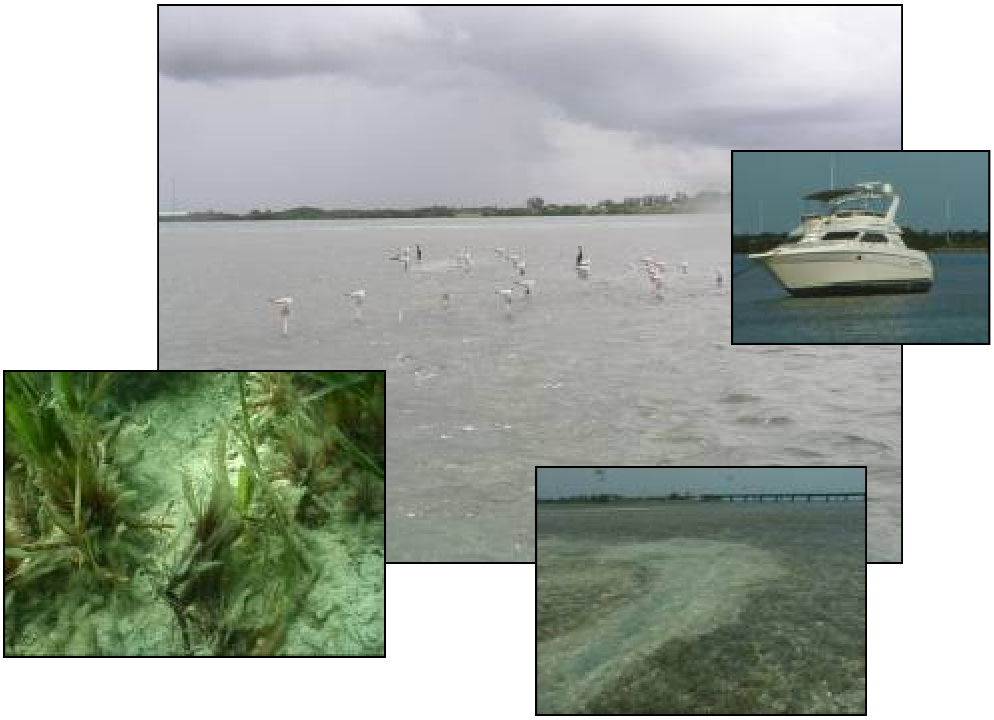
Marine Sanctuaries Conservation Series ONMS-10-06



N-Control
Seagrass Restoration Monitoring Report
Monitoring Events 2003-2008
Florida Keys National Marine Sanctuary
Monroe County, Florida

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service
Office of Ocean and Coastal Resource Management
Office of National Marine Sanctuaries

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About the Marine Sanctuaries Conservation Series

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Seagrass Restoration Monitoring Report
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A. A. Farrer

Florida Keys National Marine Sanctuary, 33 East Quay Road, Key West, FL 33040

U.S. Department of Commerce
Gary Locke, Secretary

National Ocean and Atmospheric Administration
Jane Lubchenco, Ph.D.
Under Secretary of Commerce for Oceans and Atmosphere

National Ocean Service
David Kennedy, Acting Assistant Administrator

Silver Spring, Maryland
November 2010

Office of National Marine Sanctuaries
Daniel J. Basta, Director

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1305 East-West Highway
Silver Spring, MD 20910

COVER

Clockwise:
Bird stakes at the *N-Control* restoration site. (Credit: NOAA)
The vessel *N-Control* aground on Knight Key bank. (Credit: NOAA)
Injury to the seagrass bed from the *N-Control* vessel. (Credit: NOAA)
Damage to Turtle grass (*Thalassia testudinum*) at the *N-Control* vessel grounding site. (Credit: NOAA)

SUGGESTED CITATION

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CONTACT

Alicia A. Farrer, Environmental Specialist II
Florida Keys National Marine Sanctuary, 33 East Quay Road, Key West, FL 33040
Email: alicia.farrer@noaa.gov

ABSTRACT

This document presents the results of the monitoring of a repaired seagrass area injured by the *N-Control* vessel grounding incident of May 29, 2001. This grounding occurred in State of Florida waters within the boundaries of the Florida Keys National Marine Sanctuary (FKNMS) and impacted a total of 96.87 m^2 of seagrass habitat, predominantly Turtle grass (*Thalassia testudinum)*. Restoration of this site was completed on March 25, 2003 and consisted of forty-four seagrass planting units (*Halodule wrightii* and *Syringodium filiforme*) and 39 bird stakes. The monitoring program of the *N-Control* site was designed to determine whether the restoration effort provided services in a manner consistent with restoration goals, and to monitor the potential need for mid-course corrections. Monitoring consisted of both quantitative and qualitative methods adapted from Fonseca et al "Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters". A total of six monitoring events were conducted over five and a half years. After 64 months (5.5 years) post-restoration, the percent cover of total seagrass in the restored injury increased from 5.6% to 17%. The target species, *T. testudinum*, increased from 0.5% to 12.1% in the restoration area by the 5.5 year monitoring event. In comparison, the percent cover of *T. testudinum* was 28.5% in the reference area adjacent to the injury during the 5.5 year monitoring event. This restoration effort accelerated the recovery of the injured area but the injury has yet to reach pre-grounding baseline levels. Research on restoration techniques and natural recovery continues, and will provide valuable information on the practicality and effectiveness of seagrass restoration of vessel grounding injuries.

KEY WORDS

N-Control, Florida Keys National Marine Sanctuary, seagrass, vessel grounding, restoration, monitoring, planting units, bird stakes

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INTRODUCTION

This document presents the results of the monitoring of a repaired seagrass area injured by the *N-Control* vessel grounding incident of May 29, 2001. This grounding occurred in State of Florida waters within the boundaries of the Florida Keys National Marine Sanctuary (FKNMS). The National Oceanic and Atmospheric Administration (NOAA) and the Board of Trustees of the Internal Improvement Trust Fund of the State of Florida, ("State of Florida" or "state") are the co-trustees for the natural resources within the FKNMS and are responsible for mediating the restoration of the damaged marine resources and monitoring the outcome of the restoration action. The restoration monitoring program tracks patterns of biological recovery, determines the success of restoration measures, and assesses the resiliency to environmental and anthropogenic disturbances of the site over time. To evaluate restoration success, reference habitats adjacent to the restoration site are concurrently monitored to compare against the condition of restored seagrass areas.

The monitoring program of the *N-Control* site was designed to determine whether the restoration effort provided services in a manner consistent with restoration goals, and to monitor the potential need for mid-course corrections. The monitoring program allowed for detection of, and response to, significant changes in seagrass recovery rates or damage to restoration components (e.g., bird stakes, seagrass transplants) as a result of external events, such as major storms or vandalism. The monitoring schedule was as follows: baseline (day 0), 0.5, 1.0, 1.5, 2.0, 2.5, 3.5 and 4.5 years after restoration implementation. Restoration of this site was initiated on March 25, 2003. The dates for each monitoring event are listed in Table 1. The planned 2.0 and 2.5 year monitoring events were not completed due to staff availability and logistical difficulties.

Table 1. Monitoring event timeline for the *N-Control* grounding restoration

Event	Date
Vessel Grounding	05/29/2001
Injury Assessment	06/05/2001
Restoration	03/25/2003
0.5 Year	09/29/2003
1.0 Year	04/26/2004
1.5 Year	10/21/2004
3.0 Year	04/17/2006
3.5 Year	09/27/2006
4.5 Year	08/07/2008*

*referred to as 5.5 year event

Background

Healthy seagrass communities serve an important ecological and socioeconomic function in the Florida Keys (FKNMS 1996). Seagrass beds are nurseries for numerous species of fish and invertebrates and many commercial fishery species rely on seagrass habitat during some part of their life cycle, including pink shrimp, lobster, snapper, and stone crab. Seagrass beds are effective storm surge buffers for the low-lying Keys, reducing property damage and coastal erosion during extreme weather events. Seagrasses also function as natural sediment filters that reduce water column turbidity. The natural filtration of water by seagrasses is a major contributor to the water clarity, a characteristic appreciated by those who live in or visit the Keysand is vital to other members of the living marine resources community, including coral reefs, which are vulnerable to suspended and dissolved substances in turbid water (Short and Short 1984).

