The Effects of Docks on Seagrasses, With Particular Emphasis on the Threatened Seagrass, *Halophila johnsonii*

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I. INTRODUCTION

In March of 2005, the National Oceanic and Atmospheric Administrations Special Projects Office released "Population Trends along the Coastal United States: 1980-2008" (Crossett et al. 2004). This report includes population changes and trends between 1980 and 2003 and projected changes in coastal populations by 2008. Given the findings, pressure on coastal resources around the country will continue to rise, particularly in Florida. Among the pertinent facts are these figures:

- The narrow coastal fringe that makes up 17 % of the nation's contiguous land area is home to more than half of its population.
- In 2003, approximately 153 million people (53 % of the nation's population) lived in the 673 U.S. coastal counties, an increase of 33 million people since 1980.
- In 2003, 23 of the 25 most densely populated U.S. counties were coastal.
- By the year 2008, this year, coastal county population is expected to increase by approximately 7 million.
- From 2003 to 2008, coastal population in the Southeast region is expected to grow by 1.1 million people or 8%.
- Florida grew by 7.1 million people between 1980 and 2003. This number is second in the nation after California at 9.9 million people. Both of these states are far beyond Texas, the third ranked state at a growth of 2.5 million people. In terms of percent population change, these numbers represent 75 %, 52 %, and 47 % increases for Florida, Texas, and California, respectively.
- Almost one quarter of the nation's seasonal homes are found in the coastal areas of Florida and 24 % of Florida's coastal housing is seasonal.
- Of the 10 leading Southeast counties in population change, 8 are expected to be in Florida. Population growth will be most prominent in the southernmost portion of Florida, with Broward County expected to increase by 167,000 people and Palm Beach County expected to increase by 151,000 people.

One of our most valuable coastal resources is seagrass, but human desire and need to live on the coast means that our habitat overlaps with suitable seagrass habitat. Seagrasses can be found in coastal areas around the world but are limited to relatively shallow, relatively clear water because of their reliance on light for photosynthesis. Seagrasses provide food for both small and large marine organisms, larval and adult stage. They provide shelter and habitat to a variety of commercially important fish and invertebrates. They baffle the water column and inhibit the resuspension of sediments. They prevent erosion and fix and recycle nutrients. The physical and ecological benefits of seagrasses make them very important to human welfare, but their light-limited coastal distribution makes them highly susceptible to anthropogenic influences (Larkum et al. 2006).

One way humans directly impact seagrasses is through the proliferation of single-family docks. Single family docks are a long-standing and popular method of gaining water access for those who own waterfront property, and the number of docks and dock construction permit applications are increasing steadily with coastal population growth (Kelty and Bliven 2003). Although single-family docks are just one of many stresses on coastal resources, their presence has been found to have multiple direct and indirect negative impacts including: loss of seagrasses from shading stress, shellfish habitat loss, contamination from chemical leachates from treated wood, construction impacts such as halos around pilings or from dredging, fragmentation of beach habitats, prop dredging and sediment resuspension from boat propellers, pollution from boat paint, gas and oil spills, and chemicals used in marine sanitation devices (Macfarlane et al. 2000). There is also evidence that docks may alter water flow and impact public access and navigation (Kelty and Bliven 2003). Given the cumulative effects that multiple docks have on the environment, coastal resource managers are faced with a daunting challenge. A waterfront homeowners' right to have a dock on their property must be balanced with the cost of its environmental and economic impact on the underlying seagrasses and functions they provide, and actions must be taken to offset, or at the very least, minimize those impacts.

The availability of photosynthetically active radiation (PAR) has previously been established as a limiting factor for seagrass growth, distribution, and productivity (Kenworthy and Fonseca 1996, Czerny and Dunton 1995) and experimental shading of seagrasses has been shown to induce stress responses and reduce productivity (Dean and Durako 2007). Moreover, the specific effect of dock shading has been shown to reduce productivity of *Halodule wrightii* (Shafer 1999, Beal and Schmidt 2000, Loflin 1995), *Syringodium filiforme* (Beal and Schmidt 2000, Loflin 1995), *Thalassia testudinum* (Loflin 1995), and *Zostera marina* (Burdick and Short 1999) in areas under and adjacent to docks, though the extent of impact varied with each site and with regard to the variability in docks. As coastal resource managers have been given the burden of balancing the protection of homeowner rights and the protection of coastal resources, the use of light transmitting materials (LTMs) (FIG.1a) in dock construction has emerged as a potential means to lessen the damaging effects of docks on the underlying seagrass without eliminating their construction altogether.

The Dade County, Florida, Department of Environmental Resource Management (DERM) conducted an investigation comparing the benefits of docks constructed with acrylic, acrylic with matting, lexan, aluminum grating, and fiberglass grating; they found that only fiberglass grating showed promise (Molnar et al. 1989). In a study that took place in St. Andrew Bay, Florida, Shafer and Robinson (2001) evaluated the effectiveness of fiberglass grating through the construction and monitoring of two experimental platforms over seagrass beds. They found that light levels below the platforms were sufficient to allow seagrass growth but still considerably less than at nearby controls. They concluded that fiberglass grated decking should reduce but not eliminate the amount of seagrass lost due to shading and help maintain the integrity of seagrass beds by reducing the fragmentation. Fresh et al. (2001, 2006) studied the benefits of using light-transmitting grated decking on docks in Puget Sound, Washington. They concluded that at least 50 % of the deck had to be grated to be of a detectable benefit to the underlying eelgrass.

Based on these results and due to the increased demand for docks and their negative impacts on the local landscape and ecology, the state of Florida has implemented a multi-step permitting process for homeowners wishing to build docks on their property. Any dock to be built in an area where there is Submerged Aquatic Vegetation (SAV) is required to adhere to the Dock Construction Guidelines put forth by the U.S. Army Corps of Engineers / National Marine Fisheries Service (*Dock Construction Guidelines in Florida for Docks or Other Minor Structures Constructed in or over Submerged Aquatic Vegetation (SAV), Marsh or Mangrove Habitat*; U.S. Army Corps of Engineers/National Marine Fisheries Service August 2001: Appendix A).

One species of seagrass, *Halophila johnsonii*, also known as Johnson's seagrass, is listed as a Threatened Species according to the Endangered Species Act (U.S. Federal Register 1998: 63 FR 49035). It is a very small statured seagrass with high turnover rates (Kenworthy et al. 1989) that is found only on the east coast of Florida, in the United States, between an area just north of Sebastian Inlet (27.855906′N, 80.453130′W) extending south to Virginia Key in Biscayne Bay (25.747142′N, 80.144286′W) (Eiseman and McMillan 1980, NMFS 2007). It maintains a patchy distribution and low densities throughout its range (NMFS 2007) but it is often observed in areas where the distribution of other marine plants is limited by high rates of sedimentation and strong currents, such as in the intertidal zone (Dawes et al. 1989; Virnstein et al. 1997; Durako et al., 2003). Because male flowers have never been observed for this species, it is presumed that its only means of reproduction is through vegetative propagation. Dean and Durako (2007) found that healthy *H. johnsonii* ramets do not support stressed ramets along its genet like many other seagrasses. This characteristic may make it particularly susceptible to habitat fragmentation and the shading effects of docks. Based on these considerations, any docks to be built in areas where *H. johnsonii* is found, or in areas designated as the species' critical habitat, have to adhere to even more stringent construction guidelines as stated in the *Key for Construction Conditions for Docks or Other Minor Structures Constructed in or Over Johnson's Seagrass, Halophila johnsonii*; National Marine Fisheries Service/U.S. Army Corps of Engineers, October 2002 (Appendix B). *Dock Construction Guidelines in Florida for Docks or Other Minor Structures Constructed in or over Submerged Aquatic Vegetation (SAV), Marsh or Mangrove Habitat*; U.S. Army Corps of Engineers/National Marine Fisheries Service August 2001 will hereafter be referred to as "SAV dock guidelines" and the *Key for Construction Conditions for Docks or Other Minor Structures Constructed in or Over Johnson's Seagrass, Halophila johnsonii*; National Marine Fisheries Service/U.S. Army Corps of Engineers, October 2002 will hereafter be referred to as "Johnson's seagrass dock guidelines."

