Baseline Biological Monitoring of Miami-Dade Limerock Module and Single Layer Boulder Reefs 2008

FINAL REPORT

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ABSTRACT

During the last 15 years, limerock boulder and module artificial reefs have been deployed offshore of Miami-Dade County for a variety of purposes including mitigation and fisheries enhancement. This study sought to examine the previously undocumented fish and benthic assemblages utilizing loosely aggregated, single-layer limerock boulders and prefabricated concrete and limerock modules. The boulders and modules are located in the Sunny Isles Artificial Reef Site at the Sunny Isles Reef Restoration (SIRR) Offsite Mitigation Site. These reefs were deployed in March of 1993. This baseline study demonstrated that both the boulders and modules provide habitat that has supported abundant and diverse biological assemblages. The benthic assemblages on both the single layer boulders and modules was dominated by turf algae coverage followed by sponge (Porifera) species and to a much lesser extent soft corals (Octocorallia) and stony corals (Scleractinia). The boulders had more soft corals while the modules had more stony corals. The fish assemblages on both the module and boulder reefs were dominated by the family Labridae (Wrasse) most commonly of the species *Thalassoma bifasciatum* (blueheaded wrasse) and the family Pomacentridae most commonly of the species *Pomacenyrus partitus* (bicolor damselfish). Solitary modules had the highest percent composition of the family Pomacentridae (damselfish). Other common reef fish families were also observed including gobies (Gobiidae), butterfly fish (Acanthuridae), grunts (Haemulidae), and parrot fish (Scaridae). The single layer boulder reef had more fish of the family Labridae (Wrasses) than the multilayer boulder reefs in the previous study. This study has provided baseline information for evaluating the effectiveness of these reefs in meeting the objectives for which they were constructed such as fisheries enhancement or habitat mitigation and will assist in future artificial reef planning. It has also provided a comparison of single layer boulder reefs to multi-layer boulder reefs.

INTRODUCTION

Artificial reefs are best known as a tool for fishery enhancement (Bohnsack and Sutherland 1985, Palmer-Zwahlen and Aseltine 1994, Pickering et al. 1998, Seaman 2000). However, during the last few decades, the uses of artificial reefs have expanded to include mitigation, habitat rehabilitation, habitat restoration, and habitat protection (Pickering et al. 1998). Seaman (2000) defined artificial reef as objects, natural or human made, deployed purposefully on the seafloor to influence physical, biological, or socioeconomic processes related to living marine resources. Seaman's definition has incorporated all such uses.

Over the last 15 years, numerous artificial reefs constructed from limerock boulders and modules have been deployed for a variety of purposes in Miami-Dade County including mitigation and fisheries enhancement. However, the benthic and fish assemblages utilizing these artificial reefs have not been well described. This project documented and quantified the biological assemblages loosely aggregated, single-layer limerock boulders and prefabricated concrete and limerock modules. The module stations were divided into three categories: solitary modules, modules with one other module in a 50 ft. radius, and modules with two or more other modules in a 50 ft. radius. Due to time and funding limitations, a 'seasonal' assessment could not be conducted. Rather two rounds of surveys were conducted on each of the boulder and module stations. This information will assist in evaluation the effectiveness of these reefs in meeting the objectives for which they were constructed such as fisheries enhancement or habitat mitigation.

SITE LOCATION AND DESCRIPTION

The SIRR (Sunny Isles Reef Restoration) Offsite artificial reef was utilized for this study (Figures 1 and 2). This site is composed of loosely aggregated single layer boulder (Figure 3) reefs and limerock modules (Figure 4). The boulder reefs were constructed with quarried limerock boulder that ranged between 3 ft. and 6 ft. diameter placed in a 'single-layered' arrangement. The modular reefs are pre-fabricated and constructed of concrete and limerock. These specifications were selected following analysis of the material for stability in storm events. Miami-Dade County stability analysis assesses the material's resistance to overturning and horizontal movement, utilizing characteristics of a 25-year return storm event, in consideration of the depth and bottom slope of the deployment location. The modules were placed in a random arrangement and the single layer boulder reefs were interspersed amongst the modules (Figure 5).

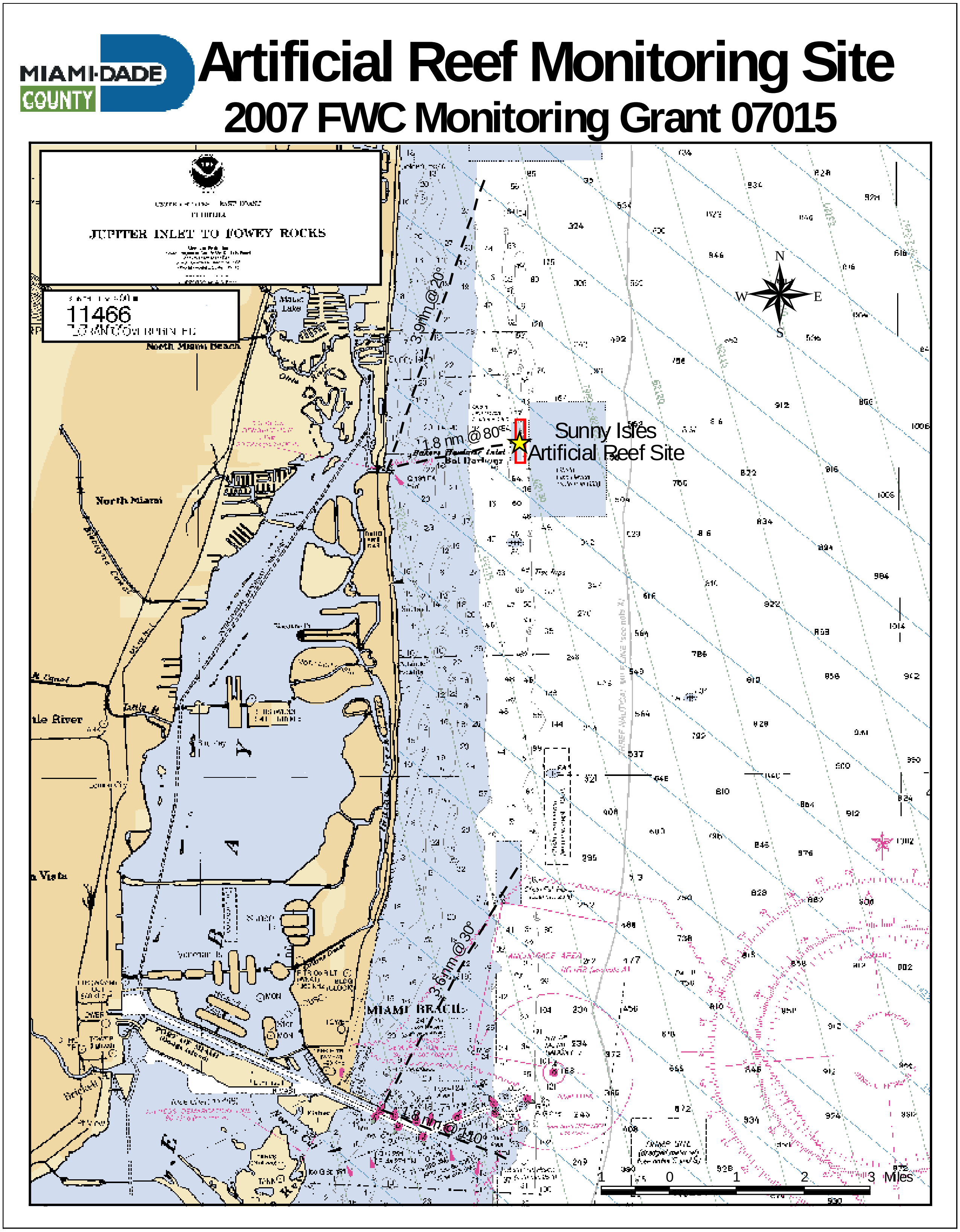

Figure 1. Location of the Sunny Isles Reef Restoration Offsite Mitigation Site and respective artificial reef site evaluated through FWC Grant 07015.

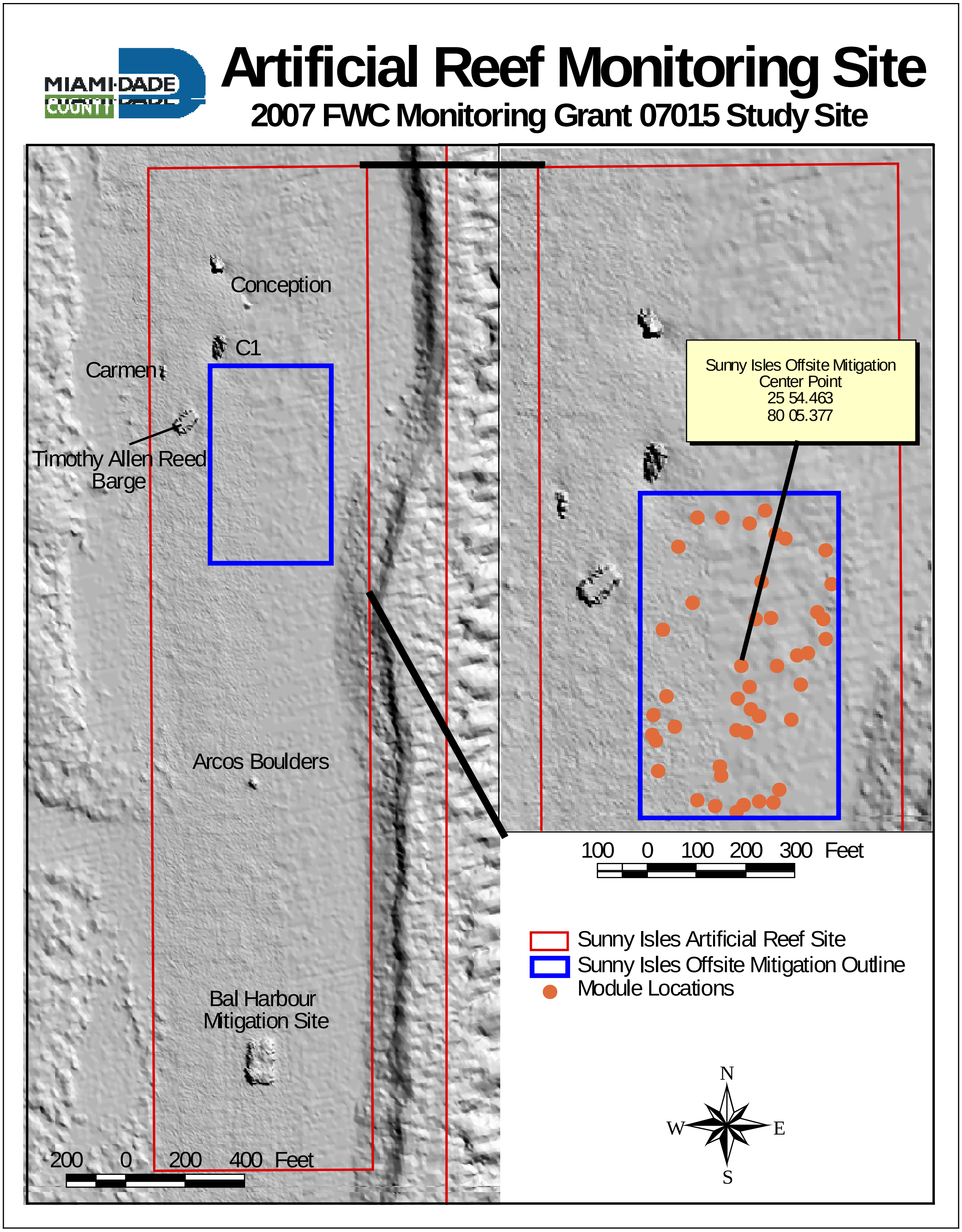

Figure 2. Sunny Isles Offsite Mitigation Artificial Reef site and study site map. Gray-scaled bottom topography is from a survey using Laser Airborne Depth Sounder or LADS (Coastal Planning and Engineering, Inc., 2003).