Seagrasses are vascular plants that produce flowers, fruits, and seeds. The predominant species of seagrass in the Florida Keys are *Thalassia testudinum* (Turtle grass), *Syringodium filiforme* (Manatee grass), and *Halodule wrightii* (Cuban shoal grass). For these species, the horizontal rhizome and root system is underground, protecting much of the plant biomass from the elements. The root/rhizome system grows laterally, sending short shoots vertically, above the sediment surface. *S. filiforme* and *H. wrightii* disperse easily and can initiate growth rapidly in relatively unstable sediments, making them the principal seagrass colonizers in this region. *T. testudinum* dominates in most areas of the Florida Keys and maintains a robust root-rhizome system deep underneath the substrate. Of particular management concern are vessel grounding injuries to *T. testudinum* because it has the lowest rate of vegetative growth and the least dispersal capability of all the Floridian seagrass species (Fonseca and Kenworthy 1987) and has a documented slow rate of recovery from injury (Zieman 1976, Williams 1990, Fonseca and Kenworthy 1987, Kenworthy et al. 2000, Whitfield et al. 2002, Kirsch et al. 2005, Hammerstrom et al. 2007).

Shallow seagrass beds in the Florida Keys are being negatively impacted by vessel groundings. The cumulative impact of these injuries has been extensive scarring of seagrass beds throughout the FKNMS (Sargent et al. 1995). In 2007, it was estimated that 217 reported boat groundings occurred in the FKNMS, with approximately 80% of these occurring on seagrass beds. This does not account for the hundreds more that happen every year and go unreported.

Damages caused by vessel groundings typically include a combination of propeller scars, berms, and blowholes. Propeller scars are formed by the dredging effect of the turning propeller as the boat travels over a shallow bank. The severity (width and depth) of propeller scars varies depending on many factors including the size and draft of the vessel and the extent to which the propeller is forced into the seagrass bed. Another common injury feature, known as a blowhole, is formed from the concentrated force of propeller wash, either from the grounded vessel attempting to power off the bank or the propeller wash of the salvage vessel pulling the grounded vessel off the bank. The depth and area of the blowholes also vary depending on the size of the vessel, extent of power used to remove the vessel, and type of seagrass bed substrate. Berms, the third most common seagrass injury feature, are produced from sand, coral fragments, and other materials excavated during the creation of propscars and blowholes and typically accumulate around the perimeter of blowholes, subsequently burying healthy seagrass.

Damage Assessment

[Note: The information in this section was adapted from the Discussion and Description of Injury sections of the *N-Control Vessel Grounding Assessment Report* prepared by the NOAA Damage Assessment Center.]

On May 29, 2001, the 45-foot Sea Ray powerboat, *N-Control*, ran aground on Knight Key Bank, a shallow seagrass bank which is approximately 0.5 kilometers (0.3 miles) northwest of Marathon, Florida (NOAA chart 11453 and Figure 1). Field personnel from the NOAA Damage Assessment Center (DAC) assessed the extent of seagrass injury caused by the *N-Control* on June 5, 2001. The assessment was conducted with differentially corrected, surveying-grade, digital global positioning system (DGPS) equipment. The grounding site was mapped by physically tracing the outline of the injury feature with the DGPS. The coordinates generated from the mapping were downloaded to a geographic information system (GIS) program to calculate the area of injury.

This grounding incident occurred in State of Florida waters within the FKNMS and resulted in direct injury to a seagrass bed and additional resident species. Specifically, the injury occurred on a seagrass bank characterized as a *Thalassia testudinum* dominated seagrass community. The injuries from the *N-Control* were comprised of a blowhole, a berm, a "scrape" area caused by the vessel's hull impacting the seafloor as it was turned by the salvage vessel, and two holes that were excavated within the scrape so the props could be removed from the vessel. The blowhole had an excavated planar area of 5.84 m^2 with a maximum depth of 0.7 meters below the surrounding seafloor. The ejected material from this blowhole created a berm due east covering an area of 20.92 m^2. The "scrape" feature had an area of 66.04 m^2 and the two holes had an area of 2.57 m^2 and 1.50 m^2 respectively with a maximum depth of 0.5 meters below the surrounding seafloor.

Percent cover of individual seagrass species, total seagrass, macroalgae and coral were determined using the Braun-Blanquet (BB) visual assessment method (Braun-Blanquet, 1932; Fourqurean et al. 2001). In this method, a numerical value is assigned based on the proportion of the total quadrat that is obscured by a species or functional group when observed from above. Only one species of seagrass, *T. testudinum,* was observed within the injury created by the *N-Control*. This single species comprised no greater than 3.05% of the bottom cover within the injury, a nearly six-fold reduction relative to the reference area. In the reference area, two species were found. This area was predominantly *T. testudinum* with an average percent cover of 17.50%. Percentage cover of each category is presented in Table 2.

The total area impacted was calculated to be 96.87 m^2 of seagrass habitat, predominantly *Thalassia testudinum*.

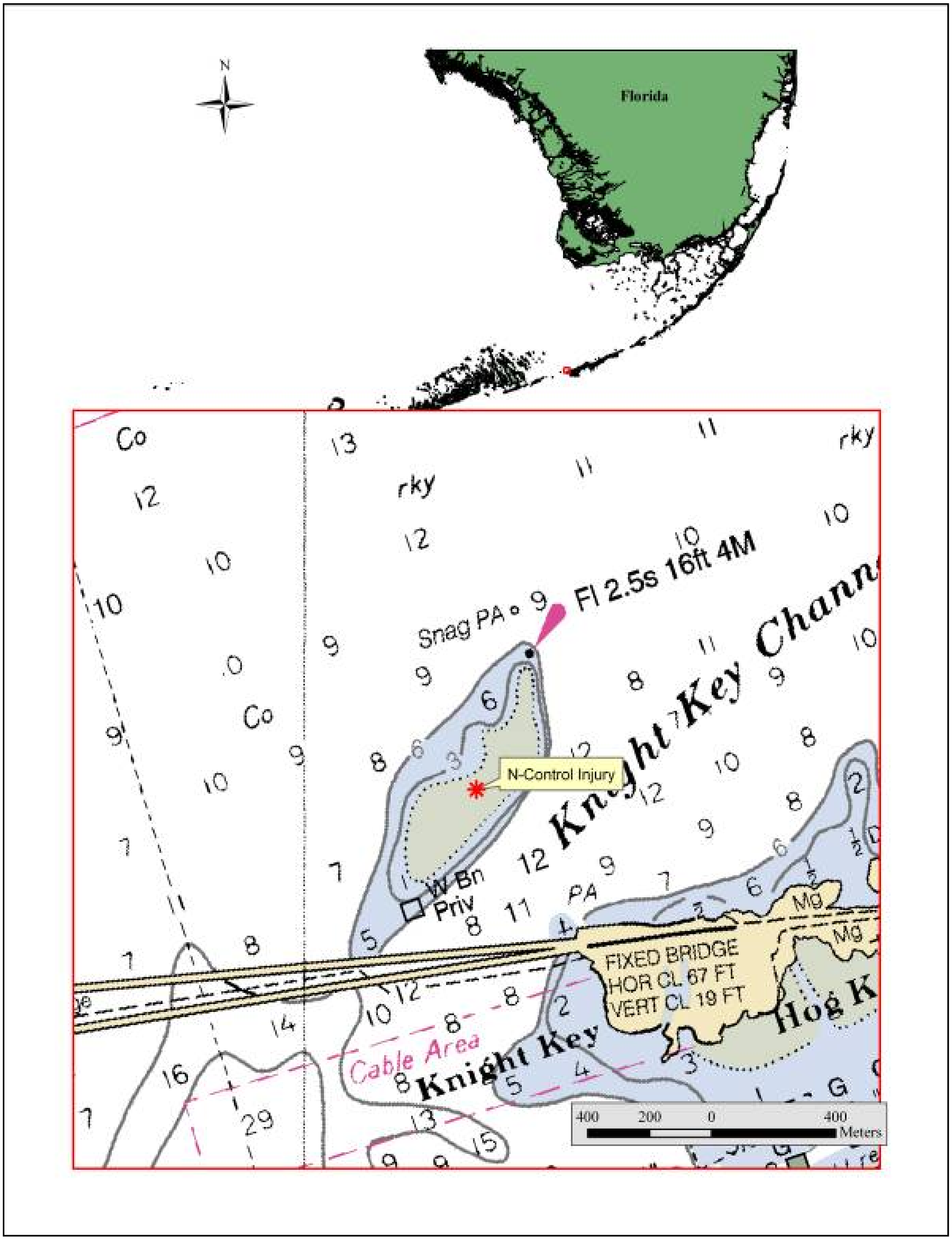

Figure 1. Location of the *N-Control* grounding injury at Knight Key Bank on May 29, 2001 (NOAA chart 11453).

