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NOVA SOUTHEASTERN UNIVERSITY OCEANOGRAPHIC CENTER

Comparison of Fish Assemblages between Mitigation Boulder Reef and Neighboring Natural Hardbottom in Broward County, Florida, USA

By

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in partial fulfillment of the requirements for
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Master of Science

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Thesis of

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I. Abstract

A beach renourishment project was initiated in May 2005 and completed in February 2006 to restore 11.1 km of shoreline in Broward County, Florida, USA. For mitigation of predicted nearshore hardbottom burial, a boulder reef totaling 3.6 ha was deployed in 2003. To examine the replacement value of the mitigation relative to fishes, this study compared fish assemblages on boulder reef to those on adjacent natural hardbottom. Twenty-five natural hardbottom sites and twenty-five boulder reef sites were surveyed six times between March 2005 and August 2007. Two non-destructive visual census methods, a transect count (30 m long x 2 m wide x 1 m high) and a 20 minute rover diver count (approximately 30 m x 30 m), were conducted at each site to assess abundance and species richness. On transect counts, 7,117 fishes of 96 species were counted on natural hardbottom, while 11,769 fishes of 119 species were counted on boulder reef. Across both survey types, a total of 271 species was recorded. Significant differences among reef fish assemblages were found in both abundance and species richness ($p<0.05$, ANOVA). In addition, a plot of Bray-Curtis similarity indices indicated differences in fish assemblage structure between natural hardbottom and boulder reef within all individual years. Natural hardbottom exhibited higher densities of newly settled (<2 cm TL) *Haemulon* spp., while boulder reef showed higher densities of early juvenile (2-5 cm TL) *Haemulon* spp. Boulder reef also had a higher abundance of fishes greater than 5 cm and piscivorous fishes in general. While boulder reef may provide a suitable habitat for many fishes, it does not mimic natural hardbottom-associated fish assemblages, nor does it provide a similar nursery habitat for juvenile fishes.

II. Acknowledgements

This thesis would not have been possible without the help and support of many people. I would like to thank my committee members Drs. Richard Spieler, Paul Arena, and Robin Sherman for all their valuable help, comments, and suggestions throughout this process. I especially thank Richard for giving me a job in the ichthyology lab. I’ve been lucky enough to go on many great research trips through this job, and have gained great experience and true appreciation working with fish while traveling to Akumal, Puerto Morelos, St. Croix, and Veracruz.

I would also like to thank the fish lab for all of their hard work collecting data for this project. There were many early mornings, long days, and even weekends spent out on the water to make sure that the surveys were completed on time. Many people over the years have helped with these fish counts: Paul Arena, Bethany Basten, David Bryan, Lance Jordan, Kirk Kilfoyle, Danielle Morley, Pat Quinn, and Richard Spieler. Special thanks goes out to Pat for getting this project going and doing a lot of the leg work to make sure everything ran smoothly.

Finally, I would like to thank my family and friends for always supporting me through this degree. Even when I told my parents I was going to move 1,000 miles away from home, they showed me love and support to follow my dreams. It has been a wonderful three years here at the OC and I will leave here with many great memories and friends.

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1.0 Introduction

1.1 Background

Beaches are the leading tourist destination in the United States, with seventy-five percent of those with summer travel plans including a visit to a beach (Houston, 2002). Beach tourism contributes $39.2 billion to Florida's state economy (Murley *et al.*, 2005), and reef-related activities, such as fishing, diving, and snorkeling, also provide large amounts of revenue to the state. Between June 2000 and May 2001, visitors to southeast Florida spent over $1.8 billion on these reef-related activities. This helped create over 35,000 full-time and part-time jobs in Broward County during the same time period (Johns *et al.*, 2003). To ensure continued benefits of this tourism, Florida spends an average of $20-40 million a year maintaining its beaches (Finkl, 1996), while larger amounts are spent on beach renourishment projects. Beach renourishment is the process of adding sand to a location where the natural shoreline has eroded. Although renourishment is expensive, the economic return is high. For example, between 1980 and 1982, a 16.9 km section of Miami Beach was renourished with dredged sand at a cost of $80 million (Pilkey *et al.*, 1984; Silberman and Klock, 1988). Renourishment, in turn, was correlated with an increase in attendance from eight million visitors in 1978 to 21 million visitors in 1983 (Frohling, 1985). Beach erosion, therefore, is a prime concern to both the Nation's beach tourism industry and local economies.

Beaches are constantly eroding due to poorly designed coastal defense structures (i.e. seawalls, jetties, groin fields), as well as by hurricanes and other natural processes which constantly change the shoreline (Silberman and Klock, 1988). Currently, there are more than 50 active beach renourishment projects being monitored in the state of Florida dating back to 1989, with about 25% of those renourished beaches occurring in Palm Beach, Broward, and Miami-Dade counties (Finkl *et al.*, 1988; Wang *et al.*, 2005) (Figure 1). The decision regarding when to undergo this expensive process is determined by weighing the pros and cons of beach renourishment. Positive aspects of beach renourishment include an increase in recreation and storm protection (Finkl *et al.*, 1988; Silberman and Klock, 1988); enhanced property values; increased sales, income, and employment (Murley *et al.*, 2005); as well as flood control and habitat for endangered species (Finkl, 1996).

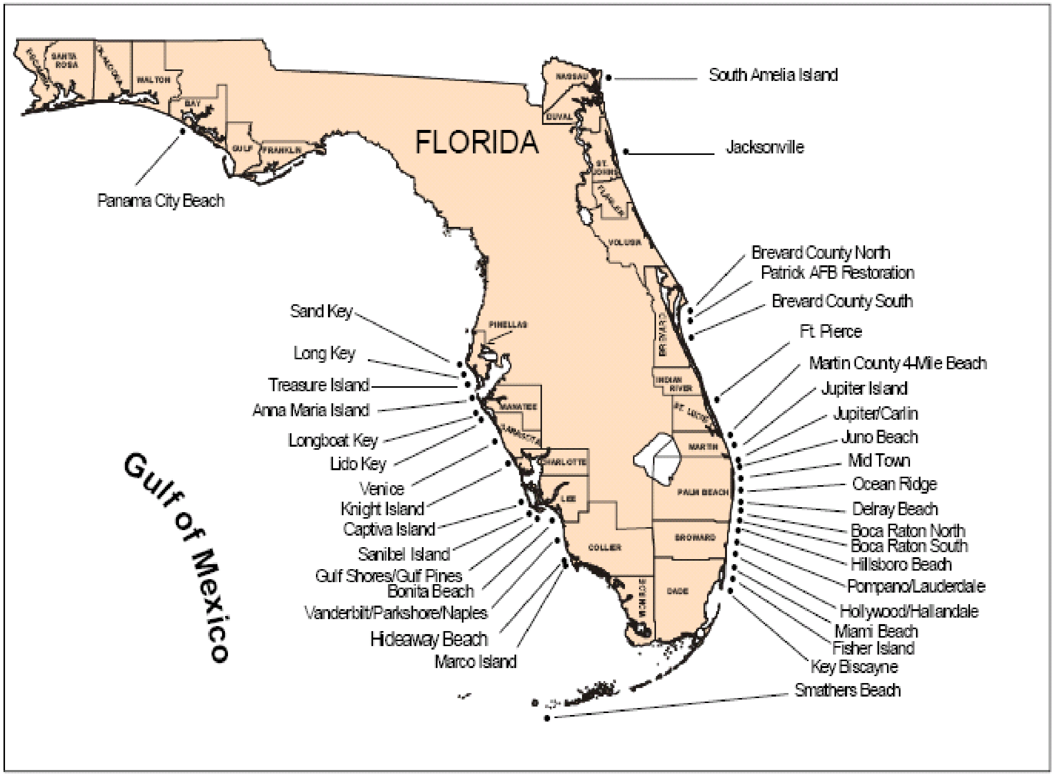


Figure 1. Monitored beach restoration/nourishment projects in Florida. The Broward County Beach Renourishment Project (Segment III) beaches are located in the Hollywood/Hallandale area. From Wang *et al.*, 2005.

However, there are also negative aspects of beach renourishment. Sand must be brought in from a borrow site and carefully placed onto the recipient beach. This process has the potential to negatively impact natural ecosystems at both sites. Nearshore habitat can become completely buried when additional sand is added, and increased sedimentation may occur as fill material is redistributed by natural processes to a more stable profile (National Research Council, 1995). A 1995 beach restoration project in Jupiter, FL, buried nearshore hardbottom habitat, reducing the number of fish species from 54 to 8 (Lindeman and Snyder, 1999). Broward County has been involved in shoreline protection, beach restoration, and beach sand management since the early 1960's to help combat the state of chronic erosion (USACOE and FDEP, 2005). Previous renourishment was conducted in John U. Lloyd State Park in 1976 and again in 1989, as well as in the Hollywood/Hallandale area in 1979 and 1991 (Murley *et al*., 2003). The current Broward County Beach Renourishment Project (Segment III) began during 2005 to restore 11.1 km of shoreline. This project aimed to restore beaches from the south jetty of Port Everglades and John U. Lloyd State Park through the Hollywood/Hallandale area. State agencies require that adverse effects of surface water activity be mitigated (Florida Statute 373.414(1)(b)). The success of one form of mitigation, boulder reef, is the focus of this study.

1.2 Natural Reef

The Florida reef tract is the northern boundary of existing hard and soft coral communities that extend from the Dry Tortugas northward through Palm Beach County, a distance of over 400 km (Goldberg, 1973; Marszalek *et al.*, 1977; Vare, 1991). The presence of this high-latitude tropical reef system is due in large part to the Florida Current. The Florida Current, a subsystem of the Gulf Stream, brings tropical water, as well as plankton and new recruits, to the reef and maintains significantly warmer water than resident shelf water masses during the winter (Jaap, 1984). In southeast Florida from Miami-Dade through Palm Beach County, there are three parallel terraces, each separated by a sand channel, that make up the reef tract (Goldberg, 1973; Moyer *et al.*, 2003; Banks *et al.*, 2007; Walker *et al.*, in press) (Figure 2). This relic reef flourished during the Holocene Transgression, but no active reef-framework accumulation has occurred for the last 7,000 years (Lighty *et al.*, 1978). Further dating of the three separate terraces has shown that a true reef backstepping has occurred, as the outer terrace ceased accreting approximately 8,000 cal BP (calibrated ^{14}C age before present), the middle terrace approximately 3,700 cal BP, and the inner terrace approximately 6,000 cal BP (Banks *et al.*, 2007). These three terraces, hereafter referred to as reefs, can be described as follows. At a water depth of approximately 16-18 m, the outer (third) reef forms (Goldberg, 1973;

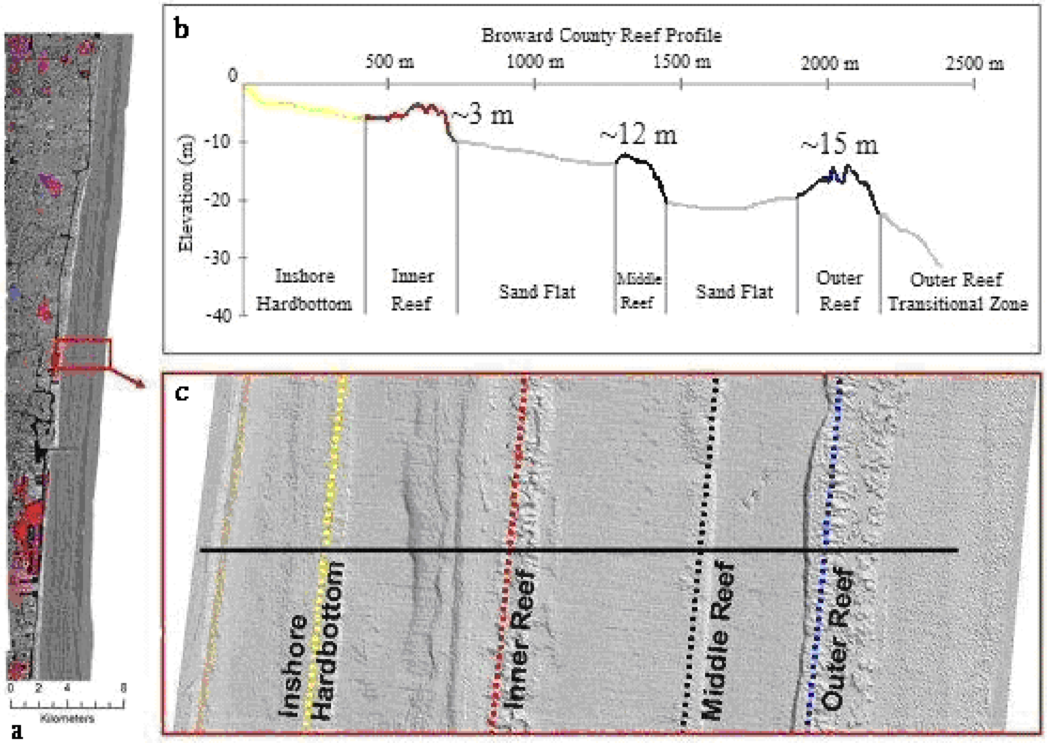


Figure 2. View of the Broward County coastline (a). The red square in (a) is enlarged in (c), showing the LIDAR bathymetry in greater detail. The black line through (c) shows the location of the bathymetric profile illustrated in (b). Modified from Gilliam, 2007.

Banks *et al.*, 2007). This reef is a relict acroporid-framework reef (Lighty, 1977; Lighty *et al.*, 1978; Toscano and Macintyre, 2003) with ledges 3-4 m in height (Goldberg, 1973). The outer reef can further be divided into four separate habitats: aggregated patch reef, spur and groove, linear reef, and deep colonized pavement (Walker *et al.*, in press). The middle (second) reef is in approximately 15 m of water 800 m offshore (Banks *et al.*, 2007), with gorgonians and flat coral colonies forming vertical relief of 2-3 m (Goldberg, 1973). The inner (first) reef forms a well developed back reef approximately 100 m offshore (Goldberg, 1973). It is located in approximately 8 m of water and consists of an *Acropora palmata* framework (Banks *et al.*, 2007). Further inshore is an area of colonized pavement that contains variable sand cover and rubble in many areas (Moyer *et al.*, 2003; Walker *et al.*, in press). This area, the nearshore habitat, is the focus of this study. It is composed primarily of beachrock and is well scoured by wave action, which often causes the area to be exposed to suspended sediments (Goldberg, 1973). Moyer *et al.* (2003) reexamined the nearshore habitat of Broward County, FL, using an acoustic sampling technique. They found the inner reef ridge complex to be dominated by encrusting zoanthids such as *Palythoa caribaeorum*, alcyonacean (soft) corals, and macroalgae (comprising 13%, 12%, and 16% total cover, respectively). This follows a trend for Caribbean reefs in general, showing that macroalgae has become the dominant benthic cover (Aronson and Precht, 2001). Nearshore reef consists of many small holes and crevices, which are valuable habitat for cryptic species and juvenile fishes (Vare, 1991). This area is also commonly used as a nursery ground for certain species of juvenile and small fishes (Lindeman and Snyder, 1999; Baron *et al.*, 2004), providing protective niches, cavities, and food items (Kobluk, 1988). Many of these fishes undergo ontogenetic shifts in habitat, and are able to move offshore to the second and/or third reefs as their ecological needs change (Werner and Gilliam, 1984; Lindeman *et al.*, 2000).

Previous studies of nearshore fishes in southeast Florida have been carried out in Broward County, Miami-Dade County, and Palm Beach County. Baron *et al.* (2004) characterized nearshore fish assemblages in Broward County and found that newly settled and early juveniles composed >84% of the nearshore fish community. Of these, >90% were haemulids (grunts). Haemulids are found in significantly higher abundance on nearshore reef as compared to outer reef (Jordan *et al.*, 2004; Ferro *et al.*, 2005), further denoting the importance of nearshore habitat. In Palm Beach County, a total of 118 fish species were observed on nearshore reefs (Vare, 1991). The three most abundant fishes were *Abudefduf saxatilis* (sergeant major), *Diplodus holbrookii* (spottail pinfish), and *Stegastes variabilis* (cocoa damselfish). The most frequently occurring family was again Haemulidae. Lindeman and Snyder (1999) also surveyed fish assemblages in Palm Beach County. They noted that early life stages (newly settled, early juvenile, and juvenile) represented >80% of individuals surveyed at three nearshore sites. The most abundant species were *Haemulon parra* (sailors choice), *Diplodus argenteus* (silver porgy), and *Stegastes variabilis*. Thanner *et al.* (2006) characterized fish assemblages at natural reef sites on the middle and outer reefs in Miami-Dade County. They used this data to compare assemblage structures on nearby prefabricated modules of limerock boulder artificial reefs. After five years of study, they found that fish assemblages on those particular natural and artificial reefs did not converge in similarity.

1.3 Artificial Reef

An artificial reef can be described as “a submerged structure placed on the seabed deliberately, to mimic some characteristics of natural reefs” (Jensen, 1997). The purpose of creating the artificial reef in Broward County was to mitigate for unavoidable damage that would be caused to natural hardbottom during the beach renourishment process. Using a mitigation ratio of 1.2:1, an artificial reef made of limestone boulders was created to mitigate for 3.1 ha of natural hardbottom predicted to be impacted by sand burial (Blankenship *et al.*, 2003). Limestone boulders were chosen as suitable substrate due to their resemblance of natural reef substrate, as well as their stability in a turbulent nearshore environment (Blankenship *et al.*, 2003). Sixty-six thousand tons of limestone boulders, averaging approximately 1.5 m in diameter, were obtained from a quarry in Freeport, Grand Bahama Island. The boulders were placed on sandy bottom in 4.5 m of water, adjacent to natural hardbottom where negative effects were anticipated. Using differential global positioning system (DGPS) for exact positioning, a single layer of boulders was deployed between June 2003 and September 2003. Upon completion of the project 8,000 limestone boulders totaling 3.6 ha were placed in three locations: Dania Beach, Hollywood Beach, and Hallandale Beach (Blankenship *et al.*, 2003).

1.4 Statement of Purpose

The purpose of this study was to compare fish assemblages between natural nearshore hardbottom and artificial boulder reef in Broward County, Florida. The renourishment project has caused certain areas of nearshore habitat to become partially or completely buried throughout Broward County. In theory, the artificial boulder reef would mitigate for the buried environment by providing similar conditions and habitat as natural reef to which fish can recruit. By performing multiple fish inventories through time, I was able to monitor the effectiveness of an artificial boulder reef, relative to fishes, by comparing their assemblages to neighboring natural hardbottom. Fish assemblages have been shown to change on artificial reefs up to ten years after deployment (Relini *et al.*, 2002). Thus, an effective comparison requires multiple years of data acquisition. Data collected from natural hardbottom can also be compared to previous and future fish studies in Broward County to monitor changes in the fish community over time.

The objectives of this study were to examine the following questions: 1) Are there differences in species richness (the number of species) between the mitigation reef and the natural hardbottom? 2) Are there species-specific differences between the mitigation reef and the natural hardbottom? 3) Are there differences in fish abundance (the total number of fishes, all species combined) between the mitigation reef and the natural hardbottom? 4) Are there differences in fish assemblage structure (a measure of abundances of individual species) between the mitigation reef and the natural hardbottom? 5) Is the mitigation reef the correct size to replace the proposed covered natural hardbottom?

2.0 Materials and Methods

The experimental design consisted of examining fishes on 25 natural reef sites and 25 artificial reef sites using two non-destructive visual survey methods. All counts were completed within a specified month (March, June, or August) and were conducted when visibility was greater than 5 m. Fish surveyors consisted of trained ichthyologists from Nova Southeastern University.

2.1 Background

Fish counts on natural nearshore hardbottom in Broward County, FL, were previously completed during June through August 2001. A total of 100 point-counts, 200 transect counts, and 98 rover diver counts were completed for approximately 30 km of shoreline. There was a transect count and either a point count or rover diver count completed for every 152 m of shoreline (Baron *et al.*, 2004). Twenty-five of the previously used 2001 study sites were used in this study as the natural hardbottom sites. Twenty-five new permanent sites were established on the mitigation boulder reef. Counts were completed during June 2004, August 2004, March 2005, August 2005, August 2006, and August 2007. Fishes were surveyed on both mitigation boulders and natural hardbottom. Twenty-five transect counts and 25 rover diver counts were completed on the mitigation boulders, and 25 transect counts and 25 rover diver counts were completed on the natural hardbottom each census period (Figure 3). DGPS was used to maintain site consistency from year to year (Appendix C).

2.2 Transect Counts

For transect counts, a 30 m tape was stretched from a specific DGPS site, heading west to east. The start and end points were established by Coastal Planning & Engineering (CPE). The SCUBA diver swam above the transect, recording all fish within 1 m to either side and 1 m above the line (Figure 4). Fish species, abundance, and total length (TL) (by size class: <2, 2-5, 5-10, 10-20, 20-30, 30-50 and >50 cm) were recorded.

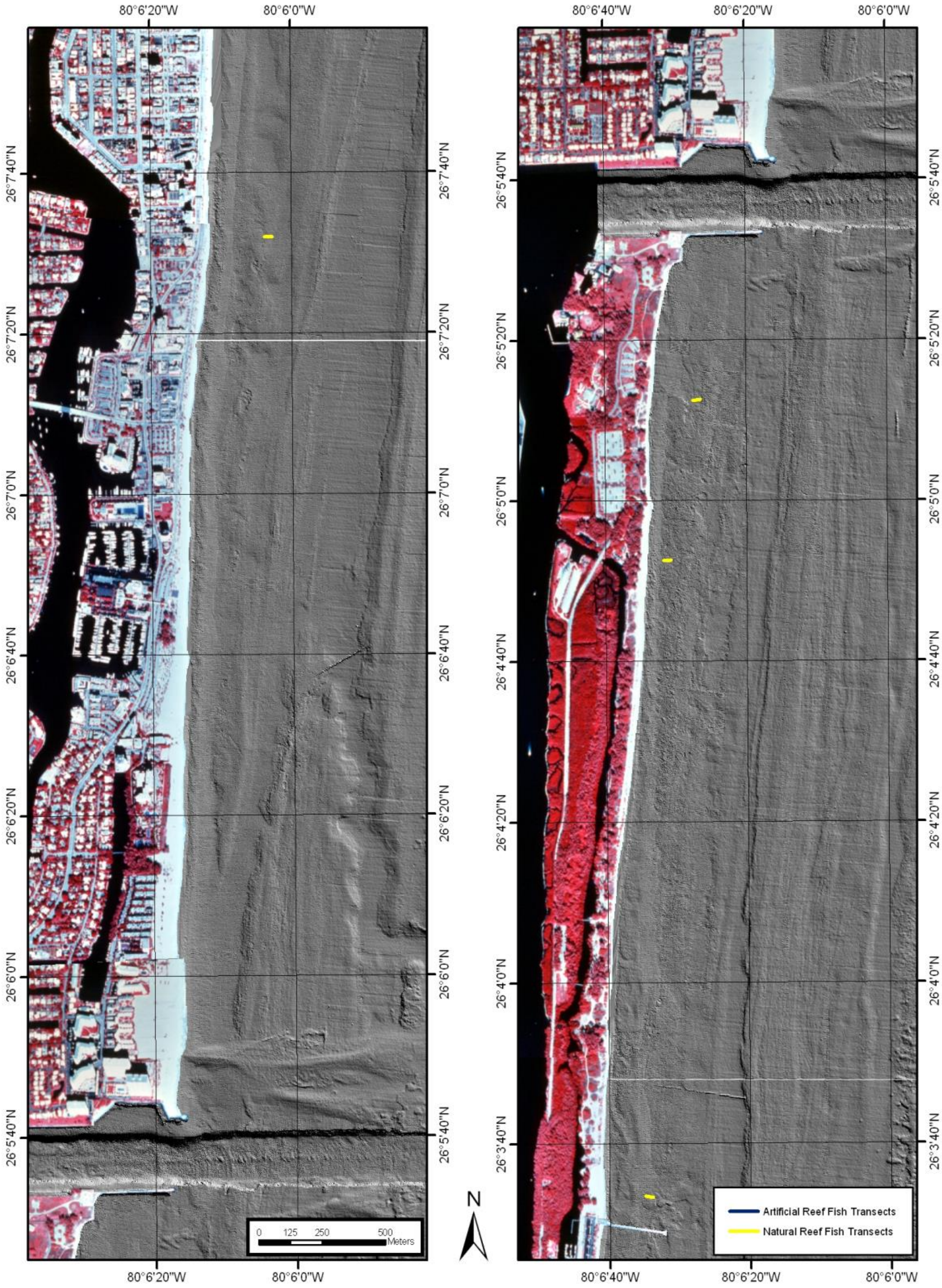


Figure 3. Laser Airborne Depth Sounding (LADS) image showing the 25 artificial reef transects (blue) and the 25 natural reef transects (yellow) surveyed.

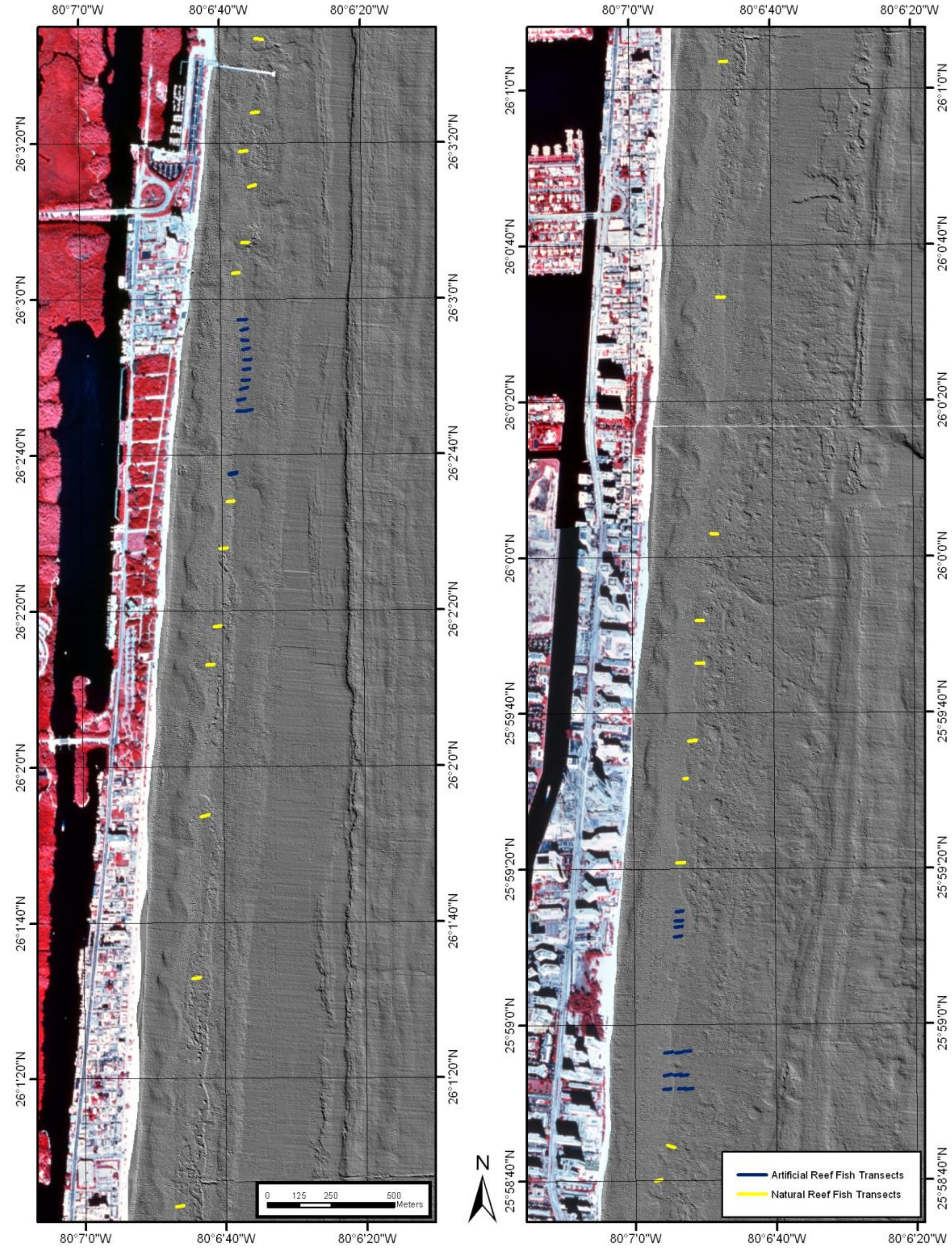


Figure 3 (cont'd). Laser Airborne Depth Sounding (LADS) image showing the 25 artificial reef transects (blue) and the 25 natural reef transects (yellow) surveyed.

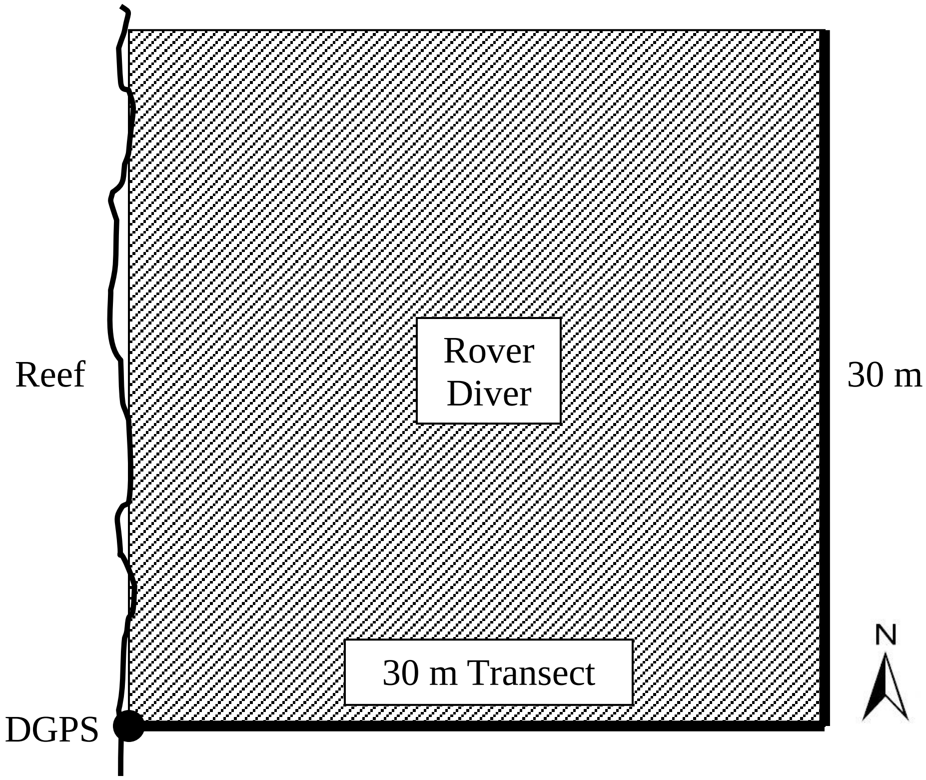


Figure 4. Layout of transect and rover diver counts at a typical site.

The diver carried a 1 m “T”- bar, with size classes marked off, to aid in estimating both transect width and total length (TL) of fishes. Areas covering greater than 3 m of continuous sand were also noted. Transect counts took approximately 10 minutes to complete, but were not time delimited. Upon completion of the fish count, a tape measure was contoured closely to the substrate, giving an approximate measure of rugosity (tape distance/30 m).

2.3 Rover Diver Counts

Rover diver counts consisted of a diver recording all fish species encountered during a 20 minute interval, giving an estimation of total species richness. The boundary of the survey area included the line used in the transect count as a southern boundary, a

30 m line stretched from the eastern end of the transect line due north, and the western edge of the natural hardbottom (Figure 4). This essentially created a 30 m square in which the rover count was performed. The rover diver was encouraged to look wherever he or she pleased to encounter the maximum number of species.

2.4 Statistics

Fish counts on nearshore natural hardbottom and mitigation boulder reef were conducted in June 2004, August 2004, March 2005, August 2005, August 2006, and August 2007. Data from all fish counts were entered into separate MS Excel files. For transect data, total fish abundance (of each size class and all size classes combined) and total fish per count were subjected to statistical analysis (Statistica, StatSoft Inc., Tulsa, OK, USA). Standardization for rugosity was accomplished by dividing the 30 m transect abundance and species richness data by the rugosity index (rugosity/30). Data were tested for normality and equal variances to determine whether transformations were needed. Abundance data exhibited a heteroscedastic, non-normal distribution, and was $\log_{10}(x+1)$ transformed to meet assumptions of the analysis of variance (ANOVA). Species richness data demonstrated a normal distribution and were analyzed without transformation. For analysis among individual years, a one-way parametric ANOVA was performed. For analysis comparing data across years, a two-way parametric ANOVA was performed between year and reef (natural vs. boulder). A p-value of <0.05 was accepted as a significant difference. A *post hoc* Student-Newman-Keuls (SNK) test was used to determine the differences among means if significant differences were found within an ANOVA.

