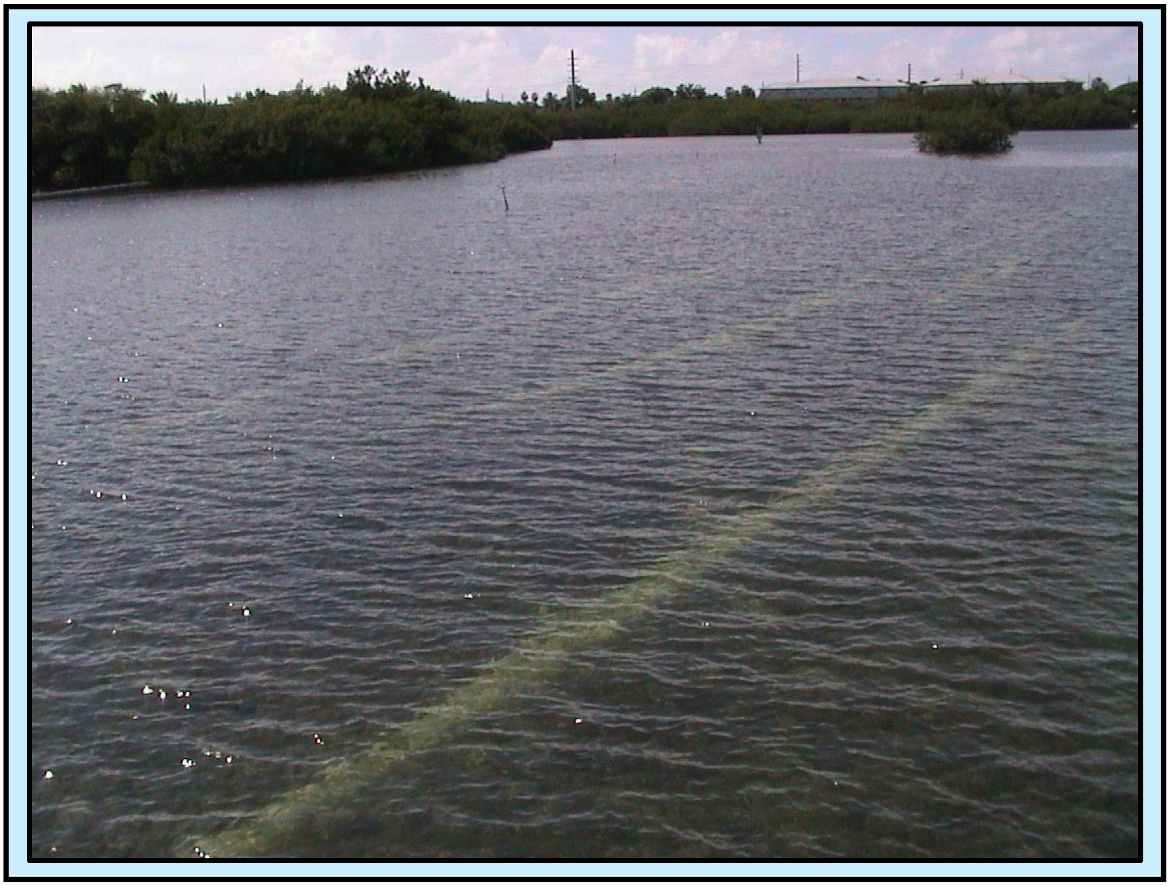
Developing Techniques to Enhance the Recovery Rates of Propeller Scars in Turtlegrass (*Thalassia testudinum)* Meadows

Final Report to USFWS



Margaret O. Hall[1], Manuel Merello[1], W. Judson Kenworthy[2], Donna Berns[1], Keri Ferenc[1], Jennifer Kunzelman[1], Farrah Hall[1], and Jitkya Hyniova[1]

[1]Florida Fish and Wildlife Conservation Commission
Florida Fish and Wildlife Research Institute
100 Eighth Ave. S.E.
St. Petersburg, Florida 33701

[2]Center for Coastal Fisheries and Habitat Research
NCCOS, NOS, NOAA
101 Pivers Island Road
Beaufort, North Carolina 28516

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FINAL REPORT

GRANT TITLE: **Developing Techniques to Enhance the Recovery Rates of Propeller Scars in Turtlegrass (*Thalassia testudinum)* Meadows.**

STATE: Florida **GRANT NUMBER:** R-4

PERIOD COVERED: 1 January 2002 through 31 December 2005

FINAL PROJECT COSTS:
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State Share: $ 48,636
Total Grant: $194,544

Background

Seagrasses form some of the world's most productive marine plant communities, and Florida's estuaries and nearshore coastal waters contain the nation's greatest seagrass resources (> 2.5 million acres; Sargent et al. 1995). Seagrasses provide food and/or shelter to numerous commercially and recreationally important fish and invertebrate species including spotted seatrout, tarpon, pink shrimp, and spiny lobster (Zieman and Zieman 1989). A variety of wading birds, as well as endangered species such as bald eagles, manatees, and sea turtles also depend, in part, on seagrass communities (Fonseca 1994). Clearly, declines in seagrass habitat could have serious consequences for Florida's economy and ecology.

During the past few decades, large declines in seagrass acreage have occurred worldwide, and Florida is no exception. Approximately 35% of the seagrasses historically present statewide have been lost, and declines are much higher in some systems (e.g. > 80% decline in Tampa Bay; Lewis et al. 1985). Although natural events such as severe storms or disease are sometimes responsible for damage to seagrass habitats, the vast majority of seagrass loss is related to human activities (Short and Wyllie-Escheveria 1996). Recent assessments of human impacts to seagrasses have focused principally on indirect causes of decline (e.g. reduction in light availability due to coastal pollution). However, human induced seagrass loss can also be the result of direct mechanical damage. For example, seagrasses in many locations are suffering extensive physical damage from watercraft, particularly from propeller scarring. Propellers damage seagrass beds by ripping up shoots and rhizomes. When the propeller penetrates the sediment, a long, narrow gap, or prop scar, is created in which seagrass density and biomass are severely reduced or completely removed. A typical prop scar created by a small vessel (< 6.5m in length) is approximately 0.25-0.50m wide and 0.1-0.5m deep. Larger vessels (> 6.5m in length), especially those with twin propellers, can produce substantially wider (0.5-1.5m) and deeper (0.25-0.75m) trenches (Fonseca et al. 1998).

Shallow water seagrasses are particularly susceptible to vessel damage because they occur at depths well within reach of boat propellers. The majority of seagrasses in Florida occur in water depths less than 2m, consequently, nearly all Florida seagrass beds show damage caused by boat propellers (Sargent et al. 1995). If boating activities are locally intense, propeller scarring may be a major source of habitat destruction. Sargent et al. (1995) reported that the greatest acreage of moderate and severe propeller scar damage occurred in regions with the densest populations and the most registered boats (e.g. Florida Keys, Biscayne Bay, Tampa Bay, Charlotte Harbor, northern Indian River Lagoon). As Florida's population increases, the problem of propeller scarring in seagrass beds is likely to get worse.

Recovery and regrowth of seagrasses from propeller damage can take many years (Zieman 1976, Durako et al. 1992, Dawes et al. 1997). The actual recovery time is influenced by such factors as the physical conditions at the site (e.g. hydrodynamic regime, sediment composition, water clarity) and the amount of seagrass damage. Once a propeller scar is created, wave action or fast moving currents can lead to erosion within the scar, resulting in scouring and deepening of the disturbed area (Eleuterius 1987). Heavily scarred beds may also be prone to further damage or destruction by severe storms (Fonseca and Bell 1998). In addition, reduction in water clarity through resuspension of sediments destabilized by seagrass removal can lead to more extensive declines in cover (Preen et al. 1995).

Recovery rate also varies with the species of seagrass that is scarred. Although the apical meristem controls rhizome elongation, branching, and shoot production in all seagrasses, the rate and pattern of growth varies considerably among species. These growth differences among species substantially influence recovery time from propeller scarring. When a propeller severs a rhizome, the portion of the seagrass plant lacking an apical meristem cannot continue to grow until a new one is generated (Dawes et al. 1997). Shoalgrass (*Halodule wrightii*) can quickly produce new apical meristems (within days or weeks), and its rhizomes branch frequently. In contrast, turtlegrass (*Thalassia testudnium*) forms new apical meristems slowly (over months or sometimes years), and its rhizomes branch only rarely (Tomlinson 1974). Consequently, propeller scarring in turtlegrass beds usually results in long-term damage. The most heavily damaged seagrass beds in south Florida are dominated by turtlegrass (Kenworthy et al. 2000), thus there is a substantial need to develop techniques which can enhance the recovery of propeller scars in *Thalassia* meadows.

In response to wide-spread propeller scarring, resource agencies have made numerous attempts to minimize seagrass damage through management actions such as increased channel marking, establishing motorboat caution and exclusion zones, and implementing public education programs, but accidental propeller scarring and vessel groundings still occur at an alarming rate. Resource agencies must have reliable options for enhancing recovery rates of extensively scarred areas under their management. Preliminary efforts to enhance propeller scar recovery have met with varying degrees of success dependent on planting technique, substrate preparation, and fertilization regime. During the past three years, we have investigated a variety of chemical, biological, and physical techniques for enhancing the recovery rates of propeller scars in *Thalassia testudinum* meadows simulataneously in two separate experiments. Results of these two studies are presented in the following report.

EXPERIMENT 1: ***Using Chemical Amendments and Supplemental Planting to Accelerate Propeller Scar Recovery in Florida Turtlegrass (<u>Thalassia testudinum</u>) Meadows.***

INTRODUCTION

Propeller scarring is a large and chronic problem in Florida seagrass meadows. The habitat value of a seagrass bed is partially derived from its continuous nature. Extensive and repeated scarring breaks up continuous seagrass habitats, reducing the productivity of an area and changing the distribution of fish, shrimp, crabs and other organisms (Uhrin and Holmquist 2003). Prior research has shown that natural recovery of propeller scars in turtlegrass (*Thalassia testudinum*) beds is an extremely slow process. In this experiment, we have addressed recovery of propeller scars from which turtlegrass shoots and rhizomes have been removed, but where scar depth remained similar to the adjacent, undamaged meadow. Our goal was to accelerate the natural recolonization of turtlegrass scars via a combination of chemical (nutrient addition) and biological (supplemental planting) techniques.

METHODS

<u>Study Sites</u>: Tampa Bay and the Florida Keys (Figure 1) were chosen as the study locations because they are among the most extensively propeller-scar damaged areas in Florida. In addition, these locations vary significantly in climatic conditions, as well as in sediment type and nutrient conditions.

<u>Experimental Scar Selection</u>: Seagrass regrowth into propeller scars may be influenced by a variety of factors (e.g. scar age, scar depth and width, sediment type, hydrodynamic regime, and light availability). To minimize variation in scar characteristics and enhance our ability to detect differences among experimental treatments, we attempted to locate existing scars for the study based on the following criteria: 1) Scars occur in dense, visually healthy turtlegrass meadows, 2) Scars occur in similar water depths, 3) Scars are approximately 40 m in length (minimum) and 0.35 m in width, 4) Scar depth is equivalent to the depth of the adjacent, undamaged meadow, 5) Scars are of recent origin (no visible seagrass recolonization), and 6) Scars can be protected from additional damage during the study (e.g. they occur in areas with boating restrictions). Six existing scars meeting the study criteria were easily identified in the Lignumvitae Key Submerged Land Management Area in the Florida Keys, however, none of the areas we surveyed in Tampa Bay contained enough "replicate" scars to accommodate the experimental treatments. In a further effort to locate experimental scars, we conducted an aerial survey to identify promising areas. These potential study sites were visited by boat, but again, none of the locations contained enough scars that met the experimental criteria. Because we could not find a sufficient number of existing scars for the study, we requested permission from Pinellas County to create propeller scars in a turtlegrass meadow in western Tampa Bay. In January 2003, six replicate scars were manufactured with a 17' Boston Whaler powered by a 100 hp Evinrude outboard engine in a boater caution zone adjacent to Jackass Key (Figure 1). Scars were established in a dense, visually healthy turtlegrass meadow at similar water depths. Scars were approximately 40 m in length and 0.35 m in width, and sediment depth within scars was similar in depth to the adjacent, undamaged meadow.

Experimental Design: The techniques we employed to reduce recovery time fell into two categories: a) Supplementary Planting and b) Chemical Amendments.

a) Supplementary Planting

The ultimate goal of propeller scar restoration in turtlegrass meadows is for turtlegrass to recolonize the scarred area. However, it is also important to promote rapid seagrass coverage in the scar to prevent additional damage to the bed from erosion, and to provide food and shelter for seagrass associated fauna. *Thalassia testudinum* is the climax seagrass species in South Florida. In a sequence known as "compressed succession" (sensu Durako and Moffler 1984), faster growing shoalgrass, the pioneer seagrass species, is initially planted into propeller scars to stabilize the scar. Once the scar is stabilized by shoalgrass, natural recolonization of the scar by the surrounding, slower-growing *Thalassia* should be facilitated. Two planting treatments were included in this experiment: 1) No supplemental planting, and 2) Installation of bare-root shoalgrass (*Halodule wrightii*) units. Shoalgrass planting units were composed of hand-harvested material from local donor beds in Tampa Bay and in the Florida Keys. Planting units were assembled by attaching *Halodule* shoots with intact roots and rhizomes to U-shaped metal staples (see Fonseca, et al. 1988 for detailed description of unit assembly). Shoalgrass planting units were installed at 0.25 m intervals along the center of selected scar segments (9 planting units per 2 m segment).

