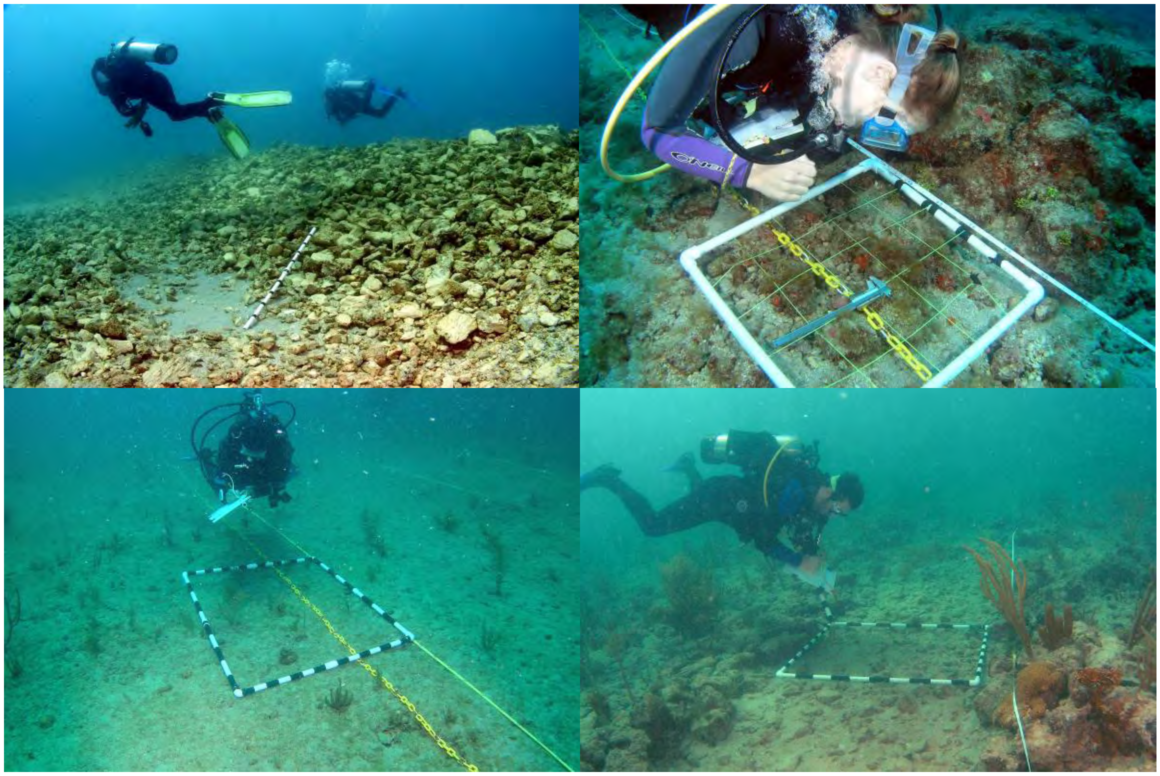
A Study to Evaluate Reef Recovery Following Injury and Mitigation Structures Offshore Southeast Florida: Phase I



Southeast Florida Coral Reef Initiative
Maritime Industry and Coastal Construction Impacts (MICCI)
Local Action Strategy Project 14, 15, and 16

Southeast
Florida
Coral Reef
Initiative
Acting above to protect what's below.

A Study to Evaluate Reef Recovery Following Injury and Mitigation Structures Offshore Southeast Florida: Phase I

Final Report

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Cover photographs: Nova Southeastern University Oceanographic Center

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INTRODUCTION

The high latitude reefs of southeast Florida are subjected to multiple natural and anthropogenic stressors due to their location along a heavily populated coast. Multiple coastal construction projects, including beach nourishment, channel dredging, and cable installation, have occurred offshore southeast Florida within, or in close proximity to, coral reef habitats. These permitted coastal construction projects impact reef resources and are expected to continue in the future.

In addition to these injury events, over a period of 13 years (1994-2006) there have been numerous ship groundings and anchor events associated with the Port Everglades commercial anchorages which have injured reef resources in Broward County (Figure 1). During this same time period such events (documented and undocumented) have also occurred offshore Miami-Dade and Palm Beach counties.

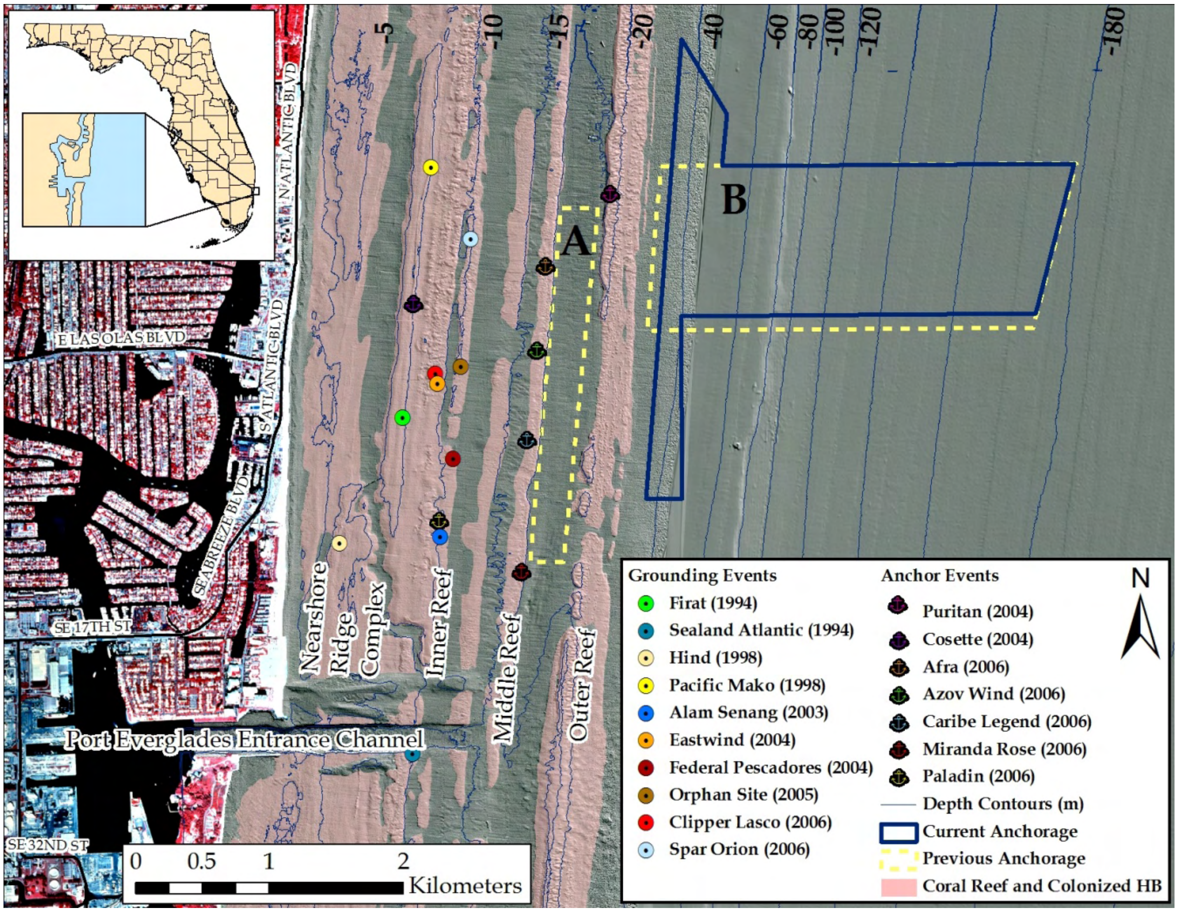

Figure 1. Map of the known grounding and anchor events offshore Ft. Lauderdale, Florida (Broward County) from 1994 to 2006 and the previous and newly authorized Port Everglades anchorage configurations (A, B).

Physical impacts from ship groundings and other injury events generally requires emergency stabilization, which ideally stabilizes the site and promotes natural recovery of the injured area; and mitigation (compensatory restoration), which offsets lost ecological services from the time of injury to a recovery state. Federally authorized coastal construction projects require sequential mitigation: first, impact avoidance; second, impact minimization; third, compensatory mitigation for unavoidable impacts (Clean Water Act 40 CFR Part 230; US Army Corps of Engineers Regulatory Guidance Letter 02-02; Marine Sanctuaries Act 50 CFR 600.920). Resource trustees require compensatory mitigation to offset lost ecological services to coral reefs and other reef resources from authorized (e.g., channel dredging) and unauthorized impacts (e.g., vessel grounding events). Methods to determine the amount of compensatory restoration required following an injury event or a permitted project include Habitat Equivalency Analysis (HEA) and Resource Equivalency Analysis (REA), both of which rely on input parameters to determine the amount of compensatory restoration (mitigation) needed to compensate for interim ecological services lost from the injury (Kohler and Dodge, 2006; Viehman et al., 2009). Permitted projects Florida resulting in injury to resources may use the Uniform Mitigation Assessment Method to determine required compensatory mitigation (Chapter 62-345, Florida Administrative Code). All of these assessment methods require data on the losses from the injury and recovery values for the compensatory action. However, data on reef resource recovery rates to support these parameters are limited, particularly for southeast Florida.

The project goal was to provide resource managers with much needed data to assist in estimating reef resource recovery rates from anthropogenic impacts to be used in determining appropriate compensatory restoration and mitigation for coral reef injury. While this study focused on vessel grounding impacts, the data will be useful in assessing other impact events. The approach was to examine identified unpermitted injury areas (Phase I) and deployed permitted mitigation structures (Phase II) and to evaluate both the benthic biological communities present and the physical characteristics of the sites that may influence recovery. Biological communities were surveyed using a population approach (density and size class) for scleractinian (stony corals), gorgonian corals, and barrel sponges (*Xestospongia muta*). In addition to percent cover for stony corals and gorgonians, other benthic communities such as sponges, zoanthids, algae, etc., were evaluated using percent cover estimates since individuals or colonies are often difficult to quantify. Physical characteristics included rubble size and amount, and topographic complexity. This examination of the recovery condition of the injury sites and possible estimation of recovery rates is directly applicable to management of coral reefs by local, state, and federal agencies to help determine appropriate restoration and mitigation amounts for future physical impacts to coral reefs. Restoration actions are imperative to preserving and protecting coral reef services into the future considering a possible continued decline from natural and anthropogenic impacts (Mumby and Steneck, 2008).

This project has two phases. Phase I compares control sites to sites that have been injured by ship groundings in Broward and Miami-Dade counties to determine differences in: 1) benthic community structure, 2) density and size of corals, gorgonians, and barrel sponges, and 3) physical characteristics such as rugosity and amount of unconsolidated substrate such as rubble and sand. Phase II will evaluate benthic community development on artificial structures deployed for mitigation in Miami-Dade, Broward, and Palm Beach counties compared to control sites. This report addresses the results of Phase I.

The southeast Florida reef system is large in area and extends along the coast from Miami-Dade County into Martin County (~75km). It is also diverse in habitats (Walker et al., 2008; Banks et al. 2007) and biological communities both within and among habitats (Moyer et al., 2003; Gilliam et al., 2009; Sathe et al., 2009; Gilliam, 2010). The geographic scale and biological diversity of the southeast Florida reef system precluded examination of the entire system. To examine recovery following injury, the approach was to specifically focus on ship grounding sites of known age offshore Broward and Miami-Dade counties. The reason for limiting sites to one injury type was to isolate the effect of time and reduce the effect of injury type. The grounding sites surveyed in Broward County included the Firat, the Alam Senang, the Federal Pescadores, the Eastwind, the Spar Orion, and the Clipper Lasco (Figure 1 and Table 1). These groundings occurred on the Inner Reef west of the Port Everglades anchorage with the exception of the *Firat* which grounded on the Nearshore Ridge Complex (NRC) west of the anchorage (Figure 1). The Anzhela Explorer grounding occurred on the NRC in Miami-Dade County. The ages of these grounding sites provided a snapshot of the reef communities fifteen (Firat) to three (Anzhela Explorer) years post-injury. Primary restoration of the two older groundings (Firat and Alam Senang) included only stony coral transplantation (Beak, 1996: MRI, 2003; CSA, 2004). The four more recent groundings included rubble removal and stabilization in addition to coral transplantation (Hudson Marine, 2004a; Hudson Marine, 2004b; Polaris, 2007; CSA, 2006).

