Scientific Evaluation of a Sediment Fill Technique for the Restoration of Motor Vessel Injuries in Seagrass Beds of the Florida Keys National Marine Sanctuary

W. Judson Kenworthy, Kamille Hammerstrom, and Mark S. Fonseca (NOAA/NOS/NCCOS Center for Coastal Fisheries and Habitat Research, Beaufort, NC)

Project Description

Cost-effective techniques to facilitate early intervention for the prevention of propeller scar erosion and to enhance seagrass growth are widely needed to restore damage to Florida Keys National Marine Sanctuary (FKNMS) resources. This project used experimental manipulation to assess the effectiveness of installing fill material encapsulated in biodegradable fabric tubes to restore propeller scars. The experiment was designed to test the efficacy of sediment tubes, alone and in conjunction with bird stakes and *Halodule wrightii* seagrass planting units and to re-grade injuries to enhance regrowth of seagrass from the margins of propeller scars.

Introduction

Deterioration in seagrass habitat has been attributed to both natural and human-induced disturbance, but human-mediated disturbance is now the most serious cause of seagrass loss worldwide (Sargent et al. 1995; Short and Wyllie-Echeverria 1996). Reduction in water clarity and quality and physical damage by motor vessels are some of the most common negative impacts of human activities on seagrass beds (Sargent et al. 1995). Motor vessels are implicated in seagrass bed damage in a number of ways, including anchoring (Walker et al. 1989; Hastings et al. 1995; Creed and Filho 1999), propeller scarring (Fig. 1) (Zieman 1976; Durako et al. 1992; Dawes et al. 1997; Dunton and Schonberg 2002; Kenworthy et al. 2002), and large excavations caused by vessel groundings (Whitfield et al. 2002; Fonseca et al. 2002). In 1995 it was estimated that 30,000 acres of seagrass beds in the Sanctuary were moderately to severely scarred by boat propellers (Sargent et al. 1995).

Propeller scar damage disrupts the seagrass rhizome matrix and excavates sediments, leaving behind unvegetated trenches that may be up to 40 cm deep, 50 cm wide,


Figure 1. Aerial photograph of a shallow seagrass bank severely scarred by boat propellers.

and hundreds of meters long. Once the damage occurs, wind-, wave-, and current-induced erosion may further enlarge these trenches, creating injuries that heal very slowly, taking years to decades to recover (Zieman 1976; Durako et al. 1992; Dawes et al. 1997; Kenworthy et al. 2002; Whitfield et al. 2002). The resulting habitat fragmentation may negatively impact macrofauna that utilize seagrass beds (Bell et al. 2001; Uhrin and Holmquist 2003), thereby compounding the damage to seagrass ecosystems. Increased population density along U.S. coasts and subsequent increased boating activity will place additional burdens on seagrass resources. Natural resource managers therefore require restoration tools that can be implemented in a timely fashion and at reasonable cost to repair damage to seagrass communities.

Seagrass Recovery, Inc., a private company based in Ruskin, FL, has created and patented the Sediment Tube®, a biodegradable cotton tube that is filled with sediment and laid directly into a propeller scar (Fig. 2). A single tube is approximately 1.5 m long, 15-20 cm in diameter, and weighs 13.6-18.2 kg when filled with crushed calcium carbonate screening sand. The sediment tubes serve three possible functions: 1) to restore propeller scars to grade; 2) to deliver a desired sediment grain size; and 3) to prevent further erosion of the scar by water flow (Fig. 3). The objective of this project was to test this method of propeller scar restoration in a variety of energy regimes and sediment types. We also combined sediment tubes with bird stakes, a proven method of enhancing growth of colonizing seagrass species (Powell et al. 1989; Powell et al. 1991; Fourqurean et al. 1995; Kenworthy et al. 2000).


Figure 2. Filled sediment tubes ready to be deployed.
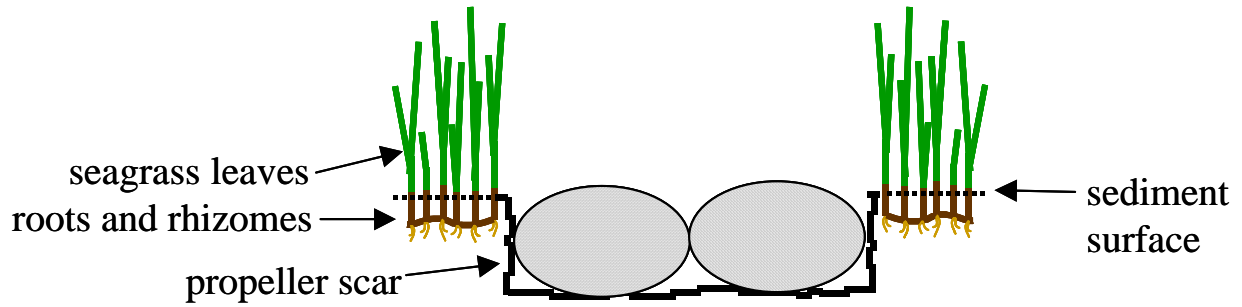
Figure 3. Cross-sectional view of sediment tube deployment into an existing propeller scar.