Chemical Amendments

The second aspect of this study was to determine if nutrients and/or growth regulators can enhance the recovery of propeller scars in *Thalassia* meadows by accelerating the growth of *Halodule* transplanted into the scar, as well as accelerating recolonization by the undamaged seagrass directly adjacent to the scars. Several different types of chemical amendments were tested:

1) A balanced N-P, slow-release, water-soluble fertilizer (Harrell's, Inc. 14-14-14) was applied to propeller scars. Fertilizer pellets were placed into permeable bags (20 g fertilizer per bag) made from knee-high panty hose (Figure 2a). Bags were buried at the depth of the *Thalassia* rhizomes at 0.25 m intervals along both sides of the scar. Fertilizer bags were also inserted into the holes with seagrass planting units. A green plastic ribbon was attached to each bag that extended into the water column so the bags could be easily relocated and replaced when the fertilizer pellets became depleted (about every 3 - 4 months).
2) A proprietary nutrient formulation developed by a private company, Seagrass Recovery, Inc. (SRI, Ruskin, FL) to promote seagrass establishment was also tested. The SRI formula contains nitrogen, phosphorus, and a combination of plant growth hormones. The nutrient formula was injected into the sediment with a modified hand-held garden sprayer (Figure 2b) at 0.25 m intervals along both sides of the scar, and into the holes with the planting units. This treatment was reapplied approximately every two months.
3) Nutrient-rich excrement from seabirds roosting on stakes can stimulate the growth of surrounding seagrasses (Powell et al. 1989, Kenworthy et al. 2000). While roosting, the birds defecate into the water and sediments beneath the stakes, acting as a passive fertilizer delivery system. Bird stakes were constructed of PVC pipe capped with a

wooden block to provide a stable roosting platform approximately 0.25 m above the water surface at mean high tide (Figure 2c). Bird stakes were installed 0.5 m from each end of the selected 2 m treatment segments.

The various combinations of supplemental planting and chemical amendment treatments are illustrated in Table 1. Each scar was divided into 8, two-meter long experimental segments separated by two-meter long buffer zones between treatments (Figure 3). Beginning and ending positions of each segment were recorded with a Differential Global Positioning System (DGPS) accurate to ± 0.5 cm, and marked with permanent stakes. Each treatment combination was randomly assigned to one of the 8 experimental segments in each scar (i.e. all 6 scars included all 8 treatments, resulting in 6 replicates per treatment combination at each site). Experimental treatments were applied to the scars in Tampa Bay in February 2003, and to those in Lignumvitae Key in April 2003.

In the "compressed succession" restoration technique used here, nutrient addition is only applied temporarily (Kenworthy, et al. 2000). The goal is to accelerate the normal successional process by stimulating growth of the transplanted pioneer species, *Halodule wrightii*, thus creating more suitable conditions for climax species, *Thalassia testudinum*. The nutrient addition is removed when the desired cover of the colonizing species is attained. Previous research has also shown that species dominance shifted from turtlegrass to shoalgrass in mixed species beds in the Florida Keys when bird stakes remained in place for more than 2 –3 years (Powell, et al. 1991, Fourqurean, et a. 1995). For these reasons, all forms of nutrient addition were discontinued at Tampa Bay and Lignumvitae Key in October 2004, less than two years after the initial treatments.

Monitoring: Experimental scars were monitored every 3–4 months from April (Tampa Bay) or May (Florida Keys) 2003 to June 2005. Seagrass abundance was estimated using a non-destructive, visual technique – the Braun-Blanquet cover/abundance procedure (Braun-Blanquet 1965, Mueller Dombois and Ellenberg 1974, Fourqurean et al. 2001). Seagrass species occurring within a 0.25m x 0.25m quadrat were assigned a cover/abundance value according to the following scale: 0 = absent; 0.1 = solitary, with small cover; 0.5 = few, with small cover, 1 = numerous, but < 5% cover; 2 = any number, with 5-25% cover, 3 = any number, with 26-50% cover; 4 = any number, with 51-75% cover; 5 = any number, with 76-100% cover. Turtlegrass and shoalgrass abundances were estimated in eight quadrats placed in succession from the beginning to the end of each 2 m treatment segment (i.e. the entire segment was surveyed). Braun-Blanquet abundance was also determined in 4 quads placed in the undamaged seagrass meadow adjacent to each treatment segment (2 quads on each side of the segment).

Data Analysis: Differences in shoalgrass and turtlegrass abundances among sampling dates and chemical treatment types were determined by Two-Way Analysis of Variance, followed by the Tukey's Pairwise Multiple Comparisons procedure. Separate analyses were conducted for each seagrass species at each location for planted and unplanted treatments. Because turtlegrass response to nutrient addition did not vary between planted and unplanted treatments at either location, the data for turtlegrass were combined. Prior to analyses, data were checked to ensure they met the assumptions for normality and homogenity of variance. There were no significant interactions between sampling date and treatment type, thus only data regarding treatment type are presented.

Differences in shoalgrass and turtlegrass abundances among planting and chemical treatment types including values in the adjacent meadow at the end of the study were also determined by Two-Way Analysis of Variance, followed by Tukey's Pairwise Multiple Comparisons procedure to determine where significant differences occurred. Separate analyses were conducted for each seagrass species at each location.

RESULTS

Tampa Bay: *Halodule* abundance was generally higher in planted segments than in unplanted segments within particular chemical amendment treatments throughout the study, however, mean shoalgrass abundance varied substantially among planted segments treated with different chemical amendments (Figure 4 a and b). Shoalgrass was more abundant in planted segments treated with the SRI formula or Slow Release Fertilizer than in No Chemical segments, and was significantly lower in the Bird Stake segments than in all other planted segment types ($p < 0.001$). Shoalgrass abundance in unplanted treatments was not stimulated by chemical amendment, was significantly higher in the No Chemical segments than in any of the nutrient addition treatments ($p < 0.001$). *Halodule* abundance was significantly higher in the planted scar segments than in the adjacent, undamaged meadow at the end of the study ($p < 0.001$; Figure 4 c). Interestingly, shoalgrass abundance was also higher in the unplanted, No Chemical treatment than in the adjacent seagrass meadow on the final sampling date.

Thalassia abundance within scars increased steadily throughout the study, but was significantly lower ($p < 0.001$) than in the adjacent meadow at end of study (Figure 5 a and b). Turtlegrass growth was not stimulated by nutrient addition, and was actually significantly lower in the Bird Stake segments than in all other treatment types ($p < 0.001$). Although turtlegrass abundance was lower in the scars than in the adjacent meadow at the end of the study, most scar segments were covered with seagrass (combined turtlegrass and shoalgrass).

Florida Keys: Shoalgrass abundances were higher in planted vs. unplanted segments throughout the study in the No Chemical and SRI formula treatment segments. However, within a few months there were no measurable differences in shoalgrass cover among planted and unplanted segments treated with either Slow Release Fertilizer or with Bird Stakes (Figure 6 a and b). Shoalgrass abundance increased in all treatments during the study, but densities were substantially higher in Slow Release Fertilizer and Bird Stake segments than in the No Chemical and SRI segments ($p < 0.001$). As in Tampa Bay, scar edges could still be discerned the end of the study, but they were completely filled with shoalgrass (Figure 7) . *Halodule* densities in both planted and unplanted scar segments were significantly higher than in the ambient seagrass meadow at the end of the study, except in the unplanted No Chemical segments ($p = 0.03$; Figure 6 c). There was a gradual increase in the *Halodule* density adjacent to the scars during the study, especially in the Bird Stake and Slow Release Fertilizer segments. Shoalgrass reached much higher densities in Florida Keys scars than in Tampa Bay scars.

Thalassia abundance increased in the Lignumvitae Key scars slowly throughout the study, and recolonization rates were not affected by planting shoalgrass (Figure 8 a and b). As in Tampa Bay, the effects of nutrient addition on turtlegrass abundance were limited. The only treatment where turtlegrass abundance was greater than in the No Chemical control was in SRI segments ($p < 0.001$). In contrast to the results for shoalgrass, the abundance of turtlegrass was substantially higher in the Tampa Bay scars than in the Lignumvitae Key scars at the end of the study.

DISCUSSION

Results of this study suggest that propeller scar recovery in Florida turtlegrass meadows can be accelerated using a combination of chemical (nutrient addition) and biological (supplemental planting with *Halodule wrightii*) techniques. However, the effects of particular treatments were seagrass species specific, and varied substantially between Tampa Bay and the Florida Keys.

Supplemental planting significantly accelerated *Halodule wrightii* growth within experimental propeller scars in Tampa Bay. Shoalgrass abundance was higher in the planted than unplanted scar segments throughout the study regardless of chemical treatment, with the exception of the unplanted No Chemical segments. At the end of the study, shoalgrass abundance in planted segments was also significantly higher than in the adjacent seagrass meadow, again with the exception of the unplanted No Chemical segments. Although shoalgrass abundance was low, scars in Tampa Bay were filled with at least sparse *Halodule* cover by the end of the study.

Planting *Halodule* in propeller scars in the Florida Keys significantly accelerated cover in the No Chemical and SRI segments; however, cover in these segments was substantially below that observed in all Slow Release Fertilizer and Bird Stake segments. Differences in shoalgrass abundance among planted and unplanted segments in the latter two chemical treatments were not apparent following the first few months of the experiment. Shoalgrass in the unplanted segments at Lignumvitae Key may have come from nearby planted segments, or from the adjacent seagrass meadows. Whatever the source, shoalgrass in segments treated with Slow Release Fertilizer or Bird Stakes grew rapidly. There was also a gradual increase in the ambient *Halodule* density adjacent to Slow Release Fertilizer and Bird Stake segments during the study. This may have been due to shoalgrass growing from the scars into the adjacent meadow, or perhaps the chemical treatment effects reached outside the segment boundaries, stimulating shoalgrass growth in the adjacent meadow. Growth of shoalgrass out of planted scars and into the adjacent meadow was observed in a previous study (Kenworthy et al., 2000). By study end, shoalgrass density within scars at Lignumvitae Key was significantly higher than in the adjacent seagrass meadow, and scars were covered with seagrass. *Halodule* abundance reached much higher levels within scars at Lignumvitae Key than in Tampa Bay, most likely due to inherent differences in environmental characteristics among these sites.

Although the addition of slow-release fertilizer stimulated shoalgrass growth in both Tampa Bay and the Florida Keys, the effects of the other nutrient addition treatments varied substantially between locations. The SRI formula positively affected shoalgrass growth in Tampa Bay, but had little influence in Florida Keys, which was consistent in part with the results of a previous study in the Florida Keys (Kenworthy et al., 2000). Most noteworthy were the differential effects of bird excrement among locations with respect to stimulating *Halodule*. Bird stakes substantially promoted shoalgrass growth in the Florida Keys, which was also consistent with the previous findings of Kenworthy et al. (2000). In contrast, they appeared to have a detrimental effect on shoalgrass growth in Tampa Bay. Shoalgrass abundance was lower in the bird stake treatments than in the other amendments and the control, indicating that bird guano was actually inhibitory to shoalgrass growth. The suggestion that it was inhibitory may be supported by the fact that shoalgrass abundance began to increase in abundance once the bird stakes were removed. These results are consistent with the observation of Powell et al. (1991), that seagrass cover was lower immediately adjacent to bird islands, possibly due to over enrichment. There is some indication that all chemical amendments were inhibitory to natural shoalgrass colonization in TB scars since the control segments in unplanted treatments were always highest.

In contrast to those results for shoalgrass, nutrient addition had very little effect on *Thalassia* growth in our study. The abundance of *Thalassia* was positively influenced by only one of the nutrient addition treatments, the SRI formula, and only in the Florida Keys. These results differed from the short term increase in *Thalassia* growth achieved with bird stakes observed in a previous study (Kenworthy et al, 2000). In fact, bird stakes appeared to negatively affect the growth of *Thalassia* in Tampa Bay. It has been suggested that *Thalassia's* ability to translocate nutrients clonally may lessen the influence of sediment nutrient additions on new vegetative growth (Kenworthy et al., 2000).

Variations in response to different chemical treatments were most likely related to differences in sediment type and associated geochemical properties between the sites. The Florida Keys are an oligotrophic system and the carbonate sediments there usually cause seagrass growth to be phosphorus limited. Since bird excrement is rich in phosphorus it is not surprising that shoalgrass growth responded positively to bird stakes in the Florida Keys. Conversely, Tampa Bay sediments tend to be nitrogen limited, if they are nutrient limited at all. Therefore, it was not surprising that nutrient additions had less of an affect on seagrass growth in Tampa Bay. Nutrient addition will only help if the added nutrients are limiting, and they are applied in a form that seagrasses can use.