METHODS

Site selection

For grounding sites, injury assessment reports, primary restoration reports, and when available, geographic information system (GIS) data, were obtained from the Florida Department of Environmental Protection (FDEP) and used to target injured areas within each site.

Table 1. Injury date, location, habitat, and approximate injury area of the evaluated ship groundings. (Note: The injury areas are not strictly defined and only provide a comparison of the injured habitat area for each event).

Vessel	Date	Location	Reef	Area (m^2)
Firat	November 1994	Ft. Lauderdale, Broward	NRC	1,000
Alam Senang	June 2003	Ft. Lauderdale, Broward	Inner	216
Eastwind	April 2004	Ft. Lauderdale, Broward	Inner	10,995
Federal Pescadores	October 2004	Ft. Lauderdale, Broward	Inner	23,399
Spar Orion	May 2006	Ft. Lauderdale, Broward	Inner	546
Clipper Lasco	September 2006	Ft. Lauderdale, Broward	Inner	558
Anzhela Explorer	March 2007	Golden Beach, Miami-Dade	NRC	1,231

For all sites, the available data were used to identify randomly generated geographic positioning system (GPS) points of locations within the injury areas which were appropriate for sampling. Available information for the Firat grounding event did not include GIS data or maps which indentified injury areas and types tagged coral locations were used.

Reconnaissance dives were performed at all sites to verify target points as appropriate sample locations and to assist with ultimate sample location choice. Only sample locations that could be visually identified as injured, were located within reef habitat (excluded large sand areas and reef edge rubble areas), positioned completely within the defined injury area, and that were large enough to accommodate the size of the sample area (see methods below) were selected for the study. These survey locations represent areas likely to have been the most severely injured during the grounding event. The current status of these grounding sites may not reflect the recovery status of all areas within the injury area, but full recovery back to pre-injury conditions of the entire injury area is defined by the most severely injured locations. Table 2 shows the location and survey date of the grounding site samples. Figures 2 through 8 show the locations of the study sample sites within each grounding site.

A common set of control, or non-injured reference sites, were selected for comparison with the Inner Reef grounding sites (Table 3). The control sites needed to be located on Inner Reef and representative of a natural state, free of visually obvious past documented or unidentified anthropogenic injury. An Inner Reef area was outlined within which twelve control sample locations were randomly chosen (see Figure 9 for control sample site locations in relation to the grounding sites and anchorages). The size and specific location of this outlined area was determined using GIS techniques and defined by the Inner Reef area which encompassed the entire Inner Reef grounding sites.

Table 2. Grounding site survey sample locations, date, and habitat.

Site	Sample	Sample Date	Latitude (N)	Longitude (W)	Reef
Eastwind	1	11-Jun-09	26° 07.065′	80° 05.555′	Inner
Eastwind	2	11-Jun-09	26° 07.105′	80° 05.548′	Inner
Eastwind	3	11-Jun-09	26° 07.027′	80° 05.551′	Inner
Spar Orion	1	12-Jun-09	26° 07.600′	80° 05.410′	Inner
Spar Orion	2	12-Jun-09	26° 07.622′	80° 05.418′	Inner
Spar Orion	3	12-Jun-09	26° 07.643′	80° 05.402′	Inner
Federal Pescadores	1	7-Jul-09	26° 06.780′	80° 05.583′	Inner
Federal Pescadores	2	7-Jul-09	26° 06.746′	80° 05.555′	Inner
Federal Pescadores	3	7-Jul-09	26° 06.750′	80° 05.537′	Inner
Alam Senang	1	26-Aug-09	26° 06.530′	80° 05.596′	Inner
Alam Senang	2	26-Aug-09	26° 06.487′	80° 05.597′	Inner
Alam Senang	3	1-Sep-09	26° 06.524′	80° 05.596′	Inner
Clipper Lasco	1	12-Oct-10	26° 07.086′	80° 05.586′	Inner
Clipper Lasco	2	12-Oct-10	26° 07.080′	80° 05.572′	Inner
Clipper Lasco	3	12-Oct-10	26° 07.101′	80° 05.480′	Inner
Firat	1	28-Aug-09	26° 06.901′	80° 05.736′	NRC
Firat	2	28-Aug-09	26° 06.913′	80° 05.741′	NRC
Firat	3	28-Aug-09	26° 06.905′	80° 05.766′	NRC
Anzhela Explorer	1	11-Oct-10	25° 58.025′	80° 06.694′	NRC
Anzhela Explorer	2	11-Oct-10	25° 58.017′	80° 06.725′	NRC
Anzhela Explorer	3	11-Oct-10	25° 58.003′	80° 06.770′	NRC

A polygon of equivalent size was created and mapped over an Inner Reef area north of the former Port Everglades Anchorage A location to avoid any previous injury from ship groundings or anchor events. The polygon width was equal to the greatest distance from the Inner Reef eastern edge to any of the grounding sites, and the polygon length was equivalent to the distance from the Alam Senang grounding site (southern grounding site) to the Spar Orion grounding site (northern grounding site). This control area polygon was mapped such that its eastern edge was along the Inner Reef eastern edge. The polygon was placed in this way to sample control sites similar to the habitat that was injured.

Because the *Firat* grounded on the NRC, three separate control sites on the nearshore ridge were chosen for comparison with the Firat (Table 3). The procedure was comparable to that used for the Inner Reef sites. A polygon of similar size to the area defined by the Firat stony coral reattachment zones was mapped over a nearshore ridge area north of the Firat injury area, and three random sample locations were chosen (see Figure 9 for control sample site locations in relation to the grounding sites and anchorages).

The *Anzhela Explorer* grounded offshore Golden Beach in Miami-Dade County. Three control sites were randomly chosen on similar habitat adjacent (north and south) to the injury location (see Figure 8 for control injury site locations).

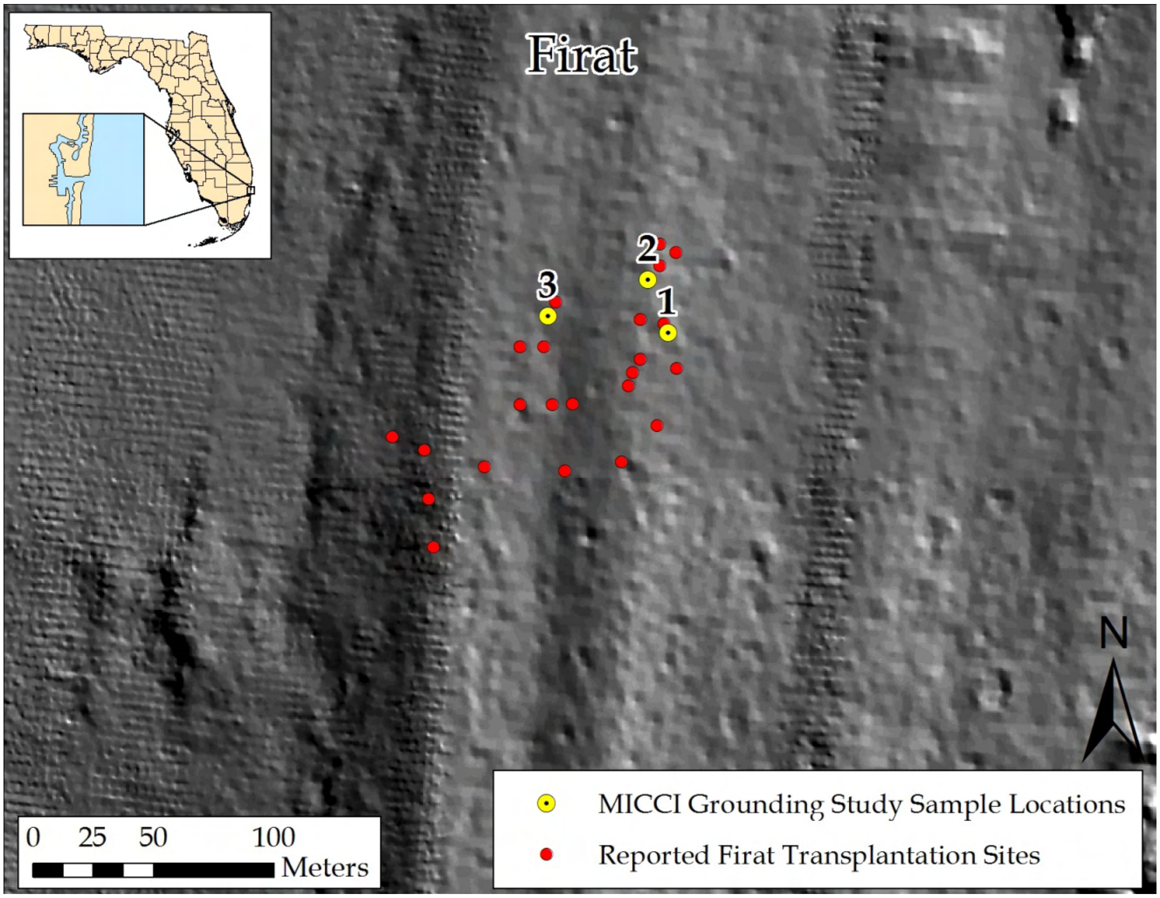

Figure 2. Sun-shaded Firat grounding site bathymetry image showing the sample locations. GPS locations of stony coral reattachment zones (Beak, 1996), indicated by red points, were used to guide the reconnaissance dives.

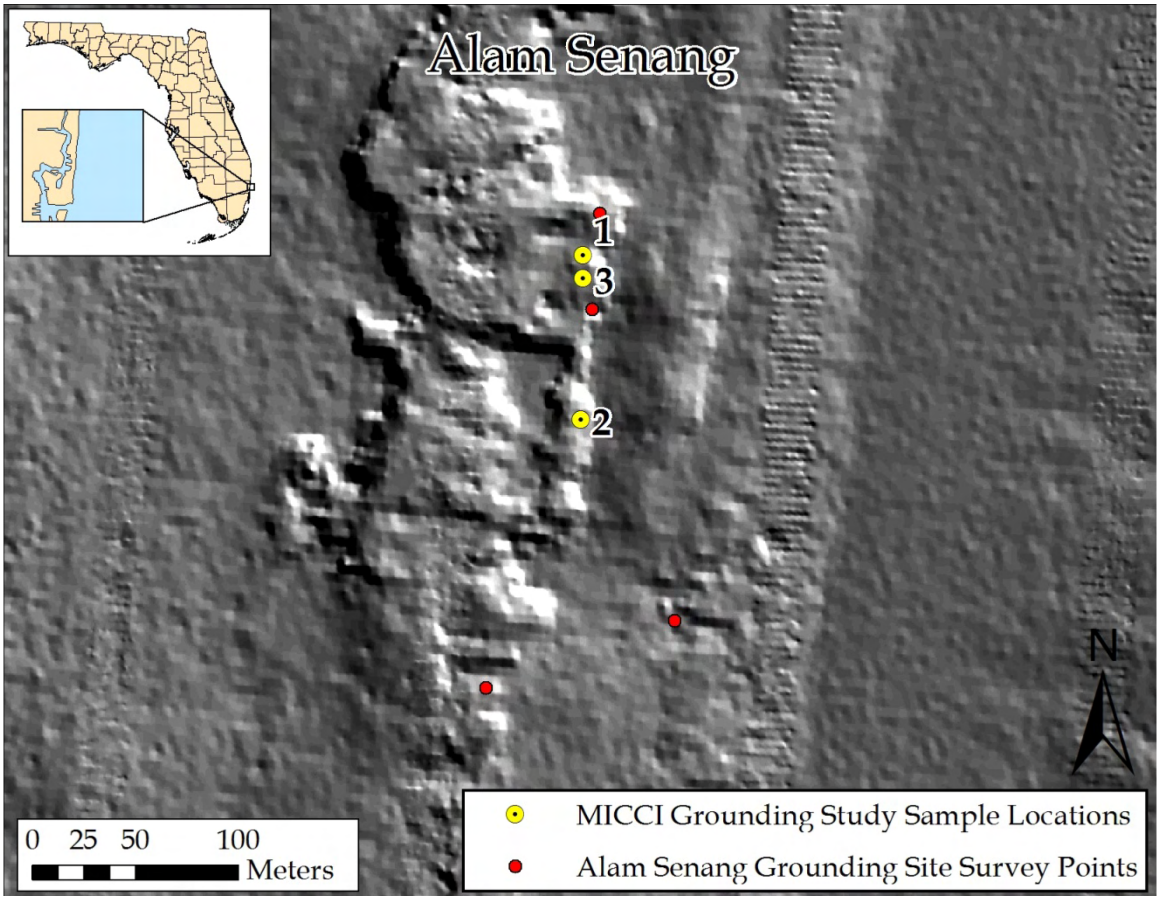

Figure 3. Sun-shaded Alam Senang grounding site bathymetry image showing the sample locations. The red points represent GPS points taken from available information to guide the reconnaissance dives.