Figure 3. Photograph of the SIRR Offsite single layer boulder reef (November 2007).

Figure 4. Photograph of an SIRR Offsite module (November 2007).

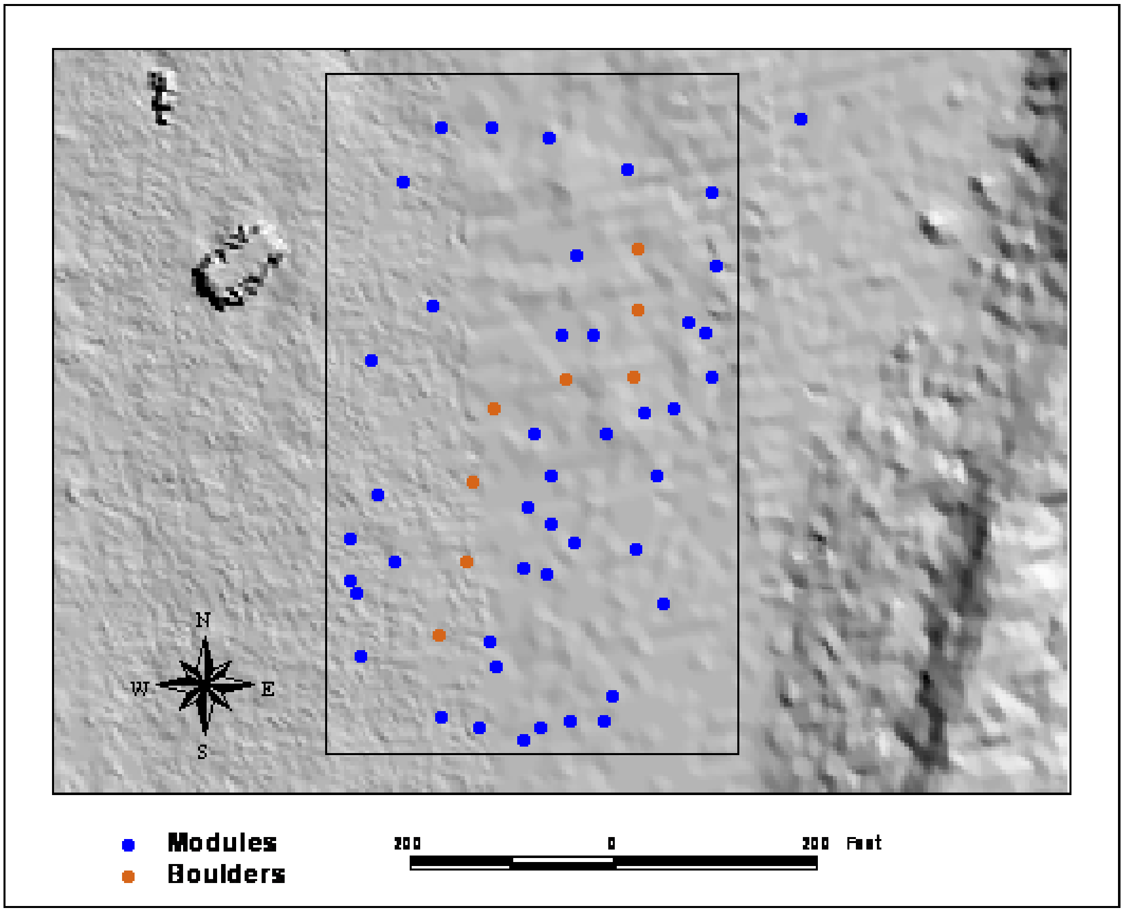

Figure 5. Detailed map of SIRR Offsite modules and boulders

METHODOLOGY

Fish surveys conducted implemented the Bohnsack-Banerot (quick visual assessment) method (1986) with one modification. With the Bohnsack-Banerot method, each fish census is made within an imaginary vertical cylinder in the water column. The diameter of the cylinder is 15m, and the height of the cylinder extends from the reef substrate up to the surface (to the limits of visibility). For the standard Bohnsack-Banerot (1986) method, the survey is conducted from a stationary position in the center of the cylinder. For this study, the method was modified in that the surveyor did not remain stationary during the survey. The modified Bohnsack-Banerot method consisted primarily of a comprehensive listing of all fish species observed within the first five minutes of the survey by generally swimming around the perimeter of the cylinder and, then a second smaller circle closer to the center of the cylinder. This modified method allows for a closer observation of smaller and cryptic species and more accurate species listing in lower visibility situations. Following the first five minutes, a count was made of the number of individuals of each previously noted species. Each listed species was counted separately (diver swims one entire rotation around the cylinder for each count). In addition to the number of individuals seen, the size range (min, mean, and max overall length) of each species was recorded. All species observed after the first five minutes of a survey were listed, counted, and measured, but not evaluated in analysis.

Although the comprehensive fish survey datasets included all species observed and recorded, fish assemblage analyses for this report were limited to those species characterized as the "resident" species or guild (Bohnsack et al. 1994). Resident species tend to remain at one site and are often observed on one or more consecutive surveys (Bohnsack et al. 1994). Other classifications such as "visitors" (only use the habitat for temporary shelter or feeding) and "transient" (roam over a wide area and appear not to react to the reef presence) were omitted from analysis unless otherwise noted in order to reduce the variability added by the inclusion of these classifications.

Nine (9) fish surveys (non-overlapping) were completed on the modules: three (3) surveys on solitary modules, three (3) surveys on modules with one other module in a 50 ft. radius, and three (3) surveys on modules with three (3) or more modules in a 50 ft. radius. Six (6) surveys (non-overlapping) were completed on different areas of the single layer boulder reefs.

Benthic assemblages were assessed using a quadrat photo method. In the quadrat photo method, digital pictures were taken of a quadrat at a fixed distance. Each quadrat was 40cm x 50cm. Over 200 images were taken on the modules as well as the boulders. Several images were discarded due to poor quality. Two hundred images were analyzed on the modules and 200 images were analyzed on the boulders. Coral Point Count Software developed by National Coral Reef Institute and Nova Southeastern University (Kohler and Gill 2006) was then used to overlay 20 random points on top of each image. The benthic organisms or substrate under each point were identified providing an estimate of relative percent cover of each benthic taxa or substrate. All hard coral colonies in the images were also measured with the Coral Point Count program. The image was first calibrated with a known dimension (the size of the quadrat) and the number of pixels per centimeter was estimated. Then each hard coral colony was outlined and the internal area was calculated based on the number of pixels/cm.

Statistical analysis. One focus of this monitoring project was to provide baseline information on the benthic and fish assemblages on the SIRR Offsite module and single layer boulder reef. Another focus of this project was to compare data on the single layer boulders sampled in this project to monitoring data from the 2007 project on mulit-layer boulders. Basic descriptive statistics, similarity indices and non-parametric multi-parameter scaling was deemed appropriate for these evaluations. The information provided in the report will hopefully serve as foundation for more rigorous scientific evaluations in the future including parametric evaluations (i.e., ANOVA).

Multiple software applications were used to summarize and analyze the benthic and fish population data. Microsoft Excel was used to calculate descriptive statistics and graph results of the data and indices. "Primer-5 for Windows®" (Primer-E, 2002) multivariate statistical software was used to calculate and display Bray-Curtis similarity indices (Bray and Curtis, 1957), similarity and evenness indices, ordination clustering of the data using non-metric multidimensional scaling (MDS) procedures, analysis of similarities (ANOSIM), and similarity percentage breakdowns (SIMPER).

Summary statistics included total abundance, relative percent cover, number of species, and diversity. The Shannon Diversity Index (H') is the most commonly used diversity measure

(Clarke and Warwick 1994). The value of the Shannon Index lies in its incorporation of species richness (S), or the total number of species, as well as the relative abundances of species. H' falls to zero when all the individuals in a population sample belong to the same species and increases as the number of species increases. Relative numbers of individuals of each species also affects the value of H'. If only a small portion of species in the sample account for most of the individuals, the value of H' will be lower than if all the individuals were distributed evenly among all the species. Pielou's Evenness measure (J) was also calculated because it expresses how evenly the individuals are distributed among the different species. The higher the value of J, the more evenly the number of individuals are spread among the different species.

Prior to the calculation of the Bray-Curtis indices, the data was fourth-root transformed in order to reduce the weight of the common species and incorporate the importance of both the intermediate and rare species (Field et. al 1982; Clark and Warwick 1994). The non-metric MDS analysis (Kruskal and Wish, 1978) generated a graph based on the calculated Bray-Curtis indices. The MDS analysis generates a "stress value" for each plot, which indicates the level of difficulty in representing the similarity relationships for all samples into a two-dimensional space. Clarke and Warwick (1994) state that a stress value ≤ 0.05 indicates a plot with excellent representation and minimal chance of misinterpretation, values from 0.05 to 0.10 correspond to a good ordination with slight chance of misinterpretation, values from 0.10 to 0.20 indicate a potentially useful plot, but have a greater chance of misinterpretation, and values between 0.20 and 0.30 are considered acceptable although conclusions should be crosschecked with other statistical measures. Plots associated with stress levels ≥0.30 represent a more or less arbitrary arrangement. SIMPER analysis produces and average dissimilarity between samples and gives each species' percent contribution to this dissimilarity. ANOSIM is similar to an ANOVA but for multivariate statistics. ANOSIM produces an R statistic which correlates to how similar the samples are. This analysis produces global (over all samples) and pairwise (between each combination of two samples) R statistics and p values. An R statistic of 1.00 indicates that samples are completely different while an R statistic of zero indicates samples are identical (Clarke and Warwick, 1994). R statistics are only interpreted here where p values are <0.05.

RESULTS

Summary of Fish Assemblages at the SIRR Offsite Artificial Reef

The fish surveys were conducted between October 2006 and January 2008.

Species Richness. Figure 6 shows the total number of fish species observed across all rounds on the module and boulder reefs. Refer to Appendix 1 for a complete species listing per round. The highest number of resident species observed occurred where there were three (3) or more modules in a 50 ft. radius with 40 species. The lowest number occurred where there were two (2) modules in a 50 ft. radius with 35 species.