The foremost principle behind the SAV dock guidelines is that whenever possible, avoidance is key. These guidelines state that the pier/dock shall be aligned so as to minimize the size of the footprint over SAV beds. In addition, the height of the pier must be a minimum of 5 feet above mean high water (MHW/OHW) and the width is limited to a maximum of 4 feet. Over-SAV portions of the pier are to be oriented in a north-south orientation to the greatest extent practicable. Pilings shall be installed so that halos do not result around the newly installed pilings and these pilings shall be spaced a minimum of 10 feet apart on center. Gaps between deckboards shall be a minimum of ½ inch. One turnaround, a terminal platform, and one uncovered boat lift are all allowed with certain restrictions on size and orientation. If the terminal platform is constructed of a light-transmitting material such as grated decking (FIG. 1a), it may be larger than if constructed using planks (FIG. 1b).

The Johnson's seagrass dock guidelines are written in the manner of a dichotomous key and are meant to complement but not supersede the SAV dock guidelines. The Johnson's seagrass dock guidelines put more emphasis on the use of grated decking to offset the effects of docks on the underlying seagrass and state that light-transmitting materials used for dock construction in the known range of *H. johnsonii* must have a minimum of 43 % open space. To summarize the Johnson's seagrass dock guidelines, consider the following: If the construction site is in the known range of *H. johnsonii* and a seagrass survey is performed at the site during the April 1st through August 31st growing season, and if *H. johnsonii* is present at the site and inside an area designated as Johnson's seagrass critical habitat, construction must follow the SAV dock guidelines except that light

Figure 1. Light transmitting (a) and planked (b) docks.

transmitting materials shall comprise 75 % of pedestrian surfaces waterward of the mean low water (MLW) line and the remainder of surfaces beyond the MLW line shall maintain a minimum of 1-inch spacing between deckboards. If, however, all of the stipulated conditions above apply except that it is not in an area designated as Johnson's seagrass critical habitat, then all pedestrian surfaces directly over *H. johnsonii* areas must be constructed of LTMs and a minimum of one inch spacing shall be maintained between all deckboards used waterward of the MLW line.

If no survey was done or it was done outside of the growing season and if the site is within critical habitat for *H. johnsonii*, the dock must adhere to the SAV dock guidelines and 100 % of all pedestrian surfaces must be comprised of LTMs waterward of the MLW line. If the same conditions apply but the site is not in critical habitat, then LTMs must comprise 75 % of all pedestrian surfaces waterward of the MLW line and a 1 inch space must be maintained between all deckboards waterward of the MLW line.

Also consider: If the construction is in the known range of *H. johnsonii* and also within an area designated as critical habitat, and the seagrass survey is done during its growing season but *H. johnsonii* is not present at the proposed construction site, then the SAV guidelines apply except that a minimum of 1 inch spacing between all deckboards is required waterward of the MLW line. If however, the construction is not to take place in critical habitat and other seagrasses are present but not *H. johnsonii*, then construction must only follow the SAV dock guidelines. If the construction is not taking place in critical habitat, and there are no seagrasses present, no construction conditions for SAV are necessary.

The additional requirements imposed by the guidelines increase the cost of dock construction. These additional costs include the time the agencies spend to supervise the permitting process and to insure that the guidelines are followed. Additional costs also include the time required for land owners to plan and implement the surveys as well as the material cost of building the docks with the grated decking. Although experimental studies have indicated that the guidelines should minimize impacts to seagrasses, no one has actually demonstrated that compliance to these guidelines benefits the resource and justifies the additional cost. Our study and this report attempt to examine the benefits of using fiberglass grated decking to reduce impacts to seagrasses, and pay particular attention to the threatened seagrass, *Halophila johnsonii*.

II. METHODS

A. Dock Identification and Study Site Selection

In 2004, the Florida Fish and Wildlife Conservation Commission (FWC) conducted a data mining project in an attempt to accumulate as many as possible known recordings of *H. johnsonii.* In addition to an exhaustive search for records of its presence through state and county permit files, the Data Mining Project compiled data from environmental consulting companies, academic institutions and federal agencies. This project resulted in a list of records with variable amounts of information, which we used to identify docks to use in this study. First this list was sorted by source (ie. the agency or consulting company) and project type in order to eliminate the recordings that had nothing to do with dock permit applications or construction. The most promising records were sourced back to Jerner & Associates (110 SW 5th St. Stuart, FL 34994 ph: 772-283-2950). For addresses and project descriptions, these records were further sorted by project type and all but dock projects were deleted. This list was then sent to Bruce Jerner at Jerner & Associates asking that he look at the list and identify the locations where docks had been built to the construction guidelines set forth for *H. johnsonii*. He listed all as either “Built to Guidelines,” “Not built to guidelines,” or “Unknown.”. We also contacted the Miami Dade Department of Environmental Resource Management (DERM) and asked them to compile a similar list for Biscayne Bay. DERM submitted a list of projects for which they had *H. johnsonii* recorded as ‘Present’ in their database. DERM suggested that all projects with Johnson’s

Seagrass listed as ‘Present’ and that qualified for a SAJ-42 General Permit were supposed to be built to the Dock Construction Guidelines for Johnson’s Seagrass. With this information, we sorted their list and eliminated all projects for which a SAJ-42 was not required. This list was then shortened to approximately twenty projects by deleting all entries not related to dock construction. From here, we concentrated on projects listed as “New Construction” because DERM suggested that docks that were being replaced or repaired did not necessarily adhere to the construction guidelines.

This process left us with two lists of docks to potentially include in our study. The Miami Dade DERM docks were concentrated in Biscayne Bay. The docks obtained by Jerner & Associates were primarily in the Indian River Lagoon (IRL).

B. Field Reconnaissance and Data Collection Methodology

Dock identification and “field reconnaissance” took place in February 2007. Dock location information was based on physical street addresses, so it was necessary to extrapolate coordinates using GoogleEarth software, which uses a method of interpolation to approximate address locations. We started with a list of approximately thirteen docks in Biscayne Bay that we thought may be built to guidelines or where construction was planned but not yet begun; of these, we were able to locate seven. Some were in narrow canals where the shoreline dropped off rapidly into deep water and most also served as dockage for very large yachts that were bigger and shaded considerably more area than the docks themselves. Additionally, there was a high degree of variability from one dock to the next in this area and the same was true of water quality in terms of turbidity and substrate. Transects were completed at five of the seven docks and very little *H. johnsonii* was recorded. These data are not included in this report, but are available from the authors upon request.

Our attentions then turned to the IRL, which proved more ideal for this study. While much of the lagoon has been altered by development, a proportion of the shoreline is still relatively uncompromised with native vegetation, unconsolidated sediments and other features more typical of a natural shoreline. We were again unable to locate all of the docks on our list, but we selected two areas just north of the St. Lucie Inlet on the eastern shoreline of the lagoon for the study. Dock height, width, and orientation have been identified as the three most important factors affecting seagrass growth (Burdick and Short 1999) so we felt it was important to find docks that were as similar to one another in these dimensions as possible. The first site was chosen because it hosts a series of non-grated docks, all of which are in fact similar to each other in dimensions, composition, and orientation.

This area is identified as Site 1 and is located at approximately -80.164894°, 27.194701° on MacArthur Blvd (FIG.2). The second site is identified as Site 2 and is located north of Site 1 at -80.184879°, 27.226349° (FIG.2). Site 2, at Northeast Shore Village, is within Johnson's seagrass critical habitat and hosts a series of grated docks that are both similar to each other and similar to the docks at Site 1.

