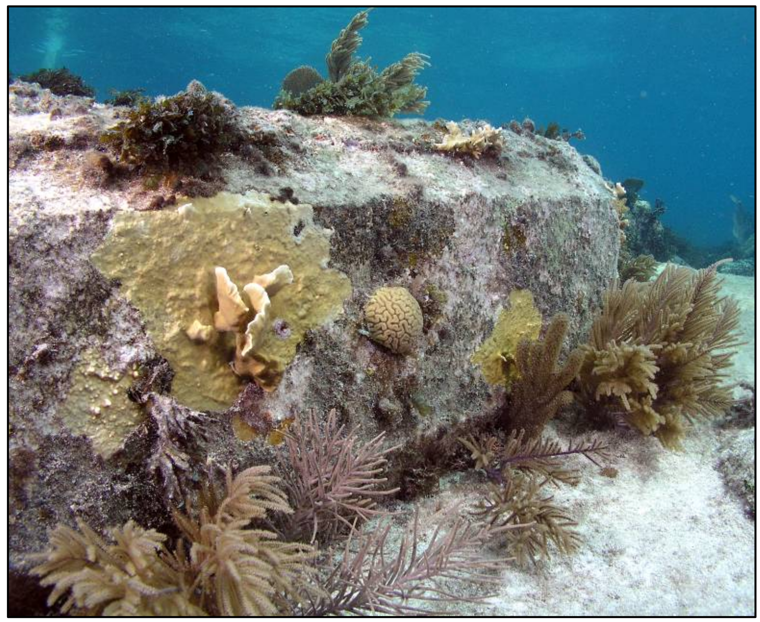
Marine Sanctuaries Conservation Series NMSP-08-01



M/V *ALEC OWEN MAITLAND*
Coral Reef Restoration Monitoring Report
Monitoring Events 2004-2007
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
National Marine Sanctuary Program

National Marine Sanctuaries

January 2008

About the Marine Sanctuaries Conservation Series

The National Oceanic and Atmospheric Administration administers the National Marine Sanctuary Program. Its mission is to identify, designate, protect and manage the ecological, recreational, research, educational, historical, and aesthetic resources and qualities of nationally significant coastal and marine areas. The existing marine sanctuaries differ widely in their natural and historical resources and include nearshore and open ocean areas ranging in size from less than one to over 5,000 square miles. Protected habitats include rocky coasts, kelp forests, coral reefs, sea grass beds, estuarine habitats, hard and soft bottom habitats, segments of whale migration routes, and shipwrecks.

Because of considerable differences in settings, resources, and threats, each marine sanctuary has a tailored management plan. Conservation, education, research, monitoring and enforcement programs vary accordingly. The integration of these programs is fundamental to marine protected area management. The Marine Sanctuaries Conservation Series reflects and supports this integration by providing a forum for publication and discussion of the complex issues currently facing the National Marine Sanctuary Program. Topics of published reports vary substantially and may include descriptions of educational programs, discussions on resource management issues, and results of scientific research and monitoring projects. The series facilitates integration of natural sciences, socioeconomic and cultural sciences, education, and policy development to accomplish the diverse needs of NOAA's resource protection mandate.

M/V *ALEC OWEN MAITLAND*
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Florida Keys National Marine Sanctuary
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January 2008

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COVER

Upper left: M/V *Alec Owen Maitland* aground south of South Carysfort Reef, Florida Keys National Marine Sanctuary. Photo credit: Florida Keys National Marine Sanctuary.

Lower right: Naturally-recruited coral colonies on reef restoration module, photographed on June 7, 2005, at the M/V *Alec Owen Maitland* restoration site, Florida Keys National Marine Sanctuary. Photo credit: Jeff Anderson, NMSP/NOAA.

SUGGESTED CITATION

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ABSTRACT

This document presents the results of the first three monitoring events to track the recovery of a repaired coral reef injured by the M/V *Alec Owen Maitland* (hereafter referred to as the "*Maitland*") vessel grounding incident of October 25, 1989. This grounding occurred within the boundaries of what at the time was designated the Key Largo National Marine Sanctuary (NMS), now designated the Key Largo NMS Existing Management Area 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, NOAA is the federal trustee for the natural and cultural resources of the FKNMS. Under Section 312 of the NMSA, NOAA has the authority to recover monetary damages for injury, destruction, or loss of Sanctuary resources, and to use the recovered monies to restore injured or lost sanctuary resources within the FKNMS. 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 the condition of Restored reef areas with "natural" coral reef areas unimpacted by the vessel grounding or other injury. Restoration of the site was completed in September 1995, and thus far three monitoring events have occurred; one in the summer of 2004, one in the summer of 2005, and the latest in the summer of 2007. The monitoring has consisted of: assessment of the structural stability of restoration armor units and comparison of the biological conditions on the restoration armor units with those of the Reference area. Monitored corals are divided into Gorgonians, Milleporans, and Scleractinians. Densities at the Restored and Reference areas are compared, and are shown to be approximately equal. Size-class frequency distributions for the most abundant Scleractinian are examined, and reveal that the Restoration is converging on the Reference area. Also, for the Scleractinians, number and percentage of colonies by species, as well as several common biodiversity indices are provided, and measures for the Restored area exceed Reference values. A quantitative comparison of colony substrate settlement preference in the Restoration area is provided for all Orders, and for Scleractinians is further broken down for the two most frequent Genera. Finally, some inter-annual comparisons for Gorgonians and Scleractinians are presented. Generally, results indicate that Restored areas have greater coral density and biodiversity than Reference areas.

KEY WORDS

Florida Keys National Marine Sanctuary, coral, grounding, restoration, reef armor units, monitoring, *Maitland*, Carysfort Reef, recruitment, Anthozoa, Hydrozoa, Octocorallia, Hexacorallia, Gorgonacea, Anthoathecata (*Millepora*), Scleractinia

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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. Thanks as well to all reviewers, with a special thanks due to Dr. Greg Piniak. All errors remain the authors' own.

INTRODUCTION

This document presents the results of the first three monitoring events to track the recovery of a repaired coral reef injured by the M/V *Alec Owen Maitland* (hereafter referred to as the "*Maitland*") vessel grounding incident of October 25, 1989. This grounding occurred within the boundaries of what at the time was designated the Key Largo National Marine Sanctuary (NMS), now designated the Key Largo NMS Existing Management Area 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, NOAA is the federal trustee for the natural and cultural resources of the FKNMS. Under Section 312 of the NMSA, NOAA has the authority to recover monetary damages for injury, destruction, or loss of Sanctuary resources, and to use the recovered monies to restore injured or lost sanctuary resources within the FKNMS. 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 the condition of Restored reef areas with "natural" coral reef areas unimpacted by the vessel grounding.

The monitoring program at the *Maitland* site includes an assessment of the structural stability of installed restoration armor units and coral recruitment patterns, to be performed on the following schedule: nine, ten, twelve, and fifteen years after restoration. Restoration of this site was completed in the summer of 1995 with monitoring planned to begin in following years. However, due to staffing and other logistical constraints, the first biological monitoring event for this site was delayed until August 2004. In June and July 2005, the second monitoring event took place, and in July, August, and September 2007, the third. This report presents the results of all three monitoring events.

Table 1. Event timeline for the M/V *Alec Owen Maitland* grounding site; assessment, restoration, and monitoring.

Event	**Date**
Vessel Grounding	October 25, 1989
Vessel Removal	October 26, 1989
Injury Assessment: Initial	October 26, 1989
Pre-Construction Survey	June-July 1993
Restoration	August-September, 1995
First Monitoring Event	August 2004
Second Monitoring Event	June-July 2005
Third Monitoring Event	July-September 2007
Fourth Monitoring Event	Summer 2010

Damage Assessment

[Note: The information in this section was adapted from: National Oceanic & Atmospheric Administration, (undated). Coral Reef Restoration Key Facts—M/V *Alec Owen Maitland* Grounding; and, Gittings, S. R., 1991. Mitigation & Recovery Enhancement at the Grounding Site of the M/V *Alec Owen Maitland*, Key Largo National Marine Sanctuary.]

On October 25, 1989, the M/V *Alec Owen Maitland*, a 47-meter oil field supply vessel, ran aground in a reef coral community south of Carysfort Reef, about 1.5 nautical miles southwest of Carysfort Light, in 2-3 meters of water (Figure 1 and Figure 2). Additional injury occurred as the result of initial attempts to power off the reef. The grounding totally destroyed 681 m^2 of living corals and partially destroyed 930 m^2 of coral reef framework (NOAA undated).

As the vessel approached the reef, it created an inbound grounding track approximately 88 m in length and injured all bottom substrate. The injury toppled or injured many large coral heads and left bottom paint embedded in exposed coral skeletons. At the end of and perpendicular to the inbound path, was an area 64 m in length where the vessel reportedly turned during initial freeing efforts. The final resting site was at the end of the turning path, parallel to the axis of the inbound path, but displaced 30 m to the west.

The grounding of the ship and subsequent attempts to free it resulted in significant injury to the reef substrate and resident marine organisms. Approximately 70 percent of the coral colonies and 79 percent of the total coral cover, as well as numerous sponges and sea fans at the site, were destroyed by the grounding. The injuries ranged from superficial scraping of the reef surface and toppling of large coral heads to complete crushing of coral heads and severe cracking of the reef framework structure. Attempts by the vessel to extricate itself caused “blowholes” (excavations caused by high-revving propellers) in the reef’s surface (Figure 3). In following years these blowholes quadrupled in size while waiting for restoration. In the absence of restoration efforts they would likely have continued to expand, and thus have perpetuated the continuing loss of Sanctuary habitat.

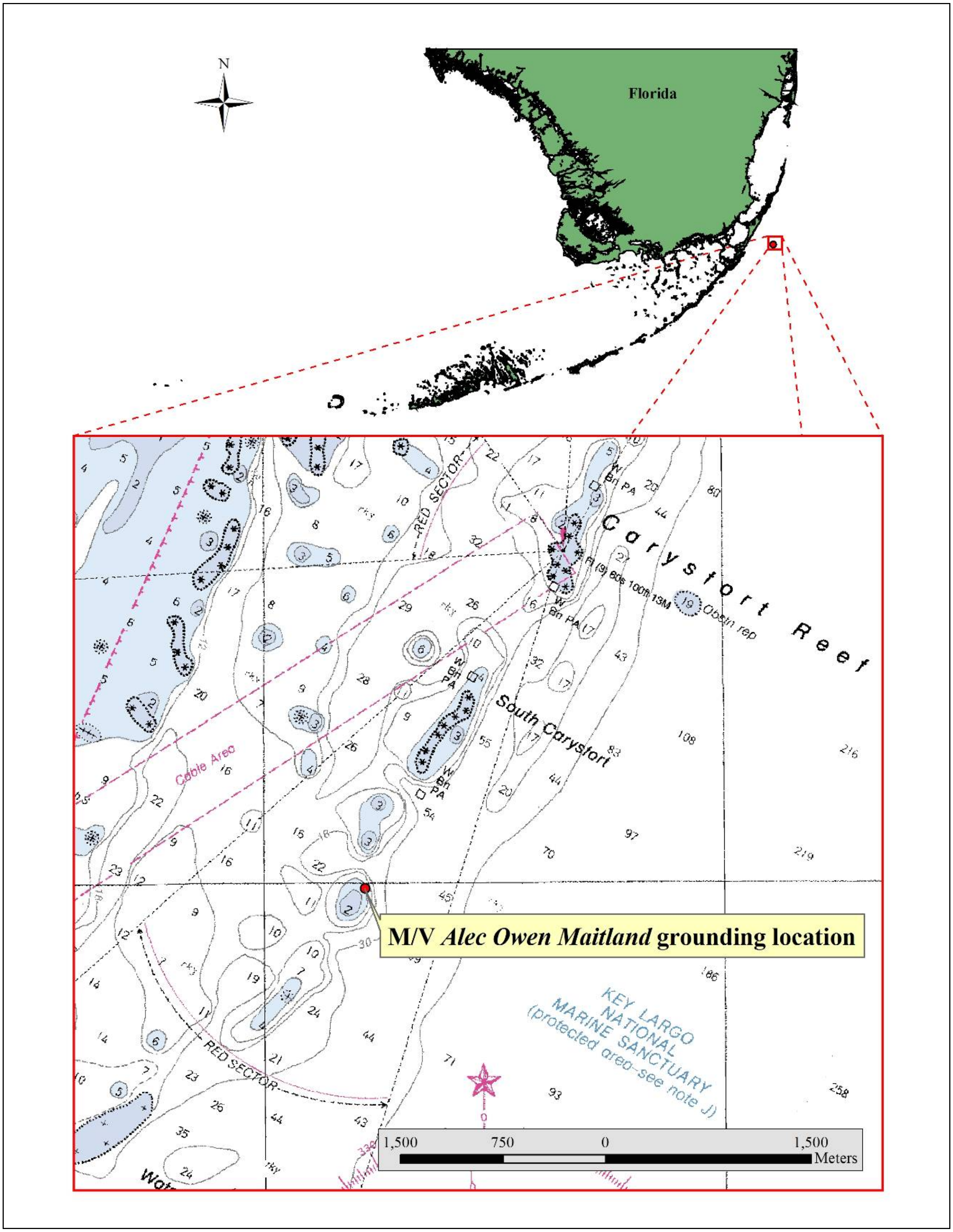


Figure 1. Location (shown on NOAA Chart 11463) that the M/V *Alec Owen Maitland* ran aground south of South Carysfort Reef on October 25, 1989.