Study Site

The study was conducted in the Lignumvitae Key Management Area in the FKNMS. The 4,050 ha park, located in the middle region of the Florida Keys (Fig. 4), is comprised of many shallow seagrass banks dominated by *Thalassia testudinum* and is a popular destination for recreational flats fishers.
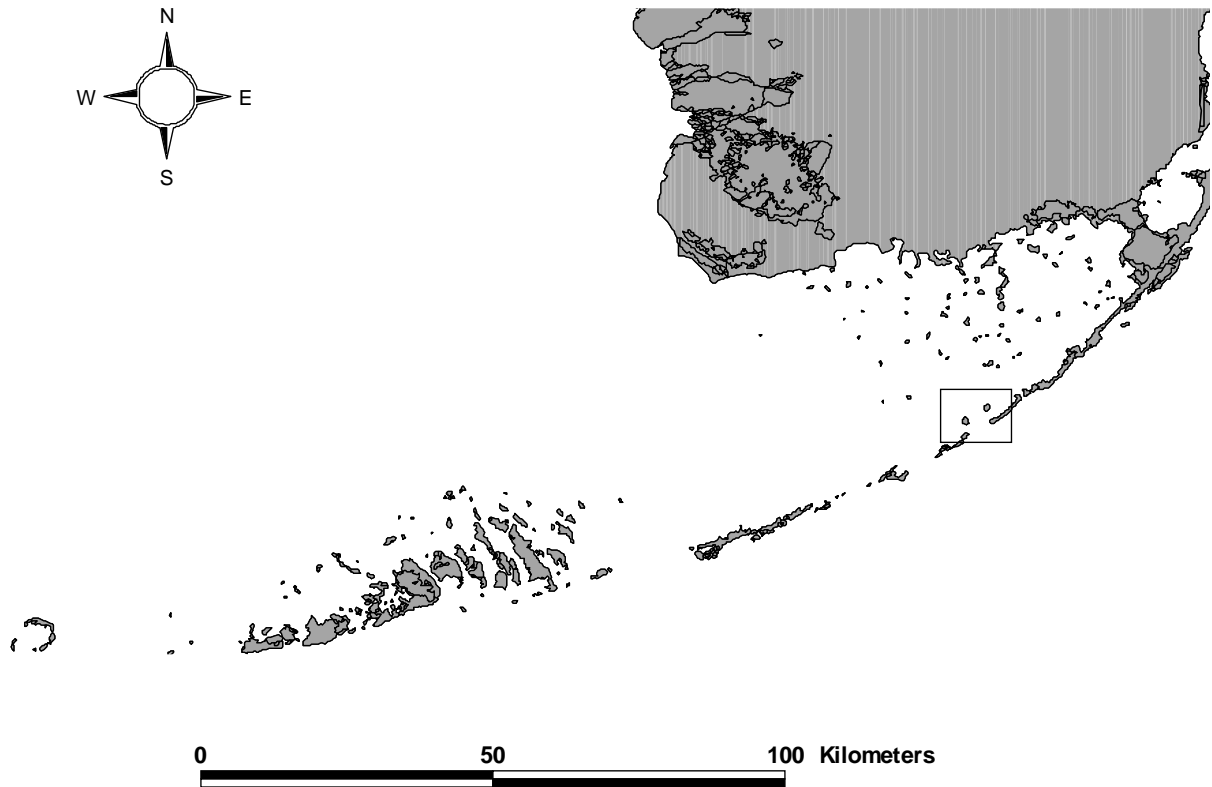
Figure 4. The experiment was deployed in the Lignumvitae Key Management Area within the Florida Keys National Marine Sanctuary. The area delineated by the box is enlarged in Figure 5.

The tidal range within the park is approximately 1 m, and the seagrass habitat outside the navigation channels is vulnerable to boat traffic during most of the tidal cycle. In 1993, after extensive motor vessel damage to seagrasses, approximately 2,430 ha of seagrass meadows within the park were protected by the creation of permanent combustion engine exclusion zones. Boaters can still access these exclusion zones in kayaks, canoes, and sailing craft; with trolling motors, and by poling with engines tilted up and turned off. Although legitimate boat channels are clearly marked within the park, local fishing guides have created "wheel ditches," or propeller scars that have eroded to form new channels in an effort to avoid traveling around the shallow seagrass banks. Injuries also occur when boaters unfamiliar with the area, who do not know how to read charts, posted signs, or the natural landmarks, accidentally go aground on the shallow banks. Park managers and the FKNMS continue to be concerned about the loss of seagrass habitat and are seeking new cost-effective and straightforward ways to restore damaged meadows.