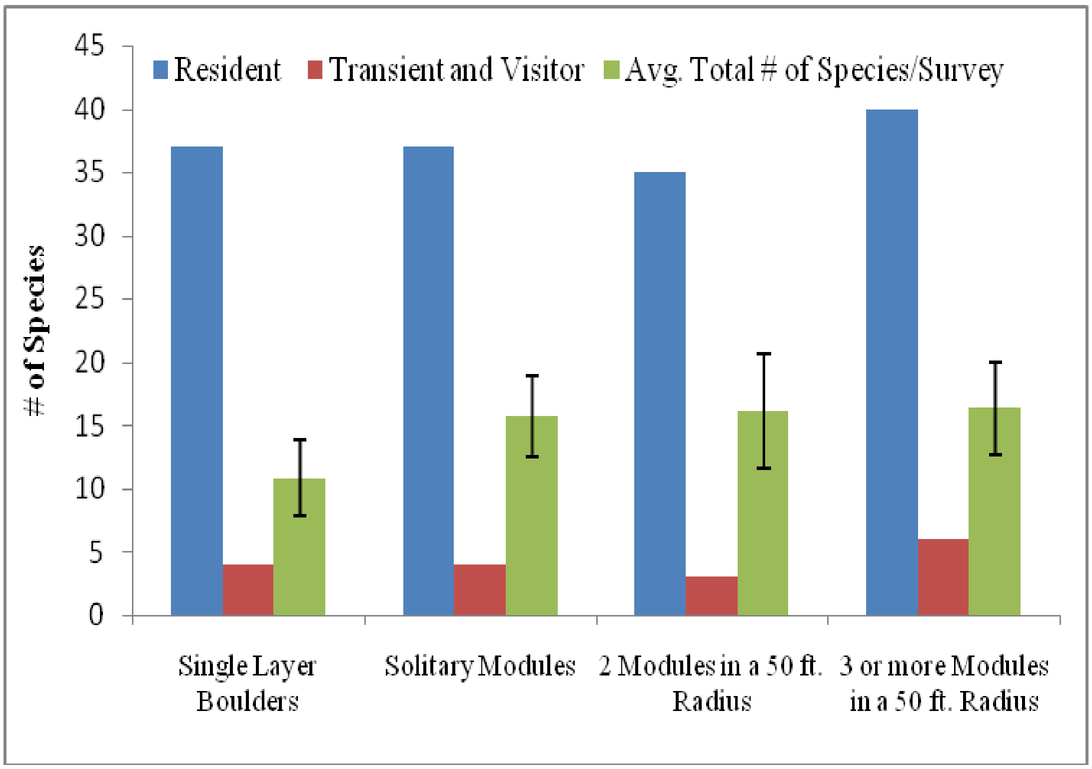

Figure 6. Total number of fish species observed across all rounds at the module and boulder reefs. NOTE: Area of each survey = 176 m^2.

Diversity. The Shannon Diversity Index (H') and Pielou's Evenness measure (J') were calculated for the resident fish assemblages at each module and boulder reef. Figure 7 shows the mean H' and J' values at each site averaged from Rounds 1-2. The single layer boulders had the highest H' value at 2.94 as well as the highest J' value at 0.89. The lowest H' (2.46) and J' (0.77) value occurred where there were two (2) modules in a 50 ft. radius. As indicated in figure 4, two (2) modules in a 50 ft. radius had the fewest amount of species.

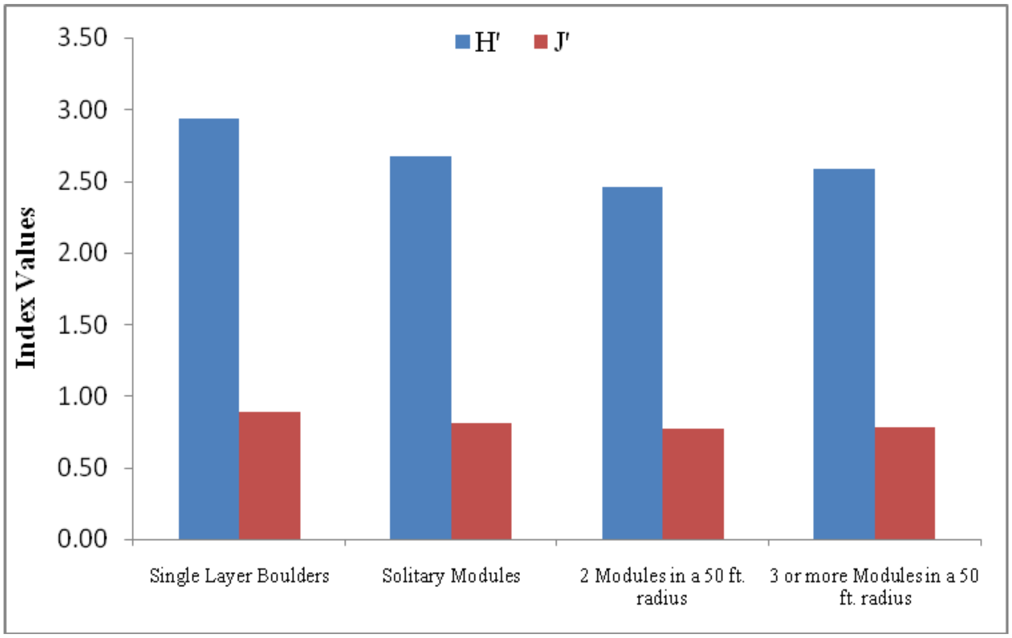

Figure 7. Mean Shannon Diversity Index (H'; range= 0.00-+3.00) and Pielou's Evenness measure (J'; range= 0.00-1.00) for the resident fish assemblages on each module and boulder reef.

Density. Figure 8 shows the mean density (individuals/m^2) per round at the module and boulder reefs. Although two (2) modules in a 50 ft. radius had the lowest species richness and diversity, they exhibited the highest density with an average of 0.66 individuals/m^2 across all surveys. The single layer boulders showed the lowest density with 0.26 individuals/m^2 across all surveys.

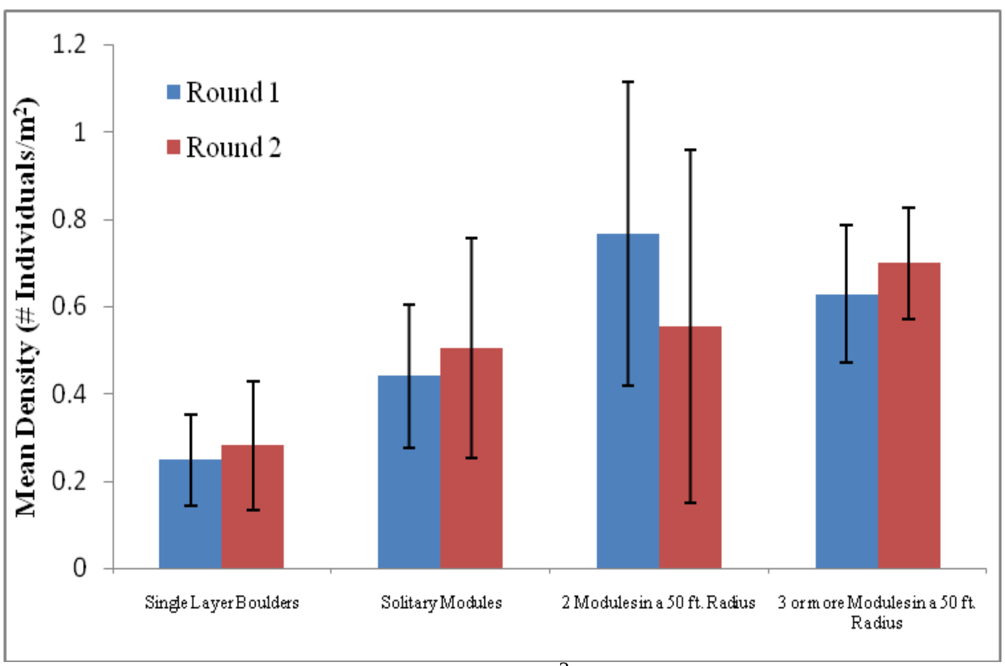

Figure 8. Mean resident fish density (individuals/m^2) for each round at the module and boulder reefs. Standard deviation bars plotted for all sites.

Family Composition. On all reefs, a large percentage of the resident fish belonged to either the Labridae (Wrasses) or Pomacentridae (damsel fish) families (Figure 9). The single layer boulder reefs had the highest percentage of the family Labridae while solitary modules had the highest percentage of the family Pomacentridae. The most abundant species on all reefs of the family Labridae was *Thalassoma bifasciatum* (Bluehead Wrasse) and *Pomacentrus partitus* (Bicolor Damselfish) of the family Pomacentridae. Two or more modules in a 50 ft. radius had the most species of the family Haemulidae.

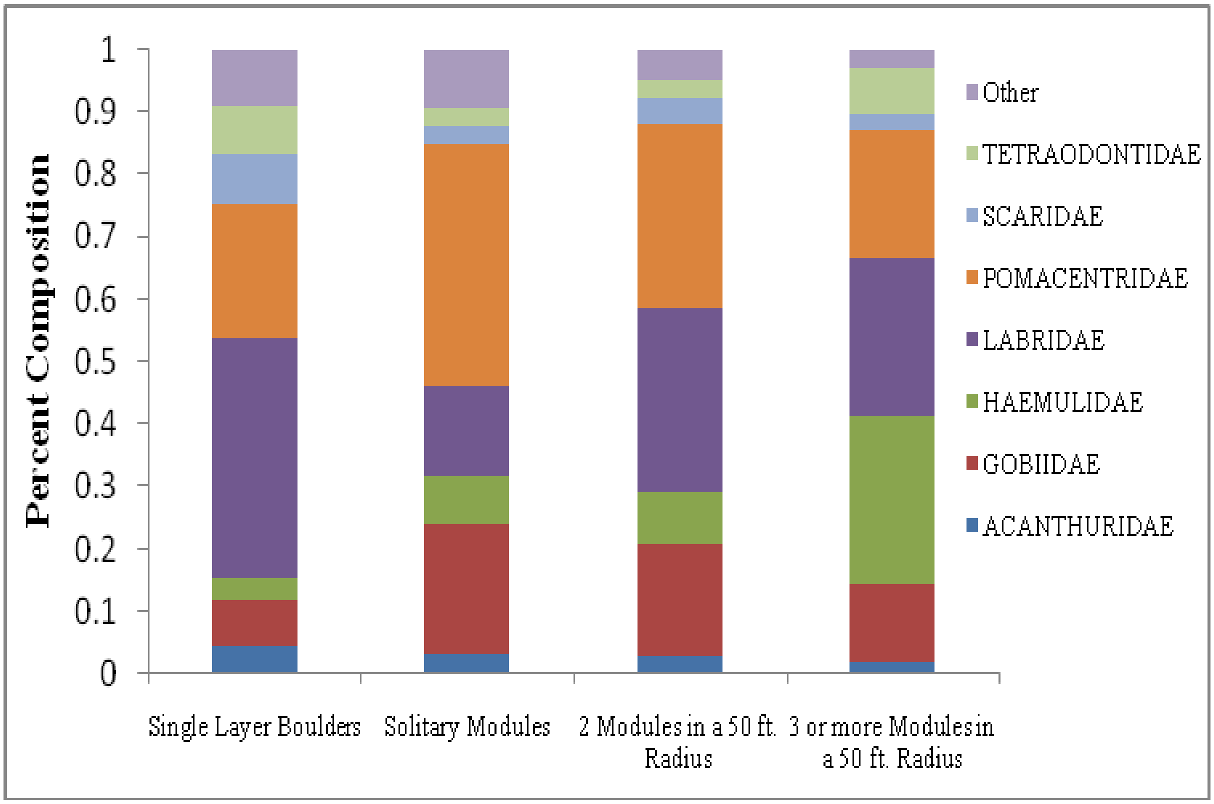

Figure 9. Mean percent composition (%) of resident individuals per survey across all rounds by major family constituents

In addition to *Thalassoma bifasciatum* and *Pomacentrus partitus*, several other species were common across all sites as indicated in Table 1. *Coryphopterus glaucofraenum* (Masked Goby) and *H. flavolineatum* (French grunt) were observed at all sites. Several species of the family Acanthuridae were found on all reefs including *Acanthurus bahianus* (Ocean Surgeonfish), *A. chirurgus* (Doctorfish), and *A. coeruleus* (Blue Tang). The Scaridae family was also represented on all sites with the species *Sparisoma aurofrenatum* (Redband parrotfish).