The goal in both of these systems was to eventually recover the propeller scarred seagrass beds to their previous state, dominated by *Thalassia* cover. Planting and chemical treatments did little to accelerate *Thalassia* regrowth into propellers scars during the course of this study. These results were not unexpected because *Thalassia* is such a slow growing species. Although we did not achieve complete succession from shoalgrass to turtlegrass in the time frame of the present study, there were steady increases of *Thalassia* in the scars, especially in Tampa Bay. So, although overall turtlegrass density remained lower than in the adjacent meadow, the trend of increasing cover in the injured areas indicated that they are well on their way to recovery.

By successfully accelerating the cover of *Halodule*, and increased scar cover, scars became more stable. The sediment binding network of roots and rhizomes and the ability of leaves to diminish particle momentum and baffle current and wave energy enable seagrasses to trap and retain sediments as well as organic matter within the meadows (Fonseca and Fisher 1986). The presence of seagrass cover in the scar, regardless of actual species present, is critically important for faunal communities as well. Thus, it appears that facilitating the faster-growing shoalgrass within the scar initially is a critical first step in the "compressed succession" process, eventually leading to *Thalassia* recolonization over the long-run.

In this study we took a "shotgun" approach to see if we could stimulate growth with a variety of treatment combinations that have showed some promise in past studies. In summary, we found that nutrient additions are not "one size fits all" with respect to both location and seagrass species. Clearly, future studies should be conducted to pinpoint the precise mechanisms behind the patterns observed here. The nutrient conditions in sediments must be characterized prior to future studies. Nutrient additions should be supplied at biologically relevant treatments and levels over time. It will also be important to determine differential species responses, with particular attention to conditions in the ambient seagrass meadow. The ambient *Thalassia* meadow monitored in the Florida Keys gradually decreased in density over time during the course of this study. Reasons for this decline are unknown and of great concern as this was once a very dense *Thalassia* population.

The small differences observed in the recovery of treatment scars versus the control scars in Tampa Bay leads to a critical conclusion. At a time when resources for ecological restoration efforts are severely limited, it is important to know when proactive restoration techniques will be beneficial and cost-effective, versus when they may be unnecessary. Accelerating cover will likely be of critical importance in an erosional setting. There are many examples of propeller scars that increase in width and depth, especially in high energy carbonate banks in Florida Keys. It appears that recovery will be accelerated by some of the techniques described here, and may in fact make recovery possible without other manipulations (see results of Experiment 2).

LIST OF TABLES AND FIGURES

Figure 1

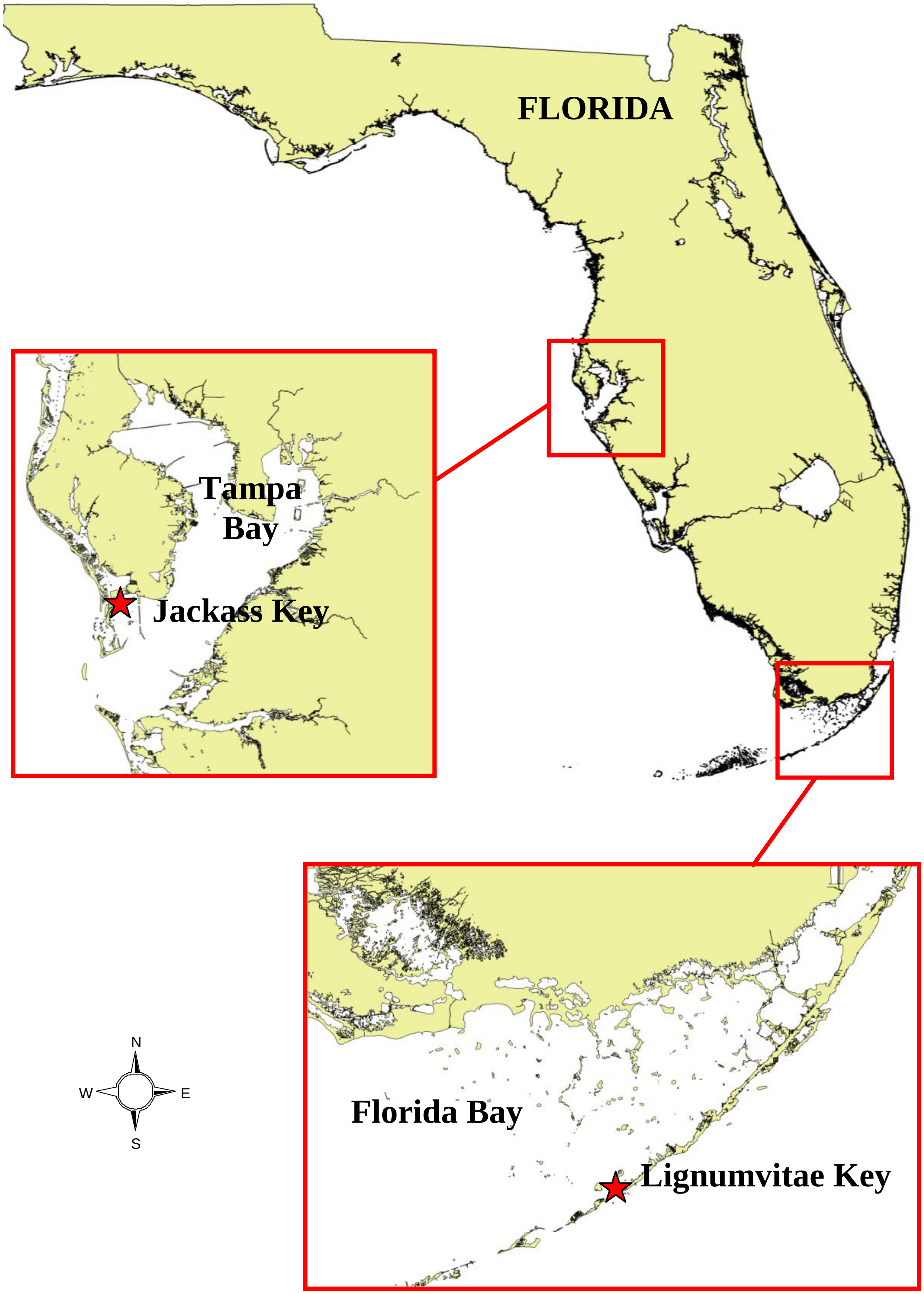

FLORIDA
Tampa Bay
Jackass Key
Florida Bay
Lignumvitae Key
N
W
E
S

Figure 2

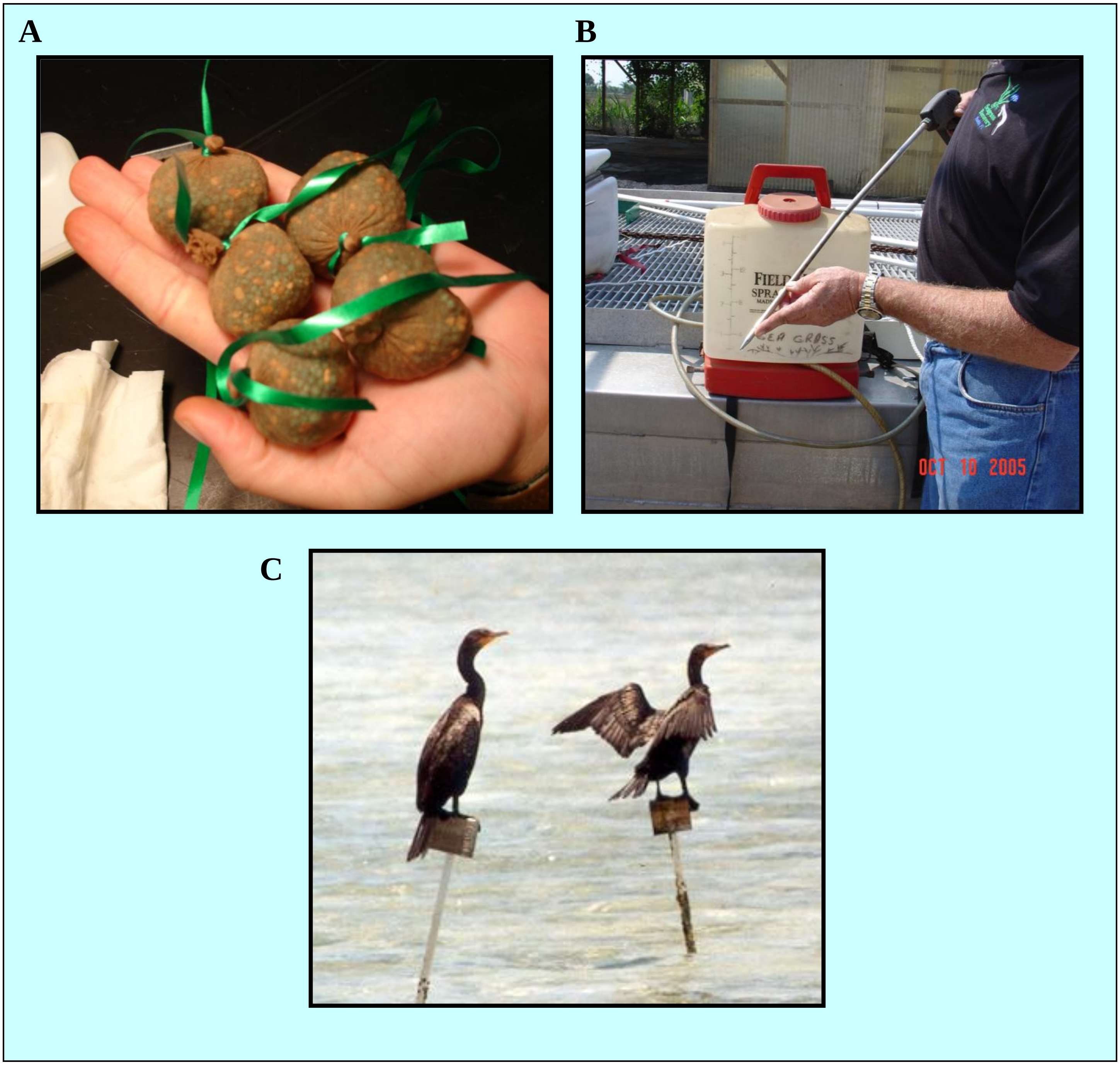


Table 1

TREATMENT TYPE	No Plants	Bare-root Halodule wrightii
No Chemical Addition	6 replicates	6 replicates
Slow-Release Fertilizer	6 replicates	6 replicates
SRI Formula	6 replicates	6 replicates
Bird Stakes	6 replicates	6 replicates

