Marine Sanctuaries Conservation Series NMSP-07-02

M/V *WELLWOOD*
Coral Reef Restoration Monitoring Report
Monitoring Events 2004-2006
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

June 2007

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.

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June 2007

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COVER

Upper left: M/V *Wellwood* aground on Molasses Reef, Florida Keys National Marine Sanctuary. Photo credit: Florida Keys National Marine Sanctuary.

Lower right: Naturally-recruited *Montastraea cavernosa* colony on reef restoration module, photographed on September 29, 2004, at the M/V *Wellwood* restoration site, Florida Keys National Marine Sanctuary. Photo credit: Jeff Anderson.

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ABSTRACT

This document presents the results of the first two monitoring events to track the recovery of a repaired coral reef injured by the M/V *Wellwood* vessel grounding incident of August 4, 1984. 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 on July 22, 2002, and thus far two monitoring events have occurred; one in the Fall of 2004, and one in the Summer/Fall of 2006. The monitoring has consisted of: assessment of the structural stability of restoration modules and comparison of the coral recruitment conditions of the modules and reference sites. Corals are divided into Gorgonians, Milleporans, and Scleractinians and (except where noted) recruits are defined as follows: Gorgonians—maximum size (height) 150 mm at first monitoring event, 270 mm at second; Milleporans—maximum size (height) 65 mm at first event, 125 mm at second; Scleractinians—maximum size (greatest diameter) 50 mm at second event (only one species was size-classed at first event, at smaller size). Recruit densities at the restored and reference areas for each event are compared, as are size-class frequency distributions. For the Scleractinians, number and percentage of recruits by species, as well as several common biodiversity indices are provided. Finally, a qualitative comparison of recruit substrate settlement preference is indicated. Generally, results indicate that restored areas are converging on reference areas, based on almost all parameters examined, with one noted exception. Further monitoring is planned and the trends are anticipated to continue; close attention will be paid to the indicated anomaly.

KEY WORDS

Florida Keys National Marine Sanctuary, coral, grounding, restoration, reef modules, monitoring, *Wellwood*, Molasses Reef, recruitment, Anthozoa, Hydrozoa, Octocorallia, Hexacorallia, Gorgonacea, Anthoathecata (*Millepora*), Scleractinia

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

Figure Number and Title (cont.) Page

Figure Number and Title (cont.) **Page**

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.

The authors also wish to express their appreciation to reviewers who generously lent their expertise in order to improve this document. Among those who deserve to be singled out are: Steve Kolinski, Margaret Miller, Russell Reardon, and Virginia Fuhs.

INTRODUCTION

This document presents the results of the first two monitoring events to track the recovery of a repaired coral reef injured by the M/V *Wellwood* vessel grounding incident of August 4, 1984. 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.

The monitoring program at the *Wellwood* site includes an assessment of the structural stability of installed restoration modules and coral recruitment patterns, which is to be performed on the following schedule: two, four, seven, and ten years after restoration. Restoration of this site was completed on July 22, 2002. The Year Two monitoring event for this site occurred between September 29 and November 5, 2004. Between July 18 and October 12, 2006, the Year Four monitoring event occurred. This report presents the results of both monitoring events.

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

Event	Date
Vessel Grounding	August 4, 1984
Vessel Removal	August 16, 1984
Injury Assessment: Initial	August 16-25, 1984
Injury Assessment: Post Hurricane Georges	Autumn 1998
Pre-Construction Coral Survey	April 23-24, 2002
Restoration	June 2-July 22, 2002
Year Two Monitoring	September 29-November 5, 2004
Year Four Monitoring	July 18-October 12, 2006
Year Seven Monitoring	Summer 2009
Year Ten Monitoring	Summer 2012

Damage Assessment

[Note: The information in this section was adapted from the National Oceanic & Atmospheric Administration, Environmental Assessment: M/V *Wellwood* Grounding Site Restoration April, 2002]

On August 4, 1984, the M/V *Wellwood*, a 122-meter Cypriot-registered freighter, ran aground on the upper forereef of Molasses Reef, about 6 nautical miles southeast of Key Largo, in a minimum of 6 meters of water (Figure 1). The *Wellwood* remained aground for 12 days, causing more destruction as time went on. Additional injury occurred as result of initial attempts to power off the reef, from tugboat propeller wash abrasion, from extended periods of shading under the vessel, and from cable abrasion during several failed attempts to remove the vessel from the reef. The grounding destroyed 5,805 m^2 of living corals and injured over 75,000 m^2 of reef habitat, including fracturing of 644 m^2 of coral reef framework (Hudson and Diaz 1988).

The grounding caused severe biological and physical damage to the reef community and led to widespread mortality of benthic fauna and displacement of mobile fauna. 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 (Figure 2). Additional injury to the reef occurred as a result of Hurricanes Elena and Kate in 1985 and the active 1998 storm season (Groundhog Day Storm, Hurricane Georges).

As the vessel approached the reef, it created an inbound grounding track approximately 20 m wide and affected bottom substrate up to 6 m deep. The injury toppled or injured 13 large coral heads and left bottom paint embedded in exposed coral skeletons.

The most prominent feature of the injury site was an area known as the "parking lot" where the hull of the *Wellwood* finally came to rest. This entire area was crushed as a result of hull pounding and experienced severe shading for the 12 days the vessel was aground. The combined effects resulted in near total destruction of the coral cover (Figure 3 and Figure 4).

Along the starboard side of the hull resting site there was an extensive area that experienced patchy areas of destruction. This was the original resting area of the vessel before it pivoted during initial removal attempts. At least 6 large boulder coral colonies and numerous smaller organisms were destroyed as the vessel scraped the bottom.

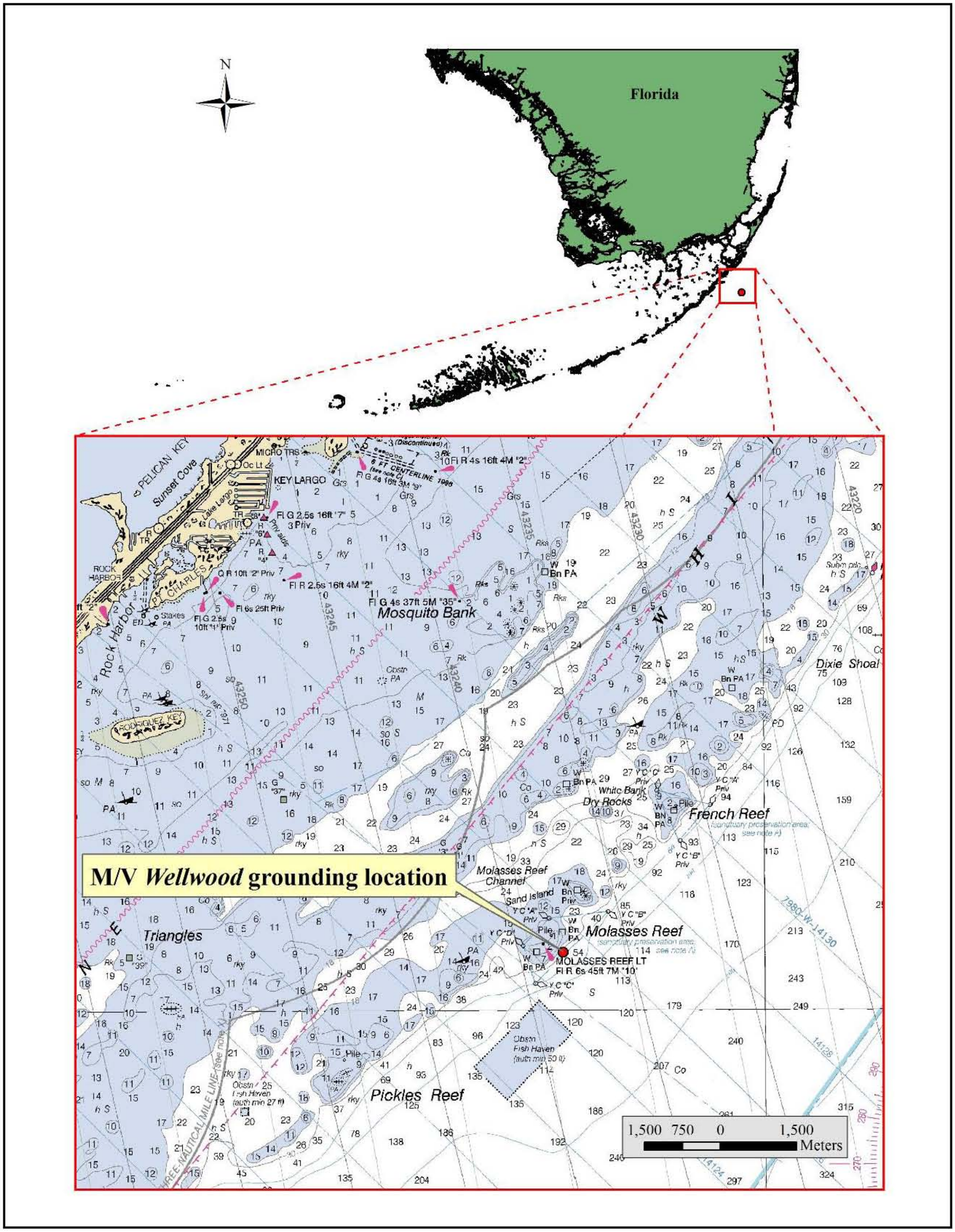


Figure 1. Location (shown on NOAA Chart 11462) that the M/V *Wellwood* ran aground at Molasses Reef on August 4, 1984.

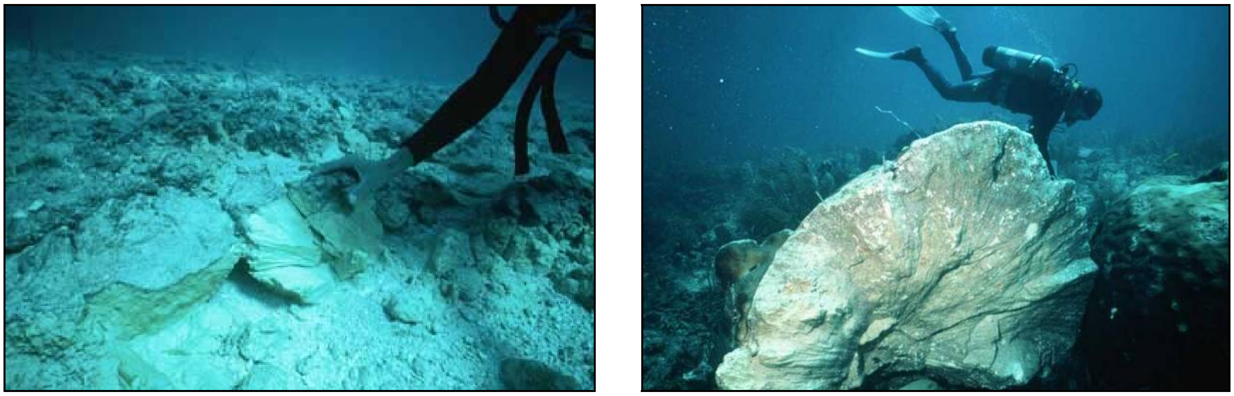
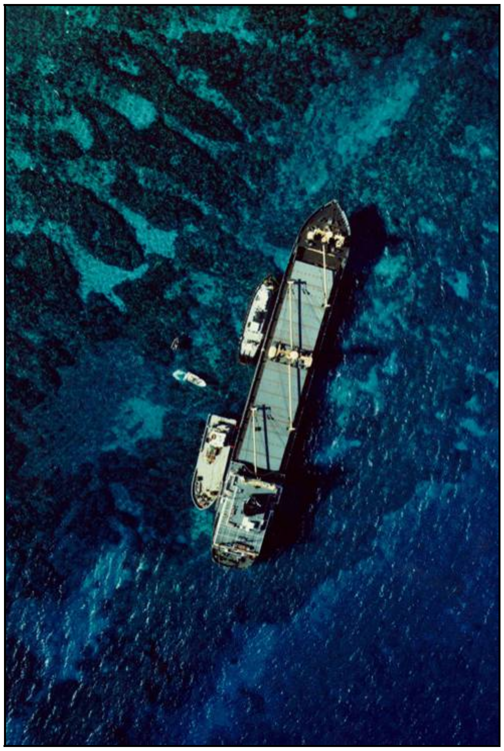


Figure 2. Fractured reef substrate exposed by hurricane Kate (Hudson and Diaz 1988) (photo credit: Harold Hudson, left) and split *Montastraea faveolata* colony (photo credit: FKNMS, right) resulting from the M/V *Wellwood* grounding

The *Wellwood* grounded in the transition zone between the shallow upper forereef (just seaward of the *Acropora palmata* reef crest) and a deeper forereef zone that is dominated by large head corals. The habitat was primarily moderate to low-relief, but included numerous large heads of boulder corals and had a diverse community of hard and soft corals and other benthic organisms. The principal scleractinian coral species present at the site included *Montastraea* spp., *A. palmata, Dendrogyra cylindrus, Agaricia agaricites, Diploria* spp*., Colpophyllia natans, Porites astreoides, Favia fragum, Meandrina meandrites,* and *Dichocoenia stokesii.* Cover also included a healthy octocoral (gorgonian) community including many sea fans (*Gorgonia ventalina*) and sea rods, the zoanthid *Palythoa caribaeorum,* and fire coral, *Millepora* spp. In addition to direct physical damage from the vessel, many colonies under the vessel's hull were seriously damaged due to shading and subsequent tissue death. The dominant species injured in the deeper forereef zone during the salvage operations included the large basket sponge *Xestospongia muta,* large *M. annularis* complex colonies, and many octocorals. Coral loss over the entire area was estimated to include the complete destruction of at least 21 large (1 to 2-m diameter) colonies of *M. annularis* complex, four colonies of *D. cylindrus*, and 6 large colonies of other coral species, as well as grazing, abrasion, toppling or other injuries to many other colonies.



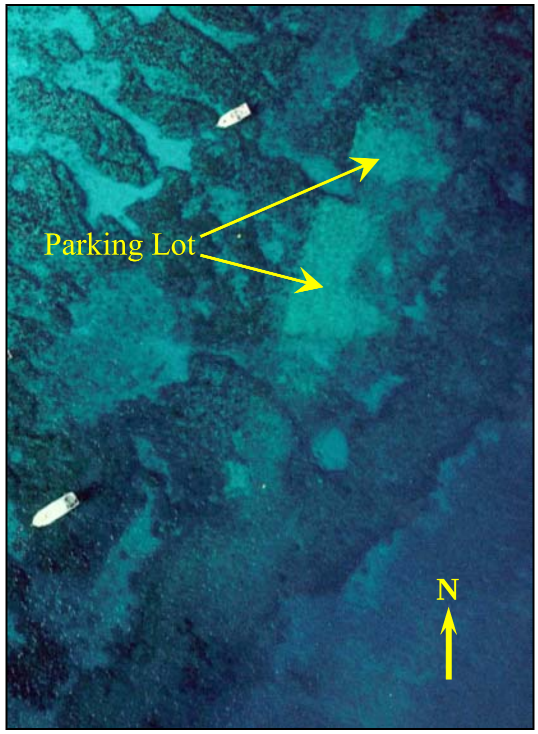


Figure 3. M/V *Wellwood* aground on Molasses Reef (left) and "parking lot" area after removal (right).

Figure 4. Diver installing 1 m diameter reference marker in the "parking lot" for geo-referencing aerial photography (photo credit: Harold Hudson).

A settlement between NOAA and the responsible parties was agreed to on December 22, 1986. Under the terms of the settlement the responsible parties purchased an annuity to be paid to NOAA over 15 years in variable annual installments beginning in 1987 and scheduled to end in 2001. Between 1987 and 1995, the bulk of the payments were allocated to payment of civil penalties and repayment of response and damage assessment costs incurred by NOAA and the U.S. Coast Guard during and immediately following the grounding. Payment allocated for restoration costs did not begin until 1989 and was completed in 2001; once the funds were available, the restoration process was initiated.

Meanwhile, in 1998 a significant storm, Hurricane Georges, had severely impacted the *Wellwood* site. The storm passed approximately 80 miles to the southwest of the site, with winds approaching 100 mph (Figure 5). At 1400 UTC (10 a.m. local time) on September 25, 1998, NOAA's National Data Buoy Center's Coastal-Marine Automated Network (C-MAN) recording station on the nearby Molasses Reef Lighthouse recorded sustained 46 kts (53 mph) winds, and a peak gust of 53 kts (61 mph). After the hurricane's passage, it was found that large areas of the site had been scoured out. Once exposed, the underlying unconsolidated rubble and sediment was mobilized during the storm, causing further scour and the formation of large craters at the site. While such scouring is typical of hurricane injury, NOAA believed the grounding injuries exacerbated the hurricane's effects, and that additional injuries would continue absent restoration. Restoration undertaken in 2002 was planned by National Marine Sanctuary Program (NMSP) headquarters and Florida Keys staff, in collaboration with marine engineers from the commercial firm of Coastal Planning and Engineering, Inc. (CP&E).