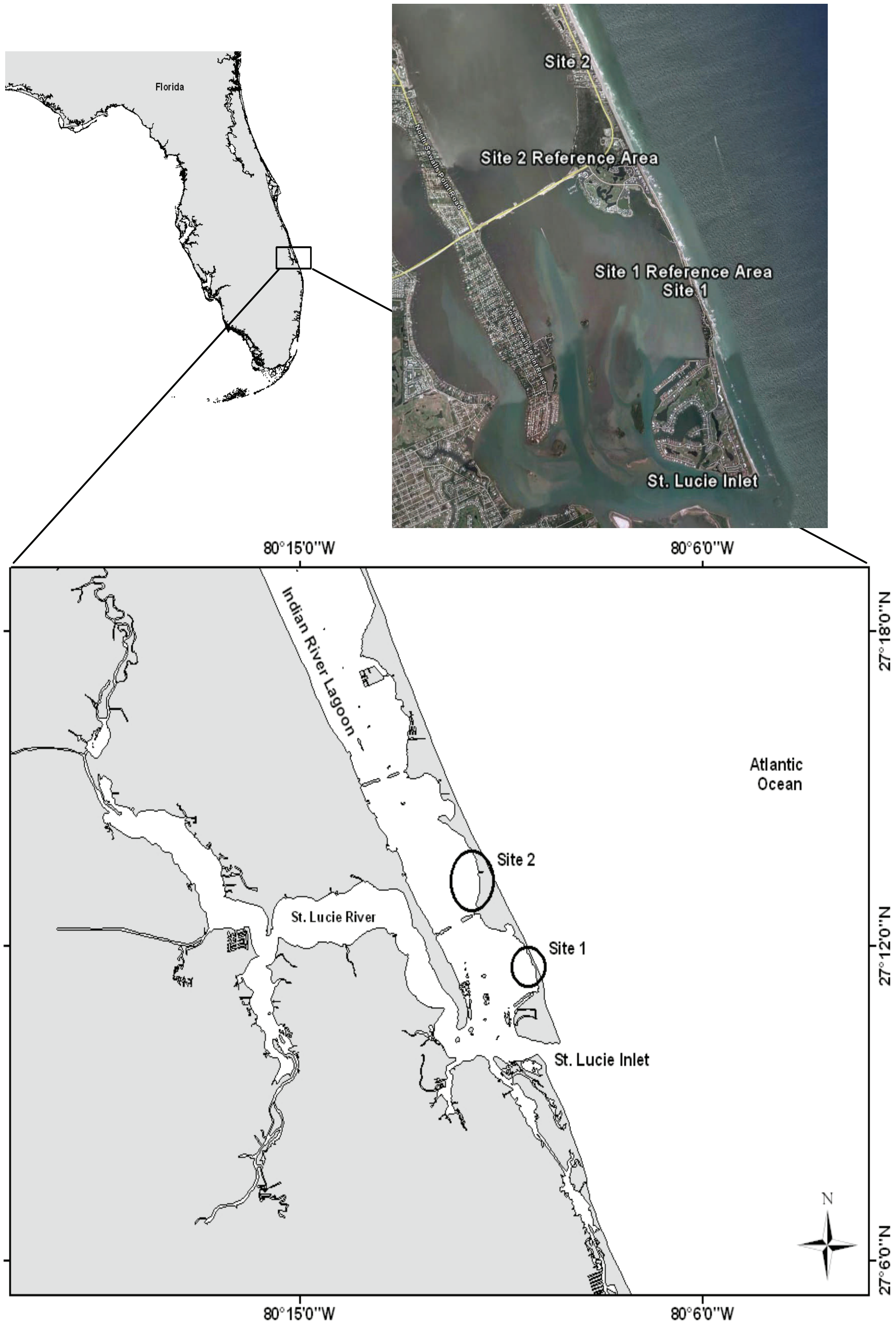

Figure 2. Site locations. Site 1 includes 3 non-grated dock transects, 6 adjacent transects, and 3 reference area transects. Site 2 includes three grated dock transects, 5 adjacent transects, and 3 reference transects and is located in Johnson's seagrass critical habitat.

The following parameters were measured at each dock: height above mean high water level, length and width of dock, terminal and any other platform measurements, number of boat lifts, and size of boat(s) if present. A transect method was used for sampling for submerged benthic vegetation (hereafter referred to as either SAV or seagrass). Meter tape transects were run under the centerline of the dock (dock) and parallel to the dock on each side (adjacent). The distance at which the adjacent transects were performed was determined by the distance between the dock in question and neighboring docks. Transects were done at the midline between the two, so actual distance from the centerline dock transects to the adjacent transects varied. Along each transect, 0.50 m^2 PVC sampling quadrats were placed along the meter tape at the centerpoint between pilings, approximately three meters apart, for the length of the dock. As docks varied in length, so did the number of quadrats sampled. Braun-Blanquet visual cover assessment values were recorded for each seagrass observed within the quadrat, as were values for total seagrass cover (See Table 1 for description of Braun-Blanquet cover categories). Water depth as well as sediment type were measured at each point sampled.

The data collected during the initial February sampling trip were not used for any statistical analyses. They were collected primarily to confirm *H. johnsonii* presence and to focus our intentions and methods for the later sampling trip to take place during the summer. In August 2007, a second, more thorough, sampling trip was conducted. During this trip, we revisited Sites 1 and 2 and designated reference areas for each site. Each reference site was selected based on its location (in the same general vicinity as the docks being referenced), similar coastline orientation, unconsolidated

Table 1. Modified Braun-Blanquet scale in which cover is the percent of the bottom that is obscured by the macrophyte when viewed by a diver from directly above.

Cover Class	Description
0	Absent
0.1	Solitary individual ramet of alga
0.5	Few ramets of alga, less than 5% cover
1	Many individual ramets or alga, less than 5% cover
2	5% - 25% cover
3	25% - 50% cover
4	50% - 75% cover
5	75% - 100% cover

sediments, and representation of a natural shoreline without docks (See Figure 3 for comparison of reference area (3a) and populated dock area (3b)). Both reference sites had fringing mangrove shorelines. Three transects were completed at each (see Fig. 2 for aerial view of shoreline showing location of reference transects in relation to docks). These data were intended to serve as “controls” for our “treatments.” For convenience, transects surveyed under Grated docks, under Non-grated docks, and Adjacent to docks are referred to as “treatment” transects throughout this report. All of the same parameters as were measured during the initial February survey were measured in August.

Figure 3. Natural shoreline (a) and populated shoreline (b).

C. Dock Descriptions

Site 1

Site 1 is located along MacArthur Blvd. in Stuart, FL. There are four docks at this site; three are not grated, and one is partially grated. Transects were completed under and adjacent to all four docks, for a total of thirteen transects including those completed in the reference area for this site. The four docks all vary only slightly in specific characteristics and all are oriented in an East-West direction. They are identified as follows: 1) South Control, 2) North Control, 3) North Control 2, and 4) Compliant Dock. The Compliant dock was our initial target dock but is only partially grated, so it was not included in any final analyses, and is only briefly referred to as an example of intermediate efforts at grating.

Site 2

During the initial sampling trip in February, only two docks were sampled, the North Dock and the South Dock. During the August sampling trip, the dock north of the North Dock was also included and called North Dock 2. All three docks are completely grated, but North Dock 2 varies from the North and South Docks in that it is longer and is oriented Southeast-Northwest, as opposed to simply East-West like the other two. Only four transects were completed during the February trip, but in August, the set was expanded to include eleven complete transects, three of which were under the grated decking docks, five of which were adjacent to those docks, and three of which were in the designated reference area for this site. See Table 2 for details about each dock.

Table 2. Dock characteristics summary. Measurements reported in inches and feet for ease of comparison to Dock Construction Guidelines.

	Site 1				Site 2		
Transect	**South Control**	**North Dock 1**	**North Dock 2**	**Compliant Dock**	**South Dock**	**North Dock**	**North Dock 2**
Grated	No	No	No	Partial	Yes	Yes	Yes
Orientation	E-W, sw	E,W, sw	E-W, sw	E-W, sw	E-W	E-W	SE-NW
Plank Spacing (in)	0.38	0.75	0.38	1.00	n/a	n/a	n/a
Boat lifts	0	0	1	1	1	1	0
Jet Ski Lift	0	0	0	0	2	1	0
Terminal Platform	yes	yes	yes	yes	yes	yes	yes
Anti-bird caps on pilings	yes	no	no	no	yes	yes	yes
Ht. above MHW (ft)	5.25	5.25	3.94	5.25	5.41	5.58	5.00
Approx width (ft)	3.94	4.1	3.94	3.94	3.94	3.94	3.94
Approx length from water edge (ft)	180.45	246.06	285.43	288.71	209.97	209.97	328.08
Approx area over water (ft^2)	710.97	1008.85	1124.59	1137.52	827.28	827.28	1292.64

D. Descriptive Statistics

To easily visualize the density of *H. johnsonii* along transects, the Braun-Blanquet values for each quadrat were entered into Excel and a color was assigned to correspond with each Braun-Blanquet value in the cell. The cell blocks with their corresponding colors were then transferred onto diagrammatic PowerPoint depictions of the docks and their layouts. The color-coded transects were also compiled into one figure to show the differences in *H. johnsonii* cover between the sites and between the treatments.