Sixteen scars within the preserve were selected (Fig. 5) in four areas: Indian Key (IK), Lignumvitae Key (LV), Soft Indian Key (SIK), and Shell Key (SK). The IK area is on the ocean side, adjacent to the high-traffic Indian Key Channel, and exposed to easterly trade winds. Sediments at the IK area are composed of *Porites* sp. coral rubble and coarse carbonate sand.
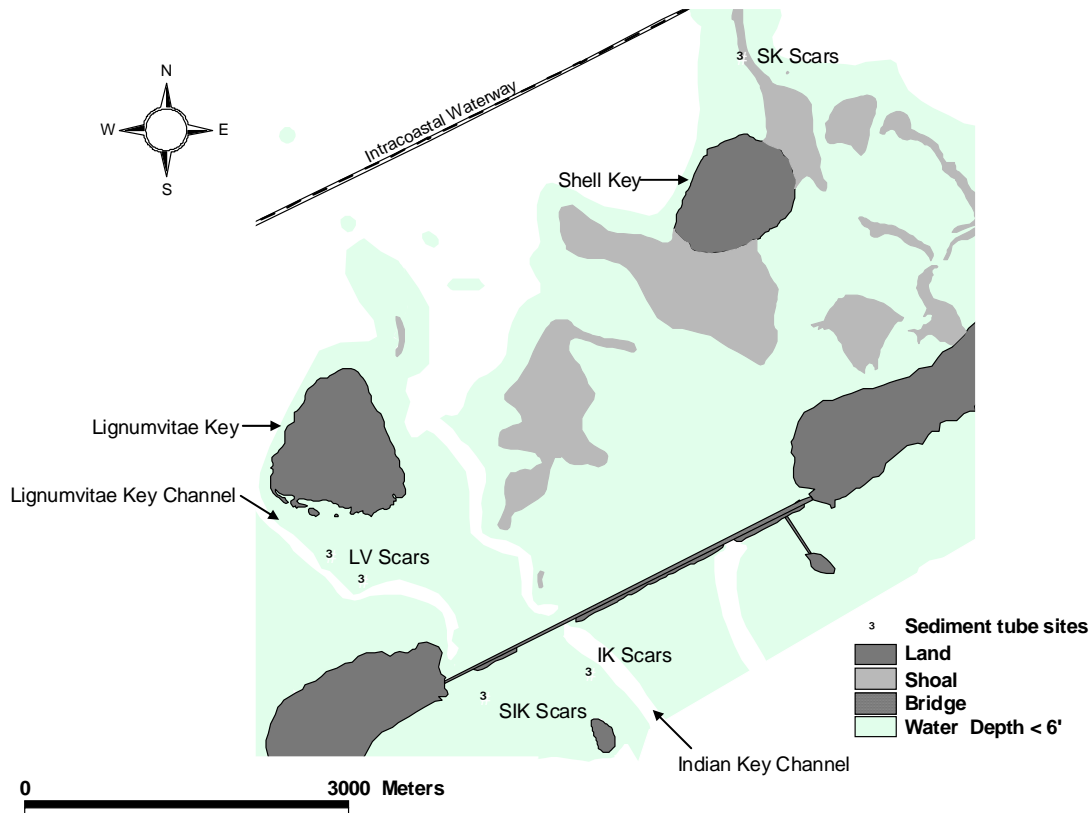
Figure 5. Lignumvitae Key Management Area. Sixteen scars were chosen in four areas of the management area.
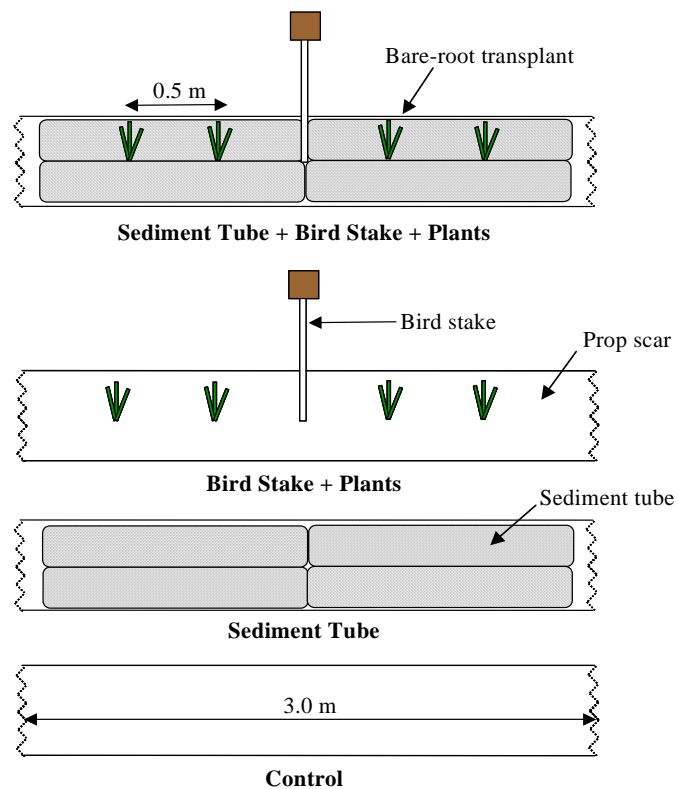
The LV area is adjacent to the well-traveled Lignumvitae Key Channel, but is on the bay side, protected by a bridge, and has little exposure to the easterly fetch. Sediment at the LV area is composed of fine carbonate mud. The SIK area is also on the ocean side, but on the more protected west side of the seagrass bank. SIK sediment is primarily fine carbonate mud. The SK area is on the bay side and is partially sheltered from easterly winds, but is exposed to northeast winds. The SK sediment type is coarse coral rubble. The scar locations were chosen to encompass a wide range of sediment types, wave exposures, and energy regimes. Four scars were treated in each area for a total of 16 replicate scars.

Experimental Design

Treatments included: 1) sediment tubes with bird stakes and transplants, 2) bird stakes with *Halodule wrightii* bare-root transplants, 3) sediment tubes only, and 4) controls (no treatment) (Fig. 6). Replicate propeller scars were 30-50 m long, approximately 40 cm wide and 15-20 cm deep. Distance between replicate scars ranged from < 10 to > 6,000 m. In each scar, four treatments were randomly assigned to 3 m sections separated by 3 m sections of untreated scar. Thus each scar contained four experimental units: 1) a 3 m sediment tube unit, 2) a 3 m bird stake + planting unit, 3) a 3 m sediment tube + bird stake + planting unit, and 4) a 3 m control unit. This was repeated in each replicate scar, for a total of 16 replicates for each treatment.

Sediment tubes were filled by hand, using a funnel and a shovel. The sediment fill was composed of native crushed carbonate screening sand. Sediment grain size ranged from 0.063 to greater than 0.85 mm, with approximately 45% of the sediment particles $\geq$ 0.85 mm in diameter. Approximately 5% of the sediment was very fine silt. Filled tubes were loaded onto a shallow-draft vessel and motored out to deployment sites. At the sites, each tube was lowered into the water near a propeller scar and then maneuvered into place (Fig. 7). Each sediment tube treatment required four tubes to complete the tube treatment (see Fig. 6).

Figure 6. Experimental design. One of each treatment was deployed into each replicate prop scar.