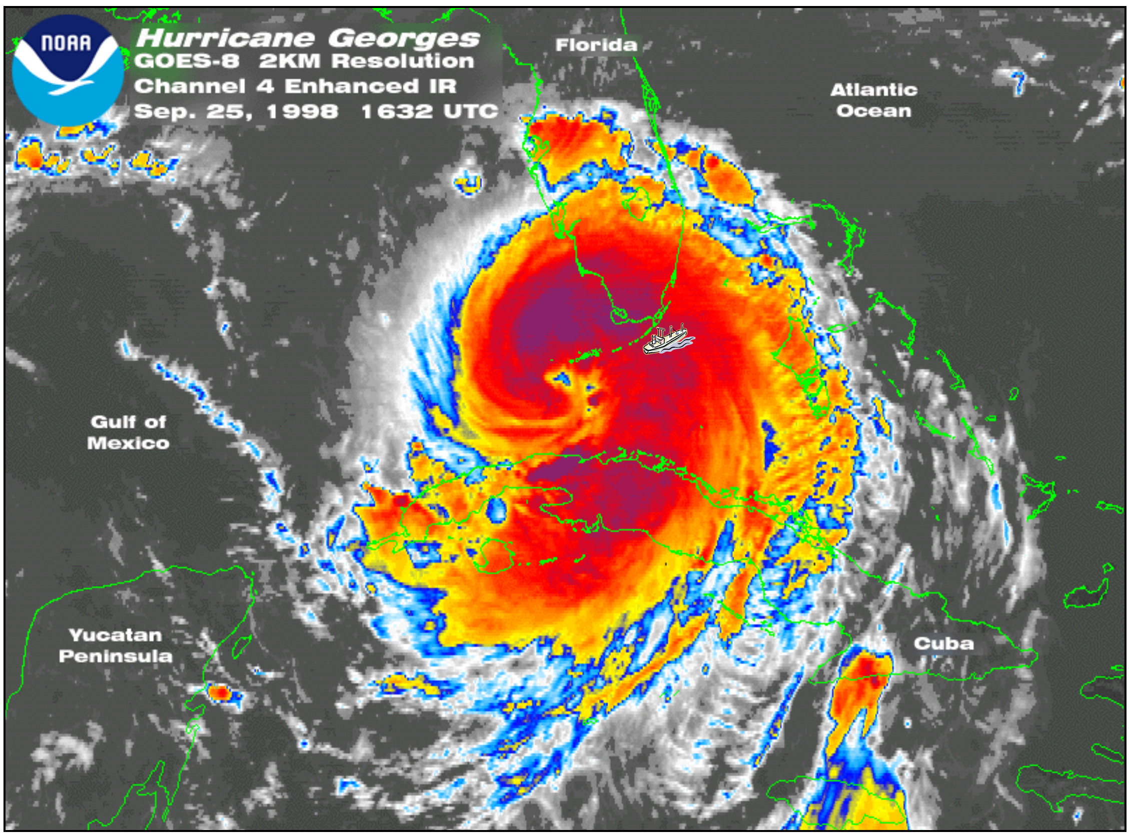


Figure 5. Hurricane Georges relative to the M/V *Wellwood* grounding site (ship graphic not to scale).

Coral Reef Restoration

[Note: The information in this section was adapted from the Molasses Coral Reef Restoration Project Post-Construction Engineering Report prepared by Coastal Planning and Engineering, Inc.]

The objectives of the M/V *Wellwood* site restoration were to 1) stabilize damaged reef framework, 2) infill hurricane-excavated craters, and 3) rebuild reef topography. To accomplish these objectives, a design concept featuring artificial reef modules was developed (Figure 6). The artificial reef modules were designed and constructed by Harold Hudson, FKNMS Reef Restoration Biologist. The artificial reef modules closely replicated the adjacent undamaged reef, infilling hurricane excavated craters and rebuilding reef topography that had been lost as a result of the grounding. Modules were five-sided (from a planar view) with an approximate height of 1.2 m, length of 1.8 m, and a width of 1.5 m. Damp sand was placed inside the form during the fabrication process to create a 30 cm high reef cave within the structure (Hudson and Franklin 2005). The hollow interior of each module provided space to be used by fish and sessile organisms, and the rough limestone provided habitat for organisms using interstitial spaces or for boring organisms. The modules minimized the concrete surface exposure and maximized the exposure of natural limestone surfaces, providing desirable settlement substrate and enhancing the environmental features of the module design.

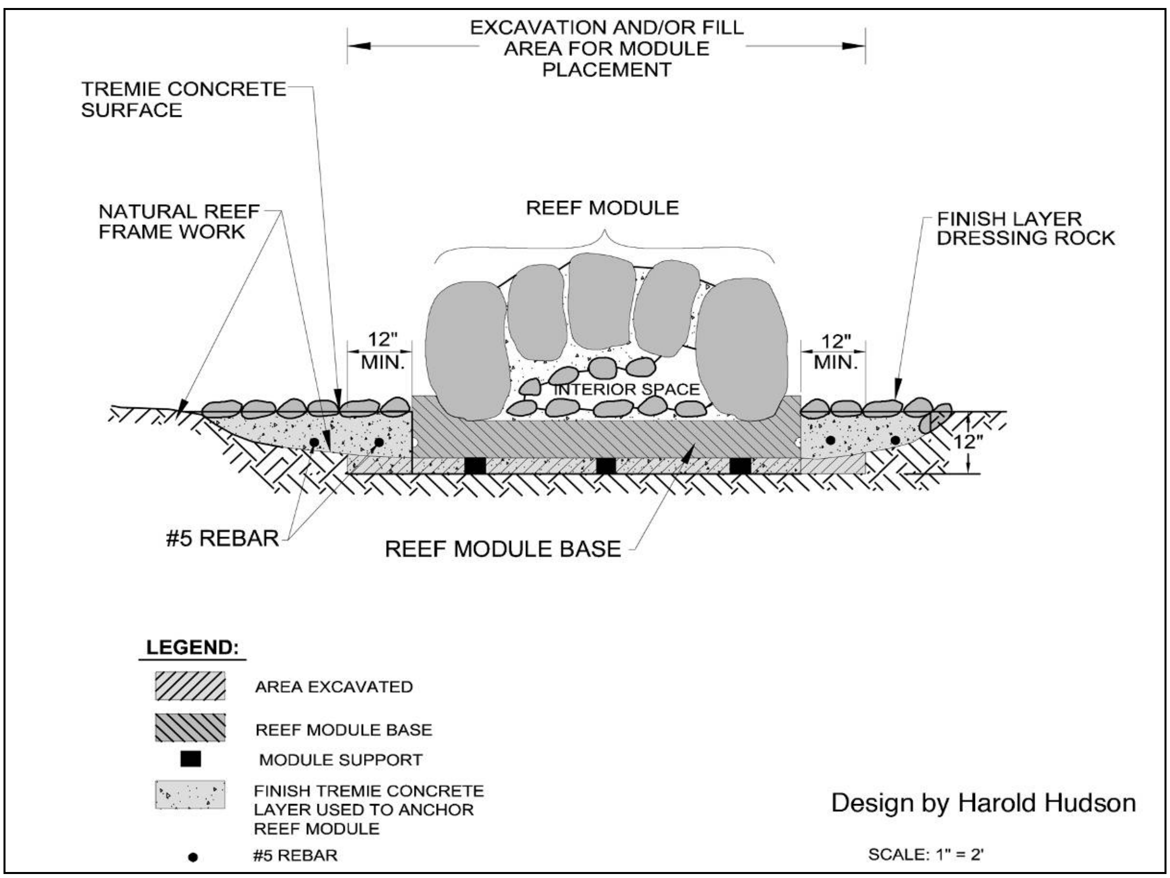


Figure 6. Cross section of installed reef restoration module.

The reef restoration design consisted of the placement of 22 reef modules and/or limestone boulders, stabilized with a tremie pour of concrete within the 14 repair sites depicted in Figure 7. An aluminum frame outline of the reef module, which was constructed by NOAA, was used to determine the exact location, orientation and accurate leveling of each reef module prior to placement at the repair site. Reef module placement was contingent upon placement of the modules in natural and/or excavated receiver sites, allowing tremie pour concrete to secure the module to the reef. Excavation of the existing rock substrate was often conducted to provide the appropriate receiver site for module placement. Each module was placed on 5-10 cm supports to allow concrete to flow under the module, in addition to providing a minimum 30 cm wide and deep apron entirely around each module (Figure 8). After the reef module was placed, concrete was tremie poured within the excavated depression, cementing the reef module into the existing reef substrate. A total of 9 repair sites received reef modules.

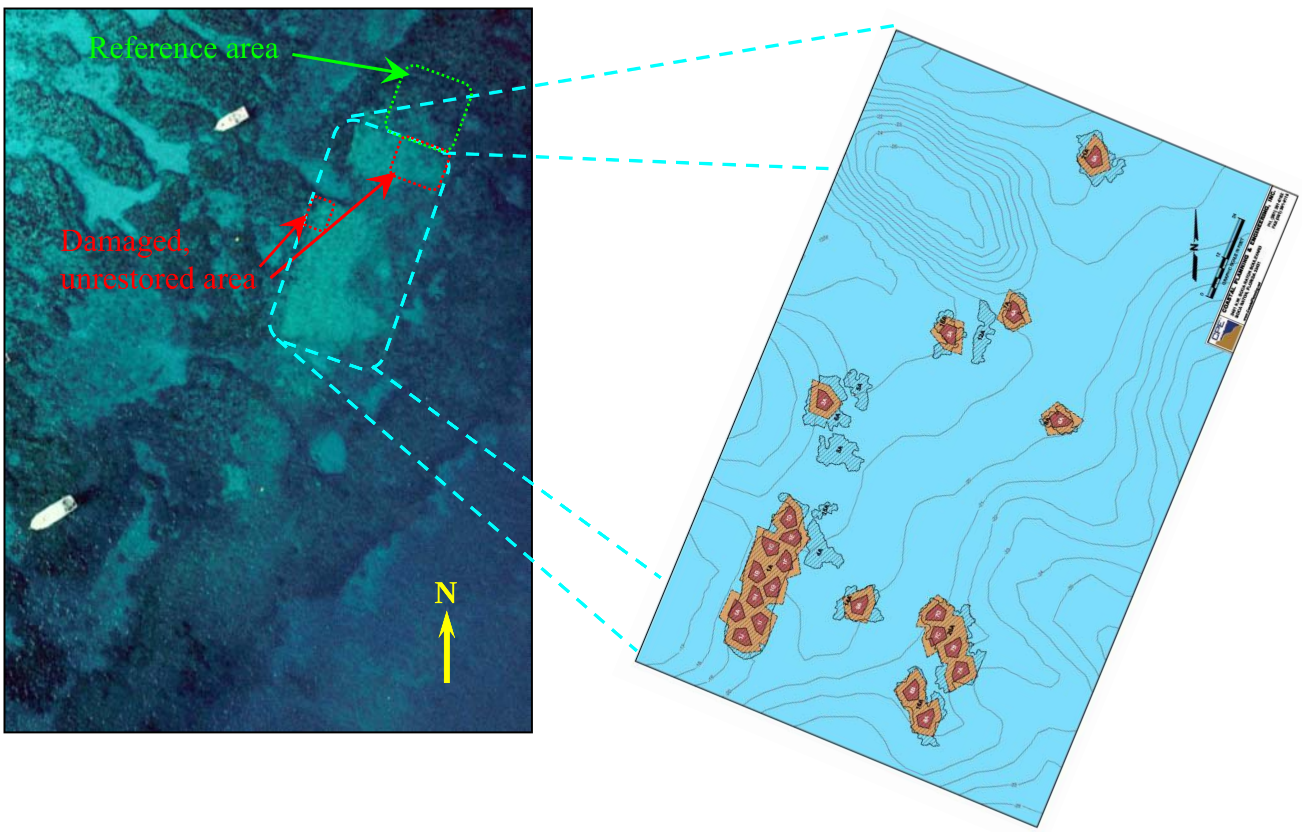


Figure 7. Aerial photograph of "parking lot" damage area with Reference and Damaged, unrestored sampling areas (left) and a bathymetric schematic diagram depicting locations of reef restoration modules (shaded in brown) and "puddle pour" restoration areas (striped areas) (right). Please note, area boundaries and reef restoration module locations are not geo-rectified in these images. Bathymetric reef restoration schematic diagram courtesy of Coastal Planning & Engineering, Inc.

Figure 8. Reef restoration module and reinforcing rods in excavation crater ready to accept tremie pour concrete (photo credit: FKNMS).

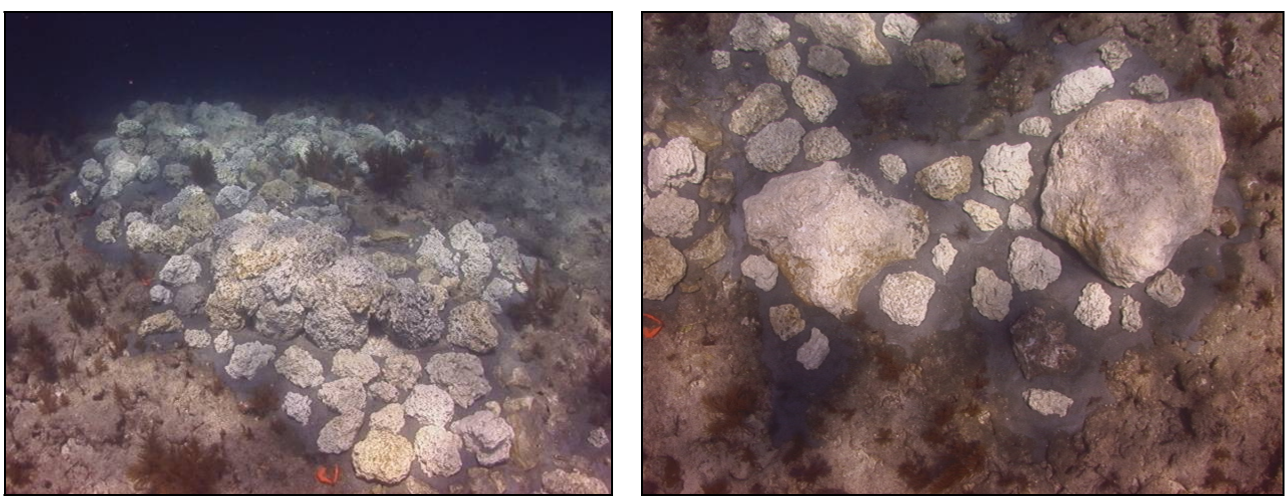


Figure 9. Completed restoration with reef restoration modules (left) and "puddle pour" with boulders (right) each surrounded by limestone "dressing" stones (photo credit: Coastal Planning and Engineering, Inc.).

The remaining 5 sites were determined to be too small and/or shallow to accommodate reef restoration modules. At these sites, a combination of 1-2 ton limestone boulders and tremie poured concrete, referred to as a "puddle pour," were used to fill the excavation. Limestone rock dressing stones, 25-45 cm in diameter were pressed into the fresh concrete at close intervals to increase rugosity and provide a more natural substrate. The concrete embedded boulders projected 50-100 cm above the dressing stones in all "puddle pour" applications (Hudson and Franklin 2005). A total of 185 m^2 of damaged reef substrate was repaired using these two restoration techniques (Figure 9).

The remaining areas damaged by the grounding but left "unrestored" were determined not to exhibit the structural instability likely to be exacerbated by storms. Thus, they were left to continue with the natural recovery that had already begun. Although decades will pass before these areas fully recover to their pre-grounding topographic complexity and coral community size and diversity (Gittings 2003), NOAA felt the combination of reef restoration modules intermixed with the unrestored areas would provide a reasonable reflection of the adjacent transition zone reef habitat.

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. For a grounding site such as the M/V *Wellwood*, 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).

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 M/V *Wellwood* site is only evaluating the structural stability and coral recruitment of the restoration site.

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

1. Is the attachment of the reef modules to the substrate stable?
2. Are there any visible cracks in the surface of the reef modules and/or puddle pour concrete?

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 (i.e., both the restored and unrestored areas) and the reference area?

The monitoring program was designed to detect significant changes in new coral recruitment or damage to the reef restoration modules and concrete puddle pour areas as a result of external events, such as major storms or vandalism, and in comparison to the surrounding habitat.

METHODOLOGY

MONITORING EVENTS

Between September 29 and November 5, 2004, the *Wellwood* restoration site was monitored using SCUBA from a small vessel (6.4 m). Another monitoring event occurred between July 18 and October 12, 2006. Between the November 2004 and the July 2006 monitoring events, four powerful hurricanes passed within 300 kilometers of the restoration site; Dennis in July 2005, Katrina in August 2005, Rita in September 2005, and Wilma in October 2005. The possible confounding effects of these hurricanes, if any, are unknown; no monitoring of the site was conducted in the interim. As discussed below however, no visually or tactilely perceptible damage was done to the restoration modules, puddle pour areas, surveyed colonies, or the site in general.

