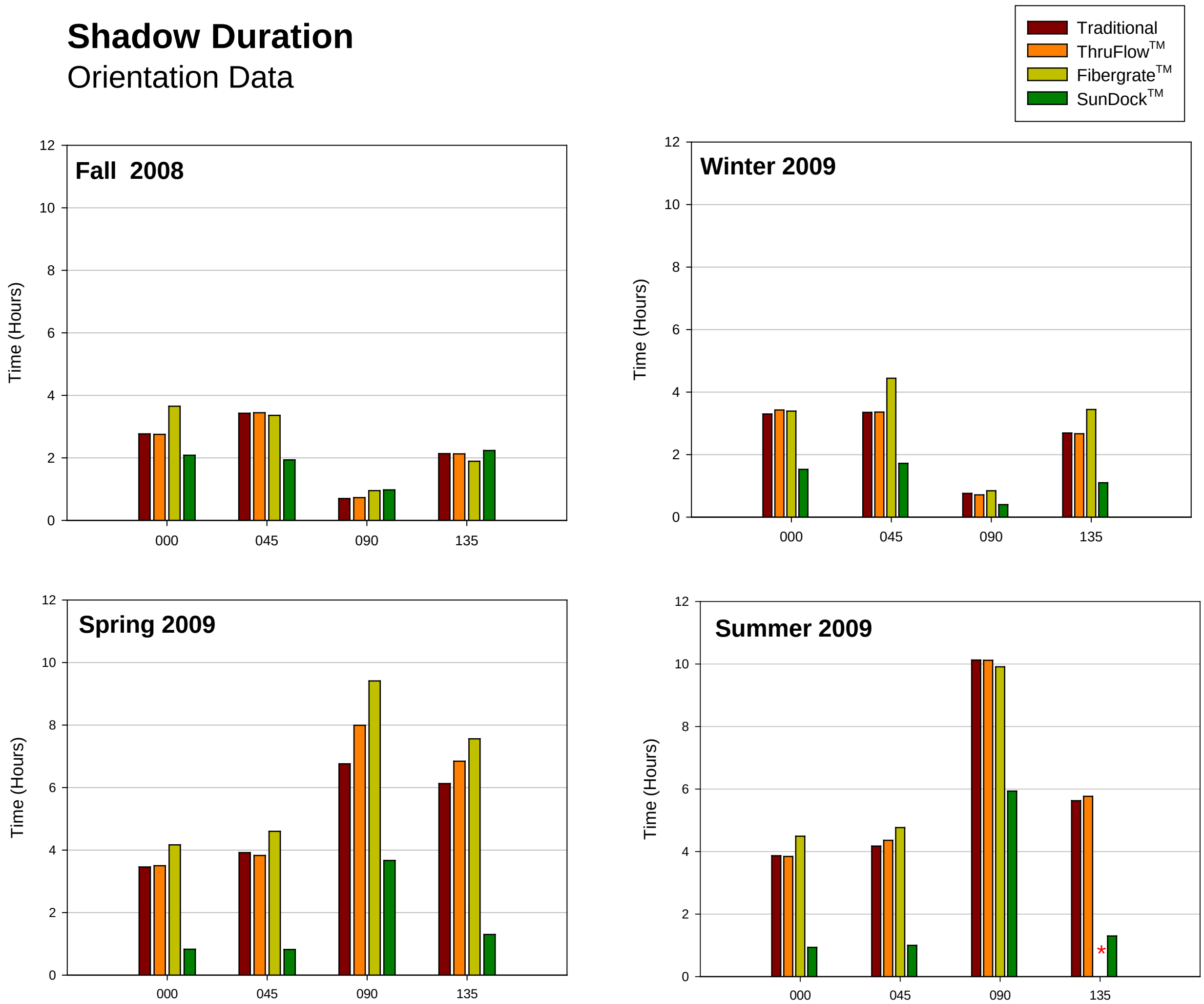


Figure 5. Shadow durations under mock docks at different orientations and seasons. Asterisk in summer 2009 plot denotes that the ending shadow was unable to be determined due to cloud cover.

3.1.2 Integrated Area of PAR

The integrated amount of PAR received above and below the docks was determined to further understand the decrease in light underneath walkway structures. The amount of daily integrated PAR lost was calculated by taking the area of the shadow and calculating what percentage it constituted of the total area of daily PAR (Figure 1). The PAR lost due to dock shading shows similar trends to that of the shadow duration data. During fall and winter, the 90º and 135º orientations exhibited the lowest reductions in PAR; for traditional decking there was a 24% and 9% loss in fall and winter, respectively. The 0º and 45º orientations exhibited the greatest PAR loss, for the traditional decking there was a loss of 40% and 49% at 0º and 45º, respectively (Figure 6, Table 4). As with the shadow duration data, the Dockrider exhibited much smaller decreases in PAR in all seasons.

As with shadow duration, the spring and summer data were distinctly different from that determined in fall and winter. For the traditional dock, PAR loss at 0º orientation was similar to that found in fall and winter at 44%. However, during spring and summer this general quantity of lost PAR represented the minimum value, not a maximum value as it did in fall and winter. In contrast, orientations of 45º, 135º and 90º showed greater PAR losses for spring and summer with averages for the two seasons of 54.5%, 61%, and 73% loss, respectively. The summer displayed elevated PAR loss compared to spring, especially at the 90º and 135º orientations (Figure 6).

From these results, decked walkways clearly decrease the amount of incident PAR underneath them. In fall and winter, there is about a 40% PAR loss when docks are oriented at 0 and 45 degrees, whereas they decrease incident PAR between 8 to 25% when oriented at 90 and 135 degrees. During spring and summer, there is about a 40% PAR loss when docks are oriented at 0 and 45 degrees, and a decrease in PAR by about 60-80% when docks are oriented at 90 and 135 degrees.

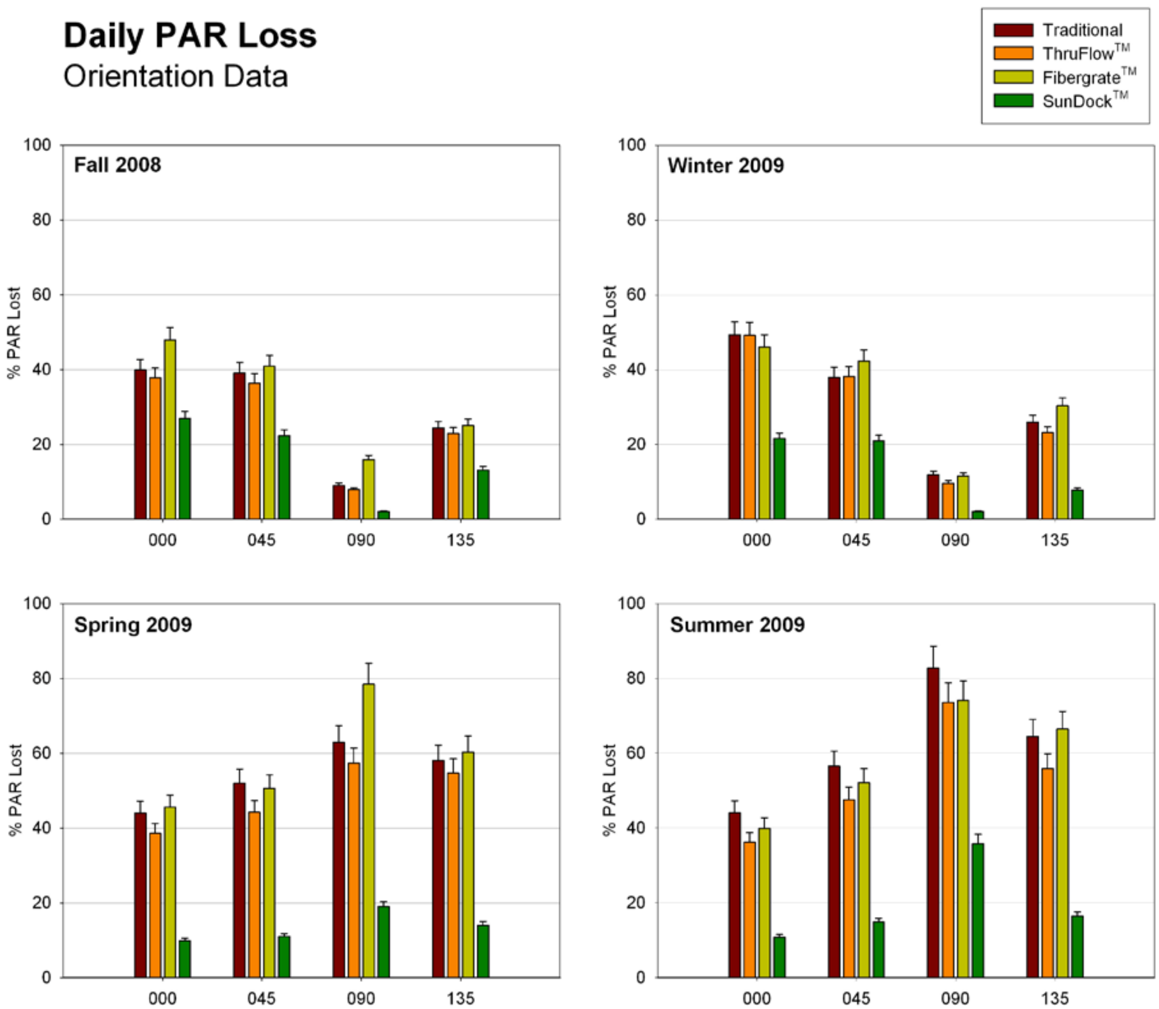


Figure 6. Daily PAR loss for seasonal and orientation variables. Percentages represent the areas of shadow compared to the area of unobstructed PAR received in daily PAR curves. See Figure 1 for discussion of shadow and total PAR areas

3.1.3 Biomass Loss Thresholds

The 0% Biomass Loss Threshold (0% BLT) that was established using the field data from Sapelo Island (1072 umol/$m^{-2}s^{-1}$ PAR, see methods and Figures 2, 3, 4) typifies the PAR levels *S. alterniflora* needs for photosynthesis and growth without any loss of biomass production. Previous studies have shown that *S. alterniflora* increases photosynthetic activity with increased light levels to approximately 1000 umol/m-²s^{-1} PAR, at which time photosynthetic production ceases to increase, and often shows inhibition (Guirgevich and Dunn, 1982; Kathilankal et al., 2011). Note that the field data from Sapelo Island showed an increase in productivity between 0% and 46% shading levels, indicating that light inhibition was occurring at high PAR levels in these plants. However, when the percent shading decreased below 46%, *S. alterniflora* did not receive sufficient PAR and biomass loss began to occur. To assess how vegetation might be affected in suboptimal conditions below the 0% BLT, we established a 25% BLT and a 50% BLT at which we expect, based on our Sapelo data, a 25% and 50% biomass loss to occur from shading.

3.1.3.1 Shadow Durations above the BLTs

Incident radiation is above the 0% BLT for only a part of each day, a period centered on the sun's highest elevation in the sky. If, during the time when incident levels are above the 0% BLT, shadows are under the dock for a significant portion of that time, then that PAR is lost to the vegetation and biomass loss will occur to some extent. To determine how important this impact could be we assessed the lengths of time that the shadows were under the dock when PAR levels were above the 0% BLT. The orientation light studies indicate that, on average during the winter, only 4.3 hours of daily PAR is above the 0% BLT. During winter the traditional dock oriented at 90º spends only 13% of the time above the 0% BLT in shadow. At 135º orientation, the area under the dock spends 25% of the time in shadow, followed by 60% in shadow at 45º orientation and 83% of time in shadow at 0º orientation. The fall exhibits similar trends (Figure 7, Table 5). The SunDock system had much lower shadow durations during times when PAR was above the 0% BLT in all orientations and seasons.

By spring, 7.7 hours of incident light were above the 0% BLT. For the traditional dock, an orientation of 0º provides shadow durations that represent 53% of the time above the 0% BLT and as the orientation shifts from 45º to 90º to 135º, the shadow duration increases to 58%, 68% and 72% of the time above the 0% BLT, respectively. Summer data show slightly more time above the 0% BLT (7.9 hours) and similar trends to spring for the traditional dock (Figure 7). However, it is important to note that in summer, shadow durations in some dock orientations, particularly at 90º and 135º, almost equal or exceed the period of time above the 0% BLT, suggesting that these orientations should not be favored when constructing a structure in the marsh. Trends, observations and conclusions for the 25% BLT and 50% BLT are similar.

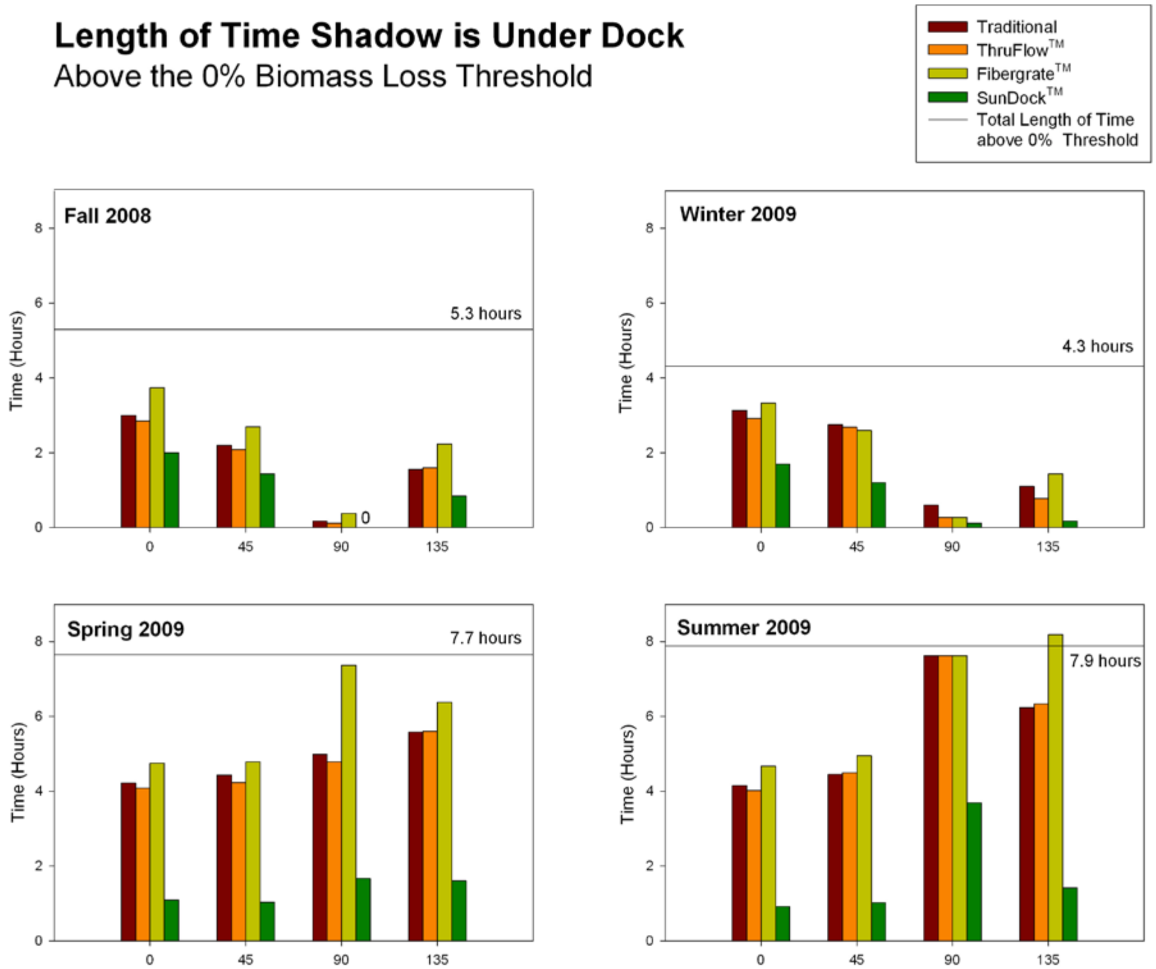


Figure 7. Length of time shadow is under the dock. Black line represents the number of hours per day during our sampling period when incident PAR was above the 0% BLT. During this time, the "length of time in shadow under dock" is calculated by counting each minute that PAR drops below 1072 umol/m^{-2} s^{-1} in incident PAR plots. This method takes into account light penetration through alternative materials.

3.1.3.2 Integrated PAR above the BLTs

The shadow duration data demonstrate that much of the time that incident PAR was above the 0% BLT, shade from the structure was reducing the incident PAR available to the vegetation under the dock. The area of PAR above the 0% BLT was compared to the area of shadow above the 0% BLT to quantify how much of the total available daily PAR above the 0% BLT plants received with dock structures in place (Figure 8, Table 6).

Results followed the trends seen in the shadow duration data. The Traditional dock during fall had little PAR reduction at 90º with only a 16% loss of PAR above the 0% BLT and showed the greatest reduction at 0º with 77% loss. During winter a 135º orientation exhibited the least PAR reduction with 33% loss and the highest reductions occurred at 0º with a 96% loss. Spring and summer data show large increases in the amount of daily PAR lost above the 0% BLT for all orientations, except at 0º, where results are similar between these two seasons. 0º presents the least PAR reduction in spring with a 74% loss in spring and summer. During summer the loss begins to diverge with a low at 0º of 75% loss and a high at 135º of 95% loss (Figure 9). As found with other datasets in this study, the SunDock had a much weaker effect on PAR loss (Figure 9). The 25% BLT and 50% BLT data exhibited similar patterns and trends as the 0% BLT data, but with somewhat smaller PAR loss (Table 6).

The large PAR losses above the 0%, 25% and 50% BLTs demonstrate that docks have a strong impact on the amount of PAR that reaches the vegetation below the structures. Traditional dock structures can effectively block 100% of the PAR above the 0%, 25% and the 50% BLT in some seasons and orientations (summer, 90º and winter, 0º). At these same seasons and orientations, alternative decking materials can only increase the amount of PAR reaching under the dock 2-8% at the same BLTs. Note that the additional PAR contribution of alternative materials is from transient, individual shafts of light that transit under the dock and do not provide sustained light for vegetation (Figure 8). During other seasons and orientations, the situation is not as dramatic, although the results for decked structures during spring and summer are notable in that no matter their orientation, they block 80-100% of the PAR above the 0% BLT. Under these same conditions, the SunDock blocks 20-40% of incident PAR above the 0% BLT.

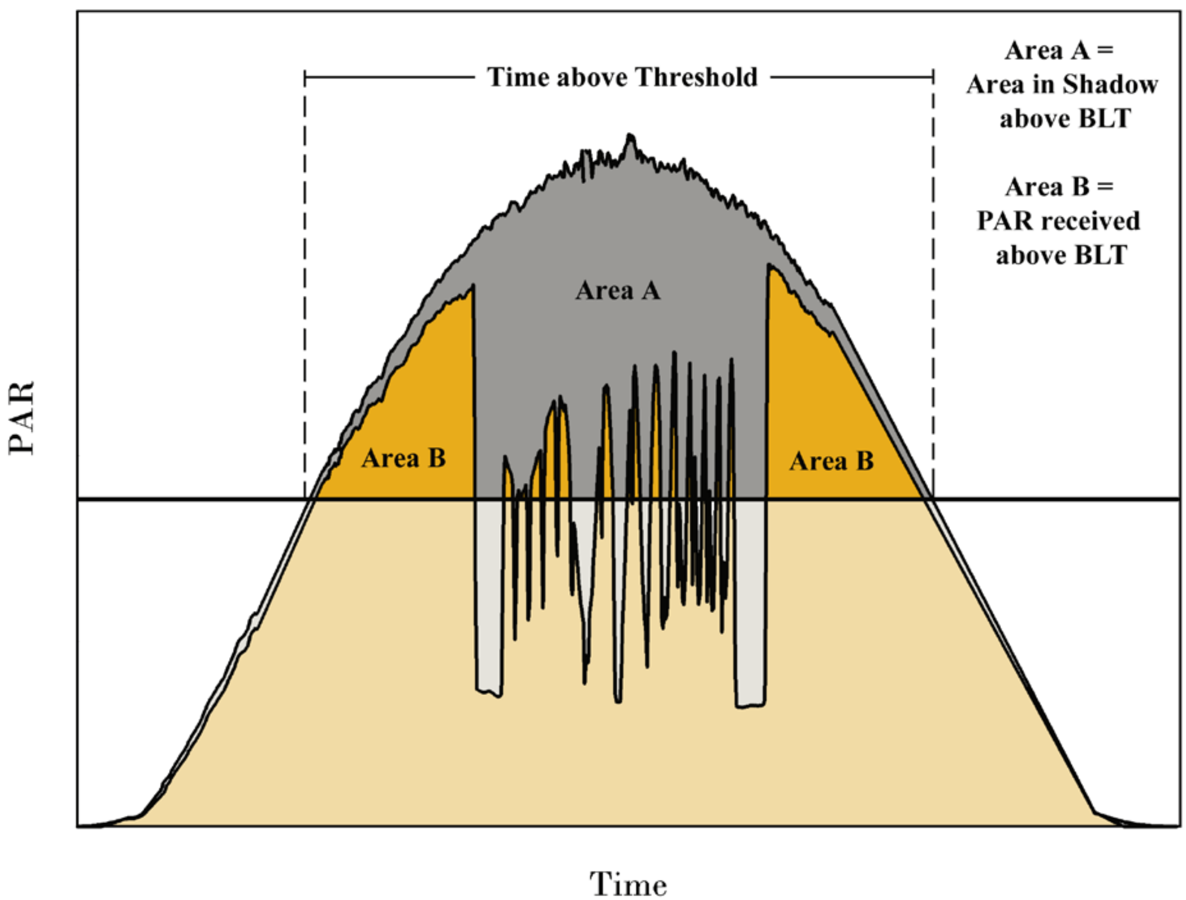


Figure 8. Schematic diagram of concepts used for determining time above biomass loss thresholds.

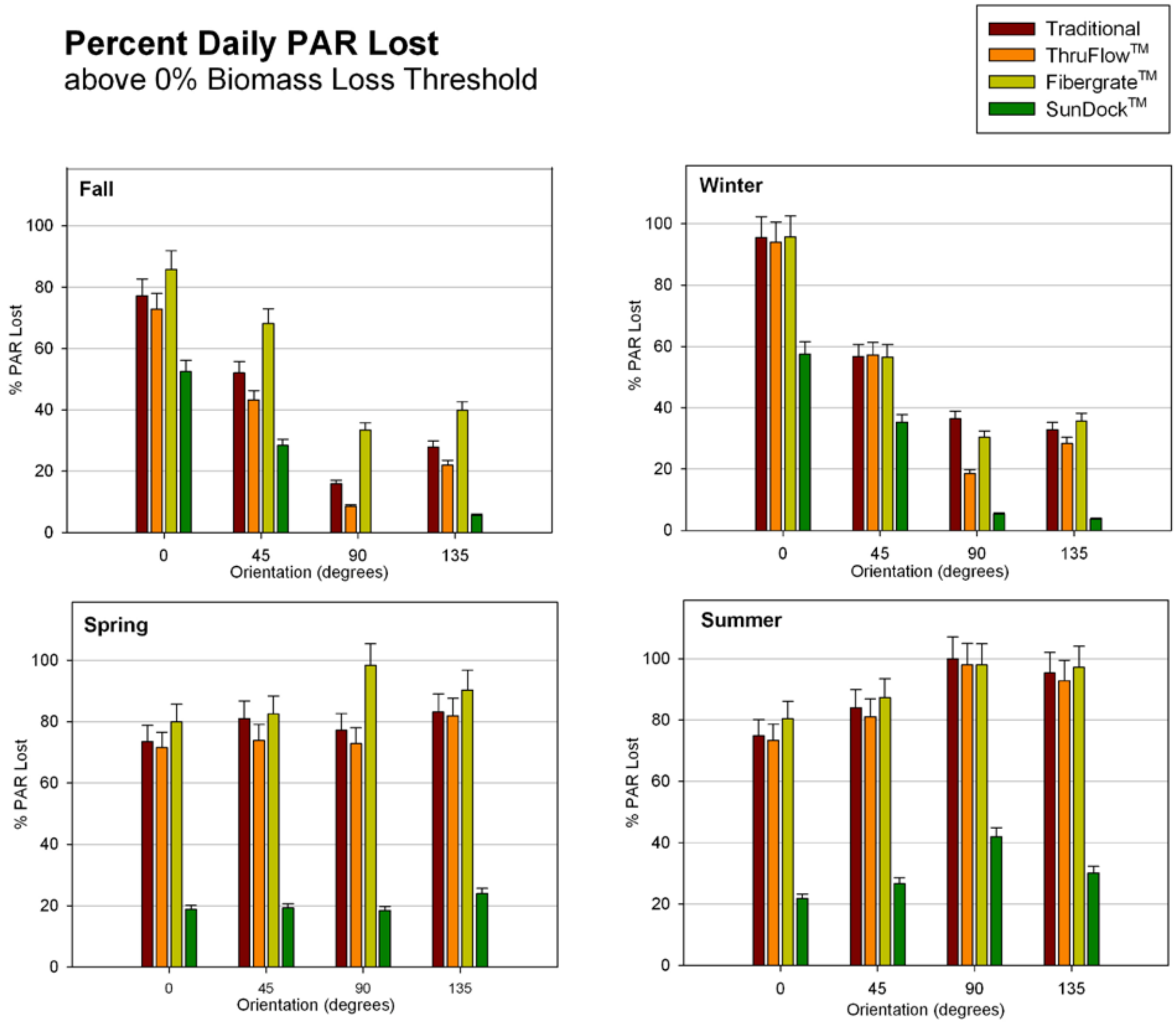


Figure 9. Daily percent PAR loss above the 0% Biomas Loss Threshold. Calculated by comparing the area of shadow above the 0% BLT to daily area above the 0% BLT (See Figure 8).

3.2 Height

3.2.1 Shadow Duration

PAR data for height was collected seasonally at 4, 5, 6, 7 and 8 feet with a dock oriented at 0º. In general, the data show that shadow durations under the docks decrease as height increases, as described by Burdick and Short (1999). At any given height, the Fibergrate dock exhibited the longest shadow duration because of its width, the traditional and ThruFlow docks produced similar shadow durations and the SunDock cast a shadow that was considerably shorter than the decked walkways (Figure 10, Table 7). Fall and winter data for the SunDock were difficult to collect, as the open support structure creates overlapping shadows at lower sun angles that are difficult to separate from that of the dock rails. Given the comparatively short shadow durations for the

SunDock, these small differences have a significant effect on the measured shadow duration in some cases. Even so, the shadow durations for the Sundock were shorter than those for the other dock materials and construction methods.

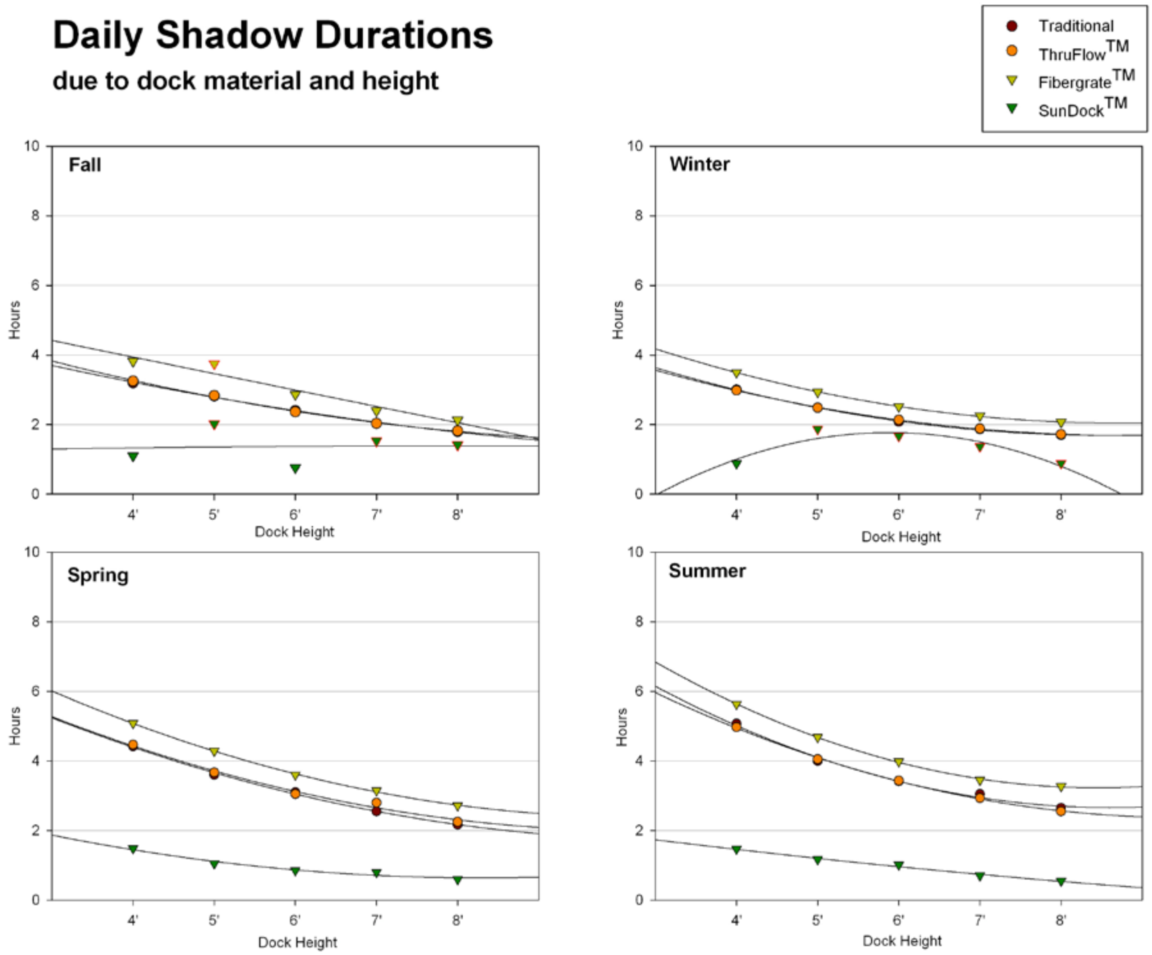


Figure 10. Shadow durations under mock docks at different heights. Red outlines on some SunDock symbols in fall and winter indicate times when shadows from the dock structure conjoined with the dock shadow, resulting in lengthened shadow durations.

3.2.2 Integrated Area of PAR

Daily PAR loss as a function of dock height was calculated in the same manner as it was as a function of orientation. Daily PAR loss decreased as dock height increased (Figure 11, Table 8). For the traditional dock and the other decked walkways, change in total incident PAR, and shadow areas, and thus in percentages of PAR loss, were similar across seasons. This characteristic was noted in the orientation data for 0° as well. The ThruFlow and Fibergrate docks were consistent during all seasons except summer when light penetration through the decking lowered PAR loss percentages. Across all seasons, the traditional dock averaged a 51% loss in daily PAR at 4 feet that declined to a 29% loss in daily PAR at 8 feet. The SunDock also displayed relatively consistent daily PAR loss percentages throughout the seasons. The few inconsistencies are attributed to support and piling shadows interfering with dock shadows as discussed in section 3.2.1.