Figure 2. M/V *Alec Owen Maitland* aground south of South Carysfort Reef (photo credit: Paige Gill NMSP/NOAA).

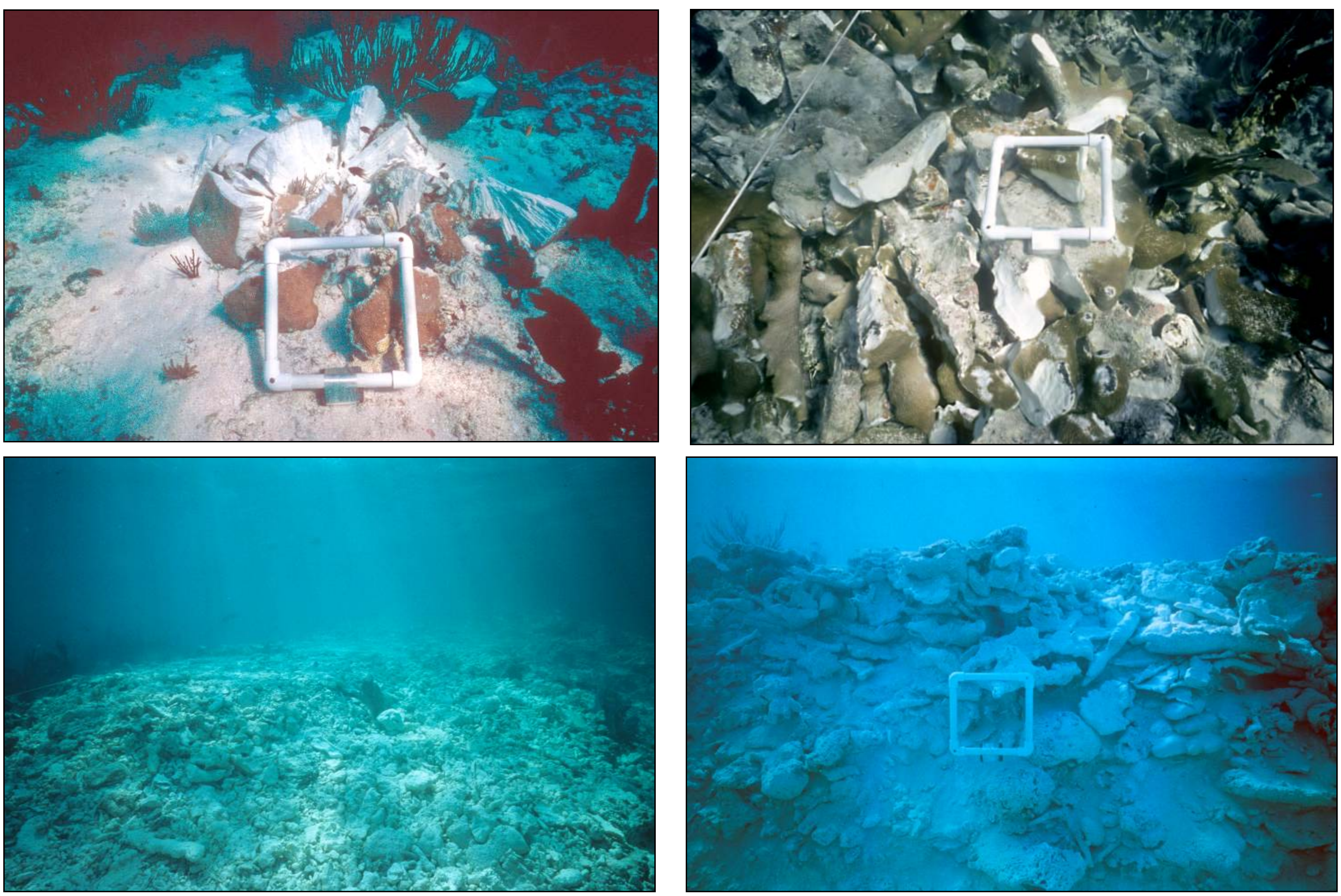


Figure 3. Top row: Fractured *Siderastrea siderea* and *Acropora palmata* colonies. Bottom row: Rubble area and wall of blowhole crater (quadrat is 25 cm × 25 cm) (photo credits: Harold Hudson NMSP/NOAA).

The *Maitland* grounding impacted two distinct communities. One, the *Gorgonia/Millepora* community, had relatively high, but quite variable cover. The other, a flat rock habitat, had very low cover of any type coral. Both are probably physically-controlled assemblages (i.e. waves control the community structure). The dominant species in the *Gorgonia/Millepora* zone were sea fans and fire corals, many of which were large. Scleractinian corals were frequent, but small. Numerically, the Scleractinian fauna at the site was dominated by colonies of species frequently found as recruits in recruitment studies (e.g. *Porites* spp.). Physically, the largest colonies at the site were *Acropora palmata, Siderastrea siderea, Diploria strigosa,* and *D. clivosa*. *A. palmata* colonies were large, and some thickets in the deeper portions of the grounding site contained a dozen or more colonies. The other species were infrequent and generally much less than 0.5 m in diameter. Areas most extensively damaged by the grounding probably did not contain *A. palmata* thickets (based on depth and topographic characteristics.).

NOAA and the responsible parties agreed to a settlement in October 1991. The damages received from the responsible parties were allocated to repayment of response and damage assessment costs and for future restoration and monitoring of the site.

In 1992 a catastrophic storm, Hurricane Andrew, severely impacted the *Maitland* site. The storm passed less than 60 miles to the north of the site, with winds exceeding 130 mph (Figure 4). At 1000 UTC (6 a.m. local time) on August 24, 1992, NOAA's National Data Buoy Center's Coastal-Marine Automated Network (C-MAN) recording station on the nearby Molasses Reef Lighthouse recorded sustained 48 kts (55 mph) winds, and a peak gust of 59 kts (68 mph). After the hurricane's passage, it was found that the blowholes had expanded and merged together (CSA 1993). NOAA believed the hurricane's effects exacerbated the grounding injuries, and that additional injuries would continue absent restoration. Restoration undertaken in 1995 was planned by National Marine Sanctuary Program (NMSP) headquarters and FKNMS staff, in collaboration with marine engineers from the commercial firm of Olsen Associates, Inc., and implemented by Team Land and Development, Inc. along with FKNMS staff.

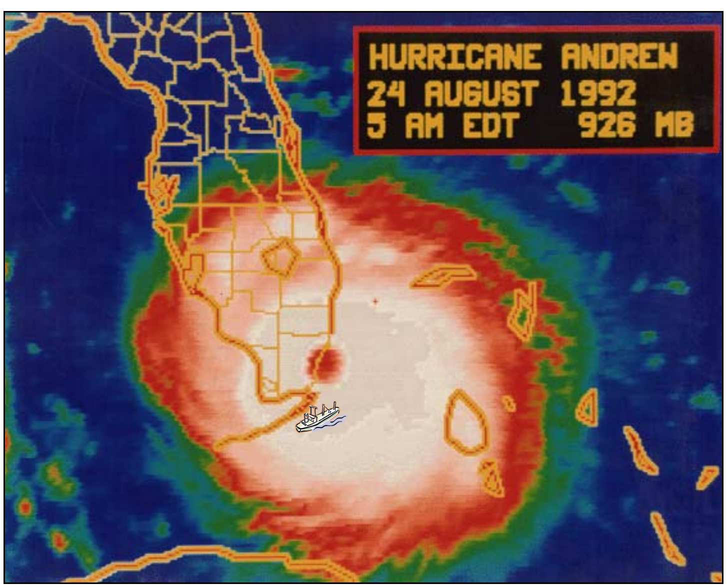


Figure 4. Hurricane Andrew relative to the *Maitland* grounding site (ship graphic not to scale).

Coral Reef Restoration

[Note: The information in this section was adapted from the “Reef Restoration Action Project” Report (undated) prepared by the (then) NOAA Sanctuaries and Reserve Division (now the National Marine Sanctuary Program).]

The objectives of the *Maitland* site restoration were to fill in the blowhole and to stabilize the damaged reef framework. Engineering design for the site was particularly challenging because of the scope of the damage, the site’s shallow-water, high energy environment, and the proximity to sensitive biological resources. Structural repairs to the site included the placement of 40 pre-cast concrete and limestone boulder armor units to fill in the grounding crater, filling approx. 800 m^2 in total. After placement, they were sealed with approximately 45 m^3 of underwater pumped concrete (a.k.a. puddle pour). Before setting, the concrete was embedded with locally quarried limestone rocks (Figure 5, Figure 6, and Figure 7).

The armor units were designed in six sizes to accommodate the crater’s complex and varying geometry. Each unit weighed approximately 9.5-10 tons above water. The units were designed to withstand wave and current forces anticipated in a once-in-25-year-storm event. The structure has withstood the passage of several close hurricanes (Georges in 1998 and at least seven more recent storms, to be discussed below). Overall, the restoration was intended to “re-create a stable foundation which closely emulates the adjacent natural seabed and which would foster future recruitment of the local biota” (Bodge 1996).

Figure 5. Pre-cast concrete and limestone boulder armor unit used in the *Maitland* restoration (photo credit: Harold Hudson NMSP/NOAA).

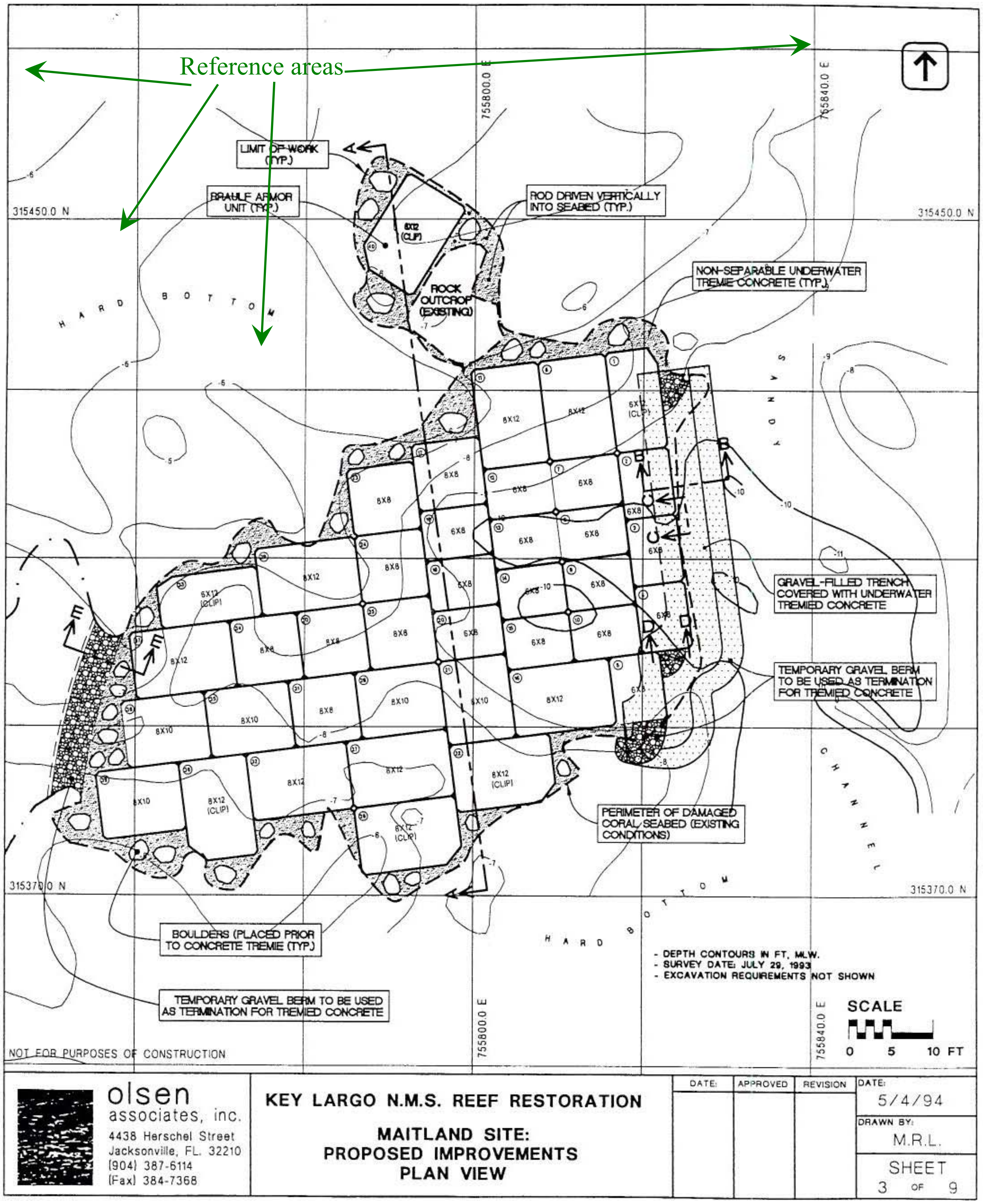


Figure 6. Schematic diagram of restoration area depicting locations of reef armor units and "puddle pour" areas (shaded areas in diagram surrounding armor units) along with approximate location of Reference sampling area.