Field Methods

Tactile and visual assessments were performed to evaluate the physical stability of the reef restoration modules and puddle pour areas. To determine the biological condition of the site, *in situ* observations, digital images, and digital videos were recorded among the 22 reef modules and concrete puddle pour areas (restored area = 185 m^2) and the remaining damaged, but unrestored area of the grounding site (area = 459 m^2). The reference area was adjacent to the northeast side of the restoration site. It is a transition zone between former shallow *Acropora palmata* stands and deeper hard ground communities. It likely contained benthic communities similar to those destroyed by the grounding (Gittings 2003). See Figure 7 for approximate locations of sampling areas. In 2004, within each sampling area, 25 one m^2 quadrats were surveyed for biological variables of interest as described in the *Biological Classifications* section. In 2006, twenty quadrats were surveyed. This sampling reduction was due to logistical constraints. A random number generator identified the reef restoration modules/puddle pour areas to survey in the restored area. Within the damaged, unrestored and reference areas, the random number generator corresponded to a digital grid of uniquely identified 1 m^2 cells overlain on the grounding site map. Transect lines were used from landmarks to determine cell locations in the field as best as possible.

Oblique digital photographs were taken of each restoration module in the restored area, 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.

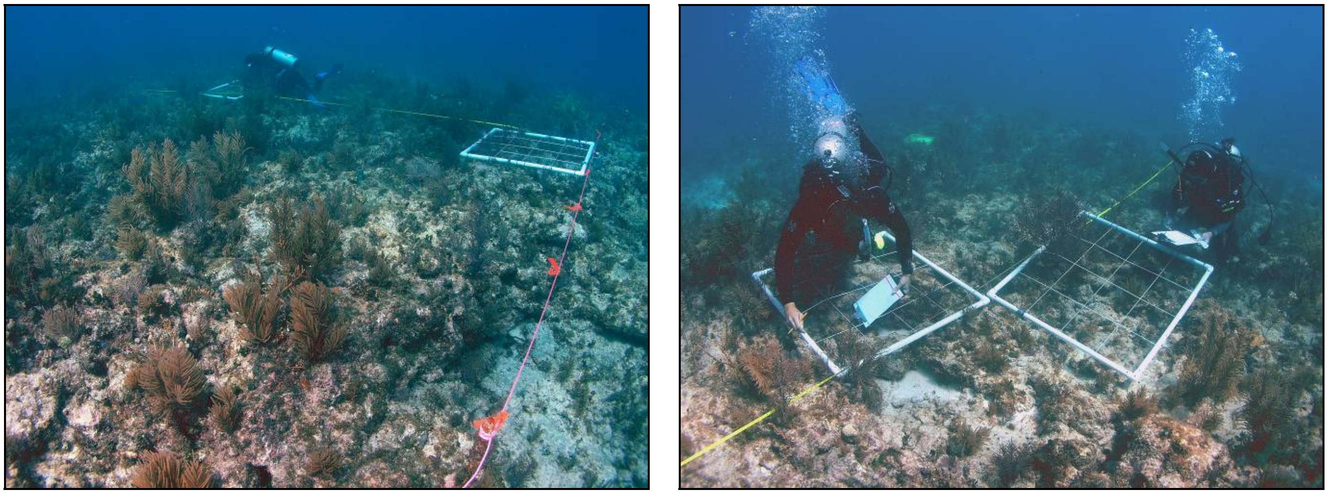


Figure 10. November 2004 photograph of delineated section of the Reference area (left) and divers conducting surveys (right) (photo credit: Jeff Anderson).

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.

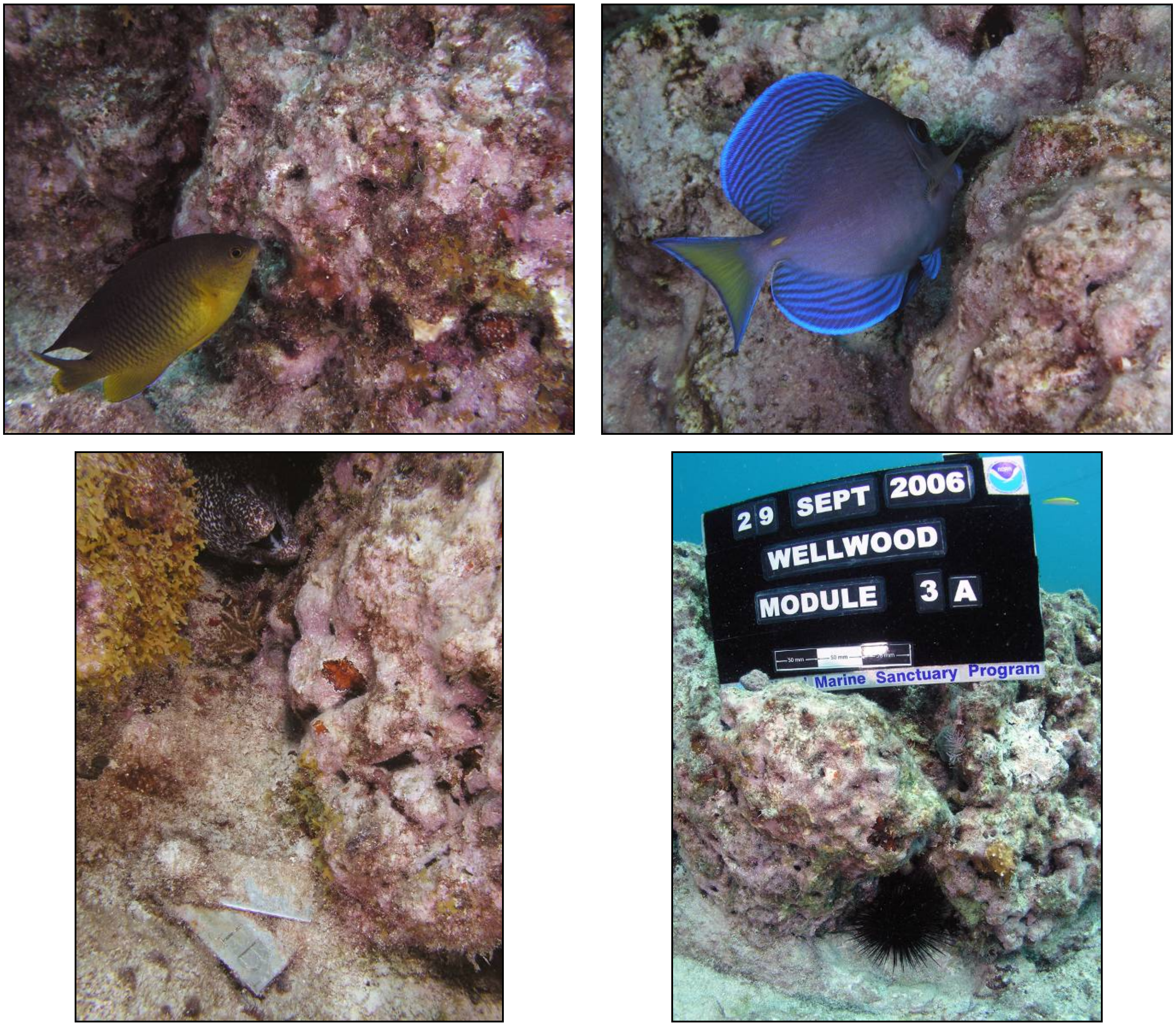
Biological Classifications

The majority of the benthos present were comprised of three Orders and most of the comparisons presented are at the Order level. Present were members of the Order Anthoathecata in the Class Hydrozoa (specimens were solely of one Genus in the Family Milliporidae and henceforth referred to by the more familiar 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.

An initial comparison was made between populations, at the Order level, of benthic organisms that had likely recruited to the site since the restoration. For the purpose of this analysis, recruits in all sampling areas were defined as organisms with sizes at or below that observed on the reef restoration modules. Thus, at the first monitoring event "recruit" is defined as follows—for Gorgonians, a maximum height of 153 mm; for Milleporans, a maximum height of 65 mm. Different species of Scleractinians grow at different rates, so a uniform size classification couldn't be utilized. Therefore a decision was made to utilize, for size categorization purposes, only the most numerous species, *Siderastrea siderea*. This species achieved a maximum diameter of 22 mm in the restored area, and so a size-class scheme based on that size was adopted. Naturally, organisms continued to grow in the interim before the second monitoring event. However, the monitoring team wished to make use of all the information integrated by four years of recruitment across the entire *Wellwood* site. So, the words "recruit" or "recruits" in connection with that event are assigned the following definition: for most Gorgonians, maximum height of 270 mm; when *Gorgonia ventalina* were analyzed separately, a maximum height of 100 mm; for Milleporans, a maximum height of 125 mm. Again, separate considerations apply for the Scleractinians. By 2006, three species were present in sufficient numbers to make size classification reasonable. For two (*Porites astreoides* and *Siderastrea siderea*), a maximum diameter of 40 mm used; for the third species (*Agaricia* spp.), a maximum diameter of 50 mm was used. These sizes represent the maxima achieved by the respective species in the restored area.

The only other benthic organism visible to the eye (besides algae) was *Palythoa caribaeorum,* of the Order Zoanthidea, Subclass Hexacorallia. However *P. caribaeorum* presence was only recorded in the reference area, and consisted of only a very few colonies (approximately 10) and their sizes were such as to cast doubt that they were recruits; they will be ignored for comparative purposes. Much the same may be said of Echinoderms; e.g., in 2004 the restored area contained seven (six *Eucidaris tribuloides* and one *Echinometra viridis*); the other two areas had one apiece (a *Diadema antillarum* in the reference and a *Eucidaris tribuloides* in the damaged unrestored areas).

Although not included in this analysis, numerous vagile fauna were observed using the restoration modules (Figure 11). This was undoubtedly due to both the benthic organisms already colonizing the module structures, as well as the shelter afforded by the cave intentionally designed within the modules (Figure 6). A separate fish monitoring project is described in the DISCUSSION section of this report.



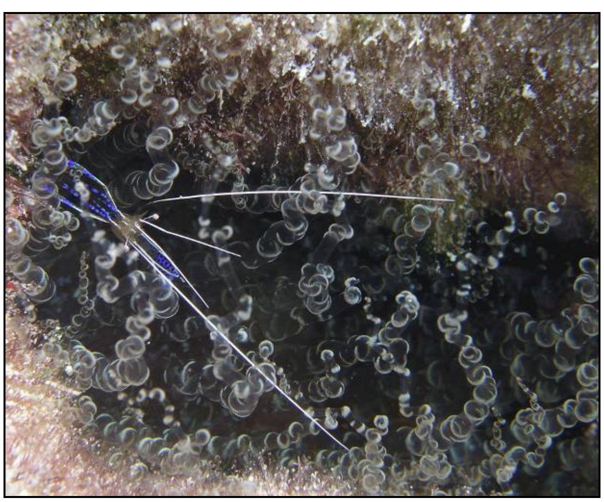


Figure 11. Fauna living in and around reef restoration modules. Starting from upper left: cocoa damselfish (*Stegastes variabilis*), blue tang (*Acanthurus coeruleus*), spotted moray eel (*Gymnothorax moringa*), long-spined urchin (*Diadema antillarum*), and Pederson cleaner shrimp in corkscrew anemone (*Periclimenes pedersoni* in *Bartholomea annulata*) (photo credit: Jeff Anderson).

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, reference, and damaged but unrestored areas, along with various analytic statistics for comparative purposes. For the Order level comparisons, a Chi-square (χ^2) test for independence utilizing a 3×3 contingency table analysis was performed in order to detect whether there were significant associations between areas and numbers of organisms present in the various categories. Regarding density analyses, for the Gorgonia populations, a square root transformation was performed to meet Gaussian distribution requirements—allowing parametric one-way Analysis of Variance (ANOVA) to be utilized, followed by Tukey-Kramer multiple comparisons tests. For both the *Millepora* and the Scleractinia recruit density analyses, the data sets displayed highly significant non-normality. Thus, Kruskal-Wallis non-parametric test was conducted, to be followed by Dunn's post-hoc pairwise tests if significant differences were detected.

RESULTS

YEAR TWO MONITORING EVENT (SEPTEMBER-NOVEMBER 2004)

Structural Integrity

The 2004 monitoring occurred 2 years after the restoration, at which time the stability and surface of all 22 restoration modules and puddle pour areas were found to be visually and tactilely sound. The modules were found in place with a stable attachment to the substrate and no visible cracks in the concrete surface.

Biological Condition

The biological condition of the restoration site was developing. Macroalgae, crustose coralline algae, soft, and hard corals were all recruiting to the restoration modules and surrounding concrete puddle pour areas (Figure 12). For photographs of all 22 restoration modules, see APPENDIX 2.

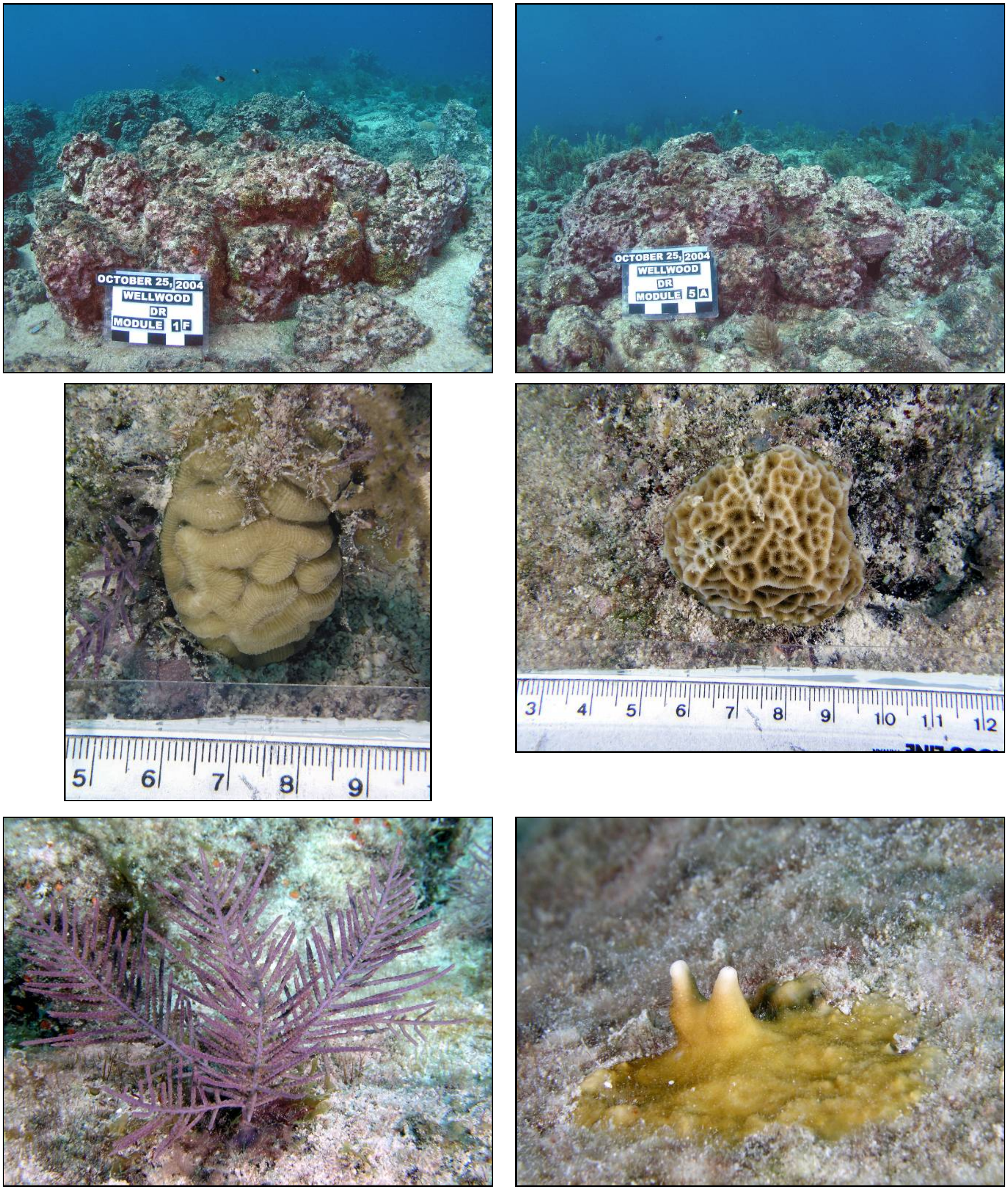


Figure 12. Restoration modules showing biological condition 2 years after installation along with close-up photos of representative benthic organisms surveyed. Starting from middle left: *Diploria labyrinthiformis*, *Agaricia* sp., *Pseudopterogorgia* sp., and *Millepora* sp. (photo credit: Jeff Anderson).

Figure 13 suggests that the three areas contained approximately the same number of organisms, with the exception of the obvious large difference in the populations of Gorgonians. Analysis revealed that sampling areas and colony numbers were highly significantly associated ($P = 0.0005$).