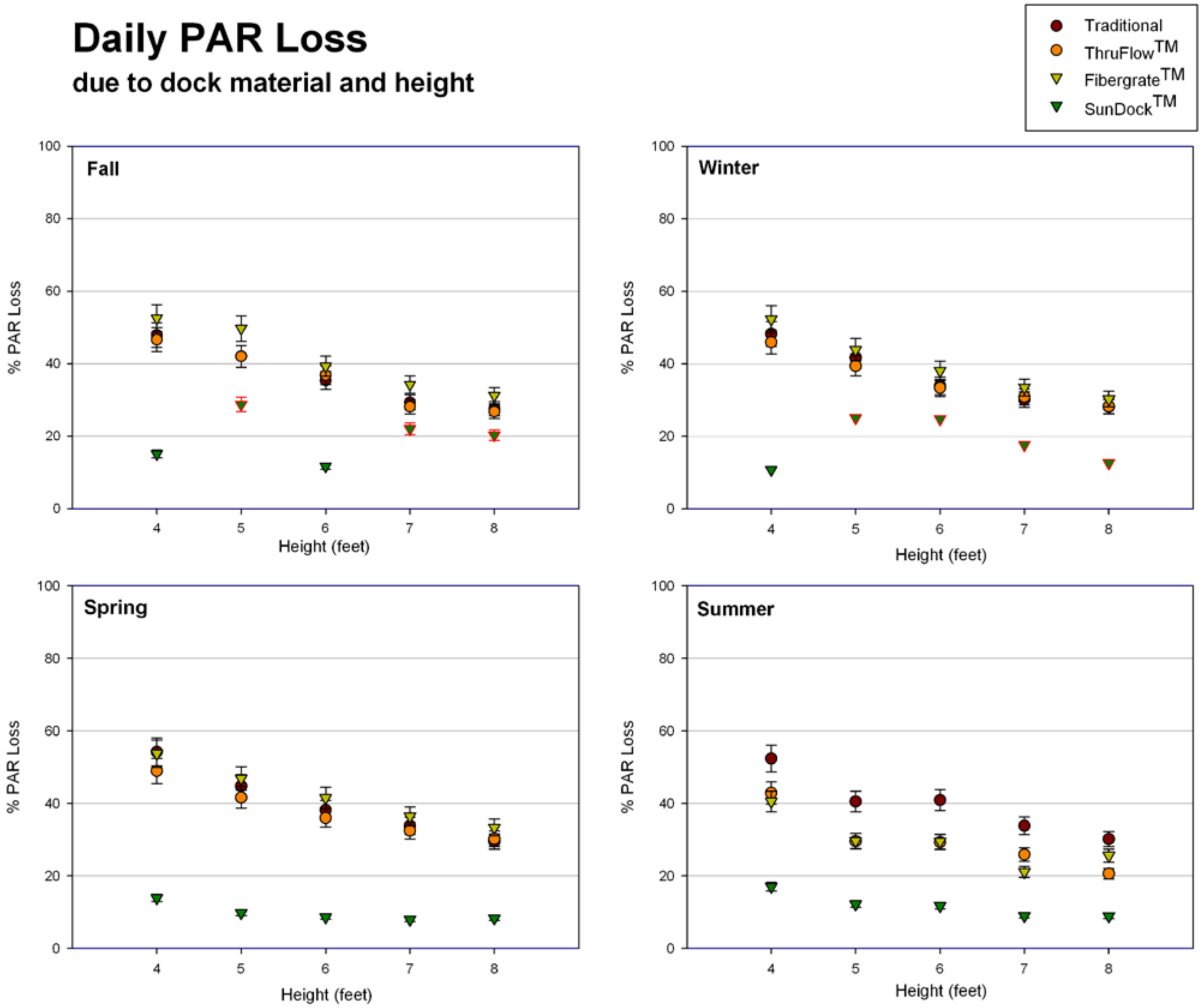


Figure 11. Daily PAR loss. Red outlines on some SunDock symbols in fall and winter indicate times when shadows from the dock structure conjoined with the dock shadow, resulting in lengthened shadow durations. Summer included days with scattered cloud cover contributing to variable PAR comparisons between days.

3.2.3 Biomass Loss Thresholds

3.2.3.1 Shadow Durations above the BLTs

The height studies indicate that during our winter sampling period, only 3.3 hours of daily PAR is above the 0% BLT. The percent of time the area under the dock spent below the 0% BLT is significantly higher during fall and winter compared to the spring and summer seasons. This is due largely to the limited number of hours of daylight that are above 1072 µmol $m^{-2}s^{-1}$, signifying the 0% BLT, during the fall and winter seasons. During the winter, daily PAR barely reached 1400 µmol $m^{-2}s^{-1}$ at solar noon allowing only 3.3 hours above the 0% BLT, while in summer daily PAR levels often reached 2000 µmol $m^{-2}s^{-1}$, providing 8.0 hours of incident PAR above the 0% BLT per day. For the traditional dock at 4 feet, the time spent in shadow during spring and summer is 64% of the time above the 0% BLT. The time in shadow drops to 55% of the time above the 0%

BLT at 8 feet (Figure 12, Table 9). This declining trend in shadow duration above the 0% BLT from short to tall heights is mimicked during winter and fall when 85-100% of the time is spent in shadow at 4 feet compared to 50-75% of the time at 8 feet. All seasonal data show decreasing shadow durations under the docks as dock height rises, except for the SunDock, which exhibited inconsistent data because of structural shadow effects as explained above. The SunDock system had much lower shadow durations during times when PAR was above the 0% BLT in all orientations and seasons. Trends, observations and conclusions for the 25% BLT and 50% BLT are similar.

It is important to remember that these data discussed above are for an orientation of 0º. In summer, shadow durations at 5 feet in height (from our orientation study) demonstrate that in some dock orientations, particularly at 90º and 135º, the time in shadow is almost equal to or exceeds the total time above the 0% BLT. That being the case, these orientations should be discouraged when constructing a structure across the marsh within State-owned water bottoms.

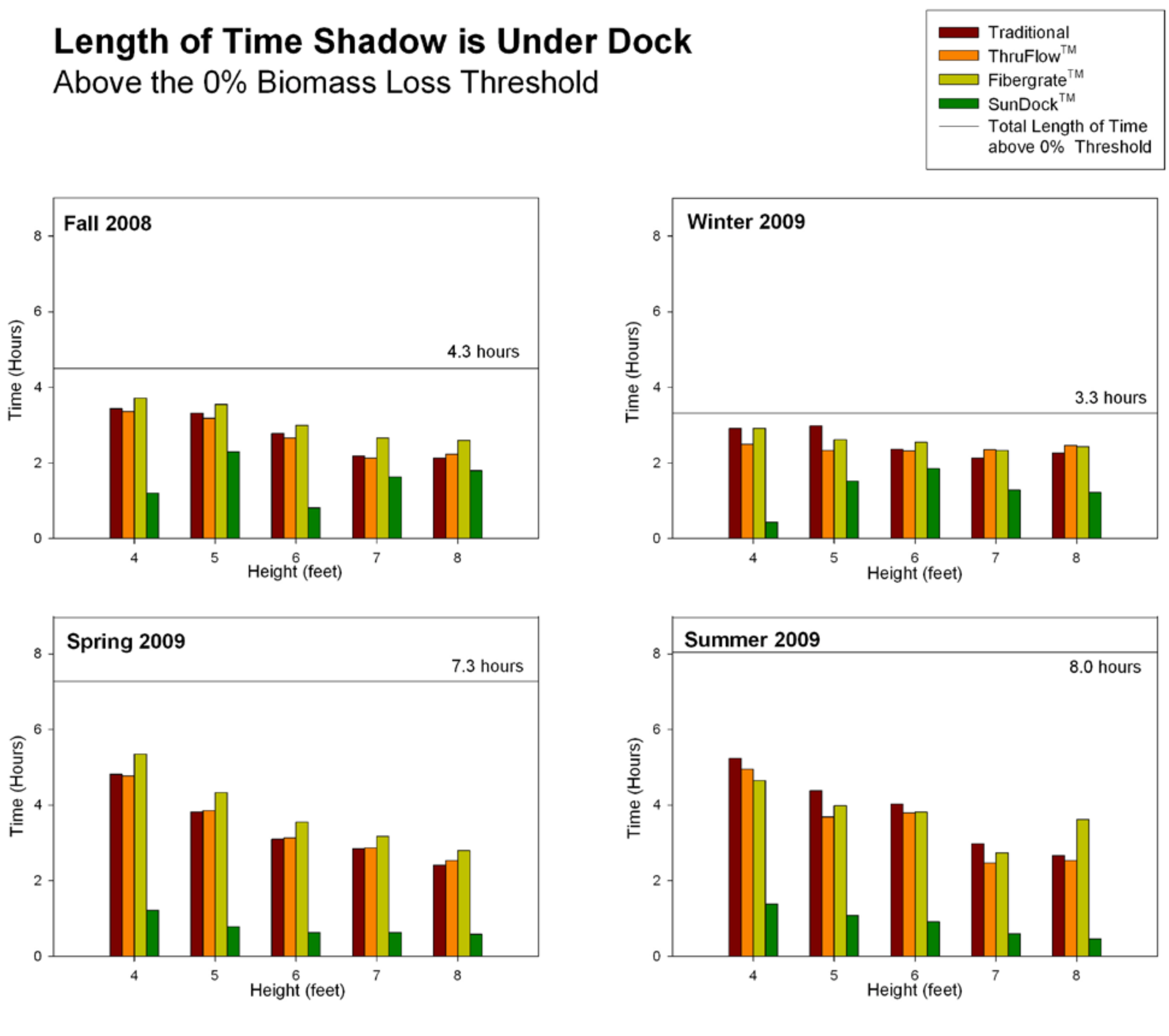


Figure 12. Length of time shadow is under dock above the 0%Biomass Loss Threshold. See Figure 7 for explanation of this figure.

3.2.3.2 Integrated PAR above the BLTs

The shadow duration data demonstrate that much of the time that incident PAR was above the 0% BLT, shade from the structure was reducing the incident PAR available to the vegetation under the dock. The area of PAR above the 0% BLT was compared to the area of shadow above the 0% BLT to quantify how much of the total available daily PAR above the 0% BLT plants received with dock structures in place (Figure 13, Table 10).

Results followed the trends seen in the shadow duration data with height. The Traditional dock (and other decked structures) during winter and fall exhibited PAR reductions of 86-100% of PAR above the 0% BLT at 4 feet and showed a lesser reduction at 8 feet with a 69-77% loss. Spring and summer data show decreases in the amount of daily PAR lost above the 0% BLT for all heights, with reductions of 74-87% of PAR above the 0% BLT at 4 feet and a lesser reduction at 8 feet with a 45-60% loss. As would be expected, the 8 foot data shows the least reduction in incident PAR. As found with other datasets in this study, the SunDock had a much weaker effect on PAR loss, with losses between 23-62% loss of PAR above the 0% BLT in the fall and winter, and a 15-40% loss of PAR in the spring and summer (Figure 13). As discussed earlier, the SunDock data collection for height was confounded by overlapping shadows. The 25% BLT and 50% BLT data for all docks exhibited similar patterns and trends as the 0% BLT data, but with a smaller PAR loss for any given height (Table 10).

As seen in earlier sections of this report, the large PAR losses above the 0%, 25% and 50% BLTs demonstrate that docks have a strong impact on the amount of PAR that reaches the vegetation below the structures. Traditional dock structures (in this study at 0º) can effectively block 90-100% of the PAR above the 0%, 25% and the 50% BLT in some seasons and at some heights (fall: 4 and 5 feet; winter: 4, 5 and 6 feet; spring: 4 feet). It is interesting to note that the ThruFlow grated material provides a small advantage over the traditional dock in fall and winter, as it allows some additional PAR (4-9% of the 0% BLT) to reach below the dock. However, this advantage declines at higher thresholds, with only 1-2% increase in PAR provided at the 50% BLT (Table 10). The Fibergrate dock was one foot wider than the other decked surfaces and would have longer shadow duration because of it. Our current data do not allow us to determine if the Fibergrate material would show similar behavior to the Thruflow material in terms of decreased PAR loss at the 0, 25 and 50% BLT over the traditional dock.

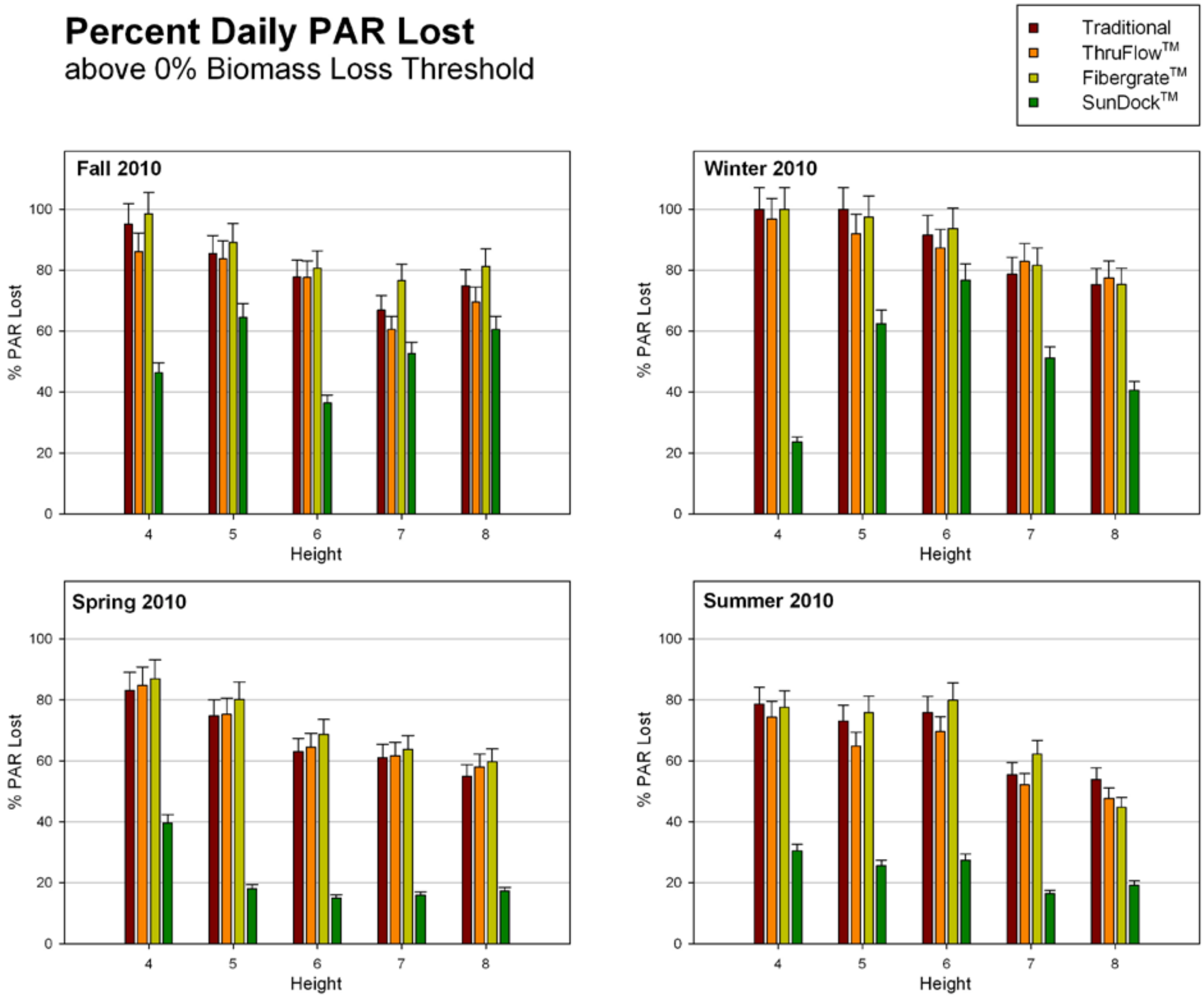


Figure 13. Daily PAR loss above the 0% Biomass Loss Threshold. Calculated by comparing area of shadow above 0% BLT to daily area above 0% BLT (See Figure 8).

3.3 Alternative Materials and Light Penetration

Four different dock materials were tested during this project; traditional wood planking, ThruFlow fiberglass-impregnated, plastic grating, Fibergrate fiberglass grating and the Dockrider Systems SunDock. Light penetration allowed by these materials was calculated by integrating the area of penetration in our PAR curves, that is, the amount of PAR received by the "under" sensor *during the time of shadow* as described in sections above. One complication in this comparison arises because of the nature of materials that are available. Wood planking can be cut to any width; most alternative materials and construction methods are only available in certain width options or built configurations. In this study, this applies to the 6-foot wide Fibergrate grating, which had greater daily PAR loss than the 5-foot wide traditional dock, when light penetration through the material was not occurring. Another consideration is that these materials all have requirements for how they are built to safely bear users. Supports below alternative decking materials can block much of the light that penetrates the materials, effectively negating the reason for the alternative materials in the first place. For example, the Thruflow dock requires five 2x4 stringers to support a 5-foot wide walkway.

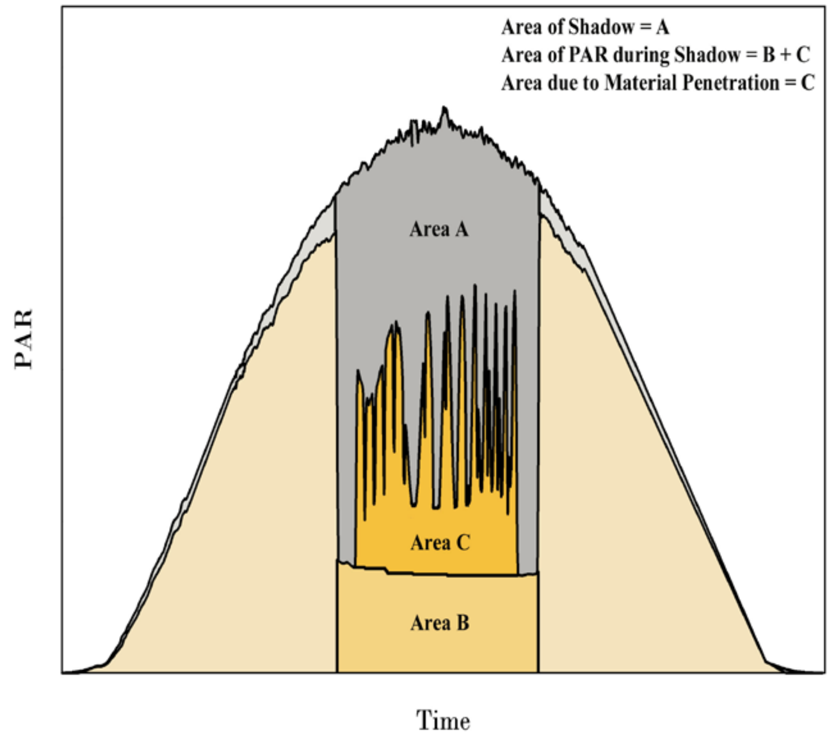


Figure 14. Schematic diagram of concepts used for determining the amount of light penetration through alternative materials. Area C is constrained by a 2-hour window around maximum insolation.

Daily light penetration was analyzed for alternative materials by comparing the daily amount of integrated PAR received by the under sensor for each material. Averaging the 5 foot data at 0° for 2009 (the orientation study) and 2010 (the height study) some seasonal trends are evident. During fall and winter, when the sun's angle of altitude is low (42º) and does not penetrate the grated materials, the equally wide traditional and ThruFlow docks exhibit a similar daily PAR loss. These docks average 41% PAR losses in fall and 45% losses in winter (Figures 6 and 11; Tables 4 and 8). The wider Fibergrate dock has the most PAR loss with an average 47% loss for the fall and winter seasons. In winter and fall, the SunDock has the least reduction in PAR with an average 26% loss.

During spring and summer the sun's angle of altitude increases to an average of 67º. The higher sun angle enables light to penetrate through the grated materials. The traditional dock and ThruFlow docks exhibit an average PAR loss in spring of 42% and in summer of 33%. The Fibergrate dock's light penetration reduces the PAR loss from 47% in winter to 35% in summer. The SunDock exhibits the lowest PAR loss in summer at 10%.

3.3.1 Daily PAR received compared to traditional decking

A direct comparison of alternative materials, using the traditional dock as a control, was conducted to quantify how these alternative materials and methods compare to conventional materials and methods. During fall and winter when light penetration through the alternative decking materials is small (Figures 5-7, 9-12), only the SunDock received more daily PAR than the traditional dock (Figures 15, Tables 11). For the SunDock, averaged 2009 and 2010 data exhibited 13% more PAR in fall and 22% more PAR in winter. The wider, Fibergrate decking averaged 7.8% less PAR in fall, and was essentially equal to the traditional dock in winter. The ThruFlow decking averaged 1% more PAR in fall and winter compared to the traditional dock. During spring and summer, the SunDock continued to exhibit considerably more daily PAR over the traditional dock, with an average of 39% more PAR daily in spring and summer. The Fibergrate dock averaged 1% less PAR in spring, but received an average of 7.6% more in summer. The ThruFlow dock received 4.3% more PAR in spring and 9.5% more in summer. Only during the summer do all alternative materials provide additional PAR to vegetation under docks when compared to traditional docks.

The dock height data illustrate that as docks get higher off the marsh surface, there is less advantage to using alternative materials (Figure 16, Table 12). As height increases, alternative materials retain the same characteristic advantage over traditional materials but the %PAR due to light penetration decreases (Table 14) and the shading effect of traditional materials decreases as well. Thus the relative difference between traditional and alternative materials decreases.

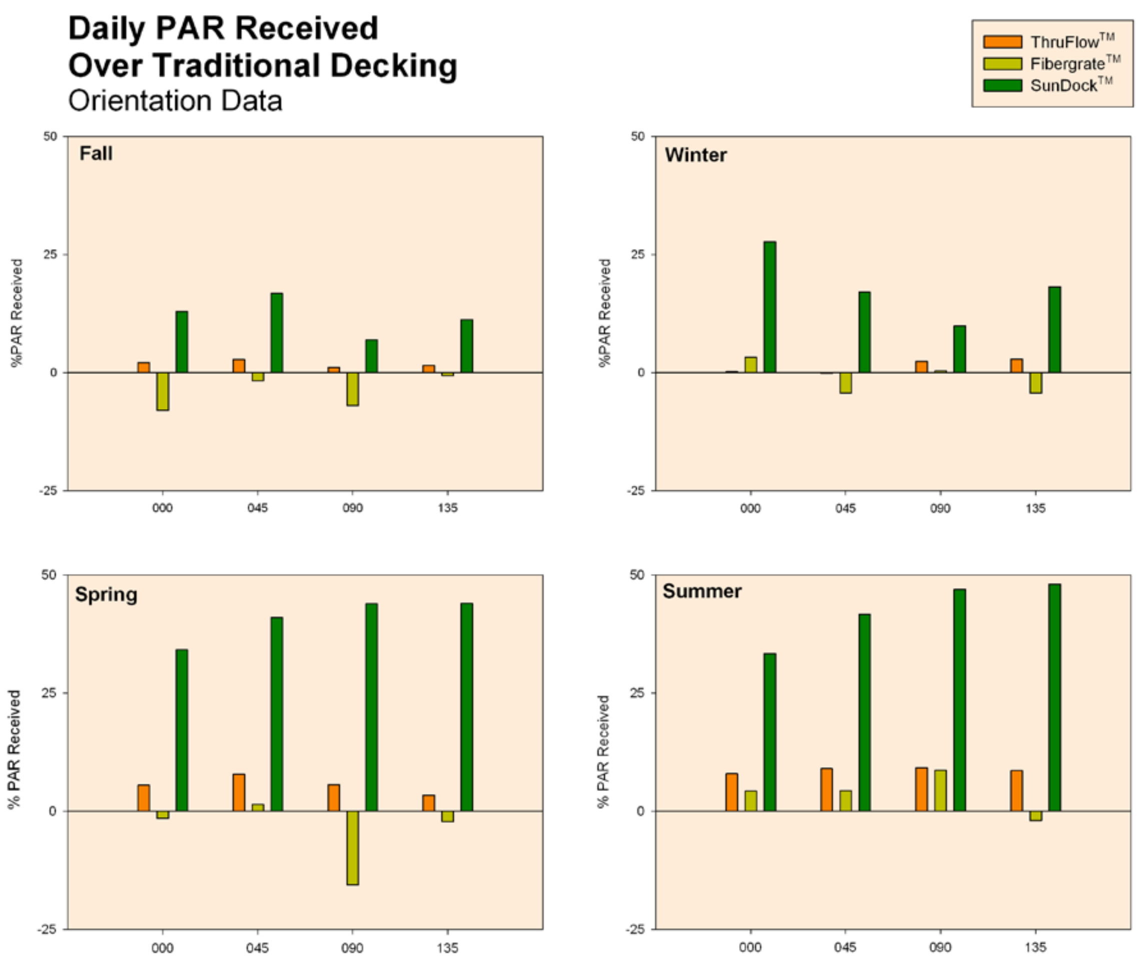


Figure 15. Percent additional PAR received under alternative docks at varying orientations. Quantity derived by subtracting %PAR loss with traditional decking from %PAR loss with alternative materials.

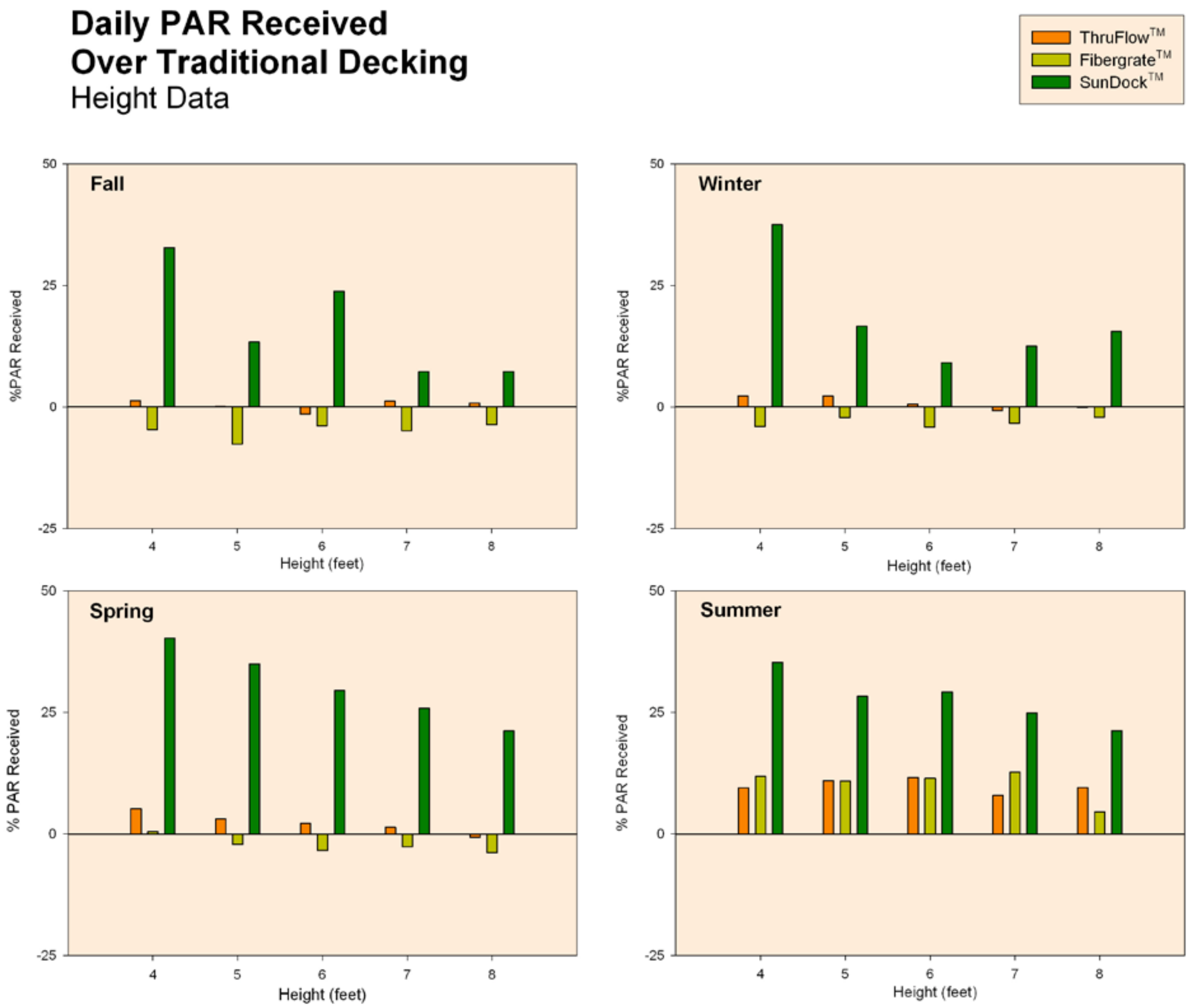


Figure 16. Percent additional PAR received under alternative docks at different heights. Quantity derived by subtracting %PAR loss with traditional decking from %PAR loss with alternative materials.

3.3.2 PAR received during shadow

A second light penetration analysis was conducted to further examine the properties of the two grated materials during the spring and summer. We focus on spring and summer as there is negligible penetration through alternative materials in the fall and winter (Figure 15 and 16). The two-hour interval around maximum insolation (and during the time when shadows were under the docks) was compared between grated materials to determine the amount of light being transmitted by the decking. This more-constrained analysis negates the confounding factor of the different widths of the ThruFlow and Fibergrate walkways. For this 2-hour interval, the areas under the curve representing the total amount of PAR received under the dock, and the area of PAR received from material light penetration alone, were compared with the amount of PAR received on top of the dock (see Figure 14).

Orientation and height studies show that the percent of total PAR received under the docks varies greatly (Figure 17, Table 13). During spring and summer, the traditional dock receives 7-9% and 10-19%, respectively, of total PAR under the dock during the 2 hours around maximum insolation (Figure 17). Figure 18 shows that at all orientations and heights there is essentially 0% PAR observed below the traditional dock from light penetration through the decking only, a result expected given that there is no light penetration through this decking. Thus all light observed below the traditional dock is always from indirect sources. For the Thruflow decking, 12-18% and 26-41% of total integrated PAR in the spring and summer, respectively, is observed under the dock (Figure 17). In contrast, 2-10% and 15-28% of total PAR in the spring and summer, respectively, is from light penetration through the material, leaving 8-10% and 11-13% from indirect sources, similar to what we observed for the traditional decking. For the Fibergrate dock, 14-31% and 26-37% of total integrated PAR in the spring and summer, respectively, is observed under the dock (Figure 17). Height data suggests that 0-7% and 27-35% of spring and summer PAR is from light transmission through the alternative materials, leaving 9-12% and 6-13% of PAR in spring and summer to be attributed to indirect sources (Table 14). Alternatively, orientation data suggest that 5-23% and 16-28% of spring and summer PAR is from light transmission through the alternative materials, leaving 8-10% and 9-11% of PAR to be attributed to indirect sources, again similar to the results for the traditional dock (Table 13). These results suggest that traditional docks typically decrease incident PAR by ~90% during the two hours around maximum insolation in the spring and summer.

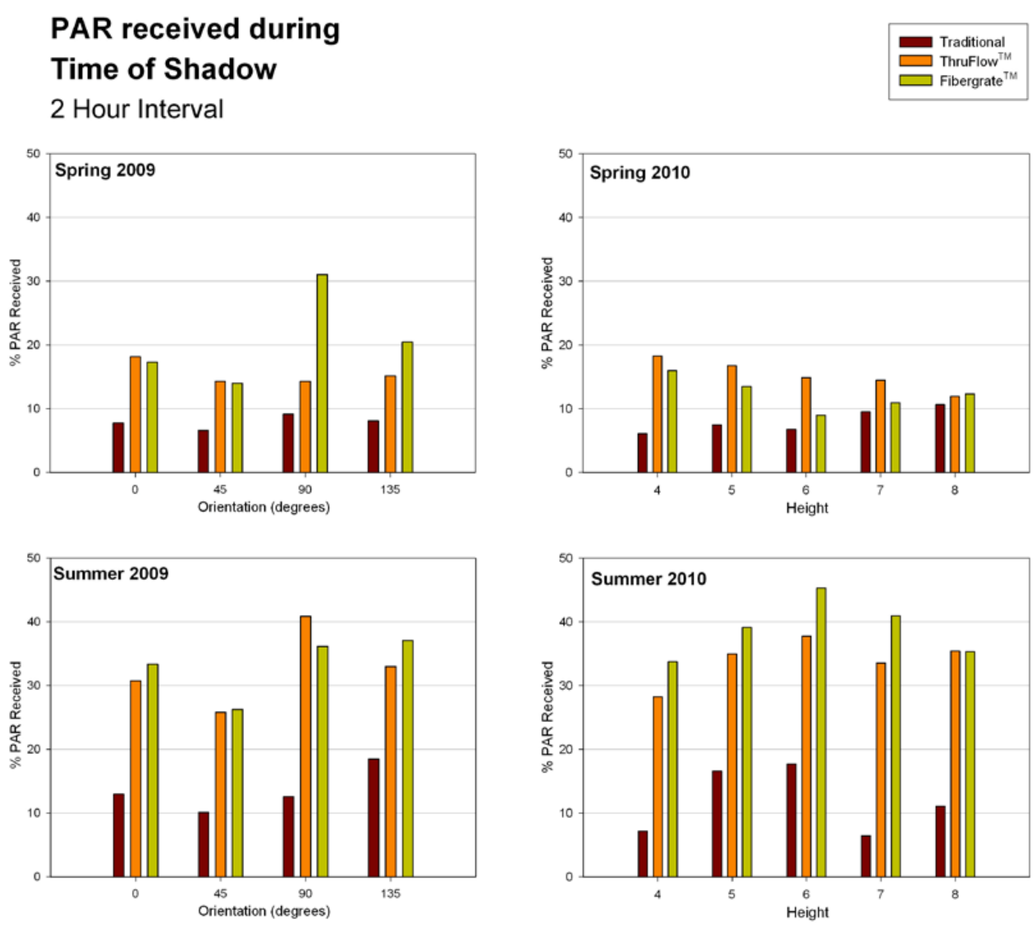


Figure 17. Percent of total PAR received during time of shadow from indirect light and light penetration through decking materials. Percentages calculated by comparing Area B+C to Area A during the 2 hour interval around maximum insolation. (See Figure 14.)