Figure 3

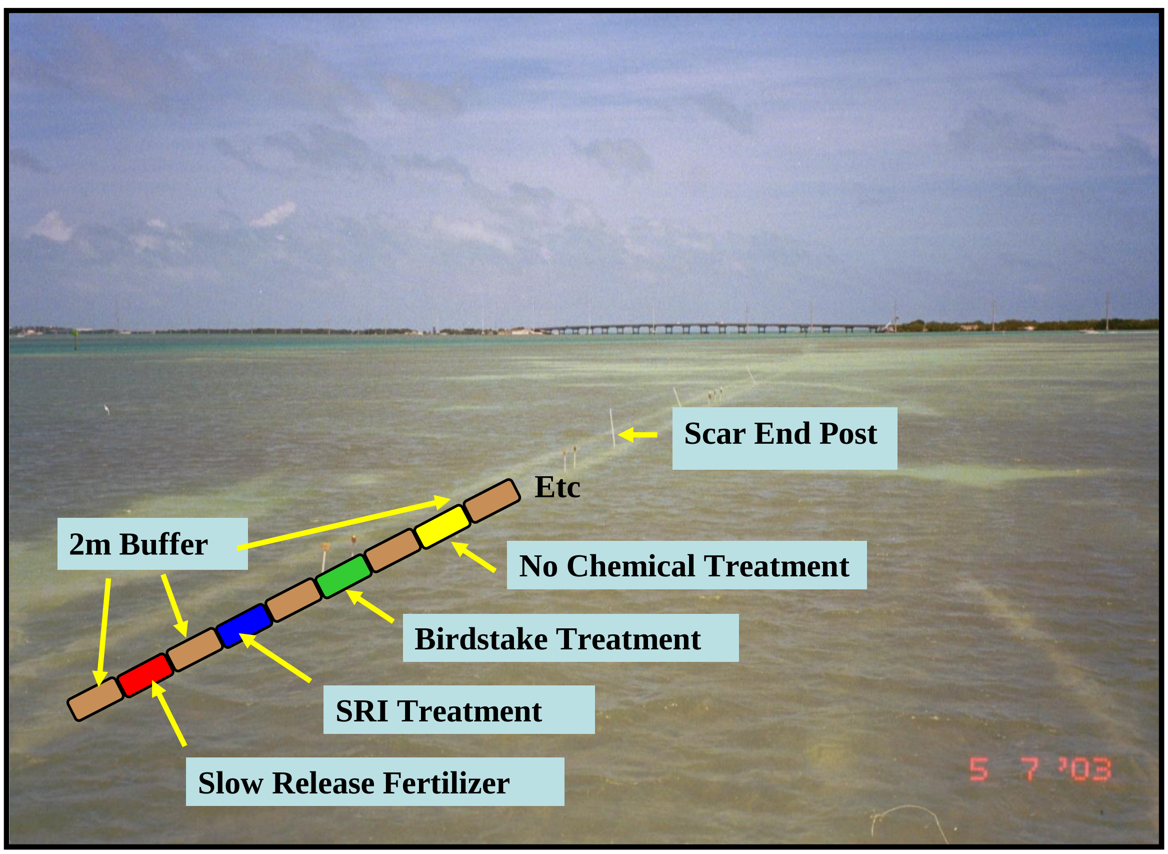
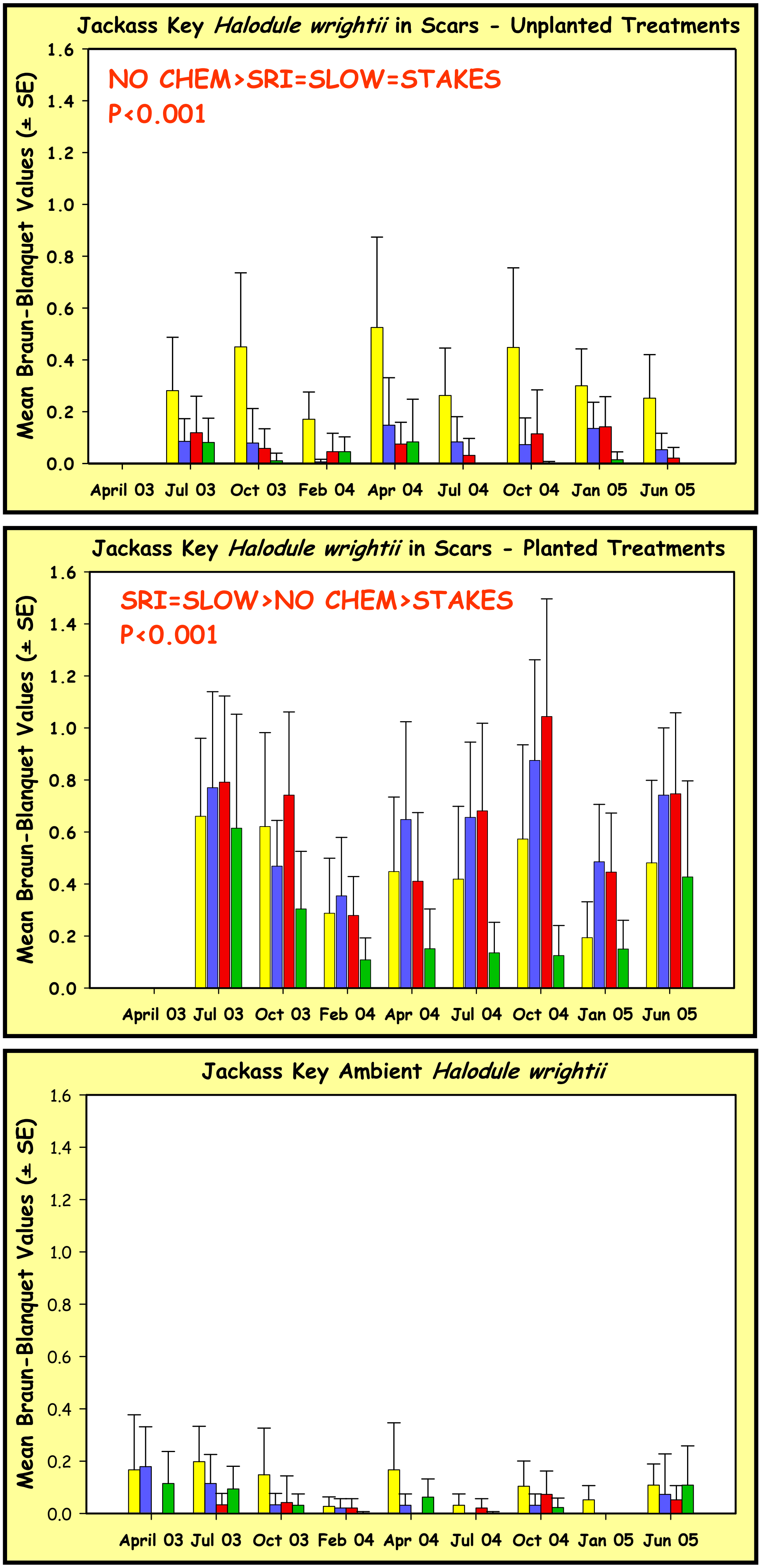


Figure 4

A

B

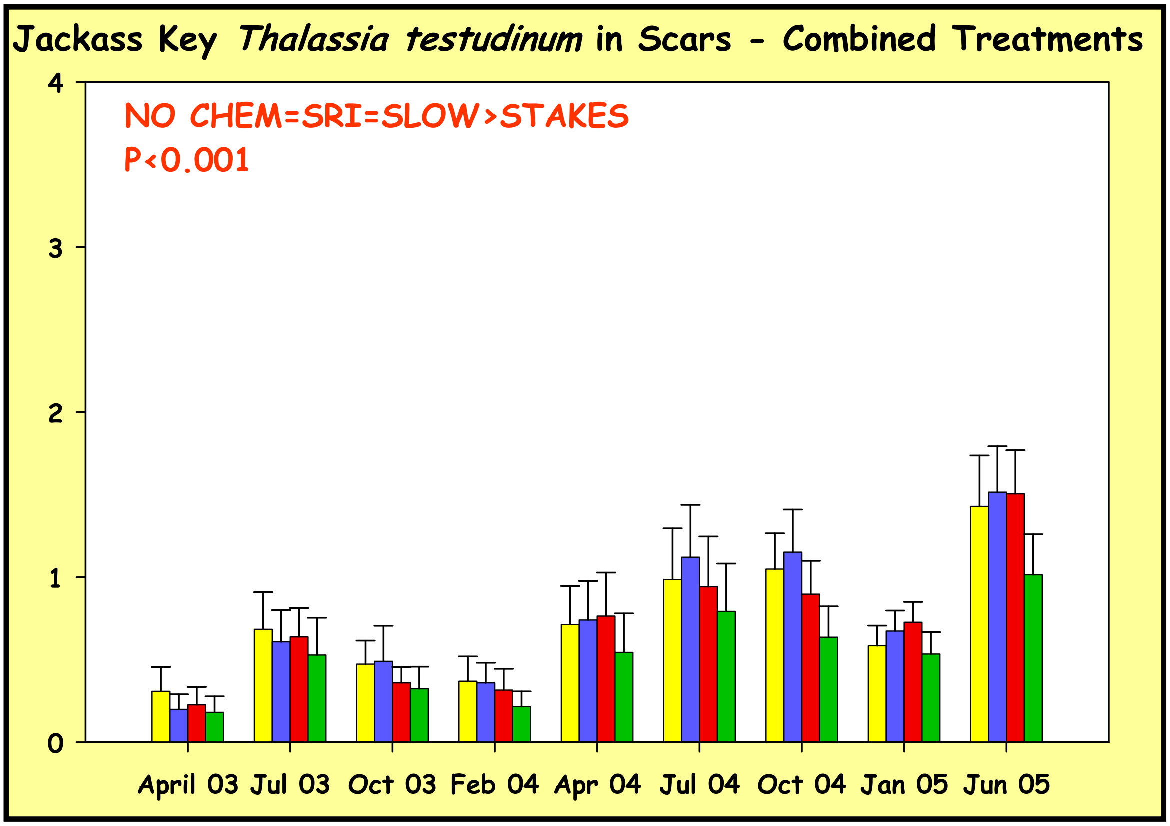
C



Jackass Key *Halodule wrightii* in Scars - Unplanted Treatments
NO CHEM>SRI=SLOW=STAKES
P<0.001
Mean Braun-Blanquet Values (± SE)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
April 03 Jul 03 Oct 03 Feb 04 Apr 04 Jul 04 Oct 04 Jan 05 Jun 05
Jackass Key *Halodule wrightii* in Scars - Planted Treatments
SRI=SLOW>NO CHEM>STAKES
P<0.001
Mean Braun-Blanquet Values (± SE)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
April 03 Jul 03 Oct 03 Feb 04 Apr 04 Jul 04 Oct 04 Jan 05 Jun 05
Jackass Key Ambient *Halodule wrightii*
Mean Braun-Blanquet Values (± SE)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
April 03 Jul 03 Oct 03 Feb 04 Apr 04 Jul 04 Oct 04 Jan 05 Jun 05

Figure 5

A


Jackass Key *Thalassia testudinum* in Scars - Combined Treatments
NO CHEM=SRI=SLOW>STAKES
P<0.001
4
3
2
1
0
April 03 Jul 03 Oct 03 Feb 04 Apr 04 Jul 04 Oct 04 Jan 05 Jun 05

B

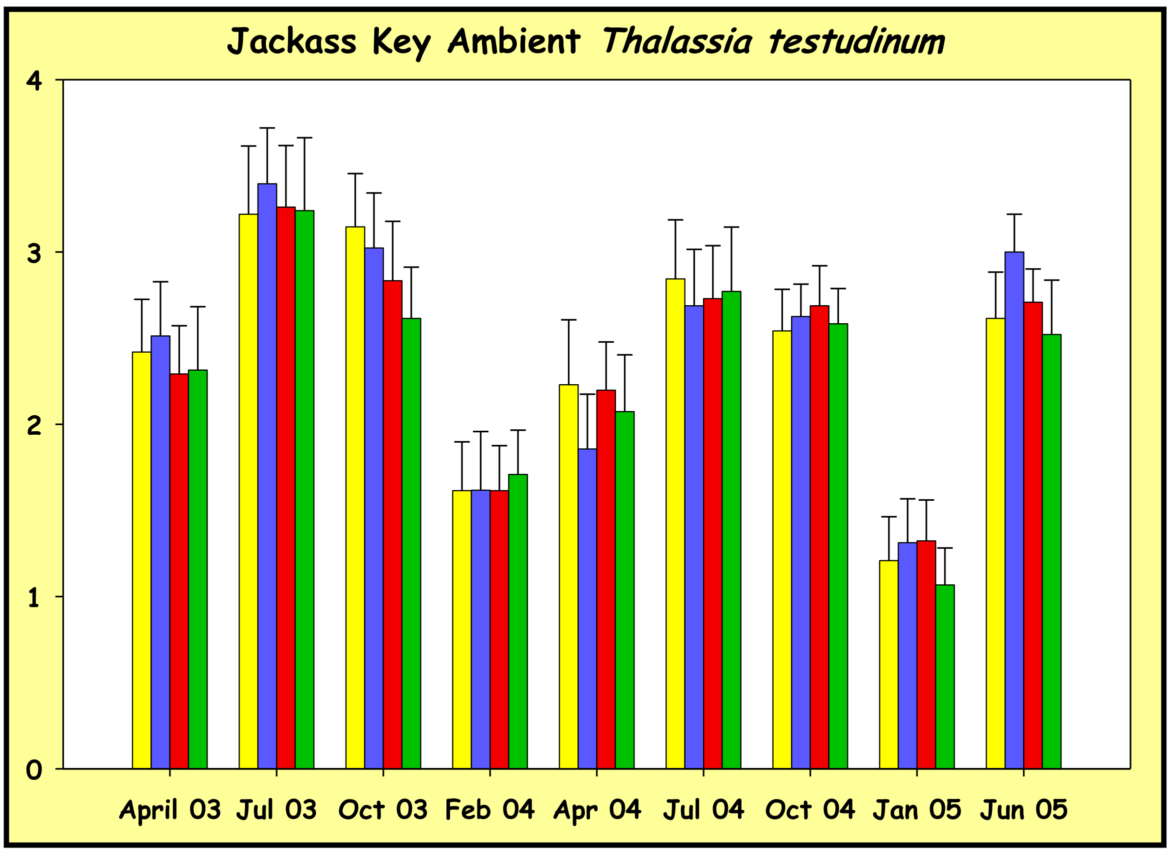

Jackass Key Ambient *Thalassia testudinum*
4
3
2
1
0
April 03 Jul 03 Oct 03 Feb 04 Apr 04 Jul 04 Oct 04 Jan 05 Jun 05