Figure 7. Completed restoration with armor units (left) and "puddle pour" with limestone "dressing" stones (right) (photo credits: Harold Hudson NMSP/NOAA).

Restoration Monitoring

The purpose of the NMSP coral restoration monitoring program is to evaluate the success of trustee actions in achieving restoration goals and to determine if remedial measures are needed. The evaluation of restoration efforts involves the identification of appropriate success criteria and the design and implementation of a sampling and analysis plan. A list of success criteria measures for structural and functional aspects of coral reef restoration as well as a framework for monitoring activities has been identified by NOAA (Thayer et al. 2003), several of which are found below.

The guiding hypotheses for the evaluation of the "restoration" site reflect the efficacy of the restoration techniques and the condition of the site relative to reference habitats. The monitoring program addresses whether the chosen restoration methods are effective and when the site could be considered restored. The monitoring program for the *Maitland* site is designed to detect significant changes in the structural stability of the reef restoration armor units and concrete puddle pour areas as a result of external events, such as major storms or vandalism, as well as significant changes in new coral recruitment, compared to the surrounding reference habitat.

The structural integrity of the restoration site was evaluated with the following questions:

1. Is the attachment of the reef restoration armor units to the substrate stable?
2. Are there any visible cracks in the surface of the reef restoration armor units and/or puddle pour concrete?
3. Is any undermining occurring around the armor units and/or puddle pour areas?

In addition, the biological condition of the restoration site was evaluated with the following question:

> Is there a difference in new coral recruitment between the grounding site and the Reference area?

METHODOLOGY

MONITORING EVENTS

Between August 5 and 10, 2004, the *Maitland* restoration site was monitored using SCUBA from a small vessel (6.4 m). The same vessel was utilized for all subsequent monitoring visits. Another monitoring event occurred on June 7 and July 26, 2005 and the latest monitoring visit occurred between July 27 and September 14, 2007. Between the August 2004 and the June 2005 monitoring events, the eyes of three powerful hurricanes passed within 250 kilometers of the restoration site; Charley in late August, and Jeanne and Frances in September 2004. Each sustained winds approximating 175-195 kph at the time of closest approach to the restoration site. The possible confounding effects of these hurricanes, if any, are discussed below; no monitoring of the site was conducted in the interim. In 2005, hurricane Dennis made its closest approach between the June and July portions of the 2005 monitoring event, at similar distance and wind speeds as noted for the 2004 storms. In addition, after the July 2005 monitoring, hurricanes Katrina, Rita, and Wilma passed within 175 km of the site. At the time of closest approach, Katrina and Rita had winds of about 130 kph. Wilma had winds of approximately 205 kph, but was over land (SW Florida) at the time. No monitoring of the site was conducted between July 2005 and the 2007 monitoring, and thus the possible confounding effects of these hurricanes, if any, are unknown. However, no visually or tactilely perceptible damage was observed at the restoration structures.

Field Methods

Tactile and visual assessments were performed to evaluate the physical stability of the reef restoration armor units. To determine the biological condition of the site, *in situ* observations, digital images, and digital videos were recorded (Restored area = 185 m^2). The reference area was adjacent to the restoration site. It contained benthic communities likely similar to those destroyed by the grounding. See Figure 6 for approximate locations of sampling areas.

In 2004, within both the restoration and adjacent Reference sampling area, 40 one m^2 quadrats were surveyed for biological variables of interest as described in the *Biological Classifications* section. In 2005 and 2007, twenty-one quadrats were surveyed. This sampling reduction was due to logistical constraints. Within each survey area, a random number generator corresponded to a digital grid of uniquely identified 1 m^2 cells overlaid on the grounding site map. Transect lines were used from landmarks to determine cell locations in the field as best as possible (Figure 8).

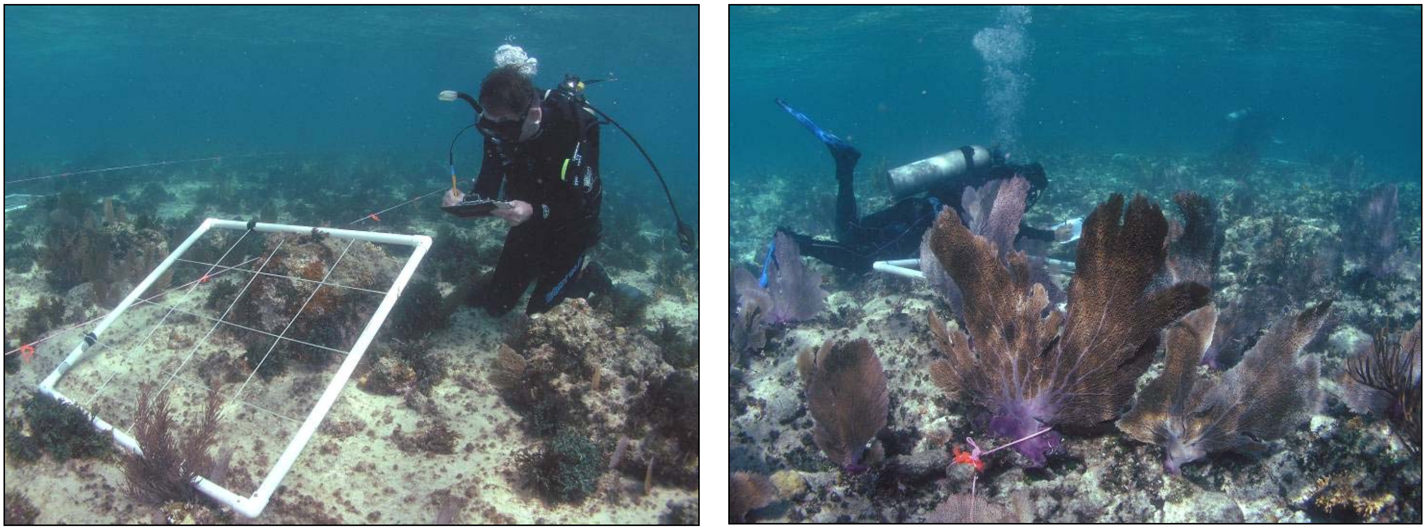


Figure 8. Diver conducting survey in Restoration area (left) and Reference area (right) (photo credits: Jeff Anderson NMSP/NOAA).

Oblique digital photographs were taken of selected coral colonies of interest and the overall landscape/topography of the surveyed areas. Underwater digital images were collected with an Olympus C-5050 digital camera in a Light & Motion Tetra 5050 underwater housing and digital videos were collected with a Sony DCR-DVD200 video camera in an Amphibico QuickView DVD underwater housing.

Photo Analysis

No quantitative analysis of photographic images was conducted. The images were used to qualitatively record the state of the restoration site in general and particular items of interest. Digital images were edited with Adobe Photoshop versions 7 and CS2 (Adobe 2002 and 2005). Image edits included color hue changes to bring out natural colors, brightness changes to compensate for original exposure, and sharpness changes to enhance image focus.

Biological Classifications

All information presented was generated by visual observation from the quadrat data. The majority of the benthos present were comprised of three Orders and most of the comparisons presented are at the Order level. The Orders discussed below include: Order Anthoathecata in the Class Hydrozoa (specimens were solely of one Genus in the Family Milliporidae and henceforth referred to by the name of that Genus—*Millepora*); and the Orders Gorgonacea and Scleractinia of the Subclasses Octocorallia and Hexacorallia respectively (Class Anthozoa). Scleractinians were further divided into species for various analytical purposes.

Although not included in this analysis, numerous vagile fauna were observed on the restoration site. The habitat value of the restoration modules was likely enhanced by the colonization of sessile fauna (Figure 9).

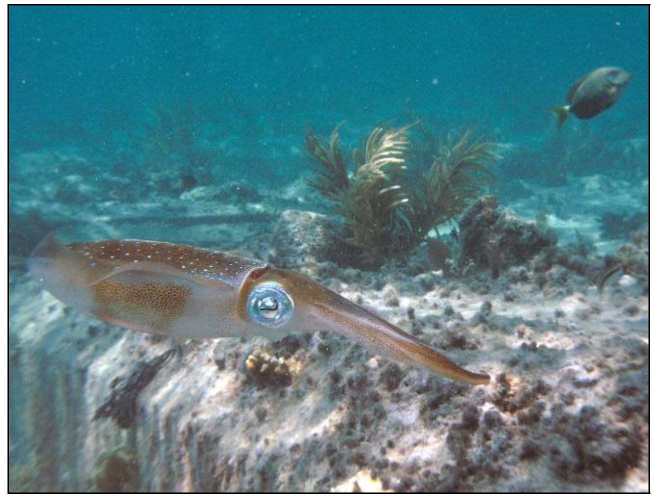




Figure 9. Fauna living in and around *Maitland* restoration armor units. Starting from upper left: young queen conch (*Strombus gigas*), Caribbean reef squid (*Sepioteuthis sepioidea*), lettuce sea slug (*Elysia crispata*), spotted scorpionfish (*Scorpaena plumieri*), and giant anemone (*Condylactis gigantea*) (photo credits: Jeff Anderson NMSP/NOAA).

Data Analysis

Data analysis was performed on a Dell PC with InStat® version 3.0 (GraphPad 2003), Prism 5 for Windows (GraphPad 2007), and Microsoft® Excel 2003 software. Descriptive statistics were generated for samples collected among the restoration and Reference areas, along with various analytic statistics for comparative purposes.

In the 2004 density analyses, for the Gorgonian and Scleractinian populations a square root transformation was performed to meet Gaussian distribution requirements (as per D'Agostino & Pearson omnibus normality tests) permitting two-tailed *t* test comparisons. The unpaired *t* tests were conducted with Welch's correction, to account for the heteroscedasticity of the data. For the *Millepora* density analysis, the data sets displayed extremely significant non-normality. Thus, a Mann-Whitney non-parametric test was utilized.

For the 2005 analyses, for the Gorgonian and Milleporan colonies, the data could not be rendered Gaussian; Mann-Whitney tests were used for both. The Scleractinian corals evidenced a normal distribution with no need for transformation, and the *t* tests were again performed by way of Welch's correction.

In the 2007 analyses, for the Gorgonians, square root transformation was necessary to enable *t* tests. For the *Millepora* and Scleractinians, no transformations were needed. All three Orders evidenced sufficient homogeneity of variance that no corrections were applied.

For all years, common biodiversity indices were calculated for the Scleractinian populations. Additionally, size-class frequency distributions are shown for *Porites astreoides*, the only species with a sample size sufficient for such calculations.

Additionally, in 2007, data on substrate attachment in the restoration area was collected for all three taxa, so as to permit Chi-square (χ^2) "Goodness of Fit" test between actual and expected settlement occurrences. Because of the low absolute numbers involved for Milleporans, the test was conducted by means of Yates' continuity correction applied to all categories.

Finally, some inter-annual comparisons are made for Scleractinians and Gorgonians. For Scleractinians, no transformations were necessary and analysis proceeded by way of a single-factor Analysis of Variance (ANOVA), followed by Bonferroni's Multiple Comparison Test. For the Gorgonians, since normality could not be achieved after any attempted transformation, analysis was achieved by way of a Kruskal-Wallis test, followed by Dunn's Multiple Comparison Test.

RESULTS

FIRST MONITORING EVENT (AUGUST 2004)

Structural Integrity

The 2004 monitoring occurred 9 years after the restoration, at which time the stability and surface of all 40 armor units were found to be visually and tactilely sound. The armor units were found in place with a stable attachment to the substrate, with no visible cracks in the concrete surface or undermining of the armor units and surrounding puddle pour areas.

Biological Condition

The biological condition of the restoration site was developing. Macroalgae, crustose coralline algae, soft, and hard corals were all recruiting to the armor units and surrounding concrete areas (Figure 10), and Scleractinians, Gorgonians, and *Millepora* were all significantly more abundant in the Restored area than in the Reference area. Density results, by Orders, for the 2004 data are shown in Figure 11. Further breakdown of some of these groups, with analysis of biodiversity, size-class distribution, etc., also follow below.