Multivariate statistical analyses were performed using the Plymouth Routines in Multivariate Ecological Research statistical package (Primer, v6). Bray-Curtis similarity indices were used to construct non-metric multi-dimensional scaling (MDS) plots from fourth-root transformed abundance data. Analysis of similarity (ANOSIM) tests and similarity percentage (SIMPER) analysis of dissimilarity were used to test for individual species differences among sites (Clarke and Warwick, 2001).

Fishes were also compared according to trophic level on natural hardbottom and mitigation boulder transect data across all years. The following categories were used to classify fishes: BC=benthic carnivore, C=cleaner, H=herbivore, O=omnivore, Pi=piscivore, and Pl=planktivore (Randall, 1967; Froese and Pauly, 2007).

3.0 Results

3.1 By Year and Across All Years

3.1.1 June 2004

Twenty-five transect counts were conducted on natural hardbottom and 25 transect counts were conducted on mitigation boulders. Natural hardbottom transect counts yielded a total of 1,166 fishes of 45 species. Juvenile and small cryptic species (≤5 cm TL) accounted for 70.3% of total fish abundance. Mean abundance ± standard error of the mean (SEM) was 46.6 ± 12.1 (Figure 5) and mean number of species (richness) was 8.76 ± 0.8 (Figure 6). Juvenile haemulids accounted for 45.5% of total fish abundance. On the boulder reef a total of 1,809 fishes comprising 64 species were recorded. Juvenile and small cryptic species (≤5 cm TL) accounted for 41.8% of total fish abundance. Mean abundance ± SEM was 72.4 ± 12.6 (Figure 5) and mean species richness was 17.4 ± 0.8

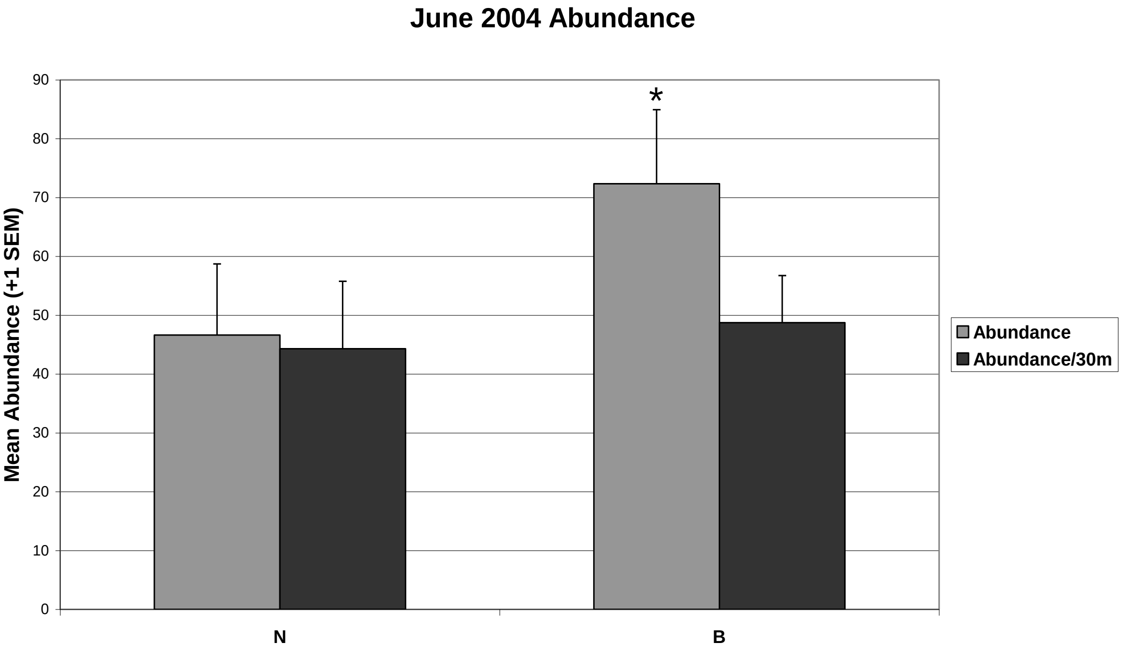


Figure 5. Mean abundance of fishes (June 2004) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization. The asterisk indicates a significant difference (p<0.05: ANOVA; SNK) in abundance between bars of the same color.

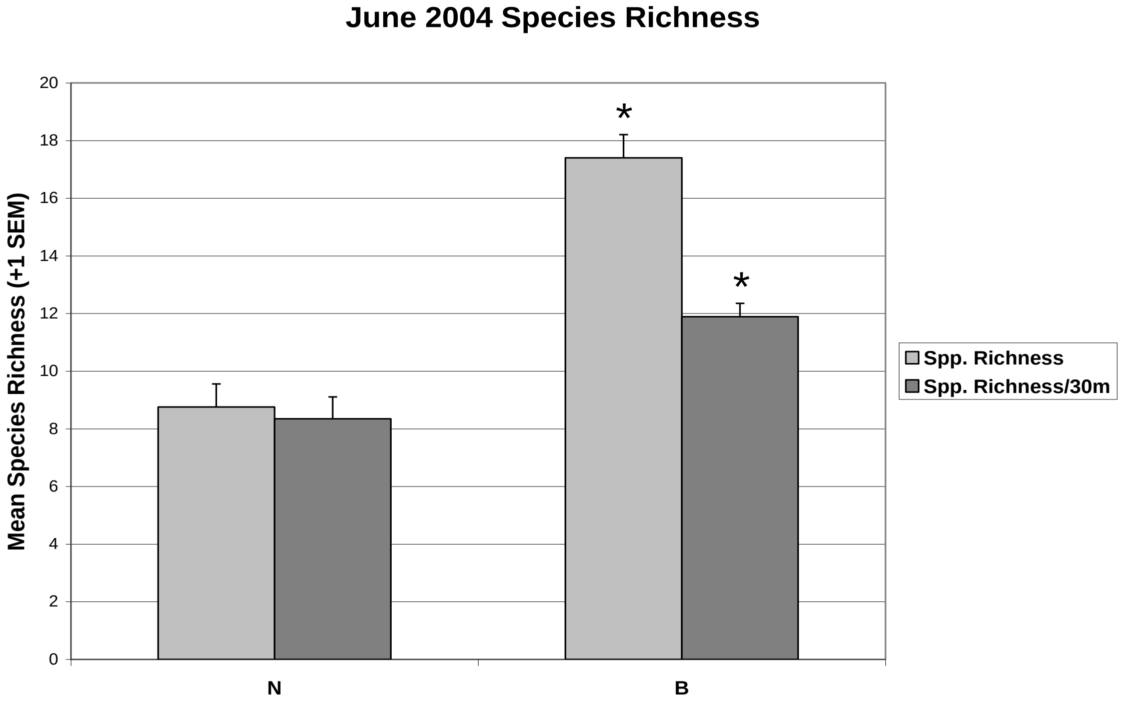


Figure 6. Mean species richness of fishes (June 2004) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization. The asterisks indicate significant differences (p<0.05: ANOVA; SNK) in species richness between bars of the same color.

(Figure 6). Juvenile haemulids accounted for 16.9% of total fish abundance. Both mean abundance and mean species richness showed significant differences between natural reef and mitigation boulders ($p<0.005$, $p<0.0002$; respectively).

If rugosity is taken into account, mean fish abundance is no longer significantly different (Mean ± SEM: 48.7 ± 8.0 versus 44.3 ± 11.5, $p>0.05$) (Figure 5), while mean species richness remains greater on the 30 m transects on the boulder reef compared to the natural hardbottom (Mean ± SEM: 11.9 ± 0.5 versus 8.3 ± 0.8, $p<0.0004$) (Figure 6), while). SIMPER analysis of dissimilarity indicated the two assemblages had an average 77% dissimilarity (Table 1). Juvenile *Haemulon* spp. contributed most to the total dissimilarity (7%). An MDS plot of Bray-Curtis similarity indices showed a clear distinction between natural hardbottom and mitigation boulder assemblages (Figure 7). Re-running the MDS plot analysis to take rugosity into effect produced similar results (Figure 8).

Table 1. SIMPER analysis of dissimilarity showing the percent contribution of each species for June 2004 between the natural hardbottom (N) and the mitigation boulders (B). The average dissimilarity was 76.57%.

Species	Group N Av.Abund	Group B Av.Abund	Contrib%	Cum.%
Haemulon spp.	1.75	1.34	7.26	7.26
Anisotremus virginicus	0.23	1.52	5.69	12.95
Thalassoma bifasciatum	0.32	1.40	5.36	18.31
Haemulon aurolineatum	0.31	1.28	5.17	23.48
Halichoeres bivittatus	1.85	1.27	4.44	27.92
Acanthurus bahianus	0.13	1.13	4.39	32.31
Abudefduf saxatilis	0.24	1.10	4.31	36.62
Haemulon plumierii	0.00	1.02	4.30	40.92
Lutjanus synagris	0.30	0.94	3.47	44.39
Archosargus rhomboidalis	0.00	0.81	3.37	47.77
Carangoides ruber	0.06	0.84	3.30	51.07

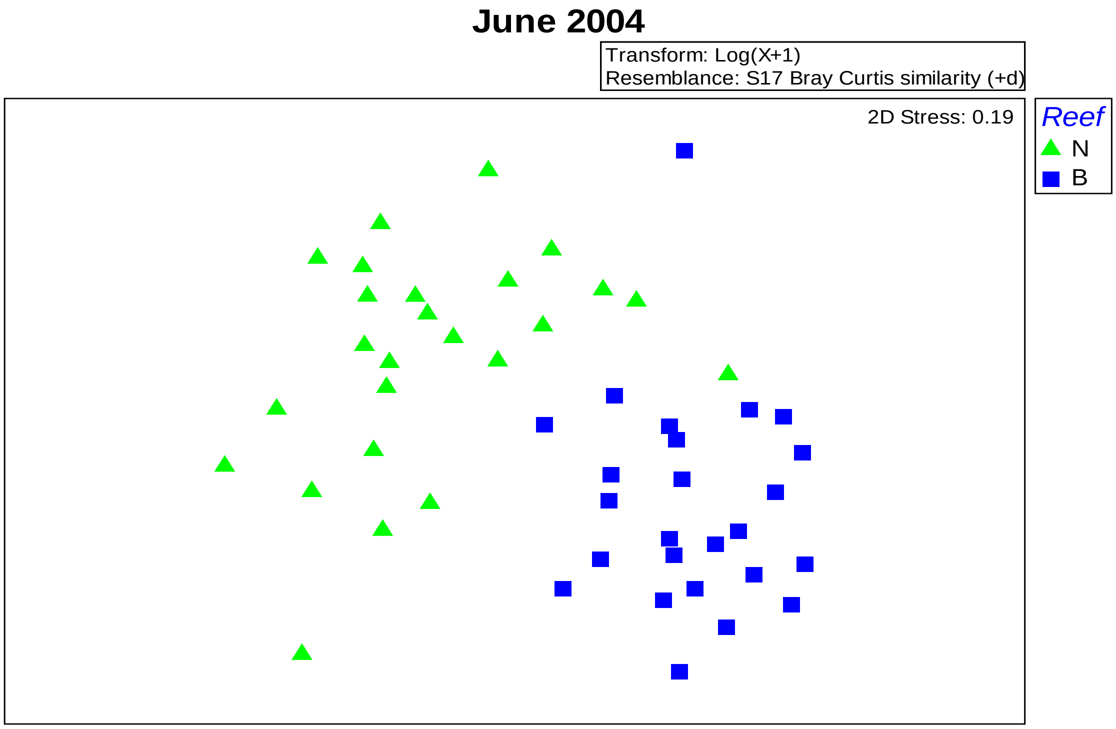


Figure 7. MDS plot (June 2004) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) not standardized for rugosity.

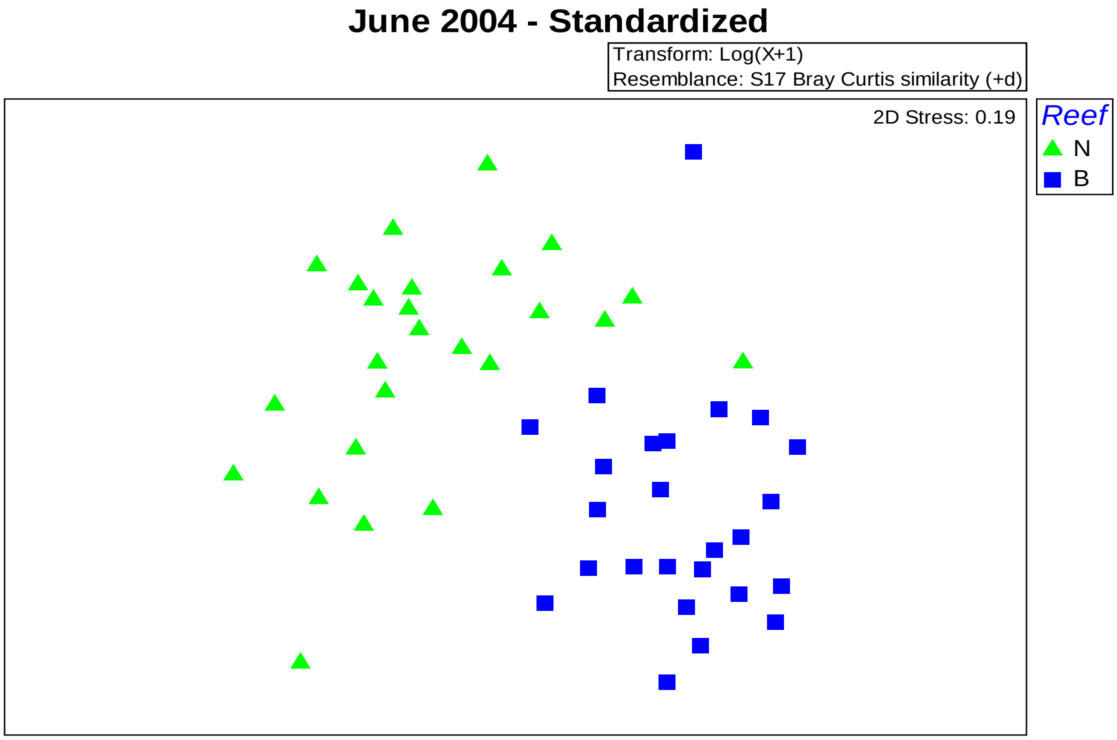


Figure 8. MDS plot (June 2004) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) standardized for rugosity.

Twenty-five rover diver counts were conducted on natural hardbottom and 25 rover diver counts were conducted on mitigation boulders. Natural hardbottom yielded 76 species from 36 families. Mitigation boulders yielded 98 species from 38 families.

3.1.2 August 2004

Twenty-five transect counts were conducted on natural hardbottom and 25 transect counts were conducted on mitigation boulders. Natural hardbottom transect counts yielded a total of 1,409 fishes of 48 species. Juvenile and small cryptic species (≤5 cm TL) accounted for 59.0% of total fish abundance. Mean abundance ± SEM was 56.4 ± 5.6 (Figure 9) and mean number of species (richness) was 10.7 ± 0.5 (Figure 10). Juvenile haemulids accounted for 13.9% of total fish abundance. On the boulder reef a total of 1,973 fishes comprising 56 species were recorded. Juveniles and small cryptic

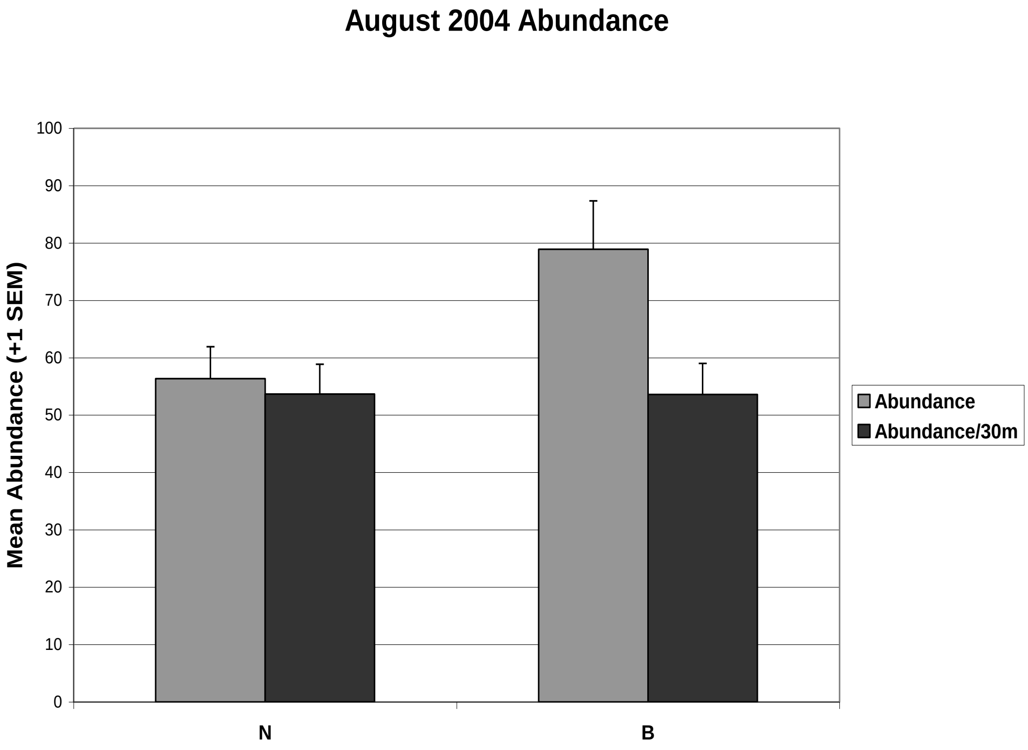


Figure 9. Mean abundance of fishes (August 2004) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization.

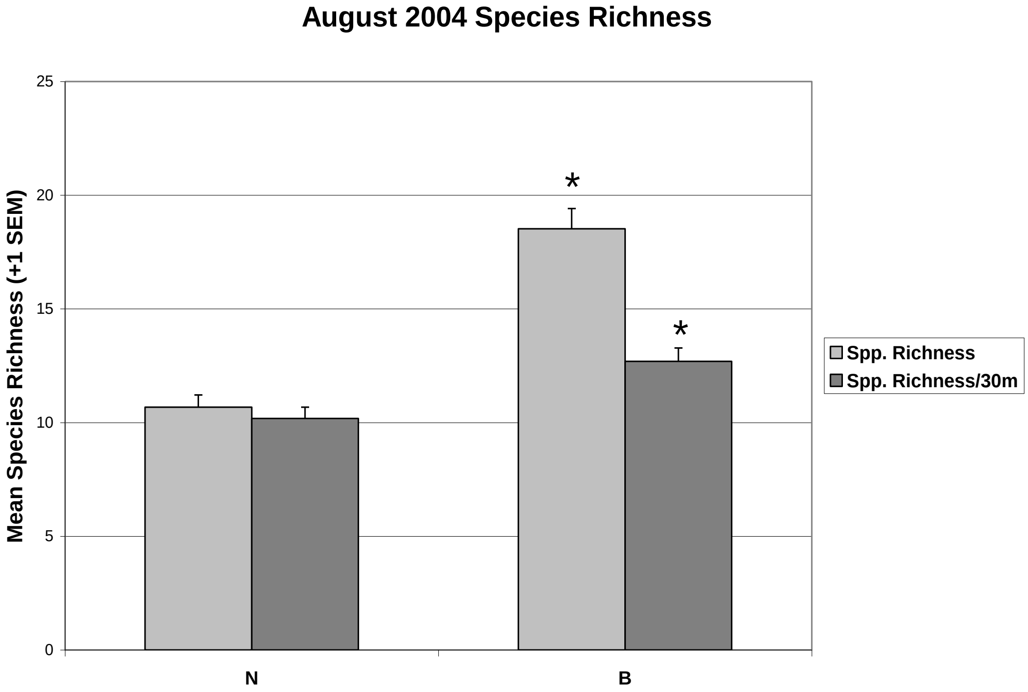


Figure 10. Mean species richness of fishes (August 2004) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization. The asterisks indicate significant differences (p<0.05: ANOVA; SNK) in species richness between bars of the same color.

species (≤5 cm TL) accounted for 31.0% of total fish abundance. Mean abundance ± SEM was 78.9 ± 8.4 (Figure 9) and mean species richness was 18.5 ± 0.9 (Figure 10). Juvenile haemulids accounted for 5.6% of total fish abundance. Mean species richness was greater on the mitigation boulders compared to the natural reefs (p<0.0001), while mean abundance showed no significant difference between the two locations (p>0.05).

If rugosity is taken into account, mean fish abundance remains not significantly different (Mean ± SEM: 53.6 ± 5.4 versus 53.7 ± 5.2, p>0.05) (Figure 9), while mean species richness remains significantly greater on the 30 m transects on the boulder reef compared to the natural hardbottom (Mean ± SEM: 12.7 ± 0.6 versus 10.2 ± 0.5, p<0.002) (Figure 10). SIMPER analysis of dissimilarity indicated the two assemblages had an average 69% dissimilarity (Table 2). *Haemulon aurolineatum* (tomtate) and

Table 2. SIMPER analysis of dissimilarity showing the percent contribution of each species for August 2004 between the natural hardbottom (N) and the mitigation boulders (B). The average dissimilarity was 69.38%.

Species	Group N Av.Abund	Group B Av.Abund	Contrib%	Cum.%
Haemulon aurolineatum	0.92	2.39	7.59	7.59
Carangoides ruber	0.00	1.83	6.78	14.37
Haemulon spp.	1.04	0.86	5.00	19.37
Thalassoma bifasciatum	0.14	1.38	4.98	24.35
Lutjanus synagris	1.47	0.69	4.44	28.79
Acanthurus bahianus	0.10	1.24	4.35	33.14
Diplectrum formosum	1.07	0.25	3.68	36.82
Anisotremus virginicus	0.10	0.98	3.56	40.38
Haemulon flavolineatum	0.32	0.85	3.32	43.71
Haemulon plumierii	0.33	0.97	3.26	46.97
Sparisoma radians	0.91	0.74	3.17	50.14

Carangoides ruber (bar jack) contributed 7.6% and 6.8%, respectively, to the dissimilarity. An MDS plot of Bray-Curtis similarity indices showed a clear distinction between natural hardbottom and mitigation boulder assemblages (Figure 11). Re-running the MDS plot analysis to take rugosity into effect produced similar results (Figure 12).

Twenty-five rover diver counts were conducted on natural hardbottom and 25 rover diver counts were conducted on mitigation boulders. Natural hardbottom yielded 81 species from 35 families. Mitigation boulders yielded 97 species from 36 families.

3.1.3 March 2005

Twenty-five transect counts were conducted on natural hardbottom and 25 transect counts were conducted on mitigation boulders. Natural hardbottom transect counts yielded a total of 538 fishes of 38 species. Juvenile and small cryptic species (≤5 cm TL) accounted for 79.0% of total fish abundance. Mean abundance ± SEM was 21.5 ± 6.4 (Figure 13) and mean number of species (richness) was 5.2 ± 0.6 (Figure 14). Juvenile haemulids accounted for 52.6% of total fish abundance. On the boulder reef a

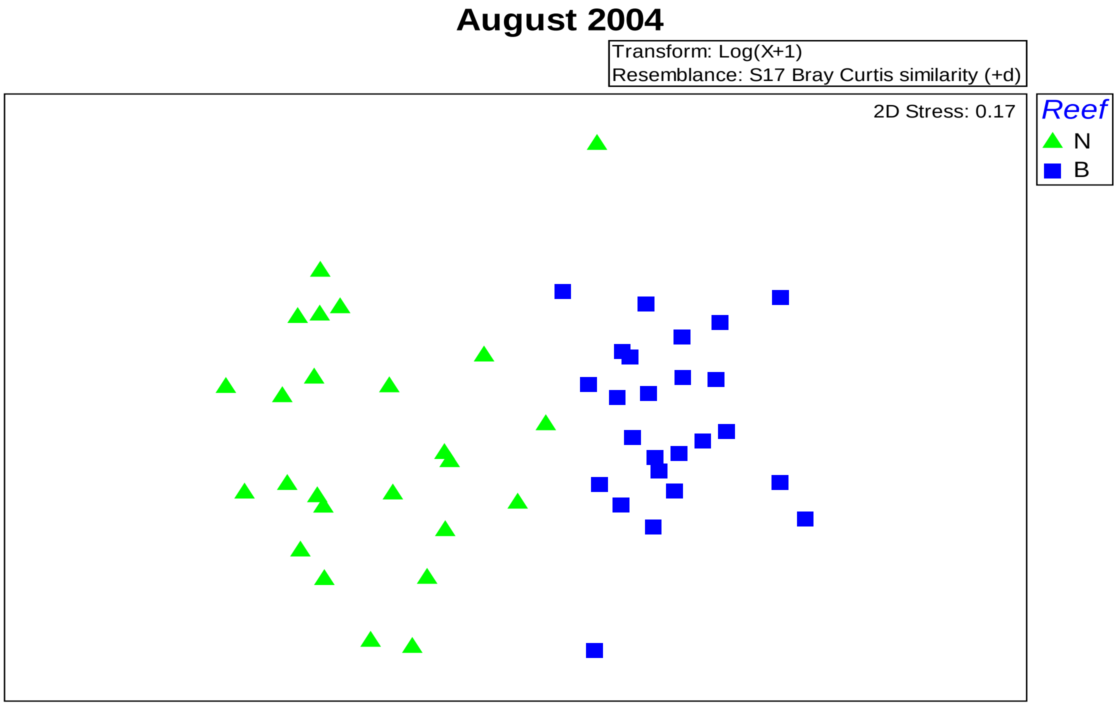


Figure 11. MDS plot (August 2004) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) not standardized for rugosity.

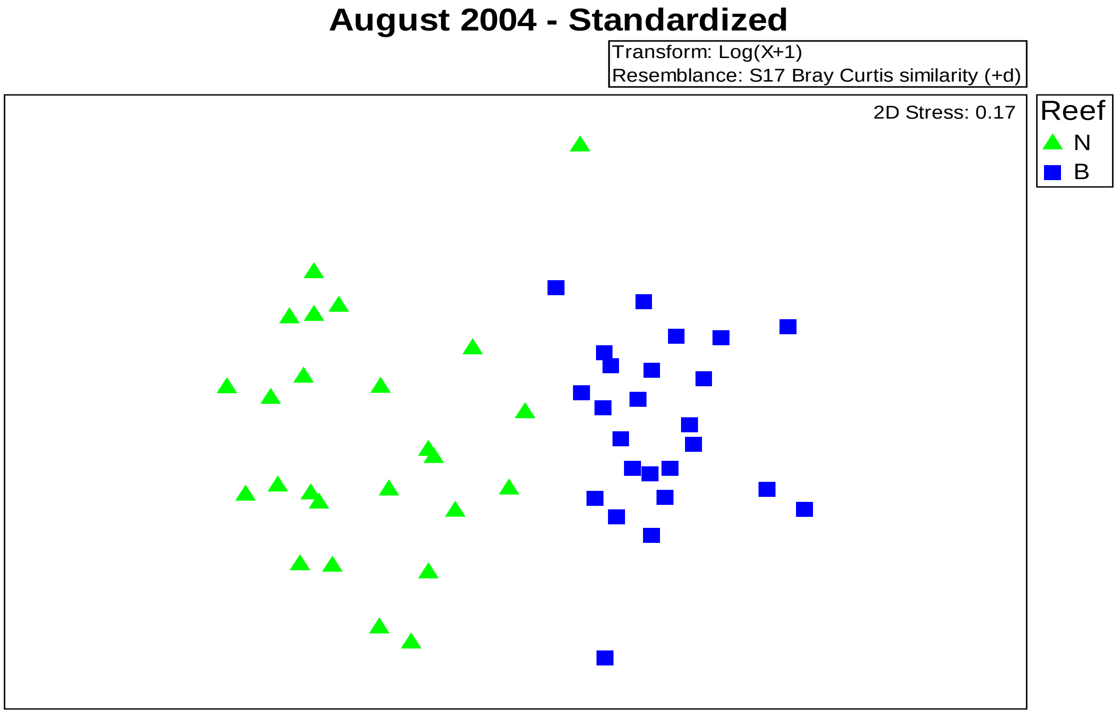


Figure 12. MDS plot (August 2004) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) standardized for rugosity.

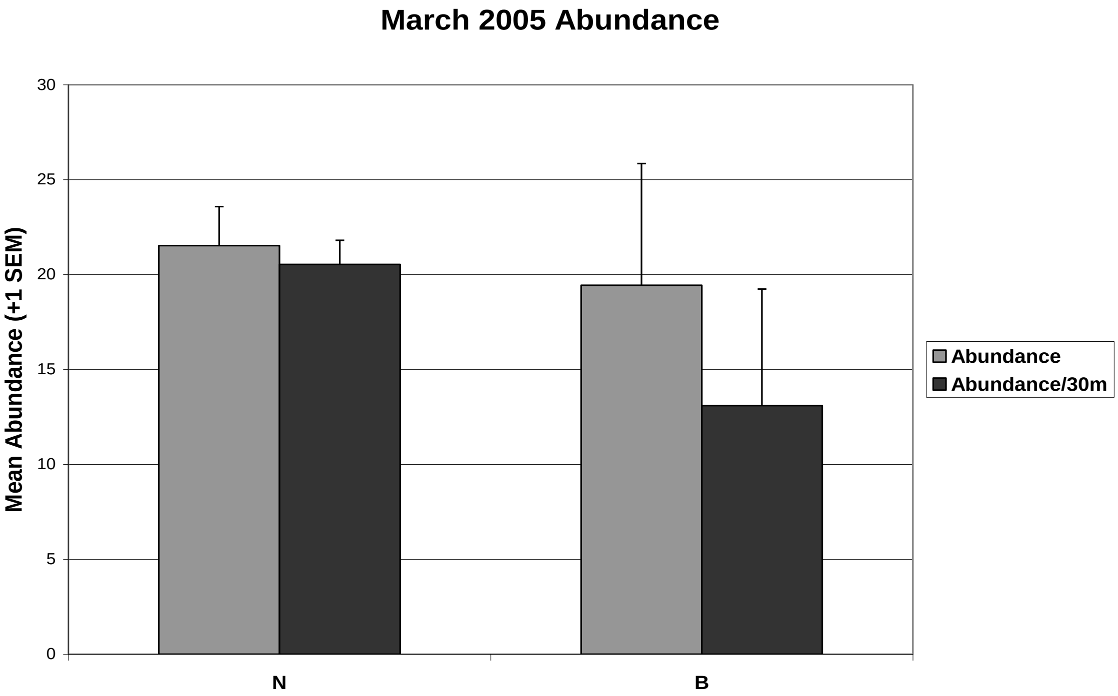


Figure 13. Mean abundance of fishes (March 2005) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization.

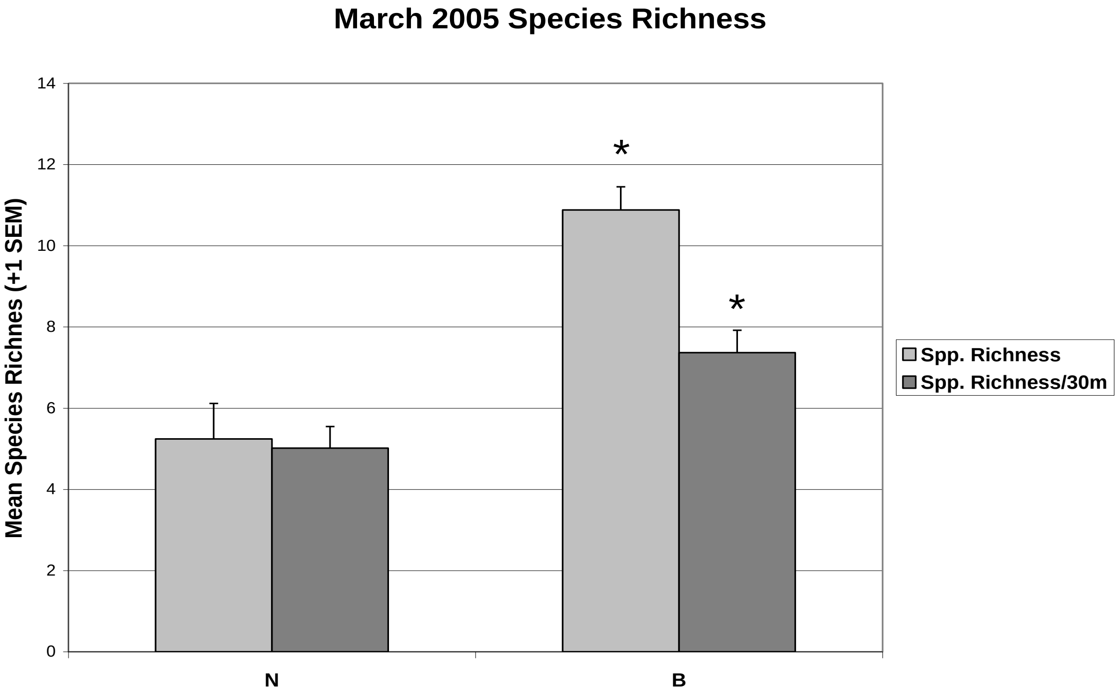


Figure 14. Mean species richness of fishes (March 2005) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization. The asterisks indicate significant differences ($p<0.05$: ANOVA; SNK) in species richness between bars of the same color.

total of 486 fishes comprising 57 species were recorded. Juvenile and small cryptic species (≤5 cm TL) accounted for 24.3% of total fish abundance. Mean abundance + SEM was 19.4 + 2.1 (Figure 13) and mean species richness was 10.9 + 0.9 (Figure 14). Juvenile haemulids accounted for 0.0% of total fish abundance. Mean abundance was not significantly different on the two reefs ($p>0.05$), while mean species richness was greater on the mitigation boulders compared to the natural reef ($p<0.0002$).