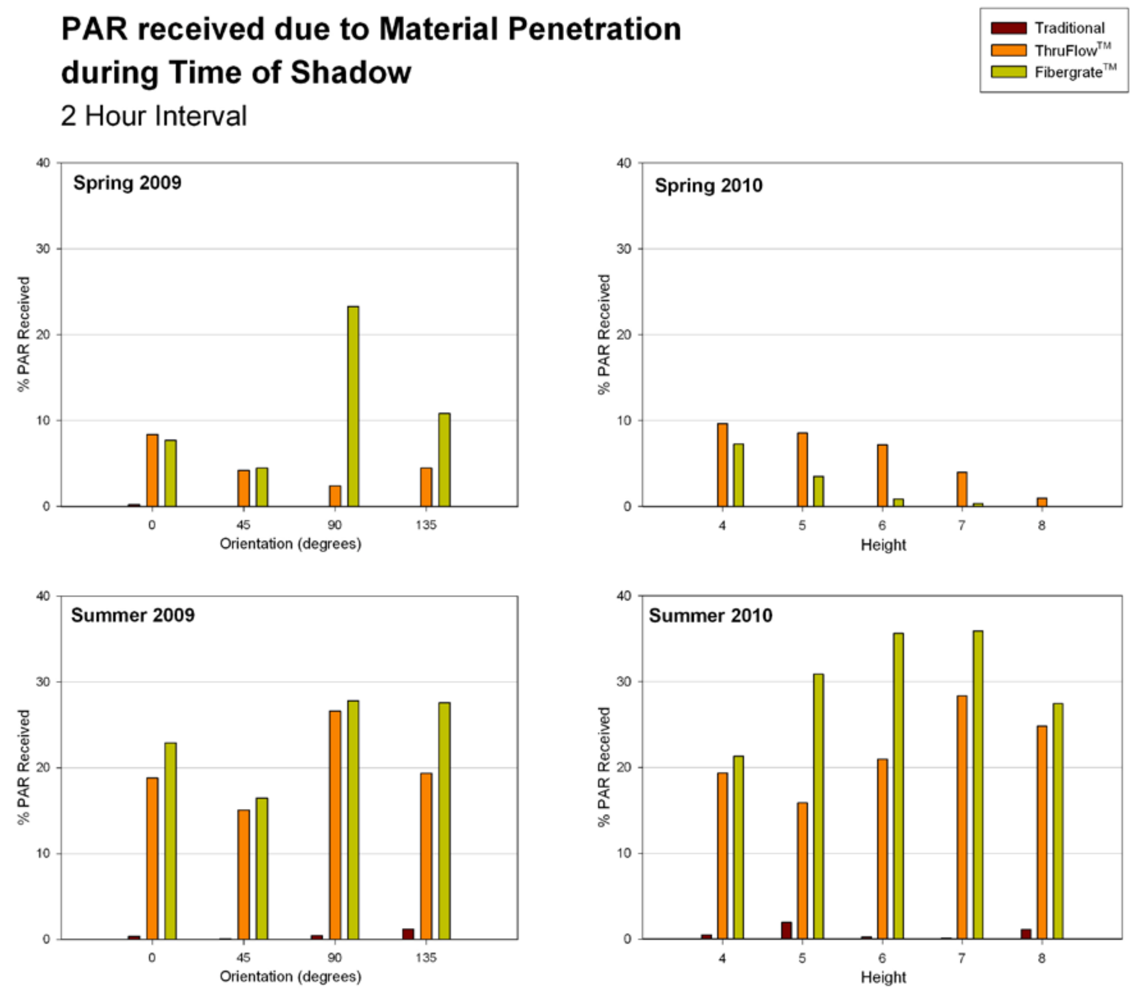


Figure 18. Percent of total PAR received during time of shadow from light penetration through alternative materials alone. Percentages calculated by comparing Area B+C to Area A during the 2 hour interval around maximum insolation. (See Figure 14.)

3.3.3 Mock dock simulation experiment summary

In the mock dock studies, we examined how different dock walkway structures affected shadow duration, daily PAR loss, and PAR loss above a 0% biomass loss threshold (0% BLT) under docks, at different orientations and heights. The 0% BLT is that light level above which we do not expect to see any biomass loss because of shading. During the orientation experiment, docks were oriented at 0º, 45º, 90º and 135º. Docks oriented at 90º and 135º during winter and fall and oriented at 0º and 45º during spring and summer created the shortest shadow periods and the least overall PAR loss. Typically, the traditional, ThruFlow, and Fibergrate docks exhibited similar characteristics during the experiments. The SunDock system had a smaller impact at all orientations and seasons. **Because spring and summer are the major growth seasons for *S. alterniflora*, these orientation results demonstrate that docks that provide the most light penetration during these seasons, those oriented N-S, have a much**

smaller shading impact on the marsh than those oriented E-W. The height study examined shadow durations and PAR loss associated with docks at 4, 5, 6, 7 and 8 feet heights with docks oriented at 0º. In general, the data show that shadow duration and PAR loss under the docks decrease as height increases, although the Sundock exhibited PAR losses that were about half those of the decked walkways. **The height study demonstrates that docks should be built as high as possible above the marsh surface to minimize shading effects.**

For both the orientation and height experiments, PAR loss above the 0% BLT follows the results of the orientation and height shadow duration and PAR loss studies. In the orientation study, traditional planked dock structures effectively block 100% of the PAR above the 0%, 25% and 50% BLTs in some seasons and orientations (summer, 90º and winter, 0º). At these same seasons and orientations, alternative decking materials increase the amount of PAR present under the dock by less than 10% at the same BLTs, thus also effectively blocking most of the incident PAR. No matter their orientation, decked structures during spring and summer block 80-100% of the PAR above the 0% BLT. Under these same conditions, the SunDock blocks 20-40% of incident PAR above the 0% BLT. Similar results are noted in the height study, where the traditional dock (and other decked structures) during winter and fall exhibited PAR losses of 86-100% above the 0% BLT at 4 feet and 69-77% losses at 8 feet. Spring and summer data show decreases in daily PAR loss above the 0% BLT for all heights, with losses of 74-87% of PAR above the 0% BLT at 4 feet and 45-60% losses at 8 feet. As with other datasets in this study, the SunDock had a smaller PAR loss, ranging between 23-62% loss of PAR above the 0% BLT in the fall and winter, and a 15-40% loss of PAR in the spring and summer. **These results show that all docks significantly reduce the amount of PAR above the 0% BLT received below the dock in all seasons, although the Dockrider system has a smaller impact. Similar results were found for the 25% and 50% BLTs.**

The results presented above are for the total integrated PAR received throughout the day. The purpose for using alternative materials is to enhance the penetration of light during the time when the dock shadow is under the dock, so we separately examined PAR levels above and below the dock during this period. When the sun's elevation is low (in fall and winter), light does not penetrate the alternative decking materials, and the PAR loss is similar among the traditional, Thruflow and Fibergrate docks (41-47% loss), whereas the Sundock exhibits an average 26% loss. When the sun's elevation is higher (in spring, but dominantly in summer), light is able to penetrate the grated materials. During these seasons, the traditional planked dock PAR loss remains at 41%, but the alternative material PAR losses decrease to 34% because of light penetration through the materials. When compared to a traditional planked walkway, only the Sundock receives more PAR under the dock throughout the year, receiving 13% and 22% more in fall and winter, respectively, and 39% more PAR during spring and summer. Other alternative docks only receive more PAR than the traditional planked dock during spring and summer, although the increase in PAR is less than 10% during both seasons. If we look just at the 2 hour period around maximum insolation, grated materials allow less than 10% additional PAR in the spring and between 20-35% more PAR in the summer, compared to a traditional planked dock. However, this 2-hour period is only a portion of the time during which the shadow is under the dock, so the increased PAR has little effect**.** The dock height data illustrate that as docks get higher off the marsh surface, there is less advantage to using alternative materials. As height increases, the shading impact of traditional planked docks decreases and the small amount of additional PAR provided by alternative materials becomes relatively less important on a percentage basis. Given that the height study showed that docks should be built as high above the marsh as possible to decrease shading impacts, there is again less need to use alternative materials for walkway decking.

These results show that, for the latitude of Skidaway Institute (31º 56' N) where the experiments were carried out, alternative decking materials do not ameliorate the impacts of dock shading, given that most of the PAR above the 0%, 25% and 50% BLT thresholds is effectively blocked from reaching below the docks. The elevation of the sun is only high enough to allow sunlight to penetrate through grated materials during spring, when penetration is relatively limited, and during summer, when penetration is at its greatest. Even at this time, grated materials provide less than 10% additional PAR under docks when compared to a traditional planked walkway. Because the elevation of the sun is related to latitude, our results are applicable from Skidaway Island north along the US east coast. Penetration of PAR through alternative materials will increase toward the south, decreasing the impact of marsh (and sea grass) shading, as the sun's elevation in the sky increases toward lower latitudes.

3.4 Field Dock Analysis

Three separate field sites along the Georgia coast were examined to determine the effects of alternative dock materials and construction methods on the marsh environment on yearly timescales. Pairs of sample stations, consisting of one dock station, located directly underneath the dock, and one control station, located parallel with, and 5 meters away from the dock, were occupied beginning at the upland-marsh boundary, and advancing at 20 meter intervals into the marsh. At each station, dock and control samples were collected to quantify the changes that dock construction, dock presence, and presence of alternative construction techniques exert on the marsh environment. For our two alternative material and construction docks, Turners Creek and Shell Point Cove, we were able to sample along the corridor used to install the docks prior to dock construction. A traditional dock at Betz Creek was also investigated to provide a control for traditional dock building techniques and any dock-induced effects on the marsh.

3.4.1 Biomass

Biomass of vegetation shows a pattern of decreased biomass beneath the docks at all three sites (Figure 19, Table 15). The biomass produced is a measure of marsh productivity, and is directly related to organic carbon production in the marsh. The data clearly show that 2010 was a very productive year in Chatham County, Georgia compared to 2009 (Table 15). Betz Creek showed an increase in biomass at dock and control sites of 60-109%, and the Turners Creek site experienced an increase between 91-137%. In 2009, at Betz Creek, the traditional dock, dock stations displayed less biomass than control stations, producing a 22% decrease compared to control sites (Figure 20A). In 2010 there was no significant difference in biomass between averaged results for all dock and control stations. However, this result arises from a significant amount of biomass at the terminal dock station closest to the channel, where nutrients are high and dock impacts would be expected to be ameliorated. Betz Creek 2010 data portray a 6% biomass loss if that one station is removed from the calculation. Turners Creek, the ThruFlow dock, exhibited the greatest biomass loss of the three field sites. The year following dock construction, 2009, there was a 63% decrease in biomass beneath the dock and in 2010 there was an average 55% decrease. Shell Point Cove also showed a significant decrease in biomass under the dock, with an average 40% decrease in biomass both years; in 2009 20 of the 27 stations reported less biomass than control stations (Figure 20B). Dock stations 3-8 represented a denuded zone, which is along a tidal creek and was the site of a wrack trapping event and has not exhibited vegetation since our pre-dock survey in 2007. Dock stations where *J. roemerianus* originally was sampled (stations 14-22, see Figure 20B) have not revegetated with *J. Roemarianus,* but in many cases have regrown sparsely with *S. alterniflora* because lowered surface elevations along dock-construction paths increases flooding frequency.

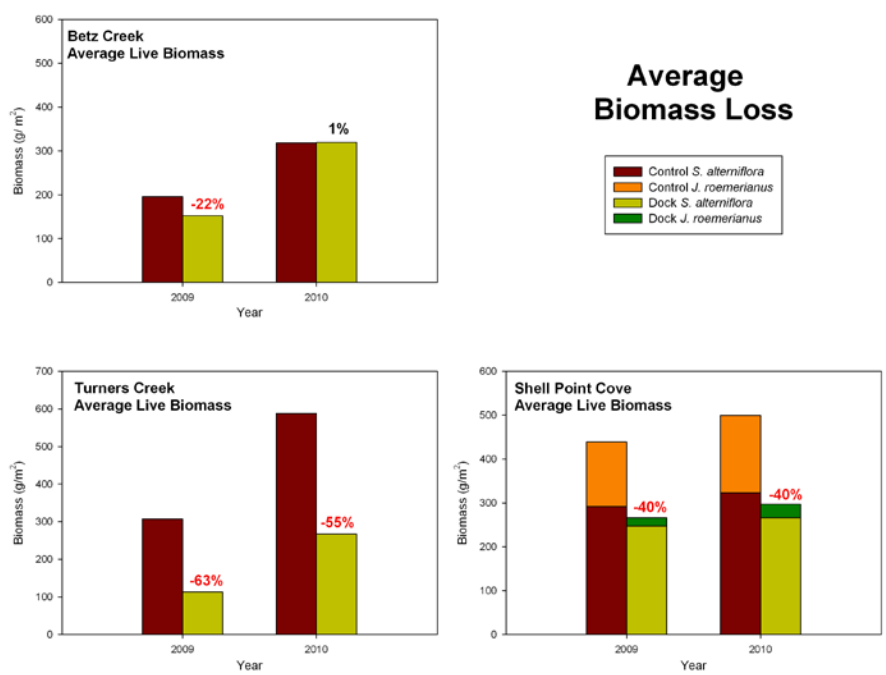


Figure 19. Average biomass loss between dock and control stations; calculated from all stations and all grass types.

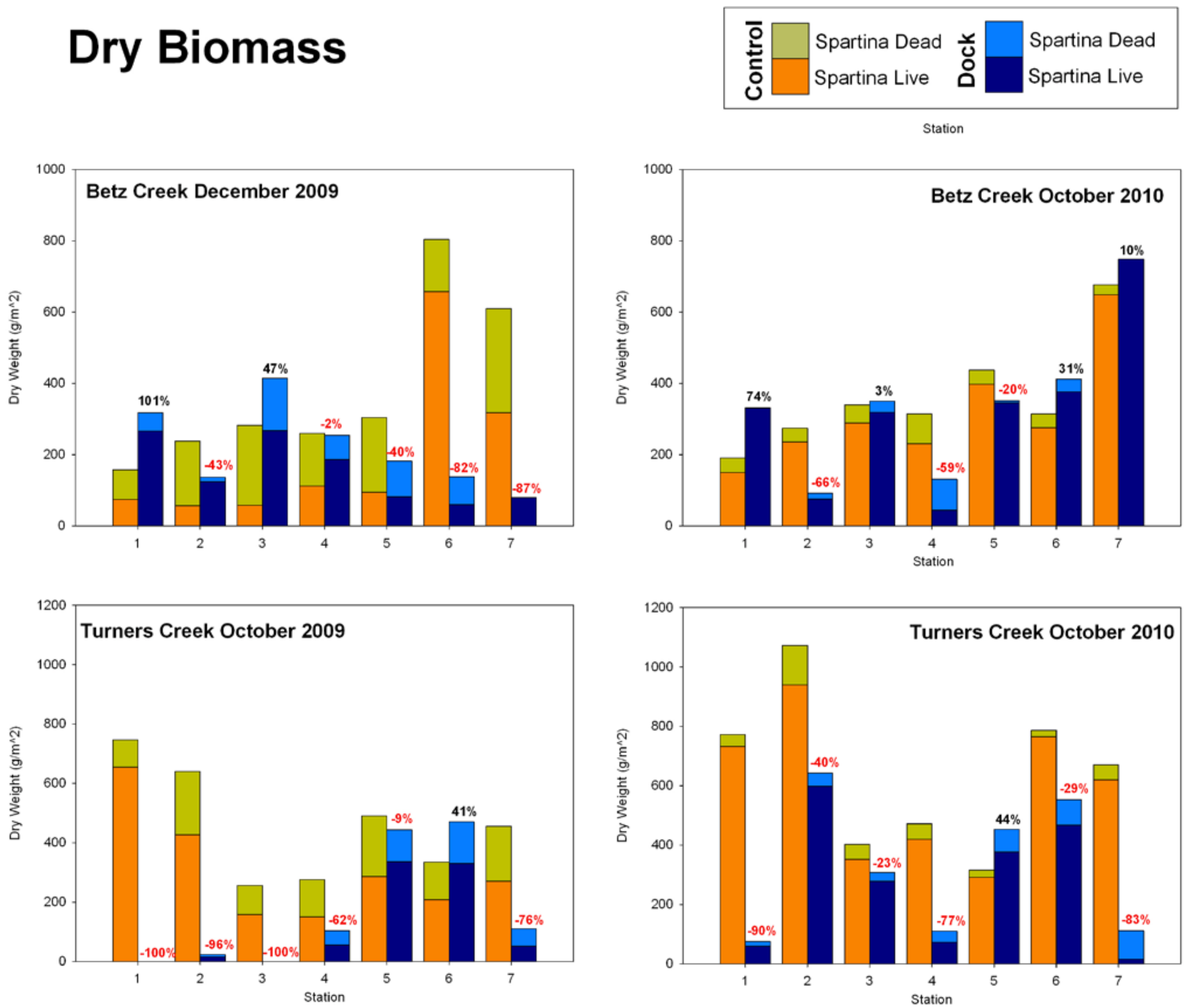


Figure 20A. Biomass comparisons between dock and control stations at field dock sites in Betz Creek and Turners Creek. Red numbers above bars represent loss of biomass under dock compared to control. Black numbers indicate increased biomass under dock compared to control.

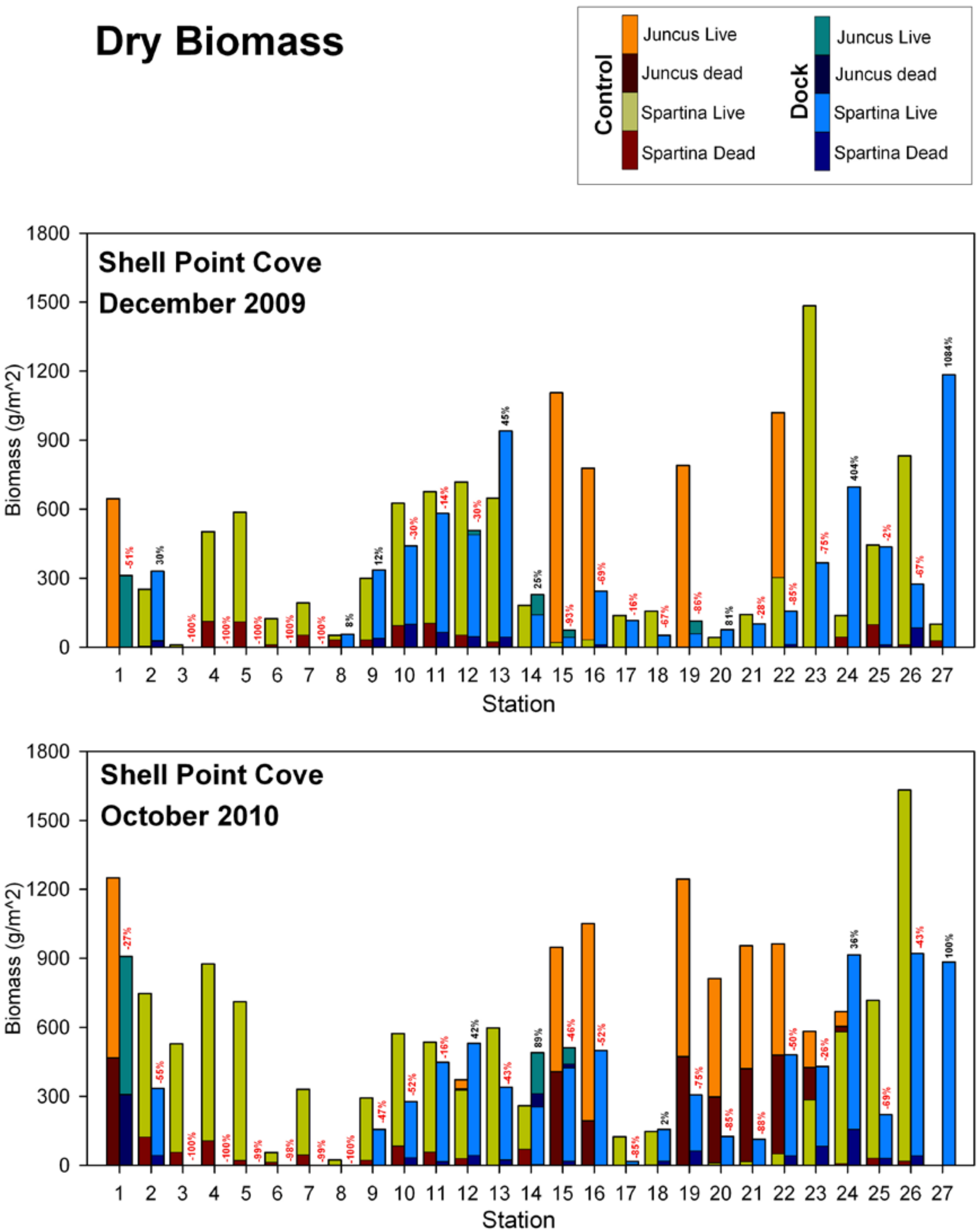


Figure 20B. Biomass comparisons between control and dock stations at Shell Point Cove. Red numbers above bars represent loss of biomass under dock compared to control. Black numbers indicate increased biomass under dock compared to control.

3.4.2 Stem Density

Post-construction stem density data showed a substantial decrease in stem density beneath all docks for all years. While the Betz Creek dock exhibited a slight decrease in biomass beneath the dock in 2010, it does exhibit a 31% reduction in density of *S.*

alterniflora compared to the control site (Figure 21, 22 and Table 16), and exhibited a 44% decrease in stem density at dock sites in 2009. The Turners Creek dock was sampled pre-construction in 2008 and showed 16% fewer stems along the corridor through which the dock was planned. The following year, after the dock had been built, there was a decrease of 58% in stem density beneath the dock and a 55% decrease beneath the dock in 2010. In 2007, before construction, Shell Point Cove had 13.5% more stems on the control plot than on the planned dock corridor. In 2008, after the dock had been built, there were 66% fewer stems under the dock compared to control. This relationship persisted in 2009 with a 54% decrease in stem density and in 2010 with a 54% decrease in stem density under the dock.

Shell Point Cove also exhibited a difference in stem density of *J.* roemerianus (Figure 22B). Pre-construction in 2007, the stem density of *J. roemerianus* was 50% greater within the dock corridor than outside it. After construction in 2008, the density under the dock dropped 80% compared to control plots. In the following years, *J. roemerianus* stem density continued to exhibit this relationship, with a 74% decrease in dock site stem density in 2009 and an 80% decrease in 2010. Where vegetation has regrown, *S. alterniflora* has often colonized at the expense of *J. Roemerianus*.

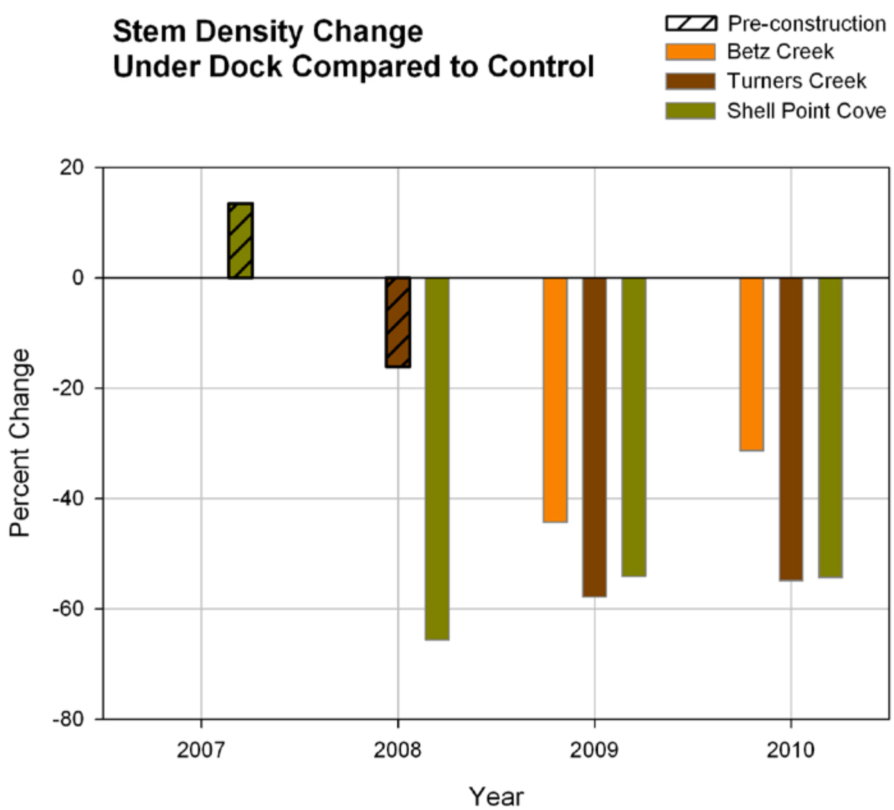


Figure 21. Average stem density change for all plots**.** Percentages calculated by averaging all dock stations per site and comparing to all averaged control sites per site.

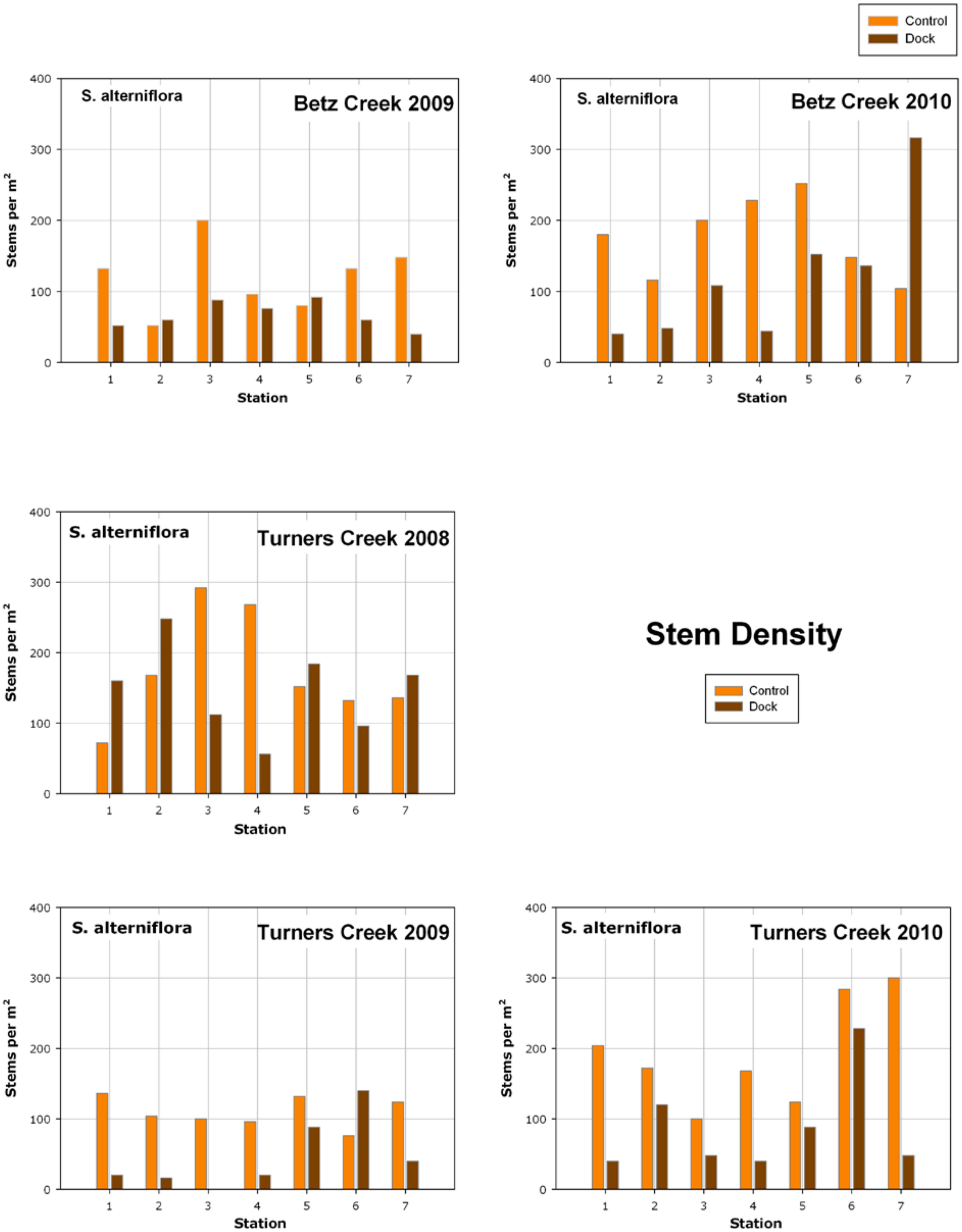


Figure 22A. Stem density for the Betz Creek and Turners Creek field study docks. Note general loss of stem density at dock sites.

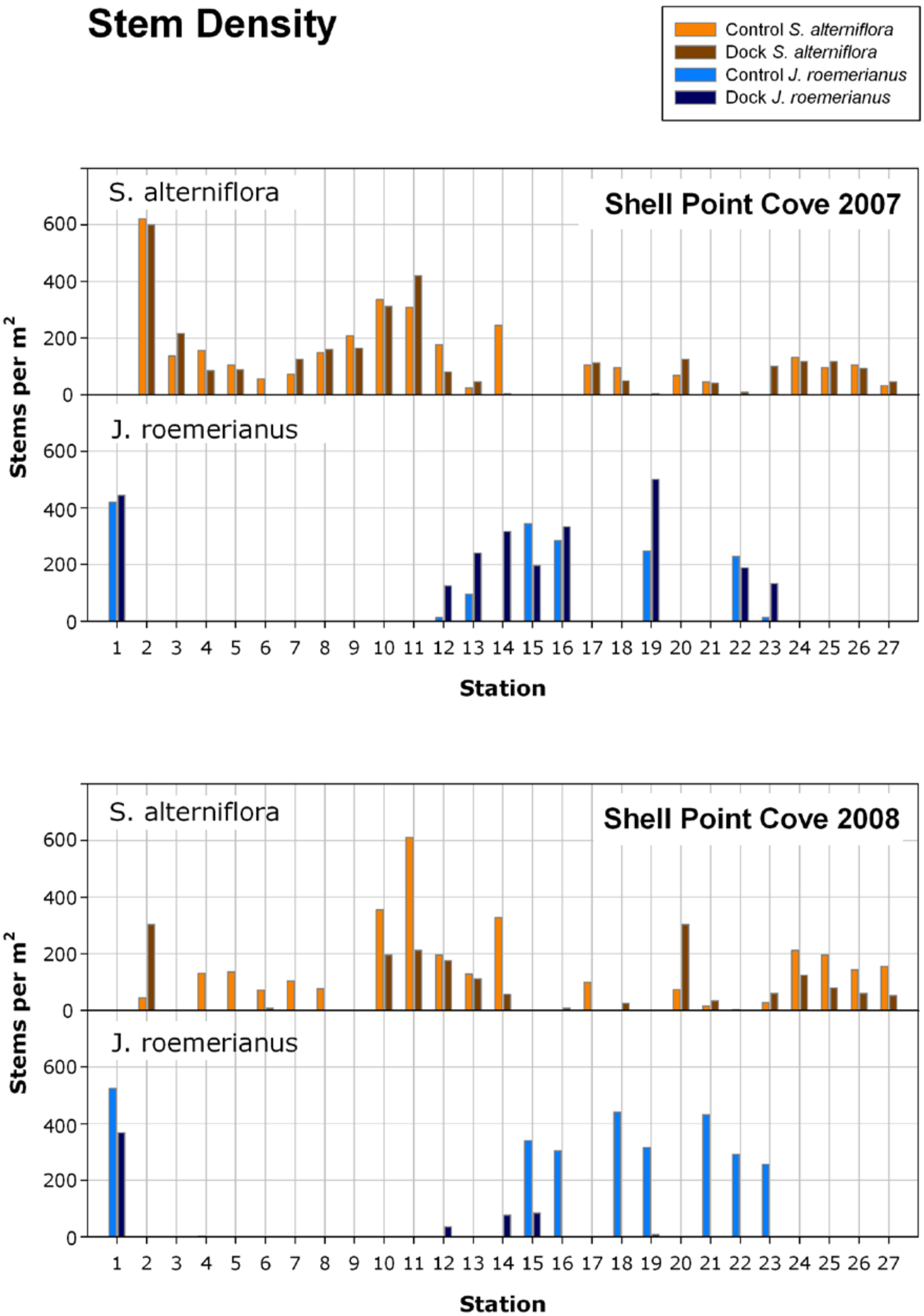
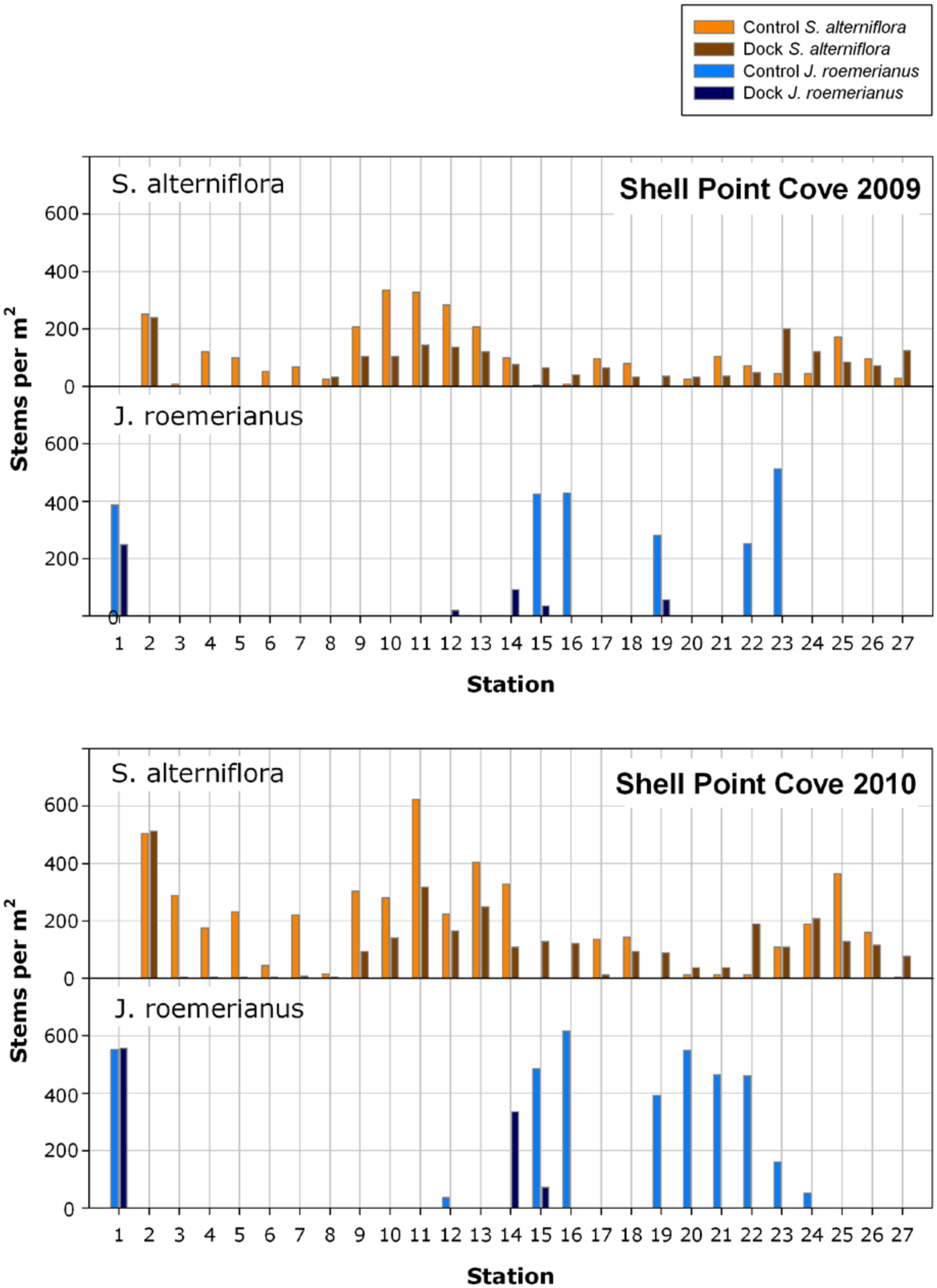


Figure 22B. Stem density for the Shell Point Cove field study dock. Note the loss of *J. Roemarianus* at stations 12-23 at dock sites because of damage during dock construction. *S. alterniflora* has grown back at some of these sites.