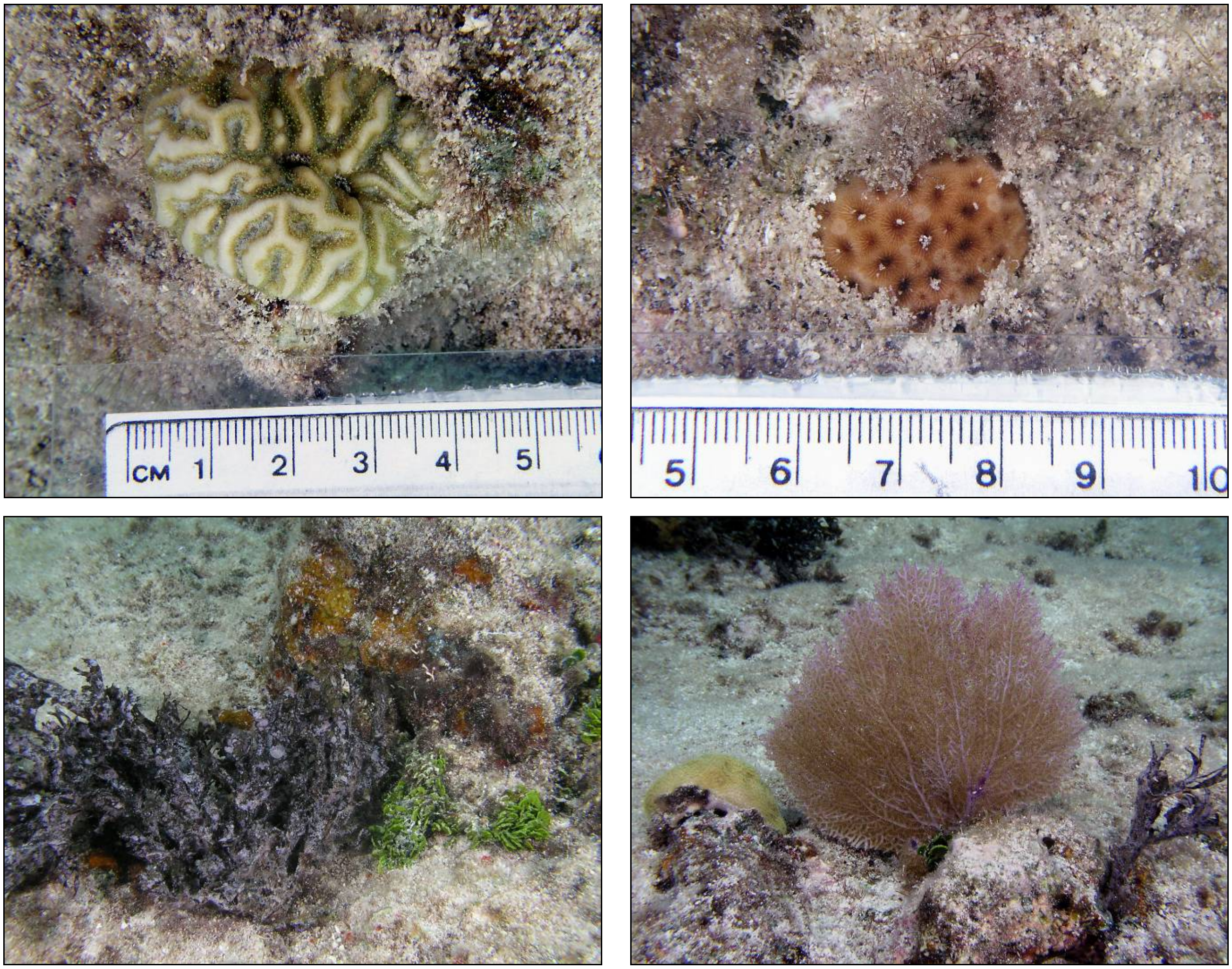
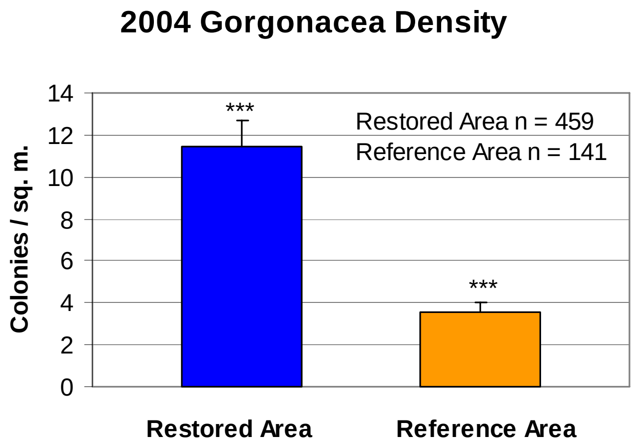
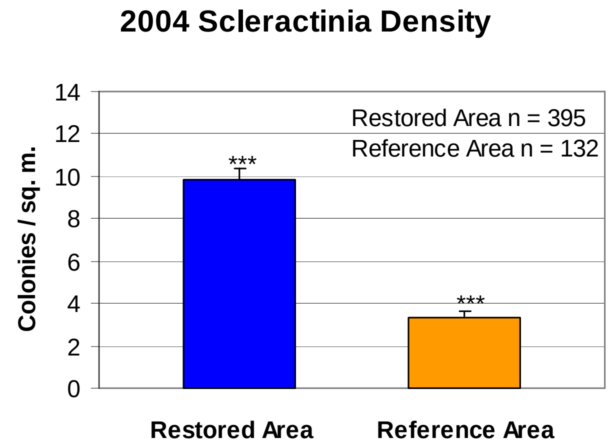


Figure 10. Representative benthic organisms surveyed on the *Maitland* restoration armor units. Starting from top left: *Diploria* sp., *Siderastrea siderea*, *Stypopodium zonale* next to *Halimeda* sp., and *Porites astreoides* next to *Gorgonia ventalina*. (photo credits: Jeff Anderson NMSP/NOAA).





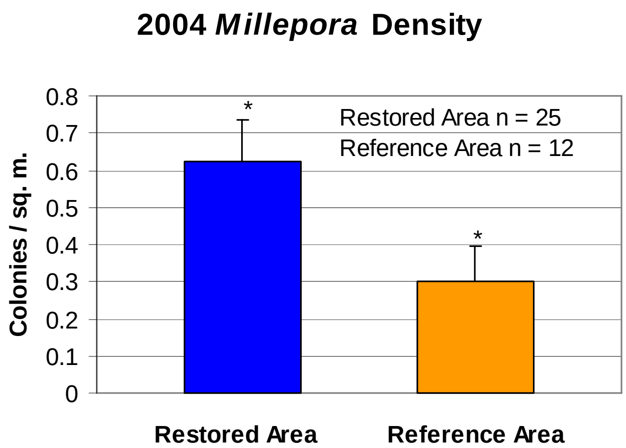


Figure 11. 2004 densities of all 3 groups of corals (Note differing scales used for *Millepora*). Error bars = Standard Error; *** notation indicates highly significant difference ($p < 0.0001$), * notation indicates significant difference.

For the Gorgonians and Scleractinians, the statistical analysis indicated that the differences between the Restoration and the Reference populations were highly significant, with $p < 0.0001$.

Milleporans were present in much lower densities than were the other two groups; however the differences between the two areas were still significant. The non-parametric test utilized revealed that $p = 0.0169$.

In addition to the density data, information regarding species identification (or in some cases only to Genus level) was gathered for Scleractinians. That data is presented in Table 2, immediately followed by Table 3, which gives several standard biodiversity index calculations.

Table 2. Number of Scleractinian colonies, by species, surveyed in 2004 at the *Maitland* restoration site.

Species	**Restored area**	**Reference area**
Agaricia spp.	3	1
Dichocoenia stokesii	4	0
Diploria spp.	11	0
Montastraea cavernosa	1	0
Porites astreoides	337	115
Porites porites	0	14
Siderastrea siderea	37	1
Stephanocoenia intersepta	1	0
Unknown	1	1
Total	**395**	**132**

Table 3. Common Biodiversity indices of the 2004 Scleractinian colony population at the *Maitland* restoration site.

Name of Index (along with formulas)	**Restored area**	**Reference area**
Species Richness: $S = \#$	8	5
Simpson's index: $D = \Sigma(P_i^2)$	0.738	0.770
Shannon-Weiner: $H = - \Sigma(P_i \log[P_i])$	0.586	0.469
Evenness: $E = H/\log(S)$	0.282	0.291

The relative proportions of Scleractinians present in both the Restored and Reference areas are graphically presented in Figure 12.

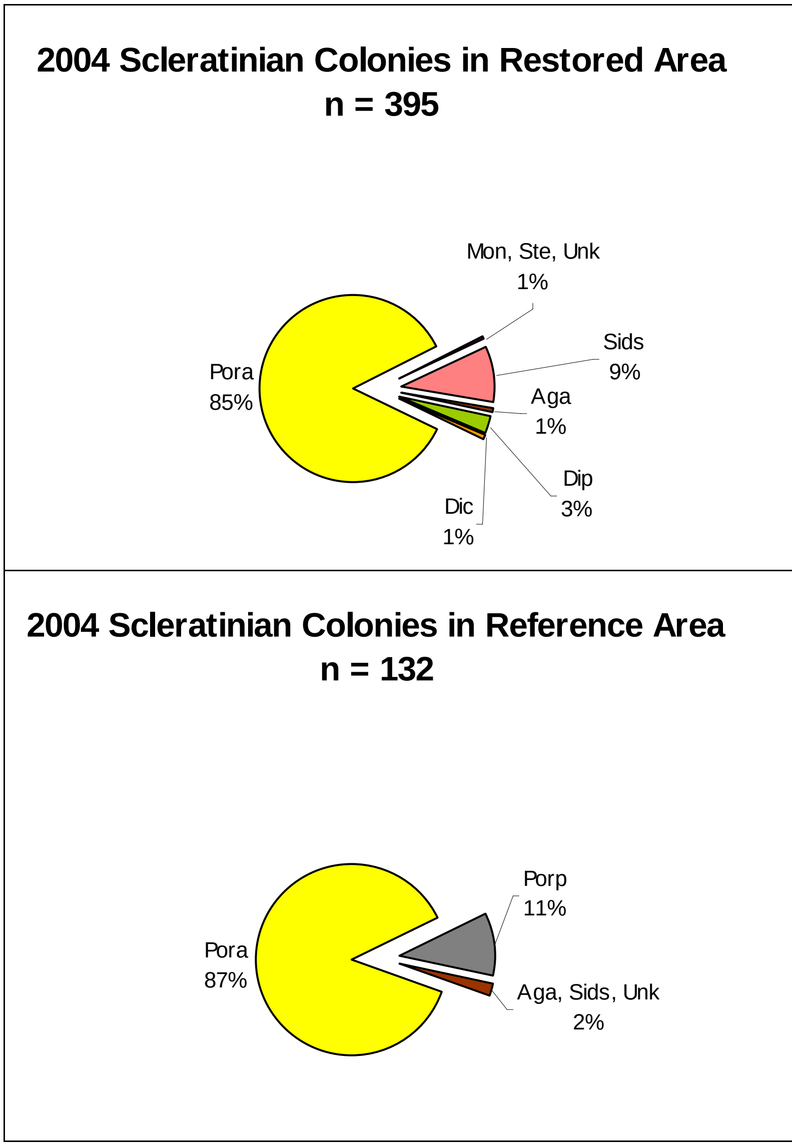


Figure 12. 2004 species (by percentage) of Scleractinian colonies.

Abbreviations:
Aga=*Agaricia* spp.;
Dic=*Dichocoenia stokesii*;
Dip=*Diploria* spp.;
Mon=*Montastraea cavernosa*;
Pora=*Porites astreoides*;
Porp=*Porites porites*;
Sids=*Siderastrea siderea*;
Ste=*Stephanocoenia intersepta*;
Unk=unknown

Finally, size-class frequency distributions were ascertained for the only coral with sufficient numbers to make such calculations meaningful, that being *Porites astreoides.* The graphs depicting the distribution are shown in Figure 13.