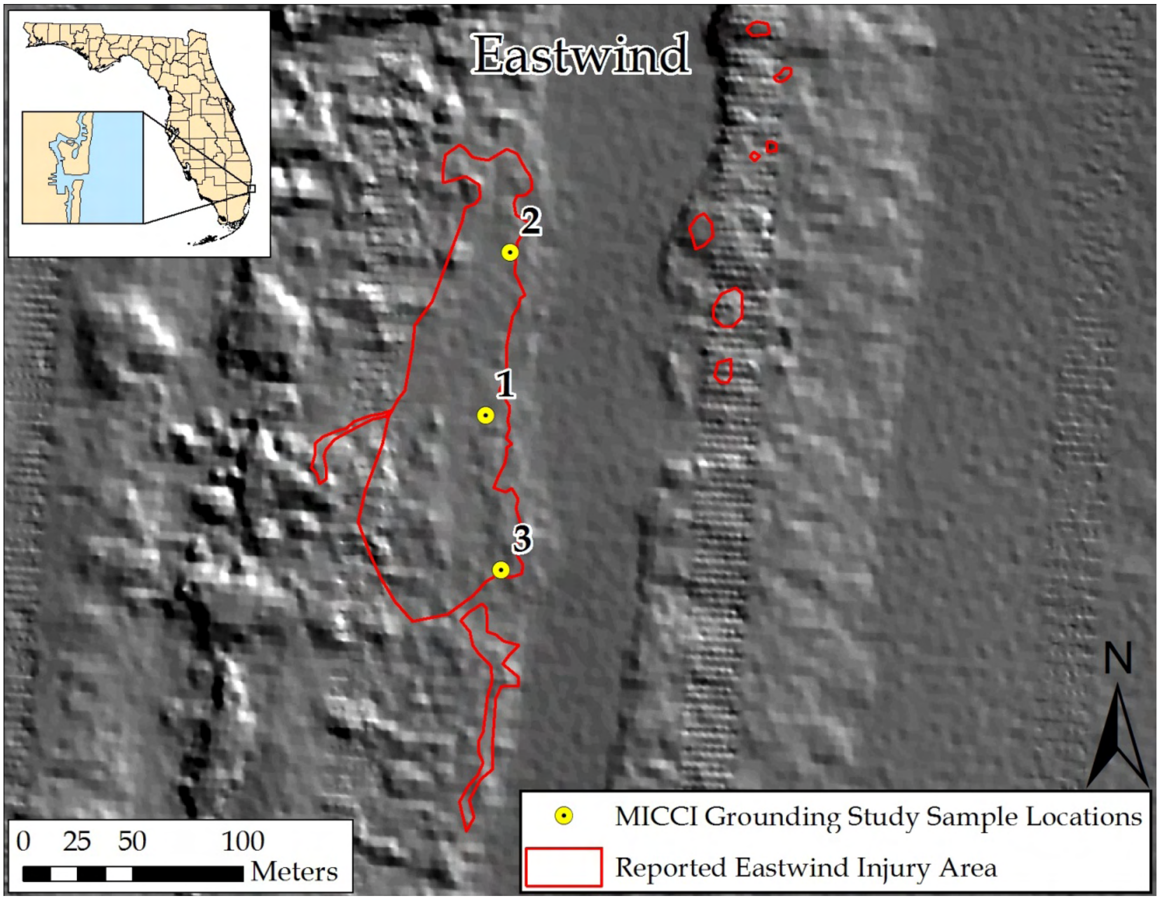

Figure 4. Sun-shaded Eastwind grounding site bathymetry image showing the sample locations. The red polygon represents the injury area (as reported by Hudson Marine, 2004a).

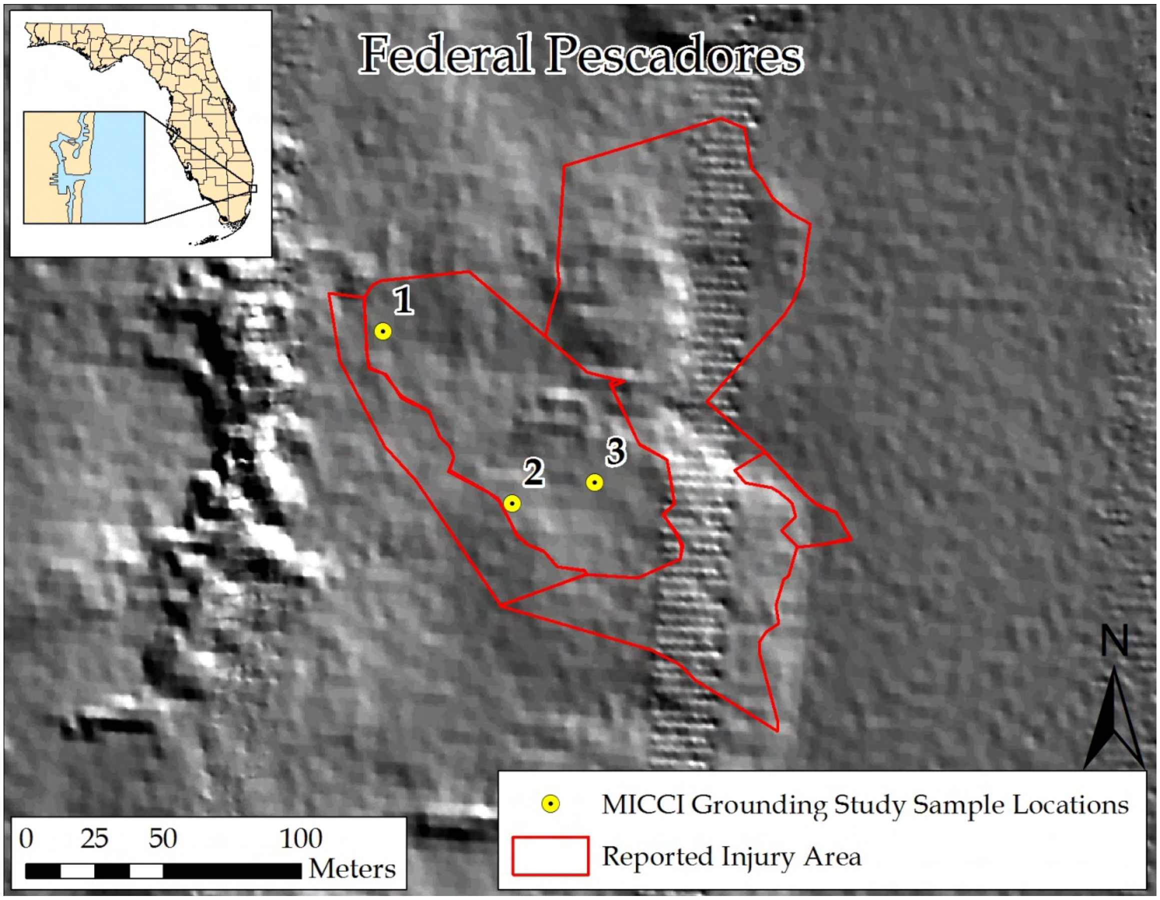

Figure 5. Sun-shaded Federal Pescadores grounding site bathymetry image showing the sample locations. The red polygons represent the injury area (as reported by Hudson Marine, 2004b).

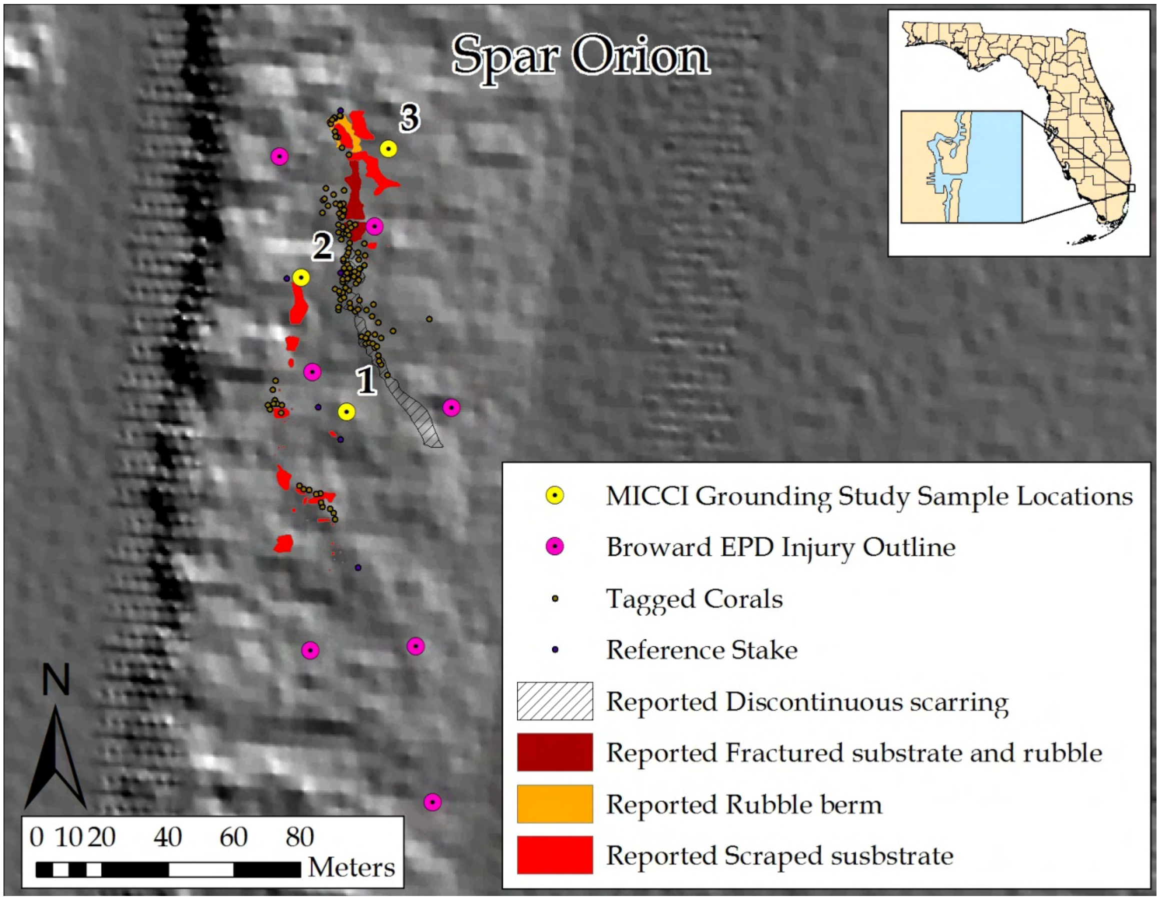

Figure 6. Sun-shaded Spar Orion grounding site bathymetry image showing the sample locations. The polygons represent the injury area as reported by CSA, 2006), and the magenta points are injury assessment points.