Control S. alterniflora
Dock S. alterniflora
Control J. roemerianus
Dock J. roemerianus
S. alterniflora
Shell Point Cove 2009
J. roemerianus
Stems per m2
0
200
400
600
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
Station
S. alterniflora
Shell Point Cove 2010
J. roemerianus
Stems per m2
0
200
400
600
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
Station

3.4.3 Stem Height

Height of *S. alterniflora* varied across sites (Figure 23, 24A,B and Table 17). Betz Creek exhibited a 44% increase in the median height of plants beneath the dock compared to control. Stems are longer under docks because of etoliation (Alexander and Robinson, 2004, 2006). Because the Betz Creek dock has been present for many years, the plants have had sufficient time to adjust to the presence of the dock and express these characteristics. Turners Creek showed no distinguishable difference between sites. Shell Point Cove had a 33% increase in median height for *S. alterniflora* under the dock. *J. roemerianus* found at Shell Point Cove displayed a distinct decrease in median height beneath the dock at all sites. *J. roemerianus* is much more sensitive to light conditions than is *S. alterniflora*, and would be expected to be affected more by a similar level of shading. Given that this site is a Dockrider SunDock, we would expect the least amount of shading to occur based on the Mock dock experiments, and this response from the plants may represent also damage from construction of the dock itself.

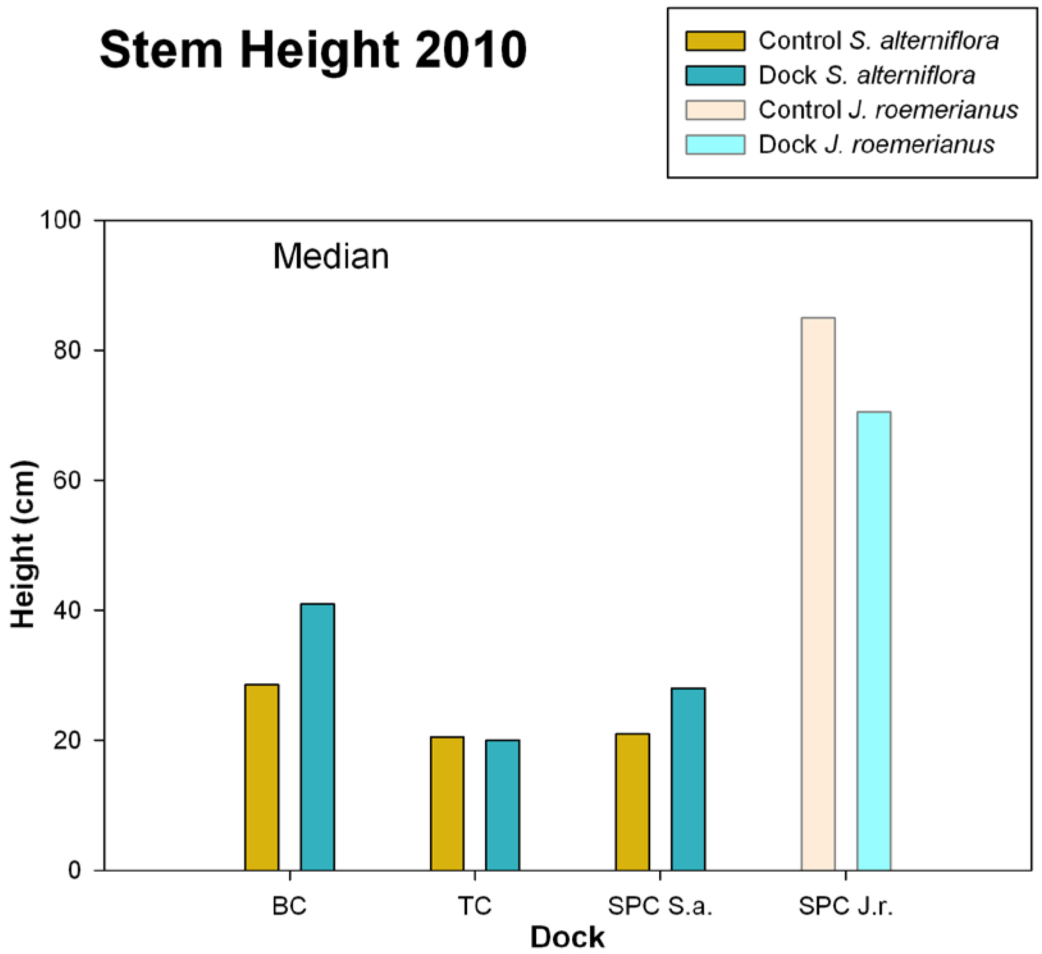


Figure 23. Median height of stems at each of the field dock study sites. Note the use of the median (the value in the middle of a distribution) as opposed to the arithmetic mean, to better illustrate the middle of the population.

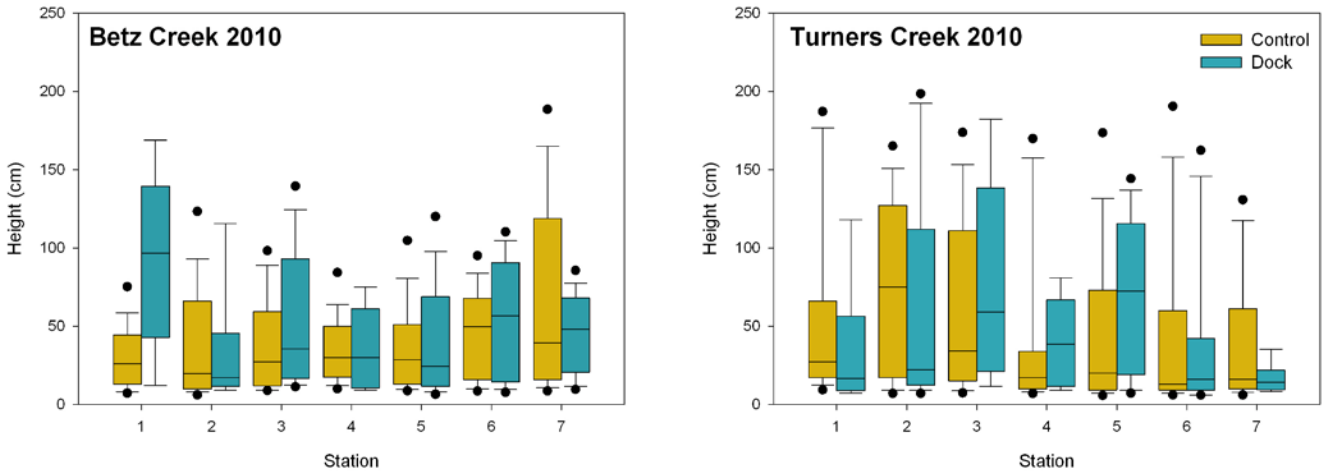


Figure 24A. Stem heights for Betz Creek and Turners Creek in 2010. Various characteristics of the data distribution are shown in this graph. The black line inside of each box represents the median. Box edges represent the 25th/75th percentile. Bars represent the 10th/90th percentile and dots represent 5th/95th percentile.

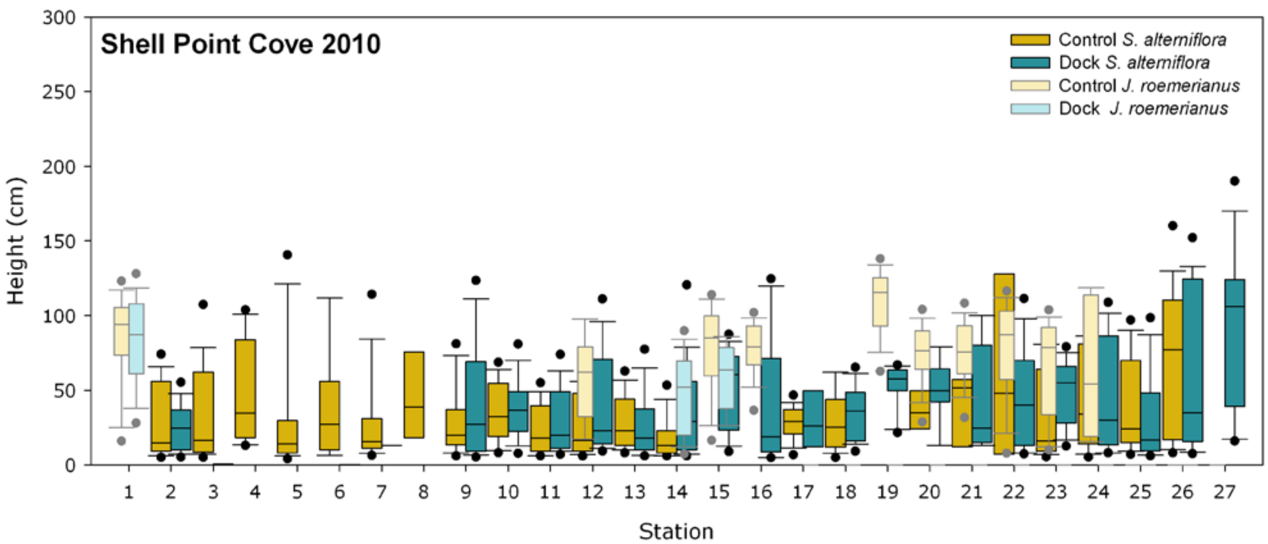


Figure 24B. Stem heights for Shell Point Cove in 2010. Various characteristics of the data distribution are shown in this graph. The black line inside of each box represents the median. Box edges represent the 25th/75th percentile. Bars represent the 10th/90th percentile and dots represent 5th/95th percentile.

3.4.4 Organic Carbon

Organic carbon content was similar at all three sites, and typical for salt marsh sites in Georgia (Figures 25, 26 and Table 18). At Betz Creek, sediment contains 1 to 5% organic carbon, with most values between 2 and 4%. C:N ratios of the carbon have remained relatively constant (Table 18). Turners Creek sediments exhibit 3 to 6% organic carbon, with most values between 3.5 to 5% carbon (Figure 25 and Table 18). In addition, the C:N ratios of the carbon at both dock and control sites are increasing, suggesting that there is more input of terrestrial-based carbon to this study site over time (Table 18). At Shell Point Cove, the transect profiles have a distinct character that can be explained by the variation in vegetation at the site (see Figure 22B). Organic carbon content is moderate near the upland (3-5%, stations 2-8), increases toward the more prolific stands of *S. alterniflora* at the site (5-10%, stations 9-12), decreases dramatically in a sandy, *J. roemarianus* dominated zone (0-3%, stations 15-21) and increases toward the channel margin where *S. alterniflora* again grows prolifically (3-8%, stations 23-25). In general, dock samples have lower organic carbon content than do control samples. Apparently, benthic algae are not able to fill that void, even with increased light reaching the sediment surface. The sediment C:N ratio reflects the transition from *S. alterniflora* to *J. roemarianus* and back as well, exhibiting higher ratios in the *J. roemarianus* zone than in either of the *S. alterniflora* zones (Table 18).

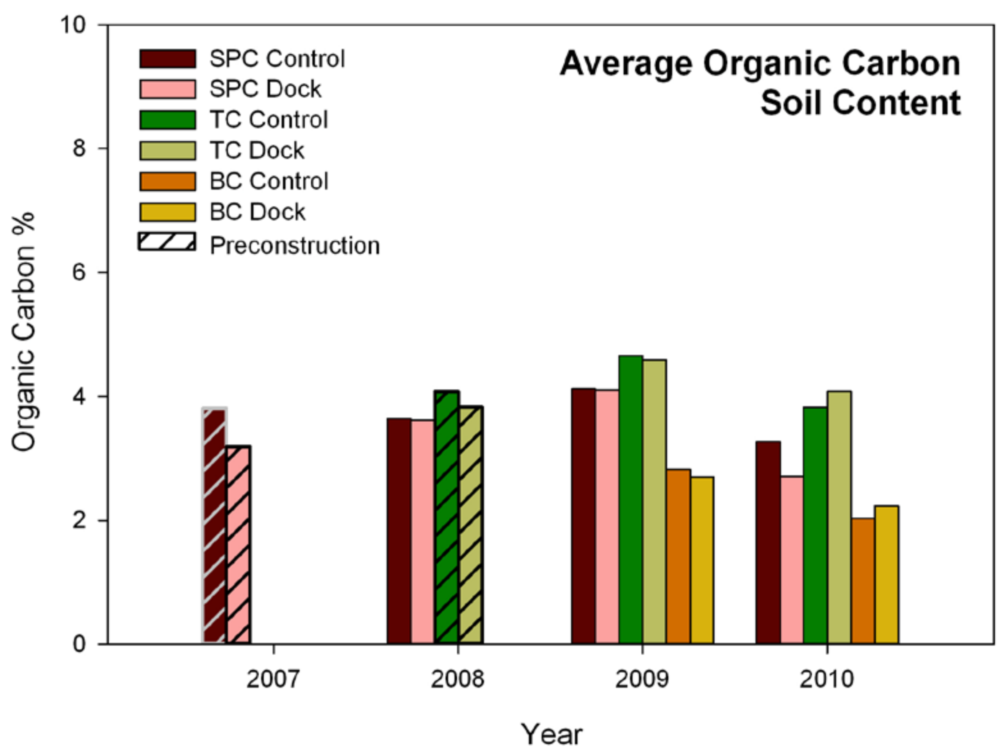


Figure 25. Average organic carbon in surface sediments at the three field study docks.

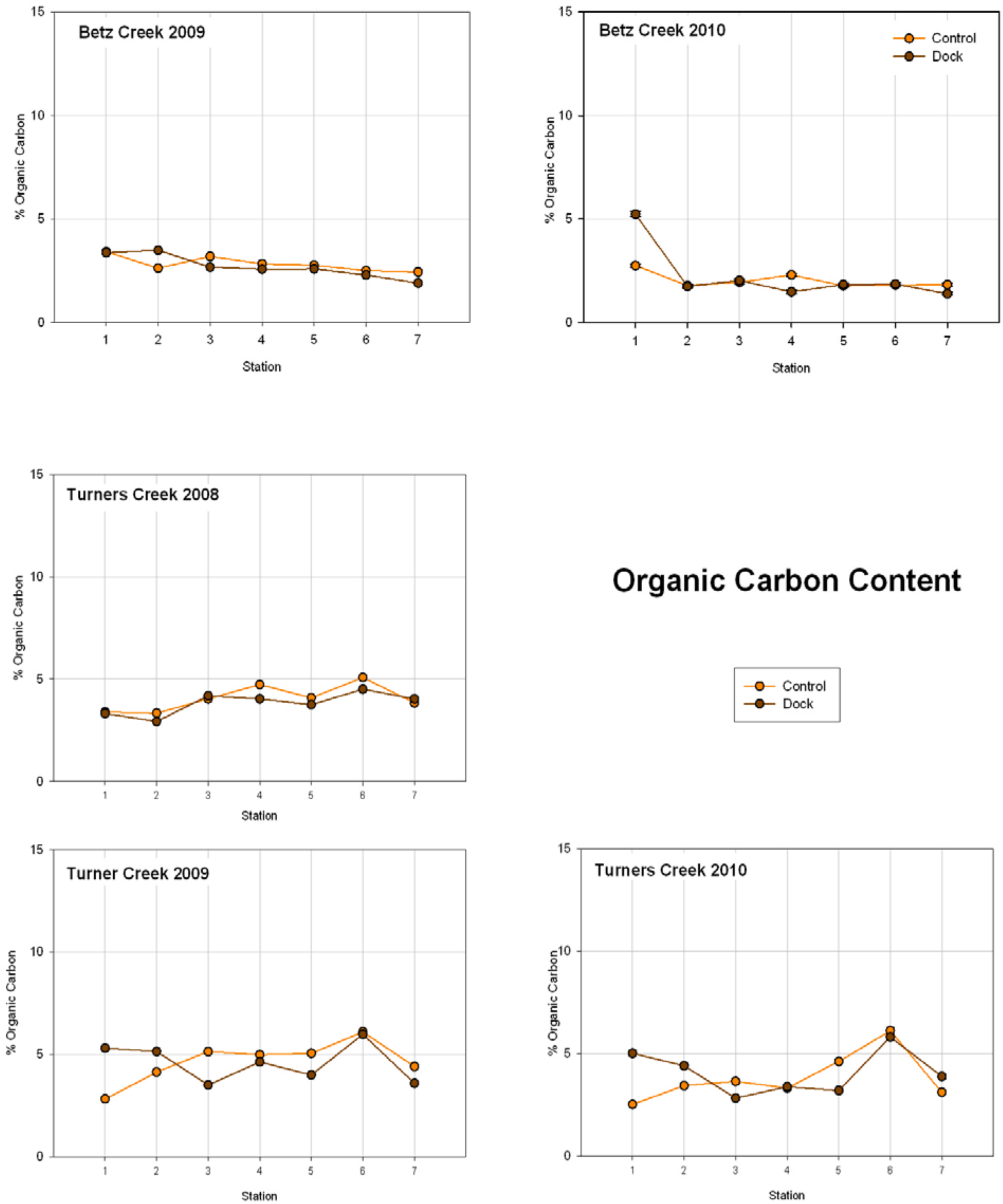


Figure 26A. Transect data of organic carbon content in the surface sediments at the Betz Creek and Turners Creek field dock study sites

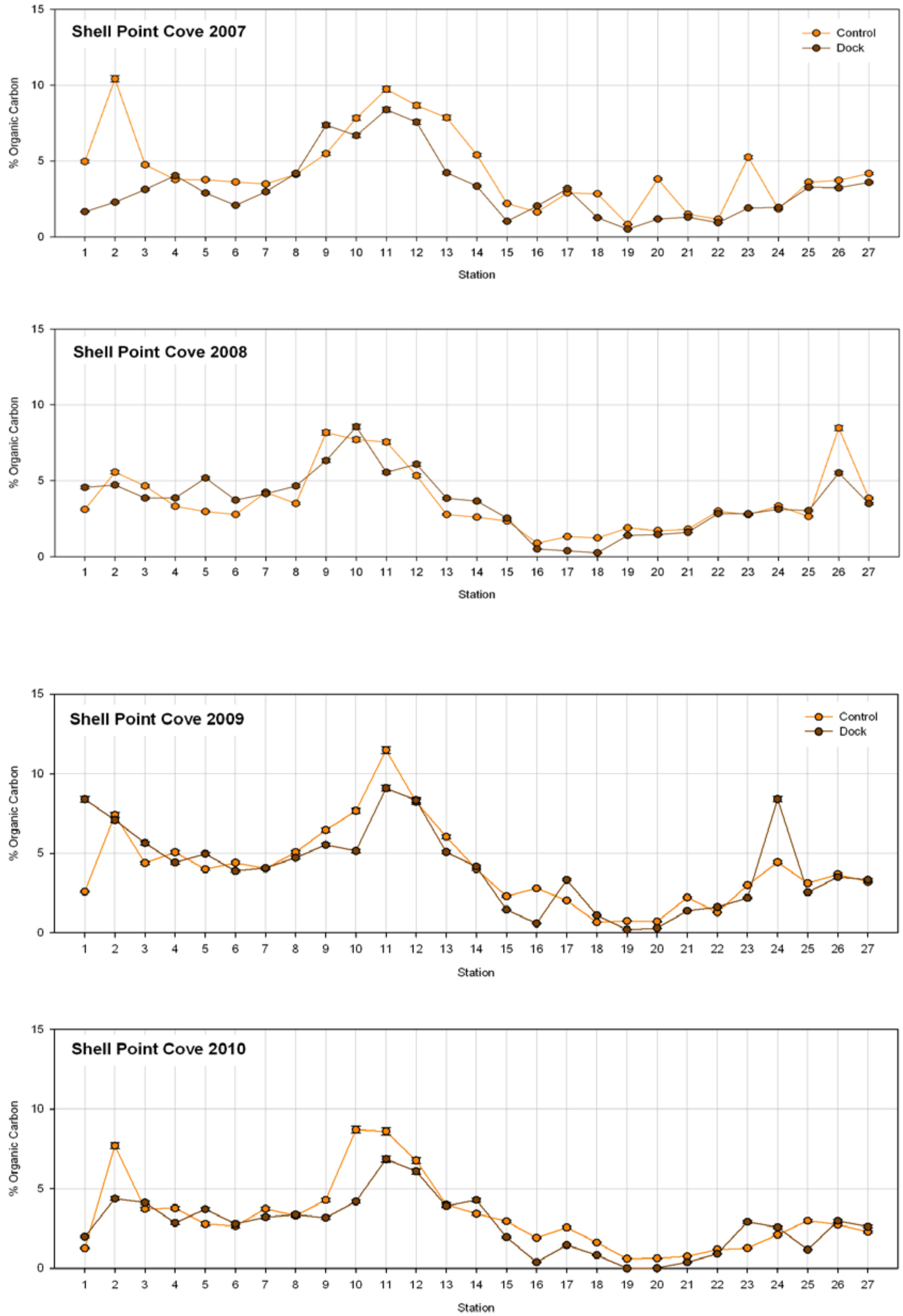


Figure 26B. Transect data of organic carbon content in the surface sediments at the Shell Point Cove field dock study sites. Note the low organic carbon content in the sandy, *J. Roemarianus* zone (stations 15-22).

3.4.5 Chlorophyll *a* and Phaeophytin

Chlorophyll *a* and phaeophytin samples, including pre-construction samples for Shell Point Cove and Turners Creek, were taken every year to assess primary production by benthic algae at the study sites. Values (15-70 mg/g Chl *a*, Table 19) are low for unvegetated mudflats, but are similar to what other studies have found in vegetated salt marshes in Georgia. A notable drop in Chl *a* pigments at under-dock sampling sites was observed at both Shell Point Cove and Turners Creek in the year following dock construction, perhaps signaling a temporary disruption of the ecological community (Figure 27). Chl *a* and phaeophytin dropped 31% and 30% respectively at Shell Point Cove, and dropped 28% and 17% at Turners Creek. The second year following construction, pigment levels under the docks appeared to have rebounded, although to lower levels for both dock and control sites, than were previously present. The large drop in Chl *a* content by at least half, from 2009 to 2010, is reflected in all three sites, and requires further examination. The long-established Betz Creek dock did not show obvious differences between control and dock sites. Transect of chl *a* and phaeophytin (Figures 28A,B) show the details of each dock and control site over time.

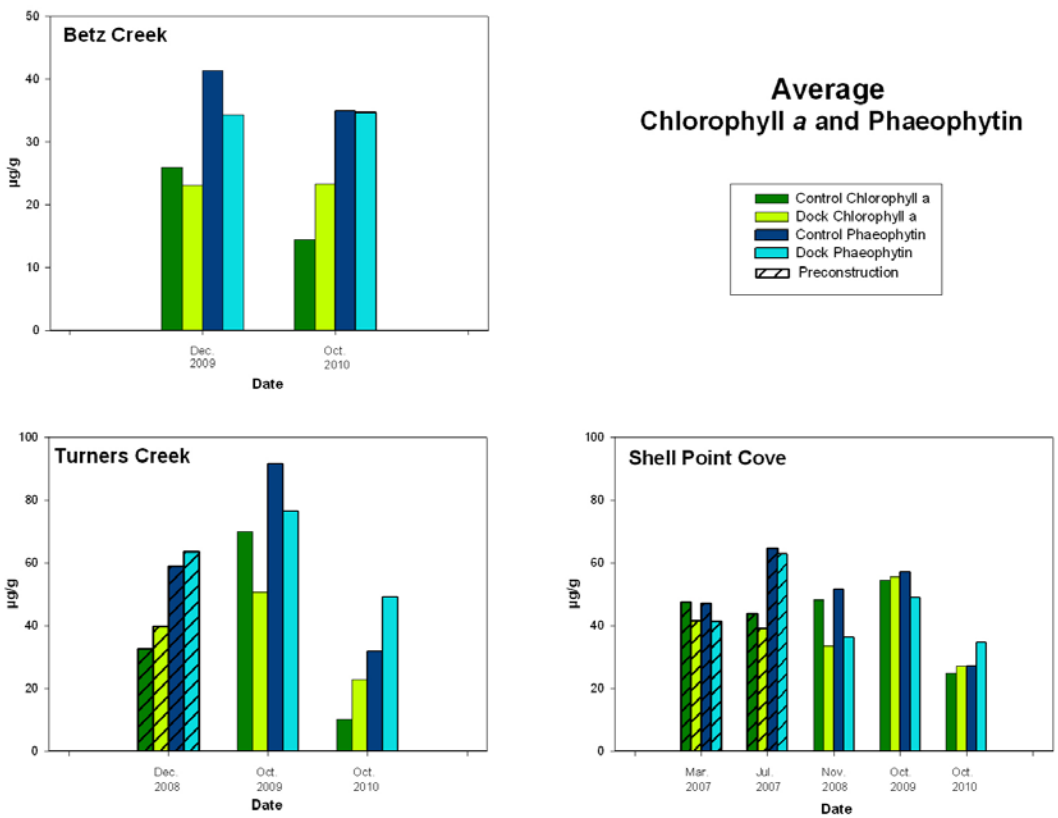


Figure 27. Average Chlorophyll *a* and phaeophytin values from all dock and control sites at each field study dock. Note that the y-axis on the Betz Creek plot is half that of the Turners Creek and Shell Point Cove axes.

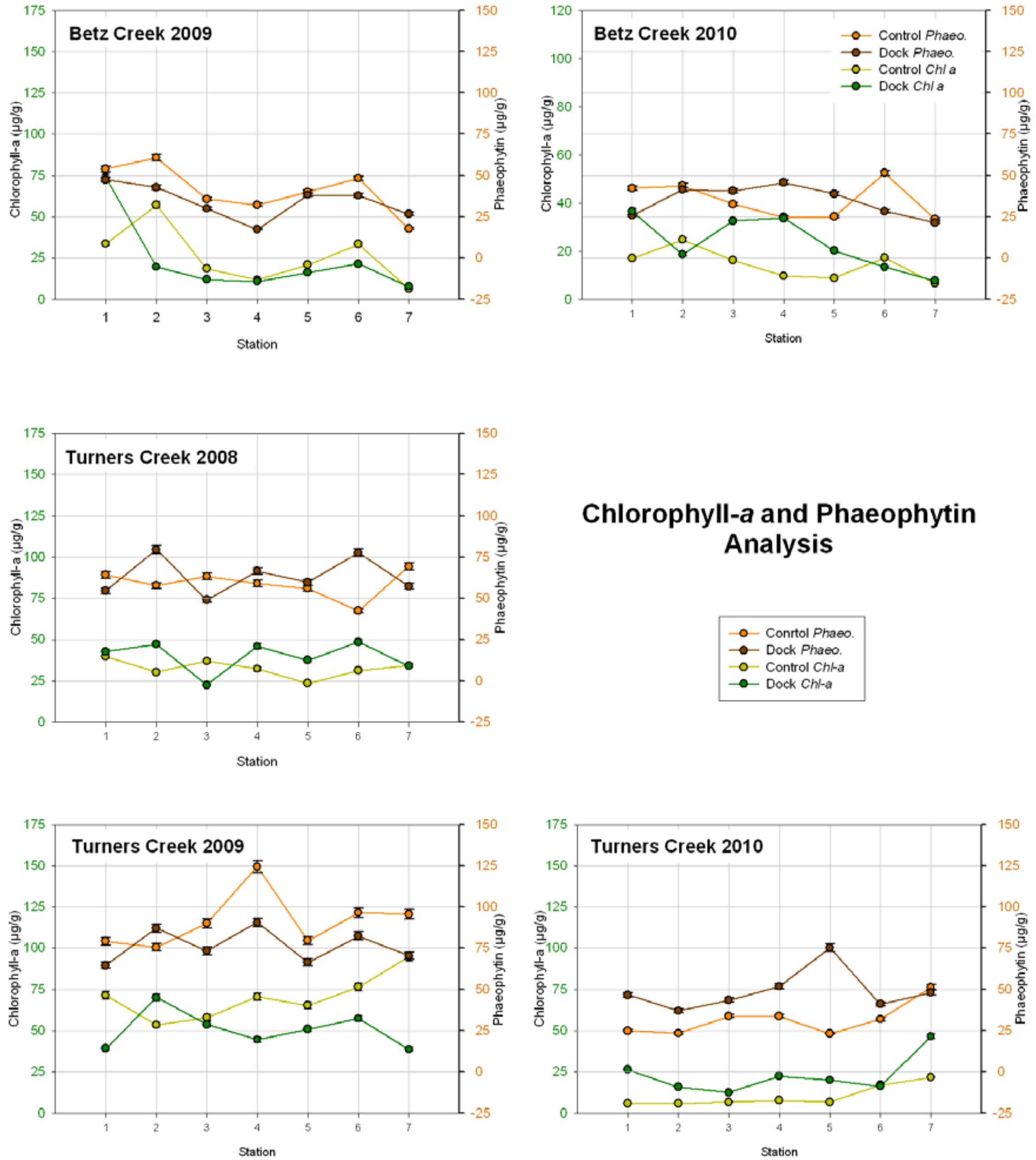


Figure 28A. Chl *a* and phaeophytin concentration at Betz Creek and Turners Creek.

Figure 28B. Chl *a* and phaeophytin concentration at Shell Point Cove. Note the low values in Chl *a* associated with the dense stands of *J. Roemarianus* in stations 15-22.

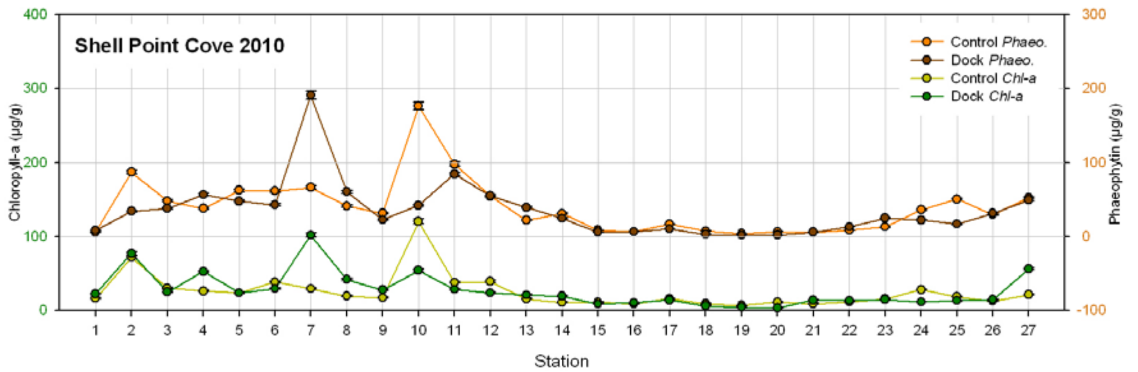


Figure 28B (continued). Chl *a* and phaeophytin concentration at Shell Point Cove. Note the low values in Chl *a* associated with the dense stands of *J. Roemarianus* in stations 15-22.