Because of the small stature and patchiness of *H. johnsonii*, its Braun-Blanquet values are generally quite low. For this reason, the Braun-Blanquet data for each seagrass were converted to binomial (0 or 1) presence/absence data and with the presence/absence data, a frequency of occurrence was calculated (the number of quadrats in which it occurred divided by the total number of quadrats surveyed along the transect) for each macrophyte for each transect. This value is given along with the number of quadrats surveyed along each transect above the diagrams just described above. The average frequency of occurrence for each treatment type was then calculated and bar graphs (including standard error bars) were created to illustrate trends in the data.

E. Statistical Analyses

Although located near each other within the Indian River Lagoon, Site 1 and Site 2 should be considered as geographically distinct as they are separated by a small peninsula of land and a causeway (FIG. 2). This, coupled with the results of the descriptive statistics, suggested that to begin, we needed to determine if Site 1 and Site 2 were different from one another in their macrophyte frequencies of occurrence. A global permutational analysis of variance (PERANOVA) was used for this purpose (Anderson 2001). The frequency of occurrence data from each site were first pooled to include transects under docks, adjacent to docks, and in reference areas. Similarity matrices were constructed for each species (*H. johnsonii, H. decipiens, H. wrightii,* and *S. filiforme*) using Bray-Curtis as a distance measure. PERANOVA analysis can be adopted for testing the simultaneous response of one or more variables (permutational multivariate analysis of variance, or PERMANOVA) to one or more factors in an ANOVA experimental design on the basis of any distance measure, using permutation methods. Specifically, PERANOVA tests (based on sums of squared distances) allow a direct additive partitioning of variation for complex models, while maintaining the flexibility and lack of formal assumptions of other non-parametric methods (McArdle and Anderson 2001). For our needs, we set the factor ‘Site’ as having 2 levels (Site 1 and Site 2), and the factor ‘Treatment’ as having three levels (dock, adjacent, reference). Both factors were considered as fixed for the analysis. This test confirmed our assumptions that the two sites were different enough to warrant separating out the data and analyzing it within each site only. This seemed particularly necessary because all of the grated docks were at one site and all of the non-grated docks at another. By separating the data by site, it was possible to determine if any significant differences were due to the treatment rather than the basic characteristics and macrophyte distributions of each site.

We then moved on to a more detailed analysis to test for differences among the three treatments– dock (grated or non-grated), adjacent and reference – for each individual species within each site. For this analysis, we performed a one-way PERANOVA with the factor ‘treatment’ as fixed with the three levels as the three treatments. We ran this analysis both for Site 1 and Site 2.

A posteriori tests were also carried out using a PERANOVA test. PRIMER v.6 was used to generate resemblance matrices and to perform all other analyses. For all tests, we allowed 9999 permutations under a reduced model.

As part of the PERANOVA analysis, the average of similarity between the level of the factor “site” was calculated wherein the higher the value, the more similar the treatments were to one another. Because it was not possible to directly compare transects under non-grated docks to transects under grated docks (due to the regional differences), we secondarily used these coefficients of similarity to determine which treatment (non-grated or grated) was more dissimilar from its reference. Theoretically, the more different the treatment is from the reference, the greater the treatment impact.

To ensure that any differences that PERANOVA missed because of the small sample size were identified, we secondarily ran simple paired comparison T-tests using SigmaPlot. T-tests were performed within each site to find differences between each pair of treatments. When equal variance tests failed, SigmaPlot automatically ran the comparison using a Mann-Whitney rank sum test.

III. RESULTS

Sediments at Sites 1 and 2 were fairly uniform and generally ranged from sandy mud to muddy sand, with sand mostly dominating at the shallowest end of the transects. Slopes were also fairly uniform within and between sites, averaging around 1.45 cm/m. The exceptions were the two reference areas. The average slope (where slope = change in depth / length of transect) for reference transects at Site 1 was steeper than the dock and adjacent transect slopes (3.01, 1.47, and 1.42 cm/m, respectively) and the average slope of the reference transects at Site 2 was less than the average slopes under and adjacent to the docks (1.14, 1.46, and 1.53 cm/m, respectively) (TABLE 3). The average maximum depth for each type of transect was also fairly uniform, ranging from .77 m to 1.43 m. The shallowest (Site 2) and deepest (Site 1) were both reference area transects. Transects under or adjacent to docks on average reached a maximum depth of about 1.13 m. Transects were longer at Site 1 than at Site 2 because the docks themselves were longer; consequently more quadrats were surveyed at Site 1 than at Site 2. Transects at the reference areas were a set length (30 m) and we surveyed every meter, therefore more quadrats were sampled at the reference areas than at the docks .

Diagrammatic depictions of the summer Braun-Blanquet scores for Johnson's seagrass along transects plainly show that it is much more dense and frequently occurring on transects adjacent to docks and in reference areas than on transects surveyed under either non-grated (FIG. 4) or grated (FIG. 5) docks. These figures also show that although it is reduced in frequency under grated docks, Johnson's seagrass was observed in higher densities under these docks than under non-grated docks. One can also see from Figures 4 and 5 that Johnson's seagrass was generally more abundant at Site 1 than at Site 2. The Site 1 reference area transects had *H. johnsonii* frequencies of occurrence of 13.1, 71.0, and 74.2 % whereas the Site 2 reference area had frequencies of occurrence at 9.7, 36.7, and 22.6 % (FIG. 6). Transects surveyed adjacent to the docks at Site 1 had frequencies of occurrence at

Table 3. Summary of average slope, maximum depth, length, and number of quadrats for each type of transect.

	Transect	**Slope (cm/m)**	**Max depth (m)**	**Transect length (m)**	**# of quads surveyed on transect**
Site 1	*Under Non-grated*	1.47	1.13	72.10	23.67
	Adjacent	1.42	1.15	77.05	24.00
	Reference	3.01	1.43	30.00	30.00
Site 2	*Under Grated*	1.46	1.20	62.87	20.67
	Adjacent	1.53	1.14	59.28	19.00
	Reference	1.14	0.77	30.00	30.00