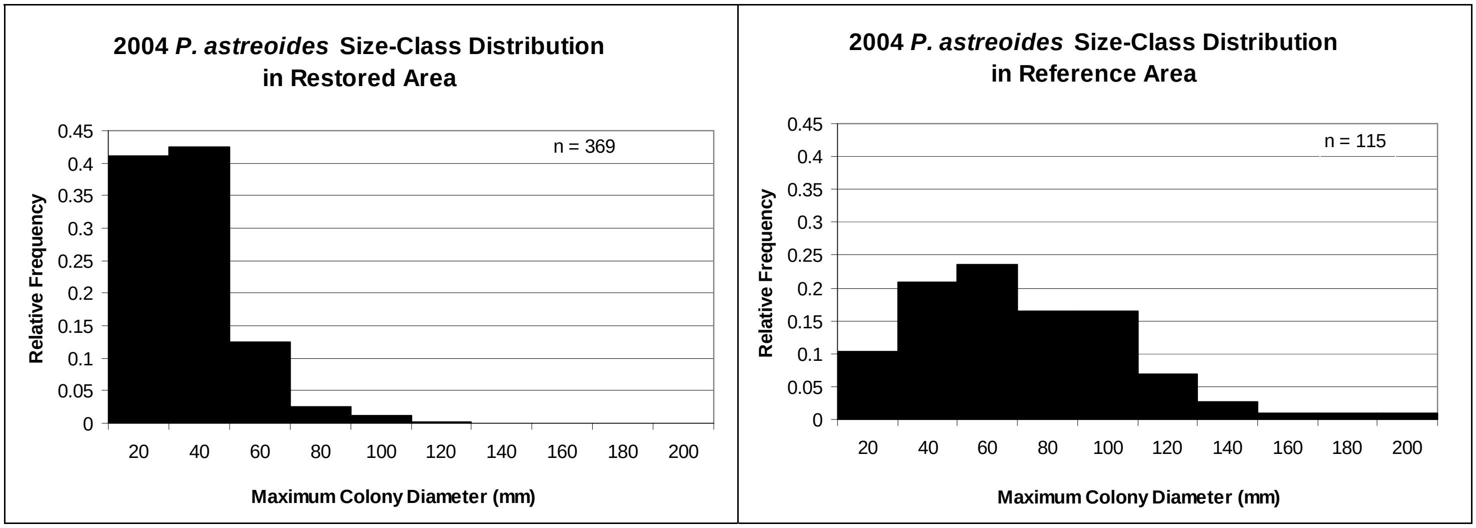


Figure 13. 2004 size-class frequency distribution of *Porites astreoides* in the Restored and Reference areas.

SECOND MONITORING EVENT (JUNE-JULY 2005)

Structural Integrity

Despite the close passage of three hurricanes between the 2004 and 2005 monitoring events (see METHODOLOGY), the stability and surface of all 40 reef restoration armor units and puddle pour areas were again found to be visually and tactilely sound with no visible cracks in the concrete surface nor undermining of the armor units and surrounding puddle pour areas.

Biological Condition

The biological condition of the restoration site continued to progress. Macroalgae, crustose coralline algae, soft, and hard corals were all still present on the armor units and surrounding concrete puddle pour areas (Figure 14). The population of Gorgonians underwent what might fairly be described as a "crash." Possible explanations for this are presented later in the DISCUSSION section. Meanwhile, Scleractinian densities in the Restored area continued to exceed those in the Reference area. For the three Orders surveyed in 2005, the data yielded the densities shown in Figure 15. Additionally, size-class frequency distribution of *Porites astreoides* in the Restored area showed some convergence to the Reference area, and biodiversity measures continued to favor the Restored area. Those results are also shown below.

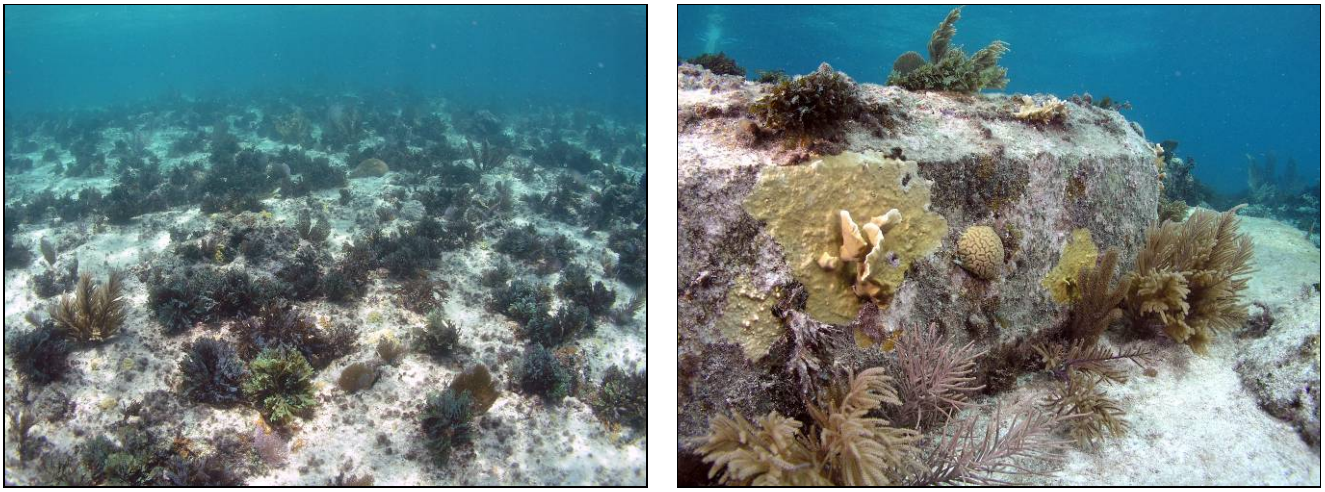
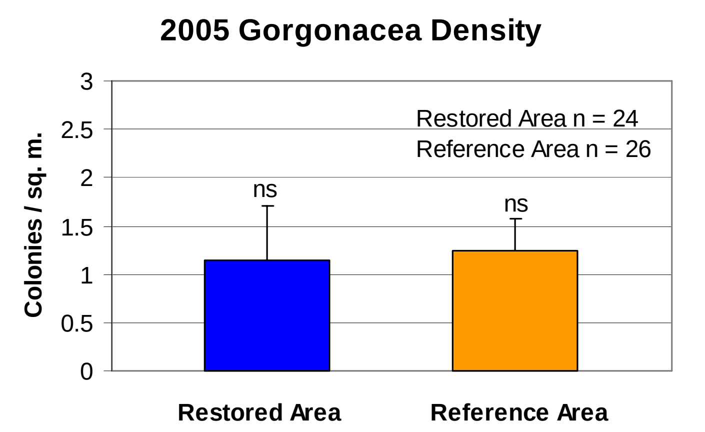
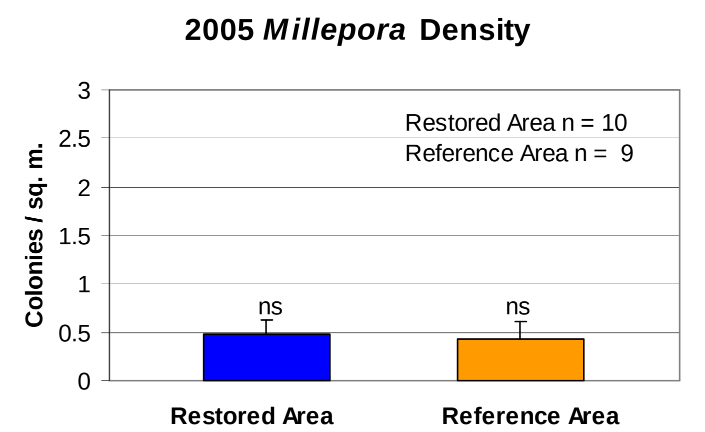


Figure 14. Restoration armor units showing biological condition 10 years after installation (photo credits: Jeff Anderson NMSP/NOAA).





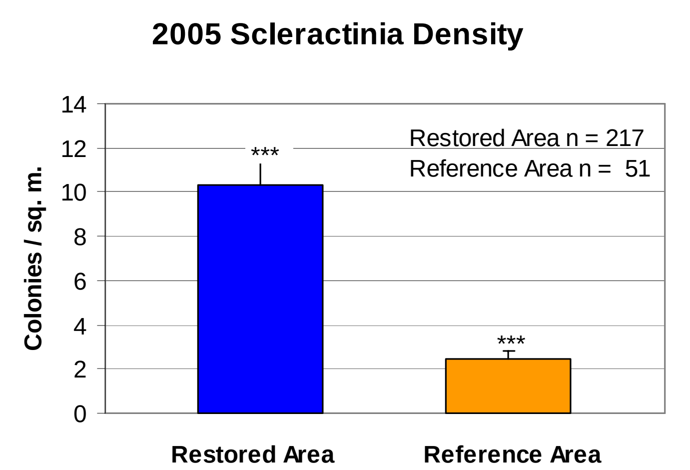


Figure 15. 2005 densities of all 3 groups of corals (Note differing scale used for Scleractinia). Error bars = Standard Error; ns notation indicates no significant difference, *** notation indicates highly significant difference.

For the Gorgonians, the non-parametric statistical test used (see METHODOLOGY) indicated that the differences between the Restoration and the Reference populations were not significant ($p = 0.1096$). The same test yielded similar non-significant results ($p = 0.5962$) for Milleporans.

For Scleractinians, absolute differences are more than four-fold, as examination of Figure 15 reveals. The statistical test utilized resulted in highly significant differences between the two areas ($p < 0.0001$).

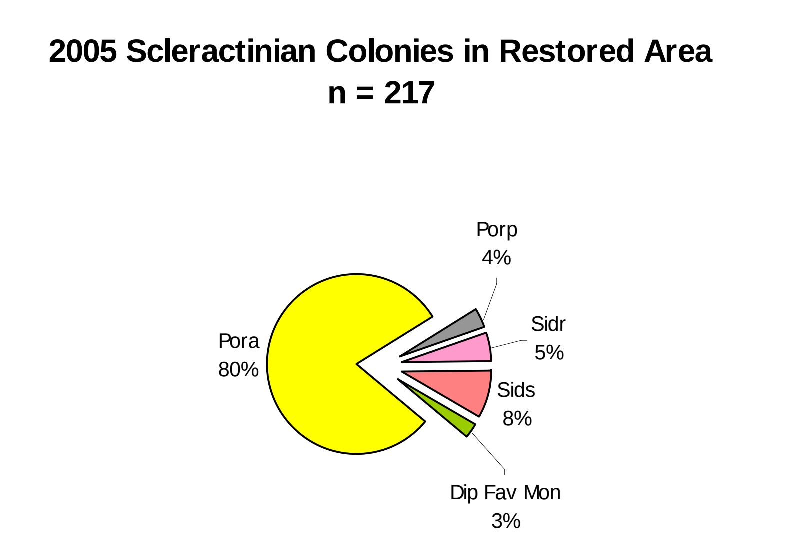
Table 4 and Figure 16 show a comparison of the biodiversity of Scleractinian colonies among the Restored and Reference sampling areas within the *Maitland* restoration site. Table 5 lists the results of a number of standard biodiversity indices performed for the Scleractinian colony population.

Table 4. Number of Scleractinian colonies, by species, surveyed in 2005 at the *Maitland* restoration site.

Species	Restored area	Reference area
Diploria spp.	4	1
Favia fragum	1	0
Montastraea cavernosa	1	0
Porites astreoides	174	47
Porites porites	8	2
Siderastrea radians	11	0
Siderastrea siderea	18	1
Total	**217**	**51**

Table 5. Common Biodiversity indices of the 2005 Scleractinian colony population at the *Maitland* restoration site.

Name of Index (along with formulas)	Restored area	Reference area
Species Richness: S = #	7	4
Simpson's index: $D = \Sigma(P_i^2)$	0.654	0.852
Shannon-Weiner: $H = - \Sigma(P_i \log[P_i])$	0.780	0.357
Evenness: $E = H/\log(S)$	0.401	0.257



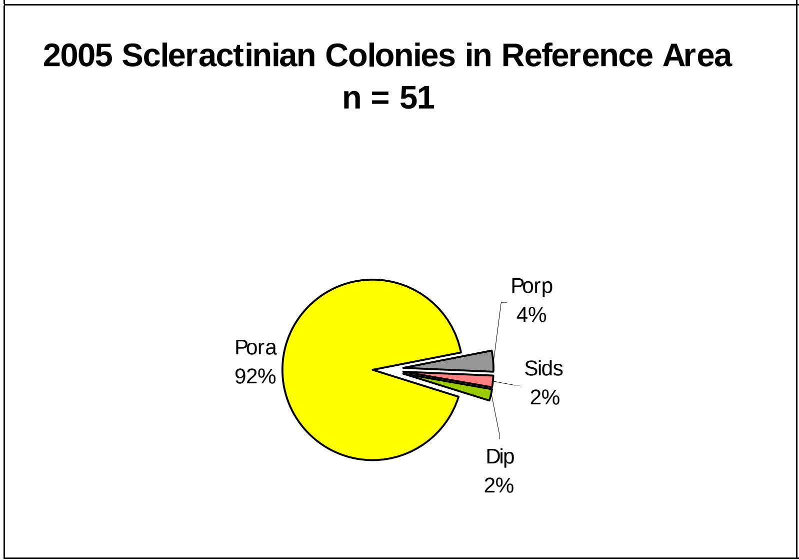


Figure 16. 2005 species (by percentage) of Scleractinian colonies.

Abbreviations:
Dip=*Diploria* spp.;
Fav=*Favia fragum*;
Mon=*Montastraea cavernosa*;
Pora=*Porites astreoides*;
Porp=*Porites porites*;
Sidr=*Siderastrea radians*;
Sids=*Siderastrea siderea*

As for the previous year, the 2005 size-class frequency distributions were ascertained for the only coral with sufficient numbers to make such calculations meaningful, *Porites astreoides.* The graphs depicting the distribution are shown in Figure 17.