Figure 6

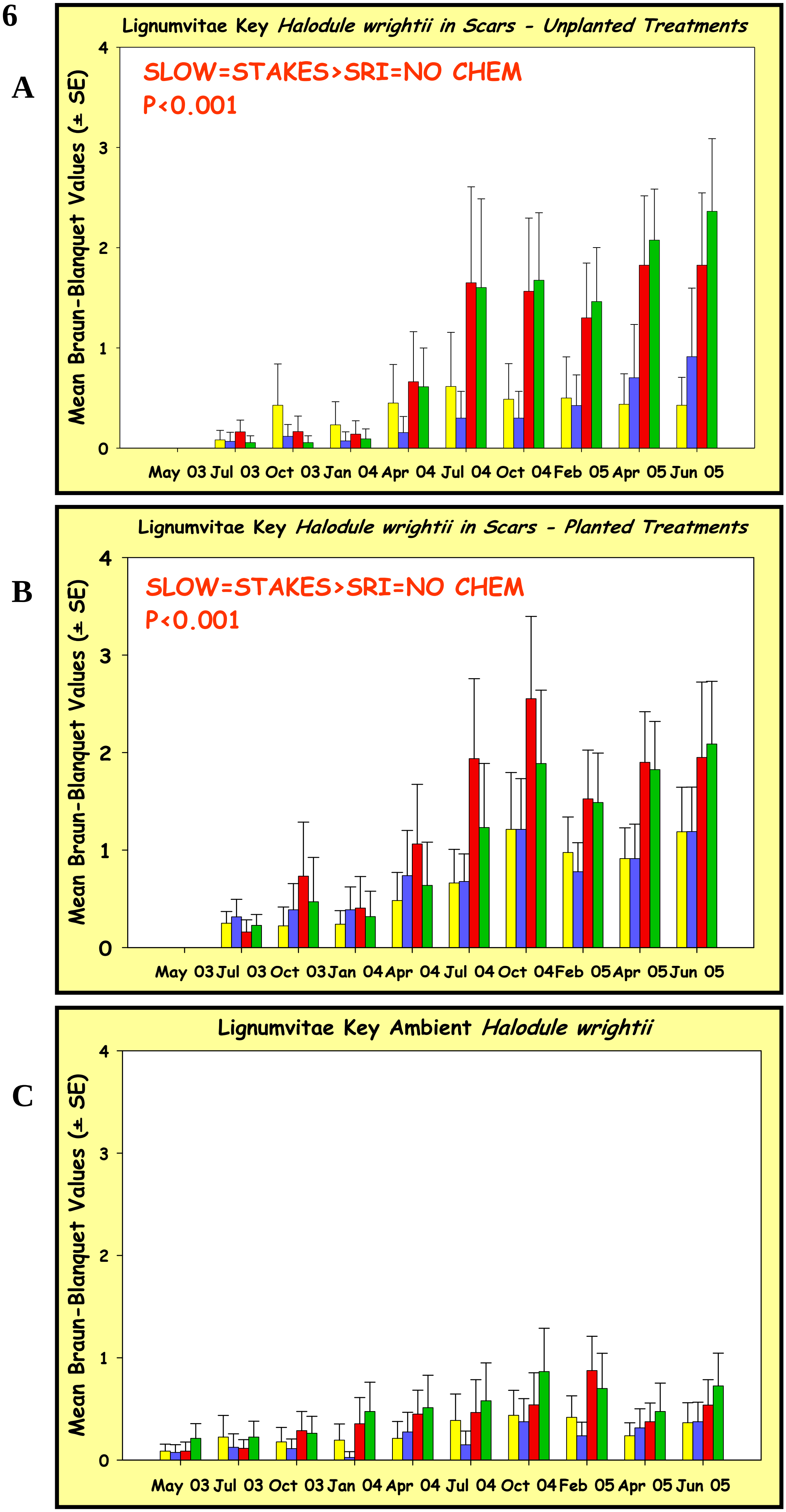

A
Lignumvitae Key Halodule wrightii in Scars - Unplanted Treatments
SLOW=STAKES>SRI=NO CHEM
P<0.001
Mean Braun-Blanquet Values (± SE)
0
1
2
3
4
May 03
Jul 03
Oct 03
Jan 04
Apr 04
Jul 04
Oct 04
Feb 05
Apr 05
Jun 05
B
Lignumvitae Key Halodule wrightii in Scars - Planted Treatments
SLOW=STAKES>SRI=NO CHEM
P<0.001
Mean Braun-Blanquet Values (± SE)
0
1
2
3
4
May 03
Jul 03
Oct 03
Jan 04
Apr 04
Jul 04
Oct 04
Feb 05
Apr 05
Jun 05
C
Lignumvitae Key Ambient Halodule wrightii
Mean Braun-Blanquet Values (± SE)
0
1
2
3
4
May 03
Jul 03
Oct 03
Jan 04
Apr 04
Jul 04
Oct 04
Feb 05
Apr 05
Jun 05

Figure 7

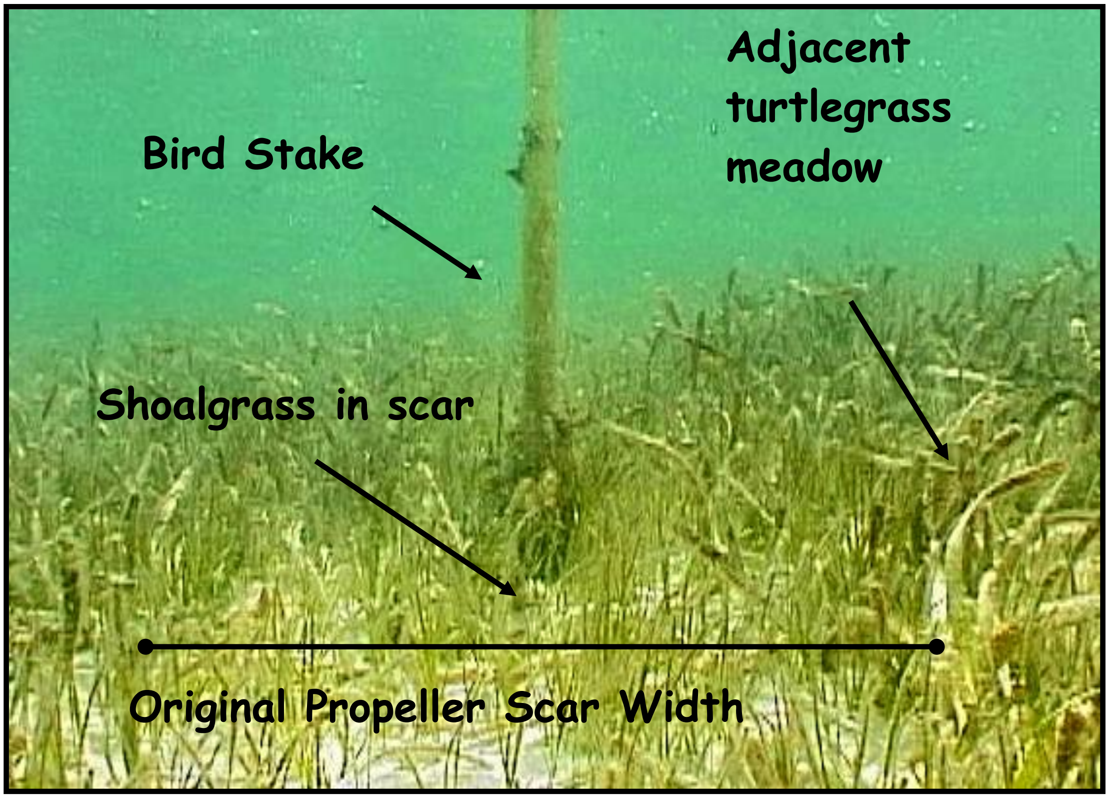
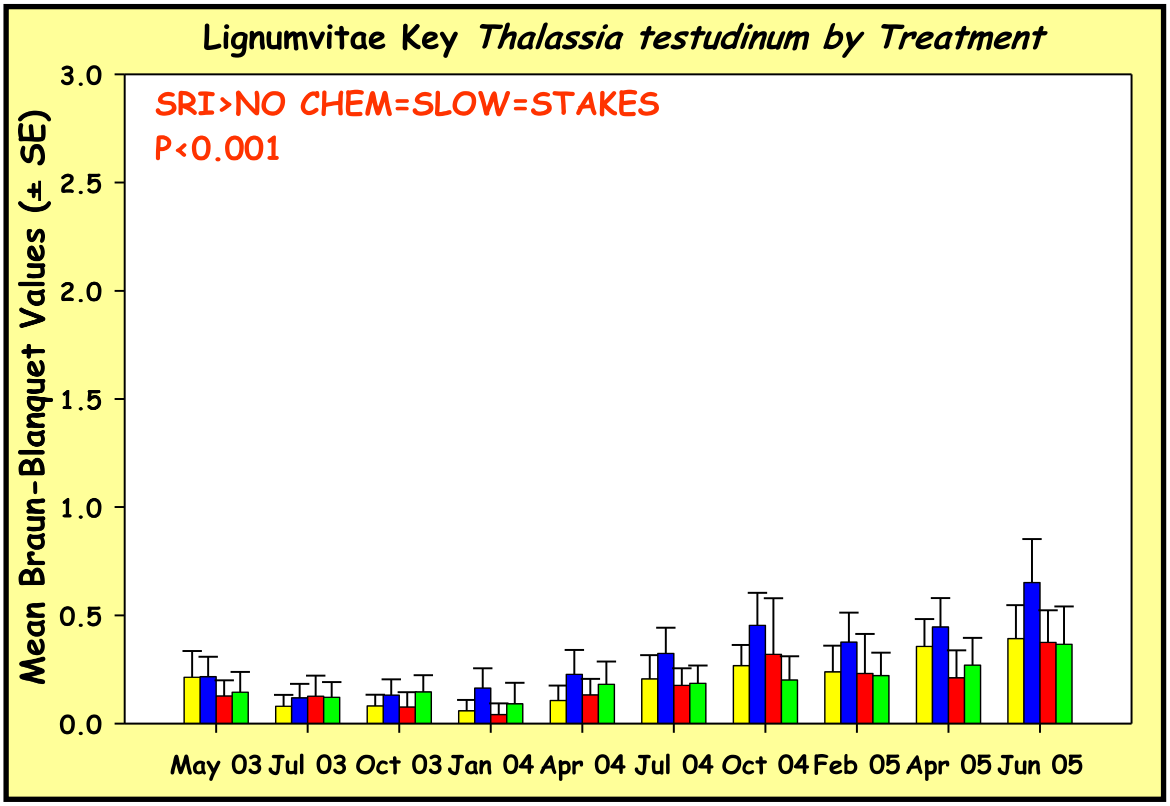

Adjacent
turtlegrass
meadow
Bird Stake
Shoalgrass in scar
Original Propeller Scar Width

Figure 8

A


Lignumvitae Key *Thalassia testudinum by Treatment*
SRI>NO CHEM=SLOW=STAKES
P<0.001
Mean Braun-Blanquet Values (± SE)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
May 03
Jul 03
Oct 03
Jan 04
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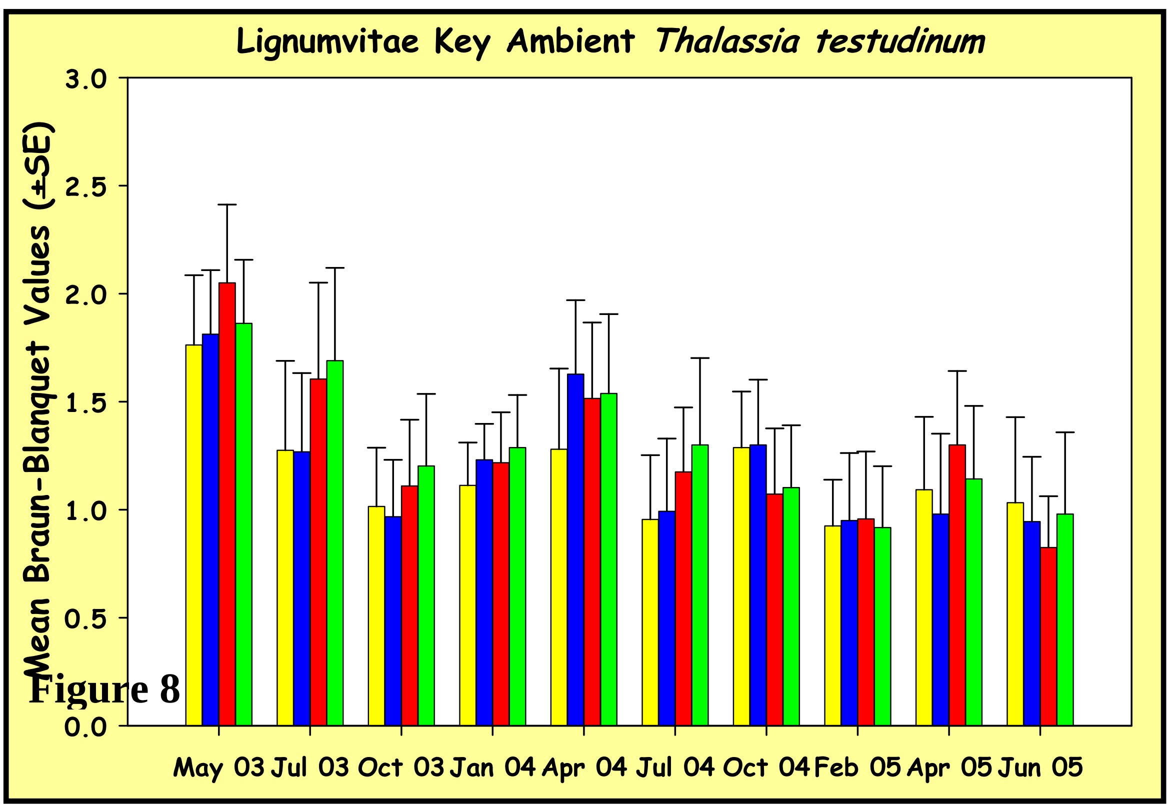
Feb 05
Apr 05
Jun 05

B


Lignumvitae Key Ambient *Thalassia testudinum*
Mean Braun-Blanquet Values (±SE)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
May 03
Jul 03
Oct 03
Jan 04
Apr 04
Jul 04
Oct 04
Feb 05
Apr 05
Jun 05
Figure 8

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EXPERIMENT 2: ***Scientific Evaluation of Methods for the Biophysical Stabilization and Restoration of Damaged Seagrass Meadows***

INTRODUCTION

Seagrasses possess extensive networks of roots and rhizomes, enabling them to stabilize sediments and retain nutrient-rich organic matter. Because unconsolidated sediments provide substrate and nutrition for seagrasses, some of the most severe disturbances to seagrass meadows are those that result in significant sediment loss (e.g. propeller scar erosion and vessel groundings). In this experiment, we addressed recovery of propeller scars from which turtlegrass shoots and rhizomes, and a substantial amount of sediment has been excavated (i.e. the depth of the scar is at least 30 cm below the depth of the adjacent, undamaged meadow). Our goal was to accelerate the natural recolonization of turtlegrass scars via a combination of physical (topographical restoration), chemical (nutrient addition), and biological techniques (supplementary planting).