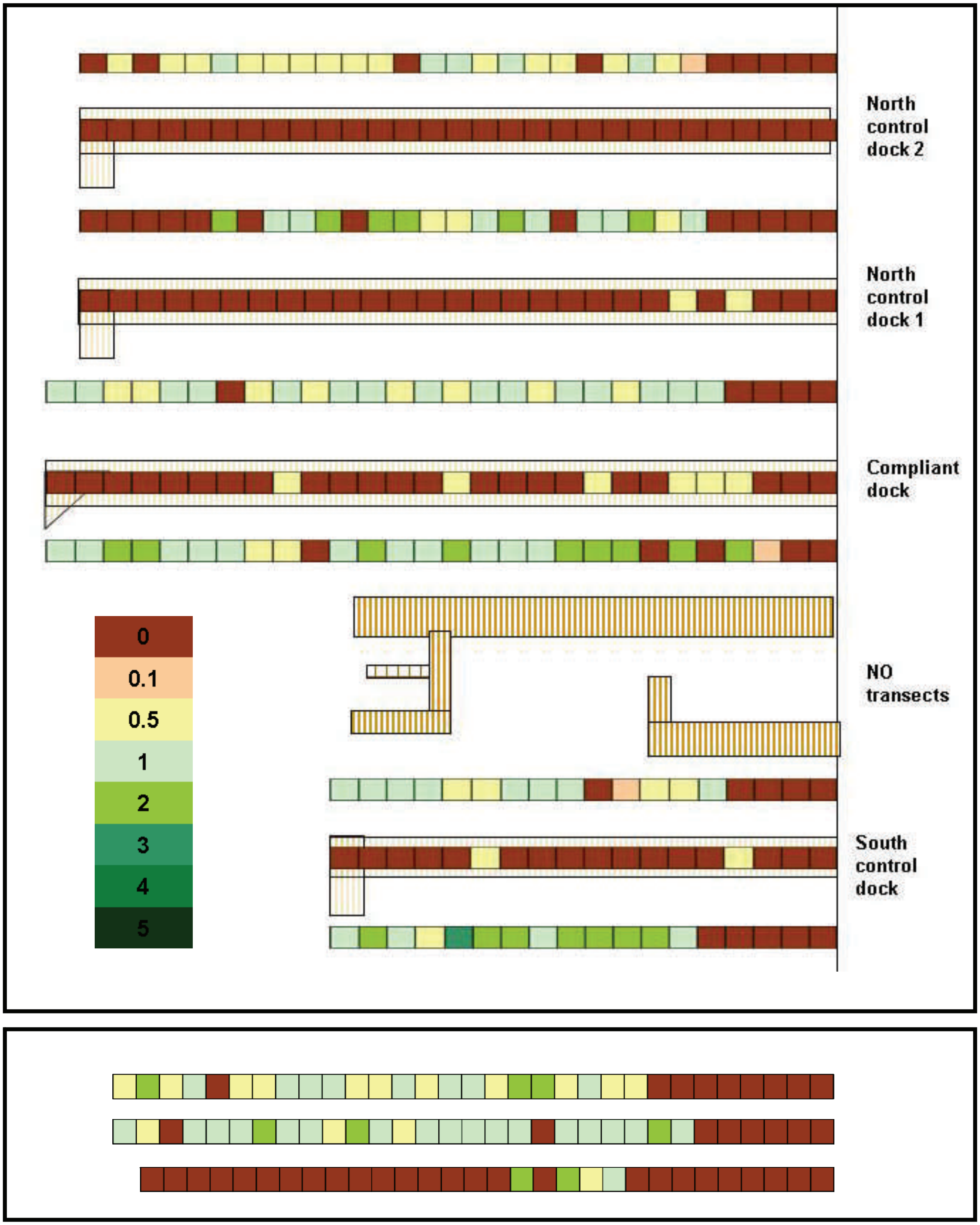

Figure 4. Diagrammatic depiction of Site 1 with series of non-grated docks. Top diagram shows site with color-coded overlays of Braun-Blanquet values on transects surveyed under docks and adjacent to docks. Bottom diagram shows reference area transects.

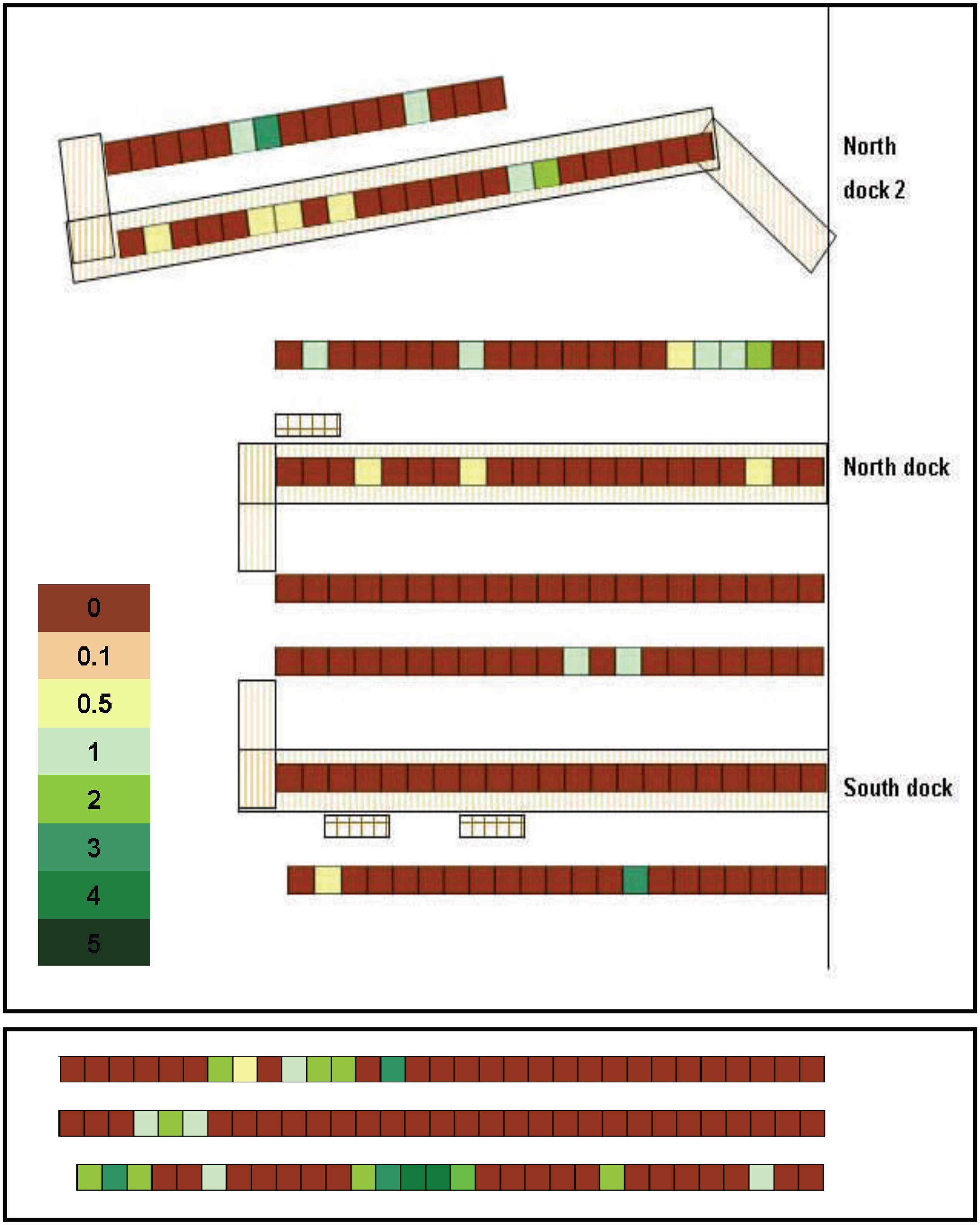

Figure 5. Diagrammatic depiction of Site 2 with series of grated docks. Top diagram shows site with color-coded overlays of Braun-Blanquet values on transects surveyed under docks and adjacent to docks. Bottom diagram shows reference area transects.