Table 1. Average number of individuals per survey across all rounds for the most abundant species of the dominant families.

		Single Layer Boulders	Solitary Modules	2 Modules in a 50 ft. radius	3 or more Modules in a 50 ft. radius
ACANTHURIDAE	*Acanthurus bahianus*	2.20	2.67	1.00	2.33
	Acanthurus chirurgus	1.33	1.00	2.25	2.00
	Acanthurus coeruleus	2.00	1.00	2.00	1.00
GOBIIDAE	*Coryphopterus glaucofraenum*	4.83	12.00	10.25	14.00
	Coryphopterus personatus	1.00	12.60	28.00	5.20
HAEMULIDAE	*Haemulon aurolineatum*		4.67	5.50	6.50
	Haemulon carbonarium	1.00	6.00	8.00	26.00
	Haemulon flavolineatum	1.50	10.75	3.20	34.33
LABRIDAE	*Halichoeres garnoti*	6.40	2.17	7.00	6.50
	Thalassoma bifasciatum	11.91	15.67	31.80	26.00
POMACENTRIDAE	*Abudefduf saxatilis*	1.00	1.50	2.00	5.25
	Pomacentrus partitus	10.25	25.67	27.00	15.67
SCARIDAE	*Sparisoma aurofrenatum*	2.86	1.75	4.00	3.20
TETRAODONTIDAE	*Canthigaster rostrata*	3.80	2.17	3.00	9.00

Similarity. Figure 10 shows the MDS plot graphically depicting the Bray-Curtis similarity values for the mean density of each resident fish species for each round. The stress value is low indicating an accurate representation of the plot. The purpose of this assessment is to provide an indication of the consistency of the resident fish population on each of the reefs, through comparison of the similarity (and thereby the composition and abundance) between the rounds of samples.

The boulder surveys showed the greatest similarity and were also separated from the module surveys in the Bray-Curtis MDS plot (Figure 10). The module groupings (solitary, two (2) modules in a 50 ft. radius, and three (3) or more modules in a 50 ft. radius) did not form distinct groups but all were separated from the boulders. SIMPER analysis showed that the species responsible for the difference between the boulders and solitary modules as well as two (2) modules in a 50 ft. radius was *C. personatus* (Masked Goby) with more individuals on the modules. The average dissimilarity between boulders and solitary modules was 54.34 with *C. personatus* contributing 6.17% to the difference. The average dissimilarity between boulders and two (2) modules in a 50 ft. radius was 53.17 with *C. personatus* contributing 9.61% to the difference. *Haemulon flavolineatum* (French Grunt) was responsible for the difference between boulders and three (3) or more modules in a 50ft. radius. The average dissimilarity was 53.44 with *H. flavolineatum* contributing to 8.01% of the difference with more individuals on the modules. ANOSIM results of mean density of resident fish populations for each round show no statistical difference in the fish assemblages between any of the boulder or module groupings. However, ANOSIM results of density of resident fish populations comparing each survey showed a significant difference between the boulders and each module group (Table 2).

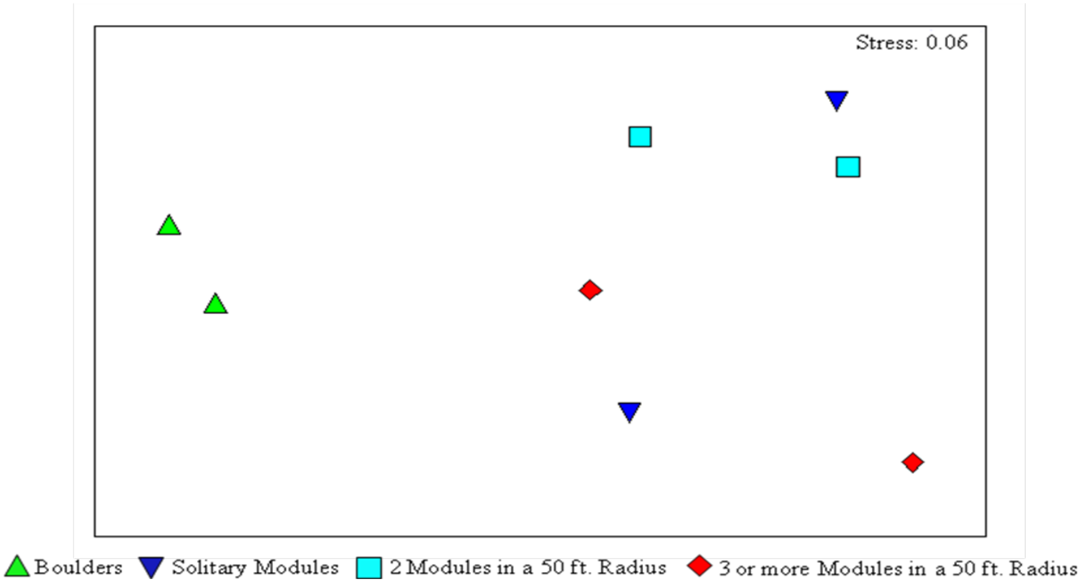

Figure 10. Multi-dimensional scaling (MDS) plot based on the Bray-Curtis Similarity values for the mean density of each resident fish species for each round.

Table 2. ANOSIM results for density of resident fish population for each survey. An R statistic of 1.00 indicates the samples are completely different, 0.0 indicates samples are identical. R statistics with P values of <0.05 are considered significant.

	R Statistic	P Value
Global (Overall)	0.345	0.001
Boulders vs. Solitary Modules	0.440	0.002
Boulders vs. 2 Modules in a 50 ft. Radius	0.624	0.001
Boulders vs. 3 or more Modules in a 50 ft. Radius	0.513	0.001

Comparison of Fish Assemblages on Single Layer vs. Multi-Lay Boulder Reefs

The previous year's grant agreement (FWCC-06121) titled Baseline Biological Monitoring of Miami-Dade Limerock Boulder Reefs evaluated fish and benthic assemblages on five multi-layer boulder reefs: Golden Beach, Arcos, Anchorage, Port of Miami (POM) Row, and POM Pile. Table 3 shows time of deployment for each of these reefs along with the SIRR Offsite single layer boulder reef. The following section compares the fish community on the multi-layer boulder reefs with that of the single layer boulder reef.

Table 3. Deployment dates for all boulder reefs

	Anchorage	Arcos	Golden Beach	POM P	POM R	Single Layer Boulders
Deployment Date	June 1994, June 1995	August 2001	January 2005	September 1996	September 1996	March 1993

The number of fish species on the single layer boulders was lower compared to most multi-layer boulder reefs (Anchorage, Arcos, Golden Beach, POM Pile, and POM Row) surveyed. Arcos was the only multi-layer boulder reef to have less species than the single layer boulder reef (Figure 11).

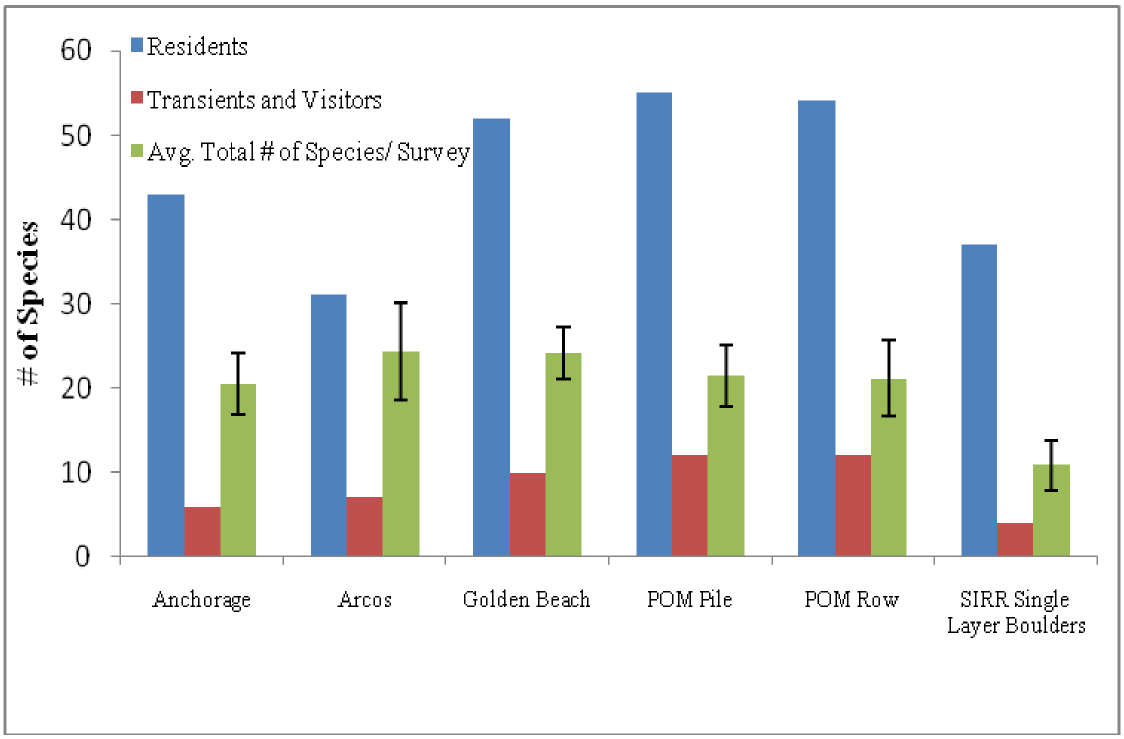

Figure 11. Total number of fish species observed across all rounds at the multi-layer and single layer and boulder reefs surveyed. NOTE: Area of each survey = 176 m^2.

Diversity was higher on the single layer boulder reef compared to all multi-layer boulders reefs except POM pile (Figure 12). The single layer boulders had an H' value of 2.94 while POM pile had an H' value of 3.00.