If rugosity is taken into account, mean fish abundance remains not significantly different (Mean + SEM: 13.1 + 1.3 versus 20.5 + 6.1, $p>0.05$), and mean species richness remains significantly greater on the 30 m transects on the boulder reef compared to the natural hardbottom (Mean + SEM: 7.4 + 0.5 versus 5.0 + 0.6, $p<0.004$) (Figure 14).

SIMPER analysis of dissimilarity indicated the two assemblages had an average 86% dissimilarity (Table 3). *Anisotremus virginicus* (porkfish), *Acanthurus bahianus* (ocean surgeonfish), and *Halichoeres bivittatus* (slippery dick) each contributed about 6% to the dissimilarity. An MDS plot of Bray-Curtis similarity indices showed a clear

Table 3. SIMPER analysis of dissimilarity showing the percent contribution of each species for March 2005 between the natural hardbottom (N) and the mitigation boulders (B). The average dissimilarity was 85.68%.

Species	Group N Av.Abund	Group B Av.Abund	Contrib%	Cum.%
Anisotremus virginicus	0.11	0.84	6.58	6.58
Acanthurus bahianus	0.12	0.79	6.46	13.04
Halichoeres bivittatus	0.89	0.67	6.18	19.22
Haemulon spp.	0.74	0.00	4.68	23.9
Haemulon plumierii	0.06	0.60	4.31	28.21
Acanthurus chirurgus	0.52	0.32	4.22	32.43
Emblemaria pandionis	0.48	0.15	4.15	36.58
Haemulon aurolineatum	0.11	0.45	3.77	40.35
Parablennius marmoreus	0.28	0.37	3.75	44.10
Lutjanus synagris	0.00	0.53	3.74	47.84
Stegastes variabilis	0.23	0.44	3.55	51.39

distinction between natural hardbottom and mitigation boulder assemblages (Figure 15). Re-running the MDS plot analysis to take rugosity into effect produced similar results (Figure 16).

Twenty-five rover diver counts were conducted on natural hardbottom and 25 rover diver counts were conducted on mitigation boulders. Natural hardbottom yielded 68 species from 32 families. Mitigation boulders yielded 86 species from 33 families.

3.1.4 August 2005

Twenty-five transect counts were conducted on natural hardbottom and 25 transect counts were conducted on mitigation boulders. Natural hardbottom transect counts yielded a total of 917 fishes of 49 species. Juvenile and small cryptic species (≤5 cm TL) accounted for 83.2% of total fish abundance. Mean abundance ± SEM was 36.6 ± 7.0 (Figure 17) and mean number of species (richness) was 9.4 ± 0.8 (Figure 18). Juvenile haemulids accounted for 39.0% of total fish abundance. On the boulder reef a total of 1,677 fishes comprising 65 species were recorded. Juvenile and small cryptic species (≤5 cm TL) accounted for 49.9% of total fish abundance. Mean abundance ± SEM was 67.1 ± 11.6 (Figure 17) and mean species richness was 15.0 ± 0.8 (Figure 18). Juvenile haemulids accounted for 38.6% of total fish abundance. Both mean abundance and mean species richness were significantly greater on the mitigation boulders compared to the natural reefs ($p<0.03$, $p<0.0002$; respectively).

If rugosity is taken into account, both mean abundance and mean species richness are no longer significantly different on the 30 m natural hardbottom transects compared to the boulder reef (Mean ± SEM: 35.2 ± 6.7 versus 46.6 ± 8.3, $p>0.05$; 9.1 ± 0.8 versus 10.3 ± 0.6, $p>0.05$; respectively) (Figures 17 and 18). SIMPER analysis of dissimilarity

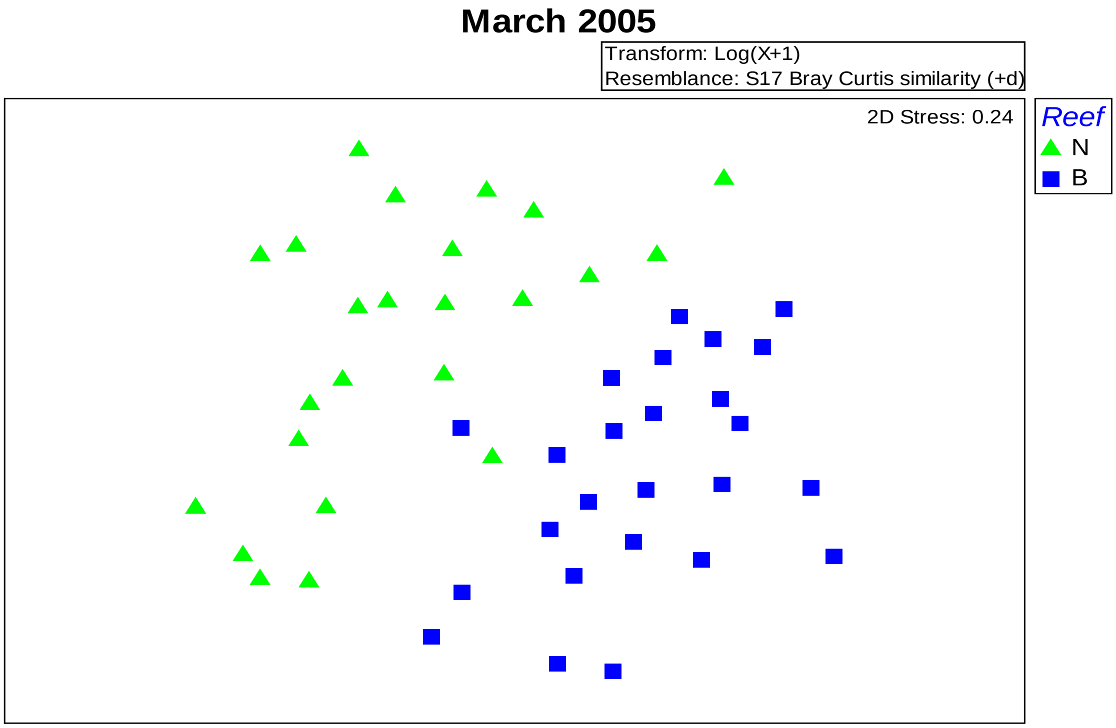


Figure 15. MDS plot (March 2005) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) not standardized for rugosity.

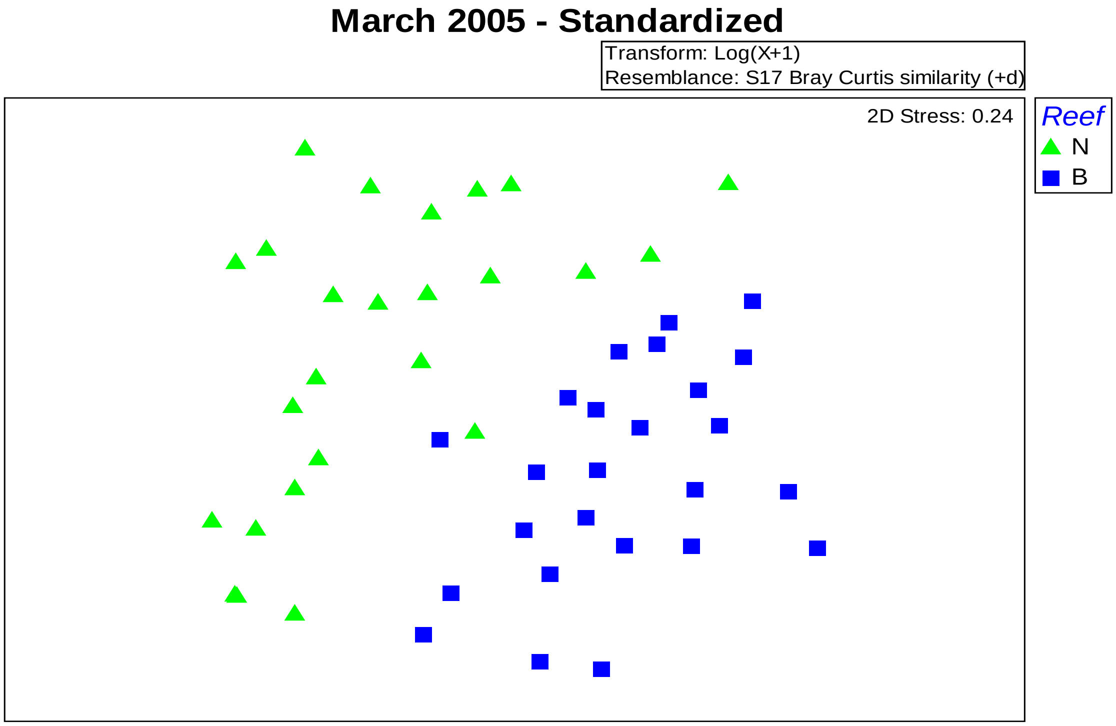


Figure 16. MDS plot (March 2005) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) standardized for rugosity.

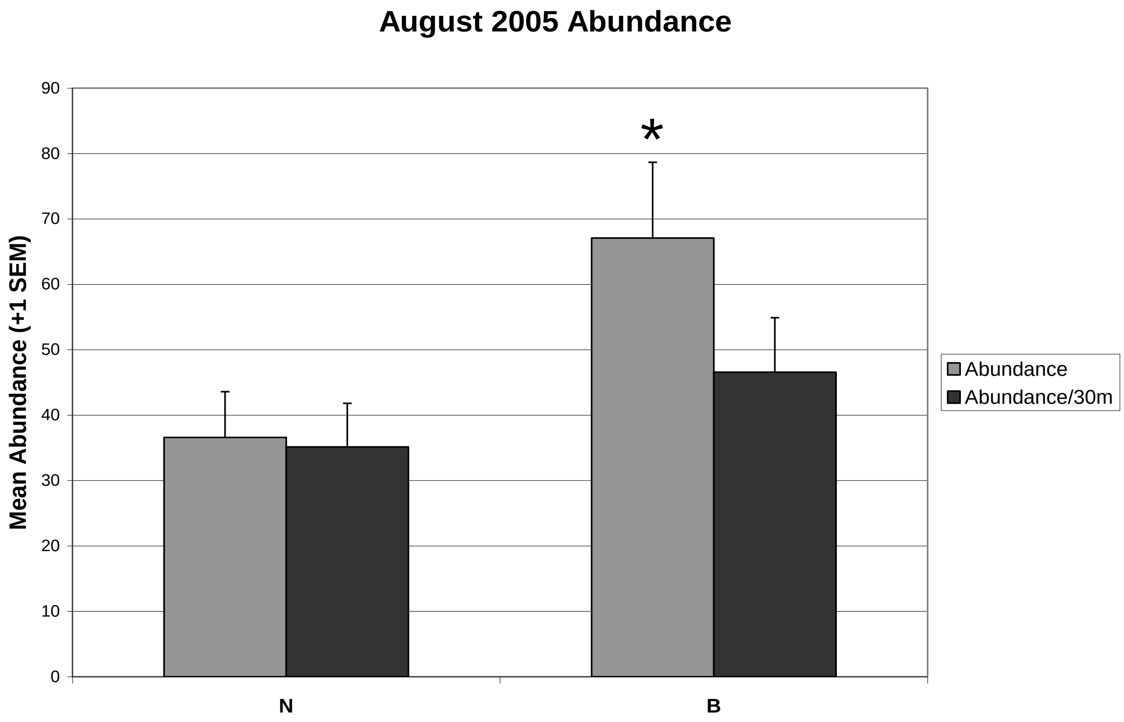


Figure 17. Mean abundance of fishes (August 2005) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization. The asterisk indicates a significant difference (p<0.05: ANOVA; SNK) in abundance between bars of the same color.

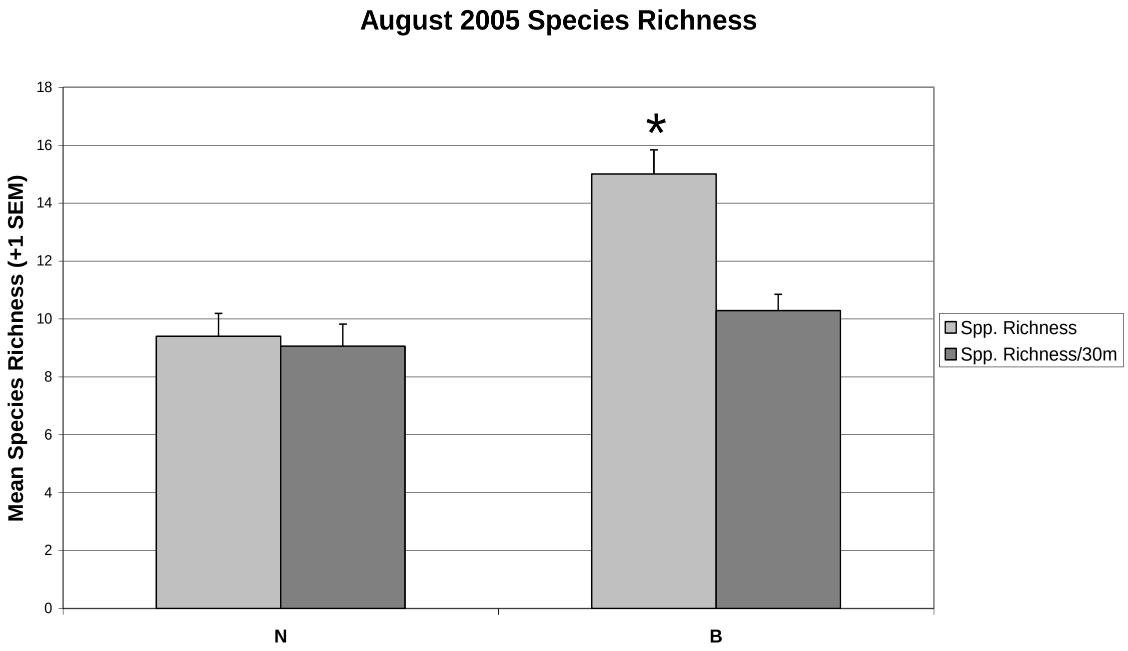


Figure 18. Mean species richness of fishes (August 2005) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization. The asterisk indicates a significant difference (p<0.05: ANOVA; SNK) in species richness between bars of the same color.

indicated the two assemblages had an average 77% dissimilarity (Table 4). Juvenile *Haemulon* spp. contributed 9% to the dissimilarity, while *Haemulon aurolineatum* (tomtate) contributed 6%. An MDS plot of Bray-Curtis similarity indices showed a clear distinction between natural hardbottom and mitigation boulder assemblages (Figure 19). Re-running the MDS plot analysis to take rugosity into effect produced similar results (Figure 20).

Table 4. SIMPER analysis of dissimilarity showing the percent contribution of each species for August 2005 between the natural hardbottom (N) and the mitigation boulders (B). The average dissimilarity was 76.67%.

Species	Group N Av.Abund	Group B Av.Abund	Contrib%	Cum.%
Haemulon spp.	1.61	1.79	8.95	8.95
Haemulon aurolineatum	0.03	1.24	5.80	14.75
Lutjanus synagris	1.54	0.67	5.39	20.14
Anisotremus virginicus	0.00	1.11	5.37	25.51
Haemulon plumierii	0.23	1.02	4.25	29.75
Halichoeres bivittatus	1.10	1.24	4.24	34.00
Acanthurus chirurgus	0.33	0.84	3.96	37.95
Acanthurus bahianus	0.40	0.79	3.74	41.70
Thalassoma bifasciatum	0.13	0.84	3.67	45.37
Haemulon flavolineatum	0.10	0.76	3.5	48.87
Stegastes variabilis	0.48	0.62	3.05	51.92

Twenty-five rover diver counts were conducted on natural hardbottom and 25 rover diver counts were conducted on mitigation boulders. Natural hardbottom yielded 75 species from 31 families. Mitigation boulders yielded 92 species from 37 families.

3.1.5 August 2006

Twenty-five transect counts were conducted on natural hardbottom and 25 transect counts were conducted on mitigation boulders. Natural hardbottom transect counts yielded a total of 713 fishes of 45 species. Juvenile and small cryptic species (≤5 cm TL) accounted for 80.8% of total fish abundance. Mean abundance ± SEM was 36.9

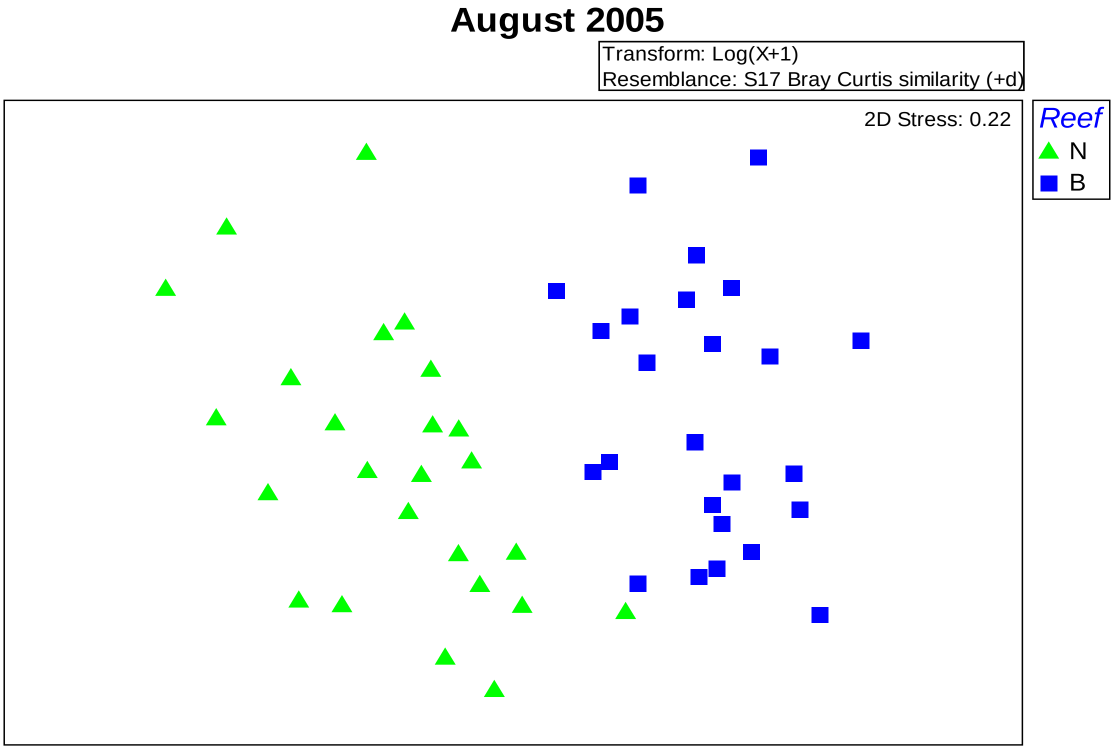


Figure 19. MDS plot (August 2005) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) not standardized for rugosity.

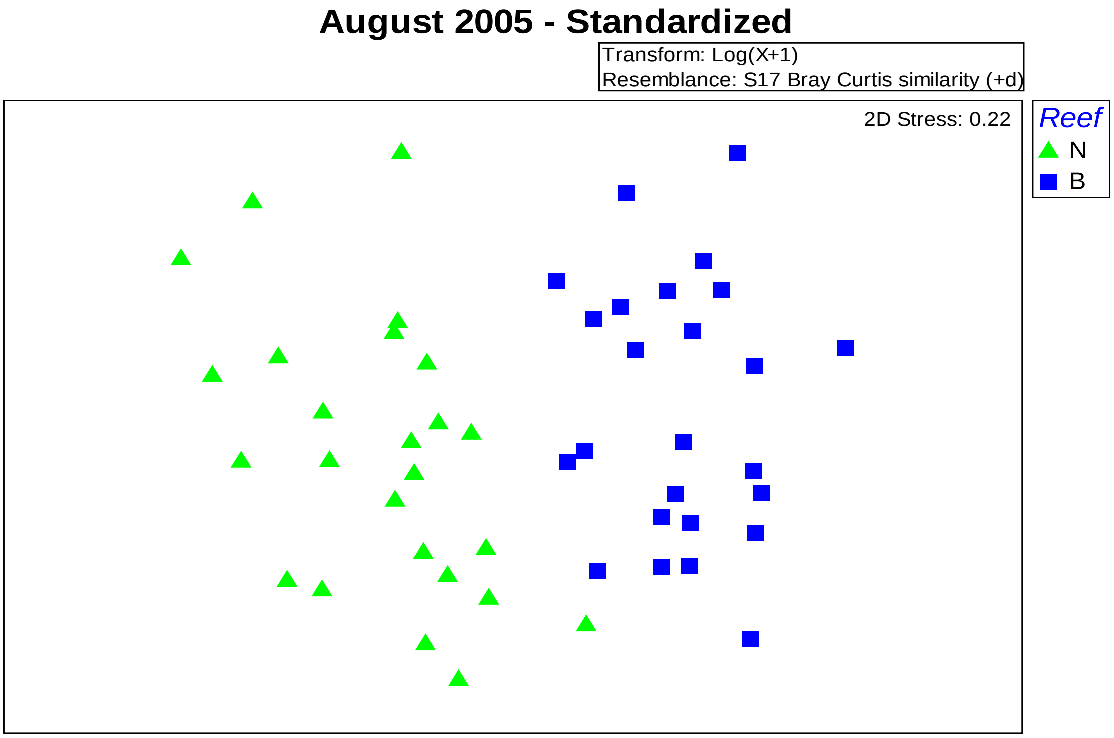


Figure 20. MDS plot (August 2005) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) standardized for rugosity.

± 9.2 (Figure 21) and mean number of species (richness) was 8.2 ± 1.1 (Figure 22). Juvenile haemulids accounted for 20.6% of total fish abundance. On the boulder reef a total of 1,510 fishes comprising 63 species were recorded. Juvenile and small cryptic species (≤5 cm TL) accounted for 60.5% of total fish abundance. Mean abundance ± SEM was 60.4 ± 6.17 (Figure 21) and mean species richness was 16.6 ± 0.8 (Figure 22). Juvenile haemulids accounted for 21.0% of total fish abundance. Both mean abundance and mean species richness were significantly greater on the mitigation boulders compared to the natural reefs (p<0.05, p<0.0002; respectively).

If rugosity is taken into account, both mean abundance and mean species richness remains significantly greater on the 30 m mitigation boulder transects compared to the

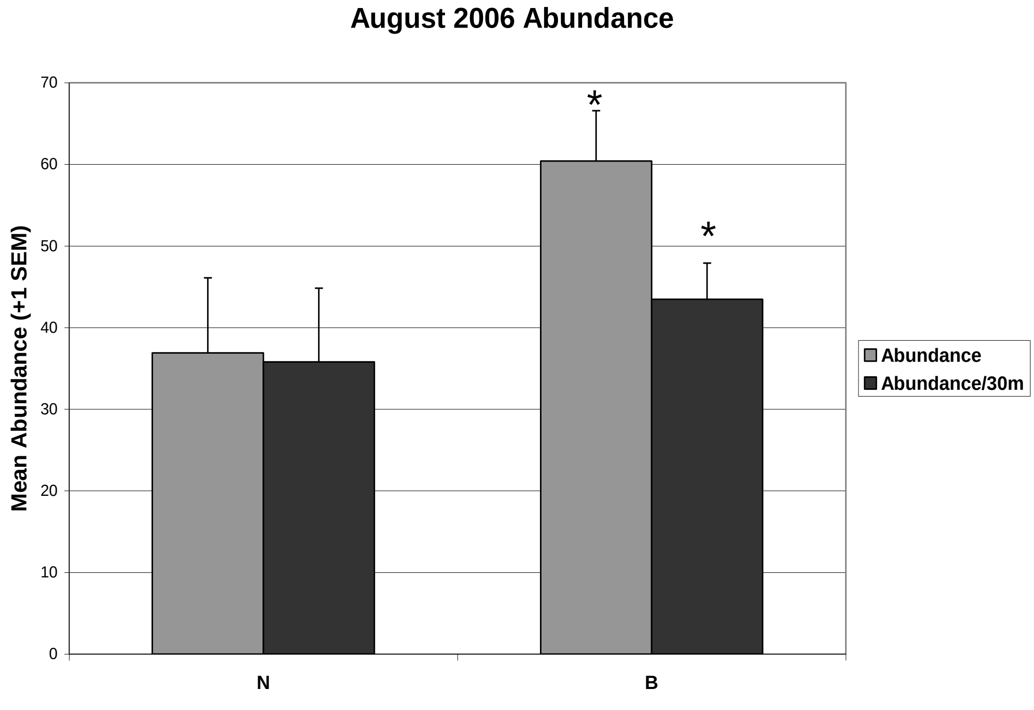


Figure 21. Mean abundance of fishes (August 2006) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization. The asterisks indicate significant differences (p<0.05: ANOVA; SNK) in abundance between bars of the same color.

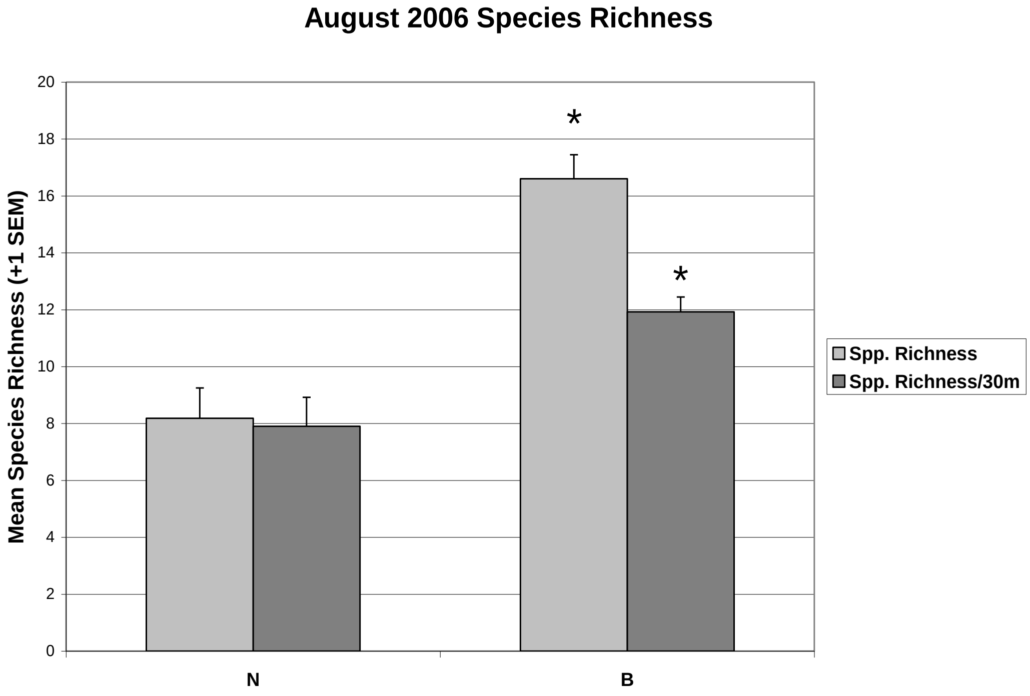


Figure 22. Mean species richness of fishes (August 2006) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization. The asterisks indicate significant differences ($p<0.05$: ANOVA; SNK) in species richness between bars of the same color.

natural hardbottom transects (Mean ± SEM: 43.5 ± 4.4 versus 35.8 ± 9.0, $p<0.006$; 11.9 ± 0.5 versus 7.9 ± 1.0, $p<0.002$; respectively) (Figures 21 & 22).

SIMPER analysis of dissimilarity indicated the two assemblages had an average 78% dissimilarity (Table 5). Fishes from family Haemulidae contributed the first 20% to the dissimilarity (*Haemulon flavolineatum*, 7.0%; *Haemulon* spp., 6.4%; *Anisotremus virginicus*, 6.4%). An MDS plot of Bray-Curtis similarity indices showed a clear distinction between the natural hardbottom and mitigation boulder assemblages. It also showed a second cluster within the natural hardbottom assemblage, noting specific sites that had been partially to mostly buried by sand (Figure 23). Re-running the MDS plot analysis to take rugosity into effect produced similar results (Figure 24).

Table 5. SIMPER analysis of dissimilarity showing the percent contribution of each species for August 2006 between the natural hardbottom (N) and the mitigation boulders (B). The average dissimilarity was 78.46%.

Species	Group N Av.Abund	Group B Av.Abund	Contrib%	Cum.%
Haemulon flavolineatum	0.07	1.51	6.98	6.98
Haemulon spp.	0.75	1.24	6.43	13.41
Anisotremus virginicus	0.08	1.43	6.38	19.79
Halichoeres bivittatus	1.17	1.67	5.60	25.39
Thalassoma bifasciatum	0.10	1.18	5.10	30.50
Abudefduf saxatilis	0.24	0.85	4.14	34.64
Haemulon plumierii	0.39	0.90	4.01	38.65
Stegastes variabilis	0.60	0.98	3.96	42.60
Lutjanus synagris	1.01	0.84	3.83	46.44
Stegastes leucostictus	0.48	0.84	3.80	50.24
Haemulon aurolineatum	0.31	0.67	3.65	53.88

Twenty-five rover diver counts were conducted on natural hardbottom and 25 rover diver counts were conducted on mitigation boulders. Natural hardbottom yielded 80 species from 32 families. Mitigation boulders yielded 114 species from 39 families.

3.1.6 August 2007

Twenty-five transect counts were conducted on natural hardbottom and 25 transect counts were conducted on mitigation boulders. Natural hardbottom transect counts yielded a total of 2,374 fishes of 60 species. Juvenile and small cryptic species (≤5 cm TL) accounted for 89.3% of total fish abundance. Mean abundance ± SEM was 95.0 ± 24.2 (Figure 25) and mean number of species (richness) was 11.8 ± 1.3 (Figure 26). Juvenile haemulids accounted for 55.2% of total fish abundance. On boulder reef a total of 4,314 fishes comprising 68 species were recorded. Juvenile and small cryptic species (≤5 cm TL) accounted for 70.8% of total fish abundance. Mean abundance ± SEM was 172.6 ± 115.2 (Figure 25) and mean species richness was 16.9 ± 0.7 (Figure 26). Juvenile

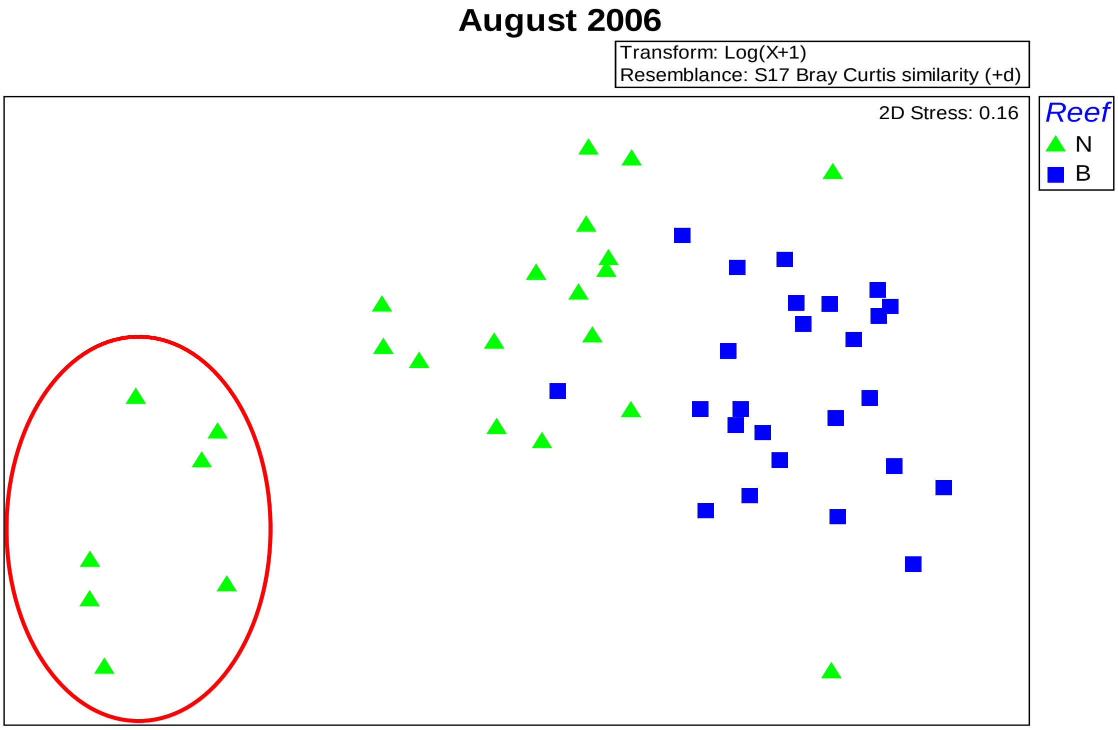


Figure 23. MDS plot (August 2006) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) not standardized for rugosity. The oval indicates a second cluster within the natural hardbottom.