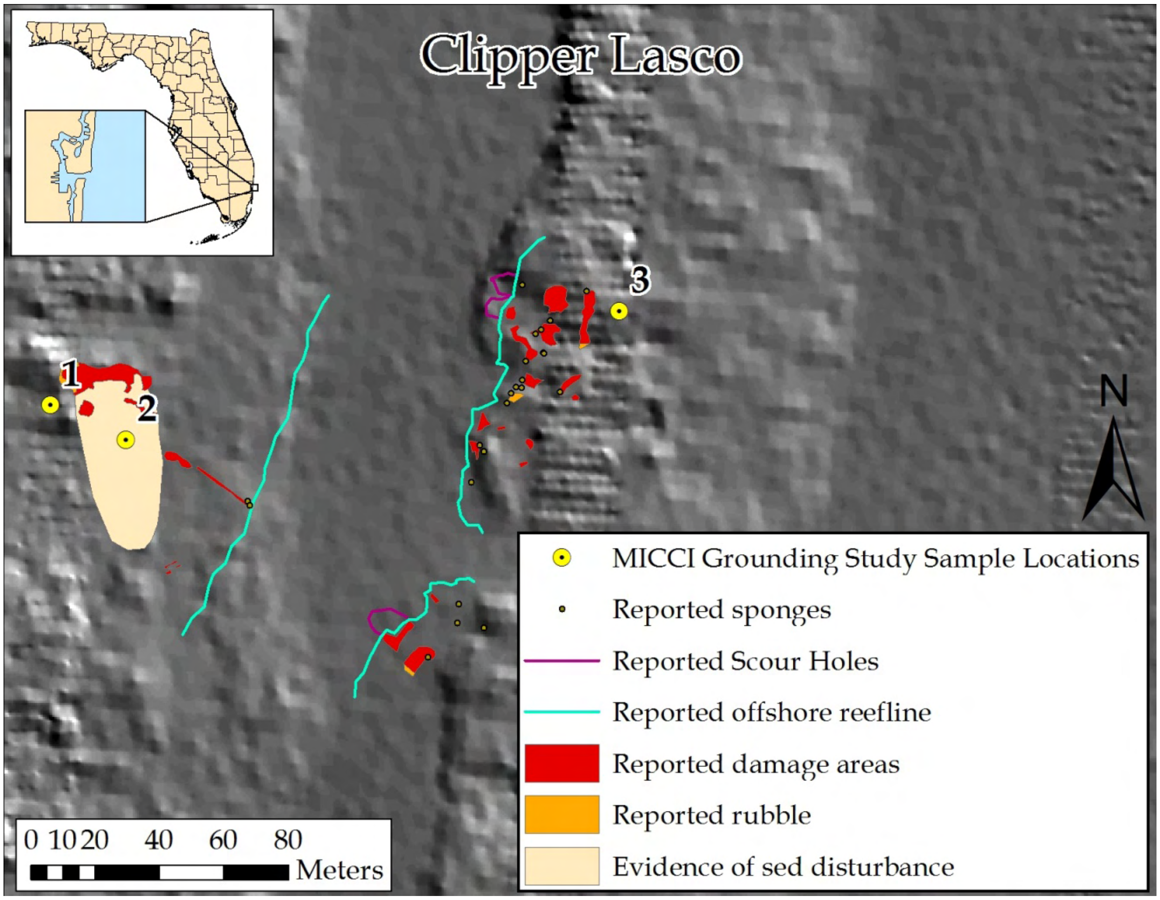

Figure 7. Sun-shaded Clipper Lasco grounding site bathymetry image showing the sample locations. The polygons represent the injury area (as reported by Polaris Applied Sciences Inc., 2007).

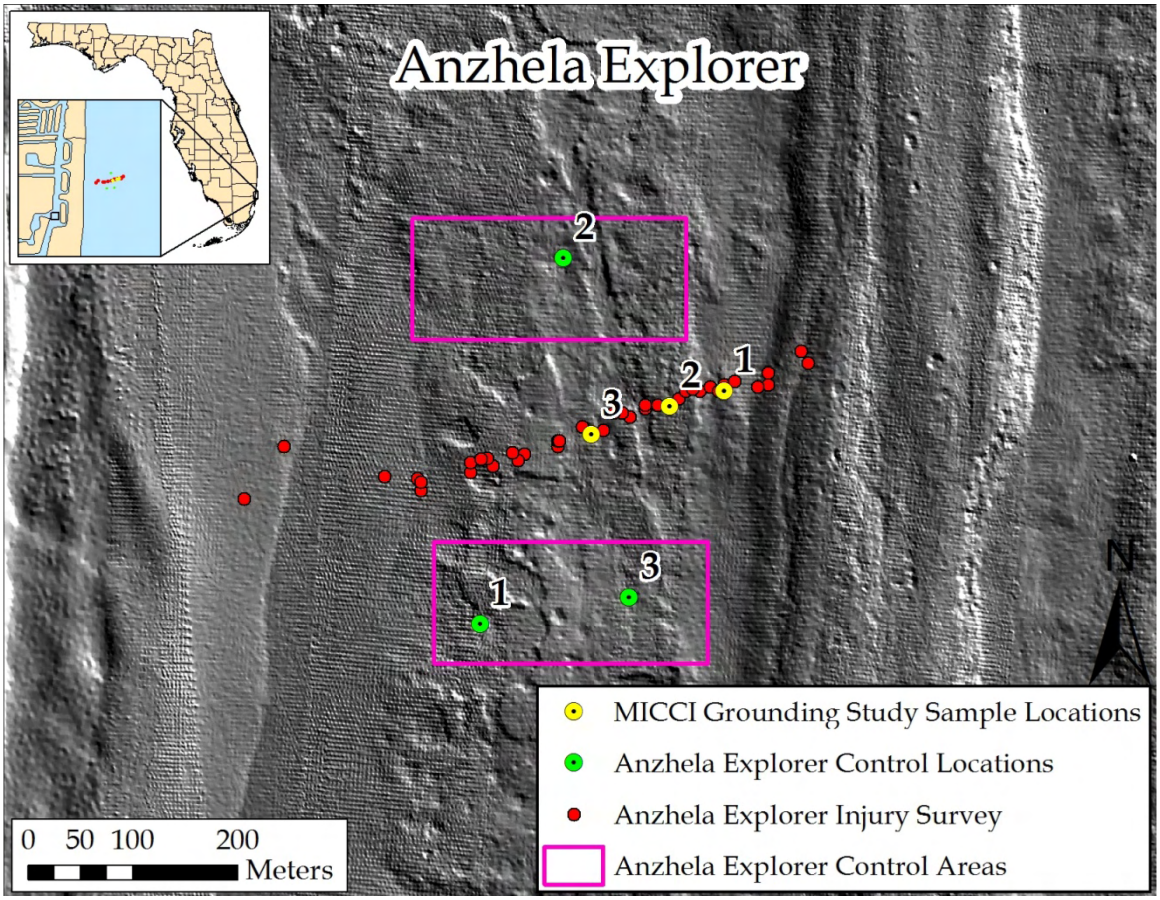

Figure 8. Sun-shaded Anzhela Explorer grounding site bathymetry image showing the sample locations. The points represent the path of the injury area (as reported by Sea Byte Inc., 2008).

Table 3. Control site locations, survey dates, and reef type.

Site	Sample	Sample Date	Latitude (N)	Longitude (W)	Reef
Inner Reef Control	1	17-Sep-09	26° 08.675′	-80° 05.362′	Inner
Inner Reef Control	2	17-Sep-09	26° 08.952′	-80° 05.380′	Inner
Inner Reef Control	3	25-Sep-09	26° 08.084′	-80° 05.391′	Inner
Inner Reef Control	4	25-Sep-09	26° 08.352′	-80° 05.408′	Inner
Inner Reef Control	5	17-Sep-09	26° 08.917′	-80° 05.377′	Inner
Inner Reef Control	6	25-Sep-09	26° 08.575′	-80° 05.406′	Inner
Inner Reef Control	7	29-Sep-09	26° 08.533′	-80° 05.340′	Inner
Inner Reef Control	8	29-Sep-09	26° 08.844′	-80° 05.350′	Inner
Inner Reef Control	9	29-Sep-09	26° 08.823′	-80° 05.336′	Inner
Inner Reef Control	10	1-Oct-09	26° 08.788′	-80° 05.359′	Inner
Inner Reef Control	11	1-Oct-09	26° 08.319′	-80° 05.455′	Inner
Inner Reef Control	12	1-Oct-09	26° 08.082′	-80° 05.480′	Inner
Firat Control	1	23-Jul-09	26° 07.097′	-80° 05.745′	NRC
Firat Control	2	23-Jul-09	26° 07.068′	-80° 05.763′	NRC
Firat Control	3	23-Jul-09	26° 07.095′	-80° 05.718′	NRC
Anzhela Explorer Control	1	17-Nov-10	25° 57.906′	-80° 06.834′	NRC
Anzhela Explorer Control	2	17-Nov-10	25° 58.094′	-80° 06.785′	NRC
Anzhela Explorer Control	3	17-Nov-10	25° 57.919′	-80° 06.749′	NRC

Data collection

Benthic biological communities were evaluated in two ways. A population approach was used to evaluate stony and gorgonian corals along belt transects. Species distribution, abundance, density, and size class were measured. Secondly, a percent cover estimate was calculated for benthic communities, including stony corals, gorgonians, sponges, zoanthids, algae, etc. These values were calculated from digital video images analyzed with Coral Point Count with Excel (CPCe) software developed by the National Coral Reef Institute (NCRI) (Kohler and Gill, 2007).

A sample consisted of three parallel transects along which data were collected. Each replicate sample included a belt-quadrat transect and three video transects (Figure 10). At the grounding sites, the direction of the belt transect was dictated by the orientation of the impacted area to keep the entire sample within the injury area. At the control sites, random compass bearings were used to orient the transects. Three replicates were sampled within each grounding site (three transects at each of three replicate points within a grounding site). Twelve replicates were sampled within the Inner reef control area (three transects at each of 12 replicate points within the polygon), and three were sampled within each of the Firat and Anzhela Explorer control areas.

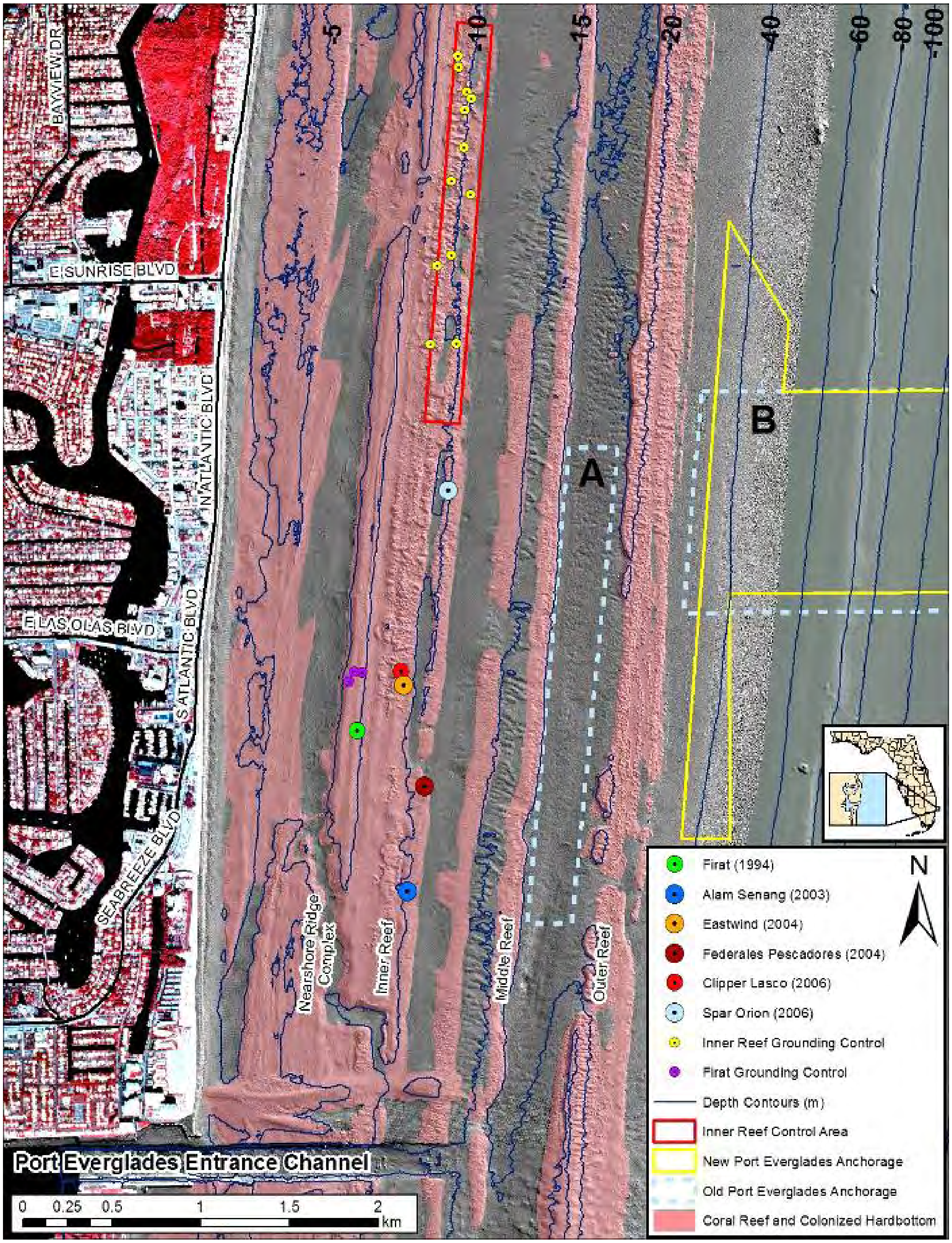

Figure 9. Map of the study area offshore Ft. Lauderdale, FL. The six grounding sites are shown as well as the Inner Reef control area and associated sample sites, and the Firat control sites. The previous (A) and newly authorized (B) Port Everglades anchorages are included to illustrate the position of the control area in reference to old Anchorage A.