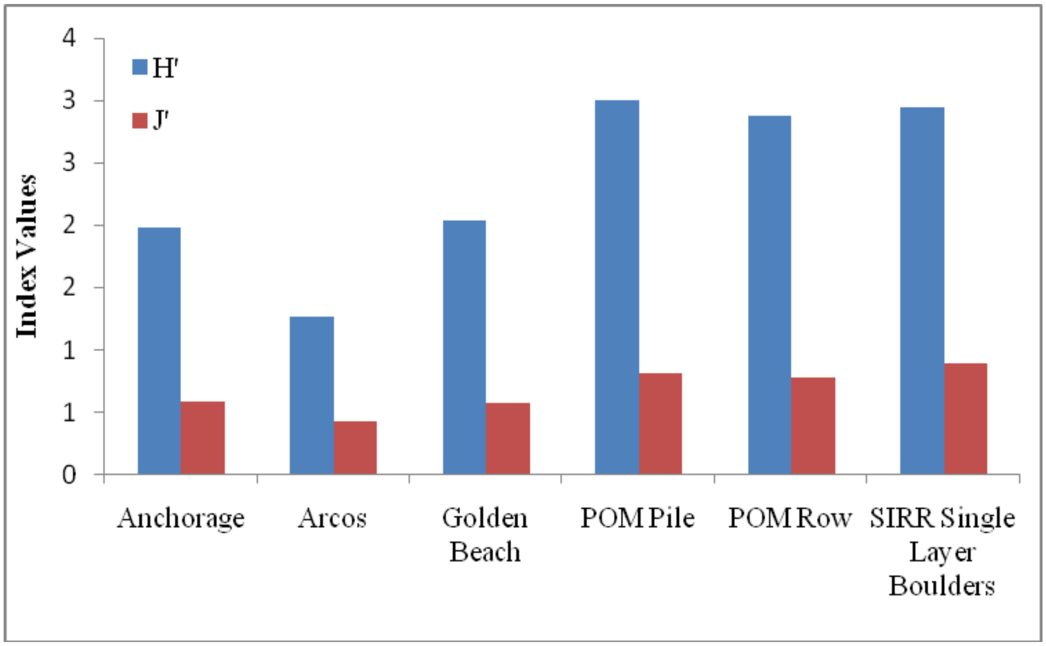

Figure 12. Mean Shannon Diversity Index (H'; range= 0.00-+3.00) and Pielou's Evenness measure (J'; range= 0.00-1.00) for the resident fish assemblages on the multi-layer and single layer boulder reefs.

Density was much lower on the single layer boulder reef compared to the multilayer boulder reefs (figure 13).

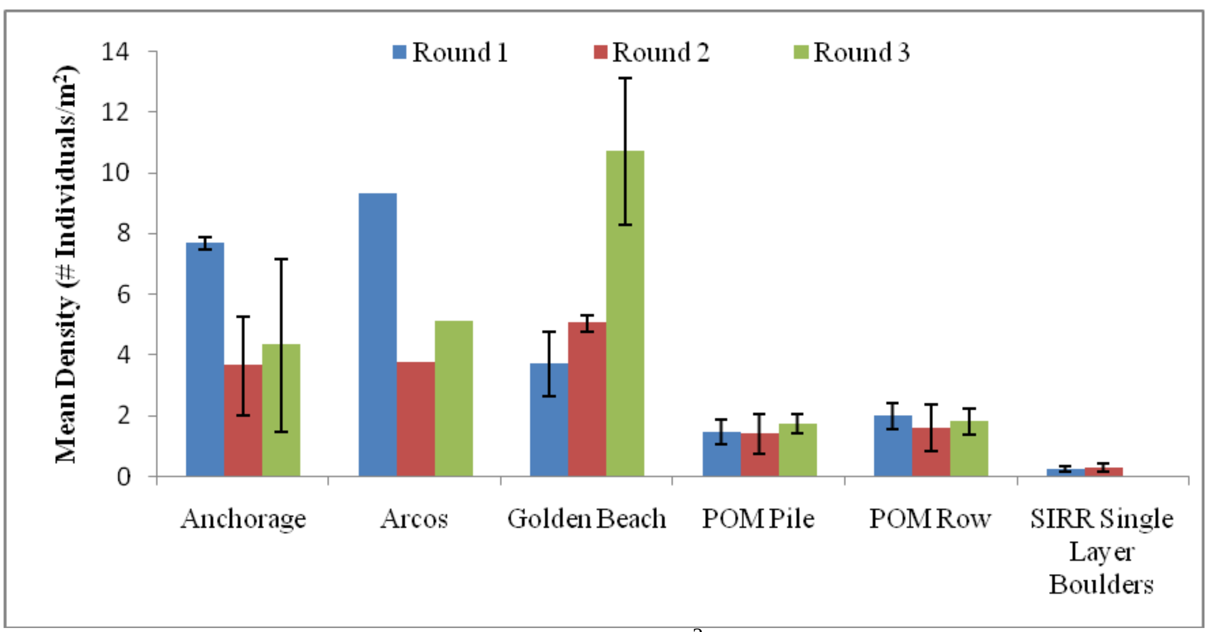

Figure 13. Mean resident fish density (individuals/m^2) for each round at the multi and single layer boulder reefs. Standard deviation bars plotted for all sites except Arcos.

The single layer boulders had more species of the family Labridae and Pomacentridae than the multi-layer boulders. The multi-layer boulders had more species of the family Haemulidae (figure 14).

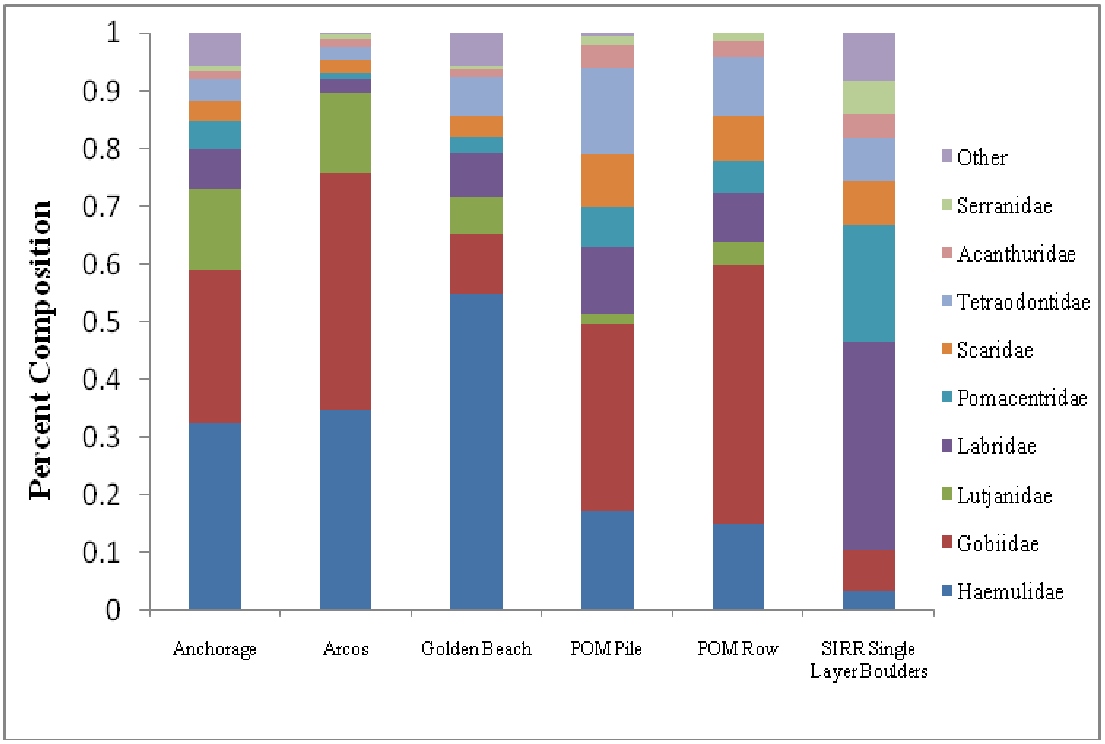

Figure 14. Mean percent composition (%) of resident individuals per survey across all rounds of the multi-layer and single layer boulder reef surveys by major family constituents

An MDS plot comparing fish density data by round from 2007's baseline biological monitoring of Miami-Dade limerock boulder reefs to this year's single layer boulder reefs shows that the multi-layer reefs are well separated from both the single layer reefs and all the module groupings (Figure 15). ANOSIM results indicate a significant difference between the multi-layer boulders and the single layer boulders (R=1.00, p=0.007), solitary modules (R=1.00, p=0.007), two (2) modules in a 50 ft. radius (R=0.999, p=0.007), and three (3) or more modules in a 50 ft. radius (R=1.00, p=0.007). SIMPER analysis shows that the species driving the difference between the multi-layer boulders and the single layer boulders and all the module groupings is *Haemulon aurolineatum* (Tomtate) contributing from 18.14% to 19.66% to the dissimilarity between samples. *H. aurolineatum* had a higher density on the multi-layer boulders.

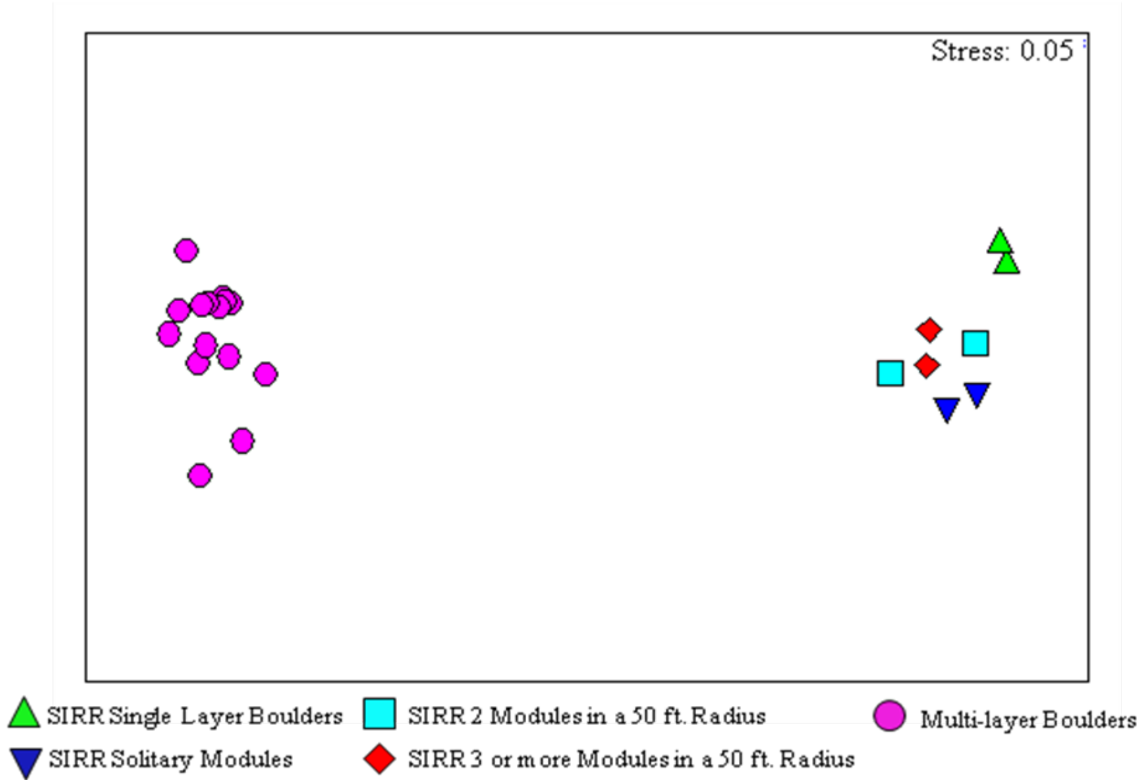

Figure 15. Multi-dimensional scaling (MDS) plot based on the Bray-Curtis Similarity values for the mean density of each resident fish species for each round on all multi-layer and single layer boulders as well as SIRR Offsite modules.