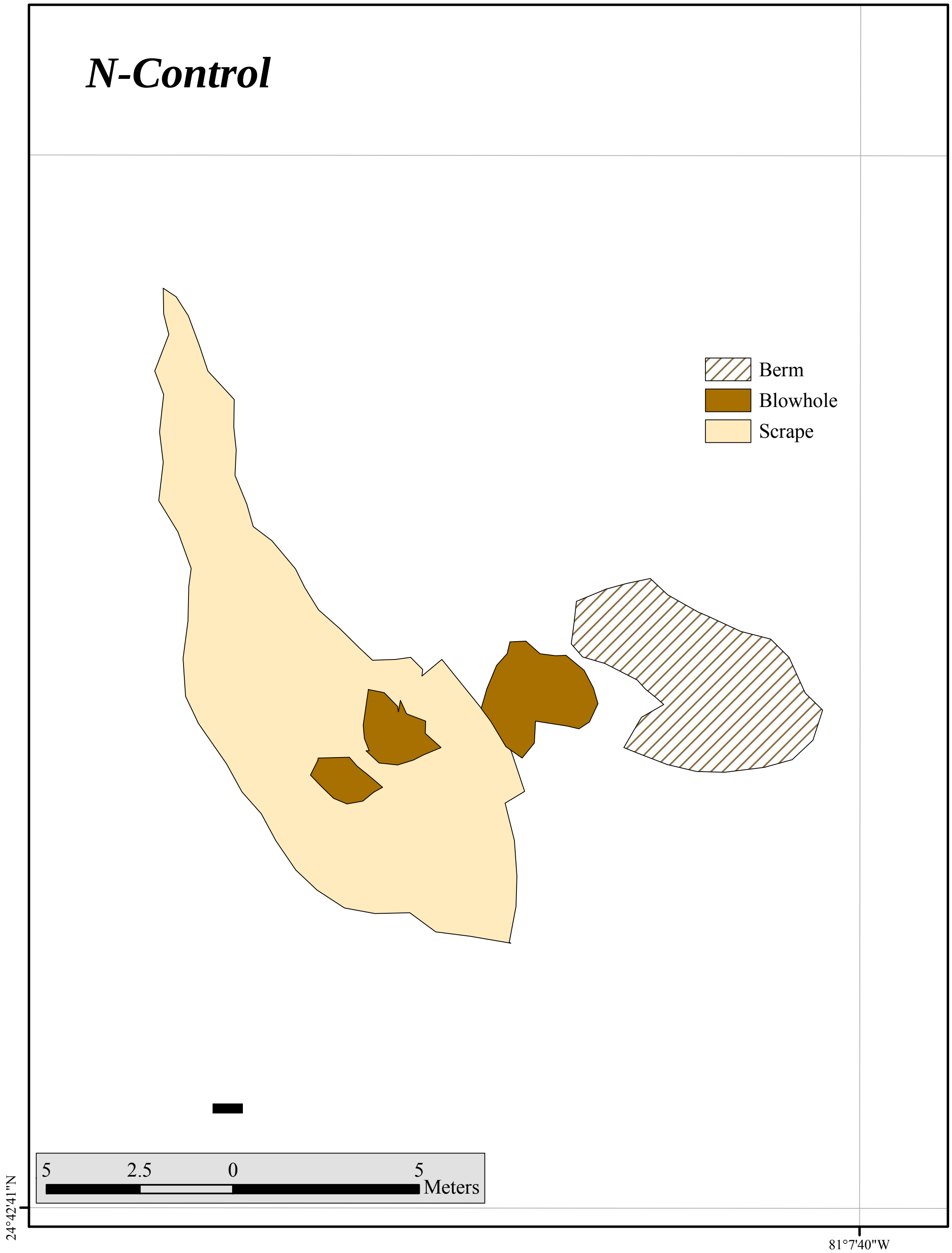

Figure 2. Georeferenced map of the *N-Control* injury as surveyed June 05, 2001.

Table 2. Percent cover of seagrass species, total seagrass, macroalgae, and coral present at the *N-Control* grounding site on June 05, 2001. Braun-Blanquet scores for each quadrat were converted to range midpoint values (Appendix B) and then averaged over the total number of quadrats assessed within each feature (total injury n=11; reference area n=9). Shaded columns show the calculated difference between cover in the reference area and that remaining in the injury area.

Category	Cover Remaining in Total Injury Area	Cover in Reference Area	Change in Cover
T.testudinum.	3.05%	17.50%	-14.45%
H.wrightii	0.00%	0.28%	-0.28%
Total Seagrass*	3.05%	17.50%	-14.45%
Macroalgae	0.64%	7.78%	-7.14%
Coral	0.00%	4.17%	-4.17%

* Total Seagrass cover is scored separately and may not equal the sum of the individual species range midpoint values.

Seagrass Restoration

Restoration is an important step in reducing the solitary and cumulative impact of seagrass injuries throughout the Keys. When the underground seagrass rhizome system is damaged and the surrounding sediment is altered by structural disturbances such as vessel groundings, the seagrass community experiences one of the most severe injuries possible and often has a difficult time re-establishing itself in the absence of restoration (Kenworthy et al. 2002). Often, non-restored seagrass injuries are subject to secondary disturbance by storms that could impede recovery and/or expand the size of the injury (Whitfield et al. 2002).

An objective in the FKNMS is to conduct feasible, cost-effective, in-kind restoration using the best available techniques to accelerate recovery to pre-grounding baseline levels. Depending on the size and severity of the injury, seagrass restoration techniques used in the FKNMS typically consists of one or a combination of the alternatives described in Table 3:

Table 3. Alternatives for seagrass restoration in the FKNMS

Alternative	Site Condition
No Action: Leaving the injury untouched.	Chosen for injuries where there is a relatively small likelihood of secondary injury before natural recovery occurs, or where any restoration is considered too difficult to undertake due to high energy conditions.
Seagrass Transplants: Planting seagrass (*S. filiforme and H. wrightii*) taken from donor sites into injured areas including berms, blowholes and/or propscars.	Appropriate for low to moderate energy sites or where the probability of transplant loss due to high water velocity is lowest.
Bird Stakes: Insertion of stakes upon which birds roost, dropping their feces on and thus fertilizing seagrass beds. Inserted into berms, blowholes and/or propscars.	Used on seagrass beds in water depths of 1.5 meters or less (mean high water).
Fertilizer Spikes: Insertion of chemical fertilizer spikes that release fertilizer into the sediments of replanted seagrass beds over a period of 3-4 months.	Used on replanted seagrass beds when water depths are greater than 1.5 meters or when bird stakes are inappropriate due to hazards to navigation or risk of vandalism.
Sediment Fill: Filling of blowholes, trenches or deep propeller scars with sediment similar to that of the surrounding area.	Used in excavations greater than 20 centimeters deep.
Sediment Tubes: Placement of biodegradable sediment-filled fabric mesh tubes inside the trench of a propscar or blowhole.	Used as a cap for sediment fill. Tubes are often used in narrow excavations (such as propscars) deeper than 20 centimeters.
Berm Redistribution: Returning displaced sediment back into the injury.	Undertaken when doing so will prevent additional injury to the surrounding seagrass bed from the natural redistribution of the sediment that was displaced. Only used if the process will not cause more harm by damaging live seagrass below the berm.

On March 25, 2003 DAC and FKNMS personnel completed the *N-Control* restoration. The primary restoration actions recommended for the *N-Control* included a combination of two alternatives: 1) the insertion of 97 bird stakes and 2) the placement of 104 planting units of *H. wrightii*. Due to changes in injury geometry post-occurrence (merging of the berm with the blowhole and some natural seagrass colonization on the south end of the scrape), adjustments to the original restoration plan had to be made on site resulting in a reduced number of bird stakes and planting units. In all, forty-four planting units (34 *H. wrightii* and 10 *S. filiforme*) and 39 bird stakes were installed within the injury (Figure 3). Though the original restoration plan called for *H. wrightii* planting units only, a combination of *S. filiforme* and *H. wrightii* was used due to the local availability of both species.