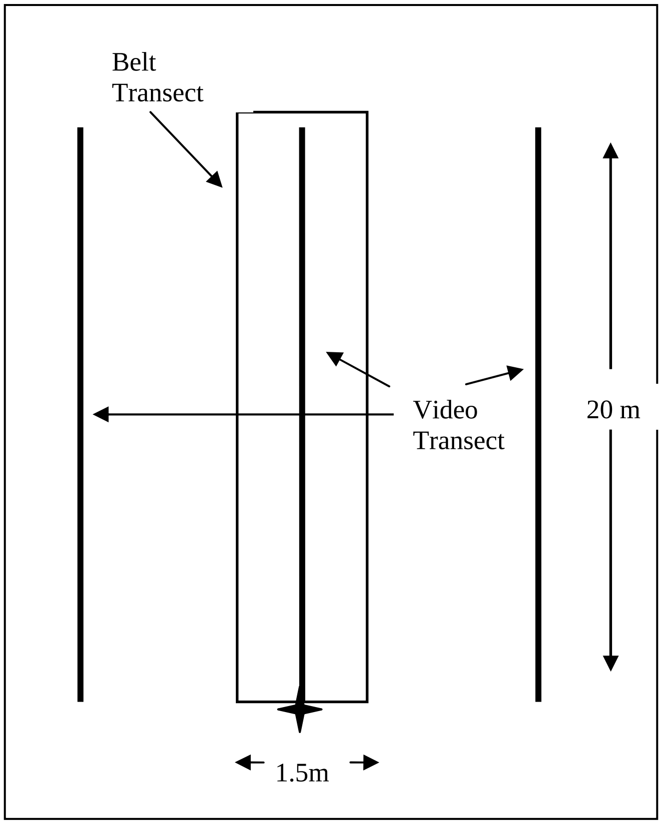

Figure 10. Diagram of the sampling method. Samples consisted of three video transects and one belt transect.

Most replicate samples (as defined by the length of the transects) were 20 meters (m) in length and 4 to 5m in width. One Spar Orion sample (sample 2) and one Clipper Lasco sample (sample 3) were shortened to 15m in length to ensure that the entire transect was within the injury area. The Anzhela Explorer samples only included two 20m video transects each of which ran down one of the parallel injury tracts (Sea Byte Inc., 2008 provides a detailed description of the Anzhela Explorer injury area)

Surveying a 0.75 square meter (m^2) quadrat (1m x 0.75m) at each meter mark along both sides of a 20m belt-transect provided $30m^2$ total area per belt transect (40m x 0.75m). In each quadrat, stony corals, gorgonians, and barrel sponges (*Xestospongia muta*) were identified and measured. For stony corals ≥5 centimeters (cm) diameter, colony diameter and colony live tissue area (colony live tissue length x width) were measured. Stony coral species percent cover was calculated by dividing the sum of each stony coral live tissue area by the total sample area. For gorgonian corals ≥2cm in height, colony height was measured and assigned to one of five size classes (2-5cm, 6-10cm, 11-25cm, 26-50cm, and

>50cm). Barrel sponge height and base width were measured, and volume was calculated. This belt-quadrat transect method is directly comparable to the on-going Broward County Yearly Monitoring Reef Program (Gilliam et al., 2009).

Due to the time-consuming nature of locating small colonies, juvenile stony corals <5cm in diameter and juvenile gorgonians <2cm in height were counted and measured in smaller 0.25m^2 quadrats. For most samples, 40 quadrats were assessed for an area of 10m^2. One Spar Orion sample (sample 2) and one Clipper Lasco sample (sample 3) included only 30 quadrats to, again, ensure that the entire transect was within the injury area.

All three transects within a replicate sample were videotaped for percent cover estimates (Figure 10). Each video transect was 0.4m x 20m for a sample area of 8m^2 per transect and 24m^2 per sample. Image software (RAVEN View by Observa, Inc.) was used to grab individual video frames (images). Each image was processed via CPCe, and 25 points were examined per image to determine percentage of functional group cover. The functional groups included biotic taxa (stony coral, gorgonian, sponge, coralline algae, macroalgae, zoanthid, and turf algae) and substrate type (consolidated reef pavement and unconsolidated rubble and sand). This video transect method is directly comparable to the on-going Southeast Florida Coral Reef Evaluation and Monitoring Program (Gilliam, 2010).

Prior to initiating the image analysis, a data quality assurance procedure was completed. All researchers completing the point counts analyzed the same transect to evaluate differences among the group. A control site for the Firat grounding was selected based on visual observations that it contained many of the functional groups represented throughout the project area. A Bray-Curtis similarity index (Primer™ v6 multivariate statistical software package, Clarke and Warwick, 2001) procedure indicated that the similarity among data sets was greater than 92%.

Several physical characteristics that may affect recovery were also evaluated at each location. The video images were used to provide information on cover of substrate types including sand, rubble, and pavement (consolidated substrate). A small scale measure of rugosity was assessed using a chain link method (Rogers et al., 1982). For each belt transect, a chain 20m length, with links approximately 2cm in size, was draped along the contours of the substrate including all the holes, crevices, and raised surfaces. A measuring tape was stretched along the same transect to determine the ratio of the chain length (20m) to tape length to get an index of rugosity (length of tape/length of chain). An index value of 1.0 is flat, and the higher the index value, the more complex (rugose) the area.

In addition to the video and belt transects, transects designed specifically to document the density of colonies greater than 20cm diameter were completed at each of the twelve control sites. Within each control site four, 4m x 30m ($120m^2$/transect and $480m^2$/site) transects were completed. The heading of each transect was chosen randomly and started 1m from the buoy marking each site. Along each transect all stony coral colonies 20cm or greater in diameter were identified and actual diameter measured.

Data analysis

The purpose of this study was to examine differences between grounding and control sites in population characteristics, community composition, and physical characteristics. The null hypotheses tested were as follows:

- H1: There is no difference in density of stony corals, gorgonians, or barrel sponges between grounding and control sites.
- H2: There is no difference in size of stony corals, gorgonians, or barrel sponges between grounding and control sites.
- H3: There is no difference in cover of stony coral, pavement, sand, or unconsolidated substrate (rubble) between grounding and control sites.
- H4: There is no difference in rugosity between grounding and control sites.
- H5: There is no difference in benthic community composition (functional group percent cover and coral species percent cover) between grounding and control sites.

The community data were analyzed in two ways. Univariate (Statistica 6.0 [Statsoft]) statistics were used to analyze the stony and gorgonian population data collected along the belt transects (H1 and H2). The percent cover estimates for substrate types (pavement, rubble, and sand) along the video transects (H3) and the rugosity data (H4) were also included in the univariate analysis. The five Inner Reef grounding sites were compared to the twelve Inner Reef control sites. The Firat samples were compared to the Firat control samples, and the Anzhela Explorer samples were compared to the Anzhela Explorer control samples.

For the Inner Reef comparisons, parametric analysis of variance techniques (ANOVA) were used, and when significant differences were found, Newman-Keuls post hoc test was used for pair-wise comparisons. Data were transformed where needed to meet the parametric assumptions of normally distributed data and equal variance among groups (sites). The percent data (substrate type and stony coral) were arc sin transformed, and the density data were log transformed

($\log_{10}[x+1]$) prior to statistical analyses. A nonparametric Kruskal-Wallis ANOVA was performed to test for differences in stony coral size (diameter) between sites. Stony coral colonies and barrel sponges were pooled within each grounding site and compared to the pooled control site data. For the Firat and Anzhela Explore comparison, T-tests were performed on the stony coral and gorgonian population data, the stony coral cover data, substrate type, and rugosity.

Multivariate (PrimerE, Clarke and Warwick, 2001) statistical analysis was performed on the video transect cover estimates of major functional groups to examine similarities between benthic communities of the grounding and control sites (H5). A matrix of Bray-Curtis Similarity coefficients were generated from stony coral species cover data and major functional group cover data. The similarity coefficients were used to create non-metric multi-dimensional scaling (MDS) plots. The MDS plots provide a visual representation or map of the similarity (or dissimilarity) between sites such that the distance between sites in these plots is a measure of the relative dissimilarity in species composition or community composition (Clarke and Gorley, 2001). These plots are a convenient way of representing a large amount of data in a two dimensional space. The MDS plot generates a stress value, which indicates the level of difficulty in representing the similarity for all samples into a two-dimensional space. A stress value ≤0.05 indicates a plot with excellent representation and minimal chance of misinterpretation. Values from 0.05 to 0.10 represent a good ordination with slight chance of misinterpretation. Stress values from 0.10 to 0.20 indicate a potentially useful plot but have a greater chance of misinterpretation, and values between 0.20 and 0.30 are considered acceptable, although conclusions should be cross-checked with other statistical measures (Clarke and Gorley, 2001). ANOSIM (analysis of similarities) tests were used to examine differences between the grounding and control sites. The ANOSIM produces p values and global (all samples) and pair-wise (comparing sites) R values of each comparison from the same Bray-Curtis similarity matrix. Sample site comparisons with R values of 1.00 indicated that the sites were completely dissimilar while site comparisons with R values of 0 indicated that the sites were completely similar. Pair-wise R values were only examined when the global (overall) p value was significant (<5% for most cases) and the global R value did not equal zero, indicating that there was a statistical difference in the community. An R value greater than 0.75 indicates that treatments were well separated. An R value between 0.45 and 0.75 indicates that treatments were clearly different but overlapping. An R value between 0.45 and 0.25 were not clearly different, and less than 0.25 indicated the treatments were barely separable (Clarke and Gorley, 2001).

A SIMPER (similarity percentage) analysis was used to determine which functional group was most responsible for driving the differences between sites. The SIMPER analysis determines average dissimilarities between treatments as well as percent contribution of each functional group to the dissimilarity. An average dissimilarity of 100 means two sites are completely different while an average dissimilarity of 0 means two sites are exactly the same. A functional group with the highest percent contribution was considered a good discriminating species (or species responsible for driving the difference between the two samples) between the sites (Clarke and Warwick, 2001).

For the Inner Reef control 4m x 30m belt transects, mean (n=12 sites) density was calculated (colonies/m^2) using the total value for each site for the following size class abundances: >20cm diameter, 20cm – 50cm, >50cm, >75cm, and >100cm.

RESULTS

Separate data analyses were completed for each of the project area studies: Inner Reef grounding sites and control, Firat grounding sites and control (NRC in Broward County), and Anzhela Explorer grounding sites and control (NRC in Miami-Dade County). For clarity, results for each of these analyses are presented separately.

<u>Inner Reef</u>

Three replicate samples were surveyed for each of the five grounding sites (total 15 grounding samples), and twelve control samples were surveyed. Table 1 lists the sampled grounding sites and the dates of each grounding event, and Tables 2 and 3 list the sample date and location for all grounding and control samples. Figures 3-8 show the locations of each sample within each grounding site and Figure 9 shows the location of the twelve control samples.