Summary of Benthic Assemblages at the SIRR Offsite Artificial Reef

The benthic assemblages were quantified through photogrametric evaluation using Coral Point Count software (Kohler and Gill, 2006) from digital photography taken October 2007 through January 2008.

Relative Percent Cover. Table 4 shows the relative percent cover of the major benthic categories for the module and boulder reefs studied. Refer to Appendix 2 for a complete listing of the relative percent cover by species (or lowest possible discernable taxonomic group). Both sites were dominated by algae cover. Porifera had the second highest percent cover on all sites. Octocorallia were more abundant at the boulders than the modules while scleractinians were more abundant on the modules than the boulders.

Table 4. Relative percent (%) cover of major benthic categories.

Major Category	Boulders	Modules
Algae	79.94	64.68
Porifera	12.61	24.62
Octocorallia	1.12	0.4
Scleractinia	1.66	3.13
Milleporidae	0.32	5.28
Zoanthidae	0	0.08
Ascidaria	1.34	0.99
Other Live	2.14	0.62
Substrate (sand or bare)	0.8	0.08

As indicated in Table 5, turf algae dominated the algae percent cover component as well as all biotic components. High algal coverage is common at other boulder and natural reef sites in Miami-Dade County (DERM, unpublished). Coralline algae and *Peysonnelia* species were much more common on the modules than the boulders while blue-green algae was the most common algae on both following turf algae. *Pseudoplexaura* species was the most common octocoral on the boulders. *Gorgonia ventalina* was the most common octocoral on the modules. *Iotrochota birotulata* was the most common poriferan species on both the modules and boulders. *Porites astreoides* was the most abundant scleractinian on both the boulders and the modules. *Stephanocoenia intersepta* was the second most abundant scleractinian on both the modules and the boulders.

Table 5. Relative percent (%) cover for the highest contributors.

		Boulders	Modules
Algae	Turf	76.30	54.88
	Blue Green Algae	2.41	3.05
	Coralline Algae	0.37	4.12
	Peysonnelia species	0.37	2.37
Octocorallia	*Pseudoplexaura* species	0.54	0.00
	Iciligorgia species	0.05	0.00
	Gorgonia ventalina	0.00	0.14
	Pseudopterogoria species	0.08	0.08
	Plexaurella species	0.08	0.00
Porifera	*Iotrochota birotulata*	3.21	4.66
	Diplastrella species	0.51	1.98
	Monanchora barbadensis	0.27	1.95
	Ircinia campana	0.62	1.75
	Ircinia felix	0.37	1.16
	Cliona delatrix	1.10	0.76
	Diplastrella megastellata	0.46	0.93
	Niphates digitales	0.64	0.45
Scleractinia	*Porites asteroides*	1.34	2.23
	Stephanocoenia intersepta	0.16	0.14
	Diploria labrinthiformes	0.00	0.23
	Madracis decactis	0.00	0.17
	Siderastrea siderea	0.00	0.11
	Agaricia fragilis	0.05	0.08

Diversity. The Shannon Diversity Index (H') and Pielou's Evenness measure (J') were evaluated for the benthic assemblages at the module and boulder reefs (Figure 16). The modules had a higher H' value (2.03) than the boulders (1.25). The modules and the boulders showed low J' values with respect to their benthic assemblages due to the overwhelming coverage of turf algae (Table 5) that reduced the even distribution of individuals among the benthic species.

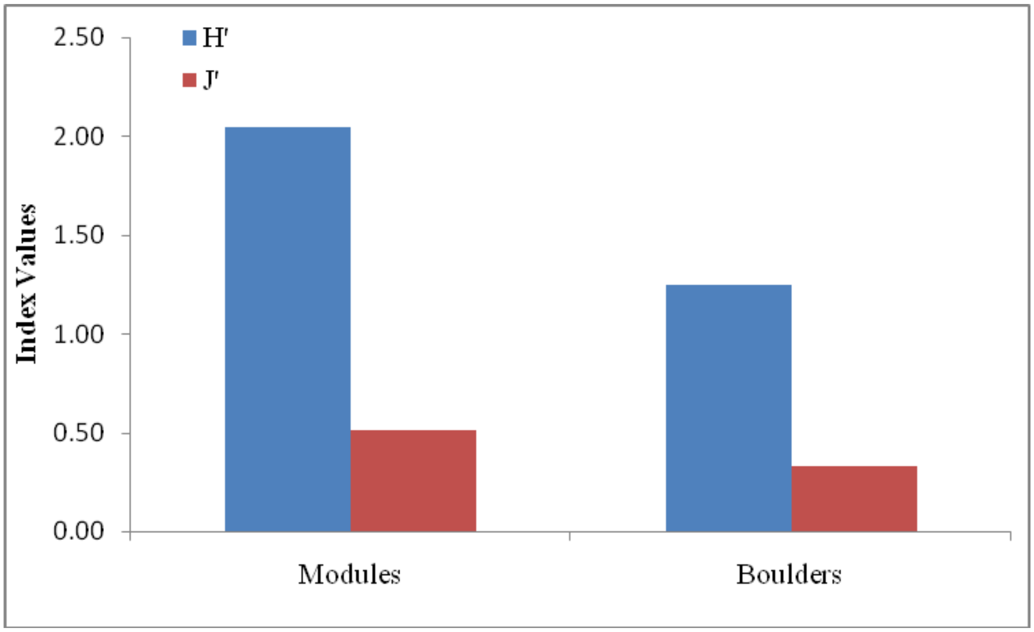

Figure 16. Mean Shannon Diversity Index (H'; range= 0.00-+3.00) and Pielou's Evenness measure (J'; range= 0.00-1.00) for the boulder and module reefs.

Scleractinian Measurements. In addition to estimating the scleractinian relative percent cover through the random point overlay method, scleractinian coverage was also estimated by tracing and calculating the area of each scleractinian colony in each photograph as seen in Figure 17.

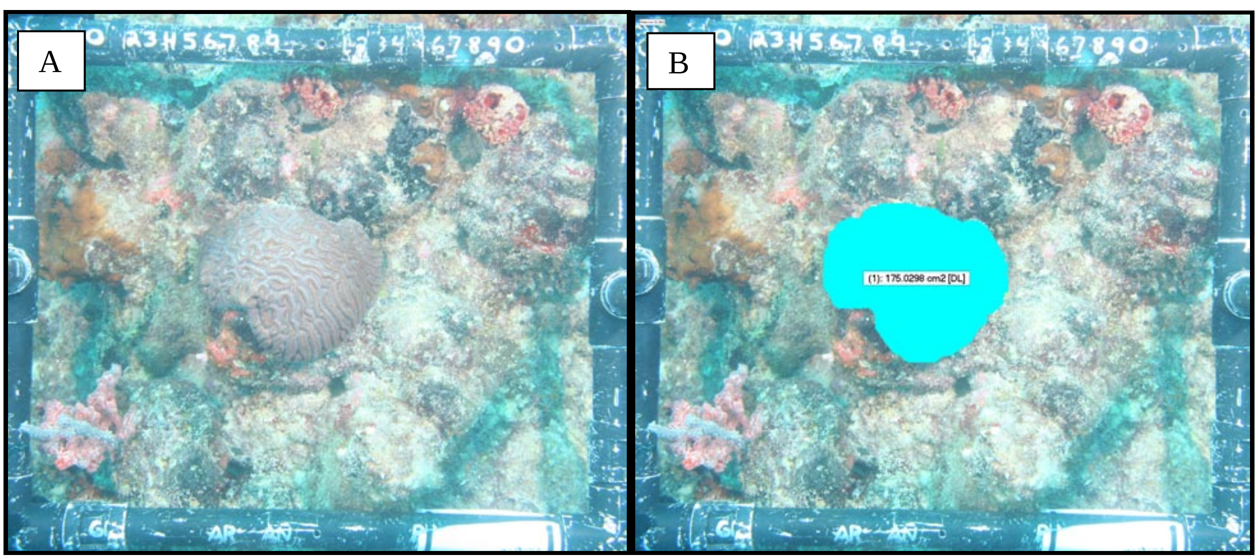

Figure 17. A). Raw quadrat image; B). Quadrat image after scleractinian colony has been traced.

Slight differences were noted between the two different methodologies as seen in table 6. The 'tracing' method consistently identified more species; however, there was not a consistent difference in estimated percent cover.

With both methodologies, the modules had the higher numbers of scleractinian species and higher percent coverage than the boulders. *Porites astreoides* was still the most abundant scleractinian and had the highest coverage on both the modules and the boulders. *Stephanocoenia intersepta* had the second largest coverage on the boulders while *Siderastrea sidera* was the second most abundant. On the modules, *Diploria strigosa* had the second largest coverage while *Stephanocoenia intersepta* was the second most abundant.

Table 6. Percent (%) cover and number of species of scleractinians for both methodologies.

		Boulders	Modules
Point Overlay	Number of Species	5	11
	Relative %	1.66	3.13
Colony Trace	Number of Species	15	17
	Actual %	1.83	2.49

The study design did not allow investigations using Primer-E (v.5). Only two categories (boulders and modules) were investigated and therefore did not produce a large enough Bray-Curtis similarity matrix to draw any conclusions on the differences or similarities in benthic community composition.

Comparison of Benthic Assemblages on Single Layer vs. Multi-Lay Boulder Reefs

Relative Percent Cover. Table 7 shows the relative percent cover of the major benthic categories for the single layer and five (5) multi-layer boulder reefs studied. All sites were evaluated during the winter months and were dominated by algae cover. Porifera was the second highest percent cover on all sites. The POM row multi-layer boulders had the highest cover of octocorallia and scleractinia

Table 7. Relative percent (%) cover of major benthic categories for the single layer boulder reef and the 5 multi-layer boulder reefs.

Major Category	Anchorage	Arcos	Golden Beach	POM Pile	POM Row	SIRR Single Layer Boulders
Algae	84.67	82.57	84.14	79.90	76.54	79.94
Porifera	12.43	14.03	10.68	10.49	5.14	12.61
Octocorallia	0.00	0.21	0.00	4.83	11.73	1.12
Scleractinia	1.14	1.28	0.04	3.57	4.04	1.66
Milleporidae	0.15	1.17	0.24	0.42	0.38	0.32
Zoanthidae	0.00	0.00	0.00	0.04	0.04	0
Ascidaria	0.00	0.21	3.38	0.00	0.11	1.34
Other Live	0.63	0.53	0.08	0.49	0.23	2.14
Substrate (sand or bare)	0.99	0.00	1.45	0.27	1.79	0.8

As indicated in table 8, turf algae dominated the algae percent cover component as well as all biotic components. *Peysonnelia* species were more common on the multi-layer boulders while blue-green algae was more common on the single layer boulders. *Pseudoplexaura* spp was the most common octocorallia on the single layer boulders while *Pseudopterogoria* spp was the most common on the multi-layer boulders. *Iotrochota birotulata* was the most common poriferan species on the single layer boulders while *Holopsamma helwigi* was the most common on the multi-layer boulders . *Porites astreoides* was the most abundant scleractinian on both types of boulders. *Stephanocoenia intersepta* was the second most abundant scleractinian on the single layer boulders, while *Siderastrea siderea* was the second most abundant on the multi-layer boulders.