METHODS

Study Site: The experiment was conducted in an eroded propeller scar located on a shallow mudbank dominated by *Thalassia testudinum* (turtlegrass) in the Lignumvitae Key Submerged Land Management Area (Figure 1). The initial vessel injury occurred in 1993, and consisted of a twin propeller scar approximately 80 m long and 0.75 - 1.0 m wide with a terminal blowhole (Fonseca et al. 2004). By 1998, the scar had increased dramatically in width and depth (approximately 5 -7 m wide and 0.3 m deep) due to erosion caused by tidal currents and boat wakes. Topographical restoration of the scar was initiated in 1999 to prevent further degradation of the seagrass bank (McNeese et al. in press). The scar was filled with coarse limestone rubble (1" – 1.25" diameter) in an effort to arrest erosion (Figure 2). In addition to filling the scar, 48 bird roosting stakes were uniformly distributed across the site (Figure 3) to encourage fertilization by birds, which defecate phosphate-rich feces onto the sediment, enhancing the growth of opportunistic seagrass species (Fourqurean et al. 1995, Kenworthy et al. 2000). No seagrasses were transplanted on the site, as it was expected that fine-grained sediments would eventually be deposited on to the coarse rock, and followed by natural recruitment of seagrasses. The site was monitored periodically for 3.5 years, however very little fine-grained sediment was deposited, and no seagrasses recruited. Rather than seagrasses, the dominant vegetation colonizing the fill was attached macroalgae.

Failure of seagrasses to recruit to the site prompted us to consider alternative methods for restoration. Seagrass Recovery, Inc., a private company based in Ruskin, Florida, has developed the Sediment Tube (Figure 4), a biodegradable, cotton fabric tube that can be filled with sediment and laid directly into an excavated site or blowhole. Sediment Tubes are approximately 1.5 m long, 15 – 20 cm in diameter, and weigh 30 – 40 pounds when filled with calcium carbonate screening sand. The tubes are flexible and can be shaped to fit the geometry of the injuries. Sediment Tubes can be used to: 1) restore the excavation to grade, 2) prevent further erosion of the scar by water flow, and 3) deliver a preferred sediment grain size. We designed a study to test the feasibility of using Sediment Tubes as a cap of finer-grained sediment placed over top of the coarse-grained ballast rock, with the hypothesis that the finer-grained sediment would be able to support seagrass growth.

<u>Experimental Design</u>:

Restoration Technique: The site was divided into 30, approximately 3m by 3m plots (Figure 5). Ten plots each of the following experimental treatments were established: 1) A single layer of sediment tubes, 2) A double layer of tubes, and 3) A control that did not receive any tubes (original coarse rubble fill). Sediment tubes were filled with native crushed calcium carbonate sand on shore (Figure 6), transported to the site by boat (Figure 7), and laid into each plot by hand (Figure 8). All of the tubes (1200 total) were fabricated and installed in the experiment over a three-day period. In the single layer plots, 40 sediment tubes were deployed adjacent to each other. In the double plots, a second layer of 40 tubes was placed perpendicularly atop the first layer.

Planting Technique: Shoalgrass planting units were composed of hand-harvested material from local donor beds. Units were assembled by attaching *Halodule* shoots with intact roots and rhizomes to U-shaped metal staples. Planting was accomplished by first making a small slit in the biodegradable tubes, and inserting the entire bundle into the sediment making sure that all of the roots and rhizomes were buried (Figure 9). We planted a total of 40 individual planting units in each plot on 0.5 m centers for a total of 800 units. No shoalgrass units were planted into the 10 untreated control plots, as several previous attempts had failed (McNeese et al. in press). We followed all recommended procedures for seagrass bare-root transplanting methods (Fonseca et al. 1998).

Transplanted *Halodule* was fertilized by the addition of bird roosting stakes to test a wider application of the modified "compressed succession" used in Experiment 1. Bird stakes were installed into experimental plots on 1.5 m centers (9 stakes per plot). Four bird stakes from the initial restoration effort were already in place at the corner of each plot. Five new bird stakes added to each plot to achieve the desired stake density.

Monitoring:

The study site was monitored every 3 – 4 months from September 2003 to September 2005. Planting unit survival was measured until individual units could no longer be distinguished. After the shoalgrass units began to merge, macrophyte abundance was estimated using a non-destructive, visual technique – the Braun-Blanquet cover/abundance procedure (Braun-Blanquet 1965, Mueller Dombois and Ellenberg 1974, Fourqurean et al. 2001). Seagrass and macroalgal species occurring within a 0.5 m x 0.5 m quadrat were assigned a cover/abundance value according to the following scale: 0 = absent; 0.1 = solitary, with small cover; 0.5 = few, with small cover, 1 = numerous, but < 5% cover; 2 = any number, with 5-25% cover; 3 = any number, with 26-50% cover; 4 = any number, with 51-75% cover; 5 = any number, with 76-100% cover. Each experimental plot was divided into 16 nearly equal sections, and four sub-plots were randomly selected for placement of the Braun-Blanquet quadrats. Short-shoot counts were initiated 8 months after planting, and at each sampling period thereafter using a 10 cm x 10 cm quadrat placed in a randomly located position within each of the Braun-Blanquet quadrats (total of four short-shoot counts per plot).

Sediment depth: The depth of unconsolidated sediment provided by the tubes was determined at four randomly selected positions in each plot by driving a metal stake into the sediment until it penetrated to the ballast rock. Sediment level was marked on the stake, then the stake was removed and measured to determine the amount of sediment above the rock. Sediment depths were measured at the start of the experiment, and approximately every 3 - 4 months thereafter until February 2005.

Statistical analyses:

Results were analyzed by One-Way Analysis of Variance using data collected during the final sampling event to assess differences among the three experimental treatments (control, single layer of tubes, and double layer of tubes) for the following parameters: *Halodule* short- shoot density, *Halodule* Braun-Blanquet abundance, macroalgal Braun-Blanquet abundance, and sediment depth. Tukey's pairwise multiple comparisons procedure was used to determine where significant differences occurred.

RESULTS

Planting unit survival: Less than 30% of the shoalgrass planting units survived until the first monitoring event in September 2003. Missing planting units were replaced in October 2003, and growth was so rapid that individual units could no longer be distinguished in January 2004.

Seagrass cover**:** *Halodule wrightii* cover was higher in both single and double layer sediment tube treatments as compared to the control throughout the experiment (Figure 10). Cover in the two sediment tube treatments increased rapidly after the replanting In October 2003 until September 2004, when the highest Braun-Blanquet values were recorded. After the September 2004 peak, cover in both single and double layer tube treatments decreased slightly, then remained fairly stable until the final monitoring date. Seagrass cover was very low in the control plots throughout the study. On the final sampling date, shoalgrass cover in the control plots was significantly lower than in either the single or double layer sediment tube plots, and there was no significant difference in shoalgrass abundance among sediment tube treatments ($p = 0.014$).

***Seagrass short shoot density*:** *Halodule wrightii* short-shoot density was consistently higher in the single and double layer tube treatments than in the controls throughout the experiment (Figure 11). Shoot density in both sediment tube treatments increased from the beginning of the study through May 2004, when the highest shoot numbers were recorded. After the May 2004 peak, shoalgrass density declined sharply in both the single and double layer tube treatments through April 2004. However, on the final monitoring date in September 2005, shoot density had rebounded considerably. *Halodule* short-shoot density at the end of the study was significantly lower in the control plots than in either the single or double layer sediment tube plots, and there was no significant difference in shoalgrass density among sediment tube treatments ($p < 0.0001$).

Macroalgal cover: Control plots had substantially higher macroalgal cover than either the single or double-layer sediment tube plots throughout the study (Figure 12). There was little variation in the level of macroalgal cover in control plots among monitoring dates, however, a sharp increase in macroalgal abundance was observed in both the single and double-layer sediment tube treatments in February 2005. This corresponded with a decline in *Halodule wrightii* short-shoot density (Figure 11). Macrolalgal cover at the end of the study was significantly higher in the control plots than in either the single or double layer sediment tube plots, and there was no significant difference in cover among sediment tube treatments ($p < 0.001$). Compared to typical Braun-Blanquet scores on the carbonate banktops in south Florida, macroalgal cover on the ballast rock control plots was very high (e.g., see Fourqurean et al. 2001).

Macroalgal Species Composition: During the first few months of the study, several species of calcareous (*Halimeda incrassata*, *Penicillus capitatus and Udotea flabellum*) and non-calcareous (*Batophora oerstedii*) green algae were the most abundant species. These species are characteristic of the plant communities in this environment. However, after several months, macroalgal species composition changed substantially. By February 2005, the three taxa contributing most to the macroalgal community were two opportunistic green algal species, *Chaetomorpha linum* and *Enteromorpha intestinalis*, and the blue-green alga *Lyngbya* spp.

Sediment depth: At the beginning of the study, sediment depths in the control, single-layer tube, and double-layer tube treatments were 1.1 cm, 7.5 cm, and 15 cm, respectively. Sediment depths in all three treatments changed very little during the study (Figure 13). At the end of the experiment, average sediment depth in control plots was < 1.0 cm, significantly less than in either the single (depth = 7.5 cm) or the double-layer (depth = 16 cm) sediment tube treatments, which were also significantly different from each other ($p < 0.001$).

DISCUSSION

Experimental evidence reveals that recovery of *Thalassia testudimum* meadows injured by propeller scarring or vessel grounding can take many years, depending on the depth and geometry of the excavation (Kenworthy et al. 2002, Whitfield et al. 2004, Fonseca et al. 2004). The slow recovery rates of turtlegrass can lead to even further meadow degradation from boat wakes, tidal currents, or the passage of severe storms (Whitfield et al. 2002, Whitfield et al. 2004), and some disturbances may in fact never recover. For these reasons, it may sometimes be necessary to reestablish sediment topography before seagrass communities can be restored in badly eroded areas.

While the first attempt to topographically restore the Lignumvitae Key scar with limestone rubble succeeded in preventing further erosion, it failed to facilitate natural seagrass recolonization. Two failed attempts at transplanting *Halodule wrightii* on the rubble confirmed that it would be necessary to introduce finer-textured sediment before the site would support seagrass. Results of the present experiment indicate that biodegradable sediment tubes filled with fine-grained crushed carbonate rock, in combination with wild bird fertilization and shoalgrass tranplants is a feasible method for topographically and biologically restoring vessel groundings and other types of seagrass damage involving the excavation of sediments.

In the present study, the original fill material was capped with sediment tubes and fertilized with bird roosting stakes to test a wider application of modified "compressed succession" technique. Initial shoalgrass transplant unit survival was less than 30%. Although low survival is not unusual for seagrass transplanting in general (Fonseca et al. 1998), there are several noteworthy features that might have contributed to transplant unit loss in this experiment. When shoalgrass planting units began to spread, they grew across the tubes and over the fabric rather than penetrate through to the sediment within the tubes. Shoalgrass shoots and rhizomes grew out into the water column to form "aerial runners". Loss of planting units at the beginning of the study may have occurred as the fabric disintegrated, uprooting the planting units as it pealed away. In addition, the large amount of shoalgrass biomass in water column created substantial drag, and the units may have been ripped from the tubes by tidal currents. There may also have been a lag time required for the bird feces to enrich sediment within the tubes. When the units were replanted, fabric on the tube surfaces had deteriorated to the point where the seagrass rhizomes could easily penetrate through to the enriched sediment, and the shoalgrass grew vigorously.

Within a year of planting, a dense cover of *Halodule* grew on the sediment tubes (Figure 14). These densities were comparable to natural populations in south Florida and throughout the tropics. This high rate of growth continued through September 2004, after which a sharp decline in the shoalgrass population coincided with a dramatic increase in macroalgal abundance. The macroalgal species composition also shifted at this time, from dominance by calcareous greens typical of this region, to opportunistic green and blue-green macroalgae. This shift may have been related to excess nutrients in the sediments. To compensate for the apparent nutrient over-enrichment five bird stakes per plot were removed, leaving only the original four. Following this modification, shoalgrass densities increased, returning to 78-80% of the highest values by May 2004. By the end of the study, shoalgrass from within the plots had extended beyond the original plot boundaries (Figure 15).

