Marine Sanctuaries Conservation Series ONMS-11-07

Lagniappe II Coral Reef Restoration Monitoring Report Monitoring Events 2002 to 2010 Florida Keys National Marine Sanctuary Monroe County, Florida

U.S. Department of Commerce
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National Ocean Service
Office of National Marine Sanctuaries

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Lagniappe II
Coral Reef Restoration Monitoring Report
Monitoring Events 2001 to 2010
Florida Keys National Marine Sanctuary
Monroe County, Florida

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COVER

Injured *Montastraea faveolata* colonies at the *Lagniappe II* grounding site (Photo Credit: NOAA)

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ABSTRACT

This document presents the results of a restoration and four subsequent monitoring events designed to track the recovery of coral habitat restored after injury involving a nearshore patch reef within the boundaries of the Florida Keys National Marine Sanctuary (FKNMS). The *Lagniappe II*, a 12 m cabin cruiser, ran aground on a patch reef near Boca Chica Key in August 2002. The damage to the reef involved a path of injury which impacted approximately 35 m^2 of living coral. The majority of the resulting coral fragments were quickly triaged and used for subsequent restoration activities that attempted to recreate the benthic structure as it had existed prior to the grounding. The majority of the stony coral injured consisted of *Montastraea faveolata*, a primary reef building species in the Florida Keys. Structural restoration was completed in October 2002 and permanent transect lines were established for long-term, digital photographic comparisons of restoration and adjacent "un-impacted" reference areas in order to track patterns of recovery. Coral Point Count with Excel extensions (CPCe) was used to analyze coral benthic coverage. Monitoring occurred at zero, two, seven, and eight years after the restoration was completed. Results showed that by 2010 the mean percent cover of coral was generally lower in the control transect than in the restored transect. The methodology used to restore the injury at the *Lagniappe II* vessel grounding site supports the intended restoration objectives of the National Marine Sanctuaries Act.

KEY WORDS

Florida Keys National Marine Sanctuary, vessel grounding, damage assessment, coral, macroalgae, monitoring, Coral Point Count analysis

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ACKNOWLEDGEMENTS

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, thus, are responsible for mediating the restoration of the damaged marine resources and monitoring the outcome of the restoration actions. The authors would like to express their appreciation to all Florida Department of Environmental Protection employees who participated in the initial response, damage assessment, restoration, and case settlement associated with this vessel grounding.

INTRODUCTION

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 Florida Keys National Marine Sanctuary (FKNMS). Pursuant to the National Marine Sanctuaries Act (NMSA) 16 U.S.C. 1431 et seq., and the Florida Keys National Marine Sanctuary and Protection Act (FKNMSPA) of 1990 (public law 101-605), NOAA and the state have the authority to seek damages from those responsible for injuring sanctuary resources. The goal of a Natural Resource Damage Assessment (NRDA) under NMSA § 312 is to assess the extent of the injury to the sanctuary resources, recover response and damage assessment costs, and implement primary and compensatory restoration to make the environment and public whole for the losses resulting from the injury (NOAA 2010). Monitoring of both primary and compensatory 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 (NOAA 2010). In addition, restoration monitoring allows the trustees to track patterns of biological recovery, determine the success of restoration measures, and assess the resiliency of the site to environmental and anthropogenic disturbances over time. Reference sites (uninjured habitats adjacent to restoration sites) are concurrently monitored for comparative purposes. This document presents a synopsis of the damage assessment, restoration methodology and timing, and the detailed monitoring results of a repaired coral reef injured by the *Lagniappe II* vessel grounding incident of August 8, 2002, which occurred within the Florida state waters within the FKNMS.

Damage Assessment[1]

On August 8, 2002, the *Lagniappe II*, a 12 m Tiara cabin cruiser ran aground on a patch reef approximately 1.0 km off Boca Chica Key in state waters of the FKNMS (Figure 1). Water depths in this area typically range from 0.9 to 3.4 m; NOAA Chart #11445 indicates <0.3 m depth at this patch at Mean Lower Low Water. The patch reef is roughly circular in outline and dominated by the stony coral *Montastraea faveolata*. Other living biota within and adjacent to the injury area include stony corals, soft corals (octocorals), sponges, macroalgae, seagrass and various species of fishes and invertebrates.

The grounding consisted of a single track running at 240°-250° with an initial impact point and numerous concentrated areas of injury extending approximately 37 m, terminating in a final impact point/final resting place of the vessel (Figure 2). A total of 596 coral fragments (> 5 cm) and/or whole colonies, predominantly *M. faveolata* (>99%),

[1] The information in this section was adapted from National Oceanic and Atmospheric Administration and Florida Department of Environmental Protection. 2002. *Lagniappe II* vessel grounding injury assessment report. 6 pp.

were injured as a result of this grounding. The area of impact was measured to be 35.13 m^2 of injury to living corals and carbonate framework.