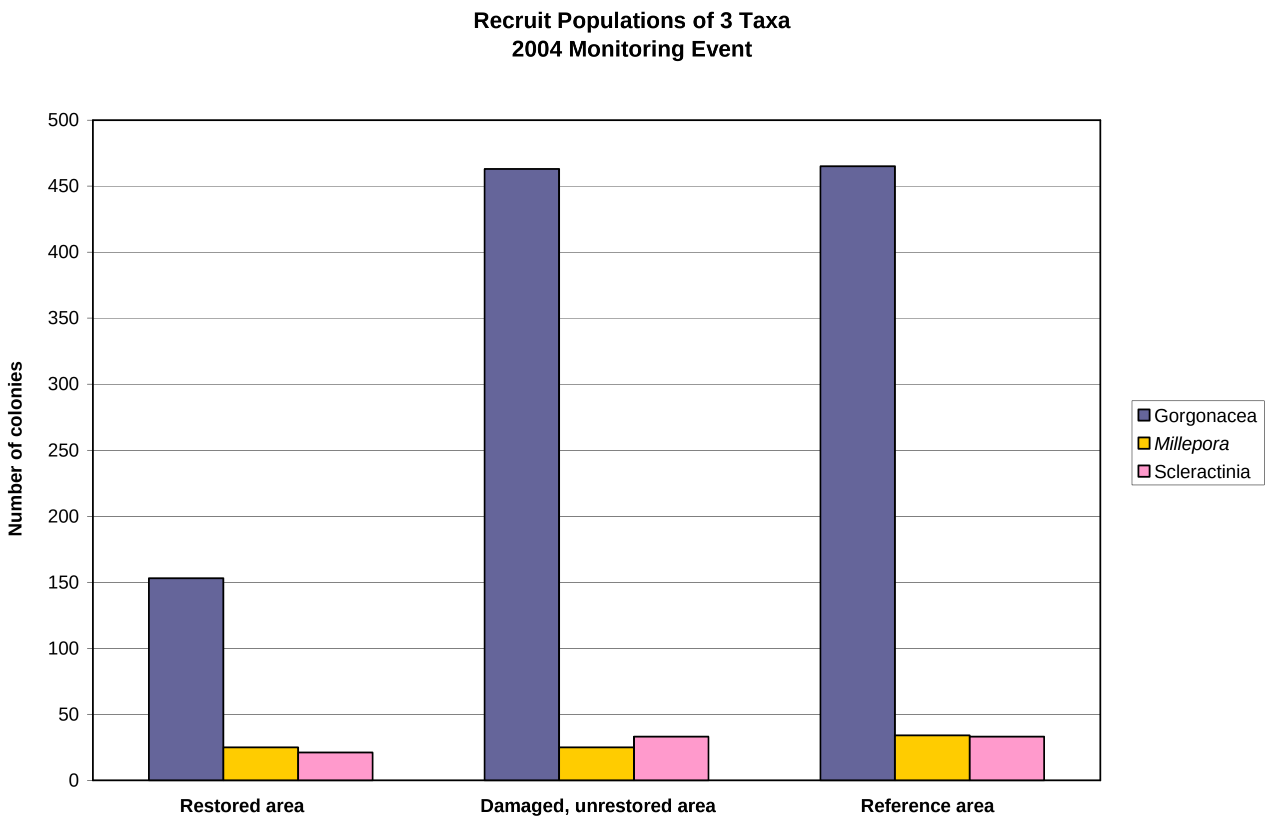
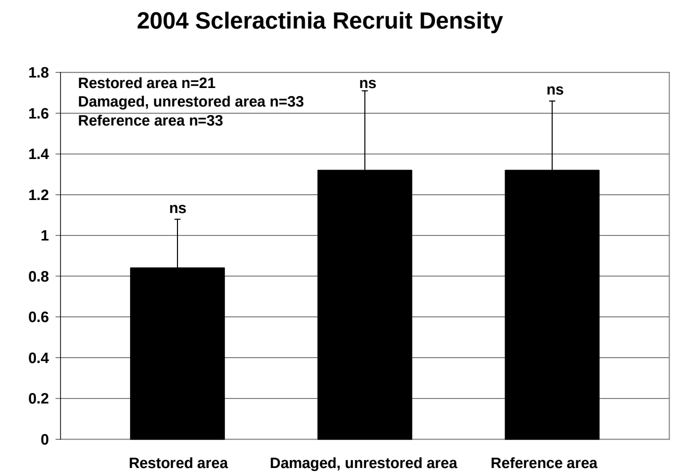
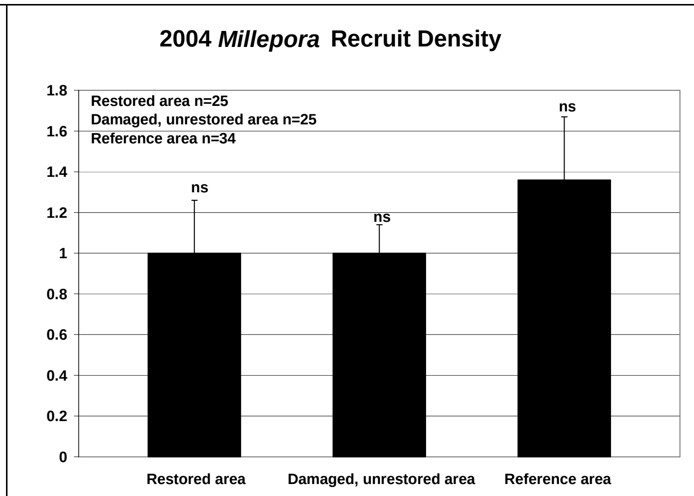


Figure 13. 2004 recruit populations, at the Order level (Genus level for *Millepora*), in the Restored, Damaged, unrestored, and Reference sampling areas at the M/V *Wellwood* restoration site.





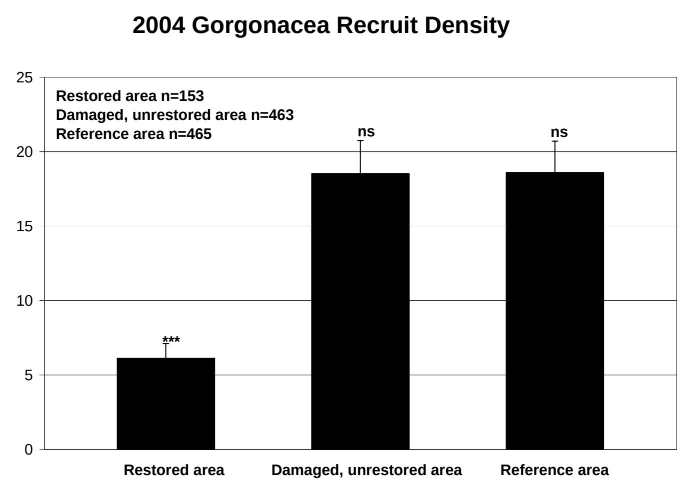


Figure 14. Density (colonies/m²) for all recruit-size classes of: Scleractinians, Milleporans, and Gorgonians (Note differing scales used for Gorgonians vs. others). Error bars = Standard Error; *** indicates extremely significant difference, ns indicates non-significance.

Statistical analysis of recruit densities (colonies/m^2) demonstrated Scleractinian recruits had no significant difference between sampling areas (P = 0.5023) (Figure 14). Similarly, analysis of *Millepora* recruits detected no significant difference between sampling areas (P = 0.5911). Analysis of Gorgonian data revealed the densities were extremely significantly different between sampling areas (P < 0.0001). The restored area evidenced difference; the other two areas were not shown to be significantly different.

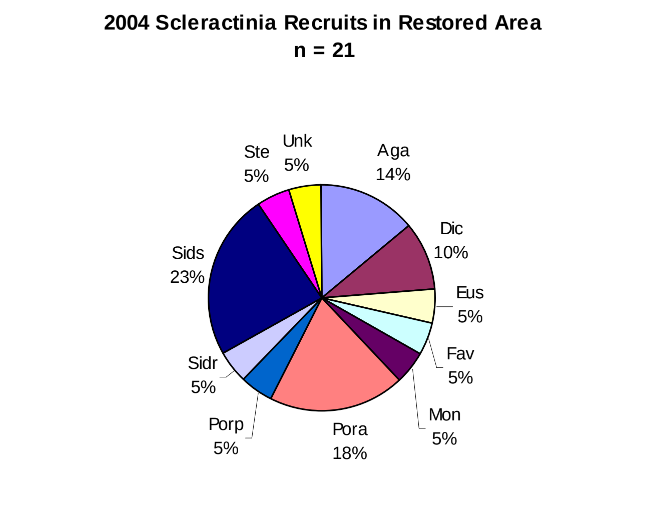
Results of a comparison of the biodiversity of Scleractinian recruits among the three areas within the M/V *Wellwood* restoration site are shown in Table 2 and Figure 15. Table 3 lists the results of a number of standard biodiversity indices performed for the recruit population.

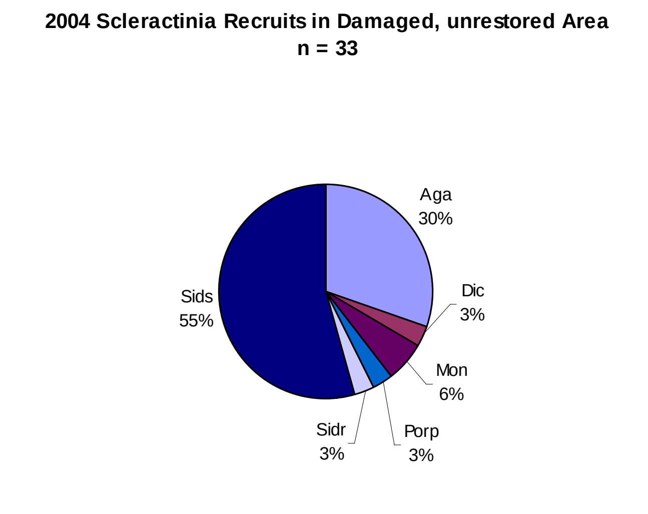
Table 2. Number of Scleractinian recruits, by species, surveyed in 2004 in each of the three areas of the M/V *Wellwood* restoration site.

Species	Restored area	Damaged, unrestored area	Reference area
Agaricia spp.	3	10	13
Dichocoenia stokesii	2	1	0
Eusimilia fastigiata	1	0	0
Favia fragum	1	0	0
Montastraea cavernosa	1	2	1
Porites astreoides	4	0	3
Porites porites	1	1	0
Siderastrea radians	1	1	2
Siderastrea siderea	5	18	10
Stephanocoenia intersepta	1	0	3
Unknown	1	0	1
Total	**21**	**33**	**33**

Table 3. Common Biodiversity indices of the 2004 Scleractinian recruit population in each of the three areas of the M/V *Wellwood* restoration site.

Name of Index (along with formulas)	Restored area	Damaged, unrestored area	Reference area
Species Richness: $S = \#$	11	6	7
Simpson's index: $D = \Sigma(P_i^2)$	0.138	0.396	0.269
Shannon-Weiner: $H = -\Sigma(P_i \log[P_i])$	2.174	1.180	1.547
Evenness: $E = H/\log(S)$	0.907	0.659	0.795





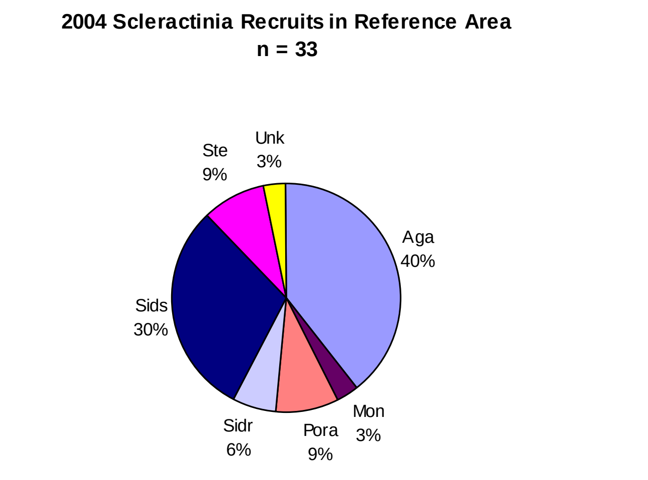
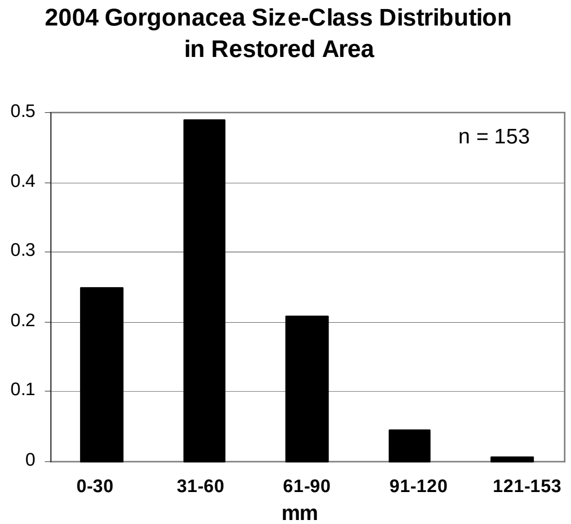
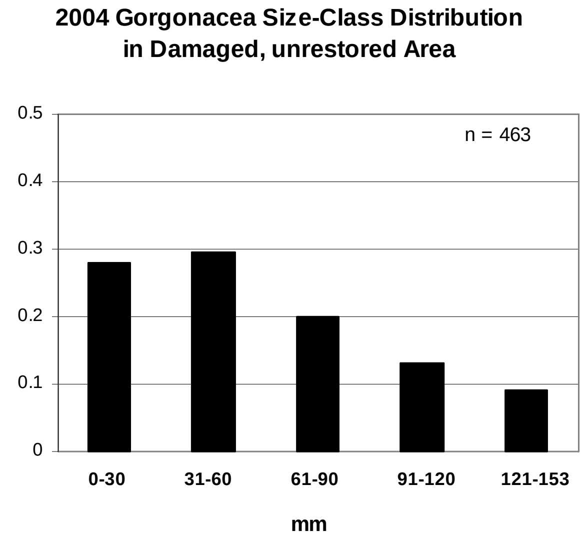


Figure 15. Species (by percentage) of Scleractinian recruits.

Abbreviations:
Aga=*Agaricia* spp.;
Dic=*Dichocoenia stokesii*;
Eus=*Eusmilia fastigiata*;
Fav=*Favia fragum*;
Mon=*Montastraea cavernosa*;
Pora=*Porites astreoides*;
Porp=*Porites porites*;
Sidr=*Siderastrea radians*;
Sids=*Siderastrea siderea*;
Ste=*Stephanocoenia intersepta*;
Unk=unknown





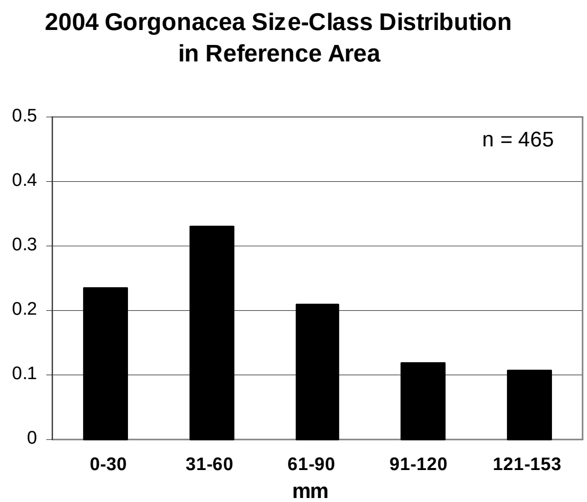
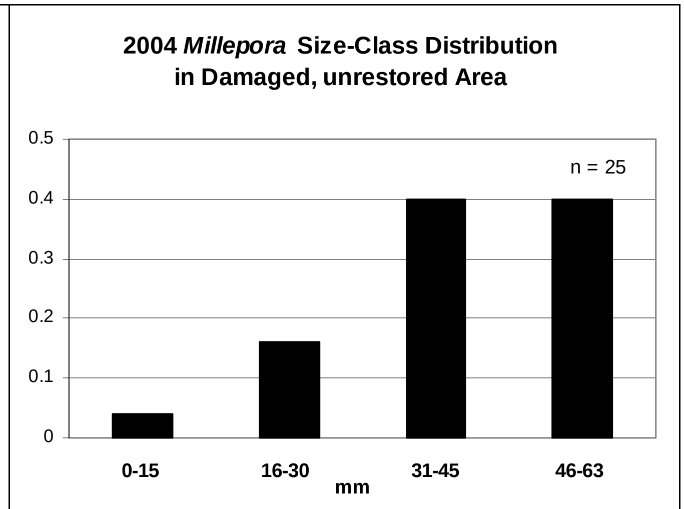


Figure 16. Gorgonian recruit size (height) class frequency distribution in each of the three areas of the M/V *Wellwood* restoration site. The y-axis shows relative frequency (proportion). The largest size was determined by the maximum achieved in the restored area. Size classes were then selected so as to yield five reasonably spaced and populated categories.

The size class frequency distributions of some of the taxa were next determined. Figure 16 shows the relative frequencies of the Gorgonians divided into size classes, the maxima of which was determined by the maximum size of the colonies in the restored area. Figure 17 shows the results of the same analysis for Milleporans.