For stony coral colonies ≥ 5cm diameter, mean percent cover (belt transect data) and mean density (colonies/m^2) were significantly greater (ANOVA, $p<0.05$) in the control samples than in any of the grounding sites (Table 4; Figures 11 and 12). There was no significant difference in coverage or density between the grounding sites. Eleven of the twelve control samples had greater stony coral coverage than all of the grounding site samples. All twelve control samples also had a greater stony coral density than all of the grounding site samples, and all grounding site samples had stony coral densities less than 0.5 colonies/m^2 as compared to the control which had ten samples with a stony coral density greater than 1/m^2 (data not shown).

Table 4. Summary data, mean (standard error [SE], for each of the five grounding sites and the twelve control sites. Means for each grounding site which are significantly different than the controls are **bolded**. (SO = Spar Orion, FP = Federal Pescadores, EW = Eastwind, AS = Alam Senang, CL = Clipper Lasco, and Con = Control).

Site	**SO**	**FP**	**EW**	**AS**	**CL**	**Con**
Number of Samples	3	3	3	3	3	12
Stony Corals						
No. of Species	**2.33 (0.67)**	**1.67 (0.88)**	**4.33 (1.76)**	**5.33 (0.88)**	**1.67 (0.33)**	8.92 (0.71)
Cover (%)	**0.10 (0.03)**	**0.03 (0.02)**	**0.18 (0.08)**	**0.21 (0.03)**	**0.03 (0.01)**	2.43 (0.61)
Density (col/m^2)	**0.26 (0.09)**	**0.09 (0.05)**	**0.25 (0.11)**	**0.43 (0.02)**	**0.09 (0.01)**	1.51 (0.18)
Colony size (dia cm)	**7.23 (0.53)**	**6.75 (1.06)**	**8.91 (0.67)**	**8.59 (0.69)**	**6.57 (1.64)**	13.53 (0.49)
Max colony size (dia cm)	**10.67 (2.03)**	**8.50 (1.22)**	**18.00 (4.00)**	**17.00 (1.00)**	**7.33 (0.33)**	49.58 (7.45)
No. of Recruit Species	7.33 (0.88)	5.67 (2.67)	9.67 (0.88)	7.33 (0.67)	9.33 (2.19)	6.83 (6.83)
Recruit Density (col/m^2)	3.67 (0.83)	6.37 (2.30)	5.03 (1.65)	5.40 (2.21)	7.37 (2.29)	3.15 (0.38)
Gorgonians						
No. of Species	5.67 (0.33)	5.33 (0.33)	6.00 (0.58)	6.33 (0.33)	5.67 (0.67)	8.83 (8.83)
Cover (%)	**2.40 (0.44)**	**1.76 (0.96)**	**2.84 (0.52)**	**3.03 (0.67)**	**1.25 (0.60)**	5.46 (0.48)
Density (col/m^2)	4.20 (0.70)	5.03 (2.60)	3.89 (1.01)	3.98 (0.33)	2.09 (1.00)	4.27 (0.56)
Recruit Density (col/m^2)	1.57 (0.79)	1.17 (0.47)	0.05 (0.21)	0.37 (0.07)	0.41 (0.25)	0.54 (0.12)
Barrel Sponge						
Density (sponge/m^2)	0.17 (0.02)	0	0.07 (0.07)	0.08 (0.08)	0.01	0.18 (0.03)
Volume (cm^3 x 1000)	0.18 (0.64)	0	4.03 (1.60)	1.49 (0.76)	4.08	9.11 (2.03)
Substrate						
Pavement Cover (%)	**67.74 (7.79)**	87.15 (4.88)	**82.4 (3.65)**	**72.33 (15.13)**	**53.22 (12.37)**	96.43 (0.71)
Rubble Cover (%)	**24.4 (5.10)**	7.46 (4.74)	8.97 (1.32)	**23.93 (14.67)**	**38.45 (7.48)**	2.37 (0.45)
Sand Cover (%)	**7.86 (2.80)**	5.39 (2.72)	**8.63 (2.33)**	3.73 (1.35)	**8.33 (5.21)**	1.21 (0.44)
Rugosity	**1.11 (.01)**	**1.05 (0.03)**	1.13 (0.01)	1.13 (0.02)	**1.09 (0.04)**	1.21 (.016)

The control samples had significantly larger (diameter) colonies (ANOVA, $p<0.05$) than each of the groundings sites (Table 4). Of the grounding sites, the Eastwind had the largest mean colony size followed very closely by Alam Senang (Table 4). In addition to the smaller mean size of the stony corals in the grounding sites, the mean size of the largest colony identified within each site was significantly greater (ANOVA, $p<0.05$) in the control sites (Table 4).

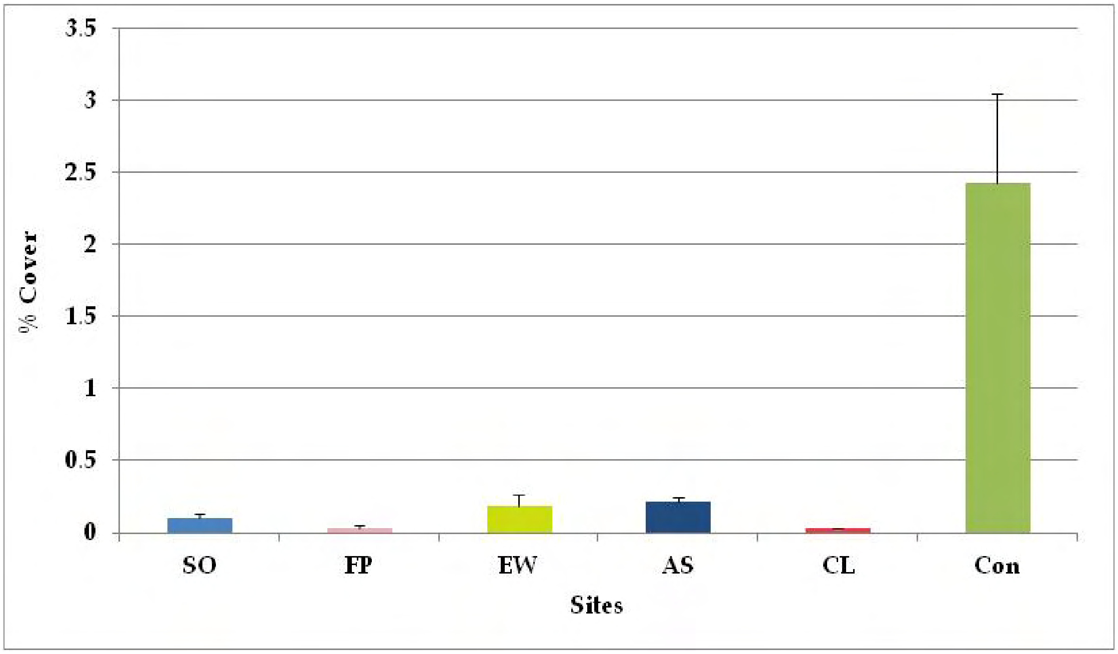

Figure 11. Mean (SE) percent stony coral cover (belt transect data) for each of the sites (SO = Spar Orion, FP = Federal Pescadores, EW = Eastwind, AS = Alam Senang, CL = Clipper Lasco, and Con = Control). All five groundings sites had significantly less cover than the control sites (ANOVA, arc sin transformed, $p < 0.05$).

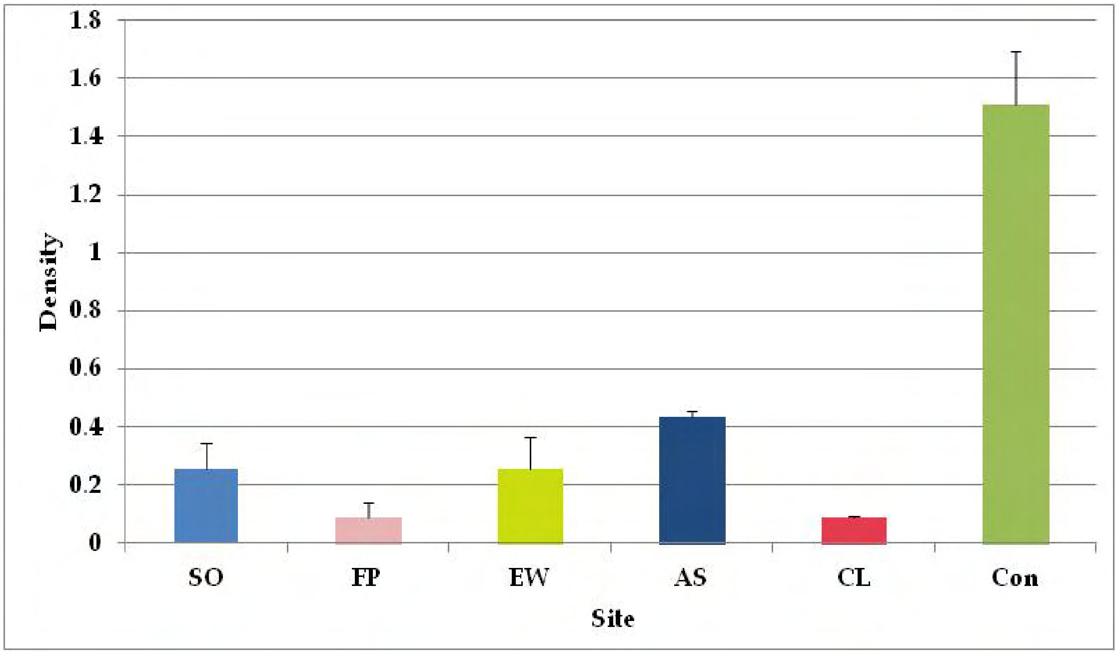

Figure 12. Mean (SE) stony coral density (colonies/m^2) for each of the sites. All five groundings sites had significantly lower density than the control sites (ANOVA, log [x+1] transformed, $p < 0.05$) (see Figure 11 for abbreviations).

No grounding site had a stony coral colony greater than 25cm, while ten control samples had colonies greater than 30cm, and six control samples had colonies greater than 50cm. The largest colonies identified were a 95cm *Montastraea cavernosa* colony and a 90cm *M. faveolata* colony in control sample 5. Colony size distribution was examined by pooling all control colonies and all colonies within each grounding site and assigning them to size (diameter) classes (5-10cm, 11-20cm, 21-30cm, 31-40cm, 41-50cm, and >50cm). The grounding sites distribution was more heavily right-skewed towards the smallest size class than the control sites with two grounding sites (Federal Pescadores and Clipper Lasco) having 100% of the colonies in the 5-10cm class (Figure 13).

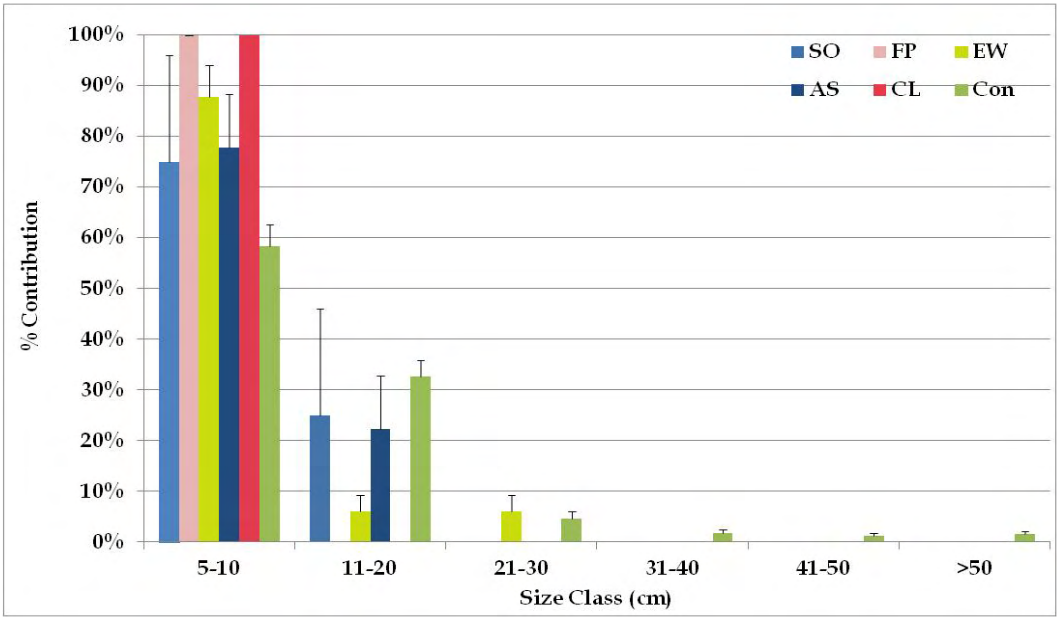

Figure 13. Mean (SE) stony coral size class (cm) contribution (percent) for each site (see Figure 11 for abbreviations).