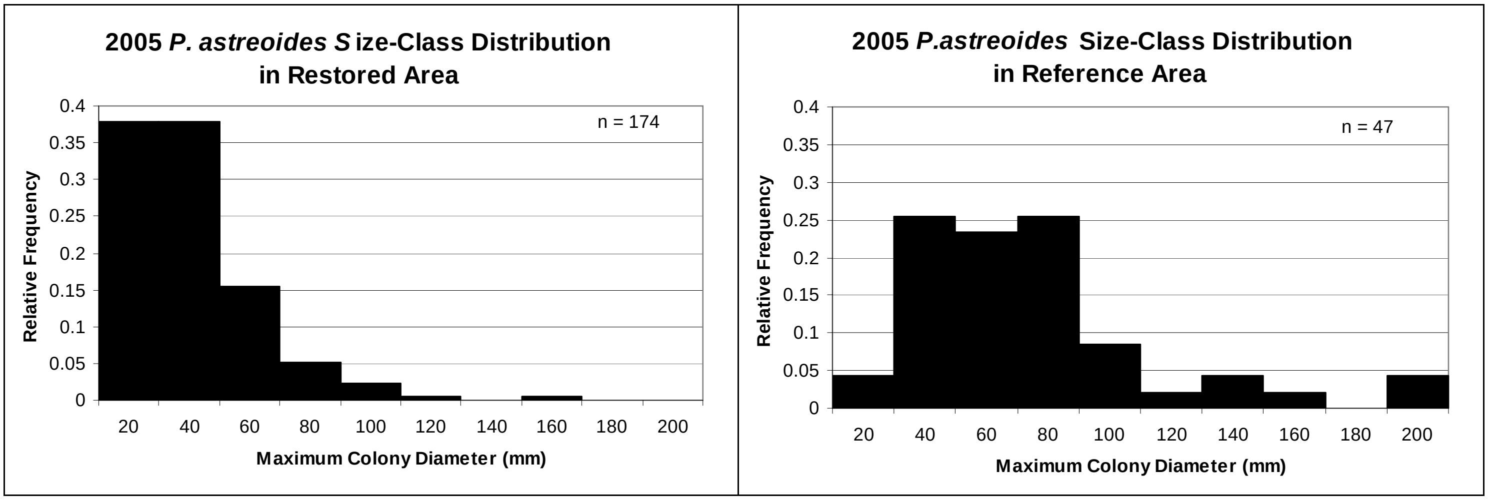


Figure 17. 2005 size-class frequency distribution of *Porites astreoides* in the Restored and Reference areas.

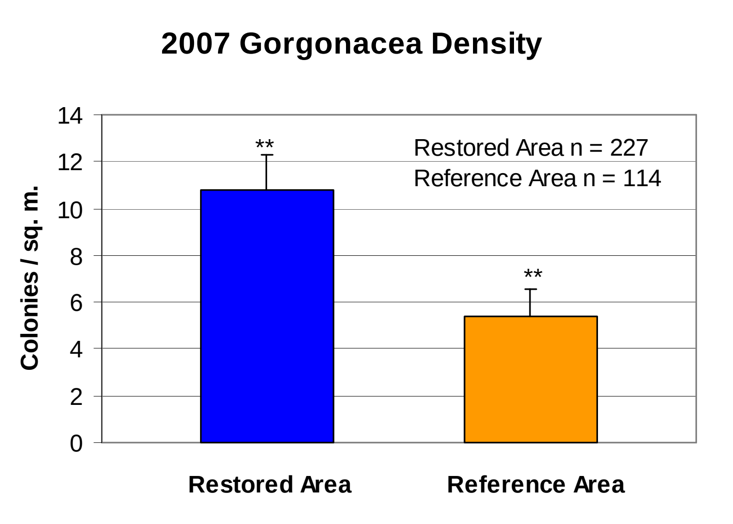
THIRD MONITORING EVENT (JULY-SEPTEMBER 2007)

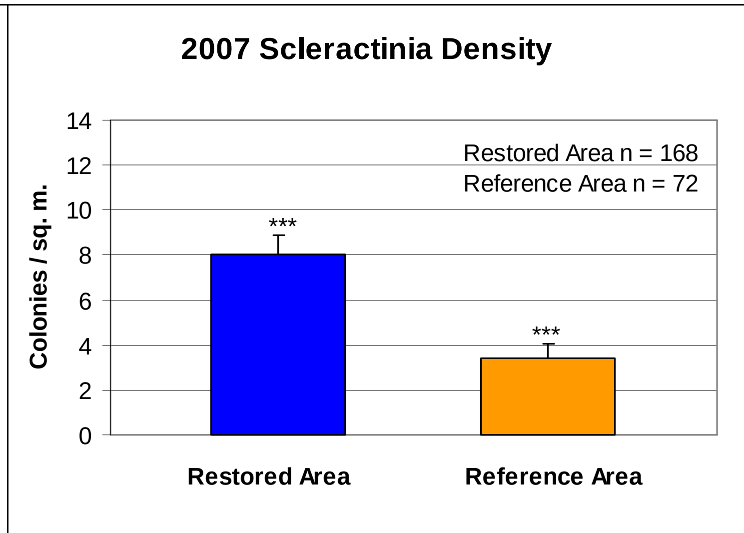
Structural Integrity

The near passage of four hurricanes during the 2005 storm season (see METHODOLOGY) did not affect the stability and surface of the 40 reef restoration armor units. However, several areas of the puddle pour on the eastern (seaward-facing) side of the restoration had been slightly undermined. While the exact cause is unknown, this undermining most likely resulted from wave energy and bottom scouring during the four hurricanes.

Biological Condition

The biological condition of the restoration site continued to progress. Macroalgae, crustose coralline algae, soft, and hard corals were all still present on the restoration armor units and surrounding concrete puddle pour areas. Gorgonians appeared to have bounced back from their previous "crash." Meanwhile, Scleractinian densities in the Restored area continued to greatly exceed those in the Reference area. For the three Orders surveyed in 2007, the data yielded the densities shown in Figure 18. Both biodiversity and size-class distribution of the two zones seemed to be approaching convergence, as shown in the results below. For this monitoring event, additional information is depicted showing overall and Scleractinian (two Genera) settlement preferences.





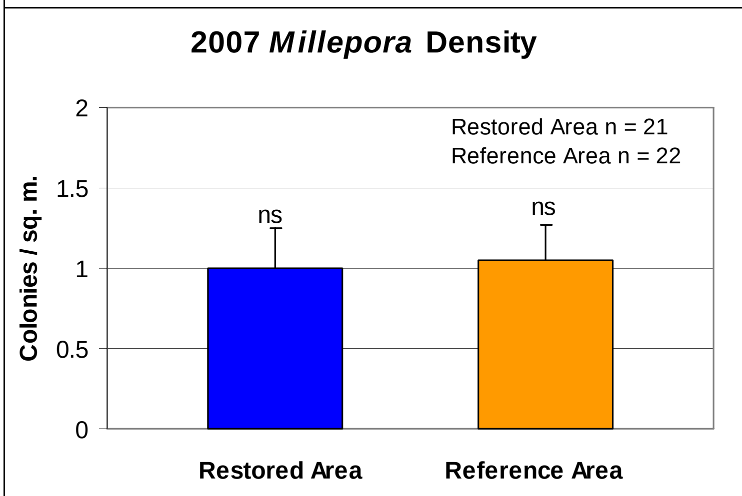


Figure 18. 2007 densities of all 3 groups of corals (Note differing scale used for *Millepora*). Error bars = Standard Error; ** notation indicates very significant difference, ns notation indicates no significant difference, *** notation indicates highly significant difference.

For the Gorgonians, the statistical test used (see METHODOLOGY) indicated that the difference between the Restoration and the Reference populations were very significantly different ($p = 0.0015$). The same test yielded non-significant results ($p = 0.8875$) for Milleporans. For Scleractinians, the statistical test utilized resulted in highly significant differences between the two areas ($p < 0.0001$).

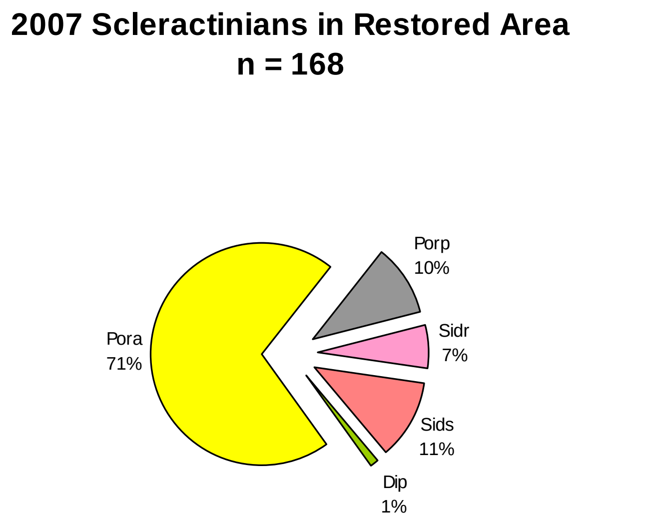
Table 6 and Figure 19 show a comparison of the biodiversity of Scleractinian colonies among the Restored and Reference sampling areas within the *Maitland* restoration site. Table 7 lists the results of a number of standard biodiversity indices performed for the Scleractinian colony population.

Table 6. Number of Scleractinian colonies, by species, surveyed in 2007 at the *Maitland* restoration site.

Species	Restored area	Reference area
Agaricia spp.	0	2
Diploria spp.	2	0
Favia fragum	0	1
Montastraea cavernosa	0	0
Porites astreoides	119	53
Porites porites	17	9
Siderastrea radians	11	3
Siderastrea siderea	19	4
Total	**168**	**72**

Table 7. Common Biodiversity indices of the 2007 Scleractinian colony population at the *Maitland* restoration site.

Name of Index (along with formulas)	Restored area	Reference area
Species Richness: S = #	5	6
Simpson's index: $D = \Sigma(P_i^2)$	0.529	0.563
Shannon-Weiner: $H = -\Sigma(P_i \log[P_i])$	0.954	0.937
Evenness: $E = H/\log(S)$	0.593	0.523



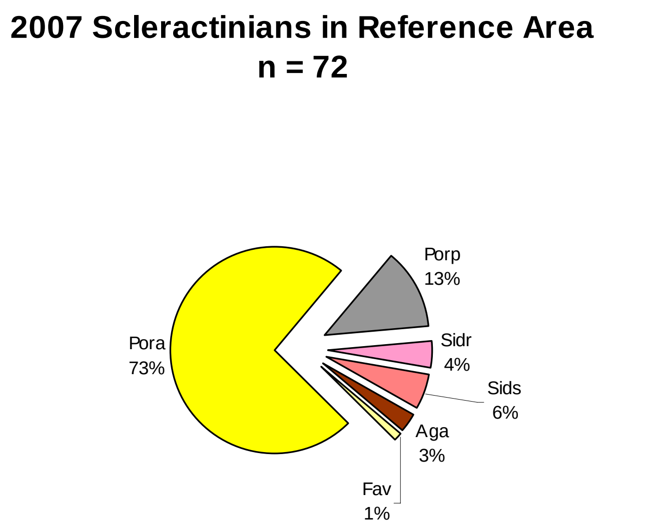


Figure 19. 2007 species (by percentage) of Scleractinian colonies.

Abbreviations:
Aga=*Agaricia* spp.;
Dip=*Diploria* spp.;
Fav=*Favia fragum*;
Pora=*Porites astreoides*;
Porp=*Porites porites*;
Sidr=*Siderastrea radians*;
Sids=*Siderastrea siderea*

As for the previous years, the 2007 size-class frequency distributions were ascertained for the only coral with sufficient numbers to make such calculations meaningful, *Porites astreoides.* The graphs depicting the distribution are shown in Figure 20.