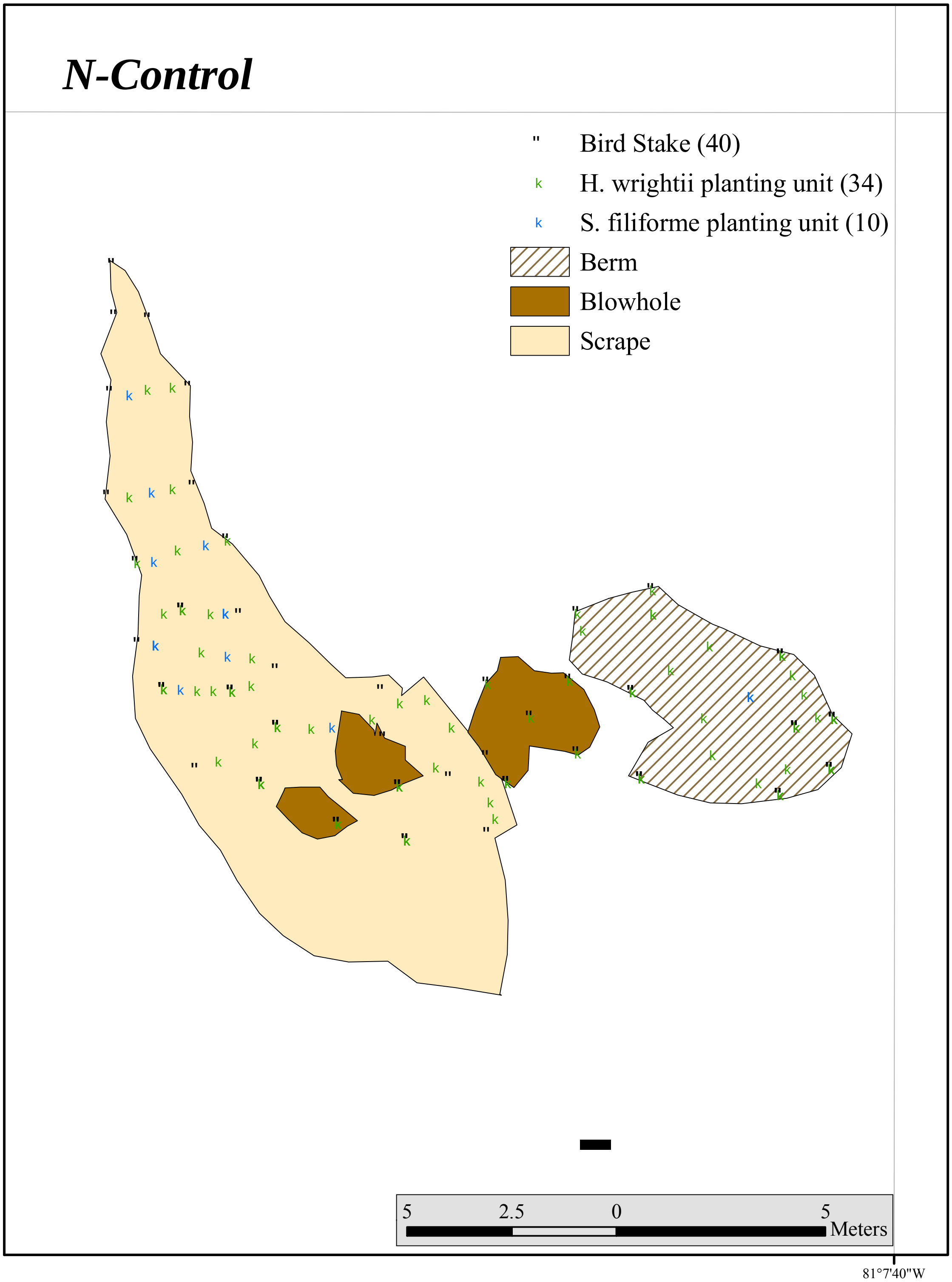

Figure 3. Restoration activities conducted at the *N-Control* injury site on March 25, 2003.

Restoration Monitoring

Monitoring of restoration projects is necessary to determine whether the projects are providing services in a manner consistent with restoration goals and to assess the potential need for mid-course corrections to ensure that the projects meet designated restoration performance standards. The monitoring events reported here assessed transplant success as well as natural re-colonization by measuring shoot density and aerial coverage, and collecting video documentation. The execution and application of the monitoring effort was adapted from "Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters", under "Appendices" pages 207-220, at http://www.cop.noaa.gov/pubs/das/das12.pdf. The monitoring data was used to determine if successful establishment of planted seagrass had occurred and whether the restoration was on an appropriate recovery trajectory. Video documentation was performed to provide a record of the status of the restoration.

The following monitoring parameters were observed and/or measured at the site:

- survival of seagrass transplants;
- incidence of transplant expansion and/or encroachment from the adjacent, undisturbed seagrass population;
- structural integrity of the bird stakes and planting units;
- growth and survival rates of transplanted seagrass;
- distribution and abundance of seagrass in surrounding reference areas;
- video documentation

The restoration monitoring plan developed for this site required six monitoring events over a 5-year period. The events were scheduled to occur at 0.5, 1.0, 1.5, 2.0, 2.5, 3.5 and 4.5 years after the baseline event (installation). The actual dates and activities for each monitoring event are listed in Table 4.

Table 4. Categories and Timing of Monitoring

Event	Date Completed	Survival Monitoring	Braun-Blanquet Abundance (reference and restored area)	Shoot density (reference and restored area)	Video Documentation
0.5 Year	09/29/2003	x	x	x	x
1.0 Year	04/26/2004	x	x	x	x
1.5 Year*	10/21/2004		N/A	N/A	x
3.0 Year	04/17/2006		x	x	x
3.5 Year	09/27/2006		x	x	x
5.5 Year	08/07/2008		x	x	x

*****Braun-Blanquet and shoot density data were unavailable for this event.

METHODS

Field Methods

The *N-Control* restoration site was monitored using snorkel gear from a small vessel (6.1 m) on the dates listed in Table 4.

For each monitoring event the structural integrity of the bird stakes and planting units (if distinguishable) was evaluated and noted on the data sheet. The restoration area was also inspected visually to assess planting unit survival, coalescence of planting units, and incidence of colonization from adjacent, undisturbed seagrass. This information was noted on the data sheet at each monitoring event.

Growth and survival rates of transplanted and colonizing seagrass in the restoration area and the distribution and abundance of seagrass in the reference area was determined using a modified BB technique (Braun-Blanquet, 1932; Fourqurean et al. 2001). PVC quadrats (0.25 m^2) were haphazardly placed on the substrate within the restoration site. Reference quadrats were distributed haphazardly throughout the undisturbed habitat surrounding the restoration site (1 to 3 meters from the perimeter of the original injury) in order to account for any variation exhibited by the habitat since restoration was initiated. The contents of each quadrat were visually inspected. Seagrass, macroalgae, and coral were identified and assigned a cover-abundance scale value (BB score) based on broad cover estimations describing the total quadrat area obscured when viewed from directly above. BB scores ranged from zero to five: 0 = not present; 0.1 = solitary specimen; 0.5 = few with small cover; 1 = numerous but less than 5% cover; 2 = 5 to 25% cover; 3 = 25 to 50% cover; 4 = 50 to 75% cover; and, 5 = 75 to100% cover.

Braun-Blanquet scores for each quadrat were converted to range midpoint values (see Appendix B) and averaged over the total number of quadrats assessed within each feature. For each event, the change in seagrass cover as a result of the restoration was determined by comparing the percentage cover of the restoration area to that of the reference area immediately surrounding the restoration.

Shoot density of transplanted and colonizing seagrass in the restoration area and the seagrass in the surrounding reference area was quantified by counting the number of short shoots of each seagrass present in one 100 cm^2 quadrat placed in the center of the 0.25 m^2 quadrat used in the modified BB technique.