There were no differences in shoalgrass cover, short-shoot densities, or macroalgal cover among sediment tube treatments at the end of the study. However, the double-layer plots had twice the amount of sediment as single-layer plots (16 cm vs. 8 cm). This was a slight increase from the original depth, indicating that sediment retention may have been enhanced. Although the limestone rubble fill had been in place for 5.5 years, sediment depth was still less than 1 cm. Repeated efforts to transplant shoalgrass into the rubble failed, so it is not expected that this will ever be a feasible medium to support turtlegrass growth. In contrast, sediment depth of the single and double layer tube plots exceeded the minimum amount of unconsolidated sediment required to support at least sparse *Thalassia* growth. To achieve lush growth, Zieman suggests that sediments need to be at least 50 cm thick to provide adequate rooting depth, organic matter, and sufficient nutrients. Since seagrass communities function in sediment stabilization and accretion, it is reasonable to expect additional sediment accumulation over time. Sediment accumulation is not a rapid process in these systems, but given the dense shoalgrass growth observed in this study, sediment accumulation over the long run could be significant. It will be interesting to see if *Thalassia* eventually recolonizes during the time frame we continue to monitor these sites. Ultimately this study has demonstrated that sediment tubes function successfully in stabilizing propeller scar topography and facilitating seagrass growth.

LIST OF TABLES AND FIGURES

Figure 1

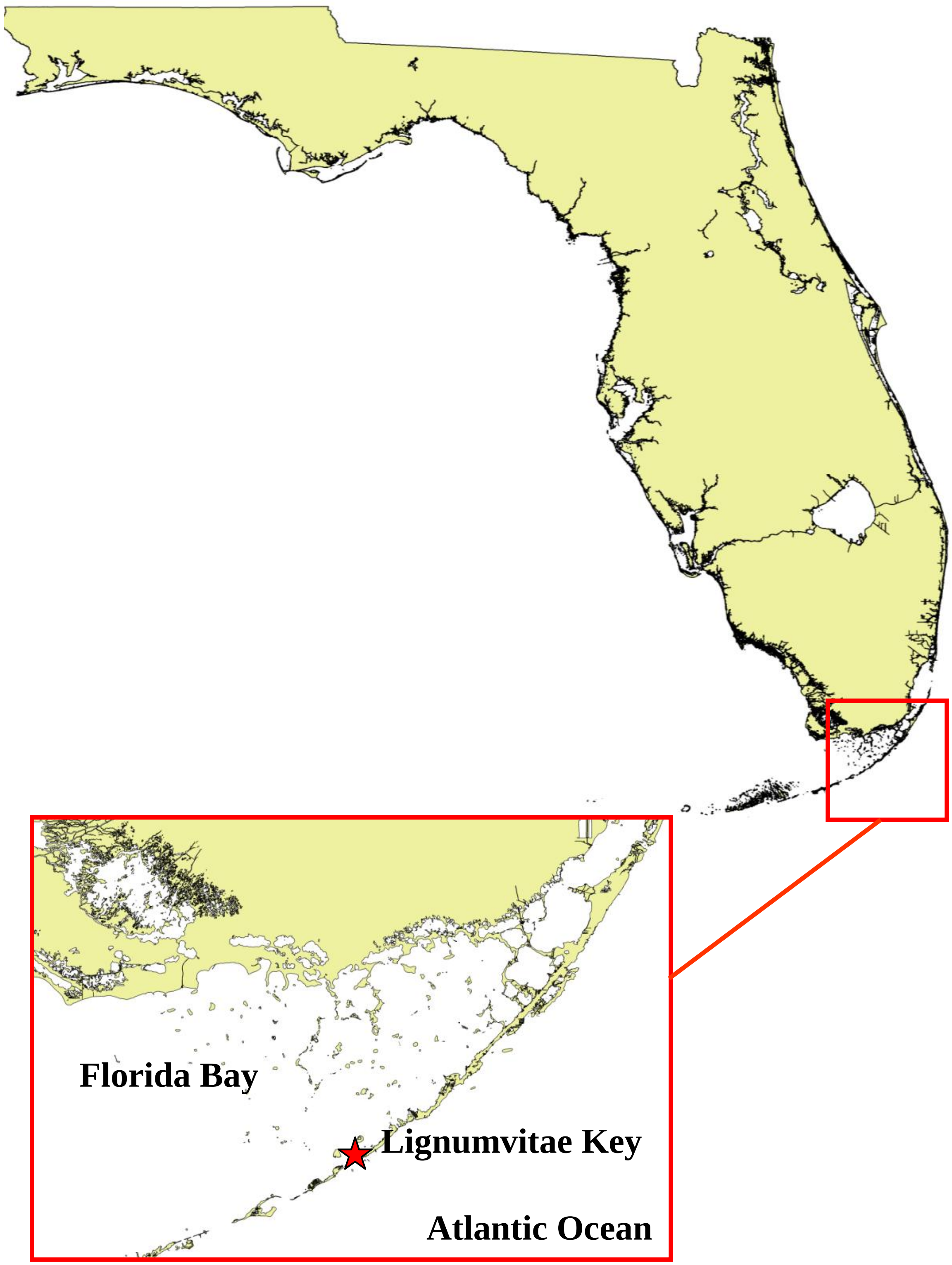


Figure 2

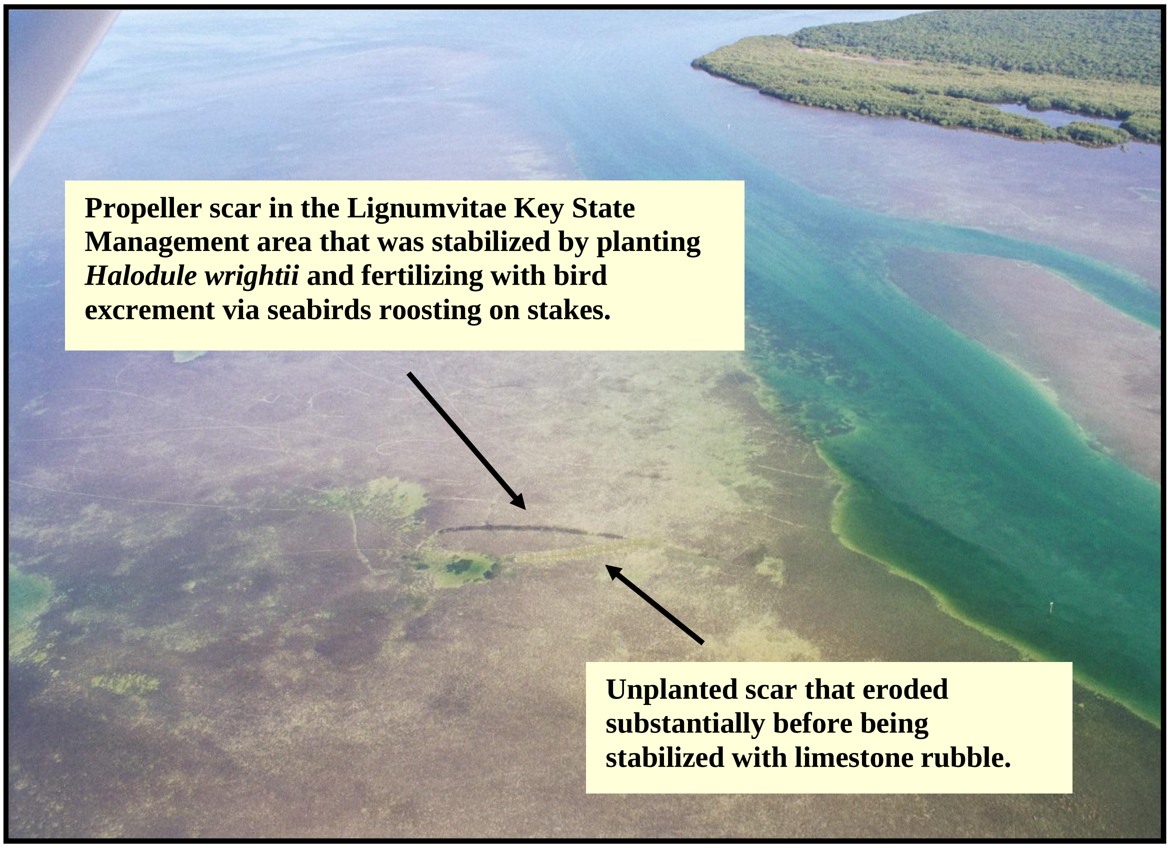
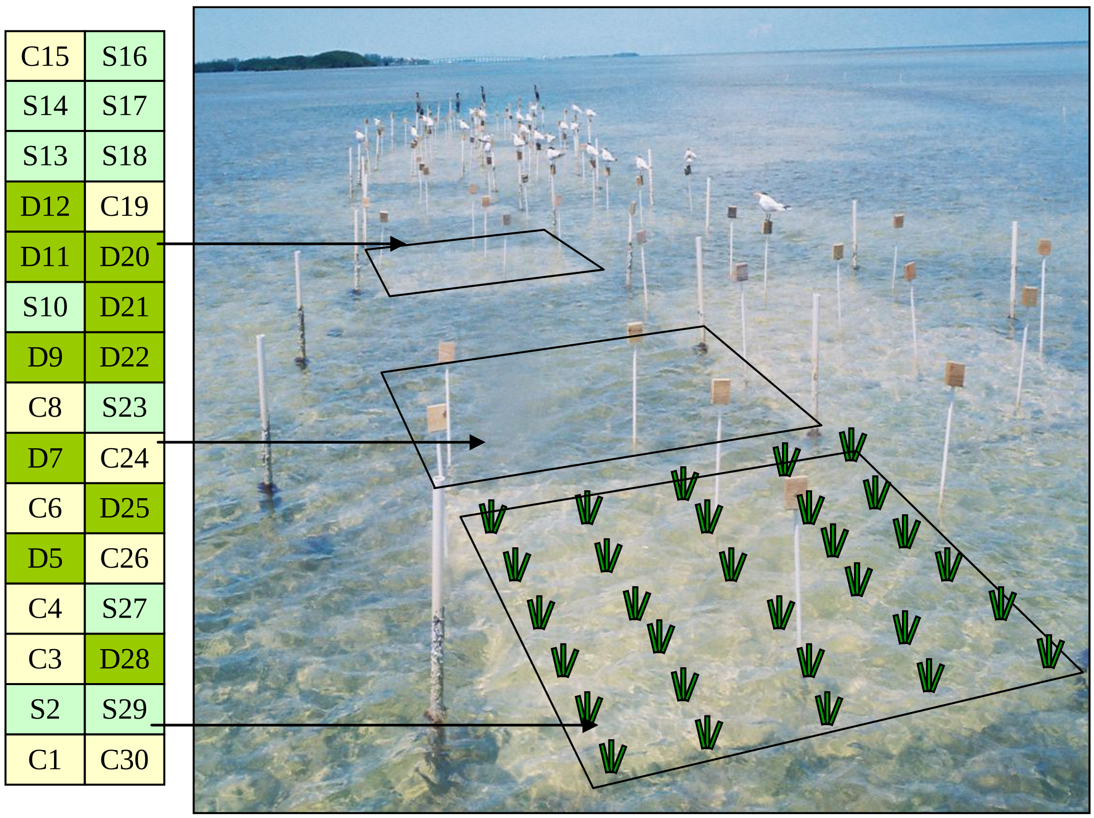

Propeller scar in the Lignumvitae Key State Management area that was stabilized by planting *Halodule wrightii* and fertilizing with bird excrement via seabirds roosting on stakes.
Unplanted scar that eroded substantially before being stabilized with limestone rubble.