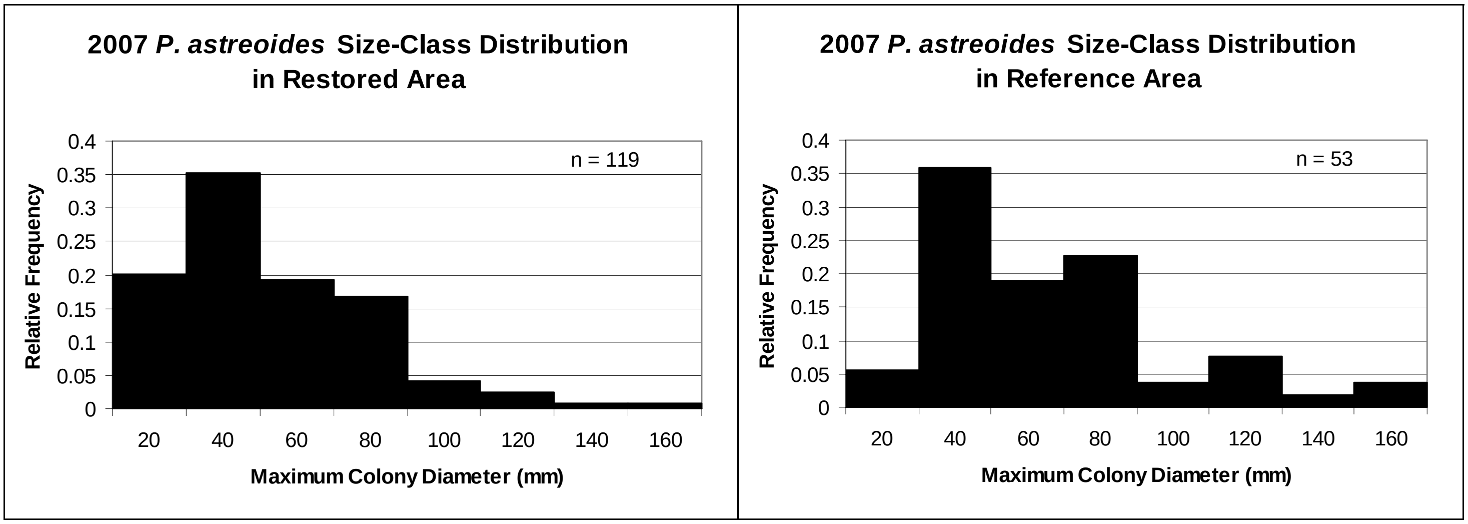


Figure 20. 2007 size-class frequency distribution of *Porites astreoides* in the Restored and Reference areas.

Finally for the 2007 data, a comparison was done of the number of colonies that had settled on the limestone rocks versus the number that had settled on the concrete matrix. The relative proportions of each surface are approximately 25% and 75% respectively (For methodology as to how these percentages were calculated, see Miller and Barimo 2001). Totally random (chance) settlement events would be expected to yield above proportions of colonies on the two different surfaces. Observed numbers varied from this expectation. This variation was tested statistically (see METHODOLOGY) i.e., a test was used to evaluate observed vs. expected settlement. The results are presented in Figure 21.

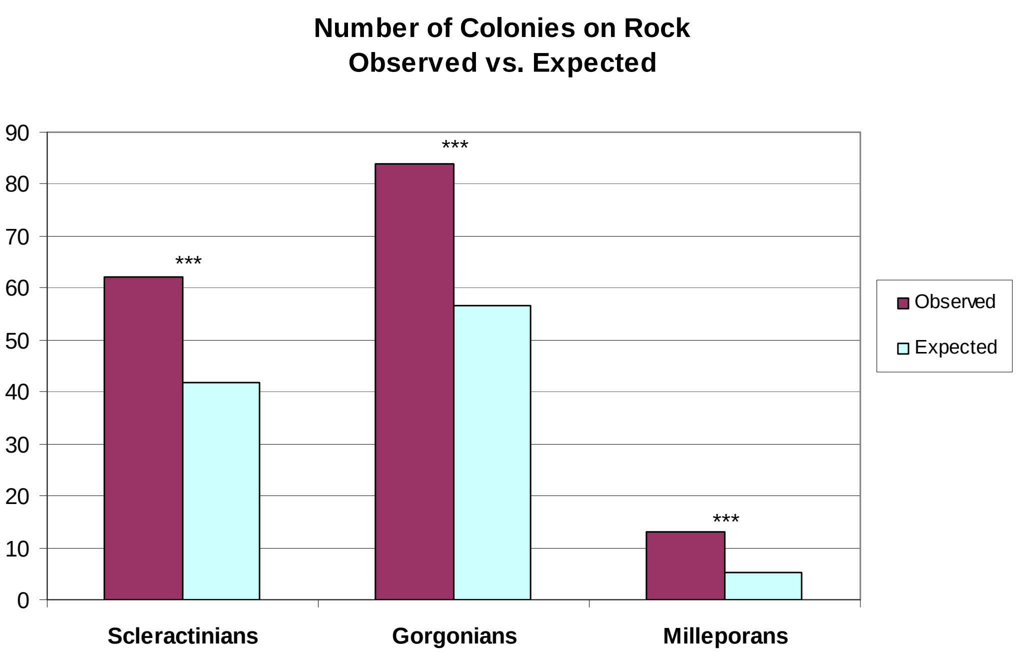


Figure 21. Evaluation of substrate settlement preference for all 3 groups of corals; *** indicates highly significant difference detected.

As can be seen, the limestone rocks were preferentially settled by Scleractinians, Gorgonians, and Milleporans, and the differences from expectations were highly significant ($p = 0.0004$, $p < 0.0001$, and $p = 0.0003$, respectively). This perhaps indicates that active settlement preferences by larvae are implicated. Though a significant difference was detected for Milleporans, the numbers involved were too low to make anything in the way of a meaningful evaluation.

For Scleractinians, this evaluation was broken down into the Genera that comprised the majority of colonies, those being *Siderastrea* and *Porites* (Note: this included virtually all Scleractinians, except one *P. astreoides* that wasn't classed, and two *Diploria* spp. that settled on cement. The remainder of the *P. astreoides* made up 87% of total *Porites*, and *S. siderea* made up 63% of total *Siderastrea*). As one would anticipate from Figure 21 and accompanying text, and since the percentage of their contribution to the overall Scleractinian population was so high, *Porites* preferentially settled on the rocks ($p \leq 0.0001$). Interestingly however, for *Siderastrea*, the test performed showed an equally highly significant trend to settle on cement, though once again low numbers did not permit robust conclusions to be drawn (though all 19 *S. siderea* present settled on cement; the sole settler on rock was a *S. radians*).

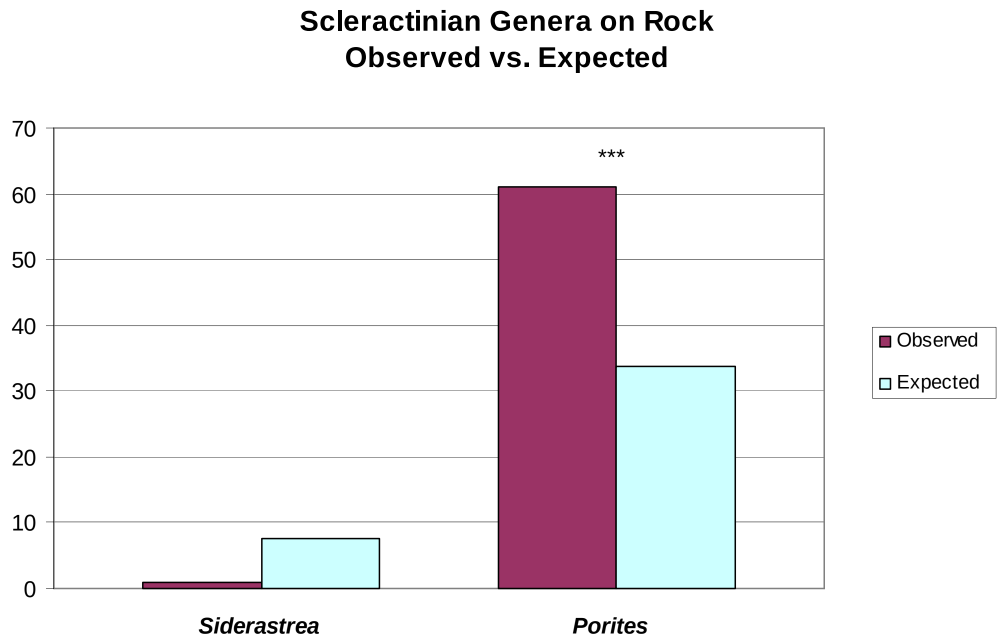


Figure 22. Evaluation of coral substrate settlement preference for selected Scleractinian Genera; *** indicates extremely significant difference detected.

In addition to examining data for individual years, some inter-annual comparisons were made. In those analyses which follow, only Scleractinian and Gorgonian data will be looked at, as Milleporan populations were too low for robust analysis. Looking first at the Scleractinians, graphs of the densities are immediately below.

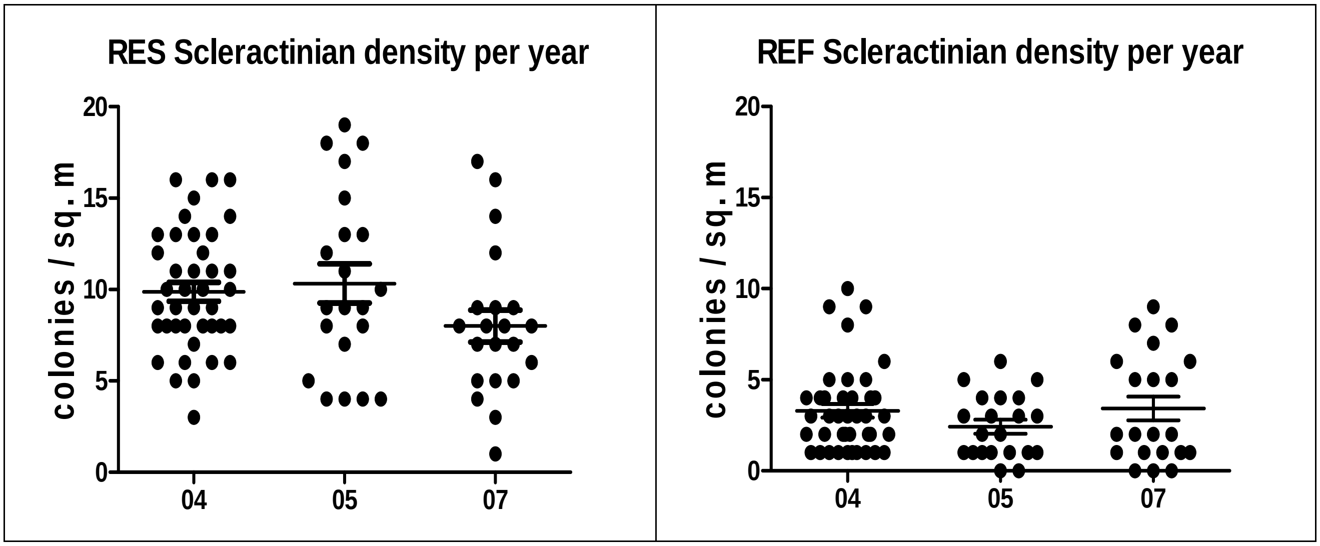


Figure 23. Scatterplots of density of Restored (RES) area and Reference (REF) area Scleractinians in each quadrat sampled in 2004, '05, and '07. The longest horizontal bar in each year's group represents the mean; the shorter bars above and below represent ± SE.

For the Restored area, densities were very similar for 2004 and 2005. While they appeared to slightly decrease in 2007, overall ANOVA revealed no significant differences, ($p = 0.1228$). For the Reference area, inter-annual differences were also non significant ($p = 0.3226$).

Using the same graphics for Gorgonians, though a different statistical analysis (see METHODOLOGY) yields the following figure.

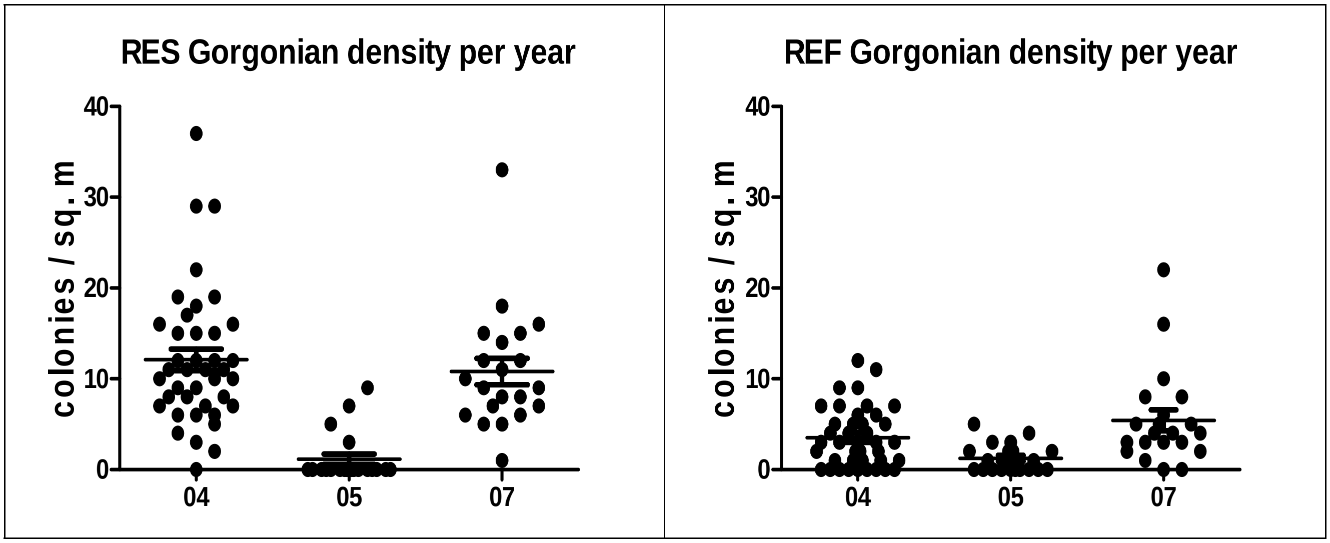


Figure 24. Scatterplots of density of Restored (RES) area and Reference (REF) area Gorgonians in each quadrat sampled in 2004, '05, and '07. The longest horizontal bar in each year's group represents the mean; the shorter bars above and below represent ± SE.