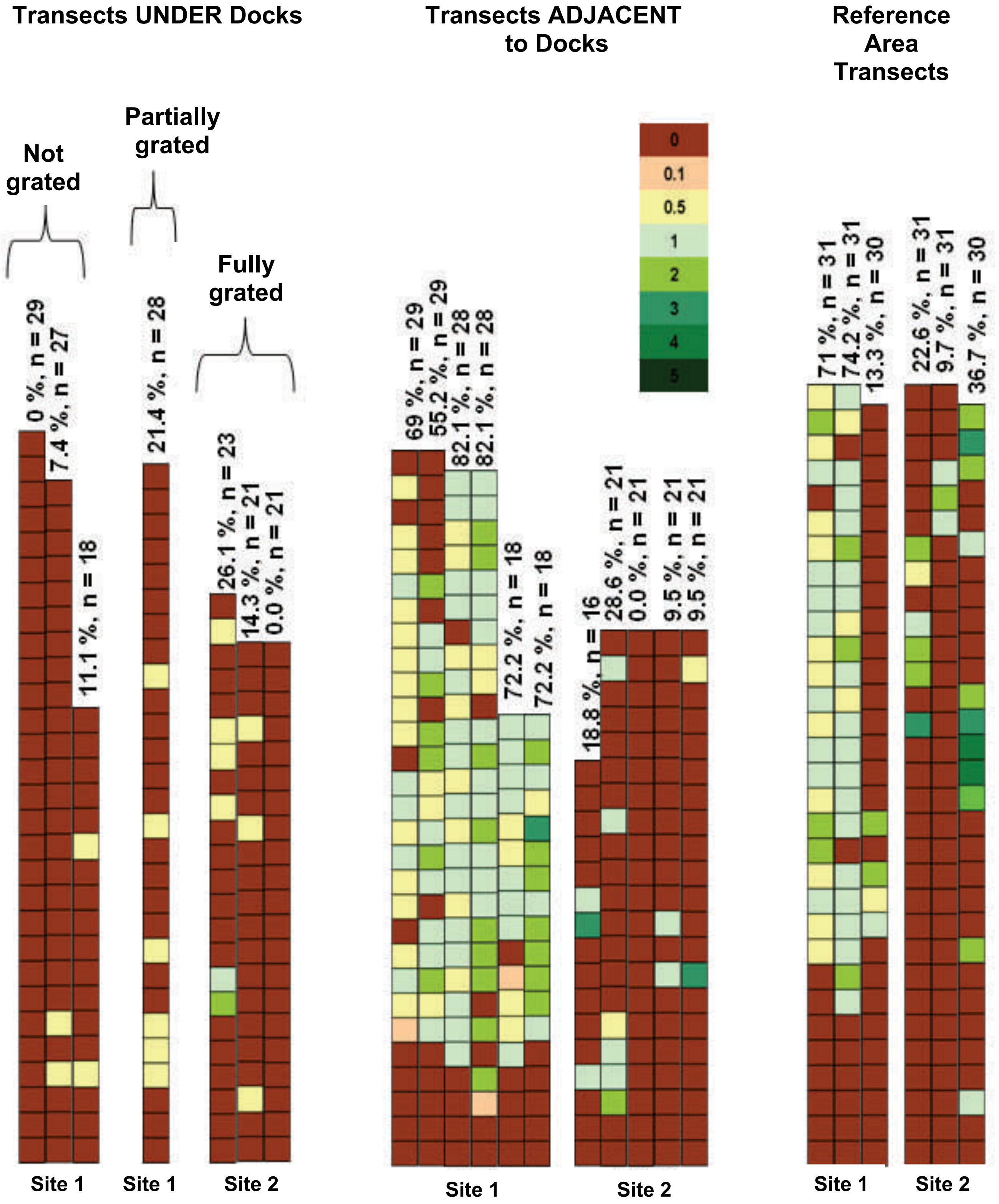

Figure 6. Graphic showing Braun-Blanquet values, color coded, for *H. johnsonii* in quadrats along transects. Length of transects and number of quadrats surveyed were determined by length of docks. Also shown are % frequency of occurrence along transect.

55.2, 69.0, 72.2, 72.2, 82.1, and 82.1 % whereas transects adjacent to docks at Site 2 had frequencies of occurrence at 0.0, 9.5, 9.5, 18.8, and 28.6 %. At Site 1 the non-grated dock transects had frequencies of occurrence of 0.0, 7.4, and 11.1 %. At Site 2 the grated dock transects had frequencies of occurrence of 0.0, 14.3, and 26.1 % (FIG. 6). The fact that Site 2 has less *H. johnsonii* in general but still maintains a greater frequency of occurrence under the grated docks than the non-grated docks at Site 1 suggests that *H. johnsonii* does benefit from the light transmitting characteristics of grated decking.

At Site 1, the partially grated compliant dock stands as a good example of intermediate efforts at grating. Where the dock is not actually grated, there are one-inch slots between the planks that allow less light through than grated decking, but more than traditional size slots. The frequency of occurrence for *H. johnsonii* at this dock was 21.4 % - a value intermediate between the two primary treatments.

Frequency of occurrence bar graphs (FIG. 7) show that *H. johnsonii* is the most frequently occurring seagrass at Site 1. *Halophila decipiens, Halodule wrightii,* and *Syringodium filiforme* are present in decreasing frequency in that order. At Site 2, *H. wrightii* dominates, followed by *S. filiforme*. The prevalence of these larger seagrasses with a corresponding decrease in frequency of the smaller seagrasses at Site 2 could indicate a degree of competitive exclusion of the *Halophila spp*. By comparing the Site 1 graph to the Site 2 graph, it is evident that non-grated decking has a more detrimental effect on all of the seagrasses than does grated decking. In every case, the macrophytes occur more frequently under grated decking docks than non-grated docks. The exception is that either type dock completely eliminates the presence of *S. filiforme*.

To solidify and complement the use of descriptive statistics, a global PERANOVA was employed to determine if there were statistically significant differences between the sites and among the treatments within each site. The PERANOVA showed that the differences in *H. decipiens* and *H. wrightii* frequencies of occurrence were significantly different between the sites, but that there was no difference in the frequencies of occurrence between the sites for *H. johnsonii* and *S. filiforme* (TABLE 4). The differences between *H. decipiens* and *H. wrightii* are what prompted us to divide the data and analyze it further by site. Although this prohibited us from directly comparing non-grated and grated docks, it did allow for us to eliminate the possibility that any differences found are attributed to site differences.

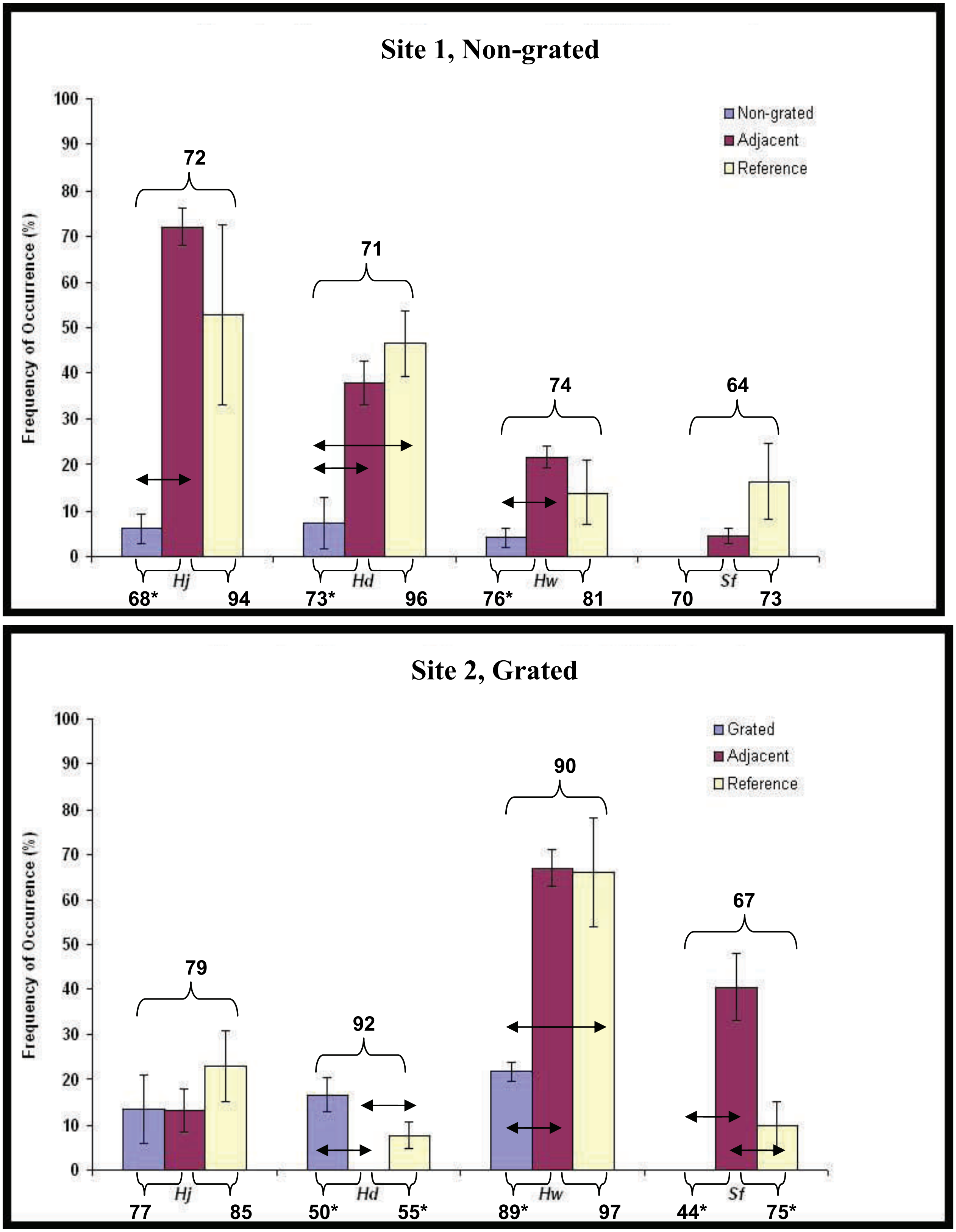

Figure 7. Macrophyte Frequency of Occurrence site and species comparisons. Error bars indicate +/- Standard Error. Numbers above and below brackets are coefficients of similarity between treatments calculated during PERANOVA. * indicates a PERANOVA significant difference. Arrows indicate significant difference between treatments when using T-tests.