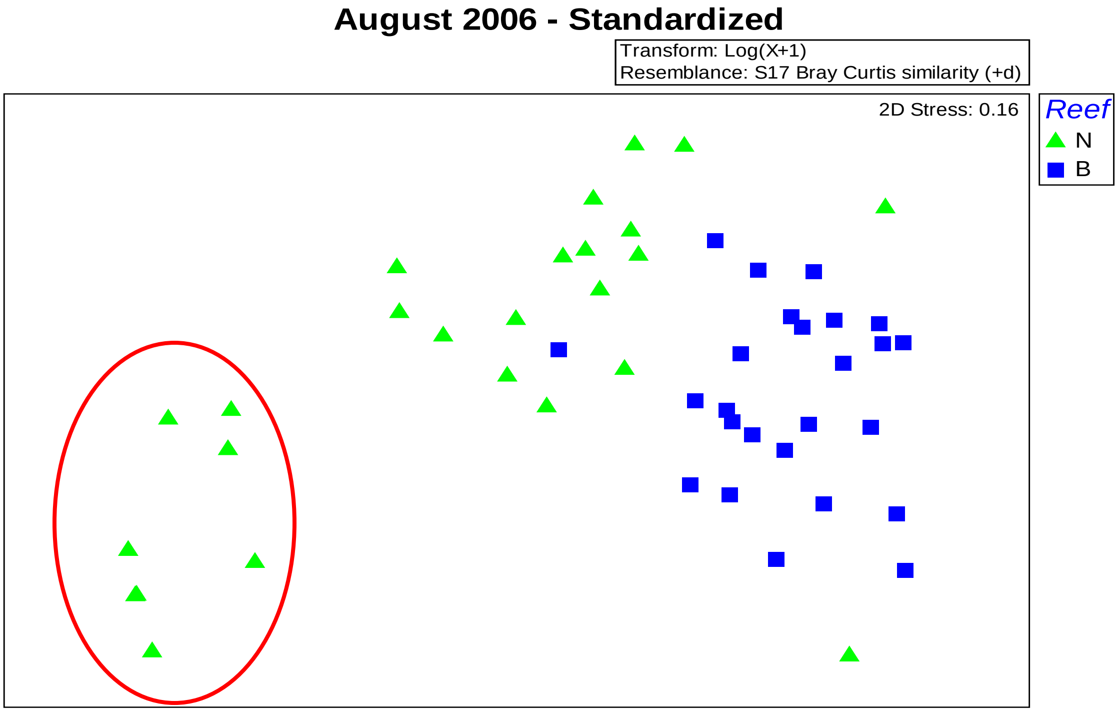


Figure 24. MDS plot (August 2006) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) standardized for rugosity. The oval indicates a second cluster within the natural hardbottom.

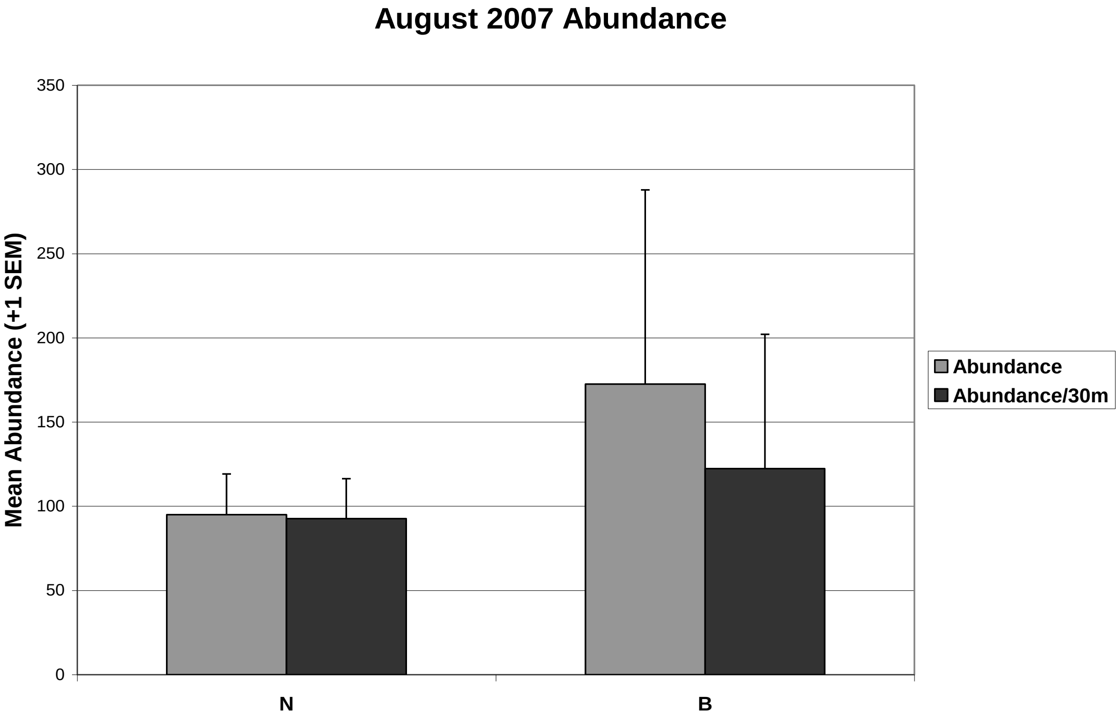


Figure 25. Mean abundance of fishes (August 2007) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization.

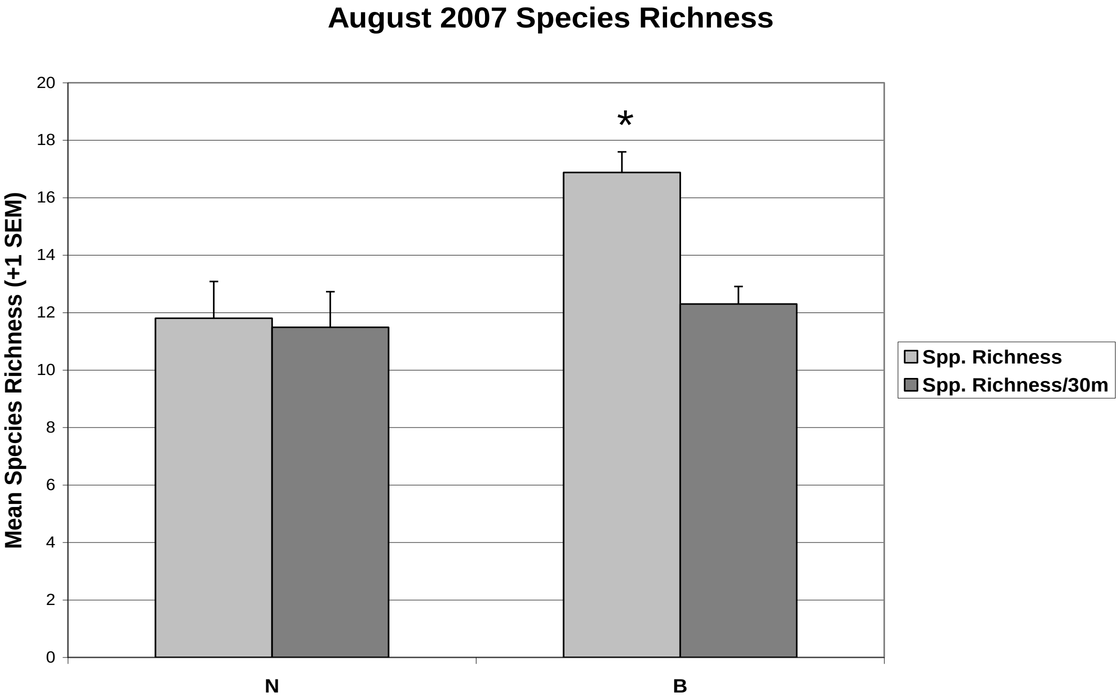


Figure 26. Mean species richness of fishes (August 2007) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization. The asterisk indicates a significant difference ($p<0.05$: ANOVA; SNK) in species richness between bars of the same color.

haemulids accounted for 48.6% of total fish abundance. Mean abundance was not significantly different ($p>0.05$), while mean species richness was significantly greater on the mitigation boulders compared to the natural reef ($p<0.002$). Due to high abundances and high variation of juvenile haemulids during this survey, a second analysis was performed after removing haemulids <5 cm TL. Abundance values became significantly different (42.6 ± 5.6 on the natural reef vs. 88.7 ± 35.5 on the boulder reef; $p<0.03$), while standardizing the data for rugosity showed no significant difference among abundance values ($p>0.05$) (Figure 27).

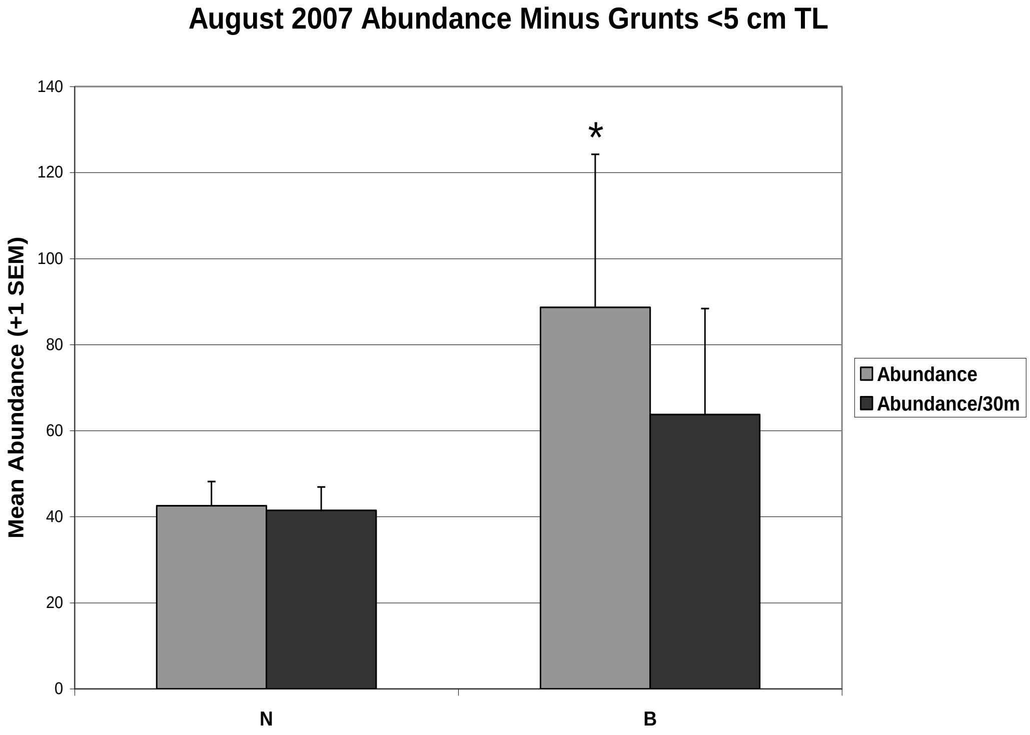


Figure 27. Mean abundance of fishes (August 2007) minus grunts <5 cm TL on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization. The asterisk indicates a significant difference ($p<0.05$: ANOVA; SNK) in abundance between bars of the same color.

If rugosity is taken into account, mean species richness is no longer significantly different on the 30 m transects at the boulder reef compared to the natural hardbottom

(12.3 ± 0.6 versus 11.5 ± 1.2, p>0.05; respectively) (Figure 26). Mean abundance remains not significantly different at the mitigation boulders compared to the natural hardbottom (122.4 ± 79.8 versus 92.6 ± 23.7, p>0.05; respectively) (Figure 25).

SIMPER analysis of dissimilarity indicated the two assemblages had an average 77% dissimilarity (Table 6). Juvenile *Haemulon* spp. and *Thalassoma bifasciatum* (bluehead wrasse) each contributed about 7% to the dissimilarity. MDS plot of Bray-Curtis similarity indices showed a clear distinction between boulder and hardbottom assemblages. A second cluster is also seen on the natural hardbottom, indicating sites that had been partially to mostly covered by sand (Figure 28). Re-running the MDS plot analysis to take rugosity into effect produced similar results (Figure 29).

Table 6. SIMPER analysis of dissimilarity showing the percent contribution of each species for August 2007 between the natural hardbottom (N) and the mitigation boulders (B). The average dissimilarity was 77.03%.

Species	Group N Av.Abund	Group B Av.Abund	Contrib%	Cum.%
Haemulon spp.	2.23	0.81	7.26	7.26
Thalassoma bifasciatum	0.49	2.03	6.72	13.97
Halichoeres bivittatus	2.19	1.41	4.97	18.94
Haemulon flavolineatum	0.28	1.42	4.87	23.81
Acanthurus bahianus	0.36	1.18	4.41	28.22
Anisotremus virginicus	0.14	1.03	3.76	31.98
Gerres cinereus	0.03	0.88	3.51	35.49
Acanthurus chirurgus	0.44	0.92	3.34	38.83
Haemulon aurolineatum	0.25	0.89	3.10	41.94
Lutjanus synagris	0.72	0.47	2.98	44.92
Acanthurus coeruleus	0.08	0.75	2.91	47.83
Malacoctenus macropus	0.91	0.06	2.83	50.66

Twenty-five rover diver counts were conducted on natural hardbottom and 25 rover diver counts were conducted on mitigation boulders. Natural hardbottom yielded 100 species from 37 families. Mitigation boulders yielded 104 species from 38 families.

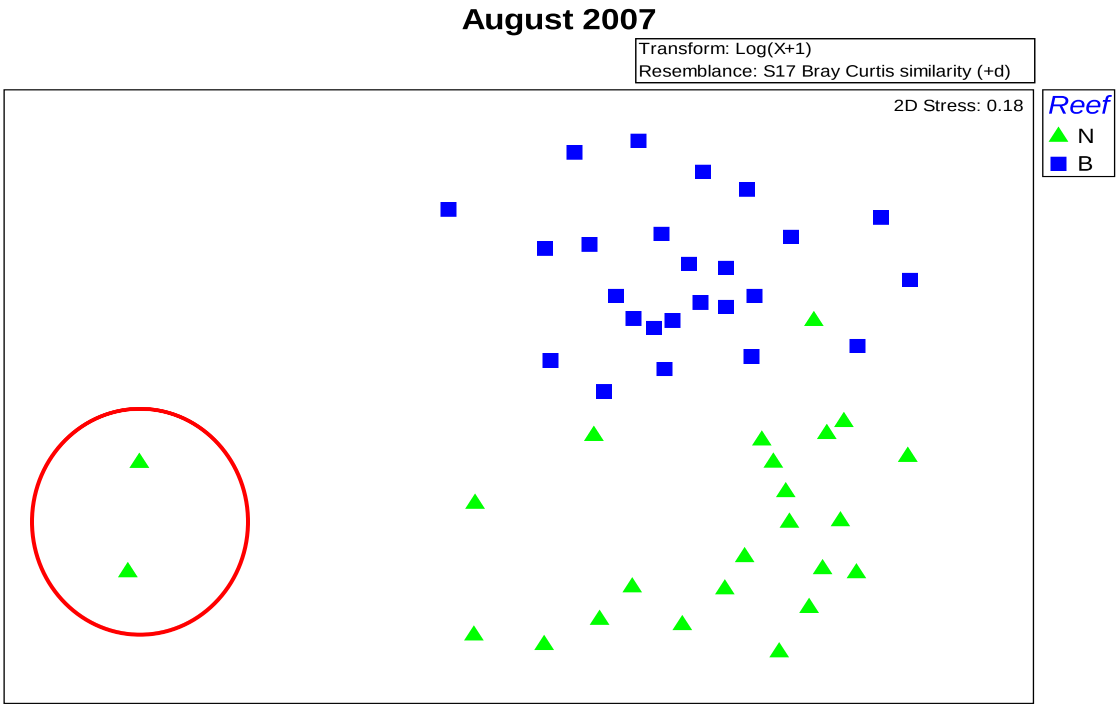


Figure 28. MDS plot (August 2007) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) not standardized for rugosity. The circle indicates a second cluster within the natural hardbottom.

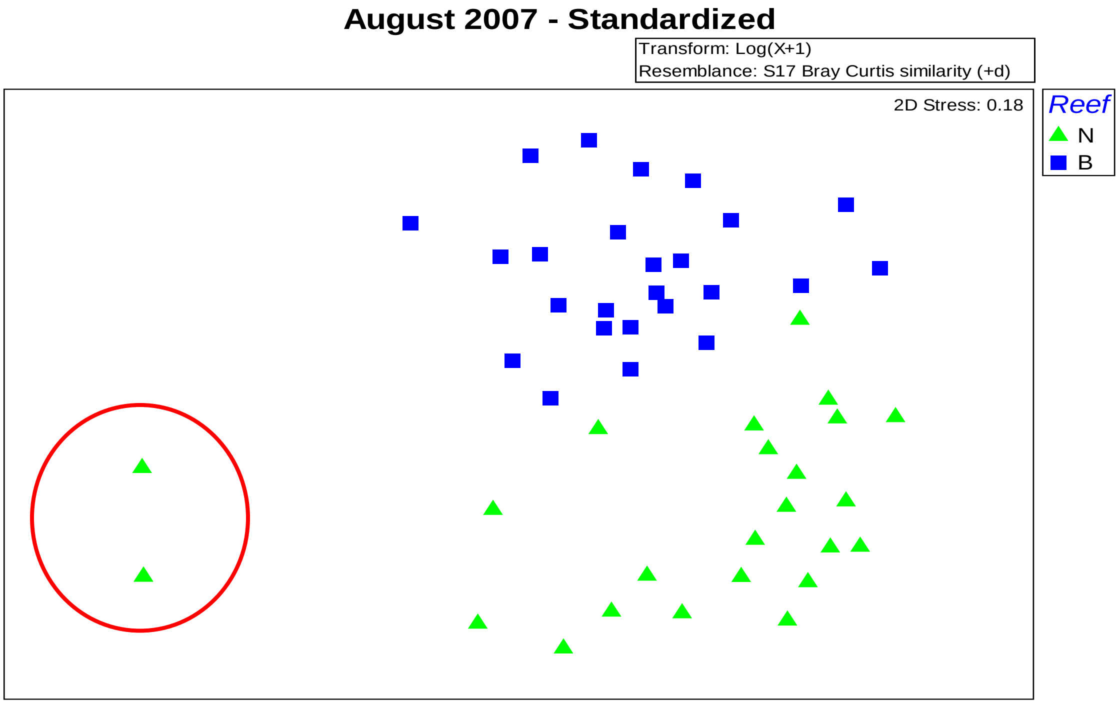


Figure 29. MDS plot (August 2007) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) standardized for rugosity. The circle indicates a second cluster within the natural hardbottom.

3.1.7 Across All Surveys

A total of 150 transect counts and 150 rover diver counts were conducted on nearshore natural hardbottom, and 150 transect counts and 150 rover diver counts were conducted on mitigation boulders. A total of 7,117 fishes were counted on natural transects (77.8% juveniles), and 11,769 fishes were counted on boulder transects (53.5% juveniles). On natural hardbottom mean abundance ± SEM was 47.4 ± 5.3 (Figure 30) and mean number of species (richness) was 8.9 ± 4.8 (Figure 31). Juvenile haemulids accounted for 39.7% of total fish abundance. On boulder reef mean abundance ± SEM was 78.5 ± 19.5 (Figure 30) and mean species richness was 15.9 ± 4.8 (Figure 31). Juvenile haemulids accounted for 30.0% of total fish abundance. Both mean abundance and mean species richness were significantly greater on the mitigation boulders compared to the natural reef (p<0.00001, p<0.00001; respectively).

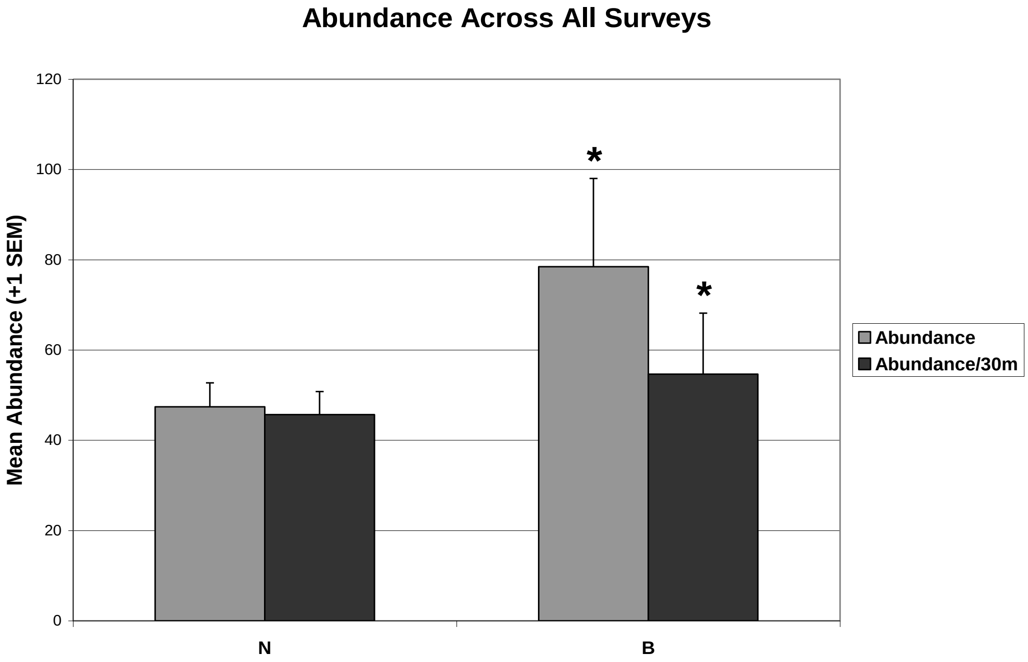


Figure 30. Mean abundance of fishes (across all surveys) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization. The asterisks indicate significant differences (p<0.05: ANOVA; SNK) in abundance between bars of the same color.

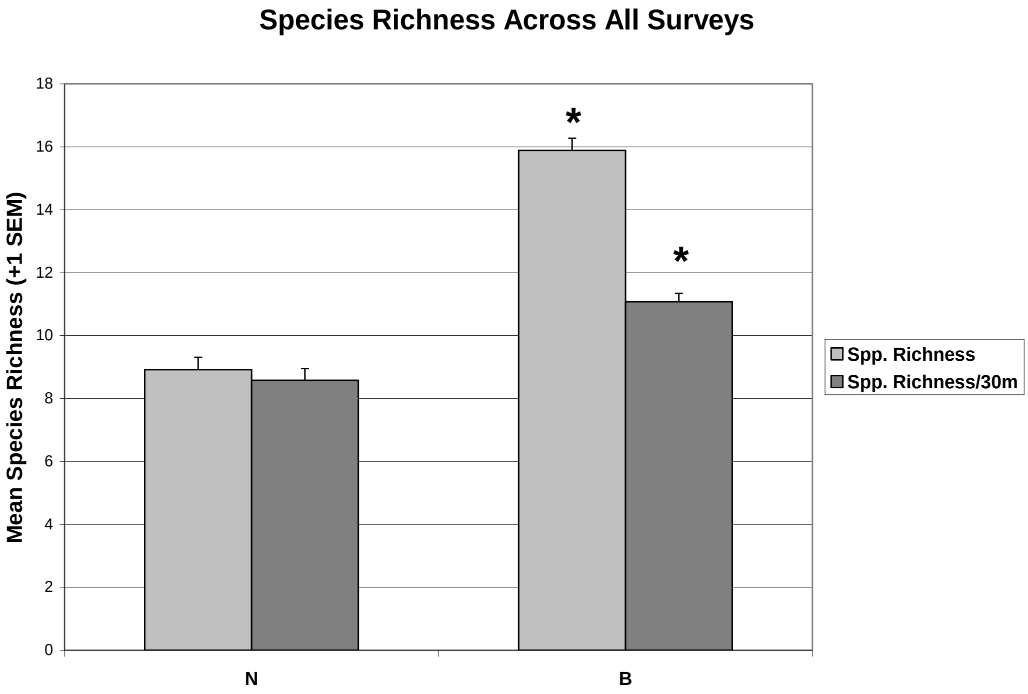


Figure 31. Mean species richness of fishes (across all surveys) on the natural hardbottom (N) versus the mitigation boulders (B) without and with rugosity standardization. The asterisks indicate significant differences ($p<0.05$: ANOVA; SNK) in species richness between bars of the same color.

If rugosity is taken into account, both mean abundance and mean species richness remain significantly different on the 30 m transects at the boulder reef compared to the natural hardbottom (Mean ± SEM: 54.6 ± 13.5 versus 45.7 ± 5.1, $p>0.02$; 11.1 ± 3.2 versus 8.6 ± 4.6, $p>0.00001$; respectively) (Figures 30 & 31).

SIMPER analysis of dissimilarity indicated the two assemblages had an average 77% dissimilarity (Table 7). Juvenile *Haemulon* spp. contributed over 6% to the dissimilarity, while *Anisotremus virginicus* (porkfish) contributed over 5%. An MDS plot of Bray-Curtis similarity indices showed a clear distinction between boulder and hardbottom assemblages. (Figure 32). Re-running the MDS plot analysis to take rugosity into effect produced similar results (Figure 33).

Table 7. SIMPER analysis of dissimilarity showing the percent contribution of each species across all surveys between the natural hardbottom (N) and the mitigation boulders (B). The average dissimilarity was 77.02%.

Species	Group N Av.Abund	Group B Av.Abund	Contrib%	Cum.%
Haemulon spp.	1.35	1.01	6.61	6.61
Anisotremus virginicus	0.13	1.15	5.28	11.89
Halichoeres bivittatus	1.59	1.37	4.80	16.69
Haemulon aurolineatum	0.32	1.15	4.79	21.48
Thalassoma bifasciatum	0.22	1.20	4.75	26.23
Acanthurus bahianus	0.19	1.00	4.55	30.78
Lutjanus synagris	0.84	0.69	3.98	34.76
Haemulon plumierii	0.23	0.86	3.78	38.54
Haemulon flavolineatum	0.13	0.83	3.51	42.05
Stegastes variabilis	0.68	0.75	3.17	45.23
Abudefduf saxatilis	0.30	0.60	3.11	48.33
Acanthurus chirurgus	0.37	0.60	3.06	51.39

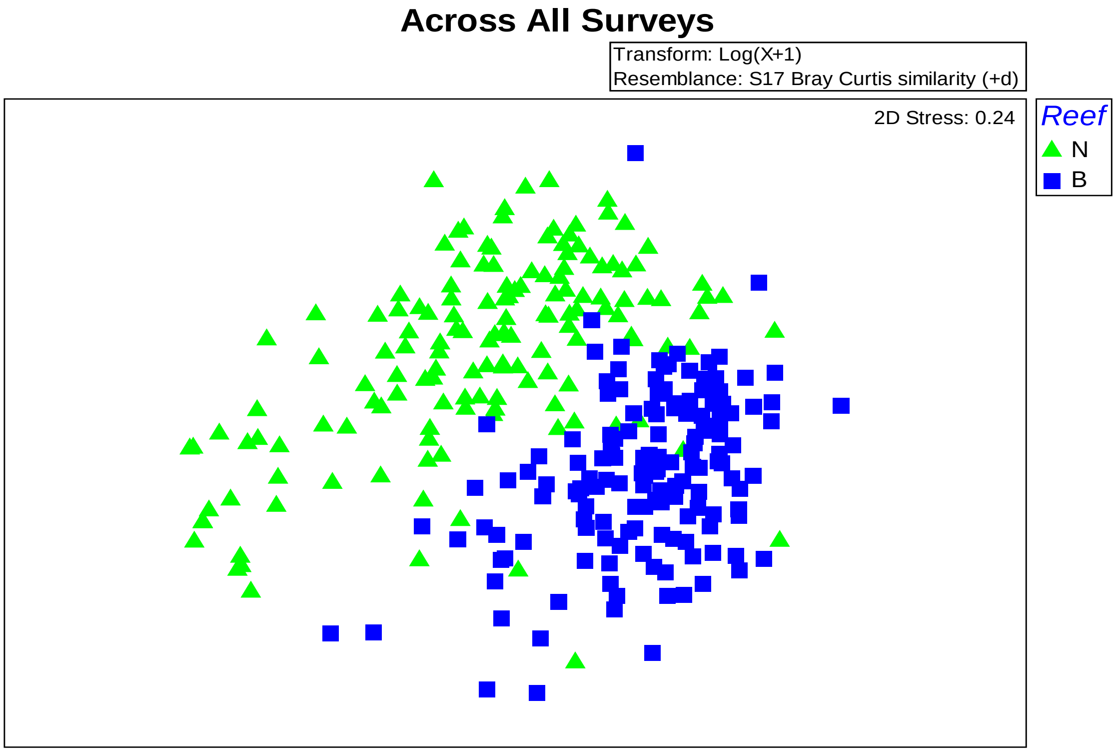


Figure 32. MDS plot (across all surveys) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) not standardized for rugosity.

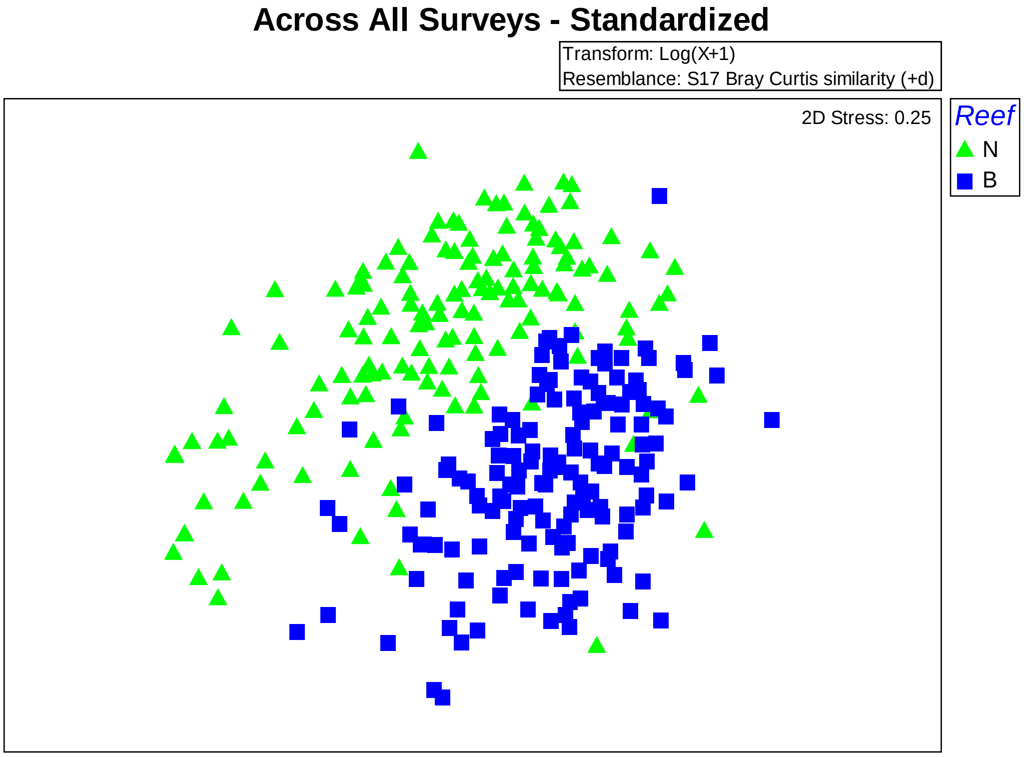


Figure 33. MDS plot (across all surveys) of Bray-Curtis similarity indices for the natural hardbottom (N) and the mitigation boulders (B) standardized for rugosity.

A total of 200 species were counted overall on rover diver surveys, 152 on the natural reef and 143 on the boulder reef. Additionally, 139 species were counted overall on transect surveys, 96 on the natural reef and 119 on the boulder reef. Grouped together, 271 different species were seen on all surveys.

Trophic assemblages were assigned to each species on both natural hardbottom and mitigation boulder transects (Appendix D). Natural hardbottom transects contained equal numbers of planktivores (primarily juvenile *Haemulon* spp.) and benthic carnivores (40%). Mitigation boulder transects had a higher percentage of benthic carnivores (47%) and contained only 31% planktivores. Herbivores (7% and 8%, respectively) and omnivores (11% and 9%, respectively) were present in similar abundances on natural hardbottom and mitigation boulder transects, while piscivores were present in larger numbers on boulder reef compared to natural hardbottom (5% vs. 2%, $p>0.05$; respectively) (Figure 34).

3.2 Temporal Variation

3.2.1 Seasonal Variation

Abundance values on natural hardbottom and boulder transects were analyzed across all years and compared by month. Multivariate examination of assemblage structure (MDS plot of Bray-Curtis similarity indices) showed a difference between March natural hardbottom transects, which form a distinct cluster, when compared to June and August natural hardbottom transects. June and August transects show some overlapping, but are not distinct (Figure 35). A similar picture emerges when comparing mitigation boulder transects by month. March transects again form a distinct cluster when compared to June and August mitigation boulder transects. There also appears to be more overlapping between June and August clusters when compared to the natural hardbottom MDS plot (Figure 36).