Video recordings of the *N-Control* restoration site were made during each monitoring event using a Sony DCR-PC1000 digital video camera with a Mako PC1000 underwater camera housing or a Sony DCR-TRV900 with an Amphibico Navigator 900 underwater camera housing.

Statistical Analysis

Data analyses were performed on the 2008 reference and restoration areas for *T. testudinum* shoot counts, areal coverage using Braun-Blanquet (BB) scores, and coral and macroalgae cover utilizing BB scores. For the shoot counts, data met all requirements for application of *t*-tests. Because the shoot counts for *T. testudinum* were close to zero at the time of restoration and for some time afterwards, the restoration area shoot counts could only approach the reference counts from a single direction (i.e. from a fewer number to a greater one). Therefore, a one-tailed *t*-test was deemed appropriate for this analysis. For the other three datasets, non-parametric methods were used, specifically, Mann-Whitney tests. Again one-tailed analysis was utilized, since levels of biota within the restoration area was nearly zero at the time of restoration (except for algae; for it, the directionality of the test makes no difference, as evidenced by the equality seen in Fig.4.c). All data analyses were performed with Prism 5.03 for Windows® (GraphPad 2009) and Statistix 9® (Analytical Software 2008).

Model Recovery Estimates

Prior to restoration, a cellular automata modeling technique was used to formulate a recovery trajectory for the *N-Control* berm and the blowhole/scrape features (Fonseca et al. 2000b; 2004). The model used an iterative process whereby each iteration represented a time step of one year and yielded a grid that continually filled with cells occupied by seagrass until all cells were designated as being occupied. The percentage of the injury that had recovered and the remaining years to complete recovery were calculated at each time step for *T. testudinum* and *S. filiforme*/*H. wrightii* combined. Percent recovery was then plotted by time in years to derive the recovery horizon for the entire injury. The resulting regression equations were used to calculate the expected percent recovery based upon two scenarios: with restoration conducted at the site (actual location and number of planting units); and without restoration (natural recovery from the surrounding population).

Calculated Recovery Estimates

From the original Braun-Blanquet cover estimates at each site, the following Density (D) statistic was calculated for the restoration area by seagrass species:

$$D_i = \sum_{j=1}^{n} S_{ij} / n$$

where D_i = density of species *i*; *j* = quadrat number from 1 to *n*, the total number of quadrats sampled in the restoration area; and S_{ij} = the Braun-Blanquet score for species *i* in quadrat *j* (Kenworthy et al. 1993; Fourqurean et al. 2001). Seagrass percent natural recovery by species was calculated following Uhrin et al. (2009):

$$\% \text{ Recovery} = (D_{ir} / D_{ic}) \times 100$$

where D_{ir} = density of species *i* from samples *r* taken from directly within the restoration area and D_{ic} = density of species *i* from control (reference) samples *c* taken at the time of each monitoring event.

RESULTS

0.5 Year Monitoring Event (September 29, 2003)

On this event, the restoration area was missing ten bird stakes and it was decided not to replace themdue to the increase in coverage of *H.wrightii* at the site. Seagrass planting units were no longer discernable due to coalescence and recolonization from the surrounding populations of *H. wrightii* and *S. filiforme*. From the data obtained using the modified Braun-Blanquet technique, *T. testudinum*, *H. wrightii* and *S. filiforme* were observed in the reference area and in the restoration area. Percent cover of each category is presented in Table 5. The average shoot density of transplanted and colonizing seagrass in the restoration area is presented in Table 6. Shoot density data was not collected in the reference area for this event.

Table 5. Percent cover of seagrass species, total seagrass, macroalgae, and coral at the *N-Control* on September 29, 2003. Reference n=10; Restoration n=10.

Category	Cover in Restoration Area	Cover in Reference Area	Difference in Cover
T.testudinum	0.5%	12.5%	-12.0%
S. filiforme	0.1%	0.9%	-0.8%
H.wrightii	5.0%	0.3%	4.7%
Total Seagrass*	5.6%	13.8%	-8.2%
Macroalgae	7.4%	19.5%	-12.1%
Coral	0.0%	6.3%	-6.3%

* Total Seagrass cover is scored separately and may not equal the sum of the individual species range midpoint values.

Table 6. Mean shoot density (±SE) of seagrass species at the *N-Control* on September 29, 2003. Short shoot counts for each quadrat ($100cm^2$) were averaged over the total number of quadrats assessed within the restoration area (n=17).

Species	Restoration Area
S. filiforme	2.9±4.7
H.wrightii	8.1±7.8

1.0 Year Monitoring Event (April 26, 2004)

From the data obtained using the modified Braun-Blanquet technique, *T. testudinum*, *H. wrightii* and *S. filiforme* were observed in the reference area and the restoration area. Percentage cover of each category is presented in Table 7. The average shoot density of transplanted and colonizing seagrass in the restoration area is presented in Table 8. Shoot density data was not collected in the reference area for this event.

Table 7. Percent cover of seagrass species, total seagrass, macroalgae, and coral at the *N-Control* on April 26, 2004. Reference n=10; Restoration n=10.

Category	Cover in Restoration Area	Cover in Reference Area	Difference in Cover
T.testudinum	0.4%	12.6%	-12.2%
S.filiforme	1.8%	1.8%	0.0%
H.wrightii	7.4%	0.3%	7.1%
Total Seagrass*	10.7%	14.9%	-4.2%
Macroalgae	2.7%	5.4%	-2.7%
Coral	1.5%	19.9%	-18.4%

* Total Seagrass cover is scored separately and may not equal the sum of the individual species range midpoint values.

Table 8. Mean shoot density (±SE) of seagrass species at the *N-Control* on April 26, 2004. Short shoot counts for each quadrat ($100cm^2$) were averaged over the total number of quadrats assessed within the restoration area (n=11).

Species	Restoration Area
T. testudinum	0.3±0.6
S.filiforme	3.6±7.0
H.wrightii	3.5±8.1

1.5 Year Monitoring Event (October 21, 2004)

On this event the bird stakes were removed, which is standard after 18 months or when 75% planting unit coalescence is reached (NOAA, 2004). BB abundance and shoot density is unavailable for this event. Video documentation is available.

3.0 Year Monitoring Event (April 17, 2006)

At this monitoring event, one area in the original “scrape” feature remained devoid of seagrass and consisted of sparse macroalgae. The remaining majority of the restoration had some type of seagrass coverage, either *S. filiforme* or *H.wrightii*, both of which were planted during the restoration.

Using the modified Braun-Blanquet technique, two species of seagrass, *T. testudinum* and *H. wrightii* were observed in the reference area. In comparison, three species of seagrass, *T. testudinum*, *H. wrightii* and *S. filiforme* were observed in the restored area. Percent cover of each category is presented in Table 9. Shoot density of transplanted and colonizing seagrass in the restoration area and the seagrass in the surrounding reference area was recorded. The average shoot density for each species of seagrass is presented in Table 10.

Table 9. Percent cover of seagrass species, total seagrass, macroalgae, and coral at the *N-Control* on April 17, 2006. Reference n=10; Restoration n=10.

Category	Cover in Restoration Area	Cover in Reference Area	Difference in Cover
T.testudinum	2.5%	45.0%	-42.6%
S.filiforme	1.5%	0.0%	1.5%
H.wrightii	14.3%	0.3%	14.0%
Total Seagrass*	18.0%	45.0%	-27.0%
Macroalgae	6.1%	2.1%	4.1%
Coral	1.8%	4.0%	-2.3%

* Total Seagrass cover is scored separately and may not equal the sum of the individual species range midpoint values.

Table 10. Mean shoot density (±SE) of seagrass species at the *N-Control* on April 17, 2006. Short shoot counts for each quadrat ($100cm^2$) were averaged over the total number of quadrats assessed within the restoration (n=10) and reference areas (n=10).

Species	Reference Area	Restoration Area
T.testudinum	8.6±2.2	0.7±1.2
S.filiforme	0.3±0.9	9.6±7.8
H.wrightii	0.0	0.6±1.9

3.5 Year Monitoring Event (September 27, 2006)

Using the modified Braun-Blanquet technique, only *T. testudinum* was observed in the reference area. In comparison, all three species of seagrass were observed in the restoration area. Percent cover of each category is presented in Table 11. Shoot density of seagrass in the restoration area and in the reference area was recorded. The average shoot density for each species of seagrass is presented in Table 12.