Table 4 also summarizes the results when using PERANOVA to find differences between treatments within each site. At Site 1, *H. johnsonii*, *H. decipiens,* and *H. wrightii* were significantly different in frequencies of occurrence between transects surveyed under non-grated docks and transects surveyed adjacent to those docks. *Syringodium filiforme* frequencies were not found to be significantly different between the non-grated dock transects and the adjacent transects, even though there was no *S. filiforme* observed under docks. The adjacent transect average frequency of occurrence was only 4.5%, which may be considered close enough to 0 % to make this difference insignificant. There were no significant differences between transects under the non-grated docks and the reference transects. This is most likely due to the very large standard deviations associated with the reference transects.

At Site 2, PERANOVA found no significant differences between any of the treatments for *H. johnsonii*. *Halophila decipiens* however showed significant differences between transects surveyed under grated docks and transects adjacent to those docks. Transects adjacent to the docks were in turn significantly different than those surveyed in the reference areas. The same is true of *S. filiforme*. *Halodule wrightii* only showed significant differences in frequencies of occurrence between transects under the grated docks and transects adjacent to the docks. All significant differences found using PERANOVA are indicated on the Figure 8 bar graphs and represented by stars (*) placed beside coefficients of similarity for the same pair.

We also used paired comparison T-tests to determine if there were any significant within site differences that PERANOVA may have missed because of the small sample size. These results are also summarized in Table 4. T-test results were identical to PERANOVA results with the exception that PERANOVA analysis failed to detect two differences: at Site 1, T-tests determined that there was

Table 4. PERANOVA and T-test significance table. Significant differences detected using PERANOVA are in black. Significant differences detected using paired comparison T-tests are in black and blue (note that T-tests detected same differences as PERANOVA as well as the two relationships highlighted in blue).

	Site 1	**Site 2**	**Geographic**
H. johnsonii	Ng-Adj	ns	ns
H. decipiens	Ng-Adj (Ng vs Ref)	Gr-Adj/Adj-Ref	$p < 0.001$
H. wrightii	Ng-Adj	Gr-Adj (Gr vs Ref)	$p < 0.001$
S. filiforme	ns	Gr-Adj/Adj-Ref	ns

significantly less *H. decipiens* under the non-grated docks than on the reference transects and at Site 2, there was significantly less *H. wrightii* under the grated docks than on the reference transects. All significant differences found using T-tests are indicated on the Figure 7 bar graphs and represented by double-headed arrows wherein each arrowhead lies over the treatments between which there is a difference.

The process of doing a permutational analysis of variance yields a coefficient of similarity (CS) as part of its outcome. This number expresses the level of similarity between two treatments and was considered here to elucidate to what extent the grated dock transects and the non-grated dock transects are similar to the adjacent and reference transects. Theoretically, the higher the CS value, the higher the level of similarity, and therefore the less impact the treatment is having. The coefficient of similarity values are summarized in Table 6. By comparing the macrophyte CS of each site to the other, one can determine which treatment is having more impact. For dock transects versus reference transects, *H. johnsonii* at Site 1 has a CS of 72, whereas *H. johnsonii* at Site 2 has a CS of 79 (TABLE 5). Although the difference is small, this means that the frequencies of occurrence for *H. johnsonii* under grated docks are more similar to the reference area transects than are the non-grated dock transects at Site 1 to their reference area transects. Hence, for J *H. johnsonii*, grated docks have less impact on their surroundings than non-grated docks. In fact, in the case of dock transects versus reference transects, the grated dock transects are more similar to their references than the non-grated docks for every seagrass observed (TABLE 5). Brackets between treatments on the Figure 8 bar graphs point to coefficient of similarity values.

When comparing dock and adjacent transects, the CS value for *H. johnsonii* is smaller at Site 1 than at Site 2. The same is true of *H. wrightii*. Both macrophytes have more similar frequencies of occurrence at Site 2 than at Site 1. *Halophila decipiens* and *S. filiforme* however have larger CS values at Site 1 than at Site 2. This means that for *H. johnsonii* and *H. wrightii*, transects surveyed under the grated docks are more similar to their surrounding adjacent transects than are transects under non-grated docks to their surrounding adjacent transects. The non-grated docks are having more of an impact on these plants. For *S filiforme*, the CS value is larger at Site 1 than at Site 2, but this is due to the very small frequency of occurrence (4.5%) at Site 1 and the relatively large (40.5%) frequency of occurrence at Site 2 (0% compared to 4.5% yields a much larger CS than 0% compared to 40.5%). There is much more *S. filiforme* on the adjacent transects at Site 2 than at Site 1. *Halophila decipiens* was completely absent on transects adjacent to docks at Site 2 but was observed frequently on transects adjacent to the docks at Site 1. This phenomenon, potentially caused by *H. decipiens* being displaced by the larger bodied seagrasses at Site 2, led to a higher CS between dock transects and adjacent transects at Site 1.

Table 5. PERANOVA results from within site analysis. Values represent **Coefficients of Similarity** between given treatments.

Dock (Non-grated or grated) vs. Reference		
Macrophyte	**Site 1**	**Site 2**
H. johnsonii	72	79
H. decipiens	71	92
H. wrightii	74	90
S. filiforme	64	67

Dock (Non-grated or grated) vs. Adjacent		
Macrophyte	**Site 1**	**Site 2**
H. johnsonii	68	77
H. decipiens	73	50
H. wrightii	76	89
S. filiforme	70	44

Adjacent vs. Reference		
Macrophyte	**Site 1**	**Site 2**
H. johnsonii	94	85
H. decipiens	96	55
H. wrightii	81	97
S. filiforme	73	75

IV. DISCUSSION

Based on the data presented, there was a difference between Sites 1 and 2 in the abundance and frequency of occurrence of *H. johnsonii*. *Halophila johnsonii* was observed more frequently and at relatively higher Braun-Blanquet cover values at Site 1 than at Site 2 (FIGS. 4,5,6). This difference, however, was not statistically significant when tested using PERANOVA (TABLE 4). Significant between site differences did exist however for *H. decipiens* and *H. wrightii* and were the impetus for separating the analyses by site and examining the treatments within each site rather than pooling the data and analyzing it together, as initially planned. By separating the data, it was our hope that analyses of the differences between treatments could be attributed to the treatments themselves and not differences in the characteristics of the two sites.

When assessing the bar graphs created to show trends in macrophyte occurrence at both sites, it is clear that both the smaller bodied *Halophila spp.* dominated Site 1, whereas the larger bodied *H. wrightii* dominated Site 2 (FIG. 7). *Syringodium filiforme* was relatively more abundant at the adjacent transects in Site 2, but not in the reference (Fig. 7). At both sites there was a very distinct dock effect on the larger species, whether grated or not. *Syringodium filiforme* was completely absent under docks and there was significantly less *H. wrightii* under both grated and non-grated docks (TABLE 4, FIG. 7)

Halophila johnsonii had the highest frequency of occurrence at Site 1 in the adjacent and reference transects and there was a significant reduction under the non-grated docks compared to the adjacent transects. There was also a large difference between the non-grated docks and the reference site but variability at the reference site was large and the differences were not significant (FIG. 7). The frequency of occurrence for *H. johnsonii* under the non-grated docks at Site 1 was lower than the frequency of occurrence under the grated docks and was not significantly different from the either the adjacent or reference transects at Site 2. Furthermore, according to the coefficients of similarity for *H. johnsonii* (TABLE 5), the grated docks were more similar to the adjacent and the reference transects than the non-grated docks were. This suggests that non-grated docks are relatively more detrimental than grated docks for this species. When combined, these analyses support the argument that grating may be having a beneficial affect by minimizing impacts to *H. johnsonii*. However, the effects of the docks on the larger species may complicate interpretation of the overall dock effect. The significant reduction of *H. wrightii* and the apparent exclusion of *S. filiforme* by the docks may have diminished the competitive dominance of the larger species and allowed the *H. johnsonii* to thrive under the docks, regardless of grating. In general, with the exception of *H. decipiens* at the grated docks at Site 2, it appears that the mere presence of docks is having negative effects on seagrasses, but that non-grated docks may be worse. Note that the prevalence of *H. wrightii* under the grated docks is greater than under the non-grated docks (FIG. 7).