3.2.2 Yearly Colonization

Fish assemblage structures for August 2004-2007 data were compared. To observe yearly change on the natural reef, fish assemblages on August natural hardbottom transects were compared on a year-to-year basis. An MDS plot of Bray-Curtis similarity indices showed no distinct differences between sites across all years (Figure 37). SIMPER analysis showed low levels of similarities between the replicates themselves (Aug. 04 – 43%, Aug. 05 – 34%, Aug. 06 – 21%, and Aug. 07 – 29%), so further analysis was done using analysis of similarities (ANOSIM). Between August 2004 and August 2005, SIMPER analysis showed 66.8% dissimilarity (Table 8). Juvenile

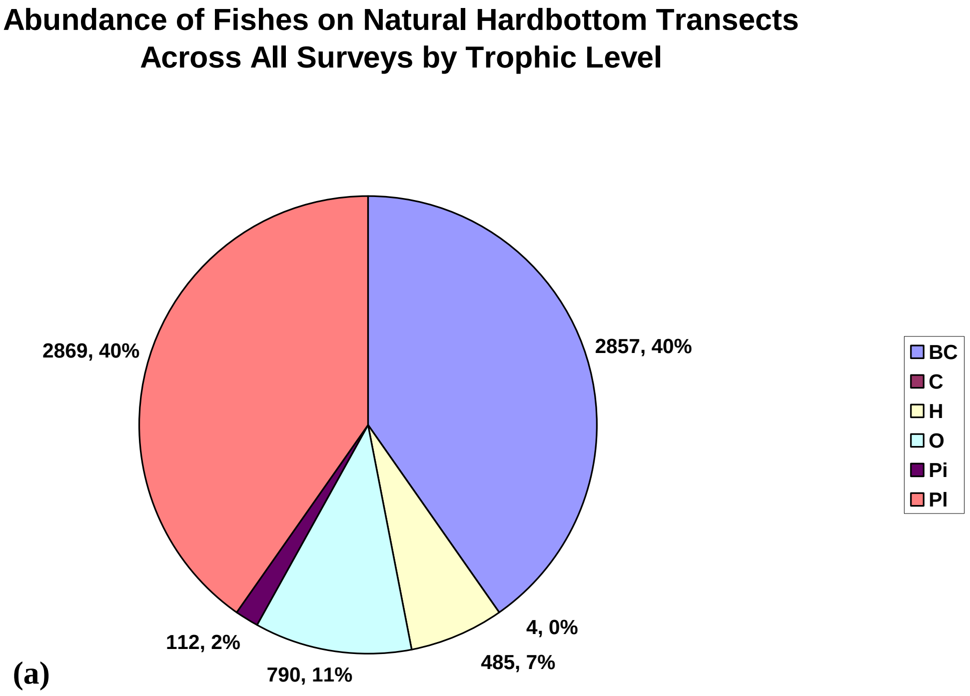
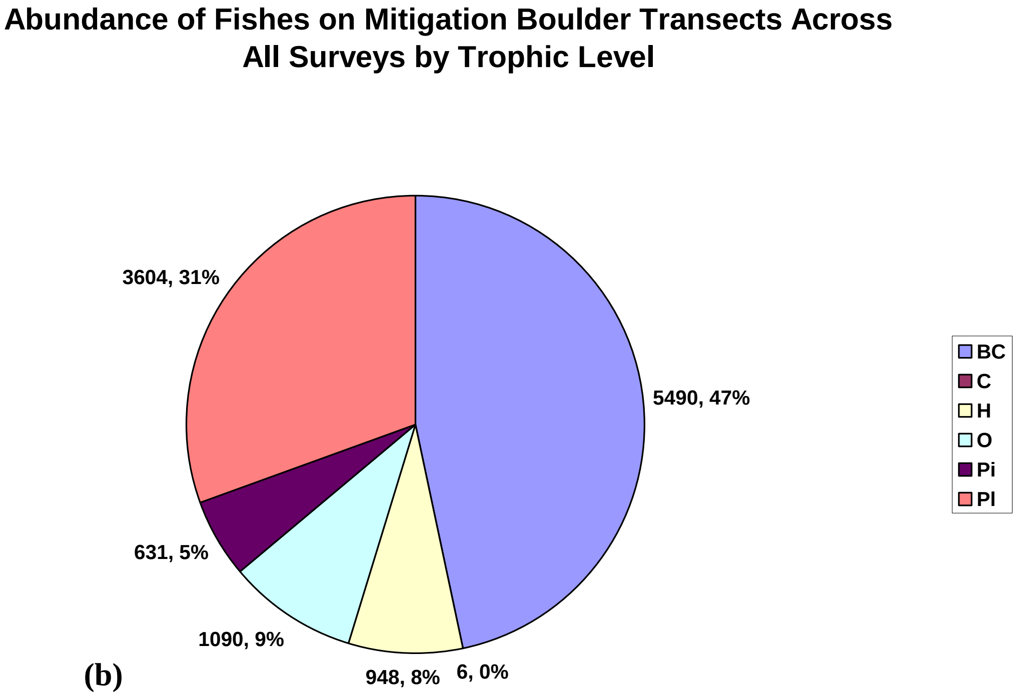


Figure 34. Abundance of fishes on natural hardbottom (a) and mitigation boulder (b) transects across all surveys by trophic level. BC=benthic carnivore, C=cleaner, H=herbivore, O=omnivore, Pi=piscivore, and Pl=planktivore.



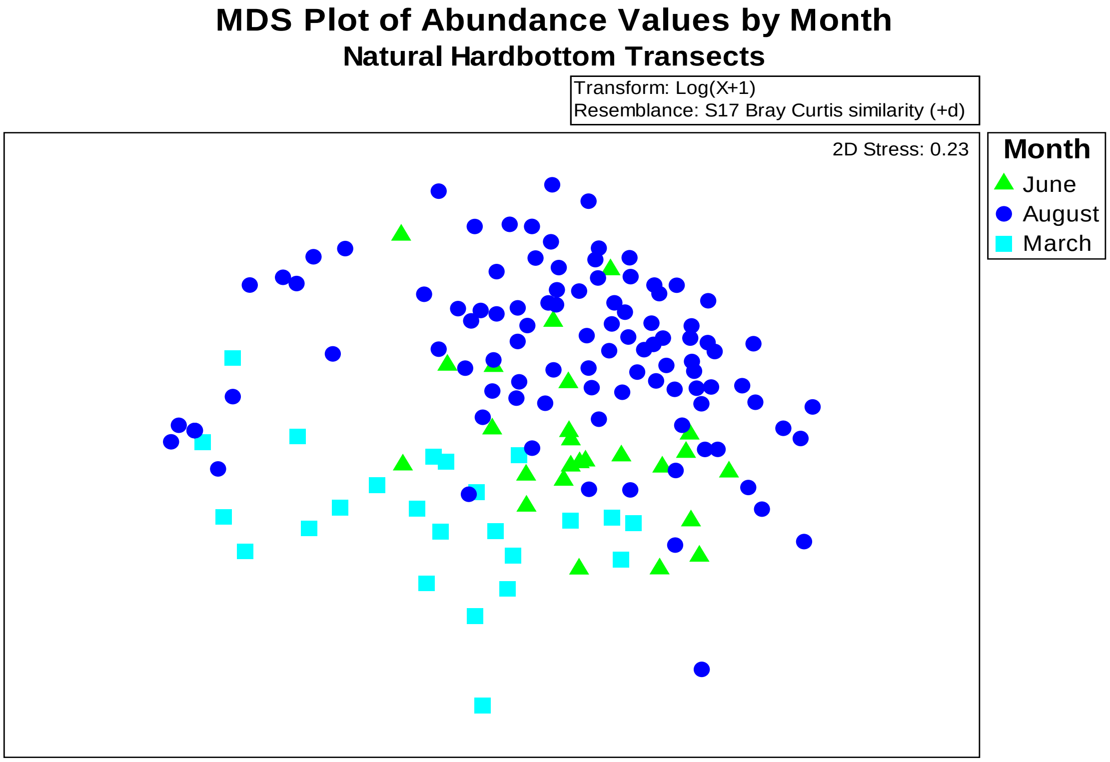


Figure 35. MDS plot of abundance values by month on natural hardbottom transects.

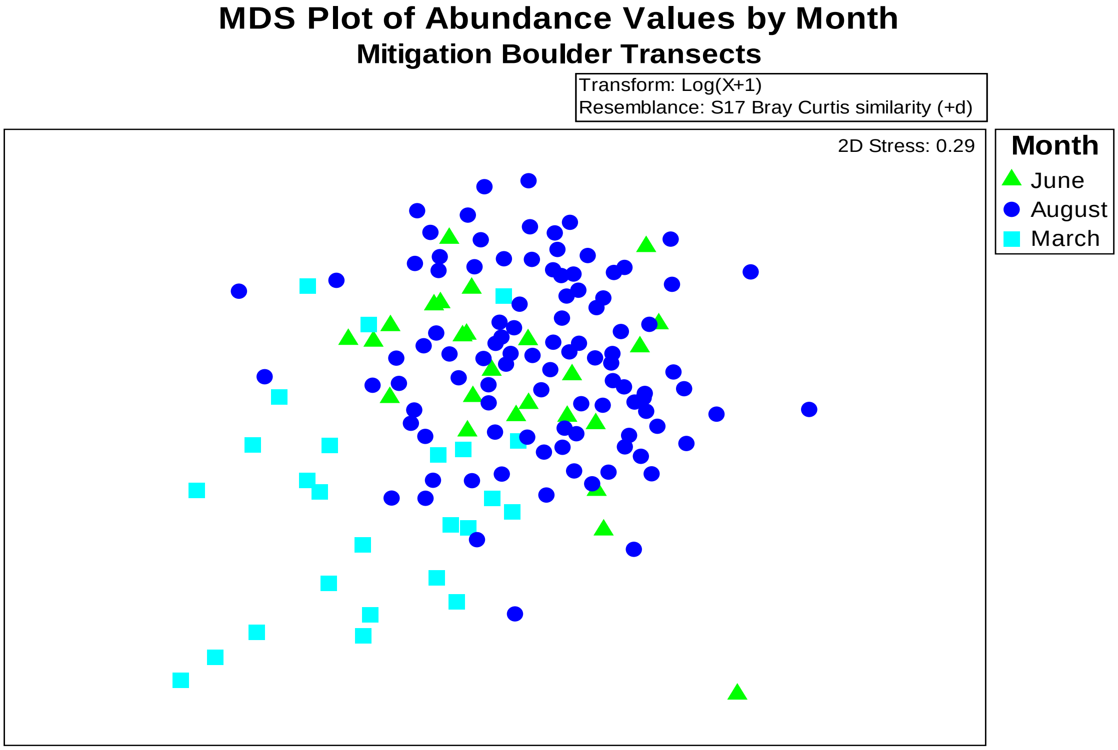


Figure 36. MDS plot of abundance values by month on mitigation boulder transects.

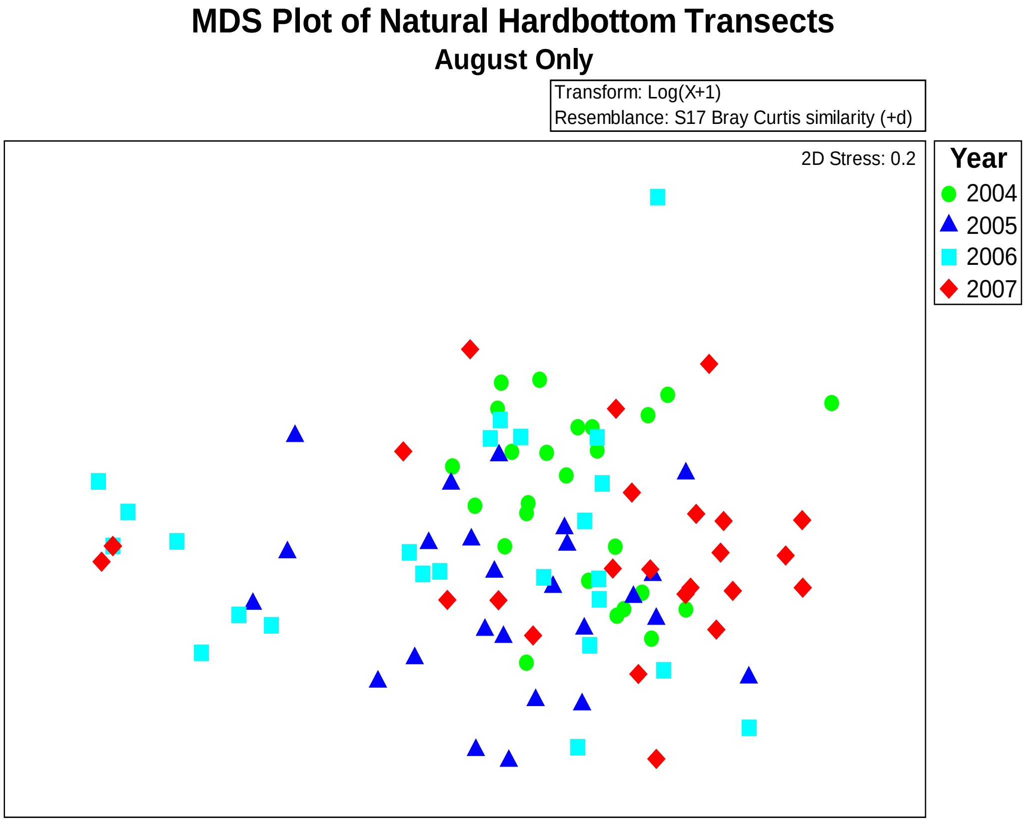


Figure 37. MDS plot of natural hardbottom transects by year, August only.

Haemulon spp., *Halichoeres bivittatus* (slippery dick), and *Lutjanus synagris* (lane snapper) contributed almost 25% to the total dissimilarity (9.5%, 8.5%, and 6.0%, respectively). ANOSIM analysis showed an R-value of 0.253 between these two years, indicating that these two assemblages were barely distinguishable from one another. SIMPER analysis showed 76.0% dissimilarity on the natural hardbottom between August 2005 and August 2006 (Table 8). Again, ANOSIM showed a very low R-value (0.159), meaning that the assemblages between these two years were barely distinguishable or separable from one another. Three groups or species each contributed about 10% to the dissimilarity: Juvenile *Haemulon* spp. (10.9%); *Lutjanus synagris* (9.1%); and *Halichoeres bivittatus* (8.3%). From August 2006 to August 2007, natural hardbottom assemblages remained similar to one another (ANOSIM R=0.148), with SIMPER

Table 8. SIMPER analysis of dissimilarity showing species contributing the top fifty percent to the dissimilarity between August 2004, 2005, 2006, and 2007 on the natural hardbottom (N).

Groups Aug 04 N & Aug 05 N Average dissimilarity = 66.76%

Species	**Group Aug 04 N Av.Abund**	**Group Aug 05 N Av.Abund**	**Contrib%**	**Cum.%**
Haemulon spp.	1.04	1.61	9.48	9.48
Halichoeres bivittatus	2.31	1.10	8.51	17.99
Lutjanus synagris	1.47	1.54	6.02	24.01
Stegastes variabilis	1.20	0.48	5.97	29.98
Diplectrum formosum	1.07	0.56	5.41	35.39
Haemulon aurolineatum	0.92	0.03	5.19	40.57
Sparisoma radians	0.91	0.52	4.98	45.55
Stegastes leucostictus	0.71	0.28	3.82	49.37

Groups Aug 05 N & Aug 06 N Average dissimilarity = 76.01%

Species	**Group Aug 05 N Av.Abund**	**Group Aug 06 N Av.Abund**	**Contrib%**	**Cum.%**
Haemulon spp.	1.61	0.75	10.90	10.90
Lutjanus synagris	1.54	1.01	9.13	20.03
Halichoeres bivittatus	1.10	1.17	8.33	28.36
Diplectrum formosum	0.56	0.15	4.71	33.07
Ocyurus chrysurus	0.68	0.10	4.64	37.71
Stegastes variabilis	0.48	0.60	4.53	42.23
Sparisoma radians	0.52	0.25	4.07	46.30
Stegastes leucostictus	0.28	0.48	3.68	49.98

Groups Aug 06 N & Aug 07 N Average dissimilarity = 78.92%

Species	**Group Aug 06 N Av.Abund**	**Group Aug 07 N Av.Abund**	**Contrib%**	**Cum.%**
Haemulon spp.	0.75	2.23	10.31	10.31
Halichoeres bivittatus	1.17	2.19	9.55	19.86
Lutjanus synagris	1.01	0.72	7.17	27.02
Malacoctenus macropus	0.25	0.91	4.28	31.30
Coryphopterus glaucofraenum	0.40	0.76	4.11	35.40
Sparisoma radians	0.25	0.68	4.01	39.41
Stegastes variabilis	0.60	0.60	3.77	43.18
Stegastes leucostictus	0.48	0.55	3.71	46.90
Abudefduf saxatilis	0.24	0.43	2.86	49.75

analysis showing 78.9% dissimilarity (Table 8). Juvenile *Haemulon* spp. contributed most to the dissimilarity (10.3%).

To observe yearly colonization on the boulders, fish assemblages on August boulder transects were compared on a year-to-year basis. Multivariate examination of assemblage structure (MDS plot of Bray-Curtis similarity indices) showed a slight distinction of August 2004 transects. However, no additional distinctions could be made across other years (Figure 38). SIMPER analysis showed low levels of similarities between the replicates themselves (Aug. 04 – 51%, Aug. 05 – 40%, Aug. 06 – 44%, and Aug. 07 – 41%), so further analysis was done using analysis of similarities (ANOSIM). Between August 2004 and August 2005, SIMPER analysis showed 60.7% dissimilarity (Table 9). *Haemulon aurolineatum* (tomtate), *Haemulon* spp. (juvenile grunts), and

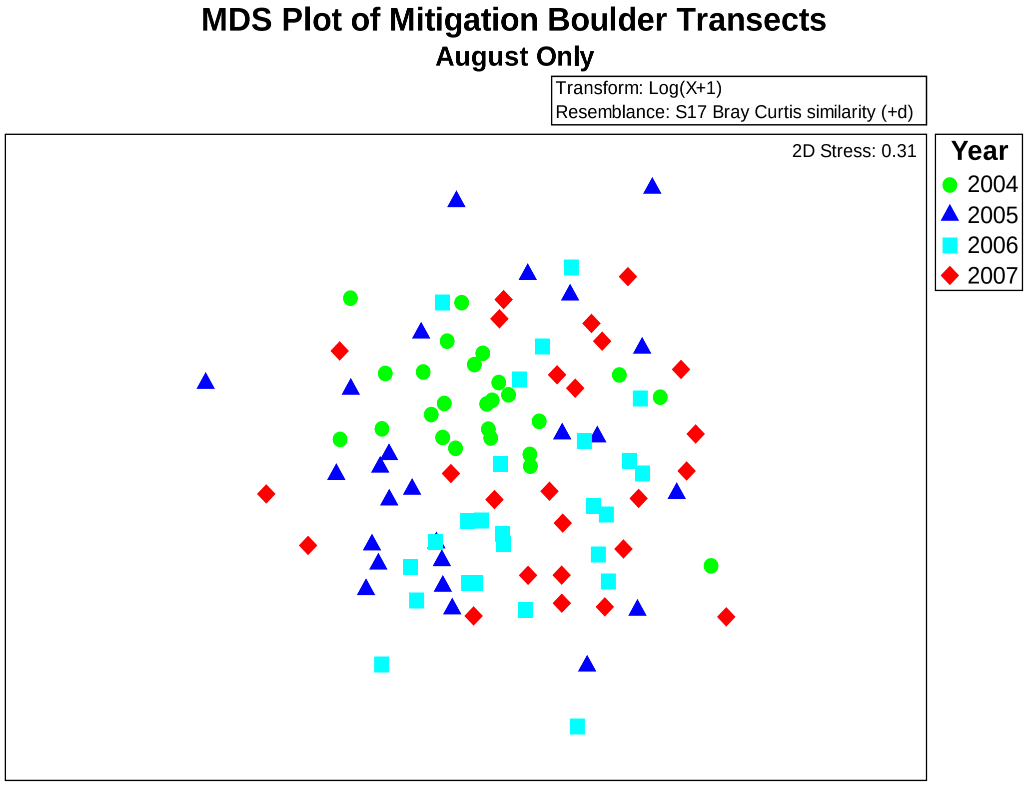


Figure 38. MDS plot of mitigation boulder transects by year, August only.

Table 9. SIMPER analysis of dissimilarity showing species contributing the top forty percent to the dissimilarity between August 2004, 2005, 2006, and 2007 on the mitigation boulders (B).

Groups Aug 04 B & Aug 05 B Average dissimilarity = 60.72%

Species	Group Aug 04 B Av.Abund	Group Aug 05 B Av.Abund	Contrib%	Cum.%
Haemulon aurolineatum	2.39	1.24	7.35	7.35
Haemulon spp.	0.86	1.79	7.27	14.62
Carangoides ruber	1.83	0.15	7.00	21.62
Acanthurus bahianus	1.24	0.79	3.84	25.46
Thalassoma bifasciatum	1.38	0.84	3.83	29.29
Haemulon flavolineatum	0.85	0.76	3.67	32.97
Halichoeres bivittatus	1.94	1.24	3.67	36.64
Acanthurus chirurgus	0.51	0.84	3.40	40.04

Groups Aug 05 B & Aug 06 B Average dissimilarity = 61.50%

Species	Group Aug 05 B Av.Abund	Group Aug 06 B Av.Abund	Contrib%	Cum.%
Haemulon spp.	1.79	1.24	8.27	8.27
Haemulon aurolineatum	1.24	0.67	5.83	14.10
Haemulon flavolineatum	0.76	1.51	5.18	19.28
Thalassoma bifasciatum	0.84	1.18	4.08	23.36
Halichoeres bivittatus	1.24	1.67	4.00	27.36
Acanthurus bahianus	0.79	0.85	3.88	31.24
Abudefduf saxatilis	0.23	0.85	3.72	34.96
Acanthurus chirurgus	0.84	0.34	3.61	38.57
Stegastes variabilis	0.62	0.98	3.26	41.83

Groups Aug 06 B & Aug 07 B Average dissimilarity = 60.70%

Species	Group Aug 06 B Av.Abund	Group Aug 07 B Av.Abund	Contrib%	Cum.%
Haemulon spp.	1.24	0.81	6.00	6.00
Haemulon flavolineatum	1.51	1.42	4.75	10.75
Thalassoma bifasciatum	1.18	2.03	4.50	15.25
Haemulon aurolineatum	0.67	0.89	4.40	19.65
Acanthurus bahianus	0.85	1.18	4.20	23.85
Halichoeres bivittatus	1.67	1.41	4.00	27.85
Gerres cinereus	0.29	0.88	3.72	31.58
Haemulon plumierii	0.90	0.62	3.53	35.11
Abudefduf saxatilis	0.85	0.42	3.52	38.63
Acanthurus chirurgus	0.34	0.92	3.37	42.00

Carangoides ruber (bar jack) contributed over 20% to the total dissimilarity (7.3%, 7.2%, and 7.0%, respectively). ANOSIM analysis showed an R-value of 0.317 between these two years. This value indicates that the two assemblages overlapped yet were still different from one another. In August 2005 a pulse of *Haemulon* spp. occurred, which comprised almost 40% of the total fish population seen on the boulder reef. SIMPER analysis showed 61.5% dissimilarity on boulders between August 2005 and 2006 (Table 9). Interestingly, ANOSIM analysis showed an R-value of 0.184, meaning that assemblages between these two years were barely distinguishable or separable from each other. Fishes from family Haemulidae contributed almost 20% to the dissimilarity between these two years: *Haemulon* spp. (8.2%), *Haemulon aurolineatum* (5.8%), and *Haemulon flavolineatum* (5.1%). From August 2006 to August 2007, boulder assemblages remained similar to one another (ANOSIM R=0.187), with SIMPER analysis showing 60.7% dissimilarity (Table 9). Juvenile *Haemulon* spp. contributed most to the dissimilarity (6.0%).

Further analysis was done to compare the increase in juvenile fishes on the boulder reef. The abundance of juvenile fishes on the boulder reef transects were shown to increase across all years: August 2004 - 611 juvenile fishes, August 2005 - 836 juvenile fishes, August 2006 - 914 juvenile fishes, and August 2007: 3055 juvenile fishes. When the abundance of juvenile fishes is looked at as a percentage of total abundance seen on boulder reef transects, an almost linear regression across all years is seen (R^2=0.975) (Figure 39). This may be due to an increase in benthic cover as time passes.

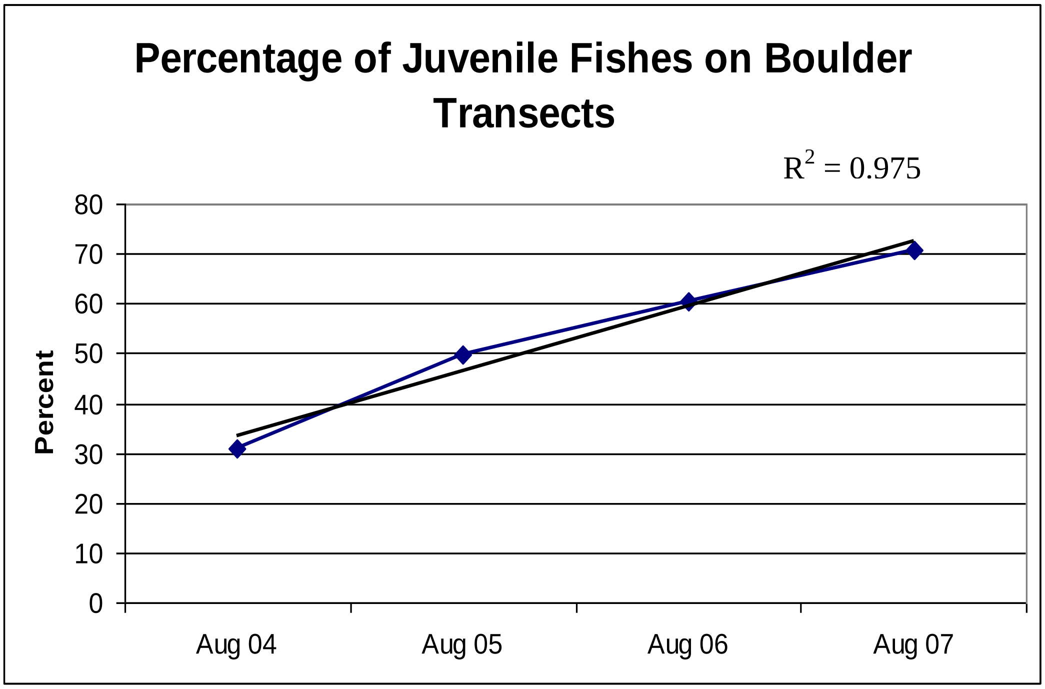


Figure 39. Percentage of juvenile fishes present on mitigation boulder transects by year.

3.3 Predator Effects

3.3.1 By Size Class

The mean abundance of all fishes among years was calculated by size class. The August 2007 fish census on the natural hardbottom had the greatest mean abundance of fishes <2 cm in length, but was not significantly different from August 2005 or August 2006 natural hardbottom data or August 2006 mitigation boulder data (ANOVA, $p>0.05$) (Figure 40). The mean abundance of fishes <2 cm in length did significantly differ between August 2007 natural hardbottom and mitigation boulder transects (ANOVA, $p<0.02$). Across all surveys, there was no significant difference in mean abundance of fishes <2 cm on mitigation boulder transects.

The greatest mean abundance of fishes 2-5 cm in length among years was found on August 2007 mitigation boulder transects (Figure 41); however, there was no

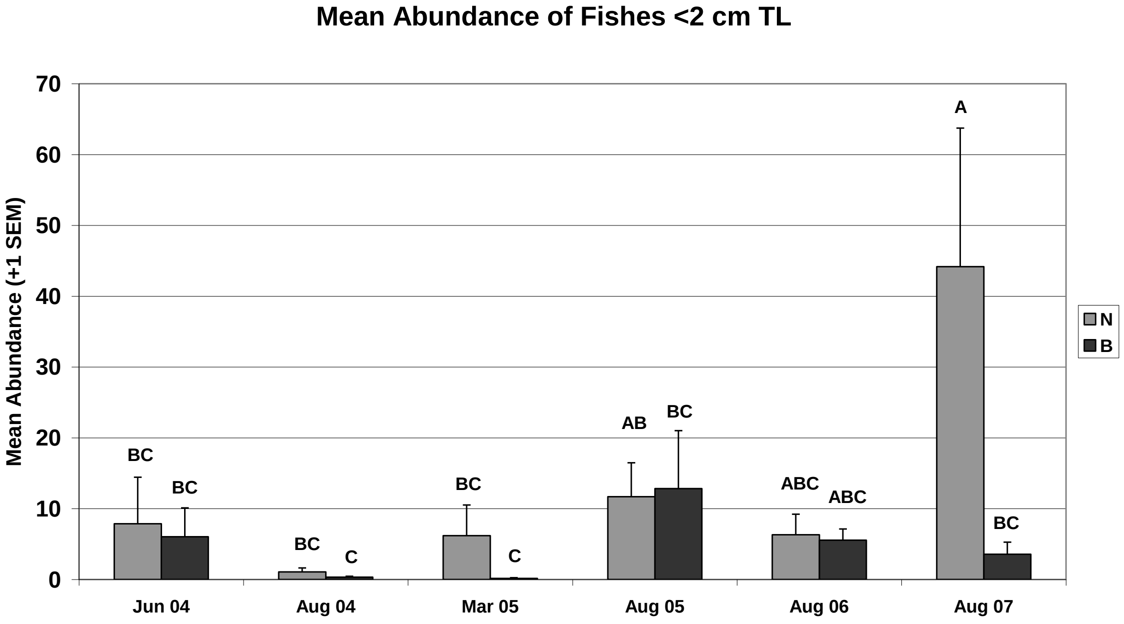


Figure 40. Mean abundance of fishes <2 cm TL on natural hardbottom (N) and mitigation boulder (B) transects across all surveys. Newman-Keuls grouping letters that are the same are not significantly different (p>0.05).

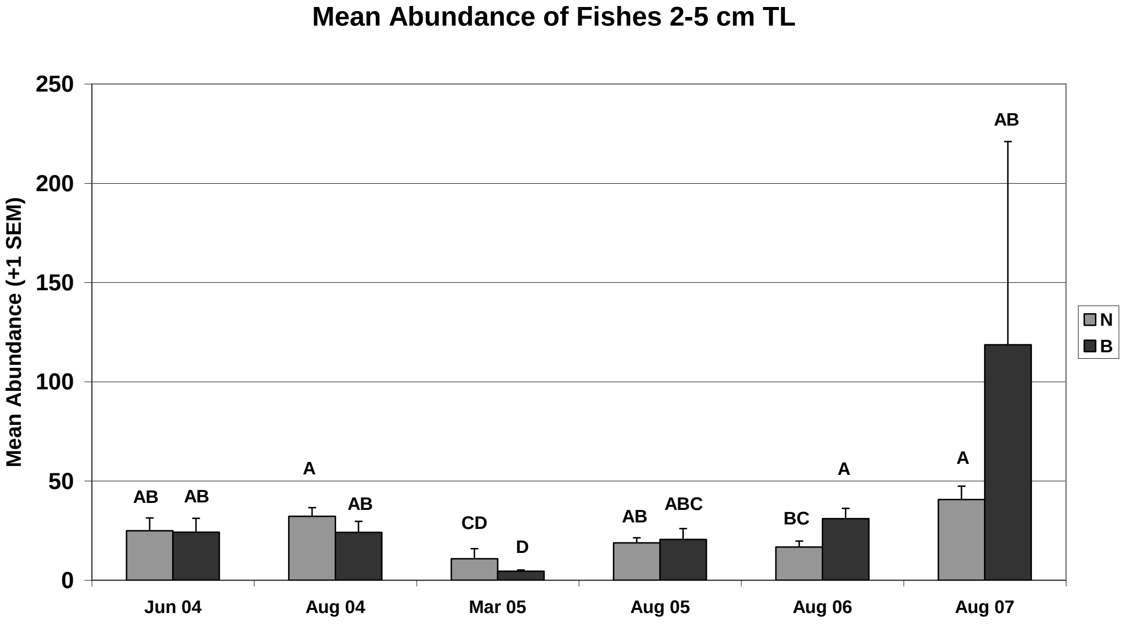


Figure 41. Mean abundance of fishes 2-5 cm TL on natural hardbottom (N) and mitigation boulder (B) transects across all surveys. Newman-Keuls grouping letters that are the same are not significantly different (p>0.05).

significant difference between boulder and natural transects of the same year. For mitigation boulder transects, there were no significant differences across all surveys for fishes 2-5 cm in length except during the March 2005 census (ANOVA, $p<0.03$). For natural hardbottom transects, August 2007 differed significantly from August 2006 (ANOVA, $p<0.05$) and March 2005 (ANOVA, $p<0.00004$).

For all fishes ≤5 cm in length (both Juvenile and small cryptic species alike) the mean abundance was significantly different between March 2005 boulder transects and all other years (ANOVA, $p<0.005$) (Figure 42). August 2006 natural hardbottom transects were significantly different than August 2007 natural transects (ANOVA, $p<0.05$).