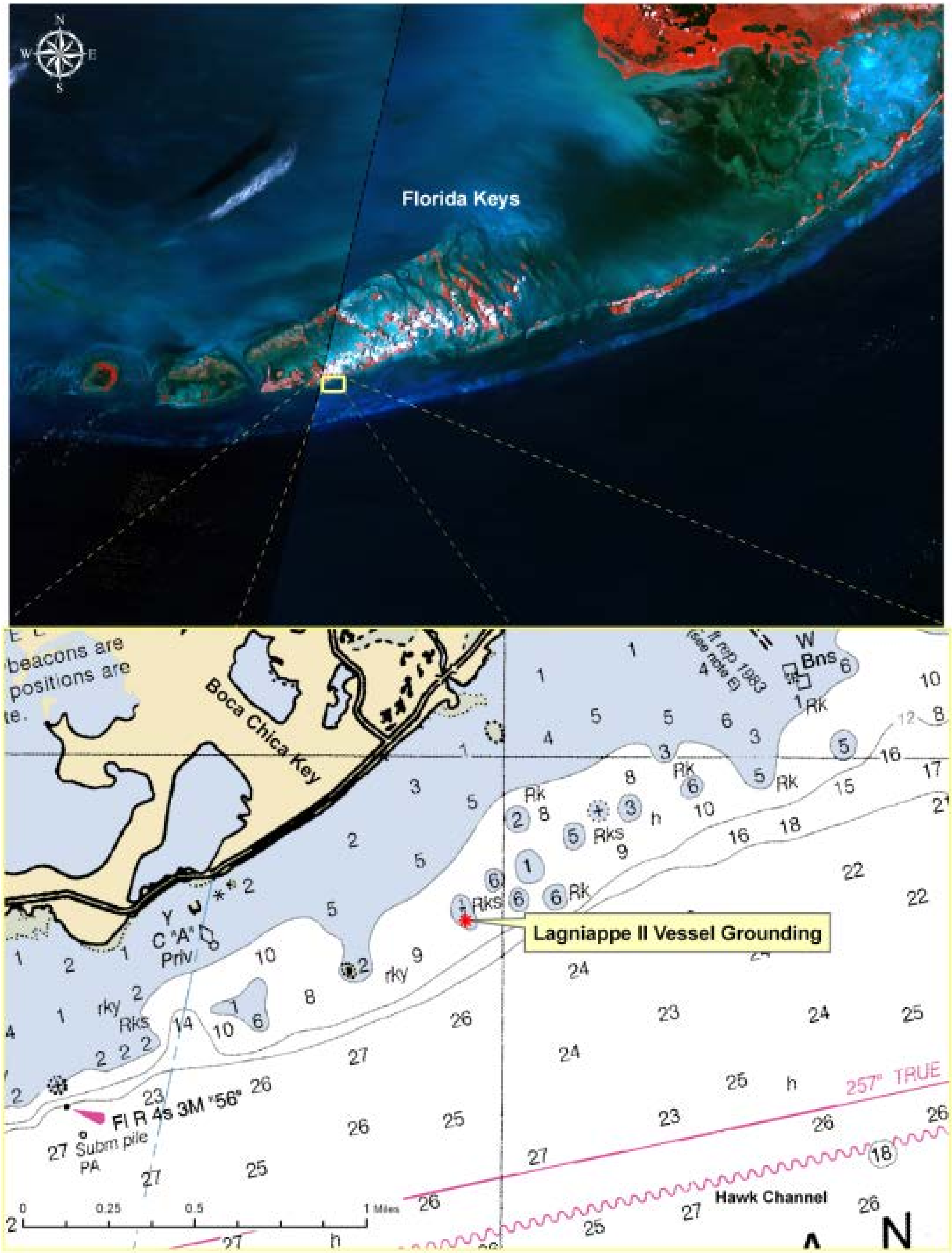

Figure 1. Map of *Lagniappe II* vessel grounding location on August 8, 2002.