Previous surveys have reported the potential negative effects of docks on *T. testudinum*, *H. wrightii* and *S. filiforme*. An evaluation of 27 docks in Charlotte Harbor reported a visible area of seagrass loss and accompanying prop dredging averaging 128 m^2 around individual docks (Loflin 1995). As in our study, shallow patches of *H. wrightii* were found growing underneath docks but at lower density then in the surrounding meadows. Unlike our study, however, they found *S. filiforme* growing under docks, but at a reduced density compared to areas outside of the "dock shadow". In a survey in Palm Beach County, FL, Smith and Mezich (1999) estimated that >50 acres of seagrass were negatively impacted by the structures but did not specify any quantitative changes or the relative impacts to individual species.

Concern for dock impacts to seagrass has been based on: 1) the effects of construction activities, 2) incidental use, for example, petroleum pollutions and prop scarring, and 3) the effect of light reduction due to the presence of an overwater structure blocking incident radiation and creating a shadow under the dock (Burdick and Short 1999). The later impact could be a function of planking design (gap width), dock width, dock height or dock orientation. In an experimental study in Perdido Bay, Shafer (1999) demonstrated a significant reduction in *H. wrightii* shoot density and biomass in plots shaded by docks vs. unshaded treatments. Where dock orientation and dock height reduced light levels to < 14% SI, *H. wrightii* was completely eliminated. Shafer (1999) suggested that in order to minimize some impacts due to shading, the preferred orientation for docks in the northern Gulf of Mexico should be north-south, which in this case is practicle because of the predominantly east-west orientation of the shoreline. Thus, in order to minimize impacts, dock platforms must be constructed to allow as much light as possible. This may be achieved by minimizing the width, maximizing the height and orienting the dock in a manner that decreases the area and time the space under the dock is left shaded during the day.

Beal and Schmit (2000) compared the effects of different dock heights (0.91m and 1.51 m above MHW) on light levels and associated impacts to *H. wrightii* and *S. filiforme*. Experimental structures simulating actual docks with platforms were constructed in the IRL, FL, just north of our site. The experimental dock structures were compared with control treatments and treatments with just pilings. A statistical comparison of pre- and post construction seagrass cover and density indicated greatest impacts to seagrasses closest to the structures but the least impacts with the 1.51 m height. Once again, light reduction was implicated as a major factor impacting the seagrasses.

The results of these studies have heightened interest for developing alternative dock construction criteria that minimize the impacts of light reduction on seagrasses. Since it is not possible to always orient a dock in a preferred direction to minimize shading, alternative platform designs have to be considered. Alternative techniques were proposed to construct dock platforms with light transmitting materials such as acrylic with matting, lexan, aluminum grating, and fiberglass grating (Molnar et al. 1989). Recommendations for criteria using grated fiberglass decking were developed for single-family residential docks in the Panhandle of Florida by an interagency team lead by the U.S. Army Corps of Engineers and consisted of Federal and State Agencies and the marine construction industry. Following these recommendations Shafer (2001) experimentally evaluated the use of grated decking on experimental platforms 4 ft. and 5 ft. above mean high water in a *T. testudinum* meadow in St. Andrews Bay, FL. Light levels under the grated platforms were between 53 % and 61 % of the unshaded controls and were consistent with the manufacturer's rating of 50 % transmission. Mean irradiance levels reaching the top of the *T. testudinum* canopies under the 5 ft. and 4 ft. platforms were 23.3 % and 20.8 %, respectively, and were not significantly different. Despite grating, seagrass density declined significantly as compared to the unshaded controls, but there were no differences between the two platform heights. At the end of the experiment, 16 months after platform construction, *T. testudinum* shoot densities were reduced by 52 % under the 5 ft. dock and 58 % under the 4 ft. dock compared to the unshaded controls. Since these studies, implementation of the dock construction criteria using grated decking and a 5 ft. height requirement have been more widespread.

Although our survey study was opportunistic by design, using existing docks and comparing seagrass abundance to adjacent and reference sites, the results are consistent with the experimental studies demonstrating the negative impacts of docks on seagrasses. However, our study is unique in the fact that this is the first to attempt to evaluate the effects of docks on the threatened seagrass *H. johnsonii.* As was the case with both the observational and experimental studies, docks which were not built to the presently recommended construction guidelines did have a negative impact on *H. johnsonii* (FIG. 7). At Site 1, *H. johnsonii* frequency of occurrence was reduced by 90 % under the non-grated docks compared to adjacent transects and 85 % compared to the reference sites. Due to high variability, the latter difference was not statistically significant. At Site 2 there was no difference between the grated and adjacent transects, but there was a 58 % reduction in occurrence compared to the reference site, however, the latter was not significant. Corresponding reductions in *H. wrightii* and *S. filiforme* at this site may have benefited *H. johnsonii*, although it is not uncommon for *H. johnsonii* to be found growing among moderate to sparse densities of *H. wrightii.*

Based on these results, there is a compelling argument supporting prior studies which indicate that docks can have negative impacts on seagrasses by reducing their abundance and in some cases, preventing seagrass from growing. In our study there is evidence that all species were impacted. Although grated docks appear to be having relatively less impact, support for grating is not nearly as clear cut, and even though *S. filiforme* was present adjacent to grated docks, it did not grow under the grating. However, given the supporting experimental evidence that fiberglass grating does improve the incident solar radiation penetrating under the structure (Shafer 2001), continuing to require grated decking will benefit the seagrasses. This may be especially true for most of the IRL because of the lagoon's predominantly north-south orientation. Generally, most docks in the lagoon have to be constructed in an east-west orientation to reach sufficiently deep water. This orientation is parallel to the daily solar incident angle such that is has potential for intercepting more light than if the docks were oriented north-south. At this latitude most of the improvement in solar gain occurs on an annual cycle in winter when the sun retreats to the south and the solar angle is steeper. In winter relatively less light is intercepted by the platform. The net gain, however, does not compensate for the daily losses experienced through most of the rest of the year, and this is where the benefits of grated decking have a positive effect.

The analytical approach we used attempted to evaluate a relatively small data set including a rare and patchily distributed species that had a very large amount of variability. In the future, it would be ideal to use these data as a baseline and expand the study. Given the recent history of storms and the destruction and reconstruction of docks in this area, we may not have been assessing the equilibrium state of this system. Seagrasses may still be responding to storm effects and the period of new dock construction and repair that took place following a series of hurricanes. Returning to these sites in the future with a modified survey design and increasing the sample size and scope of sampling may improve the evaluation process. Enlisting more docks in this study would be helpful. We had hoped to do just that, but given the available information, we were unable to locate more grated docks. Lack of information on construction and compliance from the permitting agencies was a severe handicap both in the Indian River Lagoon and Biscayne Bay. While they could tell us that a dock construction permit had been applied for and granted, they could not reliably tell us whether or not that dock had been built yet or whether it was in fact built to guidelines. During our reconnaissance trip we came across several docks that should have been built to guidelines, but were not.

V. RECOMMENDATIONS

During the course of this study, we made several important observations and based on these observations, offer the following recommendations:

With regard to permitting;

1. The various agencies responsible for dock permitting are detrimentally short-handed. They do not have the manpower or financial support necessary to appropriately handle the daily onslaught of construction permit applications that they receive, nor do they have the manpower to enforce adherence to construction guidelines. Additional assistance is needed.

2. Obtaining information regarding dock construction in Florida is a difficult process. There should be a state-wide searchable database in which the various agencies can track the progress of all construction permits through to completion, including verification of said construction completion. Such a tool would, for example, allow one to search for specific types of overwater structures or calculate the overwater area obstructed throughout Florida.

With regard to dock construction;

3. All of the docks assessed during this study were built to extend out into deep water for boating purposes, as opposed to dredging into shallow water. This has not always been standard practice and appears to be beneficial to maintaining the integrity of the shallow water seagrass beds between docks. Unless absolutely unavoidable, extending docks into deep water should be mandatory.

4. Grated decking allows more light to pass through to the water column than standard planking. In conjunction with other best management practices such as north–south dock orientation, building a minimum of 5 feet above mean high water, and building a maximum of 4 feet in width, impact to underlying seagrass beds is reduced. Therefore, to minimize seagrass loss and bed fragmentation, grated decking should be used for any dock construction to take place over SAV, most importantly the threatened Johnson's seagrass.

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