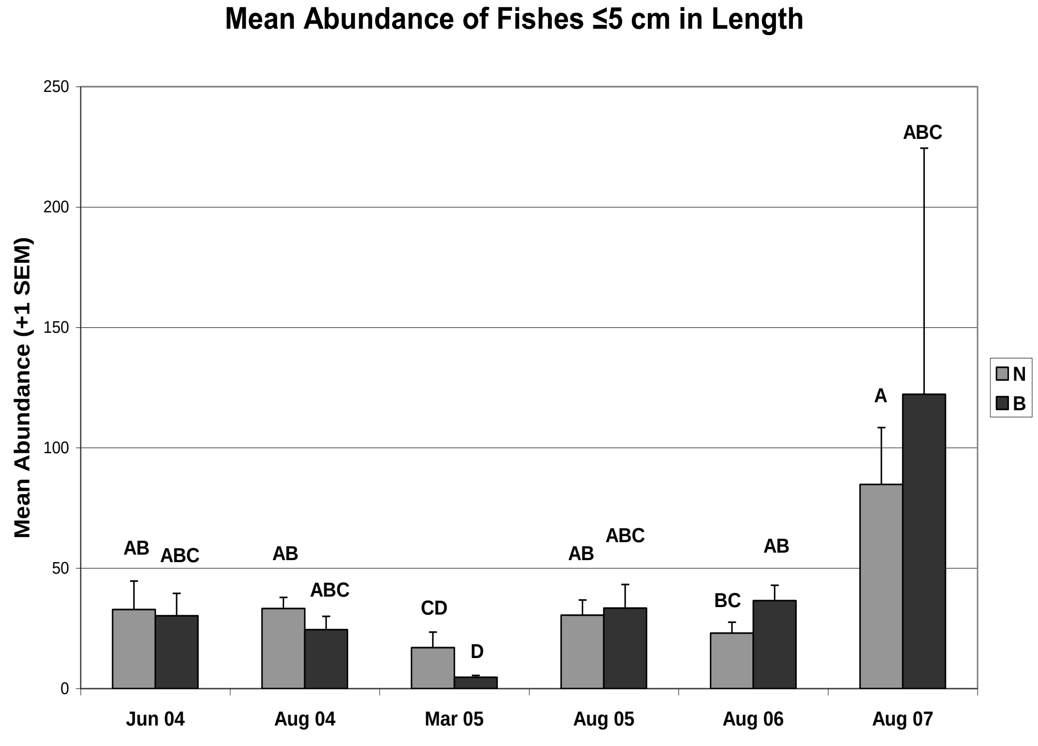


Figure 42. Mean abundance of fishes ≤5 cm TL on natural hardbottom (N) and mitigation boulder (B) transects across all surveys. Newman-Keuls grouping letters that are the same are not significantly different ($p>0.05$).

The greatest variation among size classes across all years occurred when observing the mean abundance of fishes 5-10 cm in length. The greatest mean abundance of fishes 5-10 cm in length occurred on the August 2004 mitigation boulder transects (Mean abundance ± 1 SEM = 40.6 ± 5.3), which was significantly different from all other counts (ANOVA, p<0.04) (Figure 43). The mean abundance of fishes 5-10 cm in length was greater on all mitigation boulder transects when compared to their respective natural transects by year.

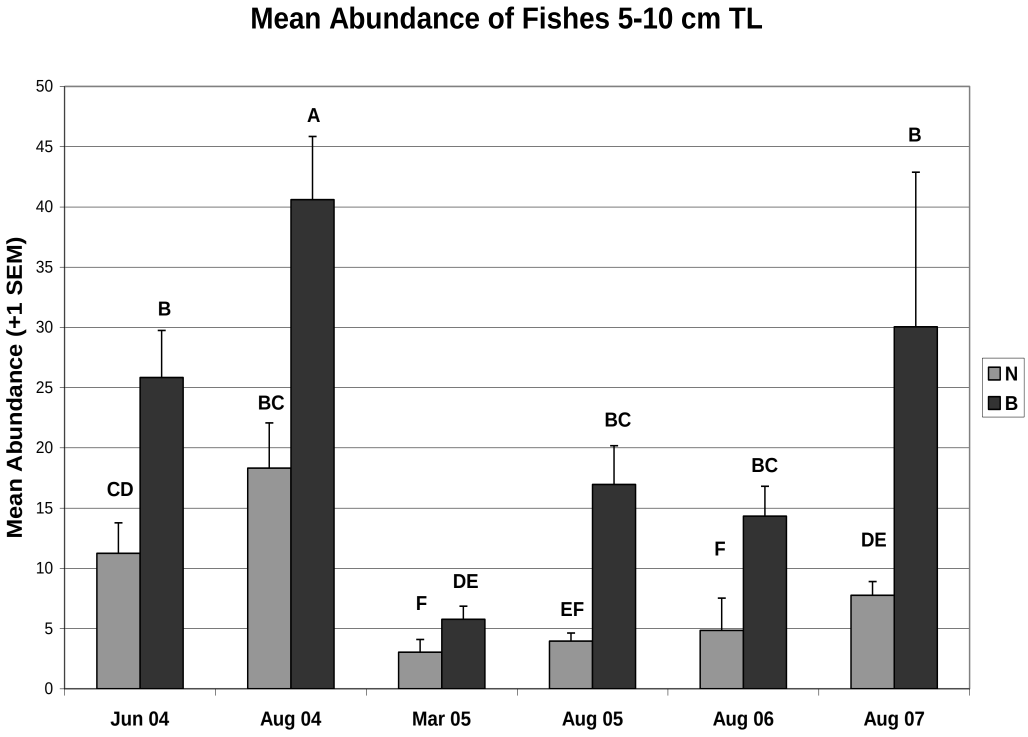


Figure 43. Mean abundance of fishes 5-10 cm TL on natural hardbottom (N) and mitigation boulder (B) transects across all surveys. Newman-Keuls grouping letters that are the same are not significantly different (p>0.05).

The mean abundance of fishes 10-20 cm in length showed a clear distinction between mitigation boulder transects and natural hardbottom transects (Figure 44). The mean abundance ± SEM across all surveys was 12.2 ± 0.9 for boulder transects and 1.6 ±

0.3 for natural transects. Only one survey, August 2004, differed significantly across all years on natural hardbottom transects, while only two surveys, March 2005 and August 2006, differed significantly across all years on mitigation boulder transects (p<0.05).

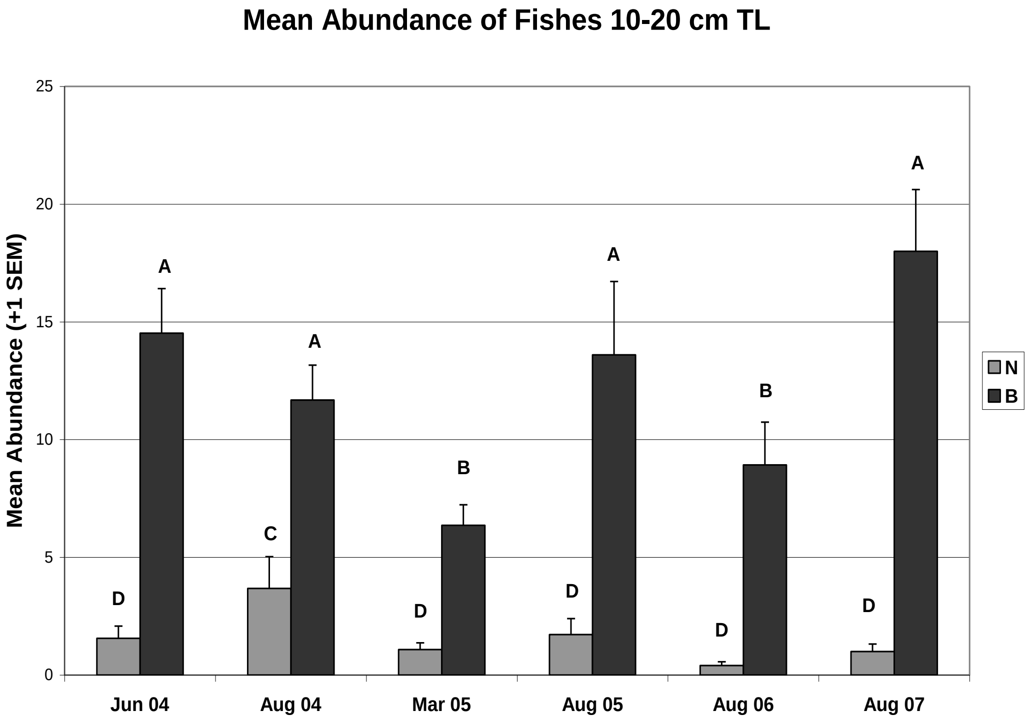


Figure 44. Mean abundance of fishes 10-20 cm TL on natural hardbottom (N) and mitigation boulder (B) transects across all surveys. Newman-Keuls grouping letters that are the same are not significantly different (p>0.05).

The mean abundance of fishes 20-30 cm in length showed no significant difference across all surveys for natural hardbottom transects (ANOVA, p>0.05) (Figure 45). On mitigation boulder transects, the August 2006 survey had the lowest mean abundance (0.52 ± 0.2) and was found to be more similar to natural hardbottom transects. Low abundances were found for fishes 30-50 cm in length and for fishes >50 cm in length. The mean abundance of fishes 30-50 cm in length ± SEM was 0.07 ± 0.03 on natural hardbottom transects and 0.15 ± 0.04 on mitigation boulder transects (Figure 46). No fishes were counted in this size class during August 2004. For the >50 cm size class,

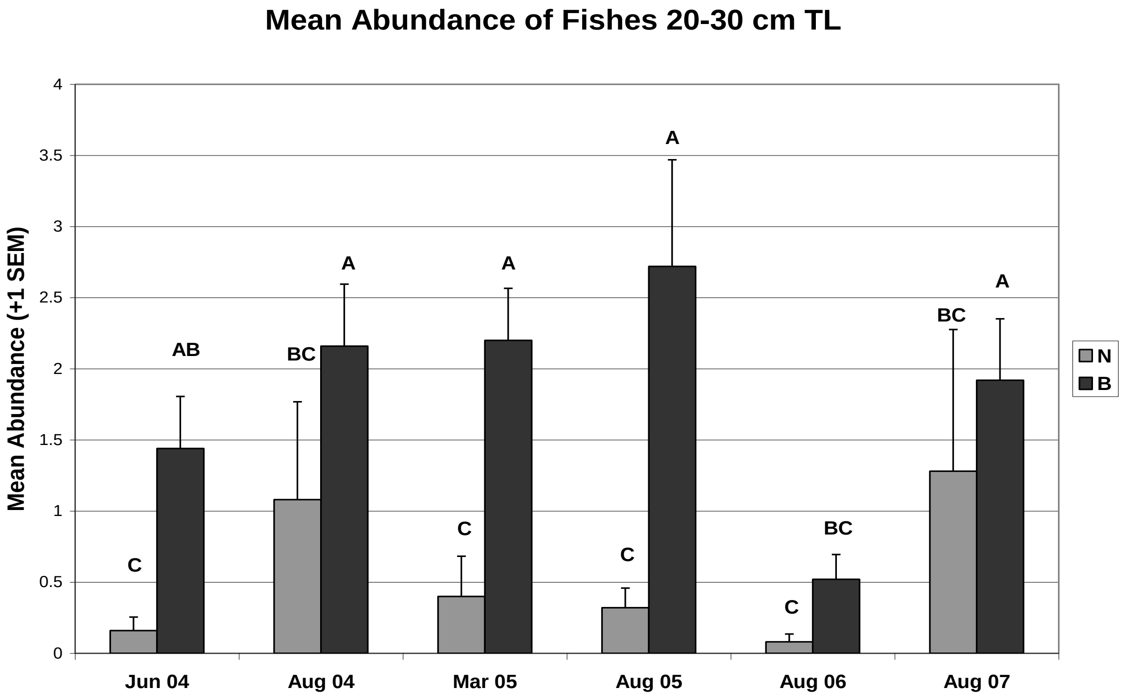


Figure 45. Mean abundance of fishes 20-30 cm TL on natural hardbottom (N) and mitigation boulder (B) transects across all surveys. Newman-Keuls grouping letters that are the same are not significantly different (p>0.05).

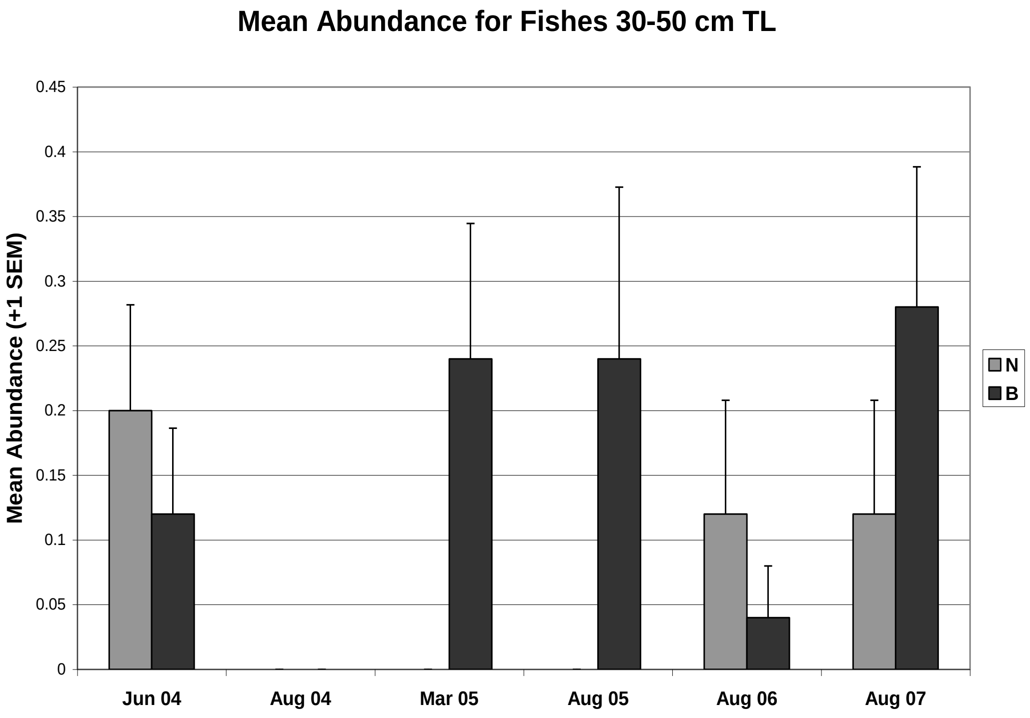


Figure 46. Mean abundance of fishes 30-50 cm TL on natural hardbottom (N) and mitigation boulder (B) transects across all surveys.

the mean abundance of fishes was found to be 0.05 ± 0.03 on natural hardbottom transects, and 0.11 ± 0.03 on mitigation boulder transects (Figure 47). No significant differences were found between years for both of these size classes (p>0.05).

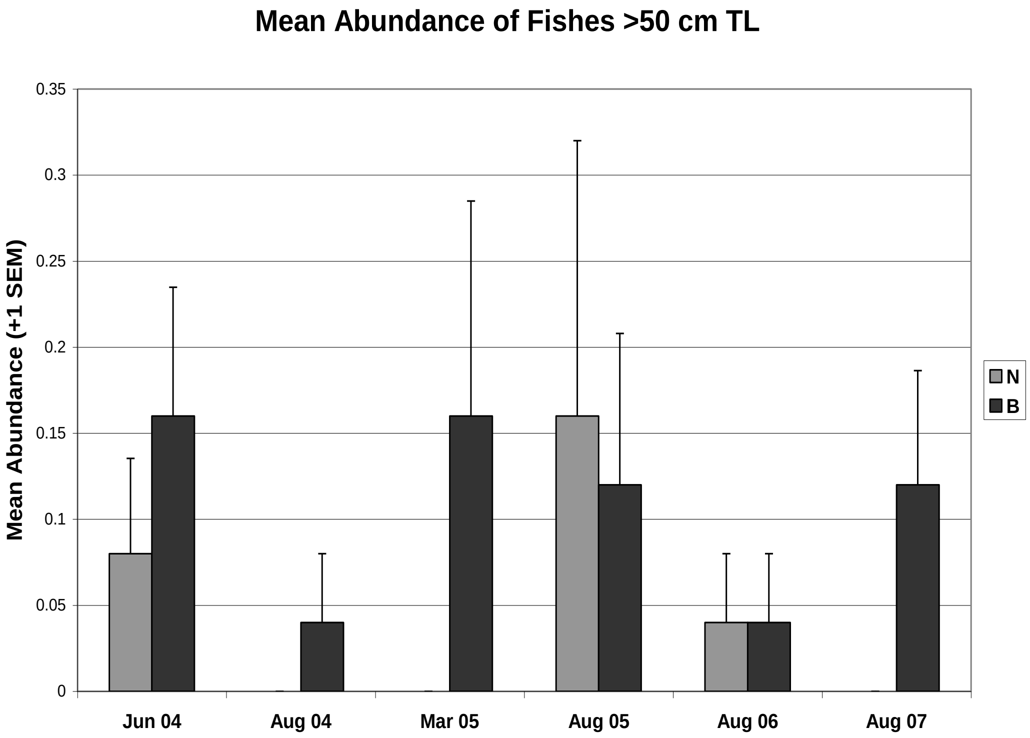


Figure 47. Mean abundance of fishes >50 cm TL on natural hardbottom (N) and mitigation boulder (B) transects across all surveys.

3.3.2 *Predators and Juveniles*

The presence of predators (piscivorous fishes: Randall, 1967; Froese and Pauly, 2007) on August 2007 transect and rover diver surveys was noted. A total of 129 predators were seen on natural hardbottom transects (Table 10), while 108 predators were counted on mitigation boulders transects (Table 11). Eighty-nine percent of predators seen on boulder transects were 10 cm or greater in length (96 total), whereas only 30% of predators seen on natural hardbottom transects were 10 cm or greater in length (39 total).

Table 10. Abundance of predators on August 2007 natural hardbottom transects by size class, common name, and scientific name.

Size Class	Common Name	Scientific Name	Abundance
30-50 cm	Mutton snapper	*Lutjanus analis*	2
20-30 cm	Blue runner	*Caranx crysos*	26
	Gray triggerfish	*Balistes capriscus*	1
	Inshore lizardfish	*Synodus foetens*	1
10-20 cm	Gray snapper	*Lutjanus griseus*	3
	Bar jack	*Carangoides ruber*	2
	Gray triggerfish	*Balistes capriscus*	2
	Spotted scorpionfish	*Scorpaena plumieri*	1
5-10 cm	Yellowtail snapper	*Ocyurus chrysurus*	9
	Lane snapper	*Lutjanus synagris*	6
	Sand perch	*Diplectrum formosum*	5
	Red grouper	*Epinephelus morio*	1
2-5 cm	Lane snapper	*Lutjanus synagris*	48
	Yellowtail snapper	*Ocyurus chrysurus*	13
	Sand perch	*Diplectrum formosum*	5
	Twospot cardinalfish	*Apogon pseudomaculatus*	1
	Lantern bass	*Serranus baldwini*	1
	Harlequin bass	*Serranus tigrinus*	1

Table 11. Abundance of predators on August 2007 mitigation boulder transects by size class, common name, and scientific name.

Size Class	Common Name	Scientific Name	Abundance
>50 cm	Green moray	*Gymnothorax funebris*	1
	Great barracuda	*Sphyraena barracuda*	2
20-30 cm	Gray triggerfish	*Balistes capriscus*	1
	Bar jack	*Carangoides ruber*	1
	Gray snapper	*Lutjanus griseus*	1
	Lane snapper	*Lutjanus synagris*	1
	Scamp	*Mycteroperca phenax*	1
	Spanish mackerel	*Scomberomoros maculatus*	1
10-20 cm	Gray triggerfish	*Balistes capriscus*	6
	Yellow jack	*Carangoides bartholomaei*	3
	Bar jack	*Carangoides ruber*	52
	Graysby	*Cephalopholis cruentata*	1
	Gray snapper	*Lutjanus griseus*	4
	Lane snapper	*Lutjanus synagris*	11
	Yellow goatfish	*Mulloidichthys martinicus*	2
	Scamp	*Mycteroperca phenax*	1
	Yellowtail snapper	*Ocyurus chrysurus*	7
5-10 cm	Bar jack	*Carangoides ruber*	2
	Lane snapper	*Lutjanus synagris*	3
	Yellowtail snapper	*Ocyurus chrysurus*	1
2-5 cm	Bar jack	*Carangoides ruber*	2
	Lane snapper	*Lutjanus synagris*	3
	Yellowtail snapper	*Ocyurus chrysurus*	1

On rover diver counts, the total number of occurrences of predators was noted based on a maximum occurrence of 25 (one for each site). A total of 91 occurrences of predators were noted on August 2007 natural hardbottom rover diver surveys (Table 12), while 120 occurrences of predators were noted on mitigation boulder rover diver surveys (Table 13).

Table 12. Total number of occurrences of predators noted on natural hardbottom rover diver surveys during August 2007.

Common Name	Scientific Name	Occurrence
Lane snapper	*Lutjanus synagris*	23
Gray snapper	*Lutjanus griseus*	20
Gray triggerfish	*Balistes capriscus*	15
Bar jack	*Carangoides ruber*	14
Yellowtail snapper	*Ocyurus chrysurus*	9
Mahogany snapper	*Lutjanus mahogoni*	6
Common snook	*Centropomus undecimalis*	5
Scamp	*Mycteroperca phenax*	5
Flamefish	*Apogon maculatus*	4
Sand diver	*Synodus intermedius*	4
Great barracuda	*Sphyraena barracuda*	3
Twospot cardinalfish	*Apogon pseudomaculatus*	2
Tarpon	*Megalops atlanticus*	2
Spotted scorpionfish	*Scorpaena plumieri*	2
Yellow jack	*Carangoides bartholomaei*	1
Sand perch	*Diplectrum formosum*	1
Nurse shark	*Ginglymostoma cirratum*	1
Mutton snapper	*Lutjanus analis*	1
Greater soapfish	*Rypticus saponaceous*	1
Greater amberjack	*Seriola dumerili*	1

The abundances of juvenile fishes (≤5 cm) versus adult fishes (>5 cm) were compared on natural hardbottom and boulder reefs across all surveys (Figure 48). All years showed a higher abundance of juvenile fishes on natural transects as compared to boulder transects. With the exception of August 2006 and August 2007, all mitigation boulder transects contained more adult fishes than juvenile fishes. If juvenile haemulids are removed from the data, more adults are seen on August 2007 mitigation boulder

Table 13. Total number of occurrences of predators noted on mitigation boulder rover diver surveys during August 2007.

Common Name	Scientific Name	Occurrence
Lane snapper	*Lutjanus synagris*	16
Yellowtail snapper	*Ocyurus chrysurus*	16
Sand perch	*Diplectrum formosum*	13
Gray triggerfish	*Balistes capriscus*	7
Bar jack	*Carangoides ruber*	5
Mutton snapper	*Lutjanus analis*	4
Tarpon	*Megalops atlanticus*	4
Scamp	*Mycteroperca phenax*	4
Flamefish	*Apogon maculatus*	3
Blue runner	*Caranx crysos*	3
Twospot cardinalfish	*Apogon pseudomaculatus*	2
Yellow jack	*Carangoides bartholomaei*	2
Spotted scorpionfish	*Scorpaena plumieri*	2
Red hind	*Epinephelus guttatus*	1
Red grouper	*Epinephelus morio*	1
Nurse shark	*Ginglymostoma cirratum*	1
Goldentail moray	*Gymnothorax miliaris*	1
Purplemouth moray	*Gymnothorax vicinus*	1
Gray snapper	*Lutjanus griseus*	1
Greater soapfish	*Rypticus saponaceous*	1
Lantern bass	*Serranus baldwini*	1
Great barracuda	*Sphyraena barracuda*	1
Lizardfish species	*Synodus* sp.	1

transects, while August 2006 mitigation boulder transects contain equal numbers of juveniles and adults.

3.3.3 Juvenile Fishes

The total abundance of fishes on August 2007 transects was calculated for the following families: Haemulidae, Pomacentridae, Labridae, Gobiidae, Lutjanidae, Scaridae, and Acanthuridae. Total abundances were noted for the <2 cm size class and the 2-5 cm size class on both the natural hardbottom and the mitigation boulder transects. Haemulids contributed to the greatest abundance of juvenile fishes for both size classes. Newly settled individuals (those <2 cm in length) were found in the greatest abundance on natural hardbottom transects (Figure 49), with 1,007 of those individuals coming from

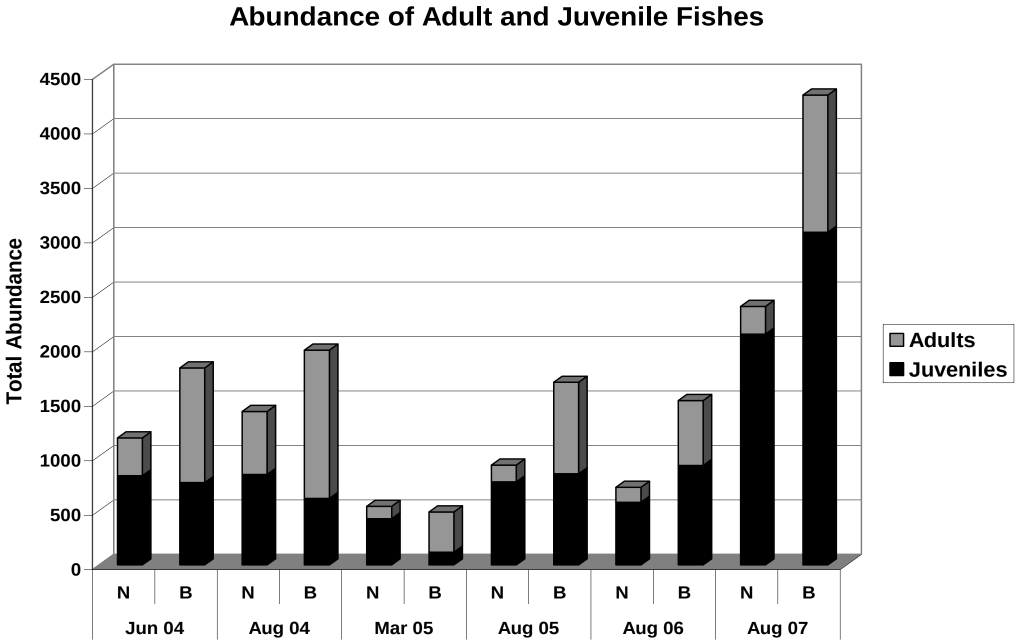


Figure 48. Abundance of adult and juvenile fishes on natural hardbottom (N) and mitigation boulder (B) transects across all surveys.

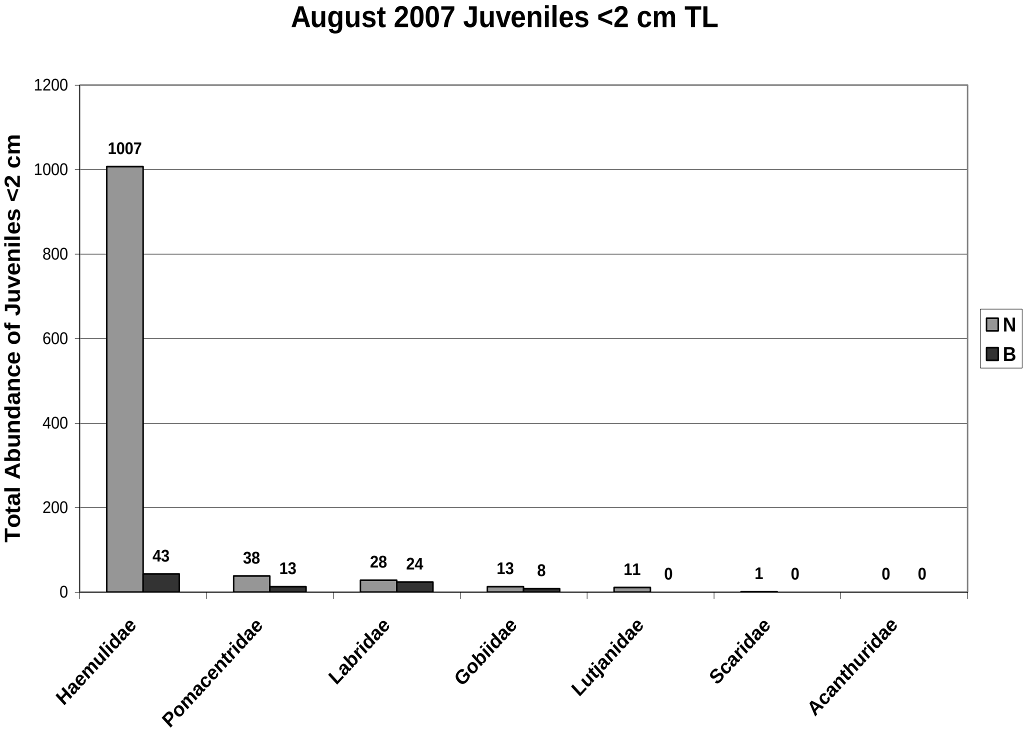


Figure 49. Abundance of juveniles <2 cm in length during August 2007 on natural hardbottom (N) and mitigation boulder (B) transects.

family Haemulidae. Only 43 newly settled haemulids were found on mitigation boulder transects. For fishes 2-5 cm in length, a shift appears to occur. Mitigation boulder transects contained the most fish in this size class, with 2,635 individual haemulids being counted on these transects (Figure 50).

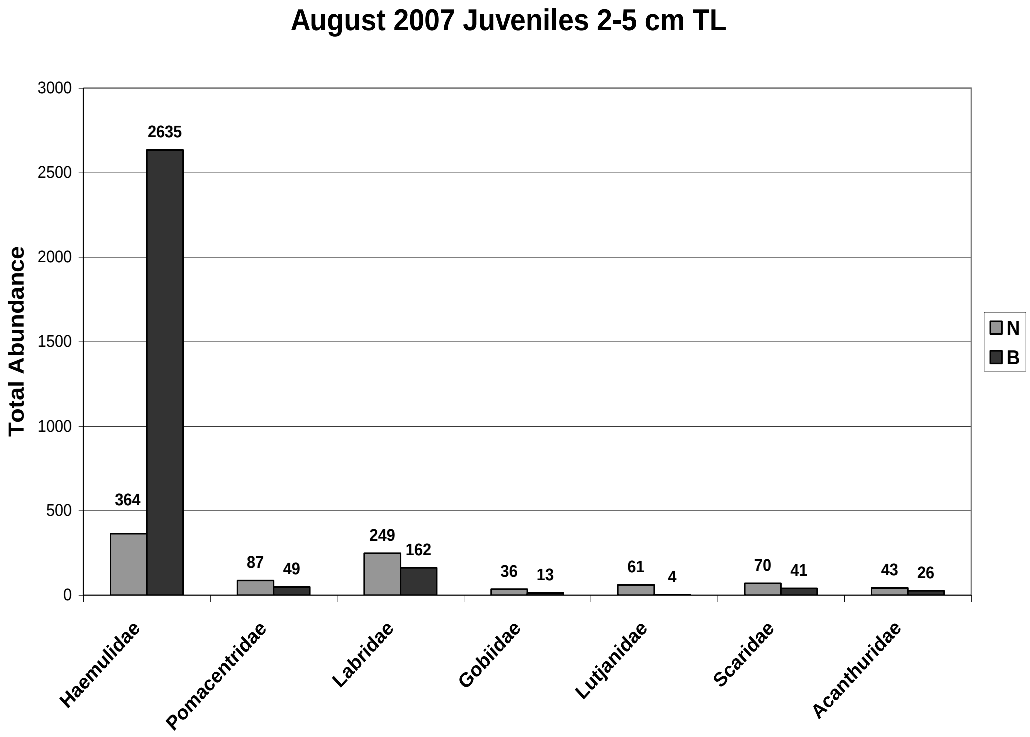


Figure 50. Abundance of juveniles 2-5 cm in length during August 2007 on natural hardbottom (N) and mitigation boulder (B) transects.

4.0 Discussion

The nearshore hardbottom and mitigation boulder habitats are different. The high species richness (271) recorded in this study indicates a high diversity of fishes present in the nearshore environment of Broward County, Florida. Results of my study are similar to previous surveys of nearshore fish assemblages conducted in Broward County. In this study, 78% of fishes counted on natural transects were juveniles (≤5 cm). Baron *et al.* (2004) found that >88% of fishes on their transect surveys were made up of juvenile fishes. However, transect surveys in this study had a lower percentage of juvenile haemulids. Only 51% of juvenile fishes were haemulids, compared to >90% found previously (Baron *et al.*, 2004). If boulder transects are factored in, the total number of juvenile fishes seen decreases to 63%, with similar percentage contribution from family Haemulidae (53%). Baron *et al.* (2004) recorded fishes in the months of June through August, and thus some of the differences between studies may be due to temporal variation.