The mean number of stony coral species (colonies >5cm diameter) identified in the control samples was more than twice that identified in all groundings sites except the Alam Senang (Table 4). There were several species which were common in most sites (Table 5). *Siderastrea siderea* was identified in all grounding and control samples. *Stephanocoenia intersepta* was identified in all grounding sites and 11 controls samples. *Porites astreoides* was identified in all control samples and all grounding sites except the Federal Pescadores sites, and *P. porites* was identified in 11 control samples and all of the Alam Senang, Eastwind, and Clipper Lasco sites. Three species were common in the control sites but not common in the grounding sites. These include *Montastraea cavernosa* which was identified in ten control sites and only in the two Eastwind sites, *Meandrina* *meandrites* identified in nine control sites and in only one Alam Senang site, and *Agaricia agaricites* identified in ten control sites and only in one Federal Pescadores and two Eastwind sites.

Table 5. Stony coral (colonies ≥5cm diameter) species contribution (%) within each site. SO = Spar Orion, FP = Federal Pescadores, EW = Eastwind, AS = Alam Senang, CL = Clipper Lasco, and Con = Control.

Species	SO	FP	EW	AS	CL	CON
Acropora cervicornis	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
Agaricia agaricites	0.0%	4.5%	18.2%	0.0%	0.0%	2.3%
Agaricia lamarkii	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
Agaricia spp.	0.0%	4.5%	0.0%	0.0%	0.0%	0.5%
Colpophyllia natans	0.0%	0.0%	0.9%	0.0%	0.0%	0.2%
Dichocoenia stokesii	0.0%	0.0%	21.2%	17.0%	17.1%	2.7%
Diploria clivosa	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
Diploria labrynthiformis	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Diploria strigosa	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
Meandrina meandrites	0.0%	0.0%	0.0%	0.8%	0.0%	5.7%
Madracis decactis	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%
Montastraea cavernosa	0.0%	0.0%	2.1%	0.0%	0.0%	19.5%
Montastraea faveolata	0.0%	0.0%	0.0%	0.0%	0.0%	7.3%
Mycetophyllia aliciae	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
Porites astreoides	2.1%	0.0%	1.4%	15.4%	7.7%	30.8%
Porites porites	0.0%	0.0%	34.7%	9.5%	33.3%	2.2%
Siderastrea siderea	51.4%	24.5%	6.3%	14.9%	25.6%	15.3%
Solenastrea bournoni	14.2%	0.0%	0.0%	20.9%	0.0%	4.4%
Stephanocoenia intersepta	32.3%	66.6%	15.2%	21.5%	16.2%	5.3%

Stony coral recruits were defined as colonies <5cm diameter. Figure 14 shows the mean (SE) recruit density for each site. Although the mean control sample recruit density (colonies/m^2) was less than each of the grounding sites (Table 4), there was no significant difference in density among the sites (ANOVA, $p>0.05$). Only one of the control samples had a recruit density greater than 5/m^2 while all grounding sites had at least one sample with a density greater 5/m^2.

Mean percent gorgonian cover was significantly greater in the control samples than in the grounding sites (Table 4) (ANOVA, $p<0.05$), but mean gorgonian density (colonies/m^2) was not significantly different among the sites (Table 4) (ANOVA, $p>0.05$).

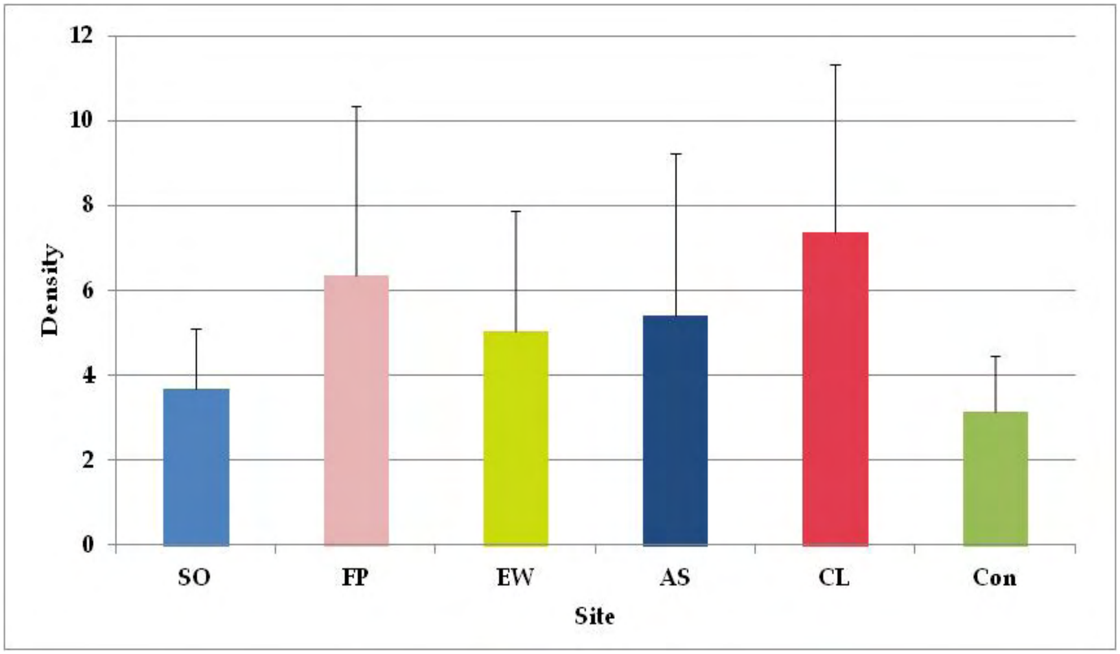

Figure 14. Mean (SE) stony coral recruit (colonies <5cm diameter) density (colonies/m^2). No significant difference was determined among the sites (ANOVA, log [x+1] transformed, $p < 0.05$ (see Figure 11 for abbreviations).

Size (height) class distribution was fairly similar between the control and grounding sites (Figure 15) with the exception of colonies greater than 20cm which contributed more to the distribution of colonies in the control sites than in any of the grounding sites. All twelve control samples had gorgonian colonies greater than 50cm as compared to the grounding sites with only five grounding samples (Alam Senang 1 and 2, Eastwind 3, and Spar Orion 1 and 3) having colonies greater than 50cm.

The mean number of gorgonian species identified in the control samples was greater than identified in any of the grounding sites (Table 4). In addition to differences recorded in species richness, there were also differences in the dominant species identified in the control and grounding sites. Although *Pseudopterogorgia* spp. (*Pseudopterogorgia* species can be difficult to identify in the field and were all pooled together) were the most common species at all sites (Table 6), they contributed a much greater proportion at the grounding sites (mean greater than 65% at all grounding sites) than at the control sites. In contrast, mean *Gorgonia ventalina* contribution was more than twice in the control sites than at any of the grounding sites.

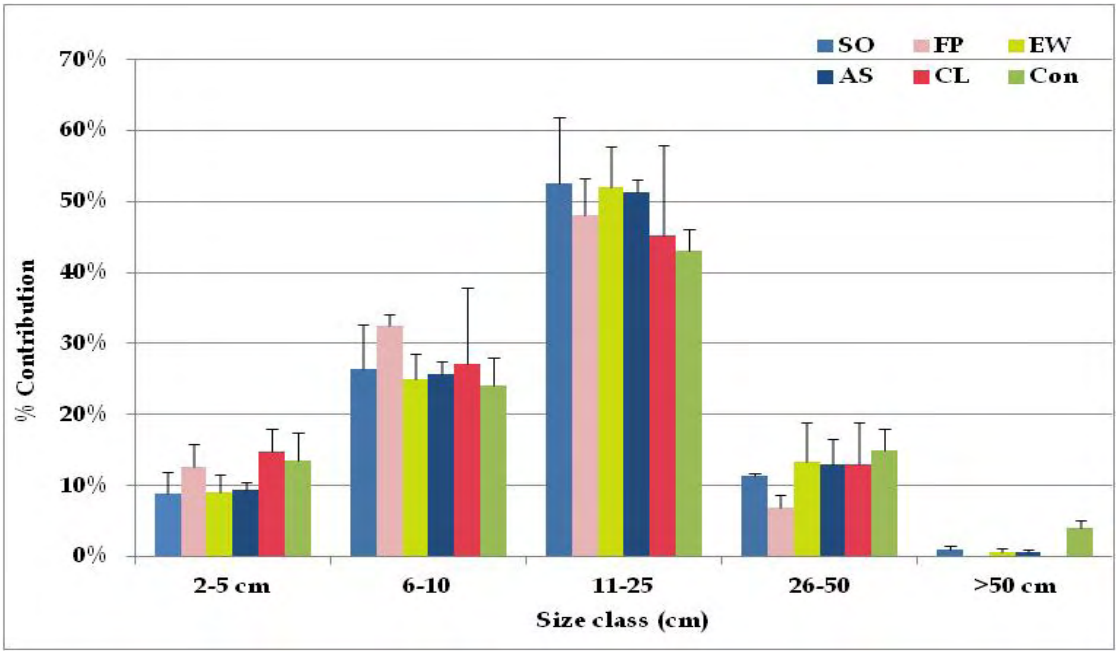

Figure 15. Mean (SE) gorgonian size (height) class contribution (percent) (see Figure 11 for abbreviations).

Table 6. Gorgonian species contribution (percent) within each site (SO = Spar Orion, FP = Federal Pescadores, EW = Eastwind, AS = Alam Senang, CL = Clipper Lasco, and Con = Control).

Species	AS	CL	EW	FP	SO	CON
Eunicea flexuosa	4.5%	2.5%	1.0%	0.0%	0.4%	7.3%
Eunicea fusca	18.5%	14.9%	20.4%	10.3%	14.8%	25.3%
Eunicea mammosa	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
Eunicea spp.	3.2%	2.9%	1.7%	2.1%	3.5%	5.9%
Eunicea succinea	0.0%	1.4%	0.0%	0.0%	0.0%	1.8%
Gorgonia ventalina	4.4%	1.0%	2.5%	0.1%	0.6%	11.2%
Muricea spp.	0.2%	0.3%	1.0%	8.1%	3.6%	3.5%
Plexaura homomalla	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Plexaurella spp.	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
Pseudoplexaura porosa	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pseudoplexaura sp.	3.0%	0.8%	2.4%	4.9%	3.7%	3.2%
Pseudopterogorgia spp.	66.1%	76.2%	70.8%	73.4%	73.5%	34.8%
Pterogorgia citrina	0.0%	0.0%	0.0%	1.1%	0.0%	5.7%

Both the Federal Pescadores and Spar Orion sites had mean gorgonian recruit (colonies <2cm height) densities greater than the control sites, but there was no significant difference determined among any of the grounding sites (ANOVA, p>0.05) (Table 4).

Mean barrel sponge density (sponge/m^2) and volume (cm^3) were greater in the control sites (Table 4). No barrel sponges were identified in the Federal Pescadores sites, and only one sponge was identified in the Clipper Lasco sites. Only the Spar Orion had barrel sponges identified in all three sites, while all twelve control sites had barrel sponges.

Percent substrate types (pavement, rubble, and sand) within each site was estimated from the transect videos. Mean percent coverage of pavement (consolidated substrate) was significantly higher (ANOVA, p<0.05) at the control sites than all grounding sites except the Federal Pescadores (Table 4) (Figure 16). The mean cover of rubble and sand (unconsolidated substrates) at the grounding sites was greater than that at the control sites (Figure 16) with all grounding sites having at least one site with more than 5% rubble and 5% sand coverage. Only one control site (site 5) had rubble coverage greater than 5%, and no control sites had sand coverage greater than 5%.