Figure 3

Figure 4

Figure 5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S2 S29
C1 C30

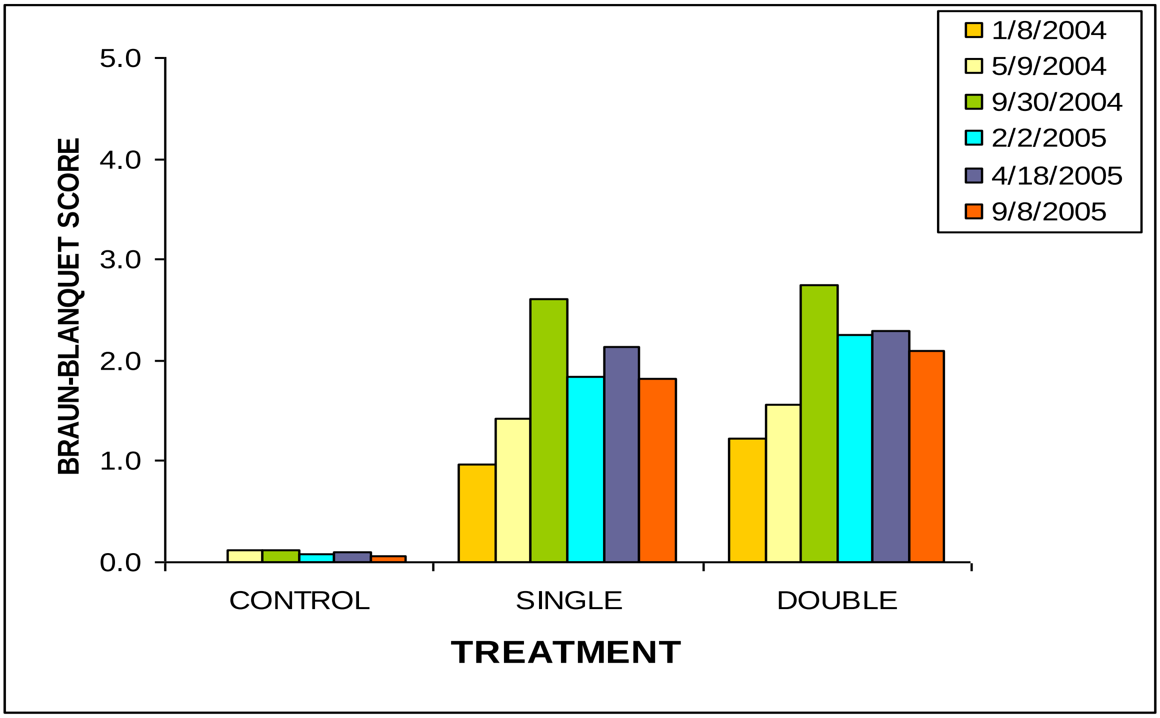
Figure 6

Figure 7

Figure 8

Figure 9

Figure 10



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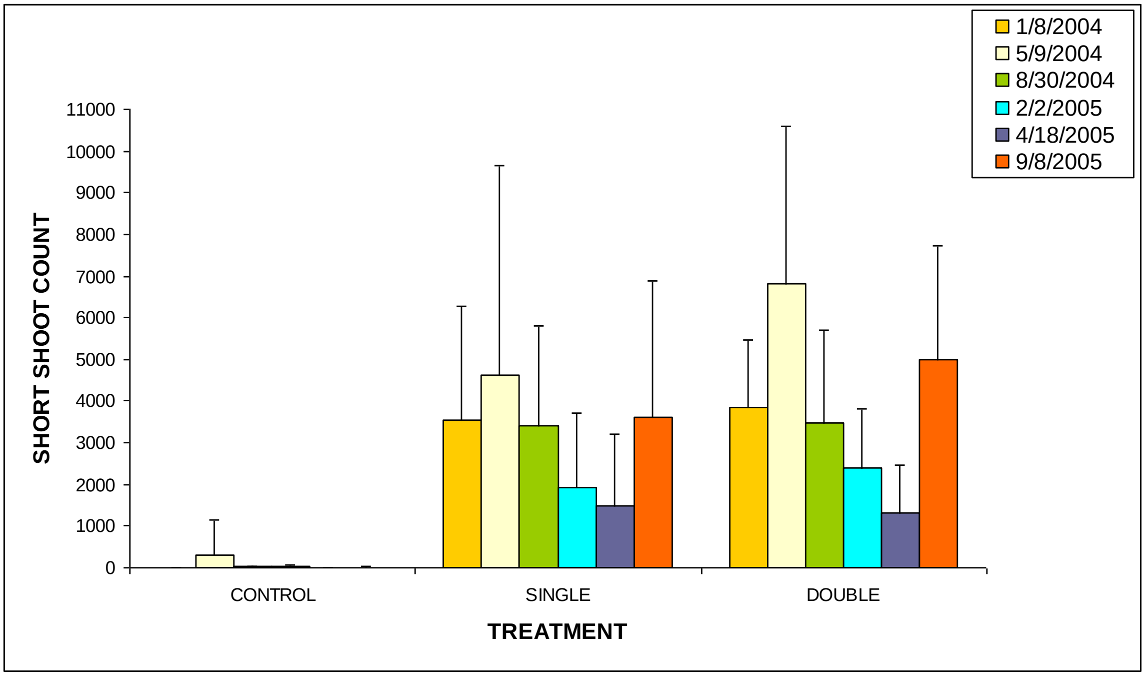
0.0
BRAUN-BLANQUET SCORE
CONTROL
SINGLE
DOUBLE
TREATMENT

Figure 11



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11000
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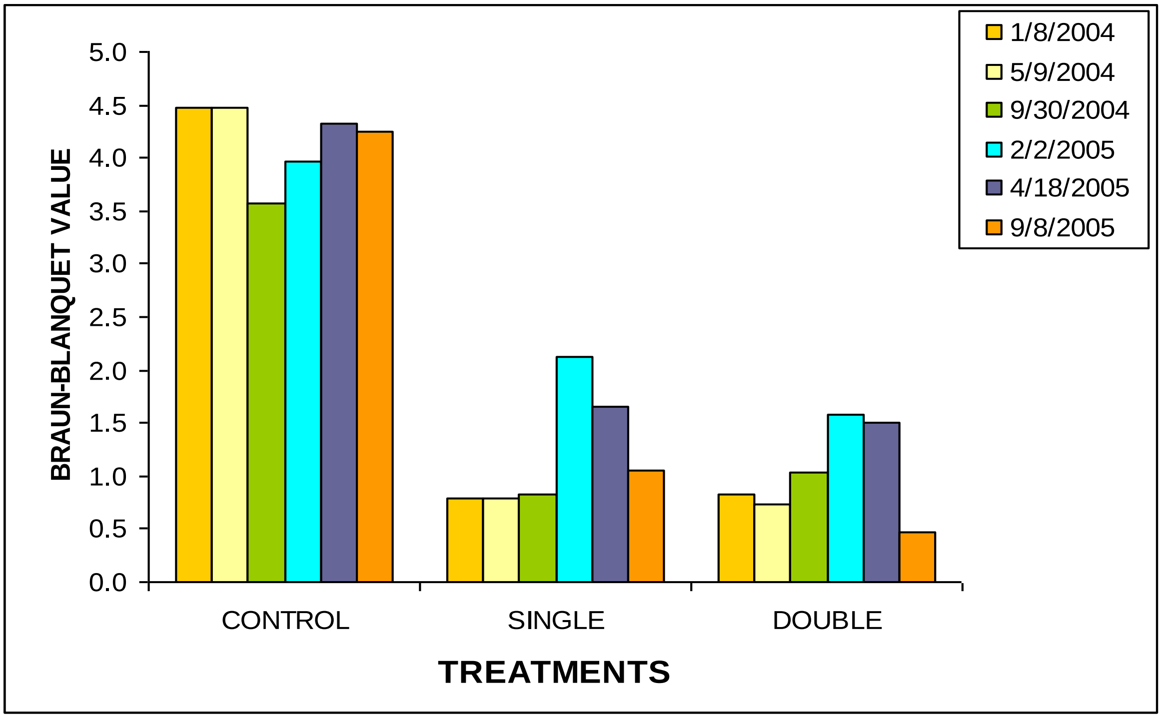
2000
1000
0
SHORT SHOOT COUNT
CONTROL
SINGLE
DOUBLE
TREATMENT

Figure 12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1.5
1.0
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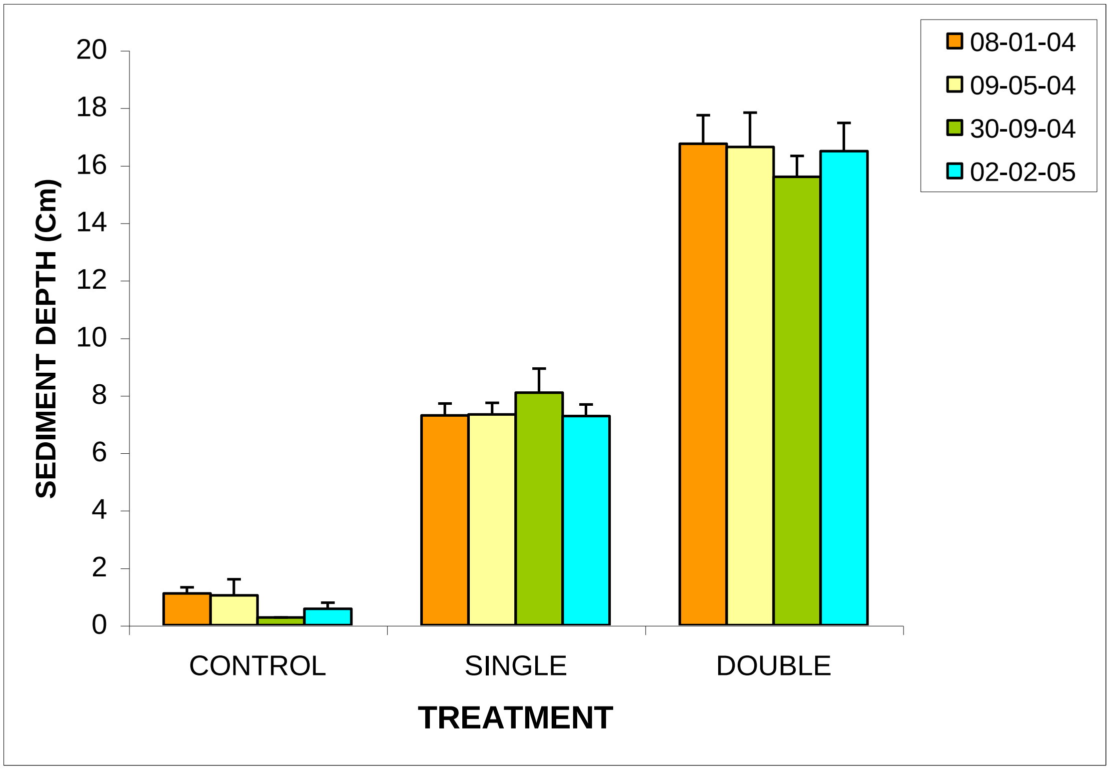
0.0
CONTROL
SINGLE
DOUBLE
TREATMENTS

Figure 13


08-01-04
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18
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SEDIMENT DEPTH (Cm)
CONTROL
SINGLE
DOUBLE
TREATMENT

Figure 14

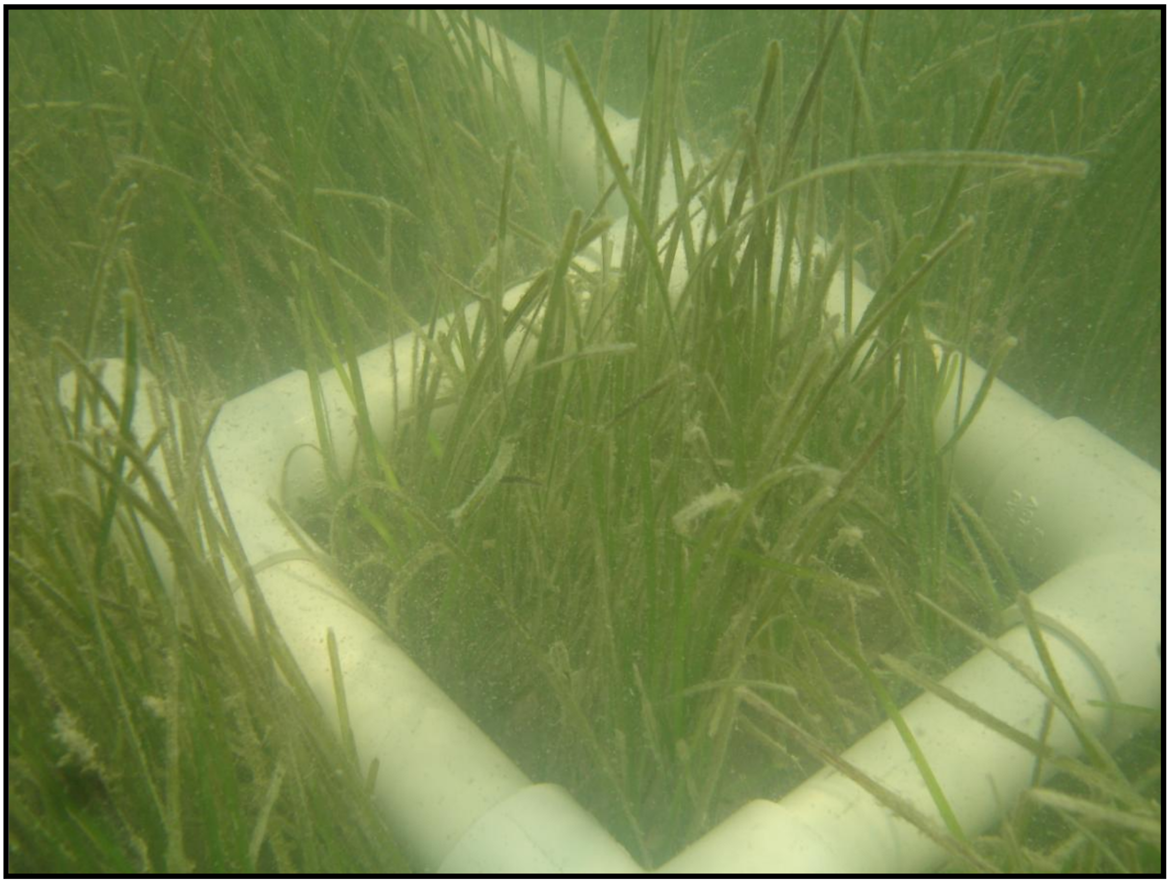

Figure 15

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