Of total fishes surveyed, more than 62% were counted on boulder reef transects. Alternatively, a higher number of species were counted on natural transects (152) versus boulder transects (143). The intricacies of each of these environments help to create assemblage structures which are unique to their respective areas. The natural hardbottom transects are made up of low-relief pavement (Walker *et al*., in press) and contain many crevices and refuge spaces, leading to the presence of large numbers of juvenile and small cryptic fishes. The boulders, on the other hand, contain large overhangs and interstices that are able to provide additional refuge space for larger fishes. Forty-six percent of the fishes on the boulders were >5 cm TL, compared to 22% on the natural hardbottom.

The statistical comparison of fish assemblages on natural hardbottom versus mitigation boulder reef indicated substantial differences across years. All sampling intervals showed clear differences in species number and composition, as well as differences in mean abundance. Mean species richness was greater on the boulder reef for both transect and rover diver counts. The March 2005 survey remained significantly different compared to most other surveys in both abundance and species richness. This survey stood out due to low abundances and low species diversity on transect counts. No juvenile haemulids were counted on boulder transects during March 2005. In other surveys, haemulids formed a large component of fishes seen on both natural and boulder transects. Previous surveys of juvenile haemulids have shown that they are present in lower numbers during the winter months (McFarland *et al.*, 1985; Jordan *et al.*, 2004).

All years showed a clear distinction between natural hardbottom and mitigation boulders on MDS plots, both with and without rugosity standardization factored in. Boulders showed a more compact clustering across years, which is indicative of a more homogenous environment. Boulders offer similar refuge space and surface area throughout all transects, allowing fish assemblages to remain similar. In contrast, natural hardbottom provides a more heterogeneous and dynamic environment (Goldsmith, 1991). Fish assemblages on natural transects may change along with the ever-changing microhabitats.

One aspect that can greatly alter and affect the nearshore environment is beach renourishment activities. Beach renourishment took place in Broward County, Florida, between May 2005 and February 2006. Fish surveys that took place after the beach renourishment activities appear to show both temporary and possibly long term detrimental side effects. In August 2006 and 2007 there were seven and three sites, respectively, which contained less than five fish per transect count on the natural hardbottom (versus the preceding means of about 45 fish per transect). During the August 2006 survey there were seven transects that were noted to have been heavily impacted by sand, containing between zero and four fish per transect: C098a (1), N104a (4), N105b (2), N106a (0), N126b (0), P101a (2), and P113a (3) (Appendix C). The reduced abundance on August 2006 transects may be due to beach renourishment. Sand that was placed on the beaches from May 2005 to February 2006 had already begun to erode back into the ocean, especially due to the active hurricane season that south Florida experienced during 2005. Hurricane Wilma crossed over Broward County on October 24th, 2005, bringing with it sustained winds over 99 mph. In turn, the newly renourished beaches of Broward County experienced minor beach and dune erosion (FDEP, 2006). This contributed to the nearshore hardbottom habitat experiencing a larger than normal influx of sand. The August 2007 survey showed that there was some recovery of the nearshore environment, as only three sites contained low abundances of fish: C098a (0), N106a (1), and P113a (0) (Appendix C). The re-exposure of these buried sites demonstrates the dynamic nature of the nearshore habitat and sand movement, as well as how some areas were able to quickly rebound from a dramatic burial event.

The question remains as to whether or not boulder reef is suitable mitigation for natural nearshore hardbottom. The boulders were observed to attract a greater abundance of fishes than the natural habitat. However, after four years these assemblages retained an almost 77% dissimilarity to the natural hardbottom. This high dissimilarity is especially applicable to juvenile haemulid species. Juvenile haemulids were found in greater abundance on the natural reef contributing 6.6% to the overall dissimilarity between natural hardbottom and mitigation boulder reef. *Haemulon aurolineatum* (>5 cm TL), *Thalassoma bifasciatum*, and *Anisotremus virginicus* were all found in higher abundances on the boulders (contributing 5.3%, 5.1%, and 4.8% to the dissimilarity, respectively).

Additionally, certain fish species found on the boulders were either present in extremely low abundances or absent altogether on the natural reef, i.e. *Carangoides ruber*, *Gerres cinereus*, *Acanthurus coeruleus*, *Archosargus rhomboidalis*, and *Lutjanus griseus*. Of these, two are piscivores and important predators of juvenile fish: *C. ruber* and *L. griseus* (Randall, 1967; Froese and Pauly, 2007). Their higher abundances on the mitigation boulders may help identify why there are lower numbers of newly settled individuals on these reefs.

The nearshore habitat is an especially important environment for many species of juvenile fishes. Juvenile haemulids have been extensively studied in Broward County, Florida (Jordan *et al.*, 2004). They exhibit both a pelagic larval stage and demersal juvenile and adult stage, and are highly abundant during the summer months (McFarland *et al*., 1985; Jordan *et al.*, 2004). It is the transitional phase between their pelagic and demersal life stages, the settlement phase, in which the greatest difference in abundance is demonstrated when comparing natural hardbottom and mitigation boulder transects. Juvenile fishes may use the nearshore environment as a nursery ground for recruitment and development. Newly settled individuals feed on plankton, and can usually be found together in large schools. This was observed on both natural hardbottom and mitigation boulders, where groups of 100's or more were often counted on a single transect. These individuals are more susceptible to predation largely due to three factors: 1) they swim more slowly; 2) they have lower visual acuity; and 3) they may be in the appropriate prey size range for many predators (Shulman and Ogden, 1987). The natural hardbottom provides adequate area for newly settled individuals, which is evidenced by the large numbers of haemulids <2 cm in length on the natural transects. The abundance of predators was found to be relatively low on the nearshore transects. However, the boulder reef is home to many predators of larger size. Even though new recruits were observed on the boulders, they were found in lower abundances. Not surprisingly, environments that contain fewer predators have higher abundances of juveniles (Beets, 1997; Beukers, 1997; Webster, 2002). The boulders do, however, provide a suitable habitat for early juveniles (2-5 cm TL). Once fish grow larger in size, they develop traits which make them less susceptible to predation: they become faster swimmers, more agile, and too large to be preyed upon by some predators (Shulman, 1985). Once they develop these traits, their dietary needs change and a habitat shift is often noted. They may begin an ontogenetic shift towards an environment more suitable to their physical and dietary needs. Once this shift occurs, the boulders seem to provide a more suitable habitat for haemulids 2-5 cm in length and their abundance becomes more noticeable on the boulder reef.

The colonization of the boulders between 2004 and 2007 was observed. August transects only were used to avoid seasonal variation. In August 2004, the MDS plot indicated a very tight clustering around the boulder transects. This is due to the fact that the boulders were recently placed in the water (between June 2003 and September 2003) and the fish assemblages on each transect highly resembled one another. As time passed, assemblages on the transects began to differ more within years and from one another when compared to previous years' data. August 2004 to August 2005 comparisons show markedly different assemblage structures from one another (60% dissimilarity). In August 2004, the boulders had been in the water for only one year (a relatively short soak time). The species which contributed the most to the dissimilarity during the first two years were *Haemulon aurolineatum*, juvenile *Haemulon* spp., and *Carangoides ruber*, each of which contributed over 7% to the dissimilarity. *C. ruber* decreased between years, while *Haemulon* spp. increased. The increase in juvenile *Haemulon* spp. may be a direct result of the decrease of the predator *C. ruber*. Between August 2005 and August 2006, the dissimilarity increased slightly, up to 61.5%. Juvenile *Haemulon* spp. contributed over 8% to the dissimilarity, but there was a decrease in abundance between years (648 vs. 317, respectively). No known predator species showed a remarkable increase, so the decrease in abundance may have possibly been due to a lower recruitment event of haemulids between years. Between August 2006 and August 2007, boulder assemblages remained dissimilar to one another (60.7%). Juvenile *Haemulon* spp. showed a marked increase (from 317 to 2,097) between these two years (likely due to stochastic recruitment events). In sum, these changes indicate that the assemblages on the boulders are continuing to fluctuate over time. They will most likely continue along this pattern for a number of years, as fish species have been shown to change on artificial reefs for up to ten years after initial deployment (Relini *et al.*, 2002). It is also possible that the assemblages will remain in flux well into the future, or never reach a fixed assemblage at all.

The question also remains as to what determines where juvenile fish settlement takes place. Assuming equal recruit availability, two major factors, competition and predation, have been linked to reduced settlement rates of fishes in a particular area (Shulman *et al.*, 1983). Thus, settlement patterns of fishes have been shown to be affected by the organisms which are already settled in an area, including predators (Shulman, 1985). The nearshore hardbottom habitat provided an area of refuge for newly settled individuals and juveniles alike. In contrast, the boulder habitat primarily provided an area for larger sized fishes. Adult and sub-adult residents may interfere with settlement by exhibiting aggressive behavior towards new fishes, by exploiting available resources, and by actively preying on new recruits (Shulman *et al.*, 1983). Therefore, priority effects (where established individuals impact fish arriving later) are seen as local assemblages help control future fish assemblages (Almany, 2003). Density dependence, predation, and competition also affect the population of fishes that can recruit to a particular area on a reef (Chase *et al*., 2002; Hixon and Webster, 2002; Webster, 2002). It is difficult to determine if density dependent mortality (the increased rate of prey mortality associated with higher predator numbers) is the actual cause of death for new recruits because it can be confounded with the effects of refuge availability. If little refuge space is available for small fish, then predation effects will be higher and there will be a higher correlation of density dependence (Hixon and Webster, 2002; Hixon and Jones, 2005). The fishes observed in this study may have exhibited such density dependence due to less size-appropriate refuge on boulder reef. The differences between the fish assemblages is also noted when looking at the trophic levels of fish associated with these habitats. In general, the boulders contained more predators than the natural environment. The increase of predators on the boulders may impact the nearshore natural population, and more research is needed to determine the overall effects of the boulders on neighboring assemblages.

5.0 Conclusion

As to the questions stated in the purpose of the study (Section 1.4): 1) There is a difference in species richness between the mitigation boulder reef and the natural hardbottom it replaces. On transect counts, 96 species were seen on the natural hardbottom compared to 119 species on the mitigation boulder reef. 2) There was a difference in specific species between the mitigation boulder reef and the natural hardbottom it replaces. The two assemblages had a combined 77% dissimilarity. 3) There was a difference in fish abundance between the mitigation boulder reef and the natural hardbottom it replaces. The boulders made up greater than 62% of the total abundance of fishes seen. 4) There was a difference in fish assemblage structure between the mitigation boulder reef and the natural hardbottom it replaces. Some species were present at one site and completely absent from the other. 5) In terms of simple abundance the mitigation boulder reef was larger than replacement required. The footprint, or areal coverage, of the mitigation boulder reef produced almost two times the abundance of fishes compared to the natural hardbottom.

With substantial differences in assemblages noted, the need for value judgment becomes apparent in evaluating the boulder reef as an effective mitigation tool. Mitigation does not always fully replace or compensate for exact ecological loss. However, what values are acceptable for resource managers? What is acceptable in terms of change? These questions, along with others, must be asked to determine what can be deemed a successful form of mitigation. Further research is required to determine the overall effectiveness of the mitigation boulders, as well as to determine the impact of burial of the nearshore natural hardbottom environment. The mitigation reef was approximately 3.6 ha in size, which mitigated for the 3.1 ha of natural hardbottom predicted to be impacted. The nearshore fish surveys have shown that more area was impacted than originally planned due to the erosion of sand after the renourishment project, and, as transect counts were only completed every 152 m of shoreline, it is possible additional nearshore environment not noted in this study was impacted.

The mitigation reef provides a habitat that is suitable for fish colonization. However, this habitat differs dramatically in size and appearance, creating an environment that is not similar to that of the natural hardbottom. Different habitat characteristics produce different assemblages (Arena *et al*., 2007). Due to the dynamic nature of sand and the unknowns associated with beach renourishment in general, mitigation reefs should not be relied upon to replace natural habitat loss. If mitigation is continually used to make up for destroying the natural environment, those habitats that serve as an essential nursery ground for juvenile fishes may be lost. By continuing these fish surveys over time, a larger and more reliable picture may emerge as to the effectiveness of the artificial reef, as well as to the final fish assemblages that may inhabit the reef. However, at a minimum, other methods and technology should be simultaneously pursued to find alternative approaches to hardbottom mitigation.

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Appendix A

Appendix A. Fish species recorded on all transects by total count (T) and the number of occurrences seen (O) on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		**Aug 2004**		**Mar 2005**		**Aug 2005**		**Aug 2006**		**Aug 2007**	
		N	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Common Name	**Scientific Name**	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O
Nurse sharks	**Ginglymostomatidae**												
Nurse shark	*Ginglymostoma cirratum*									**1**/1			
Stingrays	**Dasyatidae**												
Southern stingray	*Dasyatis americana*		**1**/1						**2**/1				
Round rays	**Urolophidae**												
Yellow stingray	*Urobatis jamaicensis*	**3**/3		**2**/2		**1**/1		**1**/1	**1**/1	**1**/1		**2**/2	
Tarpons	**Megalopidae**												
Tarpon	*Megalops atlanticus*		**2**/2					**4**/1	**2**/1				
Moray eels	**Muraenidae**												
Green moray	*Gymnothorax funebris*									**1**/1			**1**/1
Spotted moray	*Gymnothorax moringa*	**1**/1											
Purplemouth moray	*Gymnothorax vicinus*	**2**/2											
Lizardfishes	**Synodontidae**												
Inshore lizardfish	*Synodus foetens*						**1**/1					**1**/1	
Lizardfish species	*Synodus* sp.												**1**/1
Sand diver	*Synodus intermedius*						**2**/2						
Squirrelfishes	**Holocentridae**												
Squirrelfish	*Holocentrus adscensionis*						**2**/2		**1**/1				
Scorpionfishes	**Scorpaenidae**												
Barbfish	*Scorpaena brasiliensis*						**1**/1						
Spotted scorpionfish	*Scorpaena plumieri*			**2**/2		**1**/1		**2**/2	**1**/1			**1**/1	
Snooks	**Centropomidae**												
Common snook	*Centropomus undecimalis*						**5**/2						
Sea basses	**Serranidae**												

Appendix A cont'd. Fish species recorded on all transects by total count (T) and the number of occurrences seen (O) on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
		N	B	N	B	N	B	N	B	N	B	N	B
Common Name	**Scientific Name**	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O
Graysby	*Cephalopholis cruentata*												**1**/1
Sand perch	*Diplectrum formosum*	**29**/12		**61**/22	**11**/7	**4**/4		**33**/11		**6**/5	**2**/1	**10**/4	
Red grouper	*Epinephelus morio*		**1**/1						**1**/1		**1**/1	**1**/1	
Butter hamlet	*Hypoplectrus unicolor*										**1**/1		
Scamp	*Mycteroperca phenax*						**1**/1		**1**/1				**2**/1
Greater soapfish	*Rypticus saponaceus*												**1**/1
Lantern bass	*Serranus baldwini*	**2**/2										**1**/1	
Belted sandfish	*Serranus subligarius*		**1**/1										
Harlequin bass	*Serranus tigrinus*											**1**/1	
Jawfishes	**Opistognathidae**												
Dusky jawfish	*Opistognathus whitehursti*							**1**/1		**27**/10	**3**/2	**2**/2	
Cardinalfishes	**Apogonidae**												
Flamefish	*Apogon maculatus*	**1**/1		**1**/1									
Twospot cardinalfish	*Apogon pseudomaculatus*	**3**/2			**1**/1							**1**/1	
Jacks	**Carangidae**												
Yellow jack	*Carangoides bartholomaei*		**5**/3	**1**/1	**6**/2				**3**/2				**3**/1
Bar jack	*Carangoides ruber*	**2**/2	**178**/12		**293**/23				**8**/3		**15**/5	**2**/1	**65**/8
Blue runner	*Caranx crysos*			**59**/3	**30**/1	**7**/1	**1**/1					**26**/2	
Crevalle jack	*Caranx hippos*								**1**/1				
Lookdown	*Selene vomer*	**1**/1											
Greater amberjack	*Seriola dumerili*				**3**/2				**3**/2				
Snappers	**Lutjanidae**												
Mutton snapper	*Lutjanus analis*		**3**/2									**2**/2	
Schoolmaster	*Lutjanus apodus*										**1**/1		

Appendix A cont'd. Fish species recorded on all transects by total count (T) and the number of occurrences seen (O) on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
		N	B	N	B	N	B	N	B	N	B	N	B
Common Name	**Scientific Name**	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O
Blackfin snapper	*Lutjanus buccanella*		1/1										
Gray snapper	*Lutjanus griseus*	2/1	13/7	3/2	18/11		1/1	1/1	28/10		9/3	3/1	8/6
Mahogany snapper	*Lutjanus mahogoni*		1/1								1/1		
Lane snapper	*Lutjanus synagris*	16/7	61/20	150/22	37/15		27/12	127/23	39/15	71/18	41/20	65/11	22/12
Yellowtail snapper	*Ocyurus chrysurus*	11/7	2/1	12/6	6/6		2/1	39/16	5/5	4/3	4/4	22/13	9/4
Mojarras	**Gerreidae**												
Slender mojarra	*Eucinostomus jonesii*		5/2		5/1	3/1	5/1		15/1			3/1	3/1
Mottled mojarra	*Eucinostomus lefroyi*			1/1									
Yellowfin mojarra	*Gerres cinereus*		31/12		50/17		11/7		7/5		14/7	1/1	75/15
Grunts	**Haemulidae**												
Black margate	*Anisotremus surinamensis*		8/6		4/4		4/4		7/7		3/3		4/4
Porkfish	*Anisotremus virginicus*	12/5	113/24	6/2	49/22	6/2	41/21	12/2	68/22	3/3	93/23	9/3	57/23
White margate	*Haemulon album*		5/1						1/1				
Tomtate	*Haemulon aurolineatum*	36/4	169/19	160/8	469/23	6/2	29/8	1/1	242/16	55/3	96/8	17/4	843/12
Caesar grunt	*Haemulon carbonarium*		1/1		1/1								
Smallmouth grunt	*Haemulon chrysargyreum*			1/1			2/2						9/1
French grunt	*Haemulon flavolineatum*		8/5	36/5	71/14	1/1	12/7	6/2	61/16	5/1	158/23	32/4	181/20
Spanish grunt	*Haemulon macrostomum*		30/1		1/1						2/2		2/2
Sailor's choice	*Haemulon parra*		23/8	30/1	6/6		6/4	1/1	11/9	6/1	4/4		3/2
White grunt	*Haemulon plumierii*	7/3	60/22	17/7	49/22	2/2	29/15	12/6	53/22	19/9	55/18	15/4	41/12
Bluestriped grunt	*Haemulon sciurus*	5/3	47/16	8/7	14/11	2/2	20/10	6/4	8/5	1/1	9/4	4/3	9/7
Juvenile grunts	*Haemulon* spp.	530/17	359/12	201/9	119/9	293/5		364/17	659/13	147/8	317/11	1314/17	2097/7
Striped grunt	*Haemulon striatum*									13/1			1/1
Pigfish	*Orthopristis chrysoptera*		3/2				6/1						

Appendix A cont'd. Fish species recorded on all transects by total count (T) and the number of occurrences seen (O) on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		**Aug 2004**		**Mar 2005**		**Aug 2005**		**Aug 2006**		**Aug 2007**	
		N	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Common Name	**Scientific Name**	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O
Porgies	**Sparidae**												
Sea bream	*Archosargus rhomboidalis*		**40**/18		**31**/15	**1**/1	**16**/9		**9**/8		**4**/3		**2**/1
Grass porgy	*Calamus arctifrons*		**1**/1										
Saucereye porgy	*Calamus calamus*										**3**/1		
Porgy species	*Calamus* spp.							**1**/1					
Silver porgy	*Diplodus argenteus*	**1**/1	**31**/16		**1**/1		**1**/1				**5**/3		
Spottail pinfish	*Diplodus holbrookii*								**4**/2				
Pinfish	*Lagodon rhomboides*		**2**/1				**3**/3		**2**/2		**1**/1		**2**/1
Drums	**Sciaenidae**												
Reef croaker	*Odontoscion dentex*				**10**/1		**1**/1				**5**/3		
Highhat	*Pareques acuminatus*	**42**/13	**2**/1	**5**/3	**5**/3	**8**/4		**11**/9	**1**/1	**4**/3	**1**/1	**14**/7	**7**/3
Goatfishes	**Mullidae**												
Yellow goatfish	*Mulloidichthys martinicus*				**3**/2								**5**/3
Spotted goatfish	*Pseudupeneus maculatus*	**10**/6	**4**/4		**2**/2	**5**/3			**2**/2			**2**/1	
Sea chubs	**Kyphosidae**												
Bermuda sea chub	*Kyphosus sectator*	**1**/1		**5**/1			**2**/2		**10**/4		**3**/3	**2**/1	**4**/1
Butterflyfishes	**Chaetodontidae**												
Spotfin butterflyfish	*Chaetodon ocellatus*		**1**/1		**1**/1			**1**/1					
Reef butterflyfish	*Chaetodon sedentarius*			**1**/1	**1**/1	**1**/1							
Angelfishes	**Pomacanthidae**												
Blue angelfish	*Holacanthus bermudensis*		**1**/1				**2**/2	**1**/1	**1**/1				**2**/2
Queen angelfish	*Holacanthus ciliaris*	**1**/1	**2**/1		**1**/1		**2**/2		**5**/4		**3**/3	**1**/1	**8**/7
Rock beauty	*Holacanthus tricolor*											**2**/2	**1**/1
Gray angelfish	*Pomacanthus arcuatus*	**2**/2	**1**/1		**8**/6		**4**/4		**8**/6	**1**/1	**7**/5		**6**/5

Appendix A cont'd. Fish species recorded on all transects by total count (T) and the number of occurrences seen (O) on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
		N	B	N	B	N	B	N	B	N	B	N	B
Common Name	**Scientific Name**	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O
French angelfish	*Pomacanthus paru*	1/1		3/3	4/4	1/1	1/1	2/2	7/4			4/4	4/4
Damselfishes	**Pomacentridae**												
Sergeant major	*Abudefduf saxatilis*	28/3	97/17	34/9	50/12	17/3	19/8	21/7	14/5	63/3	60/15	33/8	25/8
Blue chromis	*Chromis cyanea*				1/1								
Yellowtail damselfish	*Microspathodon chrysurus*												5/4
Dusky damselfish	*Stegastes adustus*	5/3	26/17	6/2	21/13	5/5	9/6	4/3	20/11	7/6	20/14	22/9	27/17
Longfin damselfish	*Stegastes diencaeus*						1/1	5/2		1/1		4/1	
Beaugregory	*Stegastes leucostictus*	20/10	9/6	40/15	14/9	3/2	16/10	11/9	19/15	30/10	44/19	28/14	12/9
Bicolor damselfish	*Stegastes partitus*			1/1				1/1			2/2	10/5	5/4
Threespot damselfish	*Stegastes planifrons*		1/1						1/1		5/4		2/2
Damselfish species	*Stegastes* sp.							1/1					
Cocoa damselfish	*Stegastes variabilis*	56/20	36/17	71/22	55/19	10/6	21/10	26/11	28/16	31/13	56/20	31/13	34/17
Wrasses	**Labridae**												
Spanish hogfish	*Bodianus rufus*				1/1						3/3		
Slippery dick	*Halichoeres bivittatus*	199/23	88/21	276/25	170/25	53/17	32/16	83/18	75/22	99/16	144/22	304/22	116/20
Clown wrasse	*Halichoeres maculipinna*	2/2	3/2	1/1	2/1	3/2		1/1	3/3	11/7	4/4	23/7	34/9
Blackear wrasse	*Halichoeres poeyi*				1/1		1/1	1/1		1/1		28/8	28/4
Puddingwife	*Halichoeres radiatus*		4/2				1/1		2/2		1/1		1/1
Hogfish	*Lachnolaimus maximus*		1/1						1/1		4/3		3/1
Bluehead	*Thalassoma bifasciatum*	32/5	120/22	8/3	92/24	7/3	17/8	7/3	52/16	7/2	80/19	43/7	212/25
Rosy razorfish	*Xyrichtys martinicensis*			1/1						2/2		1/1	
Green razorfish	*Xyrichtys splendens*	11/5		6/4		2/2		1/1		3/3			
Razorfish species	*Xyrichtys* spp.									2/1			
Parrotfishes	**Scaridae**												

Appendix A cont'd. Fish species recorded on all transects by total count (T) and the number of occurrences seen (O) on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
		N	B	N	B	N	B	N	B	N	B	N	B
Common Name	**Scientific Name**	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O
Midnight parrotfish	*Scarus coelestinus*										**1**/1		
Rainbow parrotfish	*Scarus guacamaia*										**2**/2		**1**/1
Striped parrotfish	*Scarus iseri*			**9**/2	**9**/5		**2**/1		**2**/1		**16**/6	**9**/1	**15**/4
Princess parrotfish	*Scarus taeniopterus*								**6**/2		**1**/1	**1**/1	
Redband parrotfish	*Sparisoma aurofrenatum*		**6**/5	**14**/4	**5**/4					**6**/2	**16**/11	**18**/8	**19**/7
Bucktooth parrotfish	*Sparisoma radians*	**8**/5	**5**/4	**58**/16	**38**/17	**1**/1		**24**/14	**3**/2	**11**/7	**8**/7	**54**/11	**16**/10
Redfin parrotfish	*Sparisoma rubripinne*	**1**/1	**4**/4	**2**/2	**5**/3				**2**/2			**1**/1	**3**/1
Stoplight parrotfish	*Sparisoma viride*	**1**/1			**6**/5		**1**/1	**1**/1	**4**/4		**26**/16	**1**/1	**17**/9
Threefin blennies	**Tripterygiidae**												
Roughhead triplefin	*Enneanectes boehlkei*									**1**/1	**1**/1		
Labrisomids	**Labrisomidae**												
Rosy blenny	*Malacoctenus macropus*	**10**/7	**2**/2	**14**/9	**14**/8	**7**/7	**10**/7	**13**/8	**1**/1	**13**/6	**1**/1	**56**/17	**2**/2
Saddled blenny	*Malacoctenus triangulatus*		**1**/1					**2**/2				**2**/2	
Banded blenny	*Paraclinus fasciatus*				**1**/1								
Tube blennies	**Chaenopsidae**												
Roughhead blenny	*Acanthemblemaria aspera*		**3**/3		**6**/3	**5**/3	**2**/2	**2**/2	**3**/2				**6**/4
Sailfin blenny	*Emblemaria pandionis*	**11**/6	**19**/8	**13**/5		**25**/11	**6**/5	**5**/3		**11**/8		**3**/1	
Combtooth blennies	**Blenniidae**												
Seaweed blenny	*Parablennius marmoreus*	**3**/3	**10**/6	**7**/5	**14**/8	**11**/9	**17**/10	**13**/8	**3**/3	**7**/6	**10**/7	**19**/12	**5**/3
Dragonets	**Callionymidae**												
Lancer dragonet	*Callionymus bairdi*									**2**/1			
Gobies	**Gobiidae**												
Colon goby	*Coryphopterus dicrus*			**2**/2									
Bridled goby	*Coryphopterus glaucofraenum*		**1**/1	**51**/9	**22**/12	**1**/1	**4**/3	**9**/5	**2**/2	**22**/9	**23**/13	**46**/16	**12**/7

Appendix A cont'd. Fish species recorded on all transects by total count (T) and the number of occurrences seen (O) on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
		N	B	N	B	N	B	N	B	N	B	N	B
Common Name	**Scientific Name**	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O	T/O
Masked goby	*Coryphopterus personatus*										**1**/1		**6**/1
Dash goby	*Ctenogobius saepepallens*			**2**/2		**2**/1		**2**/1					
Tiger goby	*Elacatinus macrodon*							**1**/1	**1**/1		**1**/1		**2**/2
Neon goby	*Elacatinus oceanops*					**2**/2	**2**/1		**2**/2	**2**/1	**1**/1		**1**/1
Goldspot goby	*Gnatholepis thompsoni*											**2**/2	
Rockcut goby	*Gobiosoma grosvenori*		**1**/1										
Seminole goby	*Microgobius carri*	**2**/1						**3**/1	**2**/1				
Dartfishes	**Ptereleotridae**												
Blue goby	*Ptereleotris calliura*			**5**/4				**1**/1	**1**/1			**1**/1	
Spadefishes	**Ephippidae**												
Atlantic spadefish	*Chaetodipterus faber*								**2**/1		**1**/1		
Surgeonfishes	**Acanthuridae**												
Ocean surgeon	*Acanthurus bahianus*	**6**/3	**77**/20	**4**/3	**81**/22	**5**/3	**38**/19	**22**/8	**50**/15	**2**/2	**54**/14	**29**/7	**95**/18
Doctorfish	*Acanthurus chirurgus*	**39**/13	**32**/16	**10**/5	**25**/12	**27**/12	**16**/7	**14**/9	**51**/16	**2**/2	**15**/10	**31**/9	**59**/17
Blue tang	*Acanthurus coeruleus*	**1**/1	**6**/4	**1**/1	**10**/9		**5**/4		**17**/11		**17**/10	**4**/2	**37**/18
Barracudas	**Sphyraenidae**												
Great barracuda	*Sphyraena barracuda*		**1**/1										**2**/2
Mackerels	**Scombridae**												
Spanish mackerel	*Scomberomoros maculatus*												**1**/1
Cero	*Scomberomorus regalis*				**1**/1								
Lefteye flounders	**Bothidae**												
Peacock flounder	*Bothus lunatus*	**1**/1						**1**/1		**1**/1			
Triggerfishes	**Balistidae**												

Appendix A cont'd. Fish species recorded on all transects by total count (T) and the number of occurrences seen (O) on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		**Aug 2004**		**Mar 2005**		**Aug 2005**		**Aug 2006**		**Aug 2007**	
		N	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Common Name	**Scientific Name**	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O	**T**/O
Gray triggerfish	*Balistes capriscus*	**5**/4	**35**/19	**6**/3	**21**/12	**5**/4	**9**/7	**10**/5	**19**/10	**6**/4	**15**/8	**3**/3	**7**/5
Filefishes	**Monacanthidae**												
Scrawled filefish	*Aluterus scriptus*						**1**/1						
Slender filefish	*Monacanthus tuckeri*											**1**/1	
Planehead filefish	*Stephanolepis hispidus*			**1**/1		**2**/2	**1**/1						
Boxfishes	**Ostraciidae**												
Honeycomb cowfish	*Acanthostracion polygonius*						**1**/1						
Scrawled cowfish	*Acanthostracion quadricornis*		**1**/1			**1**/1			**1**/1		**1**/1		**3**/3
Spotted trunkfish	*Lactophrys bicaudalis*											**1**/1	
Smooth trunkfish	*Lactophrys triqueter*		**2**/2		**1**/1	**1**/1	**2**/1			**1**/1	**3**/2		**3**/2
Puffers	**Tetraodontidae**												
Sharpnose puffer	*Canthigaster rostrata*	**1**/1	**1**/1				**11**/10	**1**/1	**10**/7	**1**/1	**6**/5	**4**/3	**17**/11
Bandtail puffer	*Sphoeroides spengleri*					**1**/1	**1**/1	**2**/2		**1**/1		**1**/1	
Porcupinefishes	**Diodontidae**												
Balloonfish	*Diodon holocanthus*	**3**/3		**1**/1				**3**/3	**3**/2	**1**/1	**6**/4		**2**/1
Porcupinefish	*Diodon hystrix*		**1**/1							**1**/1			
	Total Abundance	**1166**	**1809**	**1409**	**1973**	**538**	**486**	**917**	**1677**	**713**	**1510**	**2374**	**4314**
	Total Species	**45**	**64**	**48**	**56**	**38**	**57**	**49**	**65**	**45**	**63**	**60**	**68**

Appendix B

Appendix B. Fish species recorded on rover diver counts for all years with the number of occurrences seen on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		**Aug 2004**		**Mar 2005**		**Aug 2005**		**Aug 2006**		**Aug 2007**	
Common Name	**Scientific Name**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Nurse sharks	**Ginglymostomatidae**												
Nurse shark	*Ginglymostoma cirratum*	1	1		2		1		1		2	1	1
Numbfishes	**Narcinidae**												
Lesser electric ray	*Narcine brasiliensis*											2	
Guitarfishes	**Rhinobatidae**												
Atlantic guitarfish	*Rhinobatus lentiginosus*					1							
Stingrays	**Dasyatidae**												
Southern stingray	*Dasyatis americana*				2		1		1				3
Eagle rays	**Myliobatidae**												
Spotted eagle ray	*Aetobatus narinari*			1									
Round rays	**Urolophidae**												
Yellow stingray	*Urobatis jamaicensis*	5	1	4	1	2	1	4	5	4	2	5	
Tarpons	**Megalopidae**												
Tarpon	*Megalops atlanticus*	1	5	1	3		2	1	3	1	2	4	2
Moray eels	**Muraenidae**												
Green moray	*Gymnothorax funebris*									1			
Goldentail moray	*Gymnothorax miliaris*	1										1	
Spotted moray	*Gymnothorax moringa*					1							
Moray species	*Gymnothorax* sp.			1									
Purplemouth moray	*Gymnothorax vicinus*	1		1		5		1		2		1	
Snake eels	**Ophichthidae**												
Goldspotted eel	*Myrichthys ocellatus*								1		1		
Lizardfishes	**Synodontidae**												
Inshore lizardfish	*Synodus foetens*				1				2		1		
Sand diver	*Synodus intermedius*		3		3		1		5	1	1		4
Lizardfish species	*Synodus* sp.											1	