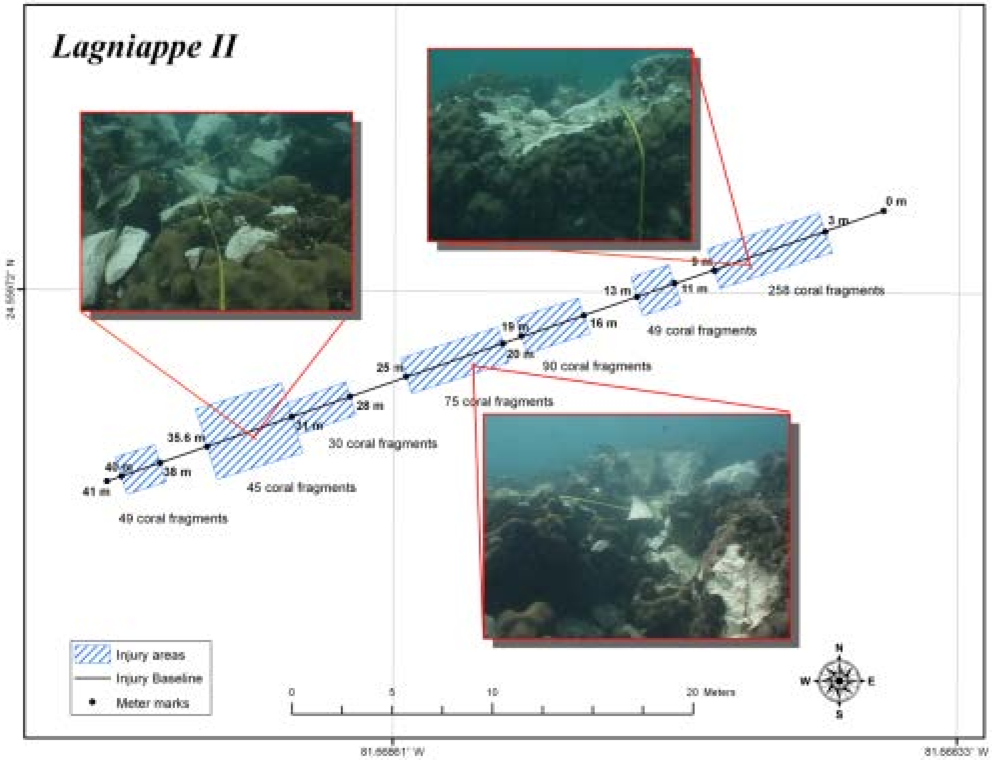

Figure 2. Graphical representation of the injury area from the *Lagniappe II* grounding off Boca Chica Key, Florida.

Coral Stabilization and Restoration[2]

According to the NMSA, the goal of restoration activities is to return injured coral communities as much as possible to pre-injury, or "baseline" conditions. The baseline conditions are typically measured in the undisturbed reef communities adjacent to the injury area.

Primary restoration of this site was completed on October 5, 2002. The efforts to meet the restoration goal at the *Lagniappe II* site were to 1) salvage and reattach displaced coral fragments, and 2) stabilize reef substrate and rubble along the impact track.

To meet the restoration goal for this site, staff from the National Coral Reef Institute (NCRI) of Nova Southeastern University Oceanographic Center (NSU OC), along with divers subcontracted from Industrial Divers Corporation (IDC), worked at the *Lagniappe II* grounding site on stabilization and restoration activities from August 24-28, 2002 and on October 5, 2002 (NCRI only).

[2] The information in this section was adapted from National Coral Reef Institute and Nova Southern University. 2002. Draft *Lagniappe II* Restoration and Baseline Monitoring Report. 38 pp.

Emergency stabilization procedures were initiated near the exit end of the injury tract first, where most of the larger coral fragments were located, and continued along the injury track toward the entry point. NCRI chose appropriate stabilization sites based on criteria discussed in the Draft Restoration Plan prepared by NOAA and DEP (NOAA 2002). Sites were prepared according to those criteria by cleaning the substrate of algae and other fouling organisms. In many cases masonry nails were used to improve stabilization of larger fragments and groups of smaller fragments that were cemented together as a unit.

All reattached coral fragments were of the species *M. faveolata* with the exception of one fragment of *Porites astreoides*. Immediately after reattachment, the plan-view living tissue area of each of the stabilized coral fragments was measured (length and width to the nearest cm), percent bleaching was recorded, and the fragment's general location along the injury tract was mapped. Figure 3 illustrates the general location and distribution of the 473 stabilized coral fragments along the injury tract.