Bird stakes were created by mounting blocks of pressure-treated lumber (approximately 10 cm x 9 cm x 4 cm thick) onto 3 m lengths of 2 cm PVC (1/2"). The bird stakes were driven into the substrate until the blocks were about 1-1.5 m above the substrate, so the blocks would be just above the water surface at mean high tide. A planting unit was composed of 3-5 runners of *Halodule wrightii*, each bearing at

least five short-shoots and one apical meristem. Bird stakes were placed in the center of the treatment, 1.5 m from either treatment end, and the planting units were placed at 50 and 100 cm intervals from the center bird stake (Fig. 6). When planting in a sediment tube, we used a dive knife to create a hole into which we inserted the planting unit, slitting about 5-10 cm of the fabric to allow horizontal rhizome growth into the tube. For "bird stake + plants" treatments, the planting units and bird stakes were spaced as above, and the planting units were inserted directly into the sediment.

Figure 7. A shallow draft vessel was maneuvered close to the propeller scar and the sediment tubes were lowered into place.

The experiment was deployed in June 2001 and monitored in September 2001, February 2002, August 2002, and May 2003. Surveys included visual assessment of seagrass and macroalgal cover within the scar and in the adjacent, undisturbed seagrass bed, measurement of scar width, and digital video transects along the entire length of each experimental unit. Cover was assessed using a Braun-Blanquet scale of 0 (no cover) to 5 (> 75% cover) (Fourqurean et al. 2001). The middle 2.5 m of each treatment was surveyed using five 50 cm x 35 cm quadrats placed end to end to assess contiguous sections of the treatment. Adjacent seagrass cover was assessed in a 50 cm x 50 cm quadrat placed perpendicular to the scar treatments at a distance of 1 m into the undisturbed seagrass. Two quadrats were assessed for each treatment, one on each side, for a total of eight adjacent quadrats per scar. The replicate quadrats were averaged to obtain one value for each treatment in each scar. Adjacent quadrats were treated in the same manner. In May 2003, in addition to Braun-Blanquet assessments, we also counted the number of *Halodule wrightii* short-shoots in each treatment. Because we used several quadrat sizes (50 cm x 50 cm,

35 cm x 50 cm, and 10 cm x 10 cm), all values were standardized to short-shoots per square meter for comparison between treatments and with values reported in the literature.

Initial scar width was recorded in several positions along the scar in June 2001. In September 2001 and August 2002, two treatment widths were measured, each 1 m from treatment ends, by laying a meter stick perpendicular to the treatment and measuring the width of unvegetated scar or treatment. Thus if seagrass began to grow into the scar from the injury margins, the width of the scar would decrease.

Data Analysis
Visual assessment data were compiled using linear regression. The recovery trajectory of three variables (*Thalassia testudinum* cover, *Halodule wrightii* cover, and total seagrass cover) in the adjacent seagrass bed and within each treatment and scar was plotted as a function of time. After satisfying assumptions of variance homogeneity and normal distribution of the data, the *T. testudinum* and total seagrass slopes generated by these regressions were used as new variables in a one-way analysis of variance testing the effect of treatment on scar recovery trajectory. Pair-wise comparisons were conducted among treatments using Tukey's studentized range tests. Transformation of *H. wrightii* slopes failed to resolve issues of non-normality and variance heterogeneity, so nonparametric Kruskal-Wallis tests were used to examine treatment effect on *H. wrightii* recovery trajectory and in paired treatment comparisons for recovery trajectory. A Kruskal-Wallis test was used to examine treatment effect on scar width, as well as to conduct pair-wise comparisons between treatments.

One-way analysis of variance was used to examine cover differences among treatments in May 2003, two years after deployment, for *Thalassia testudinum* and total seagrass. Differences in cover of *Halodule wrightii* in May 2003 were examined using Kruskal-Wallis tests due to data non-normality and variance heterogeneity. May 2003 *H. wrightii* shoot counts were natural log transformed to meet assumptions of normality and variance homogeneity and treatments were compared using one-way analysis of variance and a Tukey's studentized range test.

Results
A few bird stakes had to be replaced, but no other treatments were damaged during the study. Rhizophytic macroalgae quickly recruited to the sediment tubes (Fig. 8). Sediment tube fabric had begun to break down by September 2001, three months after deployment. By August 2002, only the seam portions of the sediment tubes were apparent and we did not find any evidence of fabric during the May 2003 survey. Despite the degradation of the fabric, most of the carbonate sand remained in the scars throughout the duration of the study. Recovery within scars was variable. Some scars reached total seagrass cover equal to the surrounding, undisturbed seagrass bed after two years, while other scars fared much worse and still had low cover values two years after treatment. The wide range of recovery rates caused very high variability about the recovery trajectories.

One-way analyses of variance revealed a significant effect of treatment on *Thalassia testudinum* cover and total seagrass cover (p < 0.0001 for both analyses, Table 1). Pair-wise comparisons showed that the only significant comparisons were between the adjacent, undisturbed seagrass bed and the treatments inside the scars (Fig. 9 and 10). There were no differences in recovery

rates of control, sediment tube, sediment tube + bird stake + planting units, and bird stake + planting units treatments for either *T. testudinum* or total seagrass cover.


Figure 8. Macroalgae and *Halodule wrightii* planting units in a sediment tube treatment in September 2001, three months after deployment.

Table 1. Analysis of variance and Kruskal-Wallis results for *Thalassia testudinum* (TT), total seagrass (TSG), and *Halodule wrightii* (HW) recovery trajectory analyses.