3.4.6 Salinity

Salinity data were collected at all three dock sites in 2010. Salinity was relatively constant for all stations at Turners Creek, averaged 29.2 and 29.7 ppt at control and dock sites, respectively, and ranged from 28-30 ppt (Figure 29 and Table 20). Salinity was slightly higher at Betz Creek, averaging 34.3 and 34.1 ppt at control and dock sites, respectively, but again salinity was relatively consistent across the stations, ranging from 31 and 33 ppt, except near the creek bank, where salinity was higher and averaged 41 ppt. Salinity levels at Shell Point Cove were the most diverse due to the range of terrains at this site. Salinity averaged 37 ppt at stations 2-12, in the lower, muddier environments. Salinity increased to 50-132 ppt in the *J. Roemarianus* zone, where sediments were sandier (see Grain Size section following) and less frequently flooded, allowing salts to build up in pore waters. Note that control sites, where there is vegetative cover to retain moisture, have lower salinities than do the dock sites, which are effectively bare.

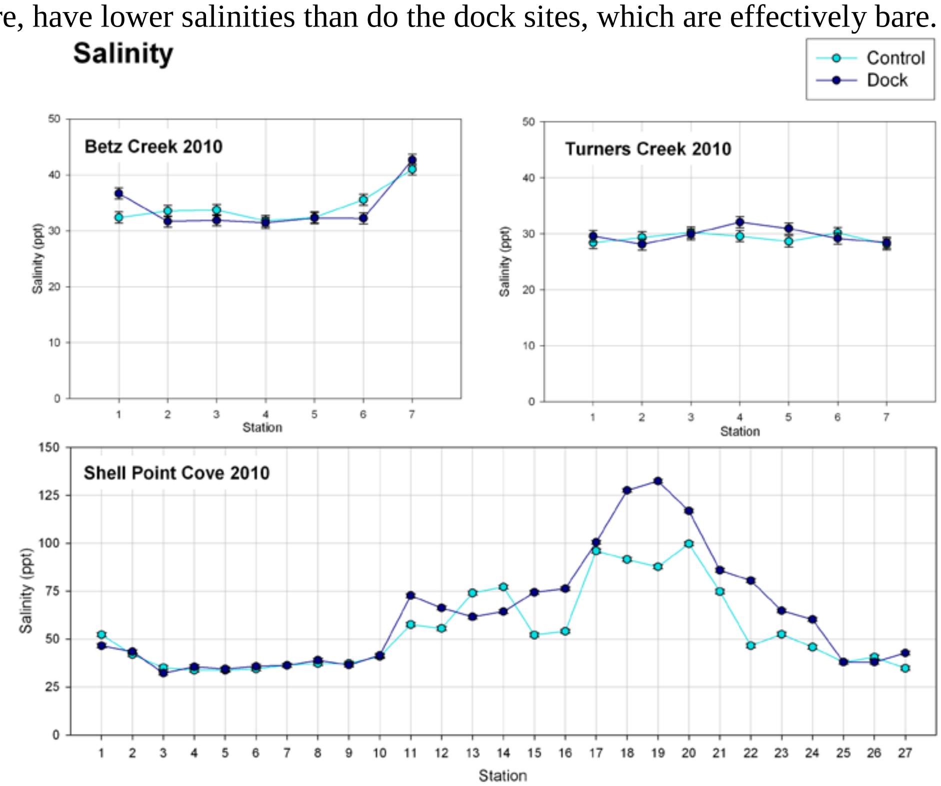


Figure 29. Salinity in sediment pore waters at all three dock study sites.

3.4.7 Grain Size

Grain size varied between all sites, with Shell Point Cove exhibiting the greatest variability (Figures 30A,B and Table 21). Typical grain sizes along the muddy, *S. alterniflora* dominated marshes fall in the range of 8-10Φ, which describes the general status of the Betz Creek and Turners Creek study sites. The most obvious change along the Shell Point Cove transects is the shift from fine-grained, muddy sediments (8-10Φ, stations 3-10) to sandier sediment in the *J. Roemarianus* zone (3-5Φ, transects 14-22) and then back to muddier sediments toward the main channel. The 2008 coarsening in grain size at the two channelward stations from ~9.5Φ to ~7Φ may result from dock construction effects. Strangely, the Turners Creek site exhibited a change in mean grain size at control sites the year after construction. In 2008 both control and dock sites averaged 9.5Φ. In 2009, however, the control sites coarsened to 8.5Φ whereas the dock sites coarsened slightly, if at all, and remained near 9.3Φ. In 2010 the control sites averaged 9.6Φ, reflecting a return to typical muddy conditions. Coarser sediments delivered from the channel seem to be the best explanation, given that the texture coarsens toward the channel, and not the upland, the other source of coarse material. If dock construction were the cause, a similar coarsening at the dock sites would be expected.

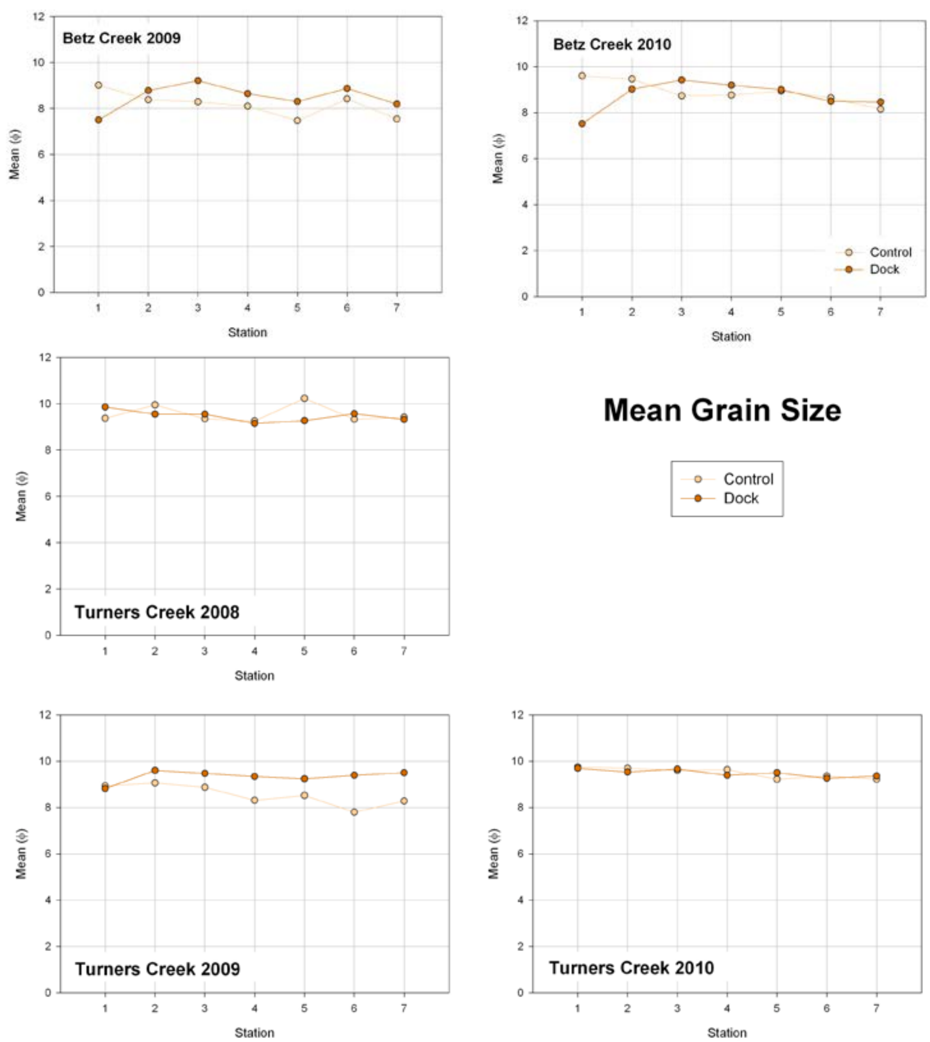


Fig. 30A. Mean grain size along the Betz Creek and Turners Creek transects.

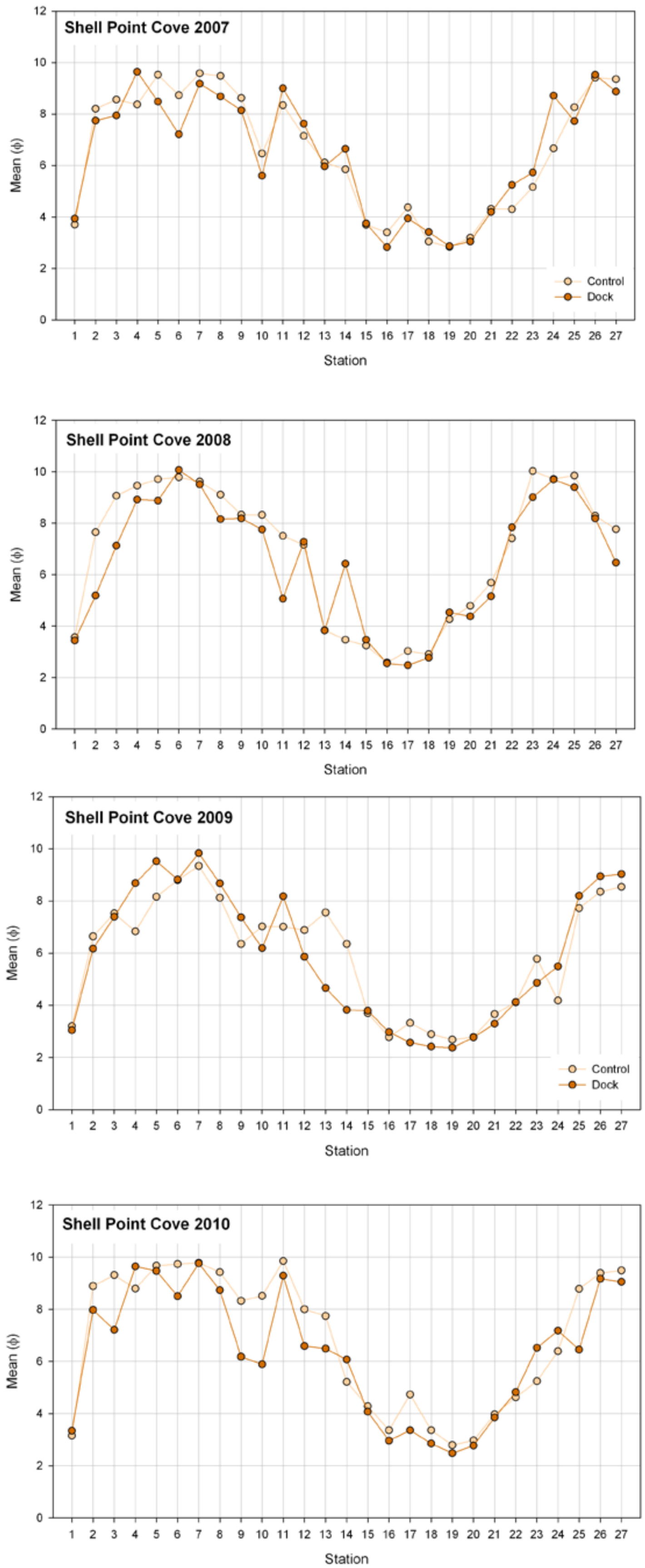


Figure 30B. Mean Grain size along the Shell Point Cove dock transects.

3.4.8 Field Assessment of Alternative Materials and Construction Methods Summary

Three separate field sites along the Georgia coast were examined to determine the effects of alternative dock materials and construction methods on the marsh environment on yearly timescales. Pairs of sample stations, consisting of one dock station, located directly underneath the dock, and one control station, located parallel with, and 5 meters away from the dock, were occupied beginning at the upland-marsh boundary, and advancing at 20 meter intervals into the marsh. At each station, dock and control samples were collected to quantify the changes that dock construction, dock presence, and presence of alternative construction techniques exert on the marsh environment. At the two alternative material and construction docks, Turners Creek (ThruFlow) and Shell Point Cove (Dockrider), we were able to sample along the corridor used to install the docks prior to dock construction; a traditional planked dock at Betz Creek was also included to provide a control for traditional dock building techniques and any dock-induced effects on the marsh.

Post-construction stem density data show a substantial decrease in stem density beneath all docks for all years, ranging from a 44% to an 80% decrease year over year, compared to control sites. Biomass shows decreases beneath the docks at all three sites as well. The ThruFlow dock exhibited the greatest biomass loss of the three field sites (63%). The dockrider system also showed a significant decrease in biomass under the dock (40%). In addition, several dock-associated impacts were observed, including transitions from vegetated marshes to persistent denuded muflats in areas of piling-associated marsh wrack accumulation and from *J. roemerianus* to *S. alterniflora* because of lowered surface elevations along dock-construction walking paths. Organic carbon content was similar at all three sites, and typical for salt marsh sites in Georgia (3-6%). In many cases, dock samples had consistently lower organic carbon values, reflecting the loss of vegetation and input of plant material. Apparently, benthic algae are not able to fill that gap, even with less vegetation to block light, given the increased shading from the dock. Chl *a* values in the sparse grass below docks, which reflect the productivity of the benthic algae community, were low compared to unvegetated mudflats, but were similar to those observed in vegetated salt marshes in Georgia. A drop in Chl *a* pigments at under-dock sampling sites was observed at both the Dockrider and ThruFlow sites in the year following dock construction, perhaps indicating a temporary disruption of the benthic algal productivity. No consistent pre-and post-construction patterns were observed in salinity or grain size at any of the sites.

The results from the field assessments of docks built using alternative construction materials and methods reinforce the conclusions from the mock dock simulation study that neither current alternative materials nor construction methods effectively negate the effects of dock shading in our region. Both docks

built using these approaches exhibited significant reductions in stem density, Chl *a*, organic carbon and biomass under the docks; however, the Thruflow dock exhibited a greater biomass loss than did the SunDock.

This study only examined the impact of dock shading on the productivity of the marsh. Several other impacts, most notably marsh wrack accumulation around dock and walkway pilings, can also negatively impact the marsh. Wrack accumulation has been implicated in killing aboveground and belowground biomass, thus lowering the marsh surface elevation and turning marshes into mudflats. Although the Sundock provided less reduction in PAR in all cases, this type of access walkway must be constructed with pilings spaced 10 feet apart, whereas other construction methods can space pilings between 12 and 20 feet apart. This closer spacing may trap more wrack than more traditional docks with a wider piling spacing. Studies are currently underway to more precisely determine the distribution and impact of wrack in the salt marshes of Georgia.

3.5 Light Transmittance Study

3.5.1 *S. alterniflora* Canopy

Light penetration data were collected within the marsh canopy to estimate the amount of PAR that reached the sediment surface through various densities of *S. alterniflora.* Light transmittance varied widely and was dependant on the density of the canopy and sun angle (Figure 31 and Table 22). Around solar noon, PAR transmittance near the sediment surface reached 78% in low densities, 50% in medium densities and 23% in high density stands. Data on light penetration through *S. alterniflora* canopy collected by the GCE-LTER show similar transmittance levels (Pennings, 2009, unpublished data). All these datasets are included in Figure 31 for comparison.

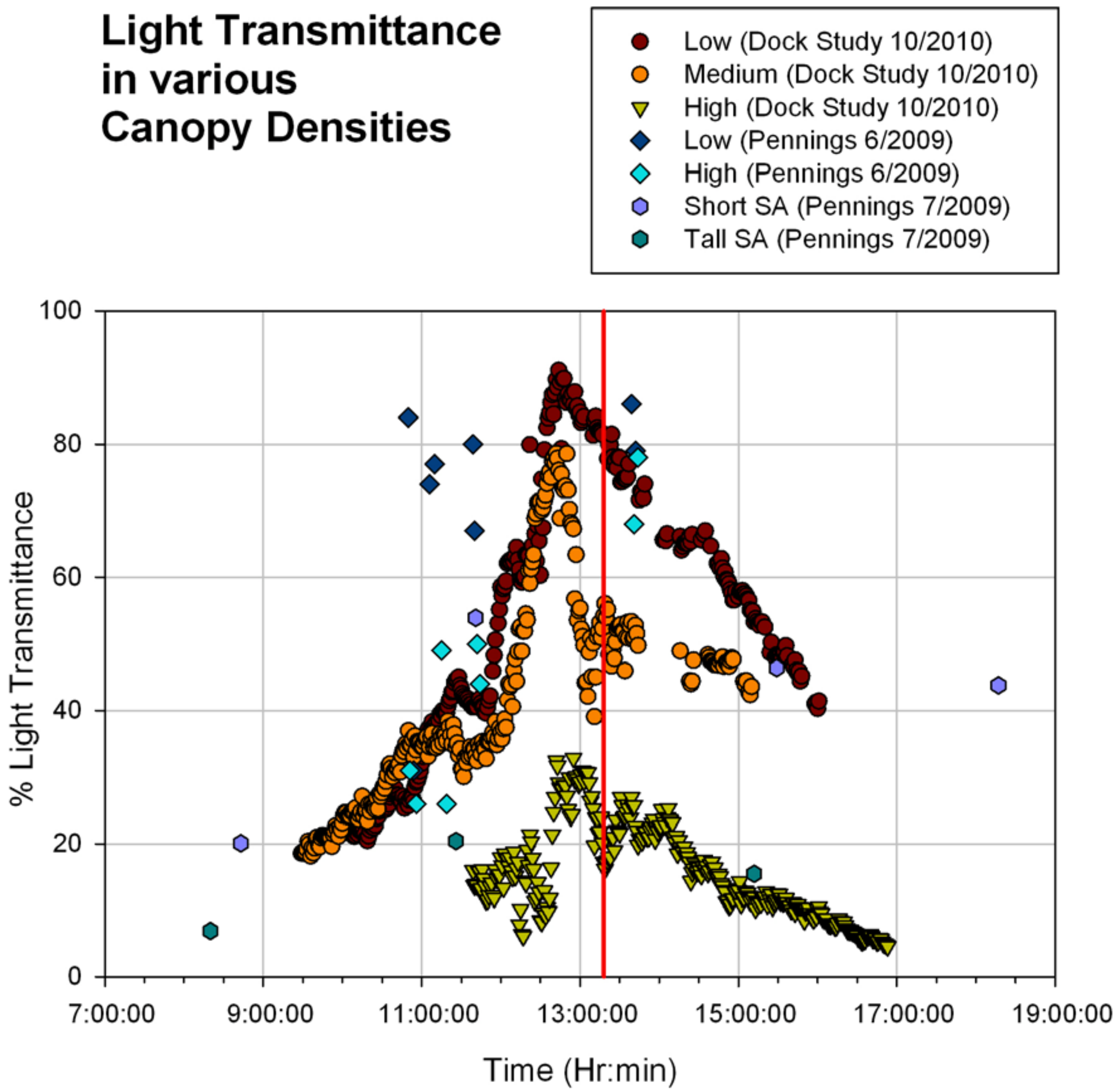


Figure 31. Light (PAR) penetration through low, medium and high densities of *S. alterniflora*. Low and medium density canopy for this study contained short form *S. alterniflora* whereas high density contained tall form *S. alterniflora*. Red line on graph represents solar noon for data in this study.

3.5.2 Water Column Turbidity

Light data was collected at two locations to determine light transmittance through two types of turbid water columns common in Georgia (Table 22). The first deployment, in a major tidal stream, the Skidaway River, showed that transmittance varied strongly with depth and depended on whether the tide was flooding or ebbing. The intertidal site along the Skidaway River reached a peak depth of 1.95 m. Light transmittance fell to 6% when the flooding tide caused the water depth to reach 1.48 m. Transmittance remained between 2 and 6% during high tide, until the water depth dropped to 1 m above the sensor with the ebbing tide. At 0.5 m depth above the sensor, transmittance was 28% during the incoming tide and 6% during the outgoing tide. The enhanced turbidity on the ebbing tide creates a longer period of time before light levels increase and plants can begin to photosynthesize. These results suggest that when intertidal vegetation is submerged in less than a meter (3.3 feet) of water, its ability to photosynthesize is hindered by turbidity that decreases available light, and by submergence causing suspension of gas exchange.

The second deployment took place on an intertidal marsh platform with an elevation of 0 feet relative to NAVD88, meaning that its elevation is close to that of mean sea level, near Skidaway Institute. During this deployment, tide level peaked at 0.89 m above the sensor. This depth of water and turbidity in this less-energetic environment allowed 28% light transmittance, whereas a similar water depth in the Skidaway River allowed only 14% transmittance.

3.5.3 Light Transmittance Study Summary

Two parameters further affect the light plants receive for photosynthesis in a salt marsh: the canopy density and inundation by turbid waters by the tides. A short study was conducted near Skidaway Island to better understand the effects of these parameters on the quality, extent and duration of light encountered by *S. alterniflora*. Over the four hours around solar noon, 25-78%, 20-61% and 7-23% of incident PAR reaches the sediment surface in low, medium and high density canopy, respectively, illustrating that self-shading and decreases in benthic algae production can be significant in marshes. Turbidity in the water column also can significantly alter light availability to salt marsh grasses, with only 0.5 m of water overlying plants needed to reduce the incident PAR by 50-70%. These effects would be less severe in winter, when our waters are clearer. These data serve as a first examination of these issues in Georgia saltmarshes.

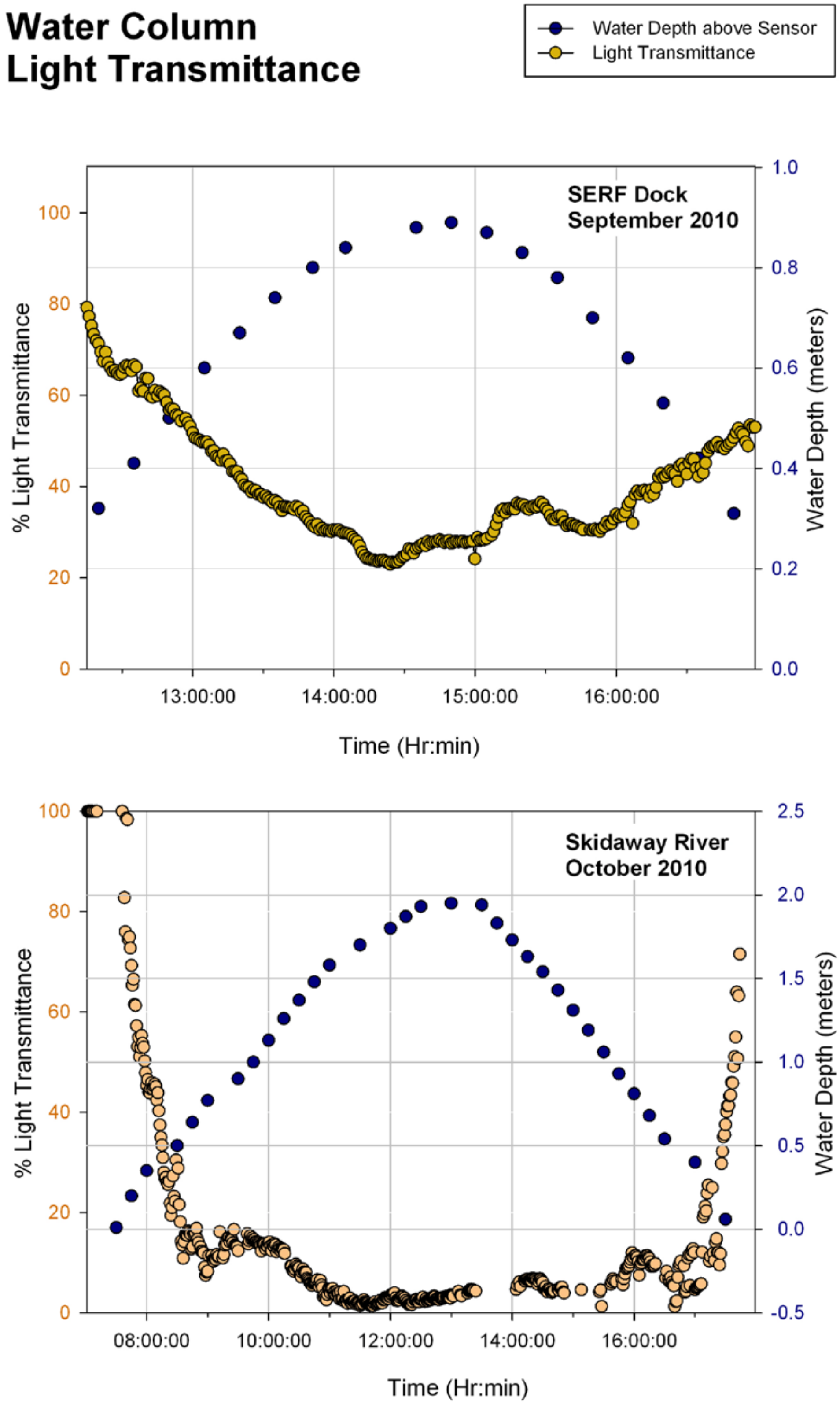


Figure 32. Light transmittance experiments through the water column. Upper panel – deployment on a marsh platform near Skidaway Institute. Note the shallow water depths and relatively good light transmittance. Lower panel – deployment in the intertidal portion of the Skidaway River. Note the poor transmittance associated with greater turbidity and turbulence.

4.0 Dock Material and Construction Cost Comparisons

The cost to build docks from alternative materials and by alternative construction methods varies based on the materials and construction techniques required. Dock Supply, Inc., in Midway, GA, provided two sets of per linear foot cost estimates: one for the cost of the materials to build standard and alternative decking, not including pilings (Table 23); and one for the cost to build the complete structure, including pilings (Table 24). These estimates are cost estimates based on current market prices in August 2011 by one vendor in coastal Georgia, and may be different for other builders/suppliers and in other regions of the country. For example, the estimated cost for a SunDock installation from Dock Supply, Inc., for a dock meeting the specifications in Table 24, is different from the estimated cost provided by Green Heron Docks, the original designer and installer of SunDocks.

According to these estimates, traditional wood decking is the most cost-effective material for building a dock, when looking at the cost of decking material alone. The SunDock decking cost appears high because it includes the cost of the $25,000 motorized cart that moves along the rails. In terms of full dock installation, however, the SunDock appears to be cost-competitive with a standard wood structure, depending on the estimate you use. This may arise because Green Heron Docks builds SunDocks with a purpose-built dock installation machine that streamlines the installation process, potentially reducing labor costs.

Alternative materials can require more pilings and supports compared to traditional wood docks (Table 25) and the decking is initially more expensive. However, the greater cost is ameliorated by features that create longevity in the materials. Aluminum, fiberglass and fiberglass-impregnated plastic alternative materials require less maintenance than wood and are corrosion and UV resistant, as well as resistant to biological attack. Their lifespans are typically decades, whereas the lifespan of wood decking is typically less than 10 years. However, given the negative impacts that arise from decked structures of any kind, there is no reasonable reason to require alternative decking material to promote conservation of natural resources. Any decked structure will stress the vegetation below it because of shading, leading to loss of biomass and productivity.

The SunDock is the least impactful on marsh resources and should be the preferred method of gaining access to the water. Additionally, Green Heron Docks deploys a purpose-built dock-building machine that keeps all materials and personnel out of the marsh, while building the dock from the structure itself. Removing the damage to the marsh from grounded barges, cranes and timber mats has obvious advantages for conserving marsh resources. There is one negative aspect of the SunDock system – it requires 10-foot pile spacing, using more piles, and potentially traps more marsh wrack, thereby locally impacting the marsh. If marsh wrack is of major concern in a given area and a dock must be built, the Fibergrate material should be explored, given its strength when framed in aluminum, as we tested the decking material. The Fibergrate material can easily support 20-foot pile spacing when appropriate pile materials (i.e., concrete) are used.

Although outside of the scope of this study, a number of alternative pile materials have now come on the market, including concrete, fiberglass and plastic, which remove one source of contaminants to the marsh – the leaching of biocides from treated wood pilings and decking. On a final note, I have recently been made aware of an engineer who has built an aluminum truss dock here in Chatham County. This dock is potentially important because it spans over 40 feet with only two sets of standard pilings, was inexpensive to build and has good longevity owing to aluminum's resistance to corrosion. The only maintenance he has done in over 30 years is to replace the deck boards, which are of standard wood.

Table 23. Estimates of relative costs of walkway decking materials. Estimates based on a 5-foot wide walkway and includes joists and stringers. Pilings and caps are excluded. Sundock includes price of cart.

Alternative Material Cost Comparison Deck and Substructure (per linear foot)	
Material	**Cost**
Traditional	$65
ThruFlow™	$105
Fibergrate™	$125
SunDock™	$138

Table 24. Estimates of relative costs of dock construction costs. Estimates based on a 5-foot wide walkway with handrail, appropriate substructures, 16-foot long pilings and including labor. Sundock includes price of cart.

Alternative Material Cost Comparison Deck, Substructure, Pilings and Labor (per linear foot)	
Material	**Cost**
Traditional	$150
ThruFlow™	$200
SunDock™ (Green Heron Docks)	$105-$145
SunDock™ (Dock Supply, Inc.)	$200
Fibergrate™	$220
Grated Aluminum	$230

Table 25. Specifications for Mock Docks and materials used in this study.

Mock Dock Specifications				
	Tradition al	**Thruflow**	**Fibergrate**	**SunDock**
Width (feet)	5	5	6	3
Length (feet)	20	20	13	20.8
Stringer Height (inches)	8.75	8.5	10	10.5
Number of Along-Dock Stringers Required	3	5	3	---
Distance between Pile centers (along-dock in feet)	11.5	11.5	10.5	10.5
Distance between Pile centers (across-dock in feet)	4.7	4.7	5.7	Varies with height
Pile Diameter (inches)	10.75	10.75	10.75	10.75
Length of alternative structural unit (inches; along dock)	---	11.5	156	---
Width of alternative structural unit (inches; across dock)	---	60	72	---
Large openings in decking (inches; L x W)	---	0.4 x 3.1	0.75 x 3.75	---
Small openings in decking (inches; L x W)	---	0.4 x 1.6	---	---
Depth of openings in material (inches)	---	1.0	1.5	---

Photos of the Mock Dock Structures used in the study.

Traditional Dock

Fibergrate Dock

ThruFlow Dock

DockRider Sundock

5.0 Acknowledgements

The author wishes to thank the Georgia Coastal Zone Management Program and NOAA for their support of this project. Special thanks go to Lee Ann DeLeo for her extensive work on this project both in collecting and analyzing data, and Harry Carter, Skidaway plant operations, for his help in constructing and manipulating the mock docks. Mike Robinson, Nick Scoville and Claudia Venherm also assisted with data collection over the life of this project. Courtney Morrison worked with us in an exploratory attempt to use architectural software for shadow duration modeling.

6.0 References

Alexander, C. R. and M. H. Robinson. 2004. GIS and Field-Based Analysis of the Impacts of Recreational Docks on the Saltmarshes of Georgia. Final Report prepared for the Georgia Coastal Zone Management Program. 40 p.

Alexander, C. R. and M. H. Robinson. 2006. Quantifying the Ecological Significance of Marsh Shading: The Impact of Private Recreational Docks in Coastal Georgia. Final Report prepared for Coastal Resources Division, Georgia Department of Natural Resources. 47 p.

Burdick, D.M., and F.T. Short, 1999. The Effect of Boat Docks on Eelgrass Beds in Coastal Waters of Massachusetts. Environmental Management 23(2): 231-240

Giurgevich, J. R. and E. L. Dunn. 1982. Seasonal Patterns of Daily Net Photosynthesis, Transpiration and Net Primary Productivity of Juncus roemerianus and Spartina alterniflora in a Georgia Salt Marsh. Oecologia. Vol. 52. p. 404-410.

Kathilankal, James C., Thomas J. Mozdzer, Jose D. Fuentes, Karen J. McGlathery, Paolo D'Odorico and Jay C. Zieman. 2011. Physiological responses of Spartina alterniflora to varying environmental conditions in Virginia marshes. Hydrobiologia, Vol. 669, No. 1, p.167-181.

Kearney, V.F., Y. Segal, and M.W. Lefor. 1983. The effects of docks on salt marsh vegetation. Connecticut State Department of Environmental Protection. Hartford, CT. 22.

Kelty, R.A. and S. Bliven. 2003. Environmental and Aesthetic Impacts of Small Docks and Piers, Workshop Report: Developing a Science-Based Decision Support Tool for Small Dock Management, Phase 1: Status of the Science. NOAA Coastal Ocean Program Decision Analysis Series No. 2. National Centers for Coastal Ocean Science, Silver Spring, MD. 69 pp.