Appendix B cont'd. Fish species recorded on rover diver counts for all years with the number of occurrences seen on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
Common Name	**Scientific Name**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Squirrelfishes	**Holocentridae**												
Squirrelfish	*Holocentrus adscensionis*	1	1		1				1		2		3
Blackbar soldierfish	*Myripristis jacobus*	1		1									
Trumpetfishes	**Aulostomidae**												
Trumpetfish	*Aulostomus maculatus*								1				
Scorpionfishes	**Scorpaenidae**												
Barbfish	*Scorpaena brasiliensis*							1					
Plumed scorpionfish	*Scorpaena grandicornis*				1								
Spotted scorpionfish	*Scorpaena plumieri*	2	1	3	1	1	5		2	1	5	2	2
Scorpionfish species	*Scorpaena* sp.		1										
Snooks	**Centropomidae**												
Common snook	*Centropomus undecimalis*		4		1		7		9		4		5
Sea basses	**Serranidae**												
Coney	*Cephalopholis fulva*			1									
Sand perch	*Diplectrum formosum*	8	4	21	9	7	1	9		11	4	13	1
Rock hind	*Epinephelus adscensionis*										1		1
Red hind	*Epinephelus guttatus*											1	
Red grouper	*Epinephelus morio*		1	2	1	1	1		3	1		1	
Butter hamlet	*Hypoplectrus unicolor*				1				1		2		1
Black grouper	*Mycteroperca bonaci*						1						
Gag	*Mycteroperca microlepis*						2		2		3		
Scamp	*Mycteroperca phenax*				1				3		3	4	5
Greater soapfish	*Rypticus saponaceus*									1	2	1	1
Lantern bass	*Serranus baldwini*	1						1				1	
Tattler bass	*Serranus phoebe*						1						
Belted sandfish	*Serranus subligarius*		1										

Appendix B cont'd. Fish species recorded on rover diver counts for all years with the number of occurrences seen on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
Common Name	**Scientific Name**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Harlequin bass	*Serranus tigrinus*			2									
Jawfishes	**Opistognathidae**												
Banded jawfish	*Opistognathus macrognathus*									1			
Dusky jawfish	*Opistognathus whitehursti*	2		10				3		11	2	3	
Bigeyes	**Priacanthidae**												
Glasseye	*Heteropriacanthus cruentatus*		1										
Cardinalfishes	**Apogonidae**												
Barred cardinalfish	*Apogon binotatus*									1			
Flamefish	*Apogon maculatus*	2	8	4	7	2	2	1	4	1	3	3	4
Twospot cardinalfish	*Apogon pseudomaculatus*	6	1		2		1	1		1	2	2	2
Cardinalfish species	*Apogonidae* sp.												1
Belted cardinalfish	*Apogon townsendi*		2										
Conchfish	*Astrapogon stellatus*				1								
Remoras	**Echeneidae**												
Sharksucker	*Echeneis naucrates*										1		1
Jacks	**Carangidae**												
Yellow jack	*Carangoides bartholomaei*		5		7	2	3		1	1	8	2	1
Bar jack	*Carangoides ruber*	3	16	4	23		5	3	7	1	12	5	14
Blue runner	*Caranx crysos*		6	8	6	2	1	1	9	1	5	3	
Crevalle jack	*Caranx hippos*		4		1		1	1	3		3		
Mackerel scad	*Decapterus macarellus*												1
Round scad	*Decapterus punctatus*				3		1						1
Leatherjack	*Oligoplites saurus*							1					
Greater amberjack	*Seriola dumerili*								1	1			1
Almaco jack	*Seriola rivoliana*								2		1		
Snappers	**Lutjanidae**												

Appendix B cont'd. Fish species recorded on rover diver counts for all years with the number of occurrences seen on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
Common Name	**Scientific Name**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Mutton snapper	*Lutjanus analis*	1	2	1		3		1	1	3	1	4	1
Schoolmaster	*Lutjanus apodus*		1		1				1		2		
Blackfin snapper	*Lutjanus buccanella*							1			1		
Gray snapper	*Lutjanus griseus*	1	22	1	22		18	1	18		19	1	20
Mahogany snapper	*Lutjanus mahogoni*		1										6
Lane snapper	*Lutjanus synagris*	7	25	24	23	3	21	24	25	24	24	16	23
Yellowtail snapper	*Ocyurus chrysurus*	12	6	17	11		9	22	13	10	10	16	9
Vermilion snapper	*Rhomboplites aurorubens*										3		
Tripletails	**Lobotidae**												
Tripletail	*Lobotes surinamensis*									1			
Mojarras	**Gerreidae**												
Slender mojarra	*Eucinostomus jonesii*		5	1	5		6		8	1	4	2	12
Mottled mojarra	*Eucinostomus lefroyi*	1	3			1	2						
Flagfin mojarra	*Eucinostomus melanopterus*											1	
Mojarra species	*Gerreidae* spp.			2				2				4	
Yellowfin mojarra	*Gerres cinereus*		22	4	23	1	17	3	18	2	21	3	24
Grunts	**Haemulidae**												
Black margate	*Anisotremus surinamensis*	1	13		10		19		16		16		13
Porkfish	*Anisotremus virginicus*	14	23	9	23	6	23	12	25	2	25	12	23
White margate	*Haemulon album*		1						4				
Tomtate	*Haemulon aurolineatum*	13	24		24	4	18	8	20	12	20	17	18
Caesar grunt	*Haemulon carbonarium*	1			4				2		1		
Smallmouth grunt	*Haemulon chrysargyreum*				1							1	1
French grunt	*Haemulon flavolineatum*	3	14	23	23	1	18	2	19	4	23	14	24
Spanish grunt	*Haemulon macrostomum*		2		1		2		4		9	1	3
Cottonwick	*Haemulon melanurum*	1		2							1		

Appendix B cont'd. Fish species recorded on rover diver counts for all years with the number of occurrences seen on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
Common Name	**Scientific Name**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Sailor's choice	*Haemulon parra*	4	21	7	20		16	3	16	4	21	5	18
White grunt	*Haemulon plumierii*	14	25	20	24	9	24	15	25	8	24	16	23
Bluestriped grunt	*Haemulon sciurus*	7	21	13	22	9	19	14	22	6	13	14	23
Juvenile grunts	*Haemulon* spp.	24	15	7	11	13	1	18	10	6	6	12	8
Striped grunt	*Haemulon striatum*		1										
Pigfish	*Orthopristis chrysoptera*		1		7		5		2				2
Bonnetmouths	**Inermiidae**												
Boga	*Inermia vittata*												1
Porgies	**Sparidae**												
Sea bream	*Archosargus rhomboidalis*		24		18		23		15		16	1	15
Sheepshead seabream	*Archosargus probatocephalus*						5						
Saucereye porgy	*Calamus calamus*		1		3	4	2	1			1		2
Sheepshead porgy	*Calamus penna*	1				1	1					1	1
Littlehead porgy	*Calamus proridens*					2							
Porgy species	*Calamus* spp.	1		2				1			1		
Silver porgy	*Diplodus argenteus*	2	24	1	19	2	19		23		13	1	12
Spottail pinfish	*Diplodus holbrookii*										13	1	16
Pinfish	*Lagodon rhomboides*		8		3		2				7		
Drums	**Sciaenidae**												
Reef croaker	*Odontoscion dentex*		6				1		2		2		1
Highhat	*Pareques acuminatus*	23	15	17	15	16	4	21	8	11	12	13	5
Goatfishes	**Mullidae**												
Yellow goatfish	*Mulloidichthys martinicus*		2		11				2		1		5
Spotted goatfish	*Pseudupeneus maculatus*	16	13	7	5	8	2	1	4		1	4	5
Sweepers	**Pempheridae**												
Glassy sweeper	*Pempheris schomburgkii*	1	3			1							

Appendix B cont'd. Fish species recorded on rover diver counts for all years with the number of occurrences seen on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
Common Name	**Scientific Name**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Sea chubs	**Kyphosidae**												
Bermuda sea chub	*Kyphosus sectator*	1	6		4		2		13		15	1	12
Butterflyfishes	**Chaetodontidae**												
Foureye butterflyfish	*Chaetodon capistratus*										1	2	
Spotfin butterflyfish	*Chaetodon ocellatus*		4		2	2	1	4		1	2	3	
Reef butterflyfish	*Chaetodon sedentarius*	3	1		2	1		1	2	1	2	2	1
Banded butterflyfish	*Chaetodon striatus*	2	1	1								1	
Angelfishes	**Pomacanthidae**												
Blue angelfish	*Holacanthus bermudensis*		6		1	1	1		5		5	1	5
Queen angelfish	*Holacanthus ciliaris*		2	1	2		5	2	5	1	6	7	14
Rock beauty	*Holacanthus tricolor*											2	
Townsend angelfish	*Holacanthus* sp.										1		
Gray angelfish	*Pomacanthus arcuatus*	2	3	5	12		9	5	13	4	15	9	16
French angelfish	*Pomacanthus paru*	4	5	3	8	1	8	4	11	2	16	6	14
Damselfishes	**Pomacentridae**												
Sergeant major	*Abudefduf saxatilis*	14	20	12	24	11	17	13	14	10	20	14	14
Brown chromis	*Chromis multilineata*												1
Yellowtail damselfish	*Microspathodon chrysurus*										1		1
Dusky damselfish	*Stegastes adustus*	7	18	5	16	8	15	8	12	9	20	14	19
Longfin damselfish	*Stegastes diencaeus*					1	1	3		1	7	1	
Beaugregory	*Stegastes leucostictus*	11	16	20	16	3	14	17	11	16	23	19	19
Bicolor damselfish	*Stegastes partitus*	2		4	3				1	3	4	7	9
Threespot damselfish	*Stegastes planifrons*	24	1	1	9				1		8		2
Cocoa damselfish	*Stegastes variabilis*		16	23	25	9	21	15	19	18	24	19	23
Wrasses	**Labridae**												
Spanish hogfish	*Bodianus rufus*								1		6		5

Appendix B cont'd. Fish species recorded on rover diver counts for all years with the number of occurrences seen on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
Common Name	**Scientific Name**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Dwarf wrasse	*Doratonotus megalepis*							1					
Slippery dick	*Halichoeres bivittatus*	25	23	24	24	25	23	23	21	21	23	23	21
Clown wrasse	*Halichoeres maculipinna*	10	7	3	1	4	2	5	9	9	16	6	11
Blackear wrasse	*Halichoeres poeyi*	5	1	2	1	1		1		4		12	7
Puddingwife	*Halichoeres radiatus*	1	12		4	6	3		6		5		5
Hogfish	*Lachnolaimus maximus*		2	2	2	1	7		7	2	11	2	4
Bluehead	*Thalassoma bifasciatum*	6	24	9	21	8	20	7	22	6	25	13	25
Rosy razorfish	*Xyrichtys martinicensis*	2		2				1		4	1		
Green razorfish	*Xyrichtys splendens*	4		11	1	8		7	1	11		10	
Parrotfishes	**Scaridae**												
Bluelip parrotfish	*Cryptotomus roseus*											1	1
Midnight parrotfish	*Scarus coelestinus*										1		
Rainbow parrotfish	*Scarus guacamaia*						1		2		3		8
Striped parrotfish	*Scarus iseri*		2	2	12		1			2	9	4	10
Princess parrotfish	*Scarus taeniopterus*										4	1	
Greenblotch parrotfish	*Sparisoma atomarium*							2	4	1	1	1	2
Redband parrotfish	*Sparisoma aurofrenatum*	14	12	12	11	5	9	8	16	10	10	16	12
Redtail parrotfish	*Sparisoma chrysopterum*	3	9		4	1	5			1	4	1	5
Bucktooth parrotfish	*Sparisoma radians*	5	4	24	18	1		14	2	15	10	13	16
Redfin parrotfish	*Sparisoma rubripinne*		5	2	16		6		4	1	5	1	9
Parrotfish species	*Sparisoma* spp.							2					
Stoplight parrotfish	*Sparisoma viride*	1	3	1	11		6	4	14	1	20	2	20
Threefin blennies	**Tripterygiidae**												
Lofty triplefin	*Enneanectes altivelis*												1
Triplefin species	*Enneanectes* sp.				1								
Labrisomids	**Labrisomidae**												

Appendix B cont'd. Fish species recorded on rover diver counts for all years with the number of occurrences seen on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
Common Name	**Scientific Name**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Downy blenny	*Labrisomus kalisherae*	3			1							1	
Spotcheek blenny	*Labrisomus nigricinctus*		1										
Rosy blenny	*Malacoctenus macropus*	7	3	20	10	8	7	12	2	7	7	17	9
Saddled blenny	*Malacoctenus triangulatus*	2	1		1			2		1		5	
Tube blennies	**Chaenopsidae**												
Roughhead blenny	*Acanthemblemaria aspera*	3	7	1	5	2	2		7		1	1	8
Blenny species	*Acanthemblemaria* spp.		2							1			1
Sailfin blenny	*Emblemaria pandionis*	1	3	7	1	17	7	5	3	10		7	2
Combtooth blennies	**Blenniidae**												
Redlip blenny	*Ophioblennius macclurei*												1
Seaweed blenny	*Parablennius marmoreus*	7	10	12	19	14	9	15	6	9	10	14	9
Molly miller	*Scartella cristata*									1			
Dragonets	**Callionymidae**												
Lancer dragonet	*Callionymus bairdi*									1			
Gobies	**Gobiidae**												
Colon goby	*Coryphopterus dicrus*			1									
Pallid goby	*Coryphopterus eidolon*							1	1				
Bridled goby	*Coryphopterus glaucofraenum*		2	19	24	9	3	9	1	8	10	12	13
Masked goby	*Coryphopterus personatus*										1		1
Dash goby	*Ctenogobius saepepallens*			2				3					
Tiger goby	*Elacatinus macrodon*		1	1		1			2	1	7		6
Neon goby	*Elacatinus oceanops*	1	3	5	1	2	1	3	5	2	8	2	7
Goldspot goby	*Gnatholepis thompsoni*			1				2				1	
Rockcut goby	*Gobiosoma grosvenori*		2										
Seminole goby	*Microgobius carri*	1		2	1			5				2	
Banner goby	*Microgobius microlepis*							2					1

Appendix B cont'd. Fish species recorded on rover diver counts for all years with the number of occurrences seen on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
Common Name	**Scientific Name**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Orangespotted goby	*Nes longus*										1		
Dartfishes	**Ptereleotridae**												
Blue goby	*Ptereleotris calliura*	3		3				1		3		7	
Hovering goby	*Ptereleotris helenae*							2					
Spadefishes	**Ephippidae**												
Atlantic spadefish	*Chaetodipterus faber*		1						3		4	1	3
Surgeonfishes	**Acanthuridae**												
Ocean surgeon	*Acanthurus bahianus*	20	22	17	24	19	22	16	16	8	20	15	18
Doctorfish	*Acanthurus chirurgus*	17	24	14	24	15	22	17	21	13	19	21	20
Blue tang	*Acanthurus coeruleus*	1	17	1	22	3	17	2	22	1	25	10	24
Barracudas	**Sphyraenidae**												
Great barracuda	*Sphyraena barracuda*	2	3	1	1				2		3	1	3
Guachanche barracuda	*Sphyraena guachancho*					1							
Mackerels	**Scombridae**												
Spanish mackerel	*Scomberomorus maculatus*			1							1		
Cero	*Scomberomorus regalis*		2	1	2	1		1					
Lefteye flounders	**Bothidae**												
Peacock flounder	*Bothus lunatus*					1				1		2	
Flounder species	*Bothus* spp.	1	1	1							1	2	
Large-tooth flounders	**Paralichthyidae**												
Gulf flounder	*Paralichthys albigutta*						1						
Triggerfishes	**Balistidae**												
Gray triggerfish	*Balistes capriscus*	7	24	8	22	11	17	13	16	9	13	7	15
Ocean triggerfish	*Canthidermis sufflamen*									1			
Filefishes	**Monacanthidae**												
Orange filefish	*Aluterus schoepfii*			1		1							

Appendix B cont'd. Fish species recorded on rover diver counts for all years with the number of occurrences seen on both the natural hardbottom (N) and the mitigation boulders (B).

		Jun 2004		Aug 2004		Mar 2005		Aug 2005		Aug 2006		Aug 2007	
Common Name	**Scientific Name**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**	**N**	**B**
Scrawled filefish	*Aluterus scriptus*		1	1	4	1	2	1	1		5		2
Orangespotted filefish	*Cantherhines pullus*	1										1	
Fringed filefish	*Monacanthus ciliatus*	1											
Slender filefish	*Monacanthus tuckeri*									1			
Planehead filefish	*Stephanolepis hispidus*	1	6	1	2	7	4	1			2	2	
Boxfishes	**Ostraciidae**												
Honeycomb cowfish	*Acanthostracion polygonius*				1						1		
Scrawled cowfish	*Acanthostracion quadricornis*	1	10	7	9	7	14	7	8	6	9	3	15
Spotted trunkfish	*Lactophrys bicaudalis*				2		1				1		2
Trunkfish	*Lactophrys trigonus*		2				1		2		1	1	
Smooth trunkfish	*Lactophrys triqueter*		4	4	6	5	3	9	2	3	10	4	8
Puffers	**Tetraodontidae**												
Sharpnose puffer	*Canthigaster rostrata*	5	1	4	2	5	14	8	16	2	9	6	19
Bandtail puffer	*Sphoeroides spengleri*			3		1	2	9	1	2	3	2	1
Checkered puffer	*Sphoeroides testudineus*					1							
Porcupinefishes	**Diodontidae**												
Striped burrfish	*Chilomycterus schoepfii*							1					
Balloonfish	*Diodon holocanthus*	6	6	15	5	7	6	8	8	8	10	5	8
Porcupinefish	*Diodon hystrix*	1	1		2		4			1	1		4
	Total Species	**76**	**98**	**81**	**97**	**68**	**86**	**75**	**92**	**80**	**114**	**100**	**104**

Appendix C

Appendix C. GPS coordinates of natural hardbottom transects.

Transect Label	West Latitude DD MM.SS	West Longitude DD MM.SS	East Latitude DD MM.SS	East Longitude DD MM.SS
C074a	26 07.533	80 06.065	26 07.533	80 06.047
P088a	26 05.207	80 06.460	26 05.210	80 06.442
P090a	26 04.875	80 06.531	26 04.877	80 06.513
C098a	26 03.557	80 06.583	26 03.555	80 06.565
N099a	26 03.398	80 06.593	26 03.400	80 06.575
N099b	26 03.315	80 06.621	26 03.317	80 06.603
P100a	26 03.240	80 06.600	26 03.244	80 06.583
P100b	26 03.120	80 06.618	26 03.121	80 06.601
P101a	26 03.055	80 06.640	26 03.057	80 06.623
N104a	26 02.567	80 06.656	26 02.568	80 06.639
N104b	26 02.466	80 06.674	26 02.468	80 06.656
N105b	26 02.299	80 06.689	26 02.301	80 06.672
N106a	26 02.217	80 06.707	26 02.219	80 06.689
P108a	26 01.893	80 06.722	26 01.897	80 06.704
N110a	26 01.547	80 06.744	26 01.549	80 06.726
P113a	26 01.059	80 06.787	26 01.061	80 06.769
P116a	26 00.555	80 06.797	26 00.557	80 06.778
P119a	26 00.050	80 06.815	26 00.049	80 06.798
P120a	25 59.864	80 06.851	25 59.864	80 06.833
N120b	25 59.773	80 06.851	25 59.773	80 06.833
N121b	25 59.607	80 06.870	25 59.609	80 06.851
N122a	25 59.526	80 06.882	25 59.527	80 06.874
P123a	25 59.346	80 06.900	25 59.347	80 06.882
N126b	25 58.742	80 06.927	25 58.738	80 06.909
N127a	25 58.666	80 06.956	25 58.670	80 06.940

Appendix C cont'd. GPS coordinates of mitigation boulder transects.

Transect Label	West Latitude DD MM.SS	West Longitude DD MM.SS	East Latitude DD MM.SS	East Longitude DD MM.SS
A101c	26 02.954	80 06.626	26 02.956	80 06.607
A101d	26 02.933	80 06.621	26 02.936	80 06.604
A101e	26 02.912	80 06.620	26 02.911	80 06.603
A101f	26 02.892	80 06.617	26 02.895	80 06.510
A102b	26 02.870	80 06.613	26 02.871	80 06.596
A102c	26 02.849	80 06.616	26 02.851	80 06.599
A102d	26 02.825	80 06.619	26 02.827	80 06.600
A102e	26 02.806	80 06.623	26 02.810	80 06.605
A102g	26 02.783	80 06.629	26 02.787	80 06.611
A102h	26 02.759	80 06.612	26 02.763	80 06.594
A102i	26 02.760	80 06.631	26 02.760	80 06.613
A103c	26 02.626	80 06.650	26 02.630	80 06.632
A123c	25 59.241	80 06.903	25 59.243	80 06.886
A123d	25 59.222	80 06.905	25 59.223	80 06.887
A123e	25 59.209	80 06.906	25 59.211	80 06.889
A123f	25 59.188	80 06.907	25 59.190	80 06.890
A125b	25 58.943	80 06.888	25 58.944	80 06.870
A125c	25 58.940	80 06.906	25 58.942	80 06.887
A125d	25 58.940	80 06.931	25 58.942	80 06.914
A125f	25 58.891	80 06.895	25 58.893	80 06.877
A125g	25 58.892	80 06.911	25 58.895	80 06.894
A125h	25 58.891	80 06.933	25 58.894	80 06.916
A125i	25 58.862	80 06.884	25 58.864	80 06.865
A125j	25 58.863	80 06.900	25 58.863	80 06.883
A125k	25 58.861	80 06.935	25 58.863	80 06.917

Appendix D

Appendix D. Fishes present on all transect surveys (both natural hardbottom and mitigation boulder combined) classified according to trophic level. BC=benthic carnivore, C=cleaner, H=herbivore, O=omnivore, Pi=piscivore, and Pl=planktivore.

Common Name	Scientific Name	Trophic Level
Nurse sharks	**Ginglymostomatidae**	
Nurse shark	*Ginglymostoma cirratum*	BC
Stingrays	**Dasyatidae**	
Southern stingray	*Dasyatis americana*	BC
Round rays	**Urolophidae**	
Yellow stingray	*Urobatis jamaicensis*	BC
Tarpons	**Megalopidae**	
Tarpon	*Megalops atlanticus*	Pi
Moray eels	**Muraenidae**	
Green moray	*Gymnothorax funebris*	Pi
Spotted moray	*Gymnothorax moringa*	Pi
Purplemouth moray	*Gymnothorax vicinus*	Pi
Lizardfishes	**Synodontidae**	
Inshore lizardfish	*Synodus foetens*	Pi
Lizardfish species	*Synodus intermedius*	Pi
Sand diver	*Synodus* sp.	Pi
Squirrelfishes	**Holocentridae**	
Squirrelfish	*Holocentrus adscensionis*	BC
Scorpionfishes	**Scorpaenidae**	
Barbfish	*Scorpaena brasiliensis*	Pi
Spotted scorpionfish	*Scorpaena plumieri*	Pi
Snooks	**Centropomidae**	
Common snook	*Centropomus undecimalis*	BC
Sea basses	**Serranidae**	
Graysby	*Cephalopholis cruentata*	BC
Sand perch	*Diplectrum formosum*	BC
Red grouper	*Epinephelus morio*	BC
Butter hamlet	*Hypoplectrus unicolor*	BC
Scamp	*Mycteroperca phenax*	BC
Greater soapfish	*Rypticus saponaceus*	BC
Lantern bass	*Serranus baldwini*	BC
Belted sandfish	*Serranus subligarius*	BC
Harlequin bass	*Serranus tigrinus*	BC
Jawfishes	**Opistognathidae**	
Dusky jawfish	*Opistognathus whitehursti*	BC
Cardinalfishes	**Apogonidae**	
Flamefish	*Apogon maculatus*	BC
Twospot cardinalfish	*Apogon pseudomaculatus*	BC
Jacks	**Carangidae**	
Yellow jack	*Carangoides bartholomaei*	Pi
Bar jack	*Carangoides ruber*	Pi
Blue runner	*Caranx crysos*	Pi
Crevalle jack	*Caranx hippos*	Pi
Lookdown	*Selene vomer*	BC

Appendix D cont'd. Fishes present on all transect surveys (both natural hardbottom and mitigation boulder combined) classified according to trophic level. BC=benthic carnivore, C=cleaner, H=herbivore, O=omnivore, Pi=piscivore, and Pl=planktivore.

Common Name	Scientific Name	Trophic Level
Greater amberjack	*Seriola dumerili*	Pi
Snappers	**Lutjanidae**	
Mutton snapper	*Lutjanus analis*	BC
Schoolmaster	*Lutjanus apodus*	BC
Blackfin snapper	*Lutjanus buccanella*	Pi
Gray snapper	*Lutjanus griseus*	BC
Mahogany snapper	*Lutjanus mahogoni*	BC
Lane snapper	*Lutjanus synagris*	BC
Yellowtail snapper	*Ocyurus chrysurus*	BC
Mojarras	**Gerreidae**	
Slender mojarra	*Eucinostomus jonesii*	BC
Mottled mojarra	*Eucinostomus lefroyi*	BC
Yellowfin mojarra	*Gerres cinereus*	BC
Grunts	**Haemulidae**	
Black margate	*Anisotremus surinamensis*	BC
Porkfish	*Anisotremus virginicus*	BC
White margate	*Haemulon album*	BC
Tomtate	*Haemulon aurolineatum*	BC
Caesar grunt	*Haemulon carbonarium*	BC
Smallmouth grunt	*Haemulon chrysargyreum*	BC
French grunt	*Haemulon flavolineatum*	BC
Spanish grunt	*Haemulon macrostomum*	BC
Sailor's choice	*Haemulon parra*	BC
White grunt	*Haemulon plumierii*	BC
Bluestriped grunt	*Haemulon sciurus*	BC
Juvenile grunts	*Haemulon* spp.	Pl
Striped grunt	*Haemulon striatum*	Pl
Pigfish	*Orthopristis chrysoptera*	BC
Porgies	**Sparidae**	
Sea bream	*Archosargus rhomboidalis*	O
Grass porgy	*Calamus arctifrons*	BC
Saucereye porgy	*Calamus calamus*	BC
Porgy species	*Calamus* spp.	BC
Silver porgy	*Diplodus argenteus*	O
Spottail pinfish	*Diplodus holbrookii*	O
Pinfish	*Lagodon rhomboides*	BC
Drums	**Sciaenidae**	
Reef croaker	*Odontoscion dentex*	BC
Highhat	*Pareques acuminatus*	BC
Goatfishes	**Mullidae**	
Yellow goatfish	*Mulloidichthys martinicus*	BC
Spotted goatfish	*Pseudupeneus maculatus*	BC
Sea chubs	**Kyphosidae**	
Bermuda sea chub	*Kyphosus sectator*	H

Appendix D cont'd. Fishes present on all transect surveys (both natural hardbottom and mitigation boulder combined) classified according to trophic level. BC=benthic carnivore, C=cleaner, H=herbivore, O=omnivore, Pi=piscivore, and Pl=planktivore.

Common Name	Scientific Name	Trophic Level
Butterflyfishes	**Chaetodontidae**	
Spotfin butterflyfish	*Chaetodon ocellatus*	BC
Reef butterflyfish	*Chaetodon sedentarius*	BC
Angelfishes	**Pomacanthidae**	
Blue angelfish	*Holacanthus bermudensis*	O
Queen angelfish	*Holacanthus ciliaris*	O
Rock beauty	*Holacanthus tricolor*	O
Gray angelfish	*Pomacanthus arcuatus*	O
French angelfish	*Pomacanthus paru*	O
Damselfishes	**Pomacentridae**	
Sergeant major	*Abudefduf saxatilis*	O
Blue chromis	*Chromis cyanea*	BC
Yellowtail damselfish	*Microspathodon chrysurus*	H
Dusky damselfish	*Stegastes adustus*	O
Longfin damselfish	*Stegastes diencaeus*	O
Beaugregory	*Stegastes leucostictus*	O
Bicolor damselfish	*Stegastes partitus*	O
Threespot damselfish	*Stegastes planifrons*	O
Damselfish species	*Stegastes* sp.	O
Cocoa damselfish	*Stegastes variabilis*	O
Wrasses	**Labridae**	
Spanish hogfish	*Bodianus rufus*	BC
Slippery dick	*Halichoeres bivittatus*	BC
Clown wrasse	*Halichoeres maculipinna*	BC
Blackear wrasse	*Halichoeres poeyi*	BC
Puddingwife	*Halichoeres radiatus*	BC
Hogfish	*Lachnolaimus maximus*	BC
Bluehead	*Thalassoma bifasciatum*	BC
Rosy razorfish	*Xyrichtys martinicensis*	BC
Green razorfish	*Xyrichtys splendens*	BC
Razorfish species	*Xyrichtys* spp.	BC
Parrotfishes	**Scaridae**	
Midnight parrotfish	*Scarus coelestinus*	H
Rainbow parrotfish	*Scarus guacamaia*	H
Striped parrotfish	*Scarus iseri*	H
Princess parrotfish	*Scarus taeniopterus*	H
Redband parrotfish	*Sparisoma aurofrenatum*	H
Bucktooth parrotfish	*Sparisoma radians*	H
Redfin parrotfish	*Sparisoma rubripinne*	H
Stoplight parrotfish	*Sparisoma viride*	H
Threefin blennies	**Tripterygiidae**	
Roughhead triplefin	*Enneanectes boehlkei*	BC
Labrisomids	**Labrisomidae**	
Rosy blenny	*Malacoctenus macropus*	BC

Appendix D cont'd. Fishes present on all transect surveys (both natural hardbottom and mitigation boulder combined) classified according to trophic level. BC=benthic carnivore, C=cleaner, H=herbivore, O=omnivore, Pi=piscivore, and Pl=planktivore.

Common Name	Scientific Name	Trophic Level
Saddled blenny	*Malacoctenus triangulatus*	BC
Banded blenny	*Paraclinus fasciatus*	BC
Tube blennies	**Chaenopsidae**	
Roughhead blenny	*Acanthemblemaria aspera*	BC
Sailfin blenny	*Emblemaria pandionis*	BC
Combtooth blennies	**Blenniidae**	
Seaweed blenny	*Parablennius marmoreus*	H
Dragonets	**Callionymidae**	
Lancer dragonet	*Callionymus bairdi*	BC
Gobies	**Gobiidae**	
Colon goby	*Coryphopterus dicrus*	BC
Bridled goby	*Coryphopterus glaucofraenum*	O
Masked goby	*Coryphopterus personatus*	Pl
Dash goby	*Ctenogobius saepepallens*	BC
Tiger goby	*Elacatinus macrodon*	BC
Neon goby	*Elacatinus oceanops*	C
Goldspot goby	*Gnatholepis thompsoni*	BC
Rockcut goby	*Gobiosoma grosvenori*	BC
Seminole goby	*Microgobius carri*	BC
Dartfishes	**Ptereleotridae**	
Blue goby	*Ptereleotris calliura*	Pl
Spadefishes	**Ephippidae**	
Atlantic spadefish	*Chaetodipterus faber*	O
Surgeonfishes	**Acanthuridae**	
Ocean surgeon	*Acanthurus bahianus*	H
Doctorfish	*Acanthurus chirurgus*	H
Blue tang	*Acanthurus coeruleus*	H
Barracudas	**Sphyraenidae**	
Great barracuda	*Sphyraena barracuda*	Pi
Mackerels	**Scombridae**	
Spanish mackerel	*Scomberomoros maculatus*	Pi
Cero	*Scomberomorus regalis*	Pi
Lefteye flounders	**Bothidae**	
Peacock flounder	*Bothus lunatus*	BC
Triggerfishes	**Balistidae**	
Gray triggerfish	*Balistes capriscus*	BC
Filefishes	**Monacanthidae**	
Scrawled filefish	*Aluterus scriptus*	O
Slender filefish	*Monacanthus tuckeri*	O
Planehead filefish	*Stephanolepis hispidus*	BC
Boxfishes	**Ostraciidae**	
Honeycomb cowfish	*Acanthostracion polygonius*	BC
Scrawled cowfish	*Acanthostracion quadricornis*	O
Spotted trunkfish	*Lactophrys bicaudalis*	O

Appendix D cont'd. Fishes present on all transect surveys (both natural hardbottom and mitigation boulder combined) classified according to trophic level. BC=benthic carnivore, C=cleaner, H=herbivore, O=omnivore, Pi=piscivore, and Pl=planktivore.

Common Name	Scientific Name	Trophic Level
Smooth trunkfish	*Lactophrys triqueter*	BC
Puffers	**Tetraodontidae**	
Sharpnose puffer	*Canthigaster rostrata*	O
Bandtail puffer	*Sphoeroides spengleri*	O
Porcupinefishes	**Diodontidae**	
Balloonfish	*Diodon holocanthus*	BC
Porcupinefish	*Diodon hystrix*	BC