Dependent Variable	Independent variable	DF	F-value/Chi-Square value	P-value
TT	treatment	4	6.98	< 0.0001
TSG	treatment	4	9.99	< 0.0001
HW	treatment	4	21.82	0.0002

Kruskal-Wallis tests results for *Halodule wrightii* cover demonstrated a significant treatment effect on recovery trajectory (Fig. 11). Pair-wise comparisons revealed that the two treatments that included bird stakes showed higher recovery trajectories than the non-bird stake treatments, and the bird stake treatments were not significantly different from each other (Fig. 11). The significant differences resulted from the presence and continued growth of the *H. wrightii* planting units. Variability in cover was high in the bird stake treatments. There was a trend of increasing cover over time. Although mean *H. wrightii* cover never exceeded 5%, cover in some individual quadrats was greater than 75% (Braun-Blanquet value of 5) in surveys conducted in May 2003.
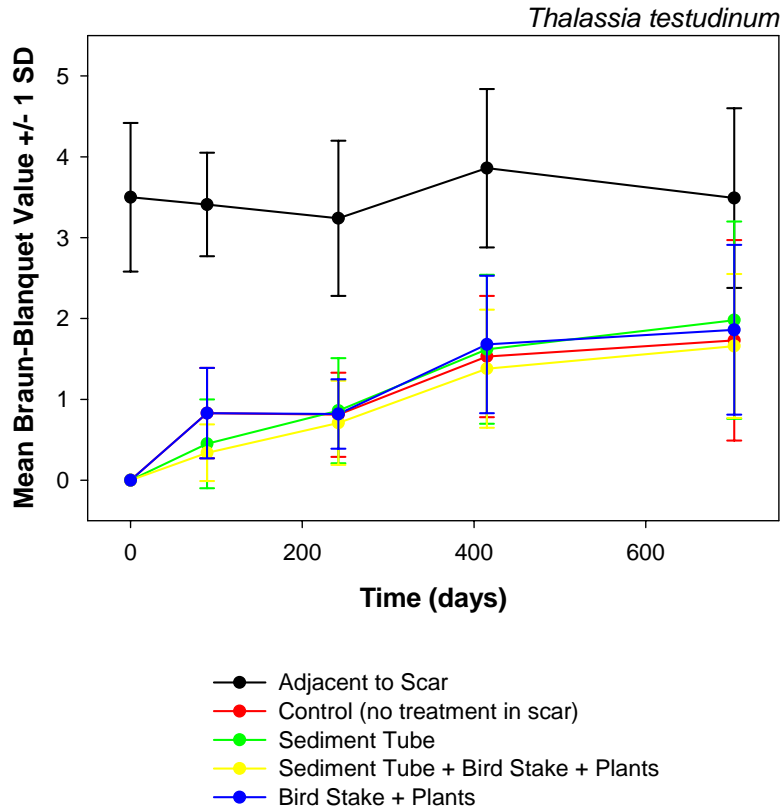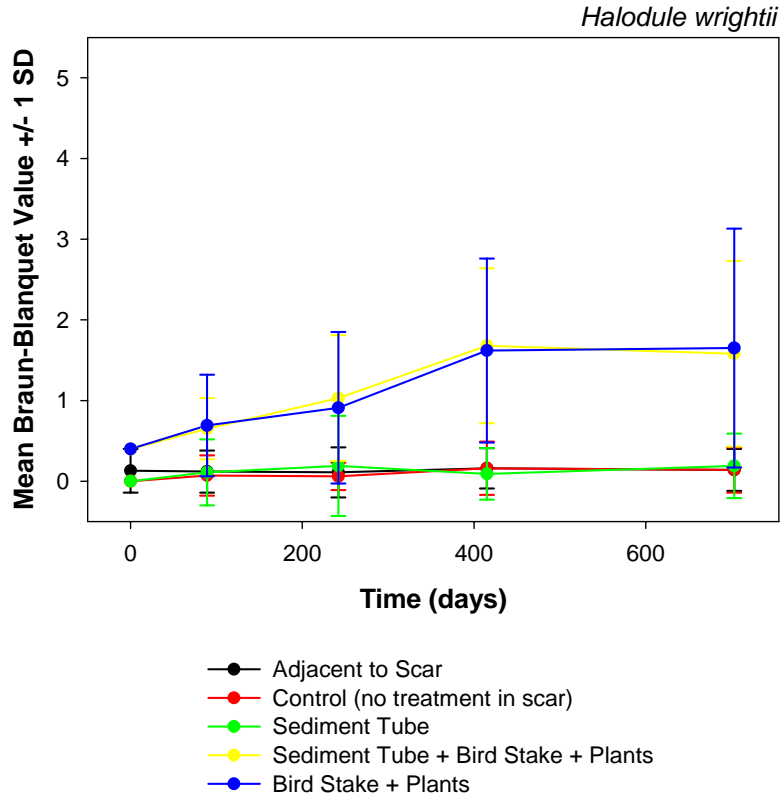
**Figure 9.** *Thalassia testudinum* recovery trajectories.
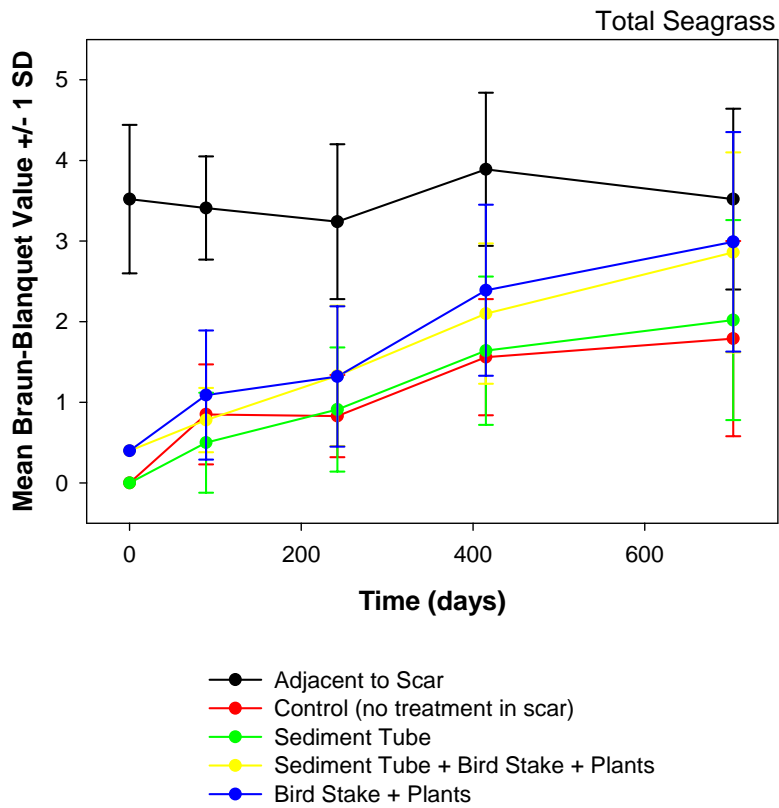
Figure 10. Total seagrass recovery trajectories.