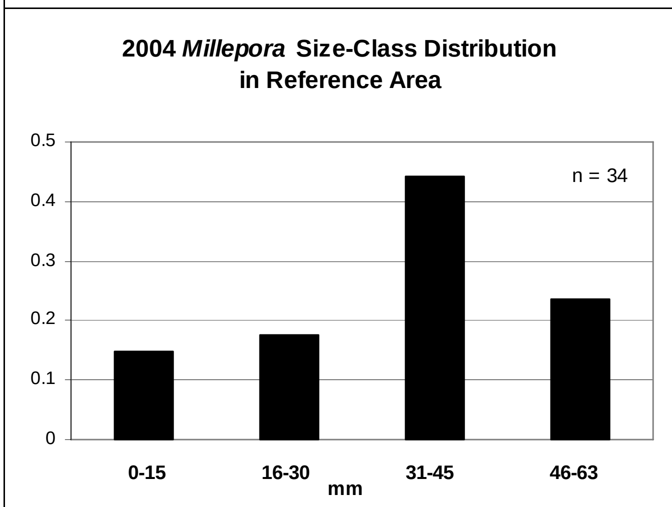
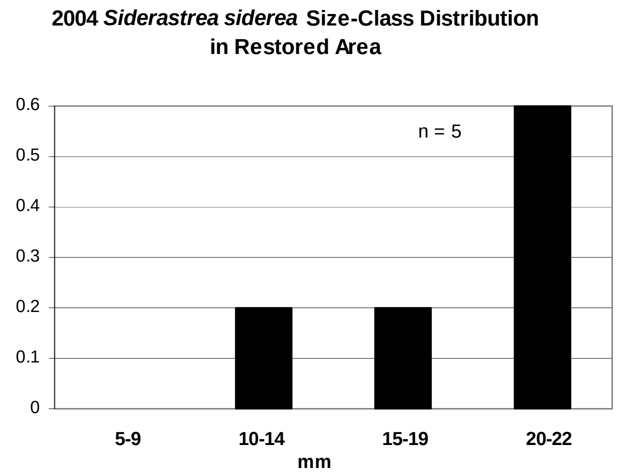
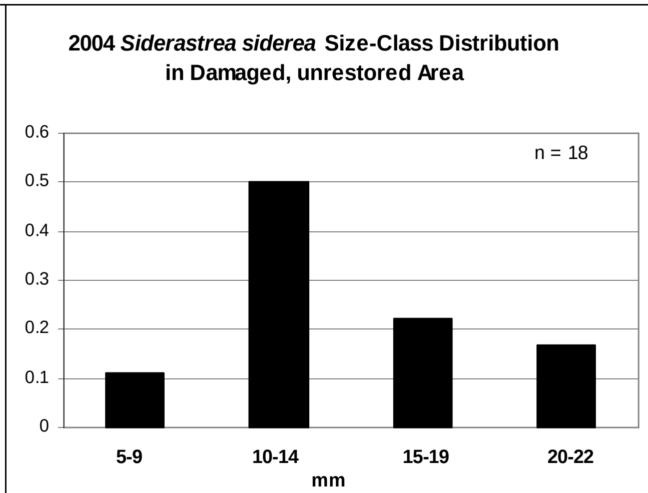


Figure 17. Milleporan recruit size (height) class frequency distribution in each of the three areas of the M/V *Wellwood* restoration site. The y-axis shows relative frequency (proportion). The largest size was determined by the maximum achieved in the restored area. Size classes were then selected so as to yield four reasonably spaced and populated categories.





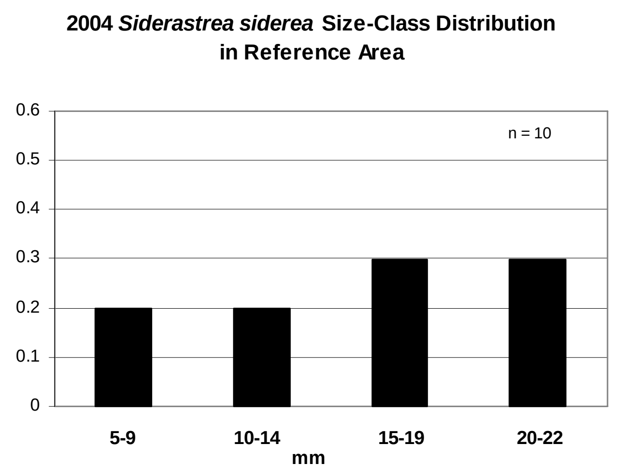


Figure 18. *Siderastrea siderea* recruit size (maximum diameter) class frequency distribution in each of the three areas of the M/V *Wellwood* restoration site. The y-axis shows relative frequency (proportion). The largest size was determined by the maximum achieved in the restored area. Size classes were then selected so as to yield four reasonably spaced and populated categories.

The final analysis was a determination of the size class frequency distribution for Scleractinians. There are two reasons for not utilizing the same size frequency analysis for Scleractinans as was done for Gorgonians and Milleporans. First, the overall number of Scleractinia recruits was fairly low, making a determination of relative frequency distribution less than meaningful, a characteristic shared by the Milleporans. However, in the case of the Scleractinians, another limitation was imposed by the life histories of the species involved. It was felt not to be proper to compare recruits sizes across species, given the disparity in growth rates among juvenile corals (Vermeij 2006). Thus, *Siderastrea siderea,* the species with the greatest number of recruits, was selected for analysis; the results are shown in Figure 18.

YEAR FOUR MONITORING EVENT (JULY-OCTOBER 2006)

Structural Integrity

Despite the near passage of 4 hurricanes during the 2005 storm season, the stability and surface of all 22 reef restoration modules and puddle pour areas were again found to be visually and tactilely sound.

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 modules and surrounding concrete puddle pour areas (Figure 19). For photographs of all 22 restoration modules, see APPENDIX 2.

Figure 19. Restoration modules showing biological condition 4 years after installation (photo credit: Jeff Anderson). Compare to the same 2 modules shown in Figure 12.

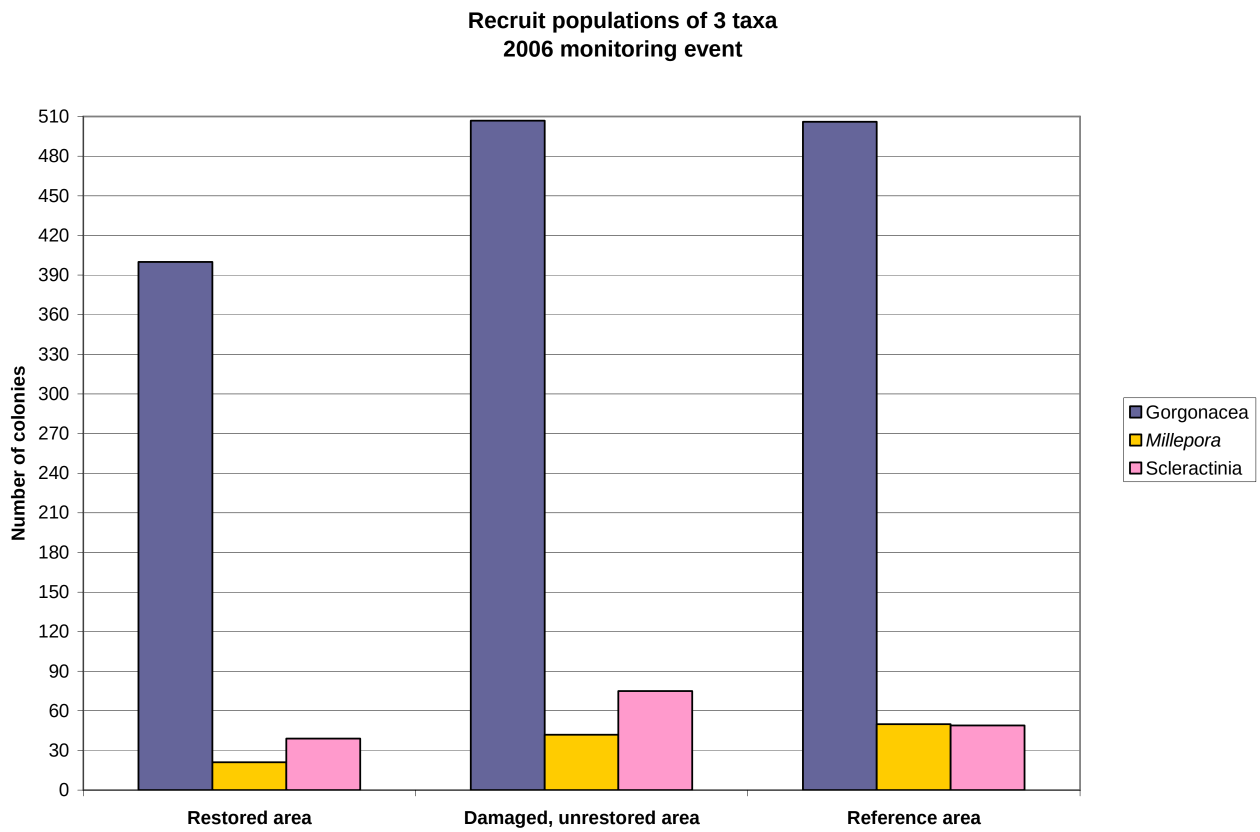
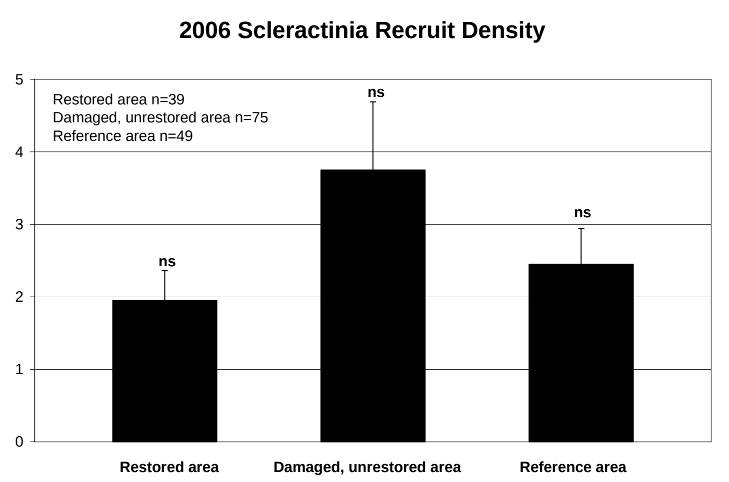
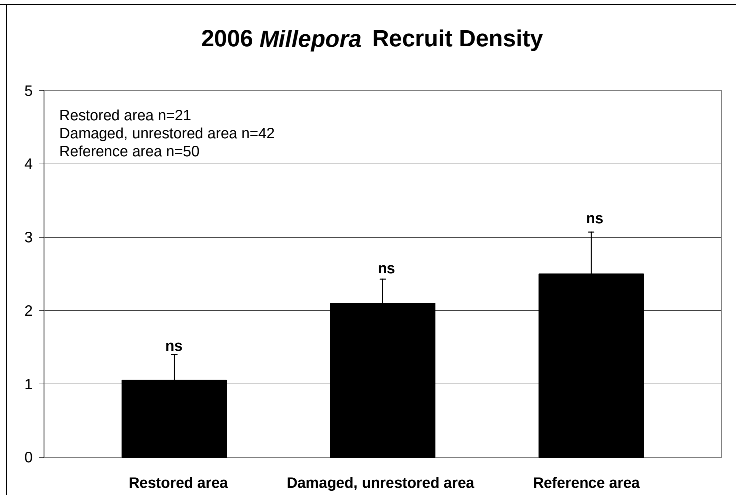


Figure 20. 2006 recruit populations, at the Order level (Genus level for *Millepora*), in the Restored, Damaged, unrestored, and Reference sampling areas at the M/V *Wellwood* restoration site.

Figure 20 suggests that the three sites contained reasonably similar recruit populations, although as in 2004, analysis revealed that areas and colony numbers were significantly associated ($P = 0.0161$).





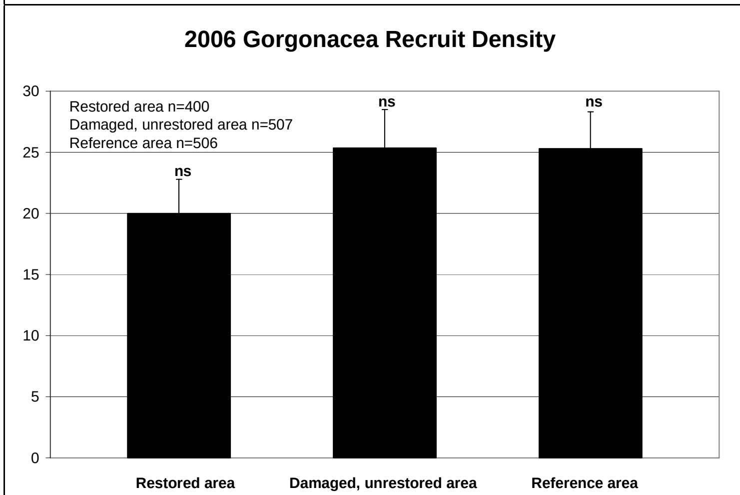


Figure 21. Density (colonies/m²) for all recruit-size classes of: Scleractinians, Milleporans, and Gorgonians (Note differing scales used for Gorgonians vs. others). Error bars = Standard Error; ns indicates non-significance.

Again, overall recruit densities (colonies/m^2) were examined (Figure 21). For Scleractinian recruits, no significant difference was detected between sampling areas (P = 0.3852). Analysis of *Millepora* recruit density revealed overall significant variation (P = 0.0412), though there were no significant differences between sampling areas found by the pairwise comparative tests. Analysis demonstrated that for Gorgonians, the densities were not significantly different between sampling areas (P = 0.3517).

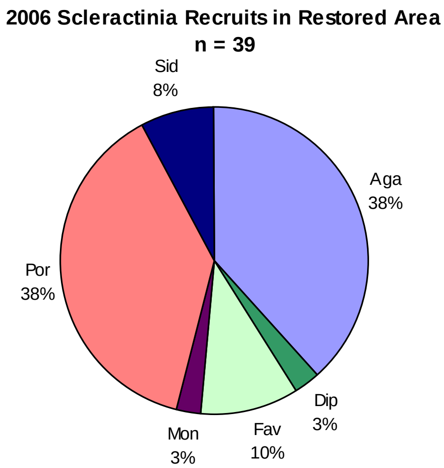
Table 4 and Figure 22 show a comparison of the biodiversity of Scleractinian recruits among the three areas within the M/V *Wellwood* restoration site. Table 5 lists the results of a number of standard biodiversity indices performed for the recruit population.

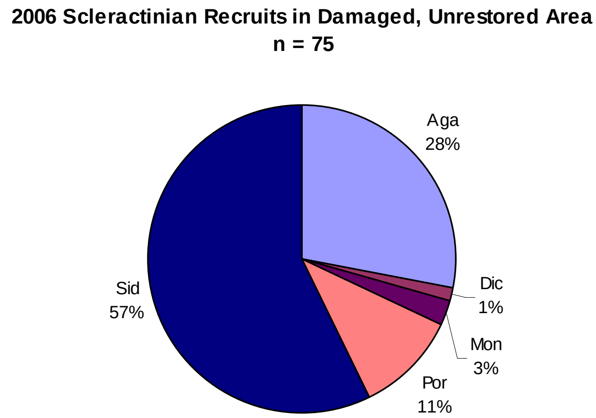
Table 4. Number of Scleractinian species recruits surveyed in 2006 in each of the three areas of the M/V *Wellwood* restoration site.

Species	**Restored area**	**Damaged, unrestored area**	**Reference area**
Agaricia spp.	15	21	21
Dichocoenia stokesii	0	1	0
Diploria spp.	1	0	0
Favia fragum	4	0	2
Montastraea cavernosa	1	2	0
Porites astreoides	15	8	7
Siderastrea siderea	3	43	19
Total	**39**	**75**	**49**

Table 5. Common Biodiversity indices of the 2006 Scleractinian recruit population in each of the three areas of the M/V *Wellwood* restoration site.