Table 8. Relative percent (%) cover for the highest contributors.

		Anchorage	Arcos	Golden Beach	POM P	POM R	Single Layer Boulders
Algae	Turf	83.68	77.79	59.25	74.73	71.10	76.30
	Blue Green Algae	0.00	0.53	0.04	1.29	0.65	2.41
	Coralline Algae	0.33	1.49	0.00	0.80	0.72	0.37
	Peysonnelia species	0.66	2.76	2.24	2.93	3.73	0.37
	Wranelia argus	0.00	0.00	22.30	0.04	0.04	0.19
Octocorallia	*Pseudoplexaura* species	0.00	0.00	0.00	0.53	0.72	0.54
	Iciligorgia species	0.00	0.00	0.00	0.00	0.00	0.05
	Gorgonia ventalina	0.00	0.00	0.00	0.53	0.04	0.00
	Pseudopterogoria species	0.00	0.21	0.00	2.89	9.25	0.08
	Plexaurella species	0.00	0.00	0.00	0.00	0.00	0.08
	Briaium	0.00	0.00	0.00	0.00	0.04	0.00
	Eunicea	0.00	0.00	0.00	0.30	0.34	0.00
Porifera	*Cliona delatrix*	0.59	0.00	0.00	0.38	0.15	1.10
	Iotrochota birotulata	2.35	0.00	0.04	2.01	0.27	3.21
	Diplastrella species	1.14	1.06	0.71	1.25	0.27	0.51
	Monanchora barbadensis	0.33	0.96	0.12	0.30	0.38	0.27
	Ircinia campana	0.55	0.00	0.00	0.46	0.11	0.62
	Ircinia felix	0.22	0.11	0.00	0.49	0.23	0.37
	Diplastrella megastellata	0.15	2.87	2.20	0.19	0.15	0.46
	Niphates digitales	0.22	0.43	0.00	0.15	0.11	0.64
	Holopsamma helwigi	3.13	4.46	5.14	2.47	0.80	0.16
Scleractinia	*Porites asteroides*	0.63	0.11	0.04	2.62	2.89	1.34
	Stephanocoenia intersepta	0.11	0.11	0.00	0.30	0.27	0.16
	Diploria labrinthiformes	0.00	0.00	0.00	0.08	0.15	0.05
	Madracis decactis	0.18	0.00	0.00	0.00	0.04	0.00
	Siderastrea siderea	0.15	0.64	0.00	0.23	0.15	0.00
	Agaricia fragilis	0.00	0.00	0.00	0.00	0.00	0.05

Diversity. The Shannon Diversity Index (H') and Pielou's Evenness measure (J') were evaluated for the benthic assemblages at each boulder reef (Figure 18). The single layer boulders had comparable diversity and evenness to the multi-layer boulders. Both types of boulders showed low J' values with respect to their benthic assemblages due to the overwhelming coverage of turf algae (Table 8) that reduced the even distribution the benthic coverage.

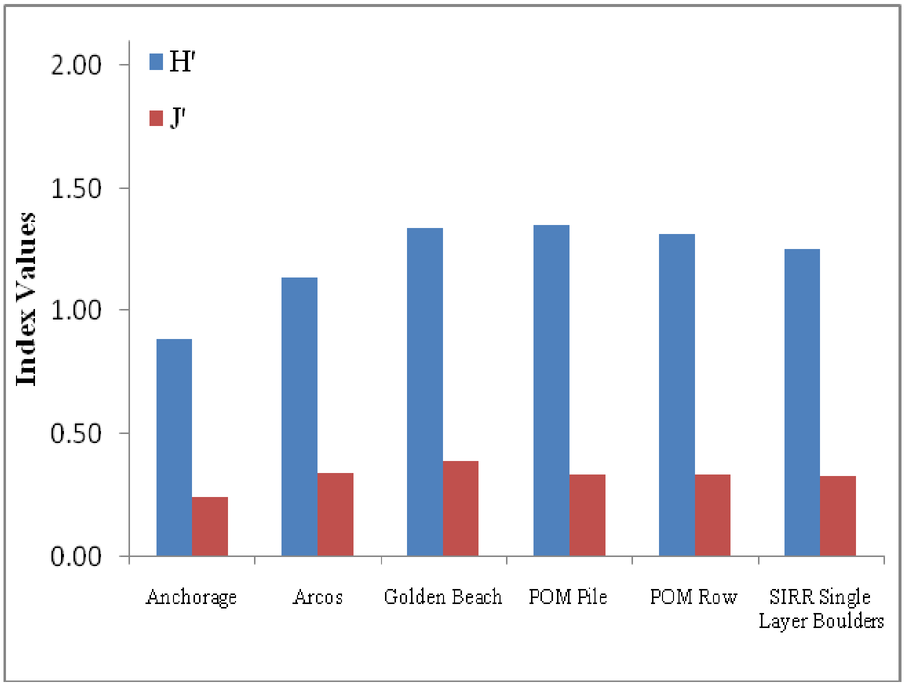

Figure 18. Mean Shannon Diversity Index (H'; range= 0.00-+3.00) and Pielou's Evenness measure (J'; range= 0.00-1.00) for the multi and single layer boulder reefs.

Similarity. Figure 19 shows the MDS plot graphically depicting the Bray-Curtis similarity values between all boulder sites for the relative percent composition of benthic species, substrate, and sand. There is a slight separation between multi and single layer boulder sites. However, ANOSIM results indicate no significant difference between the two (R=0.40, p=0.50).

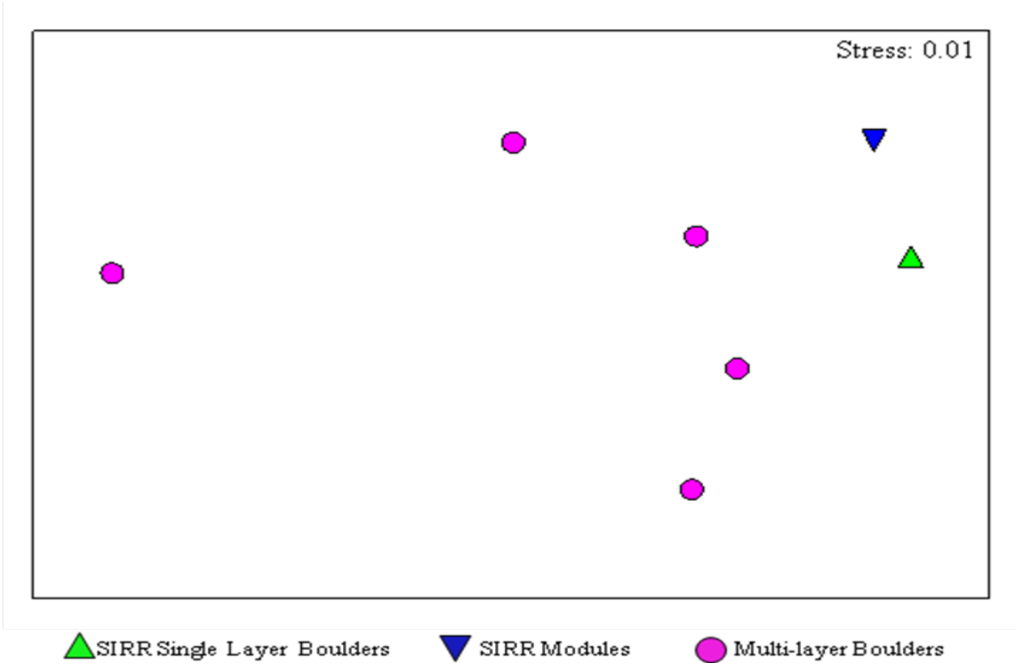

Figure 19. Multi-dimensional scaling (MDS) plot based on the Bray-Curtis Similarity values for relative percent composition of benthic species, substrate, and sand for each round on all multi-layer and single layer boulders as well as SIRR Offsite modules.

DISCUSSION

Fish Assemblages. The baseline fish surveys at the SIRR Offsite showed that both the boulder and module reefs support a wide variety of fish species and numerous individuals (Figures 6-9 and Appendix 1). The boulders contained more diverse and evenly distributed fish assemblages compared to all module groupings (Figure 7). The boulders also had the lowest resident fish density (Figure 8). Two (2) modules in a 50 ft. radius had the highest resident fish density of the module groupings (Figure 8). Some of the most abundant families included Gobiidae, Labridae, Pomacentridae, Acanthuidae, Haemulidae, Scaridae, and Tetraodontidae (Figure 9 and Table 2). Very few game fish species were observed. The only game fish species observed were *Caranx ruber* (Bar Jack), *Ocyurus chrysurus* (Yellowtail Snapper), and *Lachnolaimus maximus* (Hogfish) (Appendix 1).

While conducting the fish surveys, no recreational fishing or scuba diving activities were observed. Monofilament fishing line, anchor line, and anchors were found at the SIRR Offsite.

The single layer boulder reef and the multi-layer boulder reefs had different fish assemblages. The biggest difference between was the density of fish at the two sites. The multi-layered had higher fish density than the single layer boulder reef (Figure 13). The multi-layer boulder reefs had a much higher density of *H. aurolineatum* (Tomtate). *Thalassoma bifasciatum* (Bluehead Wrasse) had the highest density on the single layer boulders.

Benthic Assemblages. The baseline evaluation of the benthic assemblages showed that the boulders and modules reefs supported a variety of benthic taxa and species (see Appendix 2). All sites were dominated by algae, in particular turf algae (Table 3 and 4). The boulders had more turf algae than the modules. It should be noted that while a large percentage of the bottom has 'turf algae', the 'turf' is composed of fine filamentous red and occasionally green algae. The 'tuft' most often does not cover 100% of the bottom, rather is a more open matrix of filaments. The actual 'cover' within a turf community can range from 30 to 80% percent.

The second most abundant benthic component on both the boulders and the modules was porifera. Scleractinians were the third most abundant benthic component. The modules had more scleractinian coverage than the boulders. Octocorallia was the fourth most abundant component with the boulders having higher octocoral cover than the modules. The modules had much greater coverage of *Millepora alcicornis* than the boulders. The boulders had greater coverage of ascidian species than the modules (Table 3 and Table 5). Overall, the modules had higher diversity (H') as indicated in Figure 16. Both modules and boulders had a low evenness measure (J') though due to the overwhelming abundance of turf algal cover.

The multi-layer boulder reefs did not greatly differ from the single layer boulder reefs. Both benthic assemblages were dominated by turf algae. The multi-layer boulders had more soft and stony corals than the single layer boulders (Table 8). However, the two did not statistically differ in benthic assemblages.