Figure 11. *Halodule wrightii* recovery trajectories.

Initial scar width was 41.8 cm (sd = 12.02), and this declined to 27.0 cm (sd = 22.7) after two years. A Kruskal-Wallis comparison of propeller scar widths measured in treatments three months and 14 months after deployment revealed a significant effect of treatment on scar width (p = 0.024). Pair-wise comparisons demonstrated that scar widths were significantly smaller in the bird stake + plants treatment than control and sediment tube treatments. The two bird stake treatments were not significantly different from each other, and the control and sediment tube treatments were also not significantly different from each other (Fig. 12). These results demonstrate that although cover of seagrasses was low, there was some evidence that bird stake treatments caused increased growth of *Halodule wrightii* planting units within scars and *Thalassia testudinum* from injury margins, resulting in decreased scar width.

One-way analysis of variance conducted in May 2003, 23 months after deployment, on *Thalassia testudinum* cover revealed that there were no treatment differences within scars, but that adjacent, undisturbed *T. testudinum* cover was significantly higher than *T. testudinum* cover inside scars (p < 0.0001, Table 2). There also were significant differences in total seagrass cover in May 2003 (p = 0.0012, Table 2). Adjacent total seagrass cover was significantly greater than control or sediment tube total seagrass cover, but no other pair-wise comparisons were significant. Kruskal-Wallis analyses on *Halodule wrightii* cover for May 2003 demonstrated that bird stake treatments, which were not significantly different than each other, were significantly greater than adjacent, control and sediment tube only treatments (p < 0.0001, Table 2). Short-shoot counts of *H. wrightii* ranged from 4.0 m^{-2} in the adjacent, undisturbed seagrass bed to
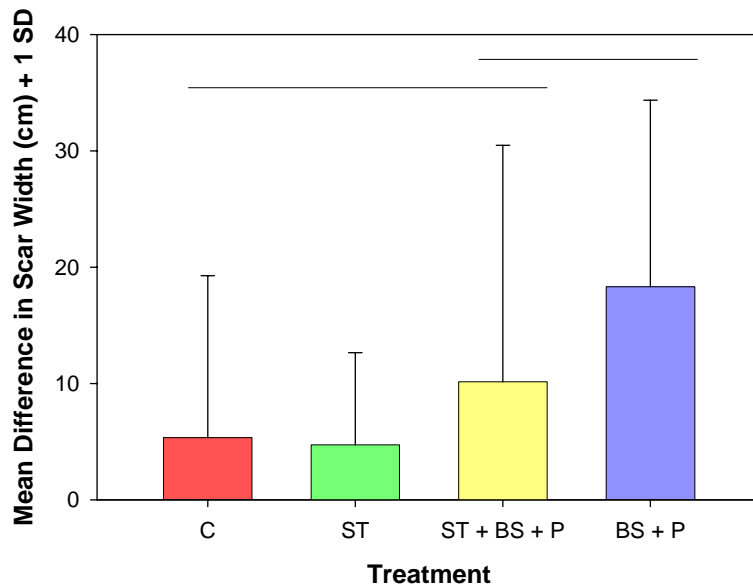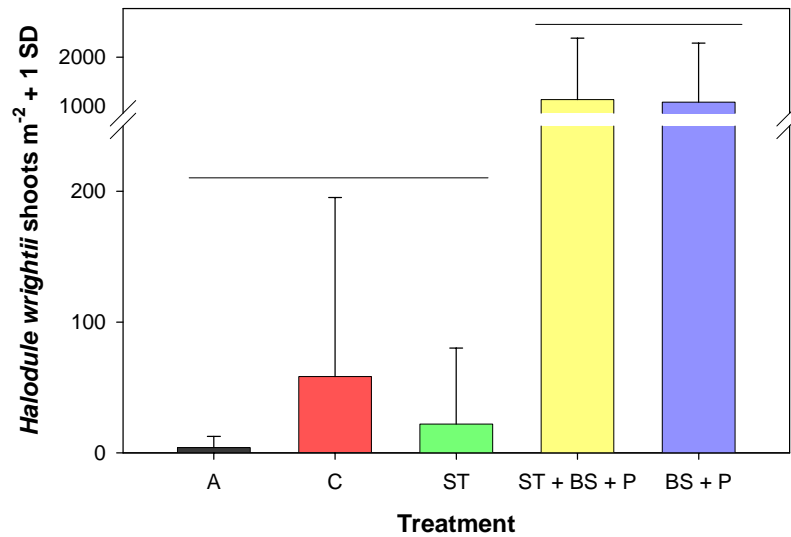
Figure 12. Mean change in scar width. C = control, ST = sediment tube, ST + BS + P = sediment tube + bird stake + plants, and BS + P = bird stake + plants. Lines over the bars indicate significant differences.