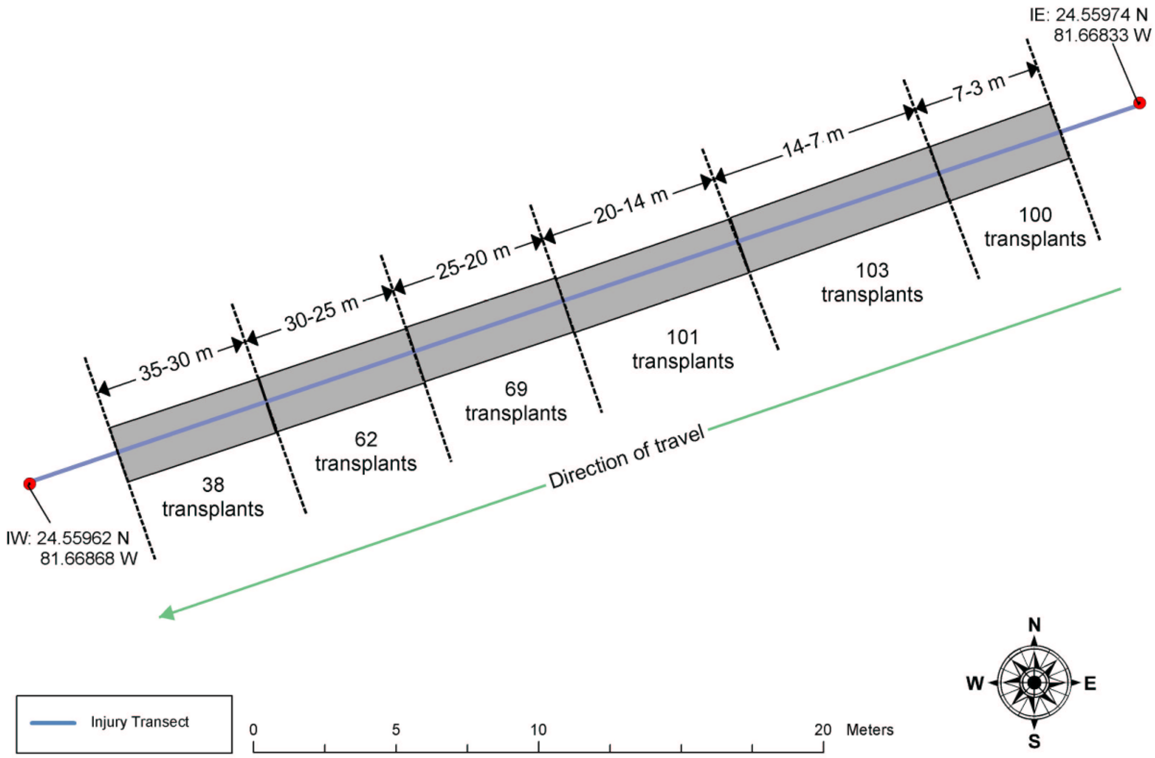

Figure 3. General location and distribution of the 473 stabilized coral fragments along the injury tract. Center line (blue) indicates original transect tape, bottom arrow (green) indicates the boat's direction of travel when injury occurred, and dashed lines show the general distribution of stabilized coral fragments.

Restoration Monitoring

The purpose of coral restoration monitoring is to evaluate the success of trustee actions in achieving restoration goals and to determine whether remedial measures are needed. A list of success criteria measures for structural and functional aspects of coral reef restoration as well as a framework for monitoring activities was identified by NOAA (Thayer et al. 2003). For the *Lagniappe II* grounding, the evaluation of restoration efforts involved the identification of appropriate success criteria and designing and implementing a sampling and analysis plan.

The guiding issues considered during the evaluation of this restoration site centered on the efficacy of the restoration techniques and the condition of the site relative to reference habitats. Thus, the restoration site was evaluated for:

- Incidence of algal cover
- Structural integrity of reef framework
- Evidence of disease or bleaching
- Increase or decrease in living coral tissue (lateral or plan-view growth)
- Evidence of new recruits on cement substrate, and
- Evidence of bioerosion of stabilized fragments.

Therefore, monitoring was designed to detect significant changes in coral cover, damage to restoration components (structural enhancements, coral transplants, etc.) as a result of external events, such as major storms or vandalism, and to compare the restored site to the surrounding habitat.

The assessment, restoration, and monitoring event timeline is shown in Table 1. Due to unavoidable operational difficulties in 2007 and 2008, the second monitoring event did not occur until June 2009.

Table 1. Event timeline for the *Lagniappe II* grounding site; assessment, restoration, and monitoring.

Event	**Date**
Vessel Grounding	August 8, 2002
Injury Assessment	August 9 and 11, 2002
Restoration	August 24-28, and October 5, 2002
Baseline Monitoring	October 5, 2002
First Monitoring Event	January 4, 2004
Second Monitoring Event	June 12 and 16, 2009
Third Monitoring Event	August 12, 2010

METHODOLOGY

Field Methods

Tactile and visual assessments of restabilized coral fragments were performed to evaluate the physical stability of the restoration site. Assessments of the biological condition of reattached corals were also performed during each monitoring event. To determine the biological condition of the site, *in situ* observations and digital images of each station were taken.

On August 27 and 28, 2002, the restoration and reference transects were each established using three permanently installed stainless steel pins, two at either ends and one at each center point. The reference transect was approximately 9 m north of the restoration area transect, and in an area that was qualitatively similar in complexity and cover to the injury area. The transect centerline for both the restoration and reference sites was a fiberglass metric ruled tape that was secured to each of the respective three stainless steel pins. This centerline served to locate the restoration and reference station tags, and consistently position the photo quadrats.

All monitoring stations were defined by a 0.75 m^2 quadrat. Twenty four restoration stations and 24 reference stations with a total area of 18 m^2 each were established along the respective transect (Figure 4). The location of each station was identified by distance (meter mark) along each transect and position to the right or left of the transect (Appendix A). Thus, 16 ‘pins’ were permanently installed along the restoration transect and 18 pins permanently installed along the reference transect (Figure 4).

Because of the shallow water depth along each transect, a single, complete image of the 0.75 m^2 station area could not be taken. Therefore, each 0.75 m^2 station was subdivided into four images. Figure 5 illustrates the position of the station (quadrat) along the transect and the location of the four images within the station. Each image was taken with an underwater camera using a wide-angle lens. At each monitoring event, qualitative digital video was also taken along the restoration and the reference transects. Due to unavoidable operational difficulties in 2007 and 2008, the second monitoring event did not occur until June, 2009.

Photo Analysis

Digital images were analyzed using a Coral Point Count with excel extensions (CPCe) software program (Kohler and Gill 2006) for coral and macroalgae cover. The analysis of the images was preceded by a statistical test of equality of two proportions in order to determine the optimum number of random points (35) to be projected on to each image.

The organism or substrate under each of these points was identified using the CPCe categories (Figure 6).

Data Analysis

Because the photo analysis was repeated in the same 48 quadrats (the same geographic spaces) each year, irrespective of transect type, a repeated measures ANOVA (Zar 1999) was used to analyze the data using SPSS for Windows, v12.0.1, which adjusted for any missing records. Image points were pooled for each quadrat (subject) each year to analyze among (transect type) and within (time) subject factor. Three null hypotheses were addressed with this analysis.