Pomeroy, L.R., Darley, W.M., Dunn, E.L., Gallagher, J.L., Haines, E.B. and D.M. Whitney. 1981. Primary Production. In: The Ecology of a Salt Marsh. Eds. L.R. Pomeroy, and R.G. Wiegert New York: Springer-Verlag pp. 38-67.

Sanger, D.M. and F. Holland. 2002. Evaluation of the Impacts of Dock Structures on South Carolina Estuarine Environments. Technical Report number 99. South Carolina Department of Natural Resources, Marine Resources Division, Marine Resource Research Institute.

Shaefer, D. 1999. "The Effects of Dock Shading on the Seagrass *Halodule wrightii* in Perdido Bay, Alabama." Estuaries 22 (4): 936–943.

Shaefer, D and J. Robinson. 2001. "An evaluation of the use of grid platforms to minimize shading impacts to seagrasses." *WRAP Technical Notes Collection* (ERDC TN-WRAP–01–02. US Army Engineer Research and Development Center, Vicksburg, MS.

Weis, J.S. and P. Weis.2006. Effects of wood treated with chromated copper arsenic on aquatic biota. In: Environmental Impacts of Treated Wood, ed. T. Townsend & H. Solo-Gabriele. CRC Press pp 173-190.

Field Assessment and Simulation of Shading from Alternative Dock Construction Materials

Appendix 1

Final Report Tables 3 - 22

Table 3. Daily shadow durations at 0, 45, 90 and 135 degrees orientation.

Daily Shadow Durations (Hours) *Orientation Data*				
Fall	**Traditional**	**ThruFlow™**	**Fibergrate™**	**SunDock™**
000	2.77	2.75	3.65	2.08
045	3.42	3.43	3.35	1.93
090	0.70	0.73	0.95	0.97
135	2.13	2.13	1.89	2.23
Winter				
000	3.30	3.43	3.39	1.53
045	3.35	3.36	4.44	1.72
090	0.75	0.71	0.84	0.40
135	2.68	2.67	3.44	1.10
Spring				
000	3.46	3.50	4.17	0.83
045	3.92	3.83	4.60	0.82
090	6.76	7.99	9.41	3.67
135	6.13	6.84	7.56	1.30
Summer				
000	3.87	3.84	4.49	0.93
045	4.17	4.36	4.77	1.00
090	10.12	10.12	9.91	5.93
135	5.62	5.77	----	1.30

Table 4. Daily integrated photosynthetically active radiation (PAR) loss because of dock shading at 0, 45, 90 and 135 degrees orientation.

Daily Integrated PAR Loss *Orientation Data*				
Fall	**Traditional**	**ThruFlow™**	**Fibergrate™**	**SunDock™**
000	39.9%	37.8%	47.9%	26.9%
045	39.1%	36.4%	40.9%	22.4%
090	9.0%	7.9%	16.0%	2.1%
135	24.4%	22.9%	25.1%	13.2%
Winter				
000	49.3%	49.1%	46.0%	21.6%
045	37.9%	38.1%	42.3%	21.0%
090	11.9%	9.6%	11.6%	2.1%
135	26.0%	23.1%	30.3%	7.8%
Spring				
000	44.0%	38.5%	45.6%	9.9%
045	52.0%	44.2%	50.6%	11.0%
090	62.9%	57.3%	78.5%	19.0%
135	58.0%	54.6%	60.3%	14.0%
Summer				
000	44.1%	36.2%	39.9%	10.8%
045	56.6%	47.6%	52.2%	14.9%
090	82.8%	73.6%	74.1%	35.8%
135	64.5%	55.9%	66.4%	16.4%

Table 5. Shadow duration above the 0, 25 and 50% biomass loss threshold (BLT) with respect to orientation. "Time in Shadow" is calculated by counting each minute that PAR drops below the specified BLT. "% Time in Shadow" calculated by comparing the "time in shadow" to the total length of time spent per day above specified BLT as measured on the "above" sensor.

Shadow Duration Above the 0% Biomass Loss Threshold					
Fall	**Time in Shadow (hours)**	**% Time in Shadow**	**Winter**	**Time in Shadow (hours)**	**% Time in Shadow**
Traditional 000	3.00	55.0	Traditional 000	3.13	83.2
ThruFlow 000	2.85	52.3	ThruFlow 000	2.92	77.4
Fibergrate 000	3.73	68.5	Fibergrate 000	3.33	88.5
SunDock 000	2.00	36.7	SunDock 000	1.70	45.1
Traditional 045	2.20	44.6	Traditional 045	2.75	59.8
ThruFlow 045	2.08	42.2	ThruFlow 045	2.68	58.3
Fibergrate 045	2.70	54.7	Fibergrate 045	2.60	56.5
SunDock 045	1.43	29.1	SunDock 045	1.20	26.1
Traditional 090	0.17	3.2	Traditional 090	0.60	13.4
ThruFlow 090	0.12	2.2	ThruFlow 090	0.27	6.0
Fibergrate 090	0.38	7.3	Fibergrate 090	0.27	6.0
SunDock 090	0.00	0.00	SunDock 090	0.12	2.6
Traditional 135	1.55	27.8	Traditional 135	1.10	24.7
ThruFlow 135	1.60	28.7	ThruFlow 135	0.78	17.6
Fibergrate 135	2.23	40.1	Fibergrate 135	1.43	32.2
SunDock 135	0.85	15.3	SunDock 135	0.17	3.7
Spring	**Time in Shadow (hours)**	**% Time in Shadow**	**Summer**	**Time in Shadow (hours)**	**% Time in Shadow**
Traditional 000	4.22	53.2	Traditional 000	4.15	52.2
ThruFlow 000	4.08	51.5	ThruFlow 000	3.73	47.0
Fibergrate 000	4.75	59.9	Fibergrate 000	4.20	52.8
SunDock 000	1.10	13.9	SunDock 000	0.92	11.5
Traditional 045	4.43	58.5	Traditional 045	4.45	56.9
ThruFlow 045	4.20	55.4	ThruFlow 045	4.17	53.3
Fibergrate 045	4.77	62.9	Fibergrate 045	4.60	58.8
SunDock 045	1.03	13.6	SunDock 045	1.02	13.0
Traditional 090	4.98	67.6	Traditional 090	7.62	100.0
ThruFlow 090	4.70	63.8	ThruFlow 090	7.10	93.2
Fibergrate 090	7.07	95.9	Fibergrate 090	7.13	93.7
SunDock 090	1.67	22.6	SunDock 090	3.68	48.4
Traditional 135	5.58	72.4	Traditional 135	6.23	76.2
ThruFlow 135	5.35	69.3	ThruFlow 135	5.73	70.1
Fibergrate 135	6.00	77.8	Fibergrate 135	7.63	93.3
SunDock 135	1.60	20.7	SunDock 135	1.42	17.3

Shadow Duration Above the 25% Biomass Loss Threshold

Fall	Time in Shadow (hours)	% Time in Shadow	Winter	Time in Shadow (hours)	% Time in Shadow
Traditional 000	3.07	41.9	Traditional 000	3.88	67.1
ThruFlow 000	2.82	38.5	ThruFlow 000	3.73	64.6
Fibergrate 000	3.67	50.1	Fibergrate 000	3.93	68.0
SunDock 000	2.08	28.5	SunDock 000	1.68	29.1
Traditional 045	2.20	42.6	Traditional 045	2.90	45.4
ThruFlow 045	2.08	41.6	ThruFlow 045	2.93	46.0
Fibergrate 045	2.70	45.9	Fibergrate 045	2.87	44.9
SunDock 045	1.43	29.3	SunDock 045	1.88	29.5
Traditional 090	0.03	0.5	Traditional 090	0.22	3.4
ThruFlow 090	0.47	6.8	ThruFlow 090	0.42	6.6
Fibergrate 090	1.03	15.0	Fibergrate 090	0.28	4.5
SunDock 090	0.03	0.5	SunDock 090	0.13	2.1
Traditional 135	2.12	29.3	Traditional 135	1.67	26.7
ThruFlow 135	2.32	32.1	ThruFlow 135	1.62	25.9
Fibergrate 135	2.07	28.6	Fibergrate 135	2.03	32.5
SunDock 135	0.90	12.5	SunDock 135	0.75	12.0
Spring	**Time in Shadow (hours)**	**% Time in Shadow**	**Summer**	**Time in Shadow (hours)**	**% Time in Shadow**
Traditional 000	3.73	41.6	Traditional 000	4.17	44.9
ThruFlow 000	3.45	38.5	ThruFlow 000	3.07	33.0
Fibergrate 000	4.22	47.0	Fibergrate 000	3.52	37.9
SunDock 000	0.75	8.4	SunDock 000	0.87	9.3
Traditional 045	4.23	48.0	Traditional 045	4.60	52.1
ThruFlow 045	3.93	44.6	ThruFlow 045	4.03	45.7
Fibergrate 045	4.57	51.8	Fibergrate 045	4.30	48.7
SunDock 045	1.05	11.9	SunDock 045	0.97	10.9
Traditional 090	6.25	71.8	Traditional 090	8.85	99.6
ThruFlow 090	5.88	67.6	ThruFlow 090	7.88	88.7
Fibergrate 090	8.22	94.4	Fibergrate 090	7.97	89.7
SunDock 090	1.82	20.9	SunDock 090	4.42	49.7
Traditional 135	5.88	64.9	Traditional 135	6.63	70.4
ThruFlow 135	5.57	61.4	ThruFlow 135	5.55	58.9
Fibergrate 135	3.98	43.9	Fibergrate 135	7.03	74.7
SunDock 135	1.33	14.7	SunDock 135	1.58	16.8

Shadow Duration Above the 50% Biomass Loss Threshold

Fall	Time in Shadow (hours)	% Time in Shadow	Winter	Time in Shadow (hours)	% Time in Shadow
Traditional 000	2.88	32.8	Traditional 000	3.62	46.8
ThruFlow 000	2.83	32.3	ThruFlow 000	3.65	47.2
Fibergrate 000	3.72	42.3	Fibergrate 000	3.82	49.4
SunDock 000	2.05	23.3	SunDock 000	1.60	20.7
Traditional 045	3.73	45.8	Traditional 045	3.28	40.1
ThruFlow 045	3.68	45.2	ThruFlow 045	3.30	40.3
Fibergrate 045	4.00	49.1	Fibergrate 045	3.78	46.2
SunDock 045	2.17	26.6	SunDock 045	1.78	21.8
Traditional 090	0.95	10.9	Traditional 090	1.02	12.5
ThruFlow 090	0.92	10.5	ThruFlow 090	0.92	11.2
Fibergrate 090	1.15	13.2	Fibergrate 090	1.13	13.9
SunDock 090	0.00	0.0	SunDock 090	0.13	1.6
Traditional 135	2.33	25.8	Traditional 135	2.43	30.5
ThruFlow 135	2.37	26.2	ThruFlow 135	2.43	30.5
Fibergrate 135	2.12	23.4	Fibergrate 135	2.80	35.1
SunDock 135	1.53	17.0	SunDock 135	0.82	10.3

Spring	Time in Shadow (hours)	% Time in Shadow	Summer	Time in Shadow (hours)	% Time in Shadow
Traditional 000	3.72	35.4	Traditional 000	4.00	36.1
ThruFlow 000	2.63	25.1	ThruFlow 000	1.97	17.8
Fibergrate 000	3.53	33.7	Fibergrate 000	2.47	22.3
SunDock 000	0.75	7.1	SunDock 000	2.45	22.1
Traditional 045	4.03	40.2	Traditional 045	5.12	46.5
ThruFlow 045	3.28	32.7	ThruFlow 045	3.65	33.2
Fibergrate 045	3.97	39.5	Fibergrate 045	3.93	35.8
SunDock 045	0.85	8.5	SunDock 045	1.45	13.2
Traditional 090	6.90	67.1	Traditional 090	10.42	99.0
ThruFlow 090	8.97	87.2	ThruFlow 090	8.47	80.5
Fibergrate 090	8.40	81.7	Fibergrate 090	9.52	90.5
SunDock 090	2.57	25.0	SunDock 090	5.57	52.9
Traditional 135	5.87	54.8	Traditional 135	5.88	55.3
ThruFlow 135	6.20	57.9	ThruFlow 135	3.72	35.0
Fibergrate 135	7.05	65.9	Fibergrate 135	4.92	46.2
SunDock 135	1.30	12.1	SunDock 135	0.90	8.5

Table 6. Percentage of daily integrated PAR loss above 0, 25 and 50% BLT with respect to orientation. Percentages calculated using integrated areas illustrated in Figure 8. See text accompanying figure for details of calculation.

Percent of Daily Integrated PAR Loss Above 0% Biomass Loss Threshold				
Fall	**Traditional**	**ThruFlow**	**Fibergrate**	**SunDock**
000	77.2	72.8	85.8	52.4
045	52.1	43.2	68.2	28.4
090	15.9	8.5	33.4	-0.2
135	27.9	22.0	39.9	5.7
Winter				
000	95.6	94.0	95.7	57.5
045	56.7	57.2	56.6	35.3
090	36.4	18.5	30.3	5.3
135	32.9	28.3	35.6	3.7
Spring				
000	73.6	71.5	80.0	18.8
045	81.0	73.9	82.5	19.2
090	77.2	72.8	98.4	18.4
135	83.1	81.9	90.4	23.9
Summer				
000	74.8	73.4	80.4	21.8
045	84.0	81.2	87.3	26.7
090	100.0	98.0	97.9	41.9
135	95.3	92.9	97.2	30.2
Percent of Daily Integrated PAR Loss Above 25% Biomass Loss Threshold				
Fall	**Traditional**	**ThruFlow**	**Fibergrate**	**SunDock**
000	61.7	58.5	72.2	42.2
045	48.9	44.0	56.7	30.3
090	9.5	6.3	22.7	0.1
135	28.8	26.1	36.3	12.0
Winter				
000	80.6	80.2	78.5	40.9
045	49.9	50.6	51.6	31.0
090	20.0	11.3	17.0	3.3
135	26.8	23.3	32.4	5.1
Spring				
000	63.7	61.8	70.1	15.6
045	71.8	65.2	73.7	16.8
090	74.4	70.3	97.1	19.3
135	78.1	75.9	83.8	21.0
Summer				
000	64.8	61.3	67.4	17.9
045	76.6	72.4	78.1	22.7
090	100.0	95.3	95.6	43.9
135	89.8	85.3	94.3	26.3

Percent of Daily Integrated PAR Loss Above 50% Biomass Loss Threshold				
Fall	**Traditional**	**ThruFlow**	**Fibergrate**	**SunDock**
000	51.0	49.0	61.6	35.5
045	46.3	42.8	51.1	28.3
090	9.4	8.4	20.0	0.4
135	29.0	27.5	31.8	13.6
Winter				
000	66.6	66.7	42.9	31.2
045	45.4	46.1	49.7	28.1
090	14.5	11.4	14.0	2.4
135	27.9	24.2	33.2	8.5
Spring				
000	55.2	51.9	60.1	13.1
045	63.0	56.9	64.3	14.2
090	72.7	68.8	94.6	20.6
135	71.7	68.1	74.9	18.3
Summer				
000	56.5	49.6	54.8	14.9
045	69.8	63.1	68.2	10.9
090	99.6	91.8	92.2	46.8
135	83.4	75.4	87.8	22.4

Table 7. Daily shadow durations for 4, 5, 6, 7 and 8 foot dock heights.

Daily Shadow Durations (Hours) *Height Data*				
Fall	**Traditional**	**ThruFlow™**	**Fibergrate™**	**SunDock™**
4'	3.20	3.25	3.82	1.10
5'	2.82	2.83	3.75	2.02
6'	2.40	2.37	2.87	0.77
7'	2.03	2.03	2.40	1.53
8'	1.80	1.82	2.13	1.42
Winter				
4'	3.02	2.98	3.50	0.88
5'	2.50	2.48	2.90	1.87
6'	2.12	2.12	2.52	1.67
7'	1.92	1.90	2.23	1.37
8'	1.72	1.70	2.03	0.88
Spring				
4'	4.42	4.47	5.02	1.48
5'	3.60	3.67	4.28	1.05
6'	3.10	3.05	3.60	0.85
7'	2.55	2.80	3.15	0.80
8'	2.17	2.25	2.72	0.60
Summer				
4'	5.07	4.97	5.63	1.47
5'	4.00	4.05	4.68	1.17
6'	3.42	3.43	3.98	1.02
7'	3.05	2.93	3.45	0.70
8'	2.65	2.55	3.27	0.55

Table 8. Percent of daily integrated PAR lost because of dock shading at 4, 5, 6, 7, and 8 foot dock elevations. Percentages calculated by comparing area of daily PAR to area of shadow (See Figure 1).

Percent of Daily Integrated PAR Lost ***Height Data***				
Fall	**Traditional**	**ThruFlow**	**Fibergrate**	**SunDock**
4'	47.9	46.6	52.5	15.1
5'	42.1	42.0	49.7	28.7
6'	35.4	36.8	39.3	11.7
7'	29.3	28.1	34.3	22.0
8'	27.6	26.8	31.2	20.3
Winter				
4'	48.2	45.9	52.3	10.7
5'	41.7	39.4	43.9	25.1
6'	33.9	33.4	38.0	24.7
7'	30.1	30.9	33.5	17.6
8'	28.1	28.2	30.2	12.6
Spring				
4'	54.2	49.0	53.7	13.9
5'	44.8	41.6	46.9	9.8
6'	38.1	36.0	41.5	8.6
7'	33.8	32.5	36.4	7.9
8'	29.5	30.2	33.4	8.3
Summer				
4'	52.3	42.9	40.5	17.0
5'	40.5	29.5	29.7	12.2
6'	40.9	29.3	29.4	11.7
7'	33.8	25.9	21.1	8.9
8'	30.1	20.6	25.6	8.9

Table 9. Shadow duration above the 0, 25 and 50% biomass loss threshold with respect to elevation. "Time in shadow" is calculated by summing minutes PAR drops below specified BLT. "% Time in Shadow" calculated by comparing the "time in shadow" to the total length of time spent per day above specified BLT.

Shadow Duration Above the 0% Biomass Loss Threshold							
Fall		**Time in Shadow (hours)**	**% Time in Shadow**	**Winter**		**Time in Shadow (hours)**	**%Time in Shadow**
Traditional	4'	3.43	85.5	Traditional	4'	2.92	100.0
ThruFlow	4'	3.37	83.8	ThruFlow	4'	2.50	85.7
Fibergrate	4'	3.72	92.5	Fibergrate	4'	2.92	100.0
SunDock	4'	1.20	29.9	SunDock	4'	0.43	14.9
Traditional	5'	3.32	67.5	Traditional	5'	2.98	100.0
ThruFlow	5'	3.18	64.7	ThruFlow	5'	2.33	78.2
Fibergrate	5'	3.55	72.2	Fibergrate	5'	2.62	87.7
SunDock	5'	2.30	46.8	SunDock	5'	1.52	50.8
Traditional	6'	2.78	57.0	Traditional	6'	2.37	76.3
ThruFlow	6'	2.67	54.6	ThruFlow	6'	2.32	74.7
Fibergrate	6'	3.00	61.4	Fibergrate	6'	2.55	82.3
SunDock	6'	0.82	16.7	SunDock	6'	1.85	59.7
Traditional	7'	2.18	48.2	Traditional	7'	2.13	61.0
ThruFlow	7'	2.13	47.1	ThruFlow	7'	2.35	67.1
Fibergrate	7'	2.67	58.8	Fibergrate	7'	2.33	66.7
SunDock	7'	1.63	36.0	SunDock	7'	1.28	36.7
Traditional	8'	2.13	51.6	Traditional	8'	2.27	54.8
ThruFlow	8'	2.23	54.0	ThruFlow	8'	2.47	59.7
Fibergrate	8'	2.60	62.9	Fibergrate	8'	2.43	58.9
SunDock	8'	1.80	43.5	SunDock	8'	1.22	29.4
Spring		**Time in Shadow (hours)**	**% Time in Shadow**	**Summer**		**Time in Shadow (hours)**	**%Time in Shadow**
Traditional	4'	4.82	64.7	Traditional	4'	5.23	64.3
ThruFlow	4'	4.77	64.0	ThruFlow	4'	4.95	60.9
Fibergrate	4'	5.35	71.8	Fibergrate	4'	4.65	57.2
SunDock	4'	1.22	16.3	SunDock	4'	1.38	17.0
Traditional	5'	3.82	51.6	Traditional	5'	4.38	53.8
ThruFlow	5'	3.85	52.0	ThruFlow	5'	3.68	45.2
Fibergrate	5'	4.33	58.6	Fibergrate	5'	3.98	48.9
SunDock	5'	0.78	10.6	SunDock	5'	1.08	13.3
Traditional	6'	3.10	42.0	Traditional	6'	4.03	51.5
ThruFlow	6'	3.13	42.4	ThruFlow	6'	3.80	48.5
Fibergrate	6'	3.55	48.1	Fibergrate	6'	3.82	48.7
SunDock	6'	0.63	8.6	SunDock	6'	0.92	11.7
Traditional	7'	2.85	39.9	Traditional	7'	2.98	36.1
ThruFlow	7'	2.87	40.1	ThruFlow	7'	2.47	29.8
Fibergrate	7'	3.18	44.5	Fibergrate	7'	2.73	33.1
SunDock	7'	0.63	8.9	SunDock	7'	0.60	7.3
Traditional	8'	2.42	34.4	Traditional	8'	2.67	34.1
ThruFlow	8'	2.53	36.0	ThruFlow	8'	2.53	32.4
Fibergrate	8'	2.80	39.8	Fibergrate	8'	3.62	46.3
SunDock	8'	0.58	8.3	SunDock	8'	0.47	6.0

Shadow Duration Above the 25% Biomass Loss Threshold							
Fall		**Time in Shadow (hours)**	**% Time in Shadow**	**Winter**		**Time in Shadow (hours)**	**%Time in Shadow**
Traditional	4'	3.78	59.1	Traditional	4'	3.47	65.0
ThruFlow	4'	3.72	58.1	ThruFlow	4'	3.28	61.6
Fibergrate	4'	4.23	66.1	Fibergrate	4'	3.68	69.1
SunDock	4'	1.37	21.4	SunDock	4'	0.75	14.1
Traditional	5'	3.07	45.8	Traditional	5'	3.05	56.7
ThruFlow	5'	3.02	45.0	ThruFlow	5'	2.73	50.8
Fibergrate	5'	3.85	57.5	Fibergrate	5'	3.03	56.3
SunDock	5'	2.08	31.1	SunDock	5'	1.97	36.5
Traditional	6'	2.57	38.2	Traditional	6'	2.53	45.9
ThruFlow	6'	2.50	37.2	ThruFlow	6'	2.38	43.2
Fibergrate	6'	2.85	42.4	Fibergrate	6'	2.63	47.7
SunDock	6'	0.62	9.2	SunDock	6'	1.83	33.2
Traditional	7'	2.07	31.9	Traditional	7'	2.08	35.6
ThruFlow	7'	2.02	31.1	ThruFlow	7'	2.12	36.2
Fibergrate	7'	2.45	37.8	Fibergrate	7'	2.28	39.0
SunDock	7'	1.40	21.6	SunDock	7'	1.27	21.7
Traditional	8'	1.98	31.9	Traditional	8'	1.93	31.8
ThruFlow	8'	1.90	30.6	ThruFlow	8'	2.00	32.9
Fibergrate	8'	2.27	36.5	Fibergrate	8'	2.15	35.3
SunDock	8'	1.52	24.4	SunDock	8'	0.97	15.9
Spring		**Time in Shadow (hours)**	**% Time in Shadow**	**Summer**		**Time in Shadow (hours)**	**%Time in Shadow**
Traditional	4'	4.67	52.6	Traditional	4'	5.22	54.3
ThruFlow	4'	4.47	50.4	ThruFlow	4'	4.63	48.3
Fibergrate	4'	5.12	57.7	Fibergrate	4'	3.98	41.5
SunDock	4'	1.22	13.7	SunDock	4'	1.40	14.6
Traditional	5'	3.78	42.9	Traditional	5'	4.08	42.8
ThruFlow	5'	3.80	43.1	ThruFlow	5'	3.40	35.6
Fibergrate	5'	4.08	46.3	Fibergrate	5'	3.42	35.8
SunDock	5'	0.82	9.3	SunDock	5'	1.17	12.2
Traditional	6'	2.95	33.8	Traditional	6'	3.87	41.7
ThruFlow	6'	3.12	35.8	ThruFlow	6'	2.52	27.1
Fibergrate	6'	3.58	41.1	Fibergrate	6'	0.22	2.3
SunDock	6'	0.67	7.6	SunDock	6'	0.83	9.0
Traditional	7'	2.70	31.5	Traditional	7'	3.02	31.0
ThruFlow	7'	2.30	26.8	ThruFlow	7'	1.98	20.4
Fibergrate	7'	3.05	35.6	Fibergrate	7'	2.07	21.2
SunDock	7'	0.55	6.4	SunDock	7'	0.62	6.3
Traditional	8'	2.30	27.4	Traditional	8'	2.62	28.1
ThruFlow	8'	2.38	28.4	ThruFlow	8'	2.02	21.6
Fibergrate	8'	2.67	31.7	Fibergrate	8'	2.87	30.8
SunDock	8'	0.43	5.2	SunDock	8'	0.48	5.2

Shadow Duration Above the 50% Biomass Loss Threshold							
Fall		**Time in Shadow (hours)**	**% Time in Shadow**	**Winter**		**Time in Shadow (hours)**	**%Time in Shadow**
Traditional	4'	3.40	42.1	Traditional	4'	3.22	43.4
ThruFlow	4'	3.35	41.4	ThruFlow	4'	3.13	42.2
Fibergrate	4'	3.85	47.6	Fibergrate	4'	3.57	48.1
SunDock	4'	0.95	11.8	SunDock	4'	0.73	9.9
Traditional	5'	3.00	35.1	Traditional	5'	2.73	36.6
ThruFlow	5'	2.92	34.1	ThruFlow	5'	2.43	32.6
Fibergrate	5'	3.82	44.6	Fibergrate	5'	2.97	39.7
SunDock	5'	2.00	23.4	SunDock	5'	1.82	24.3
Traditional	6'	2.55	29.6	Traditional	6'	2.22	29.8
ThruFlow	6'	2.45	28.4	ThruFlow	6'	2.05	27.5
Fibergrate	6'	2.88	33.5	Fibergrate	6'	2.37	31.8
SunDock	6'	0.42	4.8	SunDock	6'	1.52	20.4
Traditional	7'	1.97	23.9	Traditional	7'	2.00	25.6
ThruFlow	7'	1.97	23.9	ThruFlow	7'	1.97	25.2
Fibergrate	7'	2.35	28.5	Fibergrate	7'	2.18	28.0
SunDock	7'	1.43	17.4	SunDock	7'	1.12	14.3
Traditional	8'	1.93	23.6	Traditional	8'	1.83	22.9
ThruFlow	8'	1.87	22.8	ThruFlow	8'	1.82	22.7
Fibergrate	8'	2.27	27.7	Fibergrate	8'	2.05	25.6
SunDock	8'	1.45	17.7	SunDock	8'	0.83	10.4
Spring		**Time in Shadow (hours)**	**% Time in Shadow**	**Summer**		**Time in Shadow (hours)**	**%Time in Shadow**
Traditional	4'	4.67	44.4	Traditional	4'	5.15	45.5
ThruFlow	4'	3.80	36.1	ThruFlow	4'	3.90	34.5
Fibergrate	4'	4.43	42.2	Fibergrate	4'	3.48	30.8
SunDock	4'	1.27	12.0	SunDock	4'	1.35	11.9
Traditional	5'	3.75	36.0	Traditional	5'	4.08	37.1
ThruFlow	5'	3.07	29.4	ThruFlow	5'	2.47	22.4
Fibergrate	5'	4.00	38.4	Fibergrate	5'	2.35	21.4
SunDock	5'	0.85	8.2	SunDock	5'	0.57	5.2
Traditional	6'	3.10	30.1	Traditional	6'	3.72	33.5
ThruFlow	6'	2.87	27.9	ThruFlow	6'	1.07	9.6
Fibergrate	6'	3.45	33.5	Fibergrate	6'	1.23	11.1
SunDock	6'	0.70	6.8	SunDock	6'	0.15	1.4
Traditional	7'	2.65	26.1	Traditional	7'	2.98	25.6
ThruFlow	7'	2.63	25.9	ThruFlow	7'	1.03	8.9
Fibergrate	7'	3.28	32.3	Fibergrate	7'	1.45	12.4
SunDock	7'	0.55	5.4	SunDock	7'	1.03	8.9
Traditional	8'	2.30	22.9	Traditional	8'	2.55	23.4
ThruFlow	8'	2.33	23.3	ThruFlow	8'	0.63	5.8
Fibergrate	8'	2.93	29.2	Fibergrate	8'	0.87	7.9
SunDock	8'	0.57	5.6	SunDock	8'	0.47	4.3

Table 10. Percentage of daily integrated PAR loss above 0, 25 and 50% BLT with respect to dock height. Percentages calculated using integrated areas illustrated in Figure 8. See text accompanying figure for details of calculation.

Percent of Daily Integrated PAR Loss Above 0% Biomass Loss Threshold ***Height Data***				
Fall	**Traditional**	**ThruFlow**	**Fibergrate**	**SunDock**
4'	95.1	86.1	98.5	46.3
5'	85.4	83.7	89.1	64.5
6'	77.7	77.6	80.7	36.4
7'	66.9	60.5	76.6	52.7
8'	74.8	69.6	81.2	60.5
Winter				
4'	100.0	96.7	100.0	23.6
5'	100.0	91.9	97.4	62.4
6'	91.5	87.2	93.7	76.6
7'	78.7	82.9	81.5	51.2
8'	75.2	77.5	75.3	40.6
Spring				
4'	83.1	84.8	87.0	39.6
5'	74.7	75.2	80.2	18.1
6'	63.0	64.4	68.7	15.0
7'	61.0	61.7	63.8	15.9
8'	54.9	58.0	59.7	17.3
Summer				
4'	78.6	74.3	77.5	30.4
5'	73.1	64.8	75.8	25.6
6'	75.8	69.6	79.9	27.4
7'	55.5	52.1	62.3	16.4
8'	53.9	47.7	44.7	19.3

Percent of Daily Integrated PAR Loss Above 25% Biomass Loss Threshold - *Height Data*				
Fall	**Traditional**	**ThruFlow**	**Fibergrate**	**SunDock**
4'	77.1	75.8	83.8	30.1
5'	67.3	66.7	76.3	48.8
6'	58.4	59.5	63.8	22.7
7'	48.4	45.4	57.0	38.0
8'	50.7	47.9	56.6	39.7
Winter				
4'	81.9	78.3	86.0	18.2
5'	77.4	70.9	76.3	46.8
6'	64.2	62.9	68.5	50.5
7'	54.0	57.1	58.1	34.4
8'	51.4	52.3	52.5	25.1
Spring				
4'	72.9	74.1	77.1	31.3
5'	64.3	64.9	70.0	15.1
6'	54.1	55.2	59.6	12.5
7'	51.1	51.8	54.1	12.7
8'	45.4	47.9	50.0	13.4
Summer				
4'	72.6	67.6	68.4	26.4
5'	61.5	51.6	59.5	20.4
6'	64.1	55.0	63.1	21.2
7'	47.6	42.6	49.4	13.2
8'	41.6	38.8	38.6	14.9

Percent of Daily Integrated PAR Loss Above 50% Biomass Loss Threshold ***Height Data***				
Fall	**Traditional**	**ThruFlow**	**Fibergrate**	**SunDock**
4'	61.8	60.7	68.3	21.4
5'	54.3	54.2	64.1	38.4
6'	46.2	47.5	51.5	15.8
7'	38.1	36.1	45.0	29.4
8'	38.2	36.3	43.3	29.1
Winter				
4'	64.1	61.5	68.8	14.3
5'	57.5	54.1	59.1	35.9
6'	47.6	46.7	51.8	35.8
7'	40.8	42.2	44.4	24.8
8'	38.3	38.5	41.4	17.8
Spring				
4'	64.0	63.1	66.6	25.4
5'	55.6	55.2	60.9	12.7
6'	46.9	47.3	52.1	10.8
7'	43.2	43.7	46.6	10.3
8'	38.2	40.2	42.6	10.8
Summer				
4'	64.1	57.2	57.2	22.5
5'	52.6	53.1	51.5	16.8
6'	54.9	41.5	47.4	16.2
7'	41.2	33.4	37.4	10.9
8'	38.4	29.0	44.7	11.9

Tables 11 and 12. Daily PAR received under docks built from alternative materials compared to the daily PAR received under a traditional dock with respect to orientation and height. Percentages derived by subtracting %PAR received under a traditional dock from the %PAR received under docks constructed with alternative materials. Positive values indicate greater PAR reaching the under dock sensor compared to a traditional dock.