Table 2. Analysis of variance and Kruskal-Wallis results for May 2003 *Thalassia testudinum* (TT), total seagrass (TSG), and *Halodule wrightii* (HW) cover and *H. wrightii* short-shoot density (HWSS).

Dependent Variable	Independent variable	DF	F-value/Chi-Square value	P-value
TT	treatment	4	7.48	< 0.0001
TSG	treatment	4	5.06	0.0012
HW	treatment	4	32.64	< 0.0001
HWSS	treatment	4	19.58	< 0.0001

$1,130 \text{ m}^{-2}$ in the sediment tube + bird stake + planting unit treatment in May 2003 (Fig. 13). One-way analysis of variance for *H. wrightii* shoot density was significant (p < 0.0001, Table 2). Pair-wise comparisons of the shoot density data revealed that the two bird stake treatments had significantly higher *H. wrightii* shoot densities than the other three treatments, which were not significantly different from each other (Fig. 13).

Figure 13. May 2003 *Halodule wrightii* shoot densities. A = adjacent to scar, C = control, ST = sediment tube, ST + BS + P = sediment tube + bird stake + plants, and BS + P = bird stake + plants. Lines over the bars indicate significant differences.

Discussion

The high level of variability in seagrass recovery resulted in no significant improvement in seagrass recovery trajectory due to the sediment tube and bird stake treatments, alone or in conjunction. Our observations revealed that sediment tubes were an effective means of deploying fine sediments into propeller scars, but the presence of tubes did not enhance seagrass growth into the scars from the scar margins. The addition of fertilizer in the form of bird feces (Fig. 14), when coupled with sediment tubes, did not enhance total seagrass or *Thalassia testudinum* recovery trajectories. In May 2003, two years after deployment, *T. testudinum* cover inside the propeller scars still had not reached the levels of *T. testudinum* cover in the adjacent, undisturbed seagrass bed. While the results for total seagrass cover analysis on May 2003 data were somewhat different, the differences are attributable to the *Halodule wrightii* planting units coupled with bird stakes, which also influenced results of the *H. wrightii* May 2003 comparison. In all cases, the high degree of variability in seagrass cover resulted in no one experimental treatment significantly outperforming another. Conversely, presence of sediment tubes did not slow recovery, and we frequently observed seagrass shoots emerging from sediment tube treatments (Fig. 15). Also worth noting is that we used conditions in adjacent, undisturbed seagrass beds as a measure of what recovery in the scars should look like, yet those conditions varied from 25 to 75% cover. Our inability to more precisely quantify what comprises ideal recovery is due to the use of the Braun-Blanquet visual assessment technique, which has broad ranges of cover for each numerical category. This assessment technique may not have the necessary resolution to detect subtle differences, but it does detect larger differences and is a cost-effective and repeatable method of visual assessment (Fourqurean et al. 2001).

Figure 14. Cormorants roosting on bird stakes.

Figure 15. *Thalassia testudinum* short shoot (arrow) growing in a sediment tube treatment.

Scar width decreased from a mean of 41.8 cm to a mean of 27.0 cm two years later. There was some evidence that bird stake treatments may have enhanced seagrass growth enough to affect the width of scars, but not enough to significantly increase total seagrass cover within scars. Variability in scar widths was much greater in August 2002 than at the beginning of the study, suggesting that seagrass growth from the scar margins was occurring in a patchy manner, perhaps driven more by processes acting at the local level than by the treatments themselves.

Recovery estimates of propeller scars in healthy monospecific *Thalassia testudinum* beds range from 3.5 to 9.6 years (Durako et al. 1992; Dawes et al. 1997; Kenworthy et al. 2002). In a similar study conducted within the Lignumvitae Key State Botanical Preserve, Kenworthy et al. (2002) predicted that scars in *T. testudinum* beds would recover in 5.4 to 9.6 years based on data collected on 1-2 year old scars followed for 18 months. In fact, 1-2 years may be required for *T. testudinum* to begin to form new rhizome apical meristems and initiate growth at scar margins (Zieman 1976).

Zieman (1976) and Kenworthy et al. (2002) postulate that several factors may cause the slow recovery of *Thalassia testudinum* in propeller scars. First, the action of the propeller excavates sediment and severs rhizomes. If new sediment is deposited in the scar, it will for a time be relatively devoid of organic material and the sediment chemistry may be different than that of surrounding healthy seagrass beds (Zieman 1976; but see Dawes et al. 1997). In some cases, the energy and current regime is such that sediments will be further scoured from the original injury, thereby exacerbating sediment loss (Whitfield et al. 2002). Disruption of and damage to rhizomes requires that new apical meristems be formed (Zieman 1976; Dawes et al. 1997), a process that requires time in a slow-growing species such as *T. testudinum*. Once rhizomes are exposed at the margins of the scar, they may be less likely to grow due to light exposure and may not possess the architecture necessary to grow down into the remaining sediment (Marba et al. 1994; Duarte et al. 1997; Kenworthy et al. 2000).

Because of the clonal integration exhibited by *Thalassia testudinum*, changes in sediment chemistry probably did not significantly impact short-term recovery. New vegetative growth from scar margins is more likely to rely on nutrient resources translocated from the intact rhizome than resources absorbed by the actively growing root and rhizome tissue. Thus it is not surprising that the bird stake treatments did not result in higher rates of recovery for *T. testudinum* over the course of this study. In fact, given the slow rhizome elongation rates for *T. testudinum*, we might not see significant recovery after 23 months even under optimal conditions, as evidenced by control treatments that were significantly lower in cover than adjacent treatments in all scars.