> H_o: The mean percent cover of coral is the same in each transect.
> H_o: The mean percent cover of coral is the same each year.
> H_o: Differences observed in the mean percent cover of coral among transects are the same each year (transect x time interaction).

Non-transformed benthic cover data was used in analysis. A comparison with arcsine transformed cover data yielded the same overall conclusions. Mauchly's test was used to test the condition of sphericity, and Huynh-Feldt estimates of sphericity were used to correct the degrees of freedom; these procedures are common to ANOVAs with repeated measures (within-subject factors).

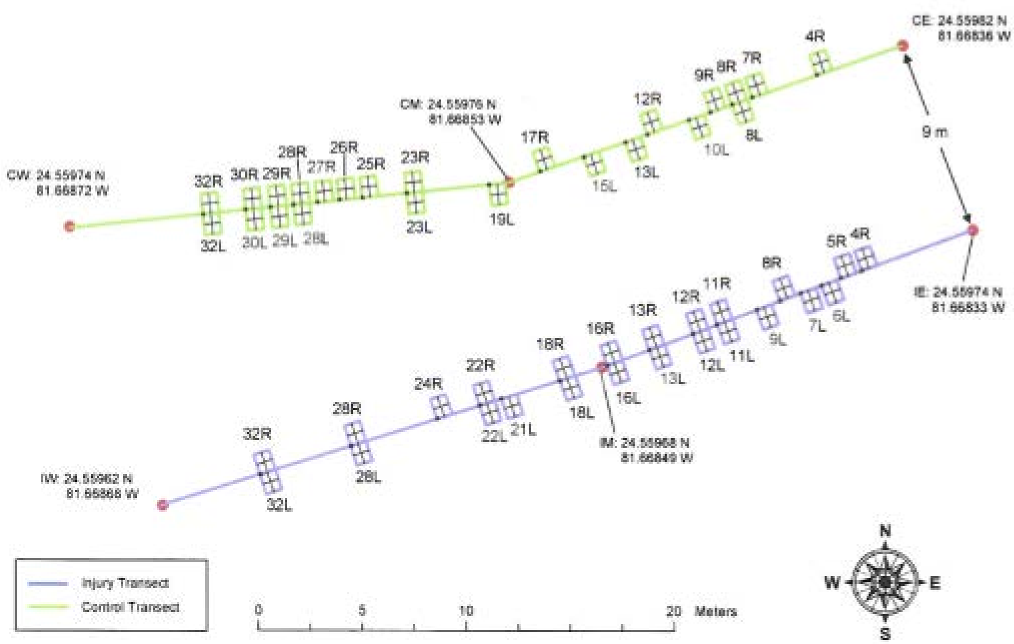

Figure 4. *Lagniappe II* restoration (blue/bottom), reference (green/top) transects and quadrat placement. Red dots indicate permanent pin placement and black dots indicate quadrat marker location. The colored squares identify the 0.75 m^2 quadrat and the black lines within define the area of individual photographs taken with the digital camera for CPCe analysis.

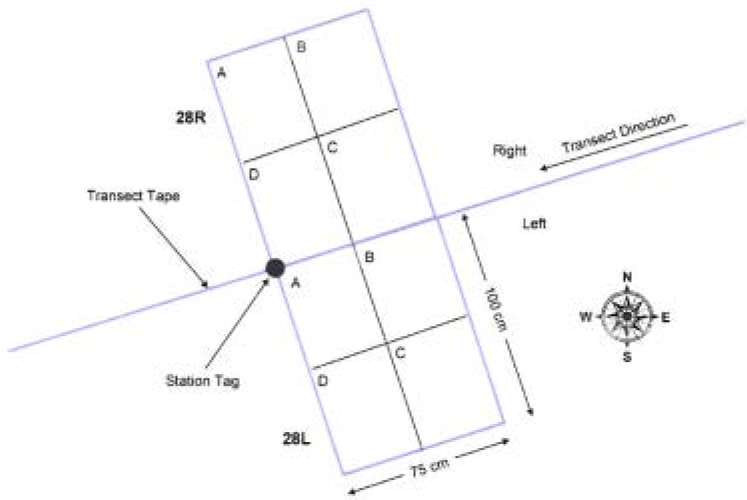

Figure 5. Schematic diagram of individual quadrat placement along the transect. The black dot indicates the quadrat marker location. The colored squares identify the 0.75 m^2 quadrat and the letters within the quad indicate the location of individual photographs taken with the digital camera for CPCe analysis.