Table 11. Percent cover of seagrass species, total seagrass, macroalgae, and coral at the *N-Control* on September 27, 2006. Reference n=10; Restoration n=10.

Category	Cover Remaining in Restoration	Cover in Reference Area	Difference in Cover
T.testudinum	1.3%	28.5%	-27.2%
S.filiforme	1.0%	0.0%	1.0%
H.wrightii	27.5%	0.0%	27.5%
Total Seagrass*	27.8%	28.5%	-0.8%
Macroalgae	4.5%	4.9%	-0.4%
Coral	0.5%	6.6%	-6.1%

* Total Seagrass cover is scored separately and may not equal the sum of the individual species range midpoint values.

Table 12. Mean shoot density (±SE) of seagrass species at the *N-Control* restoration site on September 27, 2006. Short shoot counts for each quadrat ($100cm^2$) were averaged over the total number of quadrats assessed within the restoration (n=10) and reference areas (n=10).

Species	Reference Area	Restoration Area
T.testudinum	7.5±4.9	0.9±1.1
S.filiforme	0.0	0.0
H.wrightii	0.0	23.3±15.3

5.5 Year Monitoring Event (August 07, 2008)

Using the modified Braun-Blanquet technique, all three species of seagrass were observed in the reference and the restoration area. Percent cover of each category is presented in Table 13. Shoot density of transplanted and colonizing seagrass in the restoration area and the seagrass in the reference area was recorded. The average shoot density for each species of seagrass is presented in Table 14.

Table 13. Percent cover of seagrass species, total seagrass, macroalgae and coral at the *N-Control* on August 07, 2008. Reference n=10; Restoration n=10.

Category	Cover Remaining in Restoration	Cover in Reference Area	Difference in Cover
T.testudinum	12.1%	28.8%	-16.7%

S.filiforme	1.0%	0.8%	0.2%
H.wrightii	2.5%	0.8%	1.7%
Total Seagrass*	17.0%	31.5%	-14.5%
Macroalgae	13.8%	12.5%	1.3%
Coral	5.6%	5.1%	0.5%

* Total Seagrass cover is scored separately and may not equal the sum of the individual species range midpoint values.

Table 14. Mean shoot density (±SE) of seagrass species at the *N-Control* restoration site on August 07, 2008. Short shoot counts for each quadrat ($100cm^2$) were averaged over the total number of quadrats assessed within the restoration (n=10) and reference areas (n=10).

Species	Reference Area	Restoration Area
T.testudinum	4.9±2.8	3.2±1.9
S.filiforme	1.2±2.7	1.7±2.5
H.wrightii	0.3±0.9	0.7±1.5

Summary of aerial coverage (BB) data

From the 0.5 year monitoring event to the 5.5 year monitoring event, the percent recovery of total seagrass in the restoration area increased from 5.6% to 17% (Table 15). *H. wrightii*, one of the two transplanted species, reached a maximum percent recovery of 27.5% at the 3.5 year event and decreased to 2.5% by the 5.5 year event. The other transplanted species, *S. filiforme*, reached a maximum percent recovery of 1.8% at the 1 year event and decreased to 1% by 5.5 year event. The climax species, *T. testudinum* , did not increase significantly from 0.5 year to 3.5 year, but went from 1.3% to 12.1% from the 3.5 year to the 5.5 year events. On the 0.5 year event, the percent recovery of macroalgae was 7.4% and for coral was 0%. By the 5.5 year event the percent recovery of macroalgae in the restoration area was 13.8% and in the reference area was 12.5%. For coral the percent recovery in the restoration area was 5.6% and 5.1% in the reference area by the final monitoring event.

Table 15. Comparison of percent recovery between the restoration (RS) and reference (RF) areas for each species of seagrass, total seagrass, macroalgae, and coral over the course of six monitoring events.

Monitoring Event		0 *	0.5	1	3	3.5	5.5
T. testudinum	RS	3.0%	0.5%	0.4%	2.5%	1.3%	12.1%
	RF	17.5%	12.5%	12.6%	45.0%	28.5%	28.8%
H. wrightii	RS	0.0%	5.0%	7.4%	14.3%	21.8%	2.5%
	RF	0.3%	0.3%	0.3%	0.3%	0.0%	0.8%

S. filiforme	RS	0.0%	0.1%	1.8%	1.5%	1.0%	1.0%
	RF	0.0%	0.9%	1.8%	0.0%	0.0%	0.8%
Total Seagrass**	RS	3.1%	5.6%	10.7%	18.0%	27.8%	17%
	RF	17.5%	13.8%	14.9%	45.0%	28.5%	31%
Macroalgae	RS	0.64%	7.4%	2.7%	6.1%	4.5%	13.8%
	RF	7.8%	19.5%	5.4%	2.1%	4.9%	12.5%
Coral	RS	0.0%	0.0%	1.5%	1.8%	0.5%	5.6%
	RF	4.2%	6.3%	19.9%	4.0%	6.6%	5.1%

*Day of injury assessment
**Total Seagrass cover is scored separately and may not equal the sum of the individual species values

Statistical Analysis

The graphical depiction of results in Figure 4 shows that by the time of the August 7, 2008 (5.5 year) monitoring event, most parameters had nearly converged between the Reference and Restoration areas. For the coral as well as the macroalgal cover (Figure 4c & d), no statistically significant differences were evident. Regarding the *T.testudinum* shoot count data (Figure 4a), which depicts Reference and Restoration area means of 4.9 and 3.2, respectively, statistical analysis likewise yielded no significant difference. However, significant difference was detected, with a p-value = 0.0376 for *Thalassia* areal coverage.

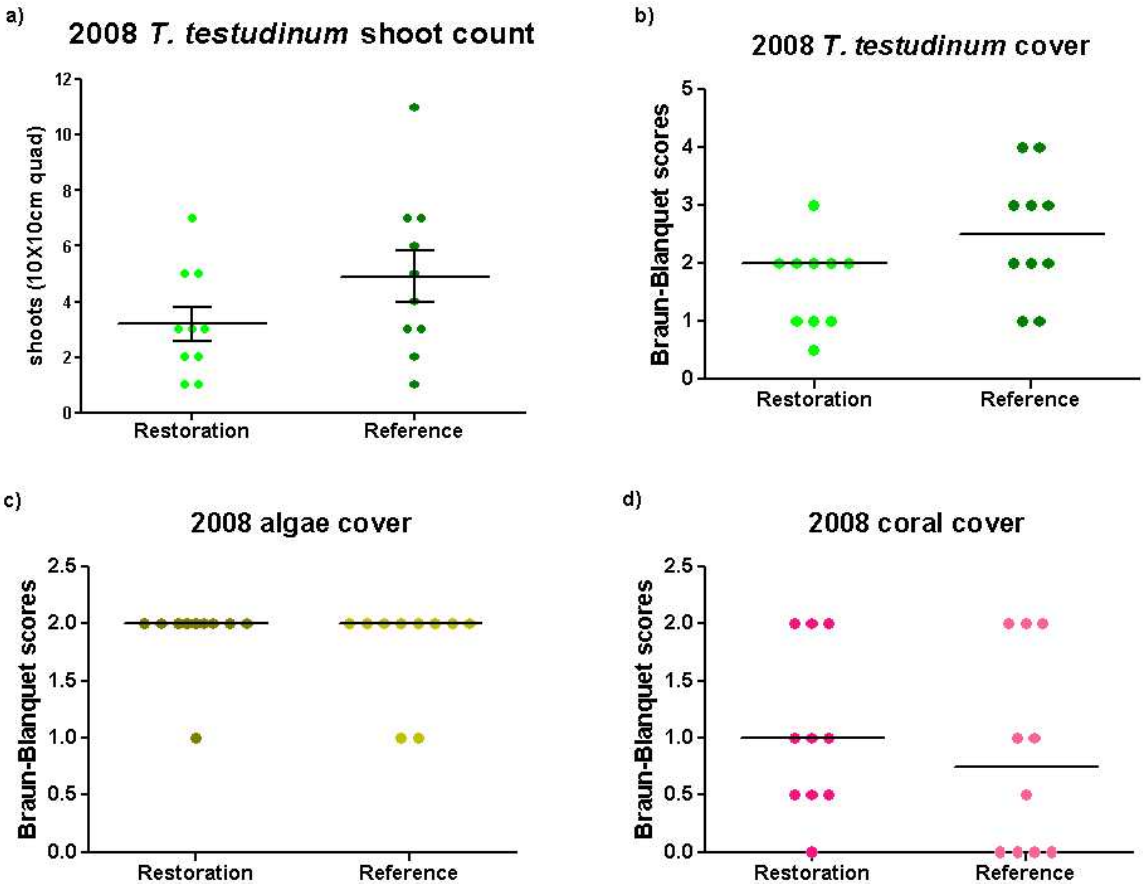

Figure 4. Circles indicate Braun-Blanquet scores. On shoot count graph (a) long horizontal lines represent means; shorter lines above and below represent +/- SEM. For all other graphs (b, c, d) long horizontal lines represent medians. The *T. testudinum* cover data (b) evidenced significant difference between the restoration and the reference area; there were no significant differences among the remaining datasets.