CONCLUSION

Documenting and quantifying the differences in biological assemblages on the single layer boulder versus module reefs and multi-layer boulder reefs is an important step in understanding the role these reefs play in artificial reef management. This baseline study demonstrated that both types of boulders and modules provide habitat that has supported abundant and diverse benthic and fish assemblages. However, each reef type exhibited some unique characteristics. Unique characteristics included the higher percent cover of octocorallia and lower fish density on the single layer boulder reef compared to the modules. The modules had higher percent cover of scleractinians than the boulders. The modules had greater benthic diversity while the boulders had greater fish diversity. There was little difference between module groupings (solitary modules, two (2) modules in a 50 ft. radius, three (3) or more modules in a 50 ft. radius) for fish assemblages indicating that the fish community is not influenced by module spacing at this artificial reef site. The multi-layer boulder reefs supported higher fish densities compared to the single layer boulder reefs. The benthic assemblages of the two did not statistically differ.

This report has provided a starting point for evaluating the effectiveness of these reefs in meeting the objectives for which they were constructed such as fisheries enhancement or habitat mitigation. The SIRR offsite modules and boulders (along with an onsite component) were constructed for the purpose of mitigation. To truly understand the extent to which the site has fulfilled this purpose, comparative evaluations of adjacent natural reefs and the onsite component would need to be conducted. Reports providing information on the status of the biological assemblages on existing limerock boulder reefs are essential in evaluating the success of current projects, planning future projects, and determining where further research and monitoring efforts are needed.

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APPENDICES

Appendix 1: All fish species observed per round at each of the five boulder reefs studied. The numbers listed in the table are the number of surveys in which the species was present and recorded in the first five minutes. The numbers in parenthesis refer to number of surveys in which the species was observed after the initial five minutes. Species are listed based on Resident, Transient, and Visitor categories (Bohnsack et al. 1994).

		Boulders 6 surveys/round		1 Module 3 surveys/round		2 Modules 3 surveys/round		3 Modules 3 surveys/round	
Resident Species	**Common Name**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
Abudefduf saxatilis	Sergeant major	1	(2)	2	(1)	1	2	2	2
Acanthurus bahianus	Ocean surgeon	3	2 (1)	1 (1)	2	1	1	1	2
Acanthurus chirurgus	Doctorfish	(2)	3	3		2	2	1 (1)	
Acanthurus coeruleus	Blue tang	1			1	2 (1)		1 (1)	
Anisotremus virginicus	Porkfish		1 (2)		1 (1)	2	1	1 (1)	
Bodianus pulchellus	Spotfin hogfish	1			1	1		1	
Bodianus rufus	Spanish hogfish			1		1	(1)	1	
Canthigaster rostrata	Sharpnose puffer	5 (1)	5 (1)	3	3	3	3	3	3
Chaetodon ocellatus	Spotfin butterflyfish		2	1				1	
Chaetodon sedentarius	Reef butterflyfish	2 (1)	5	2	1	2	1 (1)	2	1
Chromis cyaneus	Blue chromis			1	1	2		1	1
Chromis insolatus	Sunshinefish					2		1	1
Chromis multilineatus	Brown chromis	(1)		1	1	2	(1)		1
Chromis scotti	Purple reeffish			(1)		1	3	2	3
Coryphopterus glaucofraenum	Bridled goby	2	4 (1)		1	1	3	1 (1)	2 (1)
Coryphopterus personatus	Masked goby	1	(1)	3	2	3	3	3	2
Coryphopterus punctipectophorus	Spotted Goby							1	
Epinephelus adscensionis	Rock Hind				1				
Epinephelus cruentatus	Graysby	1	1		(1)	1	1	1	(1)
Epinephelus guttatus	Red Hind			1		1			
Equetus acuminatus	Highhat							1	
Gnatholepis thompsoni	Goldspot goby	1	1						
Gobiosoma oceanops	Neon goby			1		(1)			
Gymnothorax miliaris	Goldentail moray				1				
Haemulon aurolineatum	Tomtate			2	1	2	-1	2	2 (1)
Haemulon carbonarium	Caesar grunt	1	(1)	1			2	1	1
Haemulon flavolineatum	French grunt	1	1	1	3	3	2	2	1

Appendix 1 (continued)

Resident Species	Common Name	Boulders 6 surveys/round 1	2	1 Module 3 surveys/round 1	2	2 Modules 3 surveys/round 1	2	3 Modules 3 surveys/round 1	2
Haemulon melanurum	Cottonwick				1				
Haemulon plumieri	White grunt				1	(1)		(2)	2
Haemulon sciurus	Bluestriped grunt					1		1	
Halichoeres bivittatus	Slippery dick	4	3 (1)						1
Halichoeres garnoti	Yellowhead wrasse	4 (2)	6	3	3	1 (2)	2 (1)	2 (1)	(1)
Halichoeres maculipinna	Clown wrasse	4 (1)	3		1	(2)	(1)	2 (1)	
Holocentrus adscensionis	Squirrelfish					1			
Holacanthus bermudensis	Blue angelfish		1 (2)	2	1 (1)	1(1)		(1)	
Holacanthus ciliaris	Queen anglefish		(1)				1	(2)	(1)
Holacanthus tricolor	Rock beauty				1			1	
Hypoplectrus unicolor	Butter hamlet	1	1	1 (1)	1			2	
Ioglossus calliurus	Blue goby		1				(1)		1
Lachnolaimus maximus	Hogfish	2	1 (1)		3		(1)	1 (1)	1
Lactophrys bicaudalis	Spotted Trunkfish			1					
Lactophrys polygonia	Honeycomb cowfish		1						
Lutjanus synagris	Lane snapper					1			
Malacoctenus triangulatus	Saddled Blenny		(1)	(1)		1			
Myripristis jacobus	Blackbar soldierfish			3	3	4	3	3	(2)
Opistognathus aurifrons	Yellowhead jawfish		1					(1)	
Opistognathus aurifrons	Yellowhead jawfish			1		1			
Pomacanthus arcuatus	Gray angelfish	1							
Pomacentrus fuscus	Dusky damselfish					1 (1)			1 (1)
Pomacentrus leucostictus	Beaugregory			1	1		1		
Pomacentrus partitus	Bicolor damselfish	6	6 (1)	3	3	3	2	3	3
Pomacanthus paru	French angelfish	1	1						
Pomacentrus variabilis	Cocoa damselfish				1				
Scarus taeniopterus	Princess parrotfish	2	1		1			(1)	1
Serranus baldwini	Lanternfish	1 (2)	1 (1)						
Serranus tabacarius	Tobaccofish	2 (2)	1 (2)			(1)			
Serranus tigrinus	Harlequin bass		(1)				1 (1)	(1)	1 (1)
Serranus tortugarum	Chalk bass		1			1			1
Sparisoma atomarium	Greenblotch parrotfish	2					(1)		1
Sparisoma aurofrenatum	Redband parrotfish	3 (2)	5	2	2	1	2 (1)	2	3
Sparisoma chrysopterum	Redtail parrotfish	1	(1)			(1)		1 (1)	
Thalassoma bifasciatum	Bluehead	6	6	3	3	3	3	3	3

Appendix 1 (continued)

Transient Species	Common Name	Boulders 6 surveys/round 1	2	1 Module 3 surveys/round 1	2	2 Modules 3 surveys/round 1	2	3 Modules 3 surveys/round 1	2
Lachnolaimus maximus	Hogfish	2	1 (1)		3		(1)	1 (1)	1
Urolophus jamaicensis	Yellow Stingray		1						
Pseudupeneus maculatus	Spotted goatfish	3 (1)	3		2	1 (1)	2 (1)	1	1 (1)
Visitor Species									
Caranx ruber	Bar jack	(1)				2		1 (1)	
Ocyurus chrysurus	Yellowtail snapper				1			1	(1)
Scarus coelestinus	Midnight parrotfish					1			
Scarus coeruleus	Blue parrotfish		1					(1)	1
Sparisoma viride	Stoplight parrotfish	2			1			1	

Appendix 2. Relative percent (%) cover of benthic subcategories (species or lowest possible taxonomic group).

	Boulders	Modules
Scleractinia (stony coral)		
Agaricia fragilis	0.05	0.08
Diploria labyrinthiformis	0.05	0.23
Diploria strigosa	0.00	0.06
Madracis decactis	0.00	0.17
Meandrina meandrites	0.00	0.03
Montastraea annularis	0.00	0.03
Montastraea cavernosa	0.00	0.03
Mycetophyllia aliciae	0.05	0.00
Mycetophyllia species	0.00	0.03
Porites astreoides	1.34	2.23
Siderastrea siderea	0.00	0.11
Stephanocoenia intersepta	0.16	0.14
Octocorallia (soft coral)		
Briareum asbestinum	0.00	0.08
Gorgonia ventalina	0.00	0.14
Gorgonian (unidentified)	0.37	0.08
Iciligorgia schrammi	0.05	0.00
Plexaurella species	0.08	0.00
Pseudoplexuara species	0.54	0.00
Pseudopterogorgia species	0.08	0.08
Porifera (sponges)		
Agelas conifera	0.00	0.03
Amphimedon compressa	0.29	0.23
Anthosigmella varians	0.00	0.03
Aplysina cauliformis	0.29	0.20
Aplysina fistularis	0.00	0.00
Aplysina fulva	0.05	0.06
Aplysina lacunosa	0.05	0.00
Callyspongia plicifera	0.00	0.08
Callyspongia vaginallis	0.35	0.48
Cliona delitrix	1.10	0.76
Cliona species	0.00	0.17
Dictyonella ruetzleri	0.05	0.34
Diplastrella megastellata	0.46	0.99
Diplastrella species	0.51	1.98
Dysidea species	0.03	0.03
Haliscara species	0.00	0.06
Holopsamma helwigi	0.16	0.34
Iotrochota birotulata	3.21	4.66

Appendix 2 (continued)

	Boulders	Modules
Porifera (sponges) continued		
Ircinai species	0.00	0.06
Ircinia campana	0.62	1.75
Ircinia felix	0.37	1.16
Ircinia strobilina	0.11	0.31
Monanchora barbadensis	0.27	1.95
Monanchora unguifera	0.35	0.93
Niphates amorpha	0.08	0.23
Niphates digitalis	0.64	0.45
Niphates erecta	0.29	0.25
Pseudoceratina crassa	0.08	0.06
Sponge (unidentified)	3.11	6.63
Strongylacidon species	0.13	0.48
Millepioridae (firecoral)		
Millipora alcicornis	0.32	5.28
Zoanthidae (zoanthids)		
Zoantus pulchellus	0.00	0.08
Ascidarian (tunicates)		
Ascidian	0.00	0.06
Clavelina	0.03	0.00
Stolonicus sabulosa	1.31	0.93
Other Live		
Filograna huxleyi	1.61	0.17
Hydroid species	0.54	0.45
Algae		
Blue-green algae	2.41	3.05
Coralline algae	0.37	4.12
Dictyota	0.03	0.00
Halimeda species	0.00	0.03
Peysonnelia species	0.37	2.37
Red filamentous algae	0.27	0.23
Turf	76.30	54.88
Wranelia argus	0.19	0.00
Substrate		
Sand Pocket	0.16	0.00
Sediment covered substrate	0.64	0.08