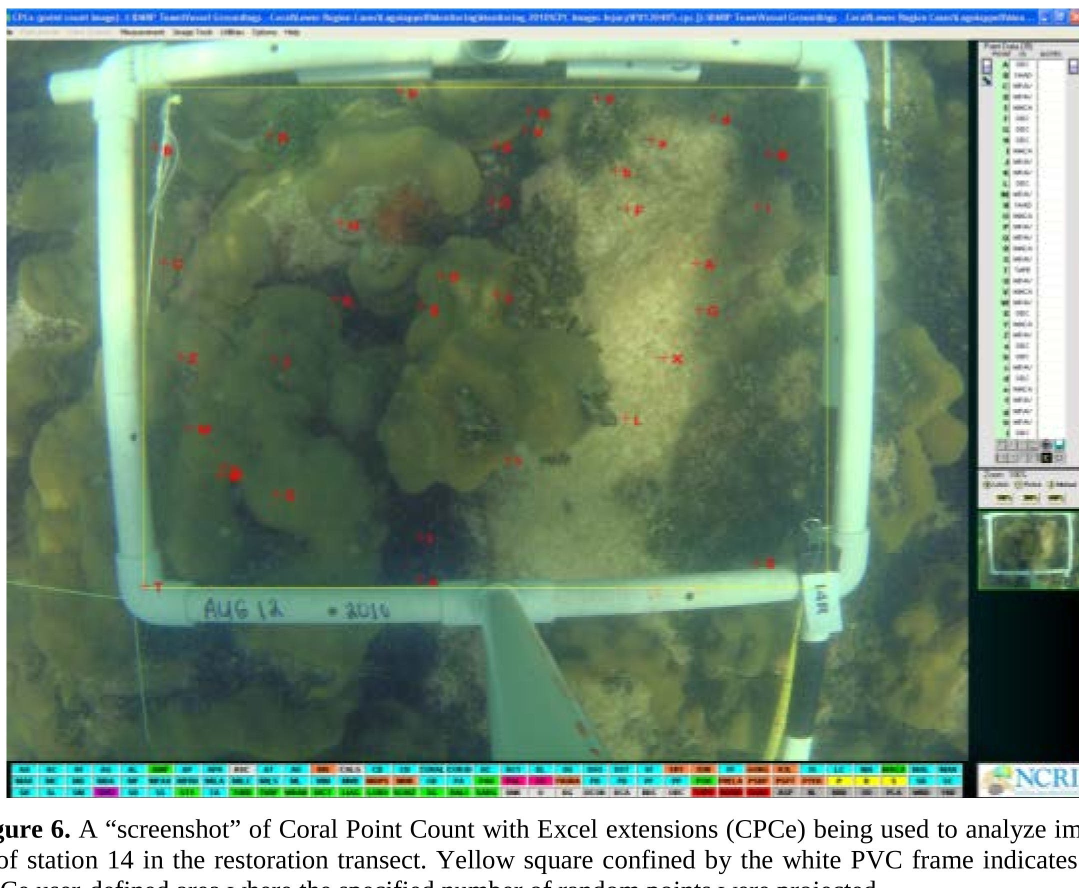

Figure 6. A "screenshot" of Coral Point Count with Excel extensions (CPCe) being used to analyze image D of station 14 in the restoration transect. Yellow square confined by the white PVC frame indicates the CPCe user-defined area where the specified number of random points were projected.

RESULTS

Structural Integrity

During the baseline monitoring event, the stability of reattached coral fragments was found to be visually and tactically sound. The fragments were in place with a stable attachment to the substrate and there were no visible cracks in the cement grout surface. By the 2009 monitoring event, the reattached coral fragments were indistinguishable from the uninjured coral colonies. There were signs of a few missing reattached coral fragments – only attaching nails that anchor the cement and substrate were observed at the west end of the restoration site. There were also signs of physical alteration to the eastern portion of the patch reef. A large boulder was found on top of one of the quadrat stations, and some of the station tags from the restoration and reference transects could not be located. The condition of reattached coral fragments during the 2010 monitoring event was similar to that of the 2009 event. However, unlike the 2009 event, the visual inspection of the entire patch reef, including *Lagniappe II* restoration and reference areas, revealed the evidence of recent mortality of *M. faveolata* colonies.

Coral Cover

Generally, coral cover in both transects had similar values until 2010, when coral cover in the reference area declined below that of the restored area (Figure 7). Mauchly's test indicated that the assumption of sphericity (inherent in repeated measures ANOVA) had been violated, χ^2 (5) = 15.778, $p < 0.05$, therefore degrees of freedom were corrected using Huynh-Feldt estimates of sphericity ($\varepsilon = 0.862$). The ANOVA results showed that mean coral cover was the same in both transects $F(1,42) = 1.184$, $p > 0.05$), and that coral cover changed over time, $F(2.585, 108.59) = 8.293$, $p < 0.01$(Appendix B). Post-hoc pair-wise comparisons indicated that the mean percent cover of coral in both transects was not significantly different in years 2002 and 2004 but was significantly different than year 2010. Because of the limitation of these comparisons, the relationship of coral cover in 2009 to the other years was unclear. Additionally, there was no interaction between year and transect $F(2.585, 108.59) = 1.893$, $p > 0.05$, suggesting differences of coral cover among years were the same in both transects. The mean percent cover of coral was generally lower in the control transect than in the restored transect by 2010.