Model Recovery Estimates

The recovery model predicted that with the addition of the 44 planting units it would take 5.64 years for *T. testudinum* to be 100% recovered in the berm,. Without planting units, the model predicted it would take 9.4 years. For the blowhole/scrape, it would take 22.56 years to reach 100% with the planting units and 30.08 years without (Table 16). For *H. wrightii* and *S. filiforme*, the model predicted it would take 0.92 years for the berm and 3.66 years for the blowhole/scrape to reach 100% recovery with the addition of planting units. Without planting units, it would take 1.53 years for the berm and 4.88 years for the blowhole/scrape (Table 17).

Table 16. Model predicted percent recovery of *T. testudinum* at the *N-Control* restoration site.

Years	Berm with PUs	Berm without PUS	Blowhole/Scrape with PUs	Blowhole/Scrape without PUs
3.76	75.71%	40.24%	51.69%	28.76%
5.64	**100.00%**	71.95%		
7.52		93.90%	76.78%	54.52%
9.40		**100.00%**		
11.28			87.27%	70.90%
15.04			94.01%	82.27%
18.80			98.88%	90.97%
22.56			**100.00%**	96.99%
26.32				99.67%
30.08				**100.00%**

Table 17. Model predicted percent recovery of *H.wrightii/S.filiforme* at the *N-Control* restoration site.

Years	Berm with PUs	Berm without PUS	Blowhole/Scrape with PUs	Blowhole/Scrape without PUs
0.61	75.71%	40.24%	51.69%	28.76%
0.92	**100.00%**	71.95%		
1.22		93.90%	76.78%	54.52%
1.53		**100.00%**		
1.83			87.27%	70.90%
2.44			94.01%	82.27%
3.05			98.88%	90.97%
3.66			**100.00%**	96.99%
4.27				99.67%
4.88				**100.00%**

Calculated Recovery Estimates

The density statistic (D_{ir}) of the restoration area was inclusive of all features (blowhole/scrape and berm) that were restored. Based on the percent recovery calculation, *T. testudinum* was 66% recovered 5.5 years after restoration was initiated (Table 18). For *H. wrightii* and *S. filiforme*, percent recovery was calculated to be 200% and 133.3%, respectively, on the 5.5 year event (Table 18).

Table 18. Percent recovery of *T. testudinum*, *S. filiforme* and *H. wrightii* at the *N-Control* restoration site based on the density statistic D_i.

Year	Density of Restoration (D_{ir})	Density of Reference (D_{ic})	Percent Recovered
T. testudinum			
0.5	0.2	1.8	11.1%
1.0	0.03	1.8	1.6%
3.0	0.6	3.3	18.2%
3.5	0.55	2.6	21.15%
5.5	1.65	2.5	66%

S. filiforme			
0.5	0.1	0.5	20%
1.0	0	1.6	0
3.0	0.2	0	0
3.5	0.4	0	0
5.5	0.4	0.3	133.3%
H. wrightii			
0.5	0.8	0.1	800%
1.0	0	0.3	0
3.0	1.7	0.1	1700%
3.5	2.2	0	0
5.5	0.6	0.3	200%

DISCUSSION

The purpose of monitoring the *N-Control* restoration site was to determine whether successful establishment of the planted seagrass had occurred and if it was on an appropriate recovery trajectory. The monitoring data was also used to assess the potential need for mid-course corrections and to ensure that the restoration project was meeting designated restoration performance standards.

This monitoring consisted of six events over a five and a half year period. The data collected using the modified Braun-Blanquet technique formed the basis of our comparison of the aerial coverage in the restoration and reference area. Over the monitoring period, the percent cover of total seagrass in the restoration area increased. We also observed an initial increase in the transplanted species, *H. wrightii* and *S. filiforme,* and then an eventual decrease, which occurred after the removal of the fertilizer source (bird stakes). The target species, *T. testudinum* also increased in percent cover in the restoration area during the monitoring period. Two other functional groups, macroalgae and coral, exhibited complete recovery by the final monitoring event.

At this time, the FKNMS DARRP program does not actively restore *Porites* spp. coral in this habitat type. As we continue to monitor restorations in seagrass beds where *Porites* spp. coral had been injured, we have observed the eventual natural recolonization of *Porites* spp. back into the site. The presence of this coral is very important because the consolidated *Porites* spp. rubble form the geologic framework of the seagrass banks in this particular area and is essential to maintaining their stability (McNeill 1988).

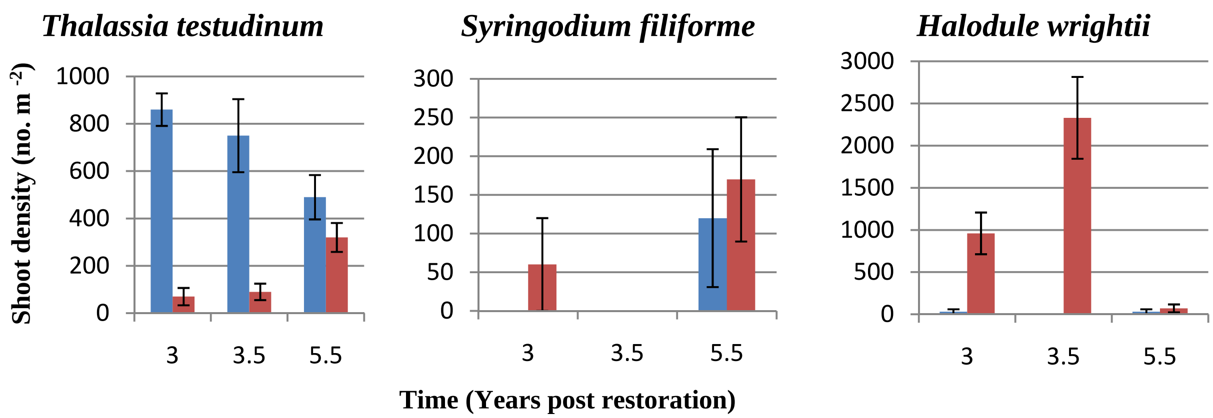

Figure 5. Shoot density (no. m^{-2}, mean ±SE) of *T. testudinum*, *S. filiforme* and *H. wrightii* in the restored and reference area. Shoot density data was unavailable for the reference area for the 0.5 and 1 year events, therefore only the 3, 3.5 and 5.5 year events are presented.

Based on the shoot density data, recovery was exhibited in the restoration area (Figure 5). Specifically, the shoot density of *H. wrightii* decreased post planting but then displayed rapid growth, typical of early colonizing seagrass species (*H. wrightii* and *S. filiforme*) in the Florida Keys. By the 5.5 year event, *H. wrightii* had decreased substantially and *T. testudinum* had become the dominant species, but had yet to reach the density of the reference area. *S. filiforme* was present in the restoration area at four out of five monitoring events, but did not exhibit the sporadic growth seen by *H. wrightii* and was only observed in the reference area on the 5.5 year event.

For the monitoring of this particular restoration project, the injury features were not consistently defined at each event, so they were combined into one “restoration area”. The recovery model, using the cellular automata technique, accounts for a difference in the rate of recovery between the blowhole/scrape and berm. For the *N-Control*, the berm was predicted to recover at a rate four times that of the blowhole with the addition of planting units. This recovery model predicted it would take 5.64 years for *T. testudinum* to be 100% recovered in the berm, and 22.56 years to be 100% recovered in the blowhole/scrape, with the addition of the 44 planting units. Using the figures from the calculated recovery estimates, a linear regression was generated and it projected that the “restoration area” would be 100% recovered for *T. testudinum* in 10.57 years (Figure 6).