For the Restored area, densities varied considerably among years, falling greatly in 2005. The Kruskal-Wallis test evidenced highly significant differences ($p < 0.0001$). The Dunn's Multiple Comparison Test revealed a highly significant difference between 2005 and either other year. For the Reference area, the same tests yielded the same results ($p = 0.0006$).

DISCUSSION

The results of the 2004, 2005, and 2007 *Maitland* restoration monitoring surveys indicate a gradual but definitive development of a healthy coral community on the restoration structures. However, several points should be kept in mind while reviewing results and this discussion, primarily the duration and scope of the monitoring program. Regarding duration, it is important to remember that this report reflects the first stages of a longer term monitoring program. The development of coral communities is well-known to be a long-term (decadal) process, so NMSP does not expect to be able to make definitive conclusions about the success of the *Maitland* restoration at this stage. However, the density and composition of coral recruits at this stage provides a good indication that the structural stability offered by the restoration armor units is already providing suitable substrate and environment for the ongoing development of a healthy reef habitat. As for the scope of the monitoring program, it should be reiterated that this monitoring effort is tracking only some aspects of coral restoration, namely, stability, density, biodiversity, settlement preference, and size distribution.

For the 2004 data (Figure 11), even a cursory look at this graph indicates that the Restored area was doing well, with more abundant populations than the adjacent Reference area. The charts show that the differences were significant for all categories of coral, highly so for both Gorgonians and Scleractinians. In fact, for each, densities were approximately three times higher in the Restored area than in the Reference area.

Looking at the 2005 density data (Figure 15) and comparing it with the earlier, an examination of the 2004 density data reveals that while the stony coral populations remained relatively constant, the Gorgonian colonies suffered a drastic reduction. This yields an intriguing question—What happened to the Gorgonians? In all probability, the decimation of the Gorgonians is attributable to the nearby passage of the three hurricanes mentioned in the "Monitoring Events" section of this report on page 9 (Refer to the following web site for more information regarding those hurricanes: http://maps.csc.noaa.gov/hurricanes/). It is to be remembered that the restoration site, and the immediately surrounding Reference area, are in very shallow water of approximately 2-2.5 m in depth. Scleractinians don't appear much affected. However, it should also be borne in mind that the Scleractinians present are primarily of the "head," "mounding," or "boulder" varieties, and are thus not readily subject to fragmentation by storms as are branching species (Lirman 2000). Whatever the reason for the differential Gorgonian decline, it seems they bounced back quickly (to be discussed below).

For the 2007 density data, either very or highly significant differences were shown for Gorgonian and Scleractinian densities respectively (Figure 18). Again as in 2005, no difference of any significance was found regarding Milleporans. The much greater densities in the Restored area give rise to some interesting questions. Are the restoration armor units really such great recruitment attractors, or do the densities only appear high in relation to mature, stable areas? Or, has young-adult colony mortality not yet had a chance to play a role as a structuring factor? (Recall that the monitoring protocol does not track actual recruitment or mortality, only resultant overall density.) Unfortunately, the frequency of monitoring permitted by available settlement funds does not permit tracking individual colonies, and the fine-scale discrimination of historical population structure that might result.

Regarding biodiversity, Table 2 and Table 3 reveal greater species richness and increased biodiversity of Scleractinians in the Restored area in 2004. This is depicted graphically in Figure 12. Again in 2005, species richness and biodiversity of Scleractinians was greater at the Restored area. In fact, the differences appeared to be increasing (Table 4 and Table 5, Figure 16). The differences had virtually disappeared by 2007 and the two areas may be fairly said to have converged by this time, at least as regards biodiversity indicators (Table 6 and Table 7, Figure 19). As the mentioned tables and charts show, large broadcasting corals (*Diploria* spp., *Montastraea cavernosa*, and *Siderastrea siderea*) were present almost exclusively on the restoration site. Just why this should be so remains somewhat of a mystery; certainly the issue of their generally low recruitment in the Keys is well known. Why then does it seem much higher in the Restored area? Certainly, one should be conservative when it comes to making predictions based upon demographics of these corals, based upon the low numbers involved. However, if any reader has any thoughts or insights regarding this issue, contact with the corresponding author would be appreciated.

In addition, it appears that the over-representation of *Porites astreoides* in the mix is lessening. At the first monitoring event in 2004, the species represented 85% of all Scleractinians in the

Restored sampling area. By the time of the 2007 monitoring, the proportion of the species had fallen somewhat, to 71% (Figure 19). However, it should be noted that a virtually identical drop in percentage occurred in the Reference sampling area. It will be interesting to see if further monitoring reveals a continuation of this trend.

The 2004 size-class frequency distribution of *P. astreoides*, shown in Figure 13 gives rise to some interesting observations. A large majority (84%) of the colonies present in the Restored area were ≤ 40 mm, while less than one third (31%) of those in the Reference area were in that size class. Potentially, this bodes well for the future of the restoration because as the small size-class cohorts grow and move through the categories, presumably coral cover and topographic complexity of the site should increase. Of course, this assumes no differential mortality between the Restored and Reference areas (Langmead and Sheppard 2004; Edmunds and Elahi 2007).

As regards the 2005 *P. astreoides* size-class frequency distribution (Figure 17), the percentage of small (≤ 40 mm) colonies in the Reference area remained relatively constant at 30% (versus 2004's 31%). Meanwhile, the proportion in the Restored area declined a bit—from 84% to 76%—as would be consistent with theory for a maturing restoration site (Epstein et al 2005). Further, the "missing" percentage appears to have advanced through the size categories rather than having been lost to mortality; the 60, 80, and 100 mm categories progressed from a total of 16 to 23%. Nevertheless, once again the modest numbers involved counsel for considering these findings as preliminary, although worthy of future investigation.

With respect to the 2007 *P. astreoides* size-class frequency distribution (Figure 20), percentage of small colonies (≤ 40 mm) increased somewhat in the Reference area, from 30 to 42%. However in the Restored sampling area, the proportion of those colonies (≤ 40 mm) displayed further diminution from the 2005 level (from 76% to 55%) while the proportion in the 60, 80, and 100 mm classes experienced an almost perfectly reciprocal increase, going from 23% to 40%. Thus, with the exception of the very smallest class (≤20 mm), where the restoration area still has a 3.5-fold advantage (20.2 v. 5.7%), the size frequency distribution in the two zones now almost mirror each other. Besides the smallest class, the only notable exception is in the very largest (≥120 mm) classes where—unsurprisingly—the Reference area remains more populous. Future monitoring could reveal whether the two sampling areas eventually totally converge in this regard.

The inter-year comparisons among the Scleractinian and Gorgonian densities (Figure 23 and Figure 24) proved interesting. For the Scleractinians, very little difference in the Restored and Reference areas across years was apparent. There was some slight (though non-significant) decrease in density in 2007 as compared to either of the previous two years. The real story to be told is that, considering the respective zones across years, the Restored area maintained approximately a three-fold advantage in population over the Reference area. Does this provide any inference regarding that most oft-cited coral health metric, percent cover? It must be remembered that the individual colonies (at least of *P. astreoides*, and presumably of other species[*]) were growing during this period (see above discussion re size-class frequency distribution). Thus while percent coral cover was not evaluated during these monitoring events, it is likely that it would have evidenced increase over the time period covered.

The Gorgonians proved equally interesting. From 2004 to 2005 they suffered a precipitous decrease. As a first suspicion, one might suspect disease brought about by *Aspergillosis sydowii* as the cause of the rapid Gorgonian decline. *Aspergillosis* is a fungal pathogen responsible for considerable Gorgonian decline in the Florida Keys. However, at least in this case, physical ablation appears a more probable cause. The passage of the three violent hurricanes in the near vicinity between the 2004 and 2005 monitoring events has already been noted. Further support for the proposition of a physically destructive causative factor is provided by the fact that colony densities experienced complete recovery to 2004 levels by the time of the 2007 monitoring event. Both before and after the population crash likely due to hurricanes, the Restored area Gorgonians evidenced a 2.5 to 3-fold population advantage over the Reference area, proving quite similar to the Scleractinians is this regard.

Lastly, among the most interesting findings, the data may provide some evidence that brooding-spawner coral larvae exhibit an active settlement preference for the limestone rock substrate, versus the concrete matrix in which the rock is embedded; see Figure 21, Figure 22, and the accompanying text. This finding is generally consistent with the work of Miller and Barimo (2001) regarding early settlement preference results (obtained 3 yrs post-settlement) conducted at this site.

Nonetheless, it should be prominently noted that nothing can be said regarding the *mechanism* of the preference. Are the larvae drawn to the rock because of chemotaxis, due to some attractant emanating from the limestone, chemicals leaching out of the concrete, differences in pH, or simply because it presents more rugosity in its surface area, providing more cryptic settlement opportunities (Babcock and Mundy 1996)? Elevation may also play a role, as the rocks project surface area above the surrounding flat, horizontal concrete.

Most intriguing is the fact that the pattern seems to be exactly reversed for the broadcasting-spawner *Siderastrea*. There would appear to be something about cement that the Genus really likes. Again, if any reader has any thoughts along these lines, contact and communication would be appreciated. This phenomenon is suggestive of future research possibilities.

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[*] An interesting, though far from statistically meaningful footnote: To evaluate the growth of a coral with a different life history strategy than *P. astreoides*, size-class frequency distributions were constructed for *Siderastrea siderea*, a framework-building, broadcasting coral. *S. siderea* also proved to be the second most abundant coral during each of the three years, and as a proportion of total Scleractinians, was consistent at about 9.5% of colonies. For two of the three years (2005 and 2007) absolute numbers of colonies were so low (18 and 19 respectively), as to make a frequency distribution less than robust, and it is for this reason that graphs of same are not depicted. Nonetheless, the story told by the coral's progression through size classes is much the same as that of *P. astreoides*, though the size classes utilized for *S. siderea* were smaller (10, 20, 30, 40, & 50 mm). The smallest two size classes started out as 62% in 2004, but by 2007 had dropped to 37%, with the larger classes gaining reciprocally. Since the density of the colonies was almost exactly the same across years (at approx. 0.9 col./m^2) the species' growth represents an absolute increase in its percentage benthic cover.

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NMSP CONSERVATION SERIES PUBLICATIONS

To date, the following reports have been published in the Marine Sanctuaries Conservation Series. All publications are available on the National Marine Sanctuary Program website (http://www.sanctuaries.noaa.gov/).

Automated, objective texture segmentation of multibeam echosounder data - Seafloor survey and substrate maps from James Island to Ozette Lake, Washington Outer Coast. (NMSP-07-05)

Observations of Deep Coral and Sponge Assemblages in Olympic Coast National Marine Sanctuary, Washington (NMSP-07-04)

A Bioregional Classification of the Continental Shelf of Northeastern North America for Conservation Analysis and Planning Based on Representation (NMSP-07-03)

M/V *WELLWOOD* Coral Reef Restoration Monitoring Report Monitoring Events 2004-2006 Florida Keys National Marine Sanctuary Monroe County, Florida (NMSP-07-02)

Survey report of NOAA Ship McArthur II cruises AR-04-04, AR-05-05 and AR-06-03: Habitat classification of side scan sonar imagery in support of deep-sea coral/sponge explorations at the Olympic Coast National Marine Sanctuary (NMSP-07-01)

2002 - 03 Florida Keys National Marine Sanctuary Science Report: An Ecosystem Report Card After Five Years of Marine Zoning (NMSP-06-12)

Habitat Mapping Effort at the Olympic Coast National Marine Sanctuary - Current Status and Future Needs (NMSP-06-11)

M/V *CONNECTED* Coral Reef Restoration Monitoring Report Monitoring Events 2004-2005 Florida Keys National Marine Sanctuary Monroe County, Florida (NMSP-06-010)

M/V *JACQUELYN L* Coral Reef Restoration Monitoring Report Monitoring Events 2004-2005 Florida Keys National Marine Sanctuary Monroe County, Florida (NMSP-06-09)

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Developing Alternatives for Optimal Representation of Seafloor Habitats and Associated Communities in Stellwagen Bank National Marine Sanctuary (ONMS-06-02)

Benthic Habitat Mapping in the Olympic Coast National Marine Sanctuary (ONMS-06-01)

Channel Islands Deep Water Monitoring Plan Development Workshop Report (ONMS-05-05)

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A Review of the Ecological Effectiveness of Subtidal Marine Reserves in Central California (MSD-04-2, MSD-04-3)

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