Name of Index (along with formulas)	**Restored area**	**Damaged, unrestored area**	**Reference area**
Species Richness: S = #	6	4	5
Simpson's index: $D = \Sigma(P_i^2)$	0.314	0.356	0.424
Shannon-Weiner: $H = - \Sigma(P_i \log[P_i])$	1.354	1.839	1.12
Evenness: $E = H/\log(S)$	0.756	0.822	0.696





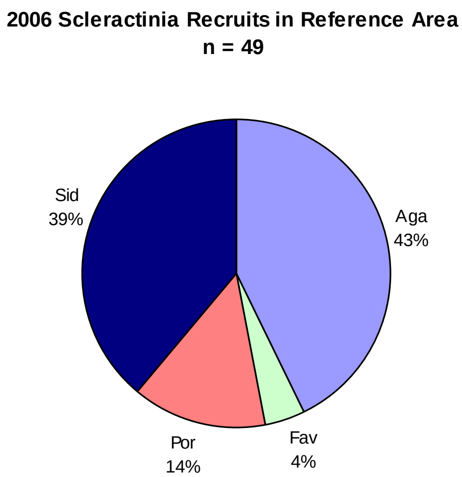
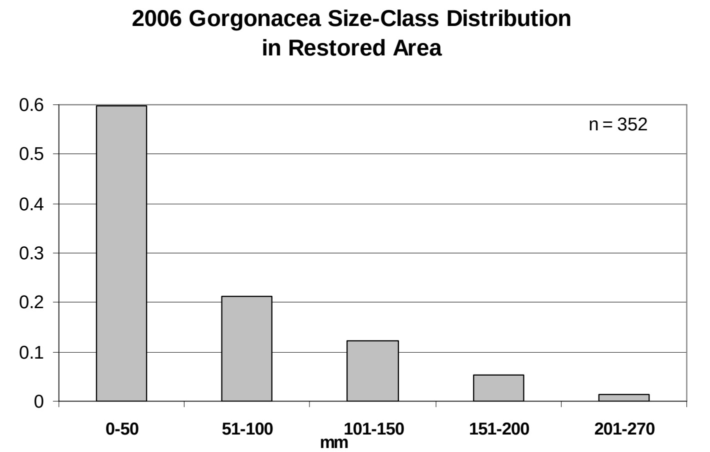
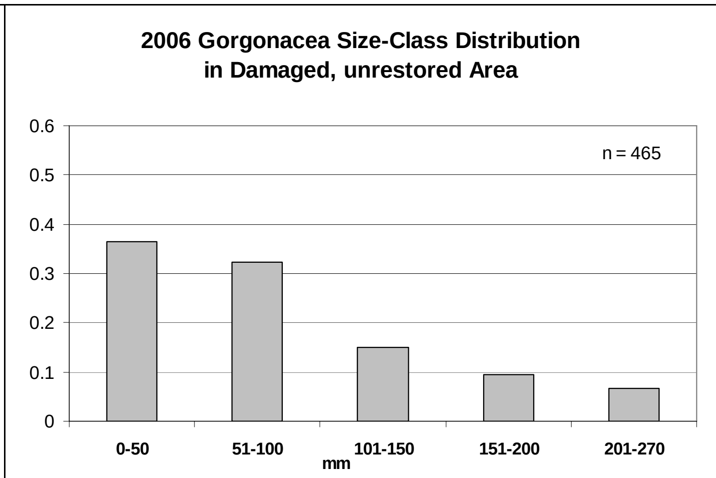


Figure 22. Species (by percentage) of Scleractinian recruits.

Abbreviations:
Aga=*Agaricia* spp.;
Dic=*Dichocoenia stokesii*;
Fav=*Favia fragum*;
Mon=*Montastraea cavernosa*;
Por=*Porites astreoides*;
Sid=*Siderastrea siderea*





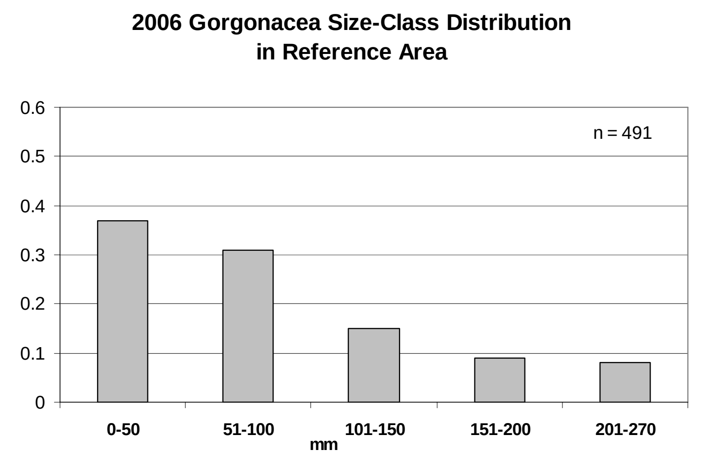
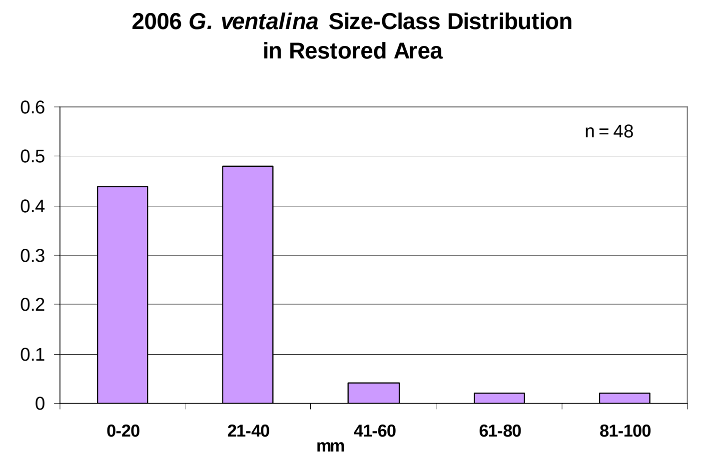
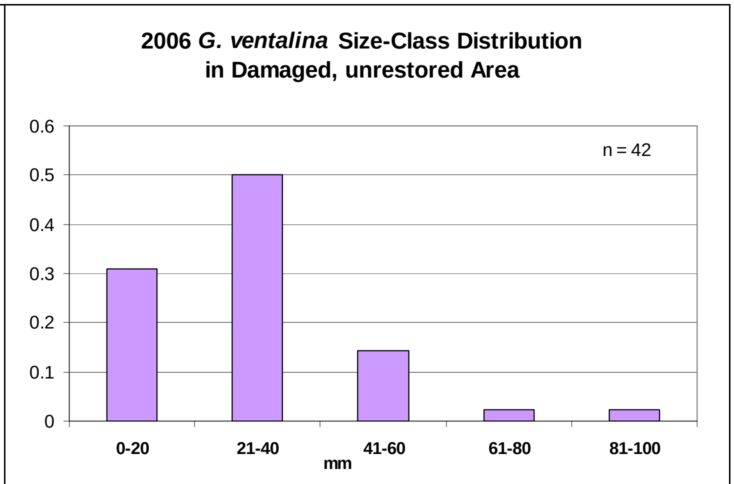


Figure 23. Recruit size (height) class frequency distribution for all Gorgonians except *Gorgonia ventalina* in each of the three areas of the M/V *Wellwood* restoration site. The y-axis shows relative frequency (proportion). The largest size was determined by the maximum achieved in the restored area. Size classes were then selected so as to yield five reasonably spaced and populated categories.

The 2006 size class frequency distribution data of the Gorgonians is presented somewhat differently than it was for the 2004 results. The change was necessitated because of the increased presence of the common sea fan, *Gorgonia ventalina*; in 2004 it comprised only about 1% of the Gorgonian populations, in 2006 it made up as much as 12% (in the restored area) of the totals (Note: practically all others in the Order were comprised of the Genus *Pseudopterogorgia*—sea plumes.). Since growth rates between the Genera differ greatly, *G. ventalina* is depicted separately. Figure 23 shows the relative frequencies of the Gorgonians except *G. ventalina*, divided into size classes, the maxima of which being determined by the maximum size of the colonies in the restored area. Figure 24 shows the same analysis for *G. ventalina* whereas Figure 25 shows the same analysis for all species of Milleporans.





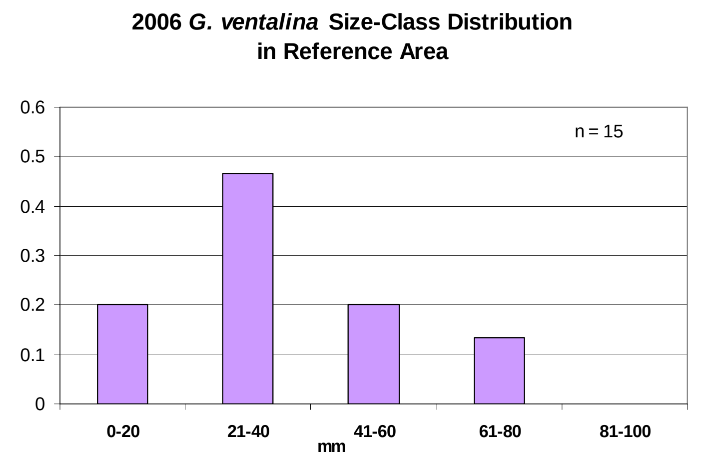
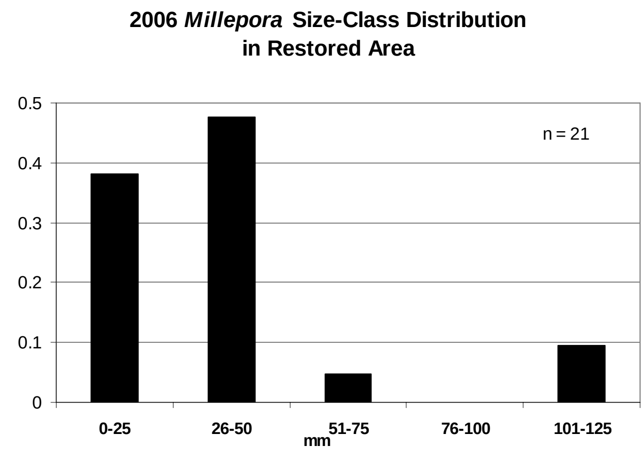
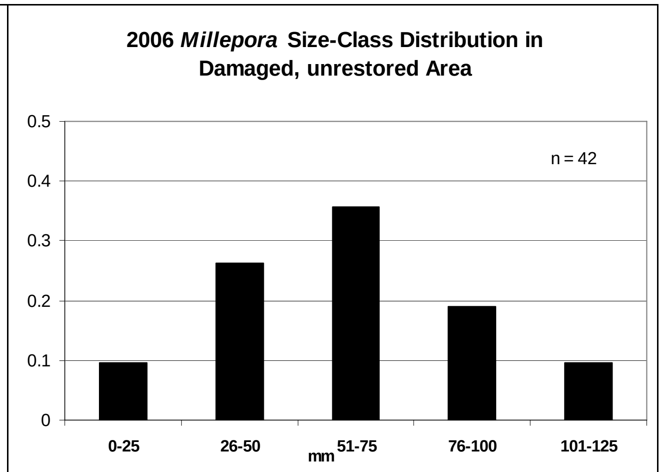


Figure 24. Recruit size (height) class frequency distribution for *Gorgonia ventalina* in each of the three areas of the M/V *Wellwood* restoration site. The y-axis shows relative frequency (proportion). The largest size was determined by the maximum achieved in the restored area. Size classes were then selected so as to yield five reasonably spaced and populated categories.





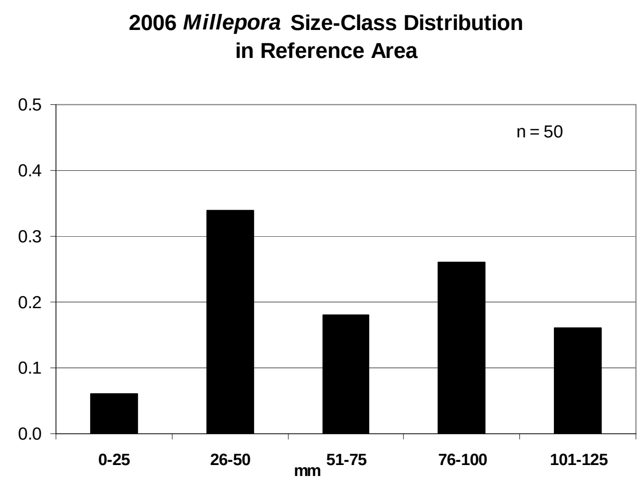
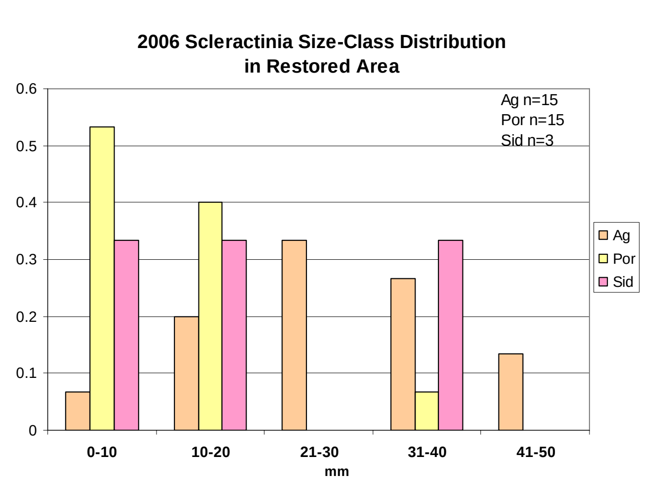
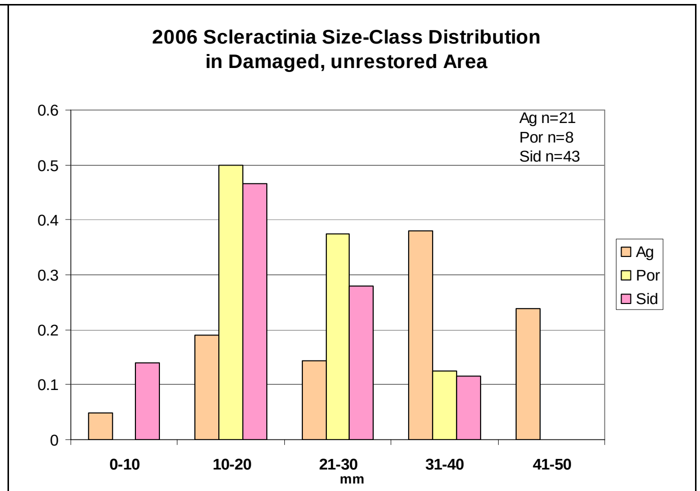


Figure 25. Milleporan recruit size (height) class frequency distribution in each of the three areas of the M/V *Wellwood* restoration site. The y-axis shows relative frequency (proportion). The largest size was determined by the maximum achieved in the restored area. Size classes were then selected so as to yield five reasonably spaced and populated categories.





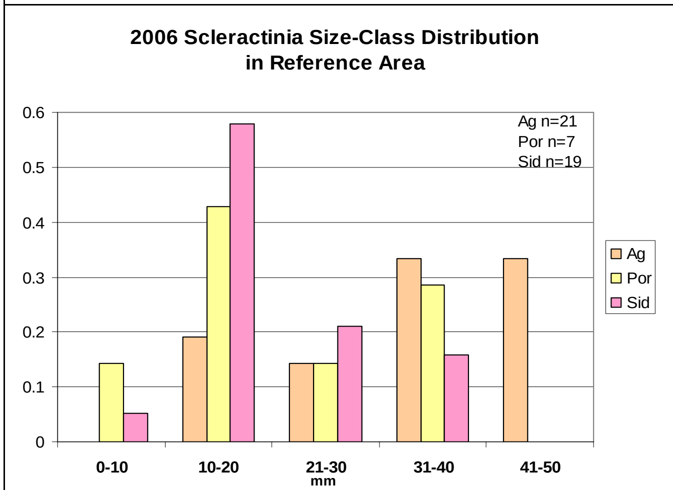
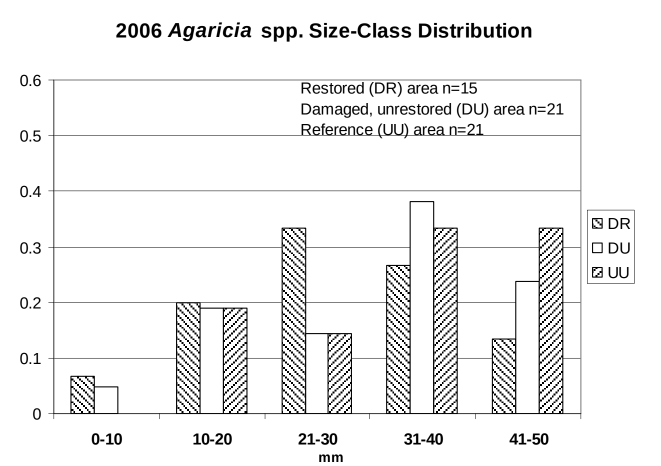


Figure 26. Recruit size (maximum diameter) class frequency distribution for three species of Scleractinians: *Agaricia* spp.; *Porites astreoides,* and *Siderastrea siderea*, grouped by location. The y-axis shows relative frequency (proportion). The largest size was determined by the maximum achieved in the restored area. Size classes were then selected so as to yield five 10 mm range categories (*Agaricia* spp.) or four categories (ending at 40 mm) for the other two species.

The final analysis was a determination of the size class frequency distribution for Scleractinians. The 2006 data showed three Scleractinian species (*Agaricia* spp.; *Porites astreoides,* and *Siderastrea siderea*) were present in sufficient numbers to allow a size class frequency distribution analysis among them to be relatively meaningful. This information is presented in two different fashions. Figure 26 shows the data categorized by location while Figure 27 depicts it grouped by species.