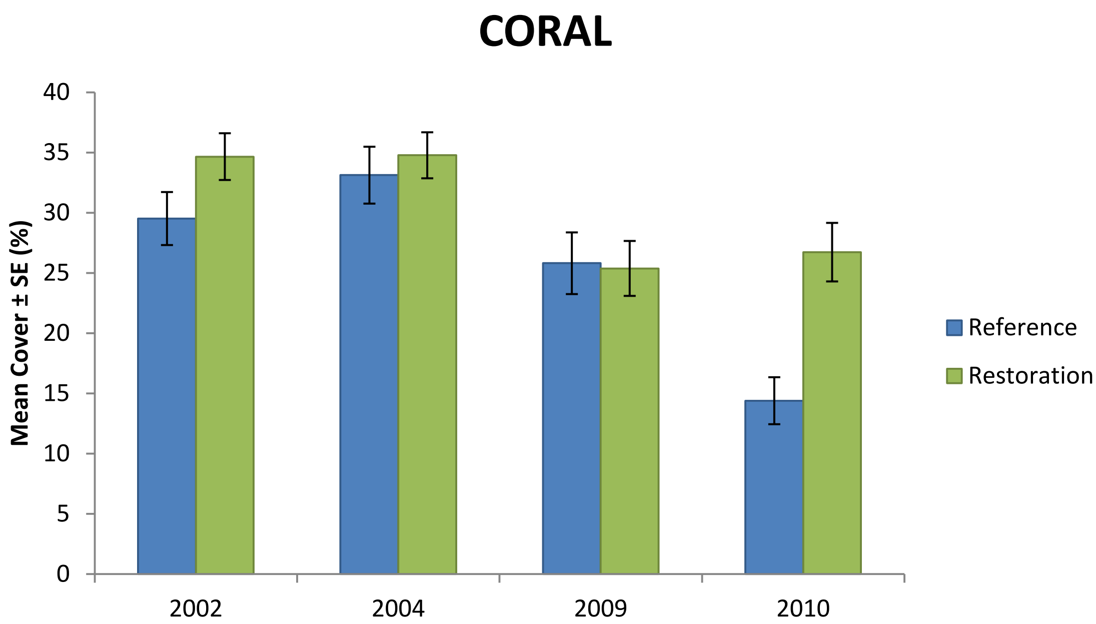

Figure 7. Mean (±SE) percent cover (%) of coral in the restoration and reference areas in 2002, 2004, 2009, and 2010.

DISCUSSION

The general goal of restoration is to return injured coral communities to pre-injury, or "baseline" conditions. The monitoring results from the *Lagniappe II* restoration site reflect the restoration goals set forth in the NMSA. At the 2010 monitoring event, coral cover in the restoration area was generally higher than that in the reference area. Even though the coral cover in the restoration area fell below the baseline (2002) condition by the 2010 monitoring event, it can be concluded that the restoration at the *Lagniappe II* grounding site was an overall success due to several reasons. First, coral cover in both transects had similar values until 2010. At the 2010 monitoring event, coral cover in the restoration area was higher than that in the reference area. Also, the coral cover in the restoration area remained closer to the baseline condition than the reference area. The restoration transect experienced a 20% decrease in coral cover from the baseline to the 2010 event, while the reference transect experienced a 50% decrease in coral cover.

Coral cover in both the restoration and reference transects declined over time and responded in a similar fashion to environmental events until the 2010 monitoring event. Many environmental factors can affect organisms on the reef and change conditions over time. There are several potential explanations for the decline in coral cover, such as the active hurricane season of 2005. Hurricane-generated waves often break coral branches and overturn coral colonies (Wilkinson and Souter 2008). The *Lagniappe II* restoration site experienced the near passage of several major hurricanes in 2005 (Hurricane Dennis in July, Hurricane Katrina in August, Hurricane Rita in September, and Hurricane Wilma in October). It is possible that the hurricane-generated waves caused the damage to corals in both transects which led to the presence of the large boulder on top of a quadrat station and missing station tags observed during the 2009 monitoring event. After the 2005 hurricane season, storm-related injury was evident at several other coral restoration monitoring sites that are within 10 km from the *Lagniappe II* grounding site. During the September 2005 monitoring event, which was after Hurricanes Dennis and Katrina, the *Connected* restoration site at Western Sambo Reef had noticeable physical damage to restored corals, and one of the restoration modules was overturned by storm-generated waves (Schittone et al. 2006). Significant site alteration was also observed and documented at the *Jacquelyn L* restoration site at Western Sambo Reef in September 2005, which resulted in the discontinuation of monitoring at this site by FKNMS staff biologists (Franklin et al. 2006).

The long term decline in coral cover throughout the Caribbean and Florida Keys has been well documented (Gardner et al. 2003, Maliao et al. 2008, Somerfield et al. 2008, Ruzicka et al. 2010). Gardner et al. (2003) reported a clear and striking decline in absolute coral cover in Caribbean reefs from 1977 to 2002. Studies specific to the Florida Keys (Maliao et al. 2008, Somerfield et al. 2008, Ruzicka et al. 2010) have also shown the decline in coral cover since 1996. A wide variety of causes and human activities have been implicated as driving forces of coral cover decline, including overfishing, nutrient pollution, climate change, and coral diseases. Any individual or combination of these factors could be the cause for the decrease in coral cover in both restoration and reference transects between the baseline and the 2010 monitoring event at the *Lagniappe II* restoration site. It should be noted that the Florida Keys Coral Reef Evaluation and Monitoring Project[3] (CREMP) survey showed that since 1999 there has been no change in coral cover on Florida Keys patch reefs, however coral cover among both shallow and deep reefs has declined (Ruzicka et al. 2010). This is not consistent with our findings at the *Lagniappe II* restoration site, which is located on the nearshore patch reef.