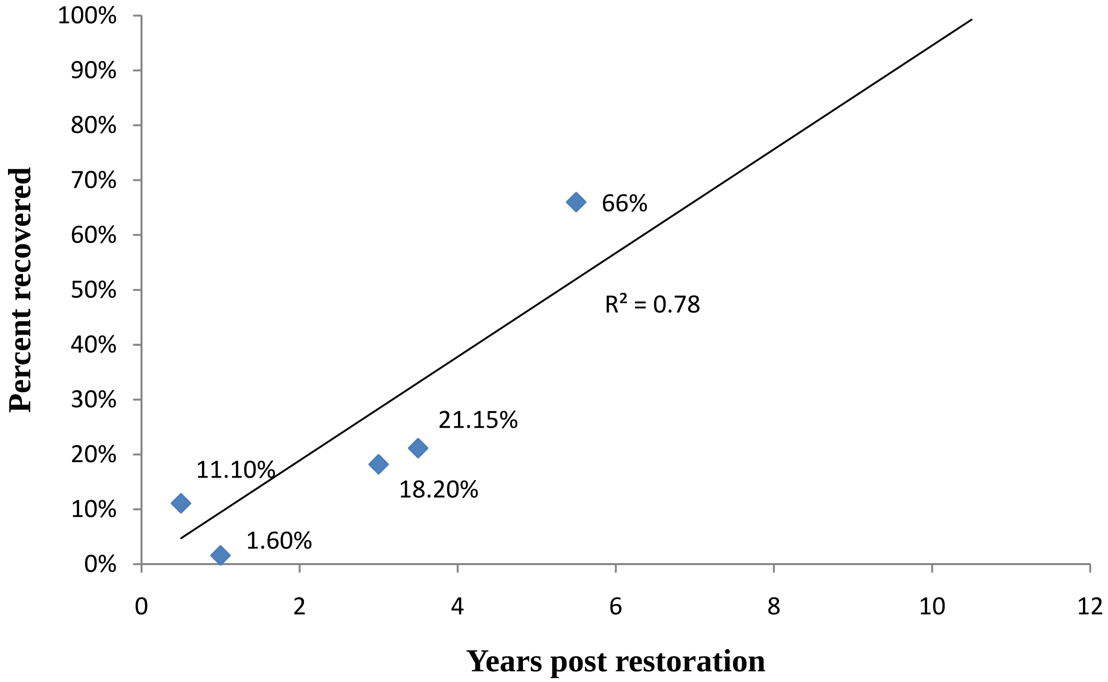

Figure 6. Calculated percent recovery of *T. testudinum* over time post restoration.

The *N-Control* ran aground in a mixed seagrass species system. In this type of habitat it is common for fast-growing, opportunistic species to temporarily substitute for, or even replace, the dominant climax species (Olesen et al. 2004). We know from existing literature that seagrass succession happens naturally in the Caribbean (Williams 1990, Gallegos et al. 1994, Kenworthy et al. 2002, Di Carlo and Kenworthy 2008) and this pattern of succession seems to hold true for injury features in seagrass (den Hartog 1971, 1977, Walker et al. 1989, Rasheed 1999, Olesen et al. 2004). The restoration area benefited from both the planting of *H. wrightii* and *S. filiforme* and the presence of opportunistic species in the surrounding reference area. Planting seagrass in injured areas is known to be an effective way of stabilizing the sediments and decreasing the injury recovery time (Fonseca et al. 1998). Research has shown that planting faster growing, opportunistic species like *H. wrightii* or *S. filiforme* serves as a temporary substitute for the climax species, *T. testudinum*. This temporary substitution is referred to as "modified compressed succession" (Durako and Moffler, 1984; Lewis, 1987). The addition of bird stakes as a form of "natural" fertilizer aided in the establishment of the newly planted fast growing species of seagrass (Kenworthy et al. 2000). The added fertilizer also encouraged the "in-growth" of seagrass from the surrounding reference area.

The goal of this restoration was to accelerate recovery of the injured area to pre-grounding baseline levels. The results show that the injured area is gaining seagrass and coral coverage and though it has yet to reach pre-grounding baseline levels for the climax species, *T. testudinum*, the coverage of the climax species is increasing. Results from the recovery model show that the time to 100% recovery has been reduced compared to if no restoration was conducted. This is of particular importance because the model was recently found to under predict recovery time of vessel grounding injuries (Uhrin et al. 2009). If the injury site had been left alone it could take much longer to recover. Research has shown that natural recovery is slow, taking several years to several decades, depending on the location and severity of the injury (Uhrin et al. 2009). Larger polygonal injuries, particularly those where sediment has been excavated in addition to the seagrass rhizomes, are particularly slow to recover and may increase substantially in area and volume, especially if subjected to strong storms, such as hurricanes (Kenworthy et al. 2002, Whitfield et al. 2002, Hammerstrom et al. 2007, Di Carlo and Kenworthy 2008, Uhrin et al. *in prep*). Research on restoration techniques and natural recovery continues to provide valuable information on the practicality and effectiveness of seagrass restoration on vessel grounding injuries (Uhrin et al. 2009, Uhrin et al. *in prep*). In the FKNMS, seagrass restoration is a common practice at vessel grounding sites. There are currently over thirty ongoing restorations that have been implemented by the FKNMS. The data collected from the monitoring of these sites will also play an important role in the further development of restoration and monitoring techniques and recovery model development.

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Appendix A: Photo documentation of the *N-Control* vessel grounding, injury site and restoration area.

Photo 1: The *N-Control* vessel aground

Photo 2: The berm injury feature

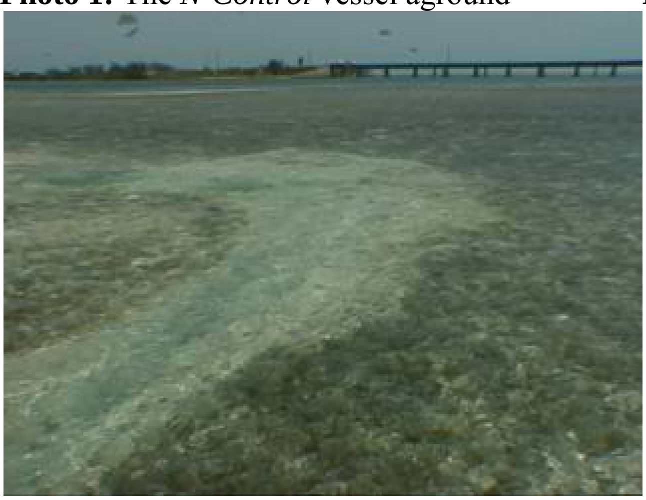

Photo 3: The scrape injury feature

Photo 4: Severed *T. testudinum* rhizomes

Photo 5: Bird stakes installed as part of the restoration.

Photo 6: An *H. wrightii* planting unit at the restoration site.

Photo 7: Evidence of expansion of an *H. wrightii* planting unit 6 months after planting.

Photo 8: Coral recruitment in the restoration area on the 1.0 year event.

Photo 9: *S. filiforme* in the restoration area on the 1.0 year event.

Photo 10: Part of the restoration area covered with *H. wrightii* on the 1.5 year event.

Photo 11: Braun-Blanquet quadrat from the restoration area on the 3.5 year event.

Photo 12: Image taken of the restoration area on the 5.5 year event.

Appendix B: The modified Braun-Blanquet Cover-Abundance Scale used in the estimation of benthic cover for this assessment.

Braun-Blanquet (BB) Cover-Abundance Scale with Range Mid-Point Values

BB Score		Cover	Range Mid-Point
0	=	Not Present	0
0.1	=	Solitary individual	1% *
0.5	=	Few, with small cover	1% *
1	=	Numerous, <5%	2.5%
2	=	5% to 25%	15%
3	=	25% to 50%	37.5%
4	=	50% to 75%	62.5%
5	=	75% to 100%	87.5%

***** Mid-point was assigned the value of 1%. Whereas the higher BB scores reference specific ranges in percent cover, the lower scores are primarily estimates of abundance (i.e. the number of individuals).

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