Percentage of Daily PAR Received Compared to a Traditional Dock ***Orientation Data***			
Fall	**ThruFlow**	**Fibergrate**	**SunDock**
000	2.1	-8.0	13.0
045	2.8	-1.8	16.8
090	1.1	-7.0	6.9
135	1.5	-0.7	11.2
Winter			
000	0.2	3.3	27.7
045	-0.2	-4.3	17.0
090	2.3	0.4	9.9
135	2.9	-4.4	18.1
Spring			
000	5.5	-1.5	34.2
045	7.8	1.4	41.0
090	5.6	-15.6	43.9
135	3.4	-2.2	44.0
Summer			
000	7.9	4.2	33.4
045	9.0	4.4	41.7
090	9.2	8.7	47.0
135	8.6	-2.0	48.1

Percentage of Daily PAR Received Compared to a Traditional Dock ***Height Data***			
Fall	**ThruFlow**	**Fibergrate**	**SunDock**
4'	1.3	-4.6	32.8
5'	0.1	-7.6	13.3
6'	-1.5	-3.9	23.7
7'	1.2	-4.9	7.3
8'	0.8	-3.7	7.3
Winter			
4'	2.3	-4.1	37.5
5'	2.3	-2.2	16.6
6'	0.5	-4.1	9.1
7'	-0.8	-3.4	12.5
8'	-0.1	-2.1	15.5
Spring			
4'	5.2	0.4	40.3
5'	3.1	-2.1	35.0
6'	2.2	-3.4	29.5
7'	1.3	-2.6	25.9
8'	-0.7	-3.9	21.2
Summer			
4'	9.5	11.8	35.3
5'	11.0	10.9	28.3
6'	11.6	11.5	29.2
7'	7.9	12.7	24.9
8'	9.5	4.5	21.2

Tables 13. Light penetration through alternative materials with respect to orientation. "% of total PAR due to light penetration" calculated by comparing Area C to Area A (See Figure 15). "% of total PAR received during time of shadow" calculated by comparing Area B + C to Area A.

Light Penetration Through Alternative Materials *Orientation Data*					
Spring			**Summer**		
Orientation (degrees)	**% of total PAR due to light penetration**	**% of total PAR received during time of shadow**	**Orientation (degrees)**	**% of total PAR due to light penetration**	**% of Total PAR received during time of shadow**
Traditional			**Traditional**		
0	0.2	7.7	0	0.4	13.0
45	0.0	6.6	45	0.1	10.1
90	0.0	9.2	90	0.4	12.6
135	0.0	8.1	135	1.2	18.5
ThruFlow			**ThruFlow**		
0	8.4	18.1	0	18.8	30.8
45	4.2	14.3	45	15.1	25.8
90	2.4	14.3	90	26.6	40.9
135	4.5	15.2	135	19.3	33.0
Fibergrate			**Fibergrate**		
0	7.7	17.3	0	22.9	33.4
45	4.5	14.0	45	16.5	26.2
90	23.3	31.1	90	27.8	36.2
135	10.8	20.5	135	27.6	37.1

Tables 14. Light penetration through alternative materials with respect to height. "% of total PAR due to light penetration" calculated by comparing Area C to Area A (see Figure 15). "% of total PAR received during time of shadow" calculated by comparing Area B + C to Area A.

Light Penetration Through Alternative Materials *Height Data*					
Spring			**Summer**		
Height (feet)	**% of total PAR due to light penetration**	**% of total PAR received during time of shadow**	**Height (feet)**	**% of total PAR due to light penetration**	**% of total PAR received during time of shadow**
Traditional			**Traditional**		
4'	0.0	6.1	4'	0.1	7.2
5'	0.0	7.5	5'	0.3	16.6
6'	0.0	6.8	6'	0.0	17.7
7'	0.0	9.5	7'	0.0	6.4
8'	0.0	10.6	8'	0.2	11.1
ThruFlow			**ThruFlow**		
4'	9.7	18.3	4'	20.0	28.2
5'	7.5	16.8	5'	22.3	35.0
6'	6.8	14.9	6'	22.2	37.8
7'	3.7	14.5	7'	28.2	33.5
8'	1.5	11.9	8'	26.2	35.4
Fibergrate			**Fibergrate**		
4'	6.9	16.0	4'	26.8	33.7
5'	3.3	13.5	5'	29.4	39.1
6'	0.7	9.0	6'	32.8	45.3
7'	0.3	10.9	7'	35.0	40.9
8'	0.0	12.3	8'	27.4	35.3

Table 15. Dry biomass (g/m²) of marsh plants collected at field dock transect stations. Percent change calculated relative to column totals.

Betz Creek 2009 Biomass (g/m²)					
Control			**Dock**		
Station	**Live**	**Dead**	**Station**	**Live**	**Dead**
1C	74	84	1D	266	52
2C	56	182	2D	124	12
3C	58	224	3D	268	268
4C	112	148	4D	186	68
5C	94	210	5D	82	100
6C	658	146	6D	60	78
7C	318	292	7D	80	0
Total	1370	1286	**Total**	1066	578
Percent Change compared to Control (Live)					-22%

Betz Creek 2010 Biomass (g/m²)					
Control			**Dock**		
Station	**Live**	**Dead**	**Station**	**Live**	**Dead**
1C	150	40	1D	330	1
2C	236	38	2D	76	16
3C	289	50	3D	318	31
4C	231	83	4D	44	86
5C	397	40	5D	345	6
6C	275	38	6D	376	36
7C	648	28	7D	748	0
Total	2226	318	**Total**	2237	176
Percent Change compared to Control (Live)					1%

Turners Creek 2009 Biomass (g/m²)					
Control			**Dock**		
Station	**Live**	**Dead**	**Station**	**Live**	**Dead**
1C	654	92	1D	0	0
2C	426	214	2D	16	8
3C	158	98	3D	0	0
4C	150	126	4D	56	48
5C	286	204	5D	336	108
6C	208	126	6D	330	140
7C	270	186	7D	52	58
Total	2152	1046	**Total**	790	362
Percent Change compared to Control (Live)					-63%

Turners Creek 2010 Biomass (g/m²)					
Control			**Dock**		
Station	**Live**	**Dead**	**Station**	**Live**	**Dead**
1C	731	40	1D	60	15
2C	939	133	2D	598	44
3C	352	50	3D	278	30
4C	420	52	4D	73	37
5C	292	24	5D	377	77
6C	765	22	6D	467	86
7C	620	50	7D	16	96
Total	4119	371	**Total**	1870	385
Percent Change compared to Control (Live)					-55%

Shell Point Cove 2009 Biomass (g/m²)									
Control					Dock				
	S. alterniflora		J. roemerianus	All		S. alterniflora		J. roemerianus	All
Station	Live	Dead	Live	Live	Station	Live	Dead	Live	Live
1C	0	0	646	646	1D	0	0	312	312
2C	248	4	0	248	2D	302	28	0	302
3C	10	0	0	10	3D	0	0	0	0
4C	388	114	0	388	4D	0	0	0	0
5C	474	112	0	474	5D	0	0	0	0
6C	112	12	0	112	6D	0	0	0	0
7C	138	54	0	138	7D	0	0	0	0
8C	18	34	0	18	8D	56	0	0	56
9C	266	34	0	266	9D	296	40	0	296
10C	530	96	0	530	10D	338	102	0	338
11C	570	106	0	570	11D	516	66	0	516
12C	664	54	0	664	12D	442	48	18	460
13C	624	24	0	624	13D	894	46	0	894
14C	182	0	0	182	14D	142	0	86	228
15C	22	0	1084	1106	15D	44	0	30	74
16C	34	0	744	778	16D	232	12	0	232
17C	138	0	0	138	17D	116	0	0	116
18C	156	0	0	156	18D	52	0	0	52
19C	0	0	790	790	19D	60	0	54	114
20	42	0	0	42	20D	76	0	0	76
21	142	0	0	142	21D	102	0	0	102
22	304	0	716	1020	22D	142	14	0	142
23C	1484	0	0	1484	23D	366	0	0	366
24C	92	46	0	92	24D	696	0	0	696
25C	344	100	0	344	25D	424	12	0	424
26C	820	12	0	820	26D	188	86	0	188
27C	70	30	0	70	27D	1184	0	0	1184
Total	7872	832	3980	11852	**Total**	6668	454	500	7168
Percent Change compared to Control (S. alterniflora – Live)									-15%
Percent Change compared to Control (J. roemerianus - Live)									-87%
Percent Change compared to Control (All - Live)									-40%

Shell Point Cove 2010 Biomass (g/m²)											
Control						**Dock**					
	S. alterniflora		**J. roemerianus**		**All**		**S. alterniflora**		**J. roemerianus**		**All**
Station	**Live**	**Dead**	**Live**	**Dead**	**Live**	**Station**	**Live**	**Dead**	**Live**	**Dead**	**Live**
1C	0	0	782	468	782	1D	0	0	601	308	601
2C	622	126	0	0	622	2D	290	45	0	0	290
3C	471	58	0	0	471	3D	2	0	0	0	2
4C	767	108	0	0	767	4D	0	0	0	0	0
5C	687	24	0	0	687	5D	0	2	0	0	0
6C	42	15	0	0	42	6D	1	0	0	0	1
7C	284	47	0	0	284	7D	2	0	0	0	2
8C	21	3	0	0	21	8D	0	0	0	0	0
9C	268	25	0	0	268	9D	153	4	0	0	153
10C	488	86	0	0	488	10D	242	35	0	0	242
11C	476	59	0	0	476	11D	430	19	0	0	430
12C	296	32	40	5	336	12D	486	45	0	0	486
13C	598	0	0	0	598	13D	315	26	0	0	315
14C	187	72	0	0	187	14D	249	6	175	59	424
15C	0	0	541	407	541	15D	405	20	69	18	474
16C	0	0	858	194	858	16D	498	3	0	0	498
17C	122	2	0	0	122	17D	10	6	0	0	10
18C	143	4	0	0	143	18D	137	20	0	0	137
19C	0	0	772	473	772	19D	242	65	0	0	242
20C	12	0	516	285	528	20D	126	0	0	0	126
21C	17	0	535	403	552	21D	114	0	0	0	114
22C	52	0	484	428	536	22D	437	44	0	0	437
23C	286	0	157	140	443	23D	345	86	0	0	345
24C	572	10	64	22	636	24D	757	158	0	0	757
25C	685	33	0	0	685	25D	188	32	0	0	188
26C	1612	20	0	0	1612	26D	878	44	0	0	878
27C	0	0	0	0	0	27D	885	0	0	0	885
Total	8710	723	4748	2824	13458	**Total**	7188	658	845	385	8033
Percent Change compared to Control (S. alterniflora - Live)											-18%
Percent Change compared to Control (J. roemerianus - Live)											-82%
Percent Change compared to Control (All - Live)											-40%

Table 16. Stem density of S. alterniflora for all docks and for J. Roemarianus for Shell Point Cove at field dock transect stations. Percent change calculated from column totals.

Betz Creek 2009 Stem Density (stems/m²)			
Control		**Dock**	
Station	**Stems**	**Station**	**Stems**
1C	132	1D	52
2C	52	2D	60
3C	200	3D	88
4C	96	4D	76
5C	80	5D	92
6C	132	6D	60
7C	148	7D	40
Total	840	**Total**	468
Percent Change compared to Control			**-44%**

Betz Creek 2010 Stem Density (stems/m²)			
Control		**Dock**	
Station	**Stems**	**Station**	**Stems**
1C	180	1D	40
2C	116	2D	48
3C	200	3D	108
4C	228	4D	44
5C	252	5D	152
6C	148	6D	136
7C	104	7D	316
Total	1228	**Total**	844
Percent Change compared to Control			**-31%**

Turners Creek 2008 – Pre-Construction Stem Density (stems/m²)			
Control		**Dock**	
Station	**Stems**	**Station**	**Stems**
1C	72	1D	160
2C	168	2D	248
3C	292	3D	112
4C	268	4D	56
5C	152	5D	184
6C	132	6D	96
7C	136	7D	168
Total	1220	**Total**	1024
Percent Change compared to Control			**-16%**

Turners Creek 2009 Stem Density (stems/m²)			
Control		**Dock**	
Station	**Stems**	**Station**	**Stems**
1C	136	1D	20
2C	104	2D	16
3C	100	3D	0
4C	96	4D	20
5C	132	5D	88
6C	76	6D	140
7C	124	7D	40
Total	768	**Total**	324
Percent Change compared to Control			**-58%**

Turners Creek 2010 Stem Density (stems/m²)			
Control		**Dock**	
Station	**Stems**	**Station**	**Stems**
1C	204	1D	40
2C	172	2D	120
3C	100	3D	48
4C	168	4D	40
5C	124	5D	88
6C	284	6D	228
7C	300	7D	48
Total	1352	**Total**	612
Percent Change compared to Control			**-55%**

Shell Point Cove 2007 - Pre-Construction Stem Density (stems/m²)							
Control				**Dock**			
	Stems				**Stems**		
Station	**S. alterniflora**	**J. roemerianus**	**All**	**Station**	**S. alterniflora**	**J. roemerianus**	**All**
1C	0	420	420	1D	0	444	444
2C	620	0	620	2D	600	0	600
3C	136	0	136	3D	216	0	216
4C	156	0	156	4D	84	0	84
5C	104	0	104	5D	88	0	88
6C	56	0	56	6D	0	0	0
7C	72	0	72	7D	124	0	124
8C	148	0	148	8D	160	0	160
9C	208	0	208	9D	164	0	164
10C	336	0	336	10D	312	0	312
11C	308	0	308	11D	420	0	420
12C	176	12	188	12D	80	124	204
13C	24	96	120	13D	44	240	284
14C	244	0	244	14D	4	316	320
15C	0	344	344	15D	0	196	196
16C	0	284	284	16D	0	332	332
17C	104	0	104	17D	112	0	112
18C	96	0	96	18D	48	0	48
19C	0	248	248	19D	4	500	504
20	68	0	68	20D	124	0	124
21	44	0	44	21D	40	0	40
22	0	228	228	22D	8	188	196
23C	0	12	12	23D	100	132	232
24C	132	0	132	24D	116	0	116
25C	96	0	96	25D	116	0	116
26C	104	0	104	26D	92	0	92
27C	32	0	32	27D	44	0	44
Total	3264	1644	4908	**Total**	3100	2472	5572
Percent Change compared to Control (S. alterniflora)							**-5%**
Percent Change compared to Control (J. roemerianus)							**50%**
Percent Change compared to Control (All)							**14%**

Shell Point Cove 2008 Stem Density (stems/m²)							
Control				**Dock**			
	Stems				**Stems**		
Station	**S. alterniflora**	**J. roemerianus**	**All**	**Station**	**S. alterniflora**	**J. roemerianus**	**All**
1C	0	524	524	1D	0	368	368
2C	44	0	44	2D	304	0	304
3C	0	0	0	3D	0	0	0
4C	132	4	136	4D	0	0	0
5C	136	0	136	5D	0	0	0
6C	72	0	72	6D	8	0	8
7C	104	0	104	7D	0	0	0
8C	76	0	76	8D	0	0	0
9C	0	0	0	9D	0	0	0
10C	356	0	356	10D	196	0	196
11C	612	0	612	11D	212	0	212
12C	196	0	196	12D	176	36	212
13C	128	0	128	13D	112	0	112
14C	328	0	328	14D	56	76	132
15C	0	340	340	15D	0	84	84
16C	0	304	304	16D	8	0	8
17C	100	0	100	17D	0	0	0
18C	0	440	440	18D	24	0	24
19C	0	316	316	19D	0	8	8
20	5	0	5	20D	0	0	0
21	16	432	448	21D	2	0	2
22	4	292	296	22D	0	0	0
23C	28	256	284	23D	60	0	60
24C	212	0	212	24D	124	0	124
25C	196	0	196	25D	80	0	80
26C	144	0	144	26D	60	0	60
27C	156	0	156	27D	52	0	52
Total	3045	2908	5953	**Total**	1474	572	2046
Percent Change compared to Control (S. alterniflora)							**-52%**
Percent Change compared to Control (J. roemerianus)							**-80%**
Percent Change compared to Control (All)							**-66%**

Shell Point Cove 2009 Stem Density (stems/m²)							
Control				Dock			
	Stems				Stems		
Station	S. alterniflora	J. roemerianus	All	Station	S. alterniflora	J. roemerianus	All
1C	0	388	388	1D	0	248	248
2C	252	0	252	2D	240	0	240
3C	8	0	8	3D	4	0	4
4C	120	0	120	4D	0	0	0
5C	100	0	100	5D	0	0	0
6C	52	0	52	6D	4	0	4
7C	68	0	68	7D	0	0	0
8C	24	0	24	8D	32	0	32
9C	208	0	208	9D	104	0	104
10C	336	0	336	10D	104	0	104
11C	328	0	328	11D	144	0	144
12C	284	0	284	12D	136	20	156
13C	208	0	208	13D	120	0	120
14C	100	0	100	14D	76	92	168
15C	4	424	428	15D	64	36	100
16C	8	428	436	16D	40	0	40
17C	96	0	96	17D	64	0	64
18C	80	0	80	18D	32	0	32
19C	0	280	280	19D	36	56	92
20	24	0	24	20D	32	0	32
21	104	0	104	21D	36	0	36
22	72	252	324	22D	48	0	48
23C	44	512	556	23D	200	0	200
24C	44	0	44	24D	120	0	120
25C	172	0	172	25D	84	0	84
26C	96	0	96	26D	72	0	72
27C	28	0	28	27D	124	0	124
Total	2860	2284	5144	**Total**	1912	452	2360
Percent Change compared to Control (S. alterniflora)							**-33%**
Percent Change compared to Control (J. roemerianus)							**-80%**
Percent Change compared to Control (All)							**-54%**

Shell Point Cove 2010 Stem Density (stems/m²)							
Control				Dock			
	Stems				Stems		
Station	S. alterniflora	J. roemerianus	All	Station	S. alterniflora	J. roemerianus	All
1C	0	552	552	1D	0	556	556
2C	504	0	504	2D	512	0	512
3C	288	0	288	3D	4	0	4
4C	176	0	176	4D	0	0	0
5C	232	0	0	5D	0	0	0
6C	44	0	232	6D	4	0	4
7C	220	0	44	7D	8	0	8
8C	16	0	220	8D	0	0	0
9C	304	0	16	9D	92	0	92
10C	280	0	304	10D	140	0	140
11C	624	0	280	11D	316	0	316
12C	224	36	660	12D	164	0	164
13C	404	0	224	13D	248	0	248
14C	328	0	404	14D	108	336	444
15C	0	484	812	15D	128	72	200
16C	0	616	616	16D	120	0	120
17C	136	0	136	17D	12	0	12
18C	144	0	144	18D	92	0	92
19C	0	392	392	19D	88	0	88
20	12	548	560	20D	36	0	36
21	12	464	476	21D	36	0	36
22	12	460	472	22D	188	0	188
23C	108	160	268	23D	108	0	108
24C	188	52	240	24D	208	0	208
25C	364	0	364	25D	128	0	128
26C	160	0	160	26D	116	0	116
27C	0	0	0	27D	76	0	76
Total	4780	3764	8448	**Total**	2932	964	3896
Percent Change compared to Control (S. alterniflora)							**-39%**
Percent Change compared to Control (J. roemerianus)							**-74%**
Percent Change compared to Control (All)							**-54%**

Table 17. Stem height for all live stems at stations along field dock transects. Percent change in mean and median calculated from full data set for control and dock sites.

Betz Creek 2010 Stem Height									
Control				**Dock**					
Station	Number of stems (.25m²)	Mean (cm)	Median (cm)	Station	Number of stems (.25m²)	Mean (cm)	Median (cm)	Change in Mean Height	Change in Median Height
1C	45	30	26	1D	10	92	97	203%	271%
2C	29	37	20	2D	12	34	17	-7%	-13%
3C	50	37	27	3D	27	54	36	48%	31%
4C	57	35	30	4D	11	37	30	6%	0%
5C	63	37	29	5D	38	41	24	9%	-15%
6C	37	47	50	6D	34	54	57	14%	14%
7C	26	68	39	7D	79	47	48	-32%	22%
All	**307**	40	29	**All**	**211**	**49**	**41**	23%	44%

Turners Creek 2010 Stem Height									
Control				**Dock**					
Station	Number of stems (.25m²)	Mean (cm)	Median (cm)	Station	Number of stems (.25m²)	Mean (cm)	Median (cm)	Change in Mean Height	Change in Median Height
1C	51	54	27	1D	10	33	17	-38%	-39%
2C	43	75	75	2D	30	61	22	-18%	-71%
3C	25	61	34	3D	12	75	59	23%	74%
4C	42	38	17	4D	10	40	39	4%	126%
5C	31	44	20	5D	22	71	73	61%	263%
6C	71	44	13	6D	57	37	16	-15%	23%
7C	75	38	16	7D	12	17	14	-56%	-13%
All	**338**	**48.69**	**20.5**	**All**	**153**	**48**	**20**	-1%	-2%

Shell Point Cove 2010									
Stem Height - S. alterniflora									
Control				**Dock**					
Station	Number of stems (.25m²)	Mean (cm)	Median (cm)	Station	Number of stems (.25m²)	Mean (cm)	Median (cm)	Change in Mean Height	Change in Median height
2C	126	28	15	2D	128	26	25	-9%	69%
3C	172	35	16	3D	1	1	10	-97%	-94%
4C	44	49	35	4D	0	0	0	-100%	-100%
5C	58	34	14	5D	0	0	0	-100%	-100%
6C	11	36	27	6D	1	1	1	-99%	-98%
7C	55	29	16	7D	2	13	13	-56%	-16%
8C	4	44	39	8D	0	0	0	-100%	-100%
9C	76	30	20	9D	23	39	27	29%	35%
10C	70	36	33	10D	35	38	37	6%	12%
11C	156	24	18	11D	79	30	20	27%	11%
12C	56	26	16	12D	41	59	23	126%	42%
13C	101	34	23	13D	62	27	18	-20%	-22%
14C	82	26	13	14D	27	37	29	46%	123%
15C	0	0	0	15D	32	52	61	---	---
16C	0	0	0	16D	30	43	19	---	---
17C	34	29	29	17D	303	29	26	2%	-10%
18C	36	164	25	18D	423	33	36	-80%	43%
19C	0	0	0	19D	22	53	58	---	---
20C	3	36	35	20D	9	51	50	40%	41%
21C	3	40	52	21D	9	46	25	15%	-52%
22C	3	61	48	22D	47	44	40	-28%	-17%
23C	27	34	16	23D	27	50	55	45%	244%
24C	47	43	34	24D	52	46	30	5%	-12%
25C	91	38	24	25D	32	31	17	-18%	-31%
26C	40	69	77	26D	29	62	35	-10%	-55%
27C	0	0	0	27D	19	95	106	---	---
All	**623**	**37**	**21**	**All**	**733**	**40**	**28**	8%	33%

Shell Point Cove 2010									
Stem Height - J. Roemerianus									
Control				Dock					
Station	Number of stems (.25m²)	Mean (cm)	Median (cm)	Station	Number of stems (.25m²)	Mean (cm)	Median (cm)	Change in Mean Height	Change in Median Height
1C	138	85	94	1D	139	90	87	6%	-7%
12C	9	57	62	12D	0	0	0	-100%	-100%
14C	0	0	0	14D	84	47	52	---	---
15C	121	80	85	15D	18	59	64	-26%	-25%
16C	155	77	79	16D	0	0	0	-100%	-100%
19C	98	118	115	19D	0	0	0	-100%	-100%
20C	137	74	77	20D	0	0	0	-100%	-100%
21C	116	75	76	21D	0	0	0	-100%	-100%
22C	115	163	87	22D	0	0	0	-100%	-100%
23C	40	65	79	23D	0	0	0	-100%	-100%
24C	13	64	54	24D	0	0	0	-100%	-100%
All	**807**	**92**	**85**	**All**	**241**	**71**	**42**	-23%	-51%

Table 18. Percent Organic Carbon in surface sediments along the field dock transects. "Difference in Control and Dock Organic Carbon (%)" was calculated by subtracting Dock percent organic carbon from Control percent organic carbon. C:N represents total C:total N.

Betz Creek 2009 Organic Carbon					
Control			**Dock**		
Station	**Organic Carbon (%)**	**C:N**	**Station**	**Organic Carbon (%)**	**C:N**
1C	3.42	11.70	1D	3.37	11.88
2C	2.63	11.25	2D	3.49	12.80
3C	3.19	11.58	3D	2.68	11.42
4C	2.83	11.88	4D	2.57	12.01
5C	2.77	12.42	5D	2.59	12.48
6C	2.50	11.53	6D	2.29	10.98
7C	2.44	13.12	7D	1.91	11.42

Betz Creek 2010 Organic Carbon					
Control			**Dock**		
Station	**Organic Carbon (%)**	**C:N**	**Station**	**Organic Carbon (%)**	**C:N**
1C	2.75	12.52	1D	5.23	16.26
2C	1.79	10.75	2D	1.75	11.92
3C	1.95	11.61	3D	2.04	10.98
4C	2.30	12.30	4D	1.48	11.34
5C	1.78	11.17	5D	1.84	11.05
6C	1.81	11.72	6D	1.86	12.11
7C	1.83	11.85	7D	1.39	11.03

Turners Creek 2008 - Pre-Construction Organic Carbon					
Control			**Dock**		
Station	**Organic Carbon (%)**	**C:N**	**Station**	**Organic Carbon (%)**	**C:N**
1C	3.40	8.34	1D	3.33	8.44
2C	3.34	8.16	2D	2.94	7.54
3C	4.04	9.51	3D	4.19	9.69
4C	4.74	10.06	4D	4.04	9.08
5C	4.09	11.67	5D	3.75	8.76
6C	5.09	10.67	6D	4.52	9.39
7C	3.85	8.88	7D	4.04	8.98

Turners Creek 2009 Organic Carbon					
Control			**Dock**		
Station	**Organic Carbon (%)**	**C:N**	**Station**	**Organic Carbon (%)**	**C:N**
1C	2.82	10.34	1D	5.30	13.72
2C	4.13	11.92	2D	5.14	13.75
3C	5.14	12.98	3D	3.50	11.07
4C	4.98	13.27	4D	4.63	12.73
5C	5.05	12.84	5D	3.99	11.66
6C	6.09	13.69	6D	5.98	13.89
7C	4.41	11.95	7D	3.59	11.02

Turners Creek 2010 Organic Carbon					
Control			**Dock**		
Station	**Organic Carbon (%)**	**C:N**	**Station**	**Organic Carbon (%)**	**C:N**
1C	2.52	12.07	1D	5.02	16.46
2C	3.44	12.53	2D	4.41	14.65
3C	3.65	13.77	3D	2.83	12.50
4C	3.32	13.39	4D	3.39	14.29
5C	4.62	15.48	5D	3.2	12.19
6C	6.12	17.90	6D	5.81	16.41
7C	3.11	12.75	7D	3.89	14.31

Shell Point Cove 2007 - Pre-construction Organic Carbon					
Control			Dock		
Station	Organic Carbon (%)	C:N	Station	Organic Carbon (%)	C:N
1C	4.97	15.04	1D	1.67	12.67
2C	10.42	11.70	2D	2.29	12.51
3C	4.75	11.45	3D	3.13	11.80
4C	3.77	10.85	4D	4.03	10.57
5C	3.76	10.82	5D	2.91	9.41
6C	3.61	10.01	6D	2.09	14.31
7C	3.48	10.80	7D	2.98	10.01
8C	4.12	11.74	8D	4.18	11.26
9C	5.48	12.44	9D	7.37	13.73
10C	7.83	11.00	10D	6.68	17.63
11C	9.74	11.96	11D	8.39	12.00
12C	8.67	20.98	12D	7.57	18.06
13C	7.87	47.34	13D	4.22	17.62
14C	5.40	33.83	14D	3.34	15.08
15C	2.20	16.39	15D	1.04	12.51
16C	1.65	14.34	16D	2.05	13.44
17C	2.91	13.84	17D	3.18	12.05
18C	2.85	13.26	18D	1.27	13.65
19C	0.83	12.81	19D	0.52	13.08
20	3.81	10.37	20D	1.18	15.66
21	1.50	12.29	21D	1.31	12.53
22	1.17	12.68	22D	0.94	12.90
23C	5.25	14.88	23D	1.91	13.96
24C	1.85	13.78	24D	1.95	12.83
25C	3.60	10.97	25D	3.28	12.25
26C	3.72	10.67	26D	3.23	9.97
27C	4.18	12.81	27D	3.59	11.78

Shell Point Cove 2008 Organic Carbon					
Control			**Dock**		
Station	**Organic Carbon (%)**	**C:N**	**Station**	**Organic Carbon (%)**	**C:N**
1C	3.10	16.69	1D	4.56	16.79
2C	5.56	11.53	2D	4.71	13.58
3C	4.66	11.82	3D	3.85	13.92
4C	3.31	10.36	4D	3.85	11.93
5C	2.96	9.80	5D	5.17	14.02
6C	2.76	9.62	6D	3.71	9.92
7C	4.23	11.00	7D	4.14	11.57
8C	3.49	11.19	8D	4.65	12.63
9C	8.18	12.38	9D	6.33	12.67
10C	7.71	12.07	10D	8.56	14.31
11C	7.55	12.89	11D	5.55	16.47
12C	5.33	13.44	12D	6.09	11.76
13C	2.76	14.96	13D	3.84	16.20
14C	2.59	14.81	14D	3.65	13.73
15C	2.33	13.15	15D	2.52	12.62
16C	0.89	13.07	16D	0.51	13.96
17C	1.33	14.27	17D	0.38	14.71
18C	1.24	12.70	18D	0.25	11.84
19C	1.89	13.20	19D	1.40	13.14
20	1.71	12.85	20D	1.46	14.23
21	1.80	13.24	21D	1.60	13.11
22	2.99	12.10	22D	2.83	12.77
23C	2.76	11.41	23D	2.81	12.13
24C	3.32	11.34	24D	3.11	11.23
25C	2.64	10.62	25D	3.02	11.69
26C	8.48	12.67	26D	5.52	10.99
27C	3.84	12.91	27D	3.49	15.15

Shell Point Cove 2009 Organic Carbon					
Control			Dock		
Station	Organic Carbon (%)	C:N	Station	Organic Carbon (%)	C:N
1C	2.60	15.76	1D	8.40	21.91
2C	7.42	9.50	2D	7.09	9.79
3C	4.39	11.10	3D	5.64	13.03
4C	5.08	11.89	4D	4.43	10.34
5C	4.01	10.75	5D	4.98	14.18
6C	4.41	9.97	6D	3.90	11.68
7C	4.05	10.17	7D	4.08	10.31
8C	5.07	10.92	8D	4.73	11.23
9C	6.46	11.63	9D	5.54	11.83
10C	7.67	12.67	10D	5.15	12.55
11C	11.49	11.69	11D	9.10	11.80
12C	8.23	12.22	12D	8.34	13.34
13C	6.04	12.79	13D	5.09	13.74
14C	4.02	10.72	14D	4.17	12.88
15C	2.30	14.50	15D	1.46	14.01
16C	2.80	13.35	16D	0.60	15.12
17C	2.04	12.68	17D	3.34	16.29
18C	0.66	13.93	18D	1.11	13.65
19C	0.75	14.43	19D	0.20	16.51
20	0.72	9.02	20D	0.30	8.75
21	2.22	10.99	21D	1.39	10.17
22	1.30	9.25	22D	1.62	8.77
23C	3.00	11.88	23D	2.19	10.01
24C	4.44	11.67	24D	8.40	14.04
25C	3.13	8.81	25D	2.55	7.92
26C	3.68	8.50	26D	3.51	8.03
27C	3.22	7.97	27D	3.35	7.81

Shell Point Cove 2010 Organic Carbon					
Control			Dock		
Station	Organic Carbon (%)	C:N	Station	Organic Carbon (%)	C:N
1C	1.25	13.42	1D	1.98	14.23
2C	7.7	13.43	2D	4.38	12.15
3C	3.73	13.01	3D	4.13	16.42
4C	3.78	11.56	4D	2.85	11.97
5C	2.78	12.07	5D	3.71	13.46
6C	2.65	11.16	6D	2.79	11.17
7C	3.74	11.23	7D	3.21	11.80
8C	3.3	12.50	8D	3.37	13.51
9C	4.29	13.82	9D	3.17	14.46
10C	8.70	14.18	10D	4.20	14.58
11C	8.59	12.37	11D	6.86	12.56
12C	6.78	13.68	12D	6.09	14.86
13C	4.00	14.15	13D	3.91	13.69
14C	3.43	13.74	14D	4.29	13.81
15C	2.95	13.60	15D	1.95	12.62
16C	1.91	12.49	16D	0.38	10.29
17C	2.56	12.77	17D	1.46	11.36
18C	1.62	12.46	18D	0.83	11.86
19C	0.60	11.95	19D	0	6.53
20	0.62	11.08	20D	0.01	9.09
21	0.75	12.47	21D	0.38	11.32
22	1.18	12.27	22D	0.91	12.27
23C	1.27	12.75	23D	2.92	14.38
24C	2.11	13.11	24D	2.57	14.44
25C	2.99	12.31	25D	1.17	12.41
26C	2.75	11.80	26D	2.98	12.17
27C	2.29	11.63	27D	2.61	11.36

Table 19. Chloropyll a (Chl a) and Phaeophytin (Phaeo.) concentrations along the field dock transects. Samples represent the surficial 1-cm of sediments.