There is evidence that sediment tubes do not prevent seagrass from growing into scars (Table 2). In fact, in most cases the sediment tube and sediment tube + bird stake combinations performed about the same (Fig. 9 and 10), although sediment-tube-only treatments did not always attain seagrass coverage equivalent to that of adjacent, undisturbed seagrass beds (Fig. 10). Sediment tubes did allow for the introduction of fine-grained sediment to fill scars, and in high energy environments this sediment would likely get washed away by water flow were it not encased in a sediment tube. Fine-grained sediments are typically found in mature, well developed seagrass beds and are a much better substrate for tropical seagrass growth than coarser sediments. Roots

and rhizomes are more easily anchored into finer sediments while the smaller grain size promotes the retention of organic matter and nutrients needed to support seagrass growth, rhizome expansion, and formation of new shoots. In addition, sediment tubes probably would prevent further erosion from occurring in propeller scars in storm events, although we did not test this hypothesis and no significant storm events occurred over the course of the study.

Halodule wrightii is a good choice for transplanting for a number of reasons. It is a smaller-bodied seagrass than *Thalassia testudinum*, which makes it easier to handle the planting units and concentrate apical meristems in those planting units. *Halodule wrightii* is also a faster-growing species that frequently and opportunistically colonizes disturbed areas (Kenworthy et al. 2002). The use of bird stakes and planting units has been shown to enhance growth of *H. wrightii* (Powell et al. 1989; Powell et al. 1991; Fourqurean et al. 1995; Kenworthy et al. 2000). The results of this experiment show that in some cases effects of the sterility of the sediment tube fill is offset by the addition of nutrients in the form of bird feces (Fig. 11 and 13). *Halodule wrightii* short-shoot counts in the bird stake treatments reached 1,076 and 1,130 m^{-2} in May 2003, nearly two years after deployment. These *H. wrightii* shoot densities are in the lower range of densities reported in another bird stake study in the Lignumvitae Key Management Area. Kenworthy et al. (2000) reported densities of 1,000-3,700 m^{-2} in planted bird stake treatments two years after deployment. The fact that *H. wrightii* densities were similar in treatments with and without sediment tubes, and similar to densities in a previous experiment, adds weight to the argument that sediment tubes do not prevent regrowth of seagrass into scars when coupled with bird stakes. Use of bird stakes allows for "compressed succession," in which the faster growing *H. wrightii* temporarily fills in unvegetated propeller scars, to be replaced eventually by the slower growing *T. testudinum*.

Summary and Recommendations
Based on the results of this study we conclude: 1) sediment tubes are a clean and efficient means of deploying fine grained sediments into excavations in seagrass beds; 2) *Halodule wrightii* can be transplanted into sediment tubes; 3) sediment tubes degrade fast enough to allow for growth of seagrass transplants; and 4) sediment tubes do not inhibit *Thalassia testudinum* growth or algal colonization. Given these results, we recommend that sediment tubes be tested for use in larger blowholes where lateral growth of seagrass into excavated injuries is very slow (Whitfield et al. 2002; Kenworthy et al. 2002; Fonseca et al. 2002). Some larger blowholes associated with vessel groundings take >5-10 years to recover and will be exposed to the destabilizing effects of severe storms and further degradation without some form of stabilization and rehabilitation. In restoration plans being developed for the NOAA Mini 312 Seagrass Damage Assessment and Restoration Program we presently recommend filling and stabilizing large blowhole injuries with carbonate pea rock (6-7 mm diameter). Although the larger sized pea rock will provide a stable substrate suitable for seagrass growth (Kenworthy et al. next chapter in this report), the addition of fine-grained sediments introduced by capping the pea rock with a layer(s) of sediment tubes may actually enhance the growth of seagrasses, especially when coupled with the method of compressed succession. Fine-grained sediment in the tubes will percolate into the upper layer of pea rock as the tube material decomposes, improving the quality of the unconsolidated substrate for seagrass growth. By installing bird stakes with sediment tubes and adding *H. wrightii* transplants we may be able to obtain sediment-stabilizing cover of the faster-growing seagrass

within two years, instead of waiting several years or even decades for seagrasses to grow in from the perimeter of a large injury.

Two previous studies (Kenworthy et al. 2000; Kenworthy et al. unpublished data) have documented the successful use of bird stakes in fine-grained sediments, but have never documented the use of bird stakes with pea rock alone. The next evaluation needed is a direct comparison between two restoration approaches to test the cost effectiveness of using sediment tubes: 1) fill replicated blowholes with pea rock, cap with sediment tubes, plant with *Halodule wrightii*, and add bird stakes; compare to; 2) fill replicated blowholes with pea rock, plant with *H. wrightii*, and add bird stakes. The second approach is presently what we propose in restoration plans where blowholes exceed an excavation depth of 20 cm. However, we have never compared pea rock alone with the sediment tubes, especially in high energy environments where regular wind turbulence and tides coupled with storm surge are such that blowholes are vulnerable to chronic and acute erosion (Whitfield et al. 2002). In these types of environments sediment tubes will restore the scars and blowholes to grade and diminish the area of eroded faces around the perimeter of the blowhole. Furthermore, by initially containing the fine-grained sediment in biodegradable fabric we minimize the potential for release of sediments and turbidity outside of the restoration site. Although untested, we predict that damage to seagrass beds in highly eroded areas would benefit from the use of sediment tubes, especially coupled with bird stakes and *H. wrightii (S. filiforme)* planting units. Sediment tubes may also be particularly useful in deeper water sites where deployment of any type of sediment with construction equipment is logistically difficult. Another possible use for sediment tubes recently suggested by Kevin Kirsch (NOAA Damage Assessment Center) is to deploy them in excavations filled with flocculent sediment with the intent to displace the flocculent material with firmer sediment more conducive to seagrass growth.

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