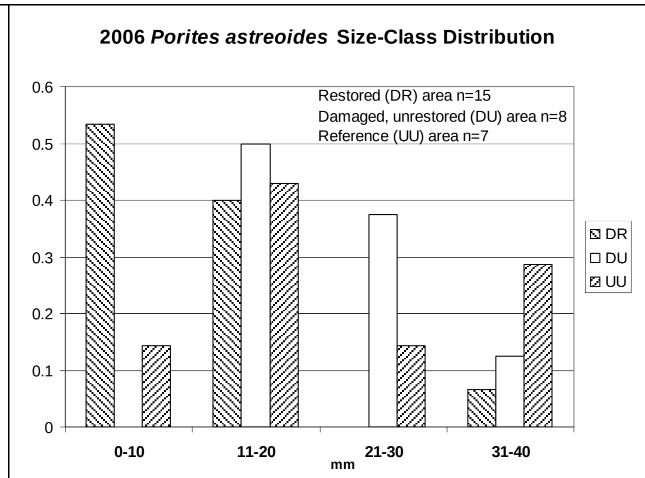


Figure 27. Recruit size (maximum diameter) class frequency distribution for three species of Scleractinians: *Agaricia* spp.; *Porites astreoides,* and *Siderastrea siderea*, grouped by species. The y-axis shows relative frequency (proportion). The largest size was determined by the maximum achieved in the restored area. Size classes were then selected so as to yield five 10 mm range categories (*Agaricia*) or four categories (ending at 40 mm) for the other two species.

DISCUSSION

The results of the 2004 and 2006 *Wellwood* 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, primarily the duration of the monitoring program, and the scope of the monitoring program. Regarding duration, it is important to remember that this report reflects only the preliminary stages of a longer term (10-year) 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 *Wellwood* restoration at this stage. However, the presence of numerous coral recruits even two years after installation provides a good indication that the structural stability and three-dimensional complexity offered by the restoration modules are 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 one portion (stability and recruitment) of the overall restoration project. Although, there are other projects that provide additional data on the recovery of the restoration site. Fish populations have been monitored since restoration implementation by the Reef Environmental Education Foundation (REEF). A final report on REEF's findings is due in late 2007. Another anecdotal indicator of restoration health is the transplantation of *Acropora cervicornis* fragments (as part of another project) to one reef restoration module in October 2003. The fragments have survived and continued to grow since placement. They exhibit noticeable tissue expansion at their bases, have multiple branches, and as of this writing, are free from disease.

The first overall impression one has from the examination of both the 2004 and the 2006 data is that the damaged, unrestored and the reference areas are relatively similar, but that each is fairly distinguishable from the restored location (Figure 13 and Figure 20). It is a rather unremarkable finding, given the fact that by 2006, the damaged, unrestored area had been undergoing recovery for some 22 years. More surprising is that by 2006, the restored area, despite having been restored only 4 years previously, was converging on the status of the other two locations (Figure 20)—at least within the parameters being monitored.

It should be noted that this suspected convergence refers only to that parameter being monitored: namely, populations of recruit- (or at least "small-") size category organisms. Thus, the status of the damaged, unrestored and the reference areas are relatively similar in that regard, and the restored area is rapidly "catching up." It is not surprising that it should have lagged a bit behind the damaged, unrestored area. It is recognized that after placing artificial substrate, often a period must elapse before it becomes "conditioned" to the reef environment (through the deposition of biofilms and other mechanisms beyond the scope of this paper) so as to become receptive to the settlement of potential coral recruits.

The methodology utilized here was constrained by certain assumptions, as well as some practical restrictions. For instance, it was assumed that the maximum size attained by recruits was equal in all sampling areas. This is probably not entirely accurate, due to the conditioning period mentioned above, which could last for several months. Once settlement occurs however, growth rates in the restored area were assumed to be as vigorous as at the other two. A converse assumption was also necessary: recruit growth at the damaged, unrestored and reference areas was equivalent to that in the restored area, such that there could be no possibility of fewer—but slower growing—recruits at those sites. In the absence of data comparing growth rates on natural substrate with those on artificial surfaces, these were felt to be reasonable assumptions. These assumptions create less than optimal monitoring methodology. More precision could have been obtained had the protocol provided for more specific (following individual recruits) as well as more frequent sampling. However, NMSP monitoring team budget, time, and manpower limitations precluded such possibilities.

Given the qualifying statements noted, what story does the data tell?

First, as noted above, recruit populations in all sampling areas are becoming more similar. In particular the population of Gorgonians, which had been extremely significantly different in

2004 (P < 0.0001) (Figure 14), were by 2006 no longer statistically different between the sampling areas (Figure 21).

Biodiversity had been a good deal greater at the restored area in 2004 as compared to the other sampling areas (Table 3), but was somewhat lessened by 2006 (Table 5) such that all areas had similar biodiversity at that time.

Given the data collected to date, one of the most interesting and potentially important results demonstrated was the fact that in 2006, the size-class frequency distributions revealed that the restored area always had a greater proportion of all taxa populations in the smallest size category (Figure 23, Figure 24, Figure 25, Figure 26, and Figure 27). Perhaps this is indicative of the fact that by this time, the modules had become preferential recruitment substrate. If so, in the coming years, as the absolute number of recruits to the areas continues to converge, and as the proportionately greater restored area small recruit cohort progresses through the size categories, overall populations in the restored area should overtake those at the other locations (assuming no differential mortality).

The above applies with equal force to Scleractinians. However, with regard to *Siderastrea,* the observation is probably not very meaningful, as only five colonies were found among the restored area quadrats in 2004 (Table 2), and only three in 2006 (Table 4).

This last statement gives rise to some intriguing questions: Why was the proportion (8%) of recruiting *Siderastrea* so low in the restored area relative to the damaged, unrestored and reference areas, where it comprised 57% and 39% respectively in 2006 (Figure 22)? Is there something about the area that is not conducive to settlement by the species? For the other two substantial recruiters, *Agaricia* and *Porites,* no such differential was exhibited. In fact, looking solely at those two species, recruitment across the three areas was almost exactly equal; cumulatively 30, 29, and 28 colonies at the restored, damaged, unrestored, and reference areas respectively (Table 4).

The questions are of more than academic interest. *Agaricia* and *Porites* are small species which brood their larvae, while *Siderastrea* is a large frame-building broadcast spawner (Edmunds et al. 2004; Miller et al. 2000). Because of the relatively small number involved, one must be guarded with respect to over interpretation of this data, and should probably consider the results conservatively as preliminary. Nonetheless, certainly this anomaly warrants heightened scrutiny; hopefully an answer may be revealed during the course of future monitoring episodes.

One final observation of coral recruitment in the restored area is that the number of recruits from all surveyed Orders was higher on limestone boulder surfaces. With the data collected to date, we are not able to determine if this substrate settlement data reflects trends different than the relative proportion of the surface areas of the 2 substrate types (sensu Miller and Barimo 2001). Some qualitative sense of the relative space available may be ascertained from the examination of photographs in APPENDIX 1. The apparent preference may not be due to the materials themselves, but perhaps to their configuration and orientation. That is to say, the rock displays a high degree of three-dimensional relief and topographic complexity, while the concrete is smooth and flat (level with the substrate). Also the rocks are packed fairly close together (see

Figure 8, Figure 9, and Appendix 1) so their projections form niches under which recruits may shelter. This type of cryptic habitat is often favored by coral recruits (Adjeroud et al. 2007; Perkol-Finkel and Benyahu 2007). Acquisition of data to model limestone boulder and concrete surface areas, enabling coral recruit substrate preference trend analysis at this site is being considered for future study.

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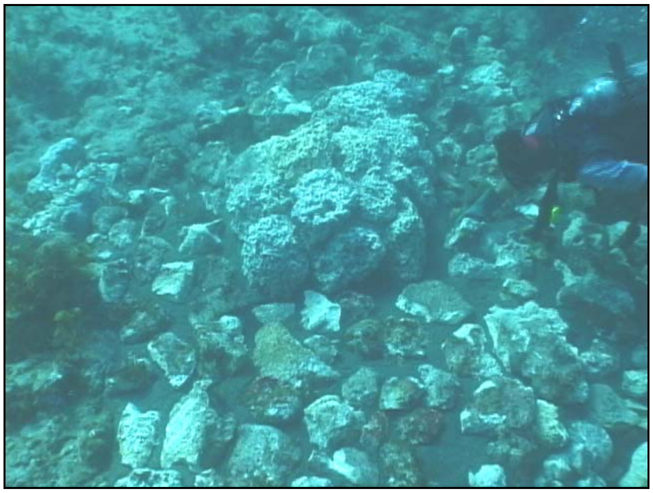
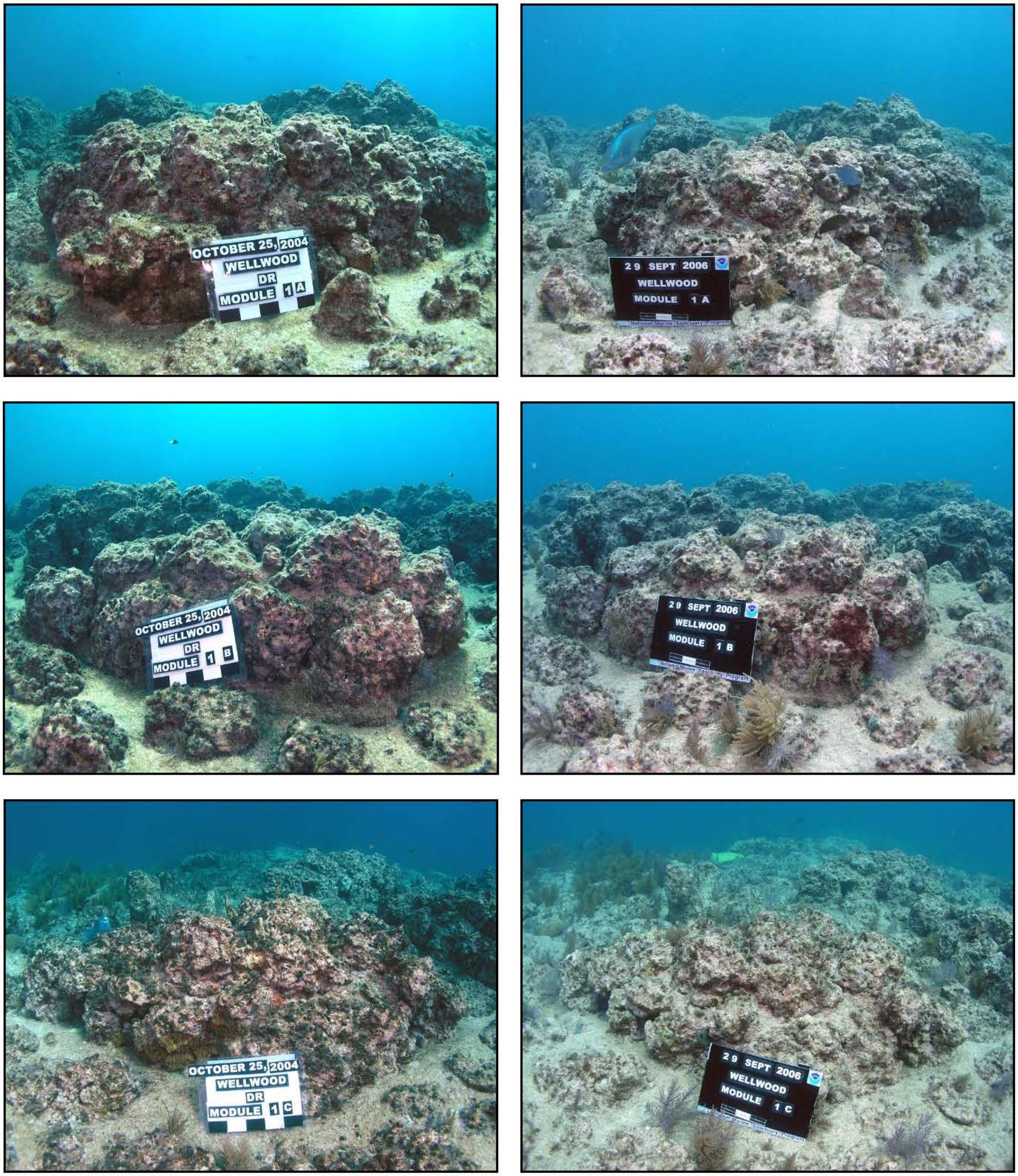
APPENDIX 1

Photographs of completed reef restoration module and puddle pour installations from June-July 2002 (photo credits: Florida Keys National Marine Sanctuary and Coastal Planning and Engineering, Inc.).



APPENDIX 2

Comparative photographs of reef restoration modules from October 2004 (left) and September 2006 (right) (photo credits: Jeff Anderson).



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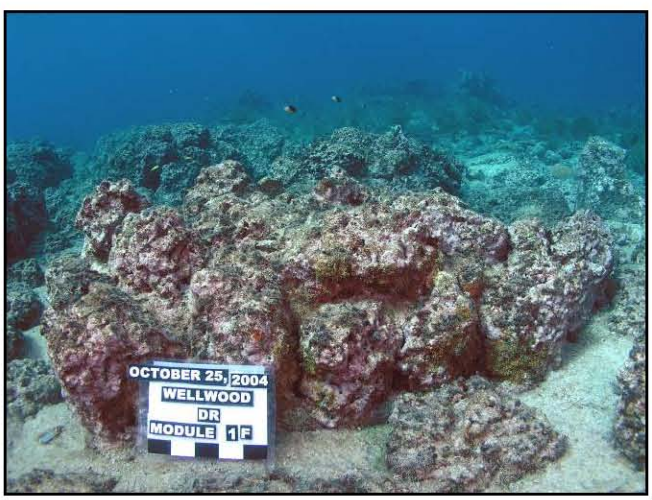

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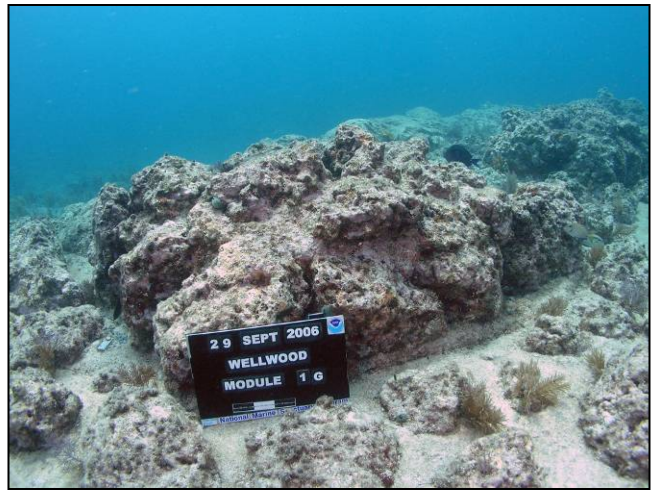

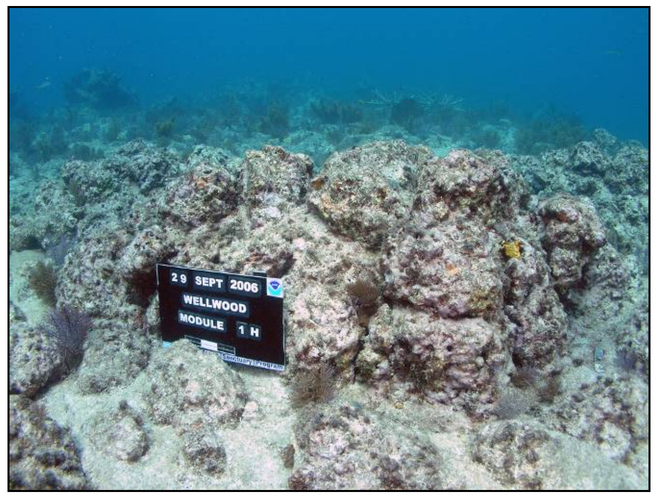

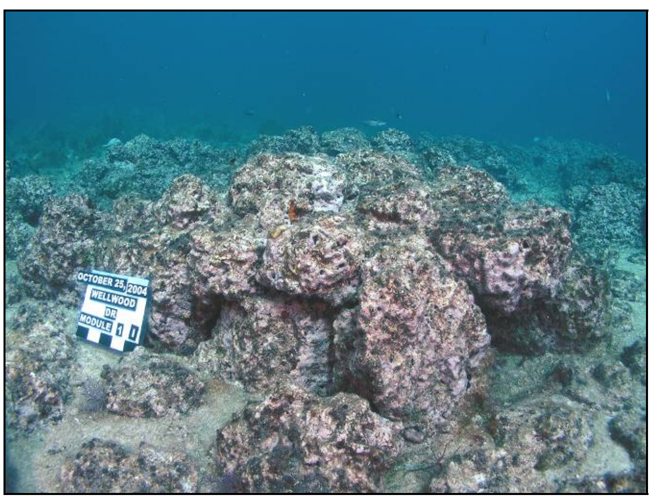

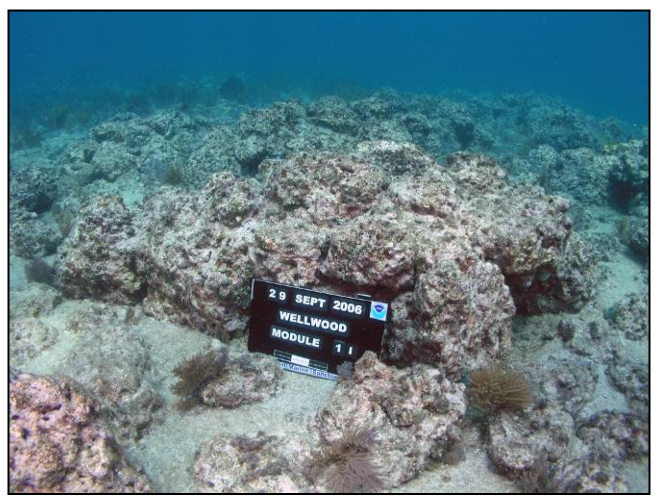

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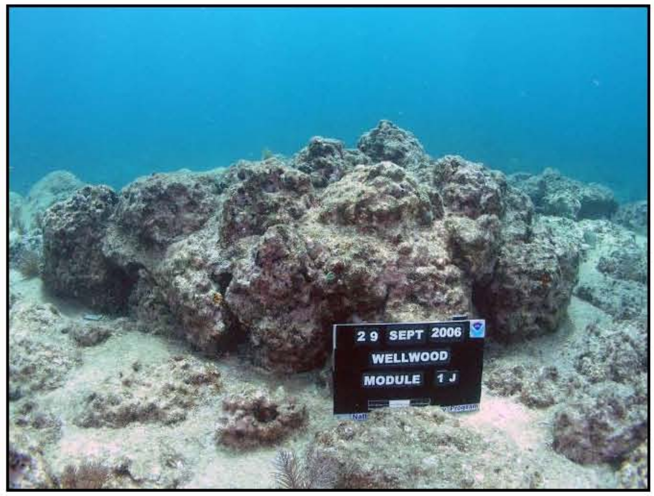