Betz Creek 2009 Chlorophyll					
Control			Dock		
Station	Chl a (µg/g)	Phaeo. (µg/g)	Station	Chl a (µg/g)	Phaeo. (µg/g)
1C	33.7	54.1	1D	73.8	47.4
2C	57.1	60.8	2D	19.7	42.8
3C	18.6	35.8	3D	12.1	30.1
4C	11.9	32.2	4D	10.8	17.3
5C	21.0	40.1	5D	16.3	38.3
6C	33.4	48.3	6D	21.6	37.9
7C	6.4	17.8	7D	7.7	26.8

Betz Creek 2010 Chlorophyll					
Control			Dock		
Station	Chl a (µg/g)	Phaeo. (µg/g)	Station	Chl a (µg/g)	Phaeo. (µg/g)
1C	17.0	42.4	1D	36.6	25.8
2C	24.8	43.9	2D	18.7	41.5
3C	16.3	32.7	3D	32.6	40.8
4C	9.8	24.8	4D	33.7	45.8
5C	8.9	25.1	5D	20.2	38.9
6C	17.3	51.5	6D	13.4	28.4
7C	6.6	23.6	7D	7.7	21.4

Turners Creek 2008 - Pre-Construction Chlorophyll					
Control			Dock		
Station	Chl a (µg/g)	Phaeo. (µg/g)	Station	Chl a (µg/g)	Phaeo. (µg/g)
1C	39.8	64.2	1D	42.7	54.7
2C	30.3	57.8	2D	47.2	79.5
3C	37.0	63.3	3D	22.5	49.0
4C	32.3	59.0	4D	46.0	66.6
5C	23.6	56.1	5D	37.5	59.7
6C	31.2	42.4	6D	48.5	77.7
7C	34.3	69.5	7D	34.0	57.3

Turners Creek 2009 Chlorophyll					
Control			Dock		
Station	Chl a (µg/g)	Phaeo. (µg/g)	Station	Chl a (µg/g)	Phaeo. (µg/g)
1C	71.4	79.2	1D	39.2	64.5
2C	53.5	75.5	2D	70.2	87.1
3C	57.9	90.1	3D	53.8	73.3
4C	70.5	124.4	4D	44.6	90.6
5C	65.3	79.6	5D	50.8	66.4
6C	76.5	96.5	6D	57.4	82.3
7C	94.7	95.7	7D	38.8	70.5

Turners Creek 2010 Chlorophyll					
Control			Dock		
Station	Chl a (µg/g)	Phaeo. (µg/g)	Station	Chl a (µg/g)	Phaeo. (µg/g)
1C	5.8	24.9	1D	26.4	46.7
2C	5.8	23.4	2D	15.9	37.1
3C	6.7	33.7	3D	12.5	43.4
4C	7.7	33.8	4D	22.6	51.9
5C	6.7	23.2	5D	20.1	75.2
6C	17.1	31.9	6D	16.3	41.0
7C	21.7	51.3	7D	46.5	48.1

Shell Point Cove March 2007 - Pre-Construction Chlorophyll					
Control			**Dock**		
Station	**Chl a (µg/g)**	**Phaeo. (µg/g)**	**Station**	**Chl a (µg/g)**	**Phaeo. (µg/g)**
1C	35.2	16.2	1D	28.5	14.5
2C	119.2	214.6	2D	30.1	23.7
3C	66.9	81.8	3D	43.7	70.9
4C	60.0	100.3	4D	130.8	125.6
5C	21.1	52.1	5D	40.6	84.6
6C	84.0	94.8	6D	72.8	107.4
7C	58.1	92.5	7D	104.2	122.5
8C	25.2	37.0	8D	63.7	112.3
9C	51.4	50.3	9D	45.5	47.5
10C	58.7	55.5	10D	59.6	39.5
11C	86.8	75.4	11D	59.6	63.6
12C	144.5	107.6	12D	40.5	33.2
13C	16.2	32.0	13D	36.0	27.4
14C	90.6	39.8	14D	37.9	20.2
15C	27.0	12.2	15D	17.2	8.4
16C	18.3	7.4	16D	38.6	11.5
17C	31.2	12.2	17D	28.7	8.4
18C	27.3	11.5	18D	26.4	8.4
19C	18.3	4.5	19D	10.3	2.5
20C	23.8	9.0	20D	11.2	2.8
21C	21.5	9.8	21D	9.7	8.6
22C	32.9	14.6	22D	17.0	4.5
23C	8.8	15.9	23D	7.2	6.6
24C	42.9	17.2	24D	37.8	20.1
25C	41.8	40.5	25D	41.2	48.8
26C	53.4	26.4	26D	69.3	52.5
27C	15.8	39.3	27D	13.3	38.1

Shell Point Cove July 2007 - Pre-Construction Chlorophyll					
Control			**Dock**		
Station	**Chl a (µg/g)**	**Phaeo. (µg/g)**	**Station**	**Chl a (µg/g)**	**Phaeo. (µg/g)**
1C	56.4	33.4	1D	17.0	25.1
2C	52.4	140.2	2D	79.2	114.9
3C	39.9	163.6	3D	25.3	60.2
4C	55.3	123.6	4D	76.7	144.2
5C	90.5	132.9	5D	53.8	125.5
6C	46.0	98.3	6D	120.4	155.5
7C	75.7	116.1	7D	83.3	137.3
8C	30.2	89.2	8D	108.0	153.8
9C	51.3	70.4	9D	38.0	97.8
10C	186.6	108.4	10D	65.4	93.7
11C	85.3	114.7	11D	129.3	149.7
12C	98.0	135.8	12D	20.2	62.4
13C	40.2	43.4	13D	22.6	36.9
14C	28.6	48.2	14D	22.1	51.0
15C	18.0	17.6	15D	9.7	11.0
16C	18.2	13.5	16D	2.4	3.9
17C	18.1	18.5	17D	27.2	16.9
18C	18.5	15.3	18D	13.6	9.1
19C	9.2	7.2	19D	7.5	4.3
20C	12.5	12.0	20D	8.6	8.5
21C	22.7	23.7	21D	21.0	16.6
22C	21.9	14.5	22D	23.5	18.1
23C	11.3	15.0	23D	13.2	16.6
24C	20.0	18.3	24D	23.8	23.2
25C	25.0	41.3	25D	10.9	43.1
26C	25.1	56.0	26D	18.4	58.8
27C	25.6	74.6	27D	14.2	59.1

Shell Point Cove 2008 Chlorophyll					
Control			Dock		
Station	Chl a (µg/g)	Phaeo. (µg/g)	Station	Chl a (µg/g)	Phaeo. (µg/g)
1C	37.9	26.3	1D	35.6	10.7
2C	311.6	113.4	2D	11.8	12.4
3C	63.5	74.1	3D	36.4	38.5
4C	25.3	66.9	4D	12.0	26.7
5C	50.3	104.6	5D	29.6	47.5
6C	47.5	107.9	6D	51.7	95.6
7C	33.5	82.4	7D	35.9	67.2
8C	27.2	61.5	8D	41.4	76.1
9C	59.6	85.8	9D	23.0	19.0
10C	108.7	160.8	10D	15.6	20.6
11C	56.2	81.1	11D	243.7	152.3
12C	85.6	92.9	12D	46.8	41.9
13C	33.2	24.0	13D	43.2	36.0
14C	41.3	30.2	14D	40.4	42.8
15C	18.4	11.4	15D	16.8	13.3
16C	20.5	11.7	16D	14.8	16.2
17C	29.3	18.7	17D	33.5	22.9
18C	11.0	8.5	18D	4.2	2.6
19C	13.0	5.8	19D	4.4	2.5
20C	22.9	6.7	20D	7.3	2.6
21C	27.1	16.6	21D	10.3	17.4
22C	29.6	19.4	22D	12.3	9.1
23C	24.8	16.9	23D	12.1	12.5
24C	44.2	42.0	24D	25.6	40.0
25C	32.8	52.8	25D	29.4	53.3
26C	17.6	23.2	26D	38.3	53.0
27C	30.4	44.7	27D	28.5	44.5

Shell Point Cove 2009 Chlorophyll					
Control			Dock		
Station	Chl a (µg/g)	Phaeo. (µg/g)	Station	Chl a (µg/g)	Phaeo. (µg/g)
1C	27.4	11.6	1D	60.1	27.1
2C	220.9	121.3	2D	235.5	150.0
3C	76.6	67.9	3D	100.1	94.1
4C	97.7	155.4	4D	131.6	88.0
5C	76.6	147.6	5D	54.9	61.9
6C	134.6	151.9	6D	35.1	53.2
7C	65.5	125.9	7D	72.7	105.8
8C	82.9	85.7	8D	72.7	85.5
9C	101.4	123.9	9D	82.1	107.1
10C	47.6	57.2	10D	32.6	28.1
11C	47.0	81.9	11D	135.2	107.8
12C	76.8	83.0	12D	63.2	70.5
13C	53.3	51.6	13D	48.5	50.1
14C	35.4	27.7	14D	46.9	33.1
15C	17.2	12.3	15D	20.1	16.2
16C	16.6	7.3	16D	7.9	6.2
17C	14.6	8.2	17D	15.9	15.1
18C	17.7	6.7	18D	15.9	7.9
19C	6.2	2.3	19D	4.6	1.4
20C	16.2	5.7	20D	6.4	1.7
21C	35.9	11.5	21D	27.0	9.2
22C	26.4	11.1	22D	33.6	14.8
23C	28.5	16.8	23D	29.8	37.5
24C	15.1	27.6	24D	54.3	29.5
25C	25.4	39.6	25D	24.4	30.8
26C	55.4	37.4	26D	55.0	46.2
27C	48.1	62.2	27D	33.3	40.4

Shell Point Cove 2010 Chlorophyll Analysis					
Control			Dock		
Station	Chl a (μg/g)	Phaeo. (μg/g)	Station	Chl a (μg/g)	Phaeo. (μg/g)
1C	16.1	6.2	1D	22.2	8.3
2C	71.8	86.7	2D	76.9	33.9
3C	30.0	47.8	3D	24.8	37.9
4C	26.2	37.8	4D	52.6	56.4
5C	23.5	62.3	5D	23.5	47.4
6C	38.3	61.1	6D	29.1	42.5
7C	29.2	66.1	7D	101.7	190.8
8C	19.2	40.9	8D	41.8	60.3
9C	17.0	31.1	9D	27.5	22.3
10C	120.0	176.0	10D	53.9	41.8
11C	37.7	97.4	11D	28.2	84.2
12C	39.1	54.0	12D	23.6	54.8
13C	15.5	21.8	13D	20.8	39.1
14C	10.6	30.6	14D	19.2	24.3
15C	10.9	8.5	15D	8.5	5.8
16C	8.8	6.4	16D	10.4	6.4
17C	15.9	16.6	17D	13.9	10.1
18C	8.8	7.1	18D	6.2	2.9
19C	6.9	3.8	19D	4.3	1.6
20C	11.1	6.4	20D	3.3	1.9
21C	8.9	5.3	21D	13.9	5.6
22C	11.8	8.5	22D	13.1	13.0
23C	15.4	12.9	23D	14.6	24.7
24C	27.9	35.9	24D	11.3	22.1
25C	18.3	50.2	25D	13.2	16.6
26C	12.4	29.1	26D	14.6	31.3
27C	21.1	52.2	27D	56.0	48.8

Table 20. Salinity in pore waters in surface sediments along the field dock transects. Percent change calculated by subtracting dock value from control value.

Betz Creek 2010 Salinity			
Control		Dock	
Station	**Porewater Salinity (ppt)**	**Station**	**Porewater Salinity (ppt)**
1C	32.4	1D	36.7
2C	33.5	2D	31.7
3C	33.7	3D	31.9
4C	31.8	4D	31.4
5C	32.4	5D	32.3
6C	35.5	6D	32.2
7C	41.0	7D	42.6
Mean	34.3	**Mean**	34.1

Turners Creek 2010 Salinity			
Control		Dock	
Station	**Porewater Salinity (ppt)**	**Station**	**Porewater Salinity (ppt)**
1C	28.4	1D	29.6
2C	29.3	2D	28.1
3C	30.2	3D	29.9
4C	29.6	4D	32.1
5C	28.6	5D	30.9
6C	30.2	6D	29.2
7C	28.1	7D	28.4
Mean	29.2	**Mean**	29.7

Shell Point Cove 2010 Salinity			
Control		Dock	
Station	**Porewater Salinity (ppt)**	**Station**	**Porewater Salinity (ppt)**
1C	52.3	1D	46.5
2C	41.9	2D	43.5
3C	35.1	3D	32.2
4C	33.8	4D	35.6
5C	33.8	5D	34.4
6C	34.4	6D	35.9
7C	36.4	7D	36.3
8C	37.2	8D	39.0
9C	37.3	9D	36.5
10C	40.9	10D	41.6
11C	57.6	11D	72.7
12C	55.6	12D	66.3
13C	74.0	13D	61.6
14C	77.2	14D	64.4
15C	52.1	15D	74.4
16C	54.1	16D	76.3
17C	96.0	17D	100.5
18C	91.6	18D	127.6
19C	87.8	19D	132.4
20C	99.7	20D	116.9
21C	74.8	21D	85.9
22C	46.6	22D	80.6
23C	52.5	23D	64.9
24C	45.8	24D	60.2
25C	38.0	25D	38.0
26C	40.6	26D	38.0
27C	34.8	27D	42.8
Mean	54.1	**Mean**	62.4

Table 21. Grain size of surface sediments along the field dock transects. Grain size reported in "phi" units, a geological conversion for quantifying particles with a wide range of sizes in a single size scale. To convert particle diameters in phi units to metric units (millimeters), use the following equations: size in (mm) = $2^{-(phi)}$ and conversely, size in phi = $\log_2$(mm).

Betz Creek 2009 Grain Size											
Control						Dock					
Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)	Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)
1C	5.5	24.8	69.7	9.0	2.7	1D	32.9	13.6	53.4	7.5	4.3
2C	7.1	34.2	58.7	8.4	2.8	2D	10.3	25.5	64.1	8.8	3.1
3C	8.5	35.5	56.0	8.3	2.9	3D	3.3	28.9	67.8	9.2	2.5
4C	10.5	36.3	53.2	8.1	3.0	4D	10.1	30.3	59.6	8.6	3.1
5C	15.5	38.0	46.4	7.5	3.4	5D	16.2	26.7	57.0	8.3	3.4
6C	9.5	30.2	60.3	8.4	2.9	6D	8.2	27.8	64.1	8.9	3.1
7C	19.3	32.8	47.9	7.5	3.3	7D	17.4	26.9	55.7	8.2	3.4

Betz Creek 2010 Grain Size											
Control						Dock					
Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)	Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)
1C	3.0	21.0	76.0	9.6	2.5	1D	31.5	16.3	52.2	7.5	3.9
2C	2.9	22.6	74.5	9.5	2.5	2D	8.1	23.1	68.7	9.0	2.9
3C	11.0	26.4	62.7	8.7	3.0	3D	3.9	23.5	72.6	9.4	2.6
4C	8.6	29.5	61.9	8.8	3.0	4D	4.5	23.3	69.2	9.2	2.7
5C	6.6	29.5	63.9	8.9	2.9	5D	5.7	26.9	67.4	9.0	2.8
6C	11.5	25.2	63.3	8.6	3.1	6D	13.4	28.4	58.3	8.5	3.2
7C	14.7	28.9	56.4	8.2	3.3	7D	13.6	25.5	60.9	8.5	3.1

Turners Creek 2008 - Pre-Construction Grain Size											
Control						Dock					
Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)	Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)
1C	4.2	19.9	76.0	9.4	2.6	1D	1.5	18.0	80.2	9.9	2.2
2C	2.8	14.9	82.3	10.0	2.4	2D	3.8	20.4	75.9	9.6	2.6
3C	4.4	23.6	72.0	9.4	2.7	3D	4.9	21.5	73.6	9.6	2.8
4C	5.1	22.8	70.9	9.3	3.0	4D	6.7	22.1	71.2	9.2	3.0
5C	3.1	12.1	84.8	10.2	2.4	5D	5.3	23.4	71.3	9.3	2.9
6C	6.4	24.9	68.7	9.3	3.1	6D	4.3	23.7	72.1	9.6	2.8
7C	4.8	23.5	71.9	9.4	2.8	7D	3.8	25.9	70.3	9.3	2.7

Turners Creek 2009 Grain Size											
Control						Dock					
Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)	Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)
1C	6.4	21.8	71.7	8.9	2.8	1D	13.0	20.4	66.6	8.8	3.3
2C	8.3	21.2	70.5	9.1	3.0	2D	4.5	18.8	76.7	9.6	2.6
3C	7.8	25.2	67.0	8.9	3.0	3D	3.8	21.0	75.2	9.5	2.6
4C	13.1	26.3	60.6	8.3	3.5	4D	6.9	21.1	72.0	9.3	3.0
5C	11.1	24.8	64.1	8.5	3.3	5D	6.3	19.9	73.7	9.2	2.9
6C	20.3	25.4	54.4	7.8	3.9	6D	8.3	20.0	71.7	9.4	3.1
7C	11.3	30.4	58.4	8.3	3.2	7D	5.2	19.4	75.4	9.5	2.7

Turners Creek 2010 Grain Size											
Control						Dock					
Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)	Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)
1C	2.4	18.7	78.9	9.8	2.3	1D	5.0	22.0	72.9	9.7	2.7
2C	3.2	17.6	79.2	9.7	2.4	2D	4.8	20.6	74.6	9.5	2.7
3C	3.7	21.1	75.3	9.6	2.6	3D	2.0	20.6	77.4	9.7	2.3
4C	2.9	21.5	75.7	9.6	2.6	4D	3.1	23.2	73.8	9.4	2.5
5C	4.3	24.9	70.8	9.2	2.6	5D	3.4	19.2	77.4	9.5	2.5
6C	4.3	25.4	70.3	9.4	2.6	6D	3.6	26.6	69.8	9.3	2.6
7C	2.1	28.2	69.6	9.2	2.5	7D	1.9	27.5	70.6	9.4	2.4

Shell Point Cove 2007 - Pre-Construction Grain Size											
Control						**Dock**					
Station	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Mean (Φ)**	**Sorting (Φ)**	**Station**	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Mean (Φ)**	**Sorting (Φ)**
1C	84.0	5.6	10.4	3.7	2.9	1D	79.5	6.8	13.7	3.9	3.3
2C	24.0	17.1	58.9	8.2	4.0	2D	27.5	18.2	54.3	7.7	4.3
3C	19.1	15.6	65.2	8.6	3.6	3D	27.1	14.8	58.1	7.9	3.9
4C	20.1	16.2	63.7	8.4	3.9	4D	7.1	16.9	76.0	9.6	2.8
5C	3.5	21.3	75.2	9.5	2.6	5D	15.0	17.6	67.5	8.5	3.3
6C	12.0	20.3	67.7	8.7	3.2	6D	34.6	15.3	50.1	7.2	3.8
7C	5.8	17.3	76.9	9.6	2.8	7D	7.9	20.1	72.1	9.2	2.9
8C	8.7	16.1	75.2	9.5	3.1	8D	18.1	11.7	70.3	8.7	3.4
9C	17.4	16.3	66.3	8.6	3.7	9D	27.1	11.6	61.3	8.1	4.0
10C	41.6	13.5	45.0	6.5	4.7	10D	57.7	9.9	32.4	5.6	4.1
11C	20.7	16.3	63.1	8.3	4.1	11D	14.7	14.6	70.7	9.0	3.7
12C	30.3	19.4	50.3	7.2	4.4	12D	35.1	11.4	53.5	7.6	4.2
13C	47.2	15.2	37.6	6.1	4.3	13D	54.3	11.2	34.5	6.0	4.2
14C	48.6	14.0	37.5	5.9	4.6	14D	41.7	15.2	43.1	6.6	4.4
15C	77.8	6.4	15.8	3.7	3.6	15D	79.6	3.9	16.6	3.7	3.7
16C	79.3	5.5	15.2	3.4	3.7	16D	85.0	4.1	10.9	2.8	3.3
17C	66.0	9.0	25.0	4.4	4.4	17D	72.8	7.4	19.8	3.9	3.9
18C	84.4	4.2	11.4	3.0	3.3	18D	81.0	4.2	14.9	3.4	3.7
19C	90.7	2.7	6.6	2.8	2.6	19D	91.6	1.7	6.8	2.9	2.7
20C	89.3	3.0	7.7	3.2	2.7	20D	92.5	1.4	6.1	3.0	2.4
21C	74.5	8.3	17.2	4.3	3.4	21D	78.6	5.4	16.0	4.2	3.4
22C	77.4	6.2	16.5	4.3	3.3	22D	67.2	6.4	26.4	5.2	3.9
23C	65.5	6.9	27.6	5.2	3.8	23D	60.1	7.1	32.8	5.7	4.1
24C	42.8	13.1	44.1	6.7	4.1	24D	18.4	14.1	67.6	8.7	4.0
25C	21.6	18.3	60.2	8.3	3.7	25D	22.2	25.0	52.8	7.7	3.5
26C	3.0	26.0	71.1	9.4	2.6	26D	3.7	23.5	72.7	9.5	2.7
27C	2.9	25.8	71.3	9.4	2.5	27D	9.0	26.3	64.6	8.9	3.2

Shell Point Cove 2008 Grain Size											
Control						Dock					
Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)	Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)
1C	86.0	2.8	11.2	3.6	2.8	1D	86.4	1.7	11.9	3.4	2.9
2C	28.1	16.9	55.1	7.7	3.7	2D	64.7	4.5	30.8	5.2	4.0
3C	11.1	19.1	69.7	9.1	3.3	3D	40.1	10.5	49.4	7.1	4.2
4C	6.7	15.7	77.6	9.5	2.7	4D	16.5	15.6	67.9	8.9	3.4
5C	1.2	20.2	78.6	9.7	2.1	5D	14.9	16.8	68.3	8.9	3.5
6C	2.0	19.0	79.0	9.8	2.2	6D	2.2	14.7	83.1	10.1	2.3
7C	3.9	19.3	76.8	9.6	2.6	7D	6.0	18.4	75.6	9.5	2.9
8C	10.0	18.0	72.1	9.1	3.0	8D	24.2	15.0	60.9	8.2	3.9
9C	17.6	20.3	62.2	8.3	3.6	9D	22.8	15.6	61.6	8.2	4.0
10C	16.5	22.2	61.3	8.3	3.4	10D	26.9	15.9	57.3	7.8	3.9
11C	26.9	20.9	52.1	7.5	4.1	11D	64.1	11.2	27.7	5.1	3.9
12C	31.8	17.3	50.9	7.2	4.6	12D	26.5	23.2	50.3	7.3	4.3
13C	74.6	7.6	17.8	3.8	3.7	13D	75.4	7.2	17.4	3.8	3.6
14C	76.8	6.6	16.7	3.5	3.7	14D	37.0	23.5	39.6	6.4	4.1
15C	78.4	7.3	14.4	3.2	3.6	15D	75.6	8.4	16.0	3.5	3.7
16C	89.0	3.1	7.9	2.6	2.9	16D	90.5	2.3	7.2	2.6	2.8
17C	87.2	3.2	9.6	3.0	2.9	17D	92.9	2.4	4.7	2.5	2.1
18C	90.1	3.9	6.1	2.9	2.2	18D	94.0	2.4	3.7	2.8	1.7
19C	75.2	7.1	17.8	4.3	3.4	19D	71.7	8.0	20.4	4.5	3.7
20C	68.5	9.0	22.5	4.8	3.7	20D	77.4	4.2	18.4	4.4	3.5
21C	59.2	7.7	33.1	5.7	4.2	21D	65.7	7.1	27.2	5.2	3.9
22C	32.7	17.0	50.3	7.4	4.1	22D	28.1	16.6	55.3	7.8	4.0
23C	5.8	15.8	78.4	10.0	2.8	23D	9.8	24.9	65.4	9.0	3.2
24C	3.0	21.6	75.4	9.7	2.6	24D	3.8	20.6	75.6	9.7	2.7
25C	3.1	21.2	75.7	9.9	2.5	25D	8.2	19.6	72.2	9.4	3.0
26C	24.5	9.6	65.9	8.3	4.0	26D	26.1	9.4	64.5	8.2	4.0
27C	32.4	12.5	55.1	7.8	4.2	27D	51.6	5.2	43.2	6.5	4.4

Shell Point Cove 2009 Grain Size											
Control						Dock					
Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)	Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)
1C	83.4	8.5	8.1	3.2	2.8	1D	93.5	3.7	2.9	3.0	1.8
2C	39.9	15.1	45.1	6.6	4.7	2D	39.9	22.6	37.5	6.2	4.5
3C	33.0	13.0	54.1	7.5	4.3	3D	29.1	19.0	52.0	7.4	3.7
4C	34.4	16.1	49.5	6.8	4.6	4D	12.8	23.6	63.6	8.7	3.2
5C	17.9	18.7	63.4	8.2	4.0	5D	1.3	20.7	78.0	9.5	2.1
6C	13.1	20.5	66.5	8.8	3.3	6D	13.1	20.3	66.6	8.8	3.3
7C	6.7	19.1	74.2	9.3	3.0	7D	3.3	17.7	79.0	9.8	2.5
8C	18.7	19.8	61.5	8.1	3.6	8D	11.4	23.8	64.8	8.7	3.4
9C	39.1	17.2	43.7	6.4	4.5	9D	28.0	19.9	52.1	7.4	4.0
10C	34.1	16.0	49.9	7.0	4.6	10D	50.7	11.9	37.4	6.2	4.3
11C	33.1	16.3	50.6	7.0	4.8	11D	23.3	17.5	59.2	8.2	4.1
12C	34.8	18.3	46.9	6.9	4.6	12D	54.1	12.7	33.2	5.9	4.1
13C	26.0	23.8	50.2	7.6	4.1	13D	66.7	10.8	22.5	4.7	3.8
14C	41.1	17.8	41.1	6.4	4.6	14D	70.4	13.4	16.2	3.8	3.6
15C	74.6	9.6	15.9	3.7	3.5	15D	74.5	10.3	15.2	3.8	3.4
16C	85.7	5.1	9.2	2.8	3.0	16D	83.3	4.2	12.6	3.0	3.4
17C	79.7	6.5	13.8	3.3	3.5	17D	86.4	4.7	9.0	2.6	3.2
18C	87.8	3.3	8.9	2.9	3.0	18D	90.3	3.3	6.4	2.4	2.7
19C	90.8	2.7	6.5	2.7	2.6	19D	95.4	1.8	2.8	2.4	1.9
20C	90.5	4.2	5.4	2.8	2.3	20D	93.0	3.2	3.8	2.8	2.1
21C	81.5	6.5	12.0	3.7	3.1	21D	87.9	4.4	7.7	3.3	2.6
22C	78.4	7.1	14.5	4.1	3.1	22D	80.5	4.6	14.9	4.1	3.2
23C	49.6	16.0	34.4	5.8	4.1	23D	68.8	7.8	23.4	4.9	3.7
24C	73.3	9.2	17.5	4.2	3.3	24D	56.9	12.4	30.7	5.5	3.9
25C	19.5	25.8	54.6	7.7	3.6	25D	16.1	26.9	57.0	8.2	3.5
26C	11.6	27.5	60.9	8.4	3.4	26D	6.2	27.4	66.4	8.9	2.9
27C	9.7	26.6	63.7	8.5	3.2	27D	7.0	26.0	67.1	9.0	3.1

Shell Point Cove 2010 Grain Size											
Control						Dock					
Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)	Station	Sand (%)	Silt (%)	Clay (%)	Mean (Φ)	Sorting (Φ)
1C	89.5	6.0	4.5	3.2	1.9	1D	85.4	6.6	7.9	3.3	2.3
2C	14.4	18.5	67.2	8.9	3.4	2D	29.1	10.0	60.9	8.0	3.9
3C	11.6	13.9	74.6	9.3	3.2	3D	38.8	11.5	49.7	7.2	4.1
4C	16.2	15.4	68.4	8.8	3.5	4D	7.1	16.9	76.0	9.6	2.8
5C	4.9	16.5	78.7	9.7	2.8	5D	9.0	16.4	74.7	9.5	3.0
6C	4.4	18.7	76.9	9.7	2.6	6D	20.0	15.4	64.6	8.5	3.5
7C	3.6	16.8	79.6	9.8	2.6	7D	4.2	17.5	78.3	9.8	2.6
8C	9.8	14.5	75.8	9.4	3.0	8D	19.7	11.4	68.9	8.7	3.6
9C	29.5	6.3	64.3	8.3	4.0	9D	53.2	7.4	39.5	6.2	4.2
10C	26.9	7.5	65.6	8.5	4.1	10D	58.0	6.0	36.0	5.9	4.3
11C	8.4	9.1	82.5	9.9	3.2	11D	13.6	13.2	73.2	9.3	3.5
12C	26.5	14.8	58.7	8.0	3.8	12D	45.4	11.5	43.2	6.6	4.1
13C	27.0	17.4	55.6	7.7	3.9	13D	45.5	12.3	42.1	6.5	4.1
14C	57.3	10.3	32.4	5.2	4.6	14D	45.1	16.0	38.9	6.1	4.3
15C	68.9	9.3	21.8	4.3	3.9	15D	74.7	5.8	19.5	4.1	3.8
16C	80.4	4.1	15.6	3.4	3.7	16D	84.2	4.0	11.8	3.0	3.3
17C	62.7	9.9	27.5	4.7	4.5	17D	79.1	5.5	15.4	3.4	3.7
18C	77.3	7.4	15.3	3.4	3.7	18D	86.6	3.9	9.6	2.9	3.0
19C	87.8	4.0	8.1	2.8	2.5	19D	93.6	2.1	4.3	2.5	2.0
20C	89.1	3.9	7.1	3.0	2.3	20D	92.4	3.1	4.5	2.8	1.9
21C	81.2	4.0	14.8	4.0	3.3	21D	82.9	3.9	13.3	3.9	3.1
22C	73.1	5.9	21.1	4.6	3.6	22D	70.7	7.0	22.4	4.8	3.7
23C	63.6	8.5	27.9	5.2	3.9	23D	46.5	11.6	41.9	6.5	4.2
24C	47.9	11.1	41.0	6.4	4.2	24D	36.3	14.7	49.0	7.2	4.1
25C	12.7	21.8	65.5	8.8	3.3	25D	42.1	19.2	38.7	6.5	4.0
26C	3.3	24.4	72.3	9.4	2.7	26D	5.1	25.0	69.9	9.2	2.8
27C	3.2	23.3	73.5	9.5	2.5	27D	5.1	28.3	66.6	9.1	2.9

Table 22. Light transmittance through marsh grass canopy and the intertidal water column. Light transmission was measured within low, medium and dense S. alterniflora canopy near Skidaway Institute, in the intertidal water column of a major tidal river (the Skidaway River) and in the waters of a marsh platform (at SERF – the Saltmarsh Ecosystem Research Facility) near the Skidaway Institute. Transmittance in canopy was averaged over 1 hour intervals.

Average Light Transmittance through *S. alterniflora* Canopy
Skidaway Institute of Oceanography

Time Interval (hours)	Transmittance (%)		
	Low Density	Medium Density	High Density
09:00 – 10:00	---	20	---
10:00 – 11:00	25	29	---
11:00 – 12:00	41	35	14
12:00 – 13:00	73	61	19
13:00 – 14:00	78	50	23
14:00 – 15:00	63	47	17
15:00 – 16:00	51	44	11
16:00 – 17:00	---	---	7

Light Transmittance Through Water Column *Skidaway River*		
Time of Day	**Depth (m)**	**Transmittance (%)**
07:30:00	0.01	100
07:45:00	0.20	75
08:00:00	0.35	48
08:30:00	0.50	28
08:45:00	0.64	15
09:00:00	0.77	11
09:30:00	0.89	14
09:45:00	1.00	14
10:00:00	1.13	13
10:15:00	1.26	12
10:30:00	1.37	9
10:45:00	1.48	6
11:00:00	1.58	4
11:30:00	1.68	2
12:00:00	1.77	3
12:15:00	1.86	2
12:30:00	1.93	3
13:00:00	1.95	3
13:30:00	1.94	4
14:00:00	1.73	5
14:15:00	1.63	7
14:30:00	1.54	6
14:45:00	1.43	4
15:15:00	1.19	5
15:30:00	1.06	4
15:45:00	0.93	7
16:00:00	0.81	10
16:15:00	0.68	10
16:30:00	0.54	6
17:00:00	0.40	11
17:30:00	0.06	35
18:00:00	0.04	102

Light Transmittance Through Water Column *Marsh Platform*		
Time of Day	**Depth (m)**	**Transmittance (%)**
11:50:00	0.24	97
12:05:00	0.26	87
12:20:00	0.32	72
12:35:00	0.41	64
12:50:00	0.50	58
13:05:00	0.60	50
13:20:00	0.67	42
13:35:00	0.74	37
13:51:00	0.80	33
14:05:00	0.84	29
14:35:00	0.88	26
14:50:00	0.89	28
15:05:00	0.87	30
15:20:00	0.83	34
15:35:00	0.78	34
15:50:00	0.70	31
16:05:00	0.62	36
16:20:00	0.53	41
16:35:00	0.42	46
16:50:00	0.31	51
17:05:00	0.19	55