The decline in coral cover in the *Lagniappe II* reference site in 2010 also could have been influenced by the cold-water event that occurred from January 2 - 13, 2010. The CREMP survey indicated that coral mortality was observed across all stations that were surveyed in February 2010; decline at nearshore sites was particularly significant. Some near-shore stations experienced a greater than 50% decline in *Montastraea* spp. coral cover (FWC 2010). During our 2010 monitoring event, the evidence of recent mortality of *M. faveolata* colonies was observed at the restoration site and surrounding area. The *M. faveolata* dominated patch reef of the *Lagniappe II* restoration and reference sites might have been affected by the 2010 winter mortality event. However, this does not fully explain the unaffected coral cover in the restoration site in 2010. The reference and restoration transects are only nine meters apart. The reference area may have been subjected to different biotic and abiotic factors such as another vessel grounding, disease outbreak or acute predation.

[3] Coral Reef Evaluation and Monitoring Project (CREMP) was initiated in 1995 to monitor the condition of selected coral reefs, patch reefs, and hardbottom areas in FKNMS. The surveys have been conducted annually at 34 fixed sites and data provides information on the temporal changes in special cover and diversity of stony corals, octocorals, macroalgae, and sponges.

Macroalgae cover was also analyzed in the same manner as coral cover. There was an increase in macroalgae cover from the 2004 to the 2009 and 2010 events. However, the results were omitted from this report because seasonal dynamics of macroalgae cover was not factored in during the analysis. Lirman and Biber (2000) and Clollado-Vides et al. (2005) observed marked seasonal patterns of macroalgae cover, especially for *Halimeda* spp and *Dictyota* spp that were abundant at *Lagniappe II* restoration and reference areas, with higher cover in summer and lower in winter. The monitoring events at *Lagniappe II* restoration site were conducted in October 2002 for the baseline event followed by three monitoring events in January 2004, June 2009, and August 2010. The results showed lower macroalgae cover during the 2004 event and higher macroalgae cover during the 2009 and 2010 events, which can be due to the seasonal dynamics of macroalgae abundance. Other studies by Norstrom et al. (2009) and Rogers and Miller (2006) indicated that a sudden loss of coral cover from an event such as passing of a major hurricane, acute predation, disease outbreak, and a vessel grounding can lead to colonization of newly available space by macroalgae, shifting towards macroalgae dominant reef communities. In contrast, the studies by Ruzicka et al. (2010) and Schutte et al. (2010) showed that the long-term trend of macroalgae cover on the Florida Keys reef communities has changed very little. Because the results were not accounted for seasonal effects of macroalgae cover, it is difficult to conclude the trends of macroalgae cover from 2002 to 2010 at *Lagniappe II* restoration and reference areas.

Though these results support the intended restoration goals of the NMSA, it is clear that a greater frequency of monitoring would provide more valuable data on habitat fluctuations which could lead to setting more effective restoration goals and improved management of sanctuary resources.

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APPENDIX A

The location of the restoration and reference monitoring stations. L or R after the tag numbers represents left or right of each transect line.

RESTORATION TRANSECT		
Station	Tag Number	Distance (m) from Entrance Pin
1	4R	5.2
2	5R	6.2
3	6L	7.1
4	7L	8.1
5	8R	9.1
6	9L	10.2
7	11R	12.2
8	11L	12.2
9	12R	13.2
10	12L	13.2
11	13R	15.3
12	13L	15.3
13	16R	17.3
14	16L	17.3
15	18R	19.5
16	18L	19.5
17	21L	22.1
18	22R	23.2
19	22L	23.2
20	24R	25.2
21	28R	29.1
22	28L	29.1
23	32R	33.3
24	32L	33.3

REFERENCE TRANSECT		
Station	Tag Number	Distance (m) from Entrance Pin
1	4R	4
2	7R	7
3	8R	8
4	8L	8
5	9R	9
6	10L	10
7	12R	12
8	13L	13
9	15L	15
10	17R	17
11	19L	19
12	23R	23
13	23L	23
14	25R	25
15	26R	26
16	27R	27
17	28R	28
18	28L	28
19	29R	29
20	29L	29
21	30R	30
22	30L	30
23	32R	32
24	32L	32

APPENDIX B

Results of the statistical analysis performed on coral and macroalgae data.

CORAL

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
time	Huynh-Feldt	4621.862	2.585	1787.630	8.293	.000
time * Transect	Huynh-Feldt	1055.012	2.585	408.054	1.893	.143
Error(time)	Huynh-Feldt	23406.218	108.590	215.547		

Tests of Between-Subjects Effects

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Transect	853.478	1	853.478	1.184	.283
Error	30283.854	42	721.044		

MACROALGAE

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
time	Huynh-Feldt	7314.262	2.636	2774.730	18.628	.000
time * Transect	Huynh-Feldt	1220.970	2.636	463.186	3.110	.035
Error(time)	Huynh-Feldt	16491.129	110.713	148.954		

Tests of Between-Subjects Effects

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Transect	179.675	1	179.675	.654	.423
Error	11546.505	42	274.917		