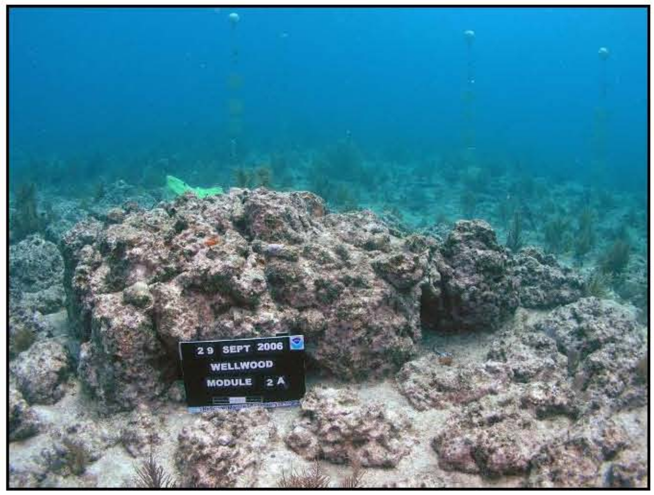

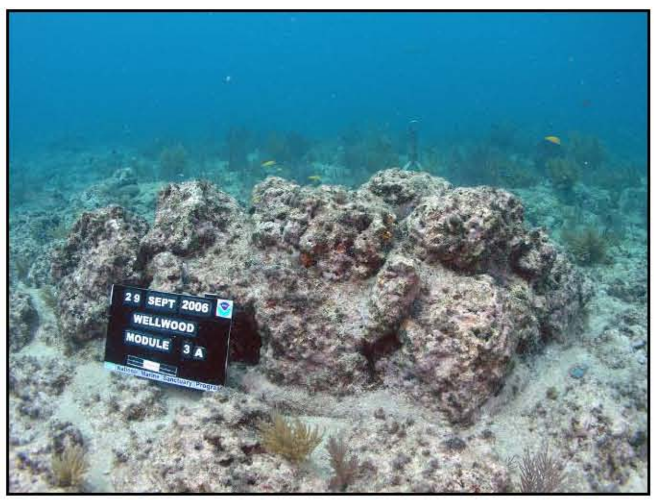

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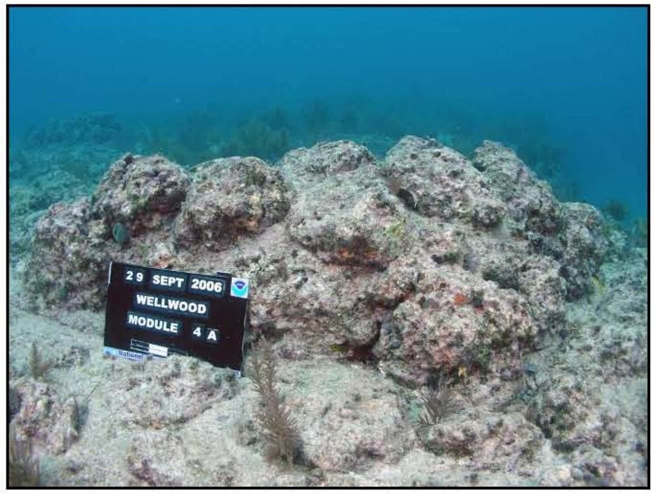

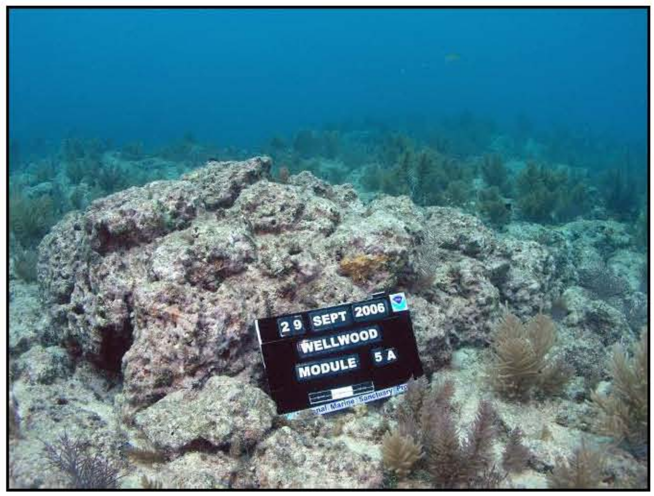


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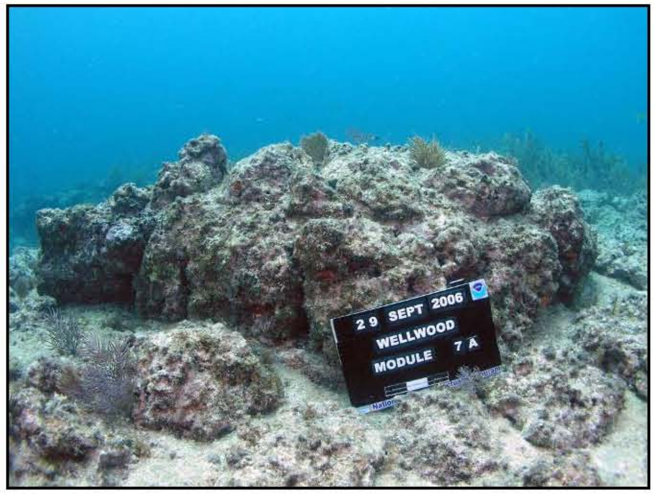
DR
MODULE 7 A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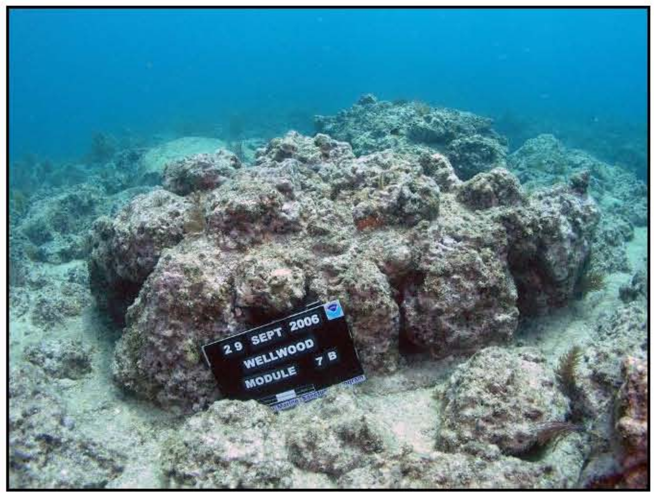
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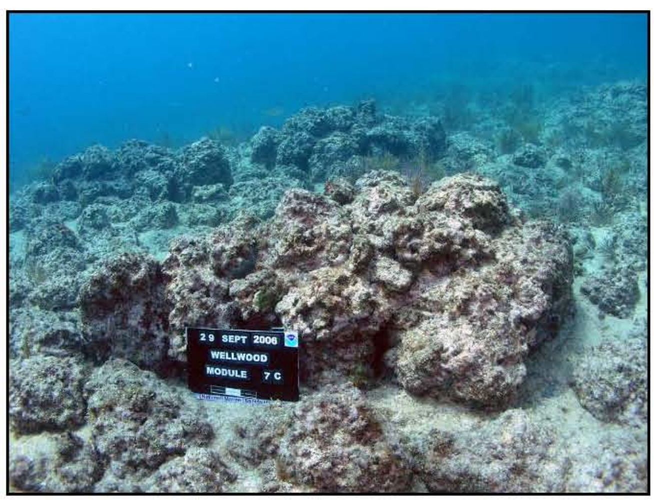
MODULE 7 C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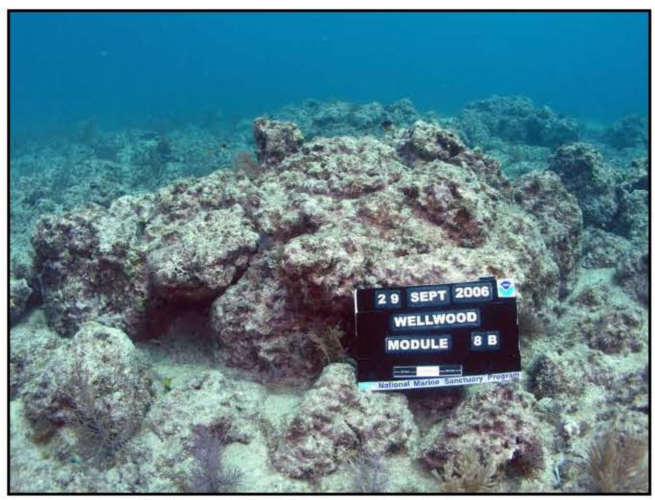

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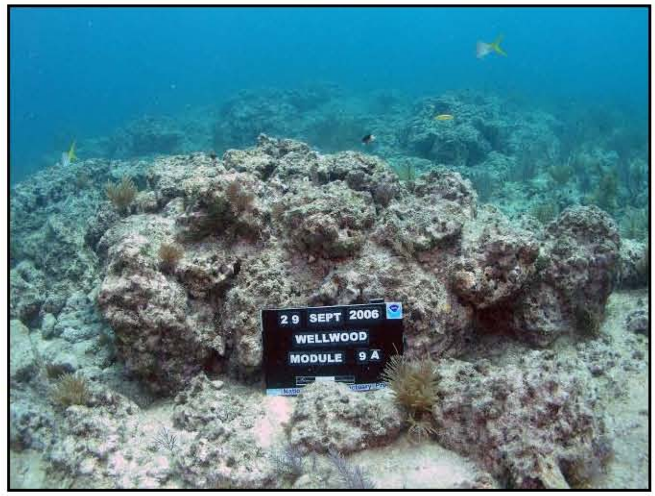
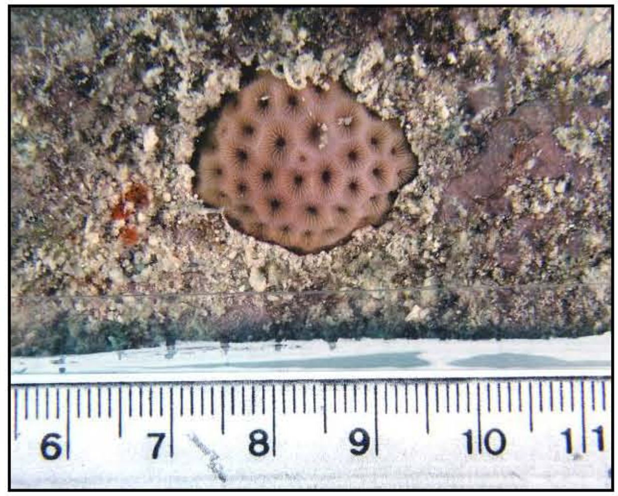


APPENDIX 3

Photographs of benthic species surveyed on reef restoration modules during September to November 2004 monitoring event (photo credits: Jeff Anderson).



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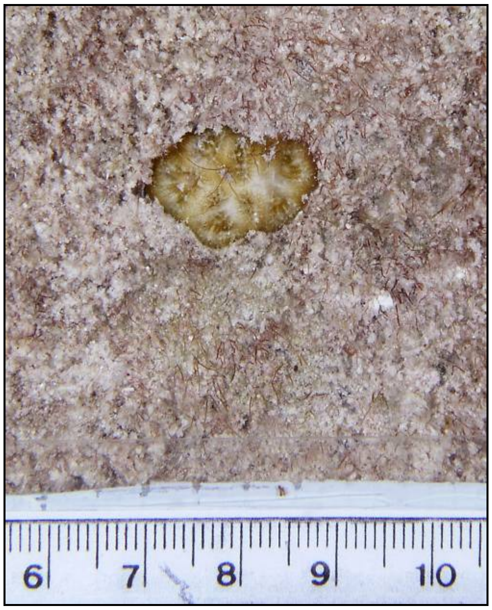

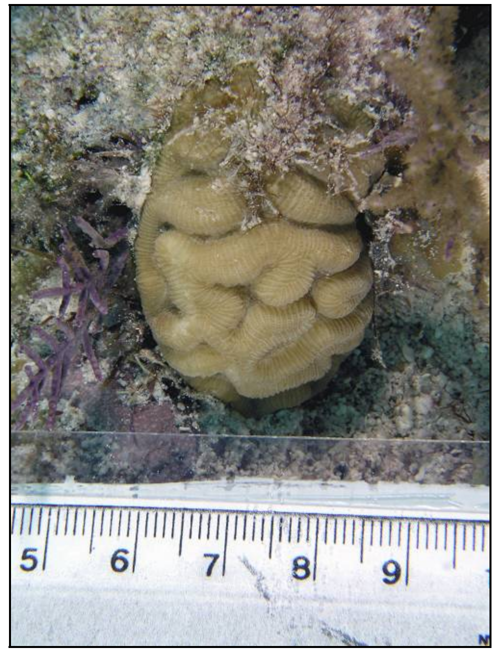

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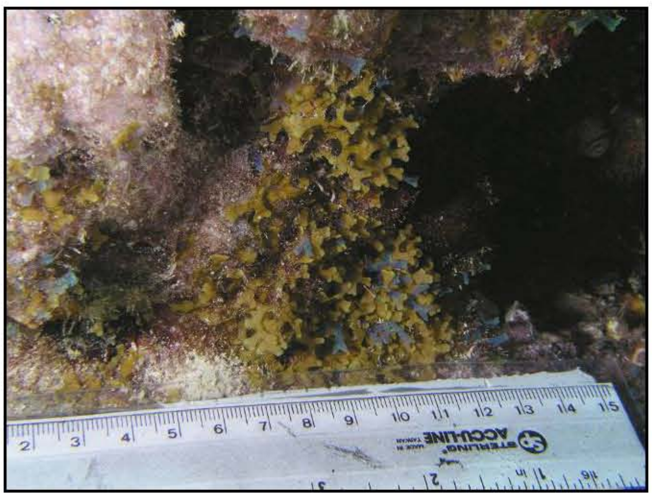

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2002 - 03 Florida Keys National Marine Sanctuary Science Report: An Ecosystem Report Card After Five Years of Marine Zoning (NMSP-06-12)

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)

M/V *WAVE WALKER* Coral Reef Restoration Baseline Monitoring Report - 2004 Florida Keys National Marine Sanctuary Monroe County, Florida (NMSP-06-08)

Olympic Coast National Marine Sanctuary Habitat Mapping: Survey report and classification of side scan sonar data from surveys HMPR-114-2004-02 and HMPR-116-2005-01 (NMSP-06-07)

A Pilot Study of Hogfish (*Lachnolaimus maximus* Walbaum 1792) Movement in the Conch Reef Research Only Area (Northern Florida Keys) (NMSP-06-06)

Comments on Hydrographic and Topographic LIDAR Acquisition and Merging with Multibeam Sounding Data Acquired in the Olympic Coast National Marine Sanctuary (ONMS-06-05)

Conservation Science in NOAA's National Marine Sanctuaries: Description and Recent Accomplishments (ONMS-06-04)

Normalization and characterization of multibeam backscatter: Koitlah Point to Point of the Arches, Olympic Coast National Marine Sanctuary - Survey HMPR-115-2004-03 (ONMS-06-03)

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)

Movement of yellowtail snapper (Ocyurus chrysurus Block 1790) and black grouper (Mycteroperca bonaci Poey 1860) in the northern Florida Keys National Marine Sanctuary as determined by acoustic telemetry (MSD-05-4)

The Impacts of Coastal Protection Structures in California's Monterey Bay National Marine Sanctuary (MSD-05-3)

An annotated bibliography of diet studies of fish of the southeast United States and Gray's Reef National Marine Sanctuary (MSD-05-2)

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Olympic Coast National Marine Sanctuary: Proceedings of the 1998 Research Workshop, Seattle, Washington (MSD-01-04)

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