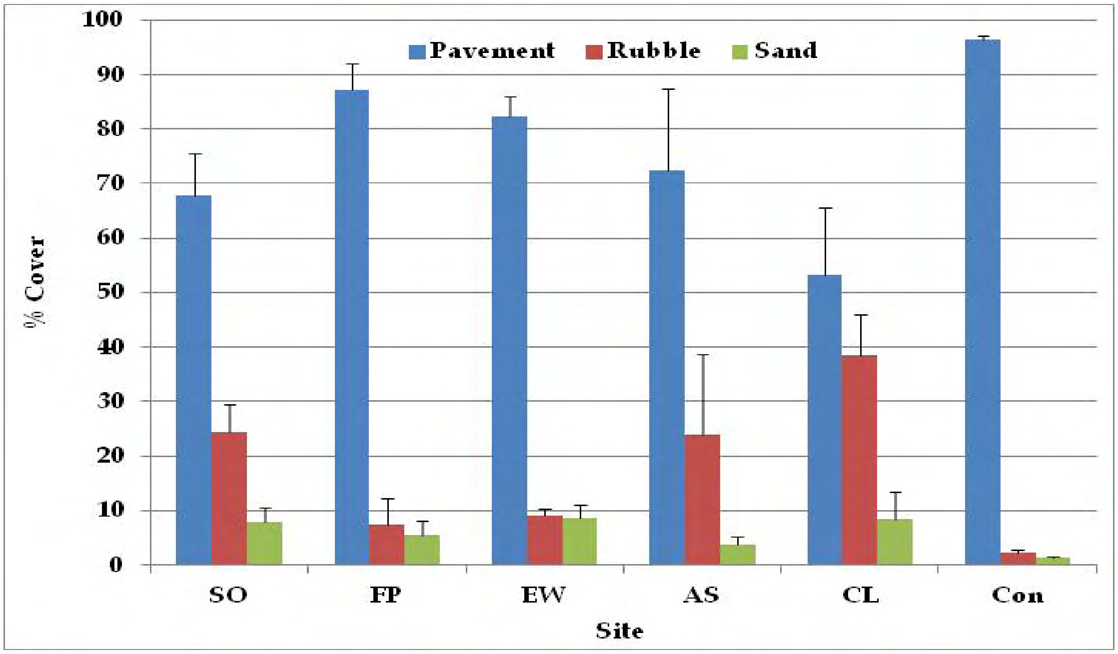

Figure 16. Mean (SE) percent substrate (pavement, rubble, and sand) for each site. Significance testing results are shown in Table 4 (see Figure 11 for abbreviations).

The groundings sites were flatter than the control sites with the mean rugosity at all of the grounding sites less than the control sites (Table 4) (Figure 17). Eleven of the individual control sites were more rugose (complex) than any of the grounding sites except for two Alam Senang sites which were slightly more rugose than one control site (control 12).

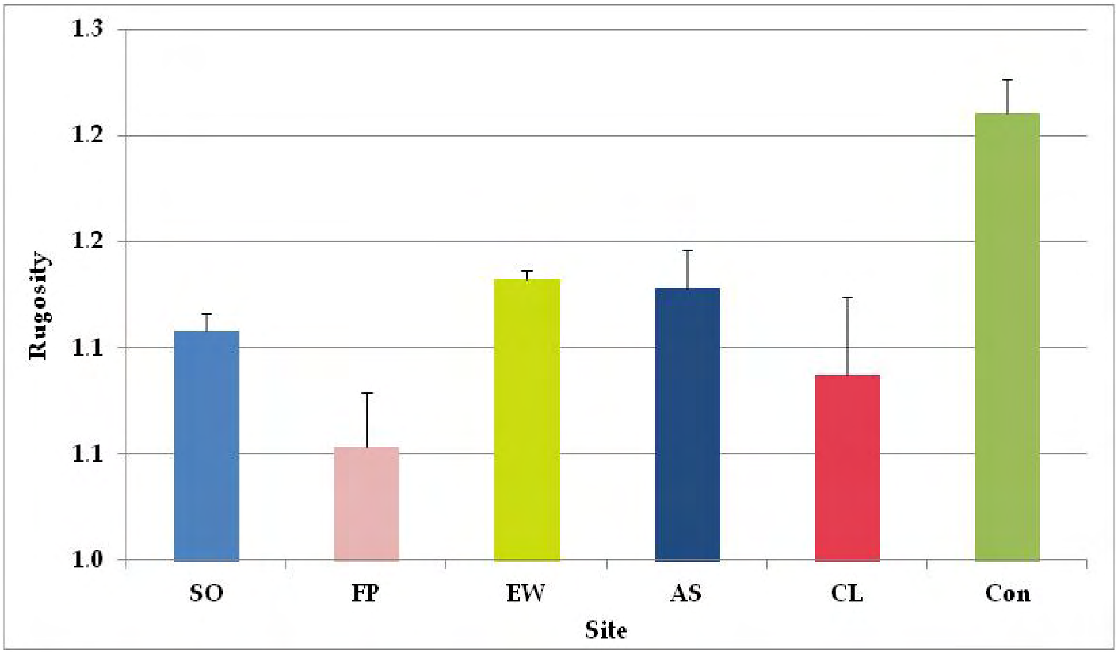

Figure 17. Mean (SE) site rugosity. Significance testing results are shown in Table 4 (see Figure 11 for abbreviations).

The functional group percent cover was estimated from the video transects. Figure 18 is the MDS ordination plot of percent functional group cover for all grounding and control samples. A significant difference was determined among sites (ANOSIM, Global R = 0.662, p = 0.01%). Pair-wise comparisons indicated that significant differences were determined between each grounding site and the control sites (Alam Senang: R = 0.24, p = 4.2%; Federal Pescadores: R = 0.964, p = 0.2%; Eastwind: R = 0.721, p = 0.4%; Spar Orion: R = 0.898, p = 0.2%; Clipper Lasco: R = 0.933, p = 0.2%). Significant groupings (SIMPROF [similarity profiles] procedure on Bray Curtis similarity indices) are superimposed over the sites in the MDS plot (Figure 18). All control samples group in the 75% similarity, except Control sample 2 (Con2). The grounding sites form two groups at 80% similarity except samples Alam Senang 3 (AS3) and two Federal Pescadores samples (FP2 and FP3) which form their own groups at 75% similarity.

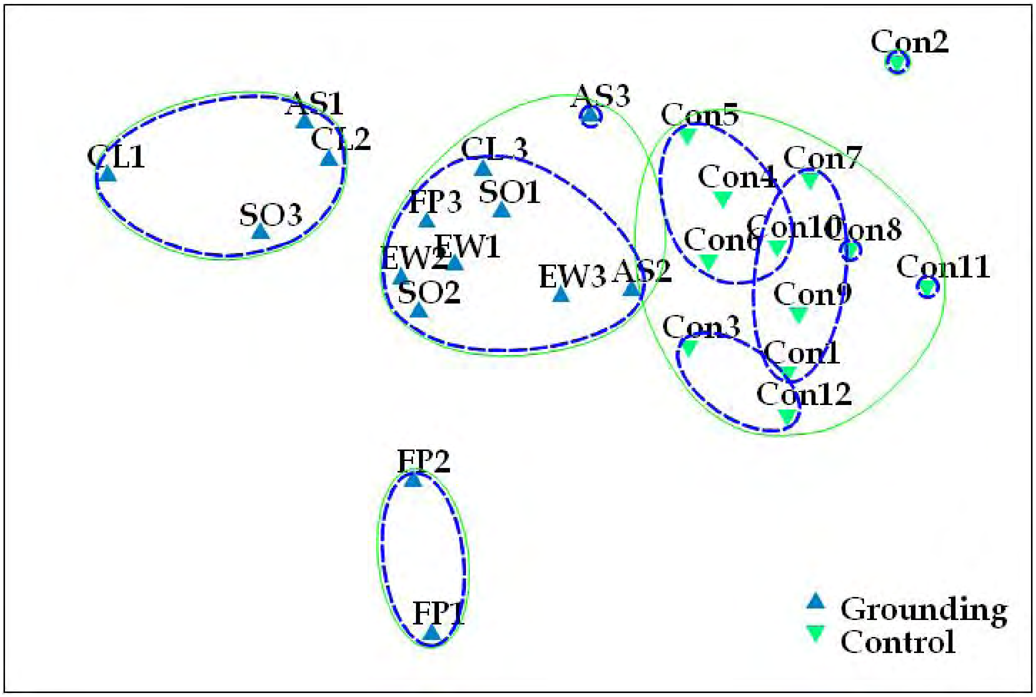

Figure 18. MDS plot of Inner Reef grounding and control sample video transect percent cover data (stress = 0.11) (SO = Spar Orion, FP = Federal Pescadores, EW = Eastwind, AS = Alam Senang, CL = Clipper Lasco, and Con = Control). The green solid line represents Bray-Curtis similarity at 75% and the blue dashed line 80%.

The SIMPER analyses were run to examine which functional groups contributed the most to the dissimilarity among sites. For each pair-wise comparison (grounding site to control sites) the rubble substrate group cover and the stony coral, gorgonian, and sponge cover were listed as functional groups contributing to the dissimilarity between each grounding site and the control samples.

In particular for the stony corals, *M. cavernosa* was a stony coral species which was found to be important. Figure 19 is the same MDS plot as shown in Figure 18, but the relative contributions of *M. cavernosa* (Figure 19), gorgonian (Figure 20), sponge (Figure 21), and turf algae on rubble (Figure 22) are shown as bubbles superimposed over the sample name. The larger the bubble, the greater the percent cover of that group at that sample, and the more that functional group contributes to the dissimilarity between sites. Figure 19 shows that the control samples have greater cover in *M. cavernosa*, gorgonians, and sponges, and lower rubble cover than the grounding samples. Figures 19-22 also illustrates the functional groups which help to explain why samples FP1 and FP2 separate from the other grounding samples. These two samples are low in stony coral cover but are also low in rubble cover.

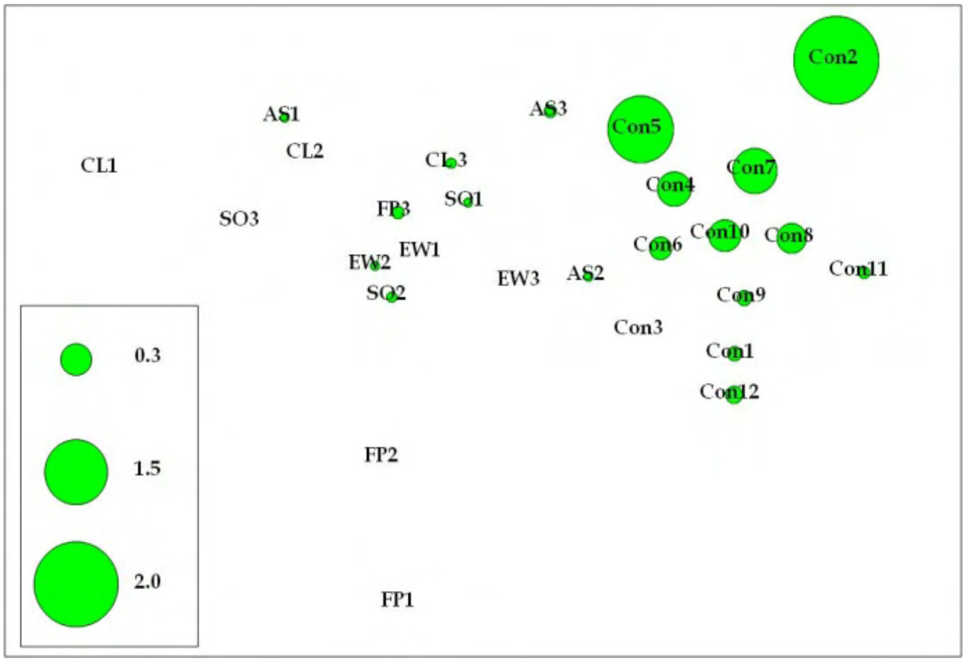

Figure 19. The Inner Reef MDS as shown in Figure 18 with superimposed bubbles over each sample. Each bubble represents the *M. cavernosa* percent cover. The bubble scale box in each plot represents the approximate percent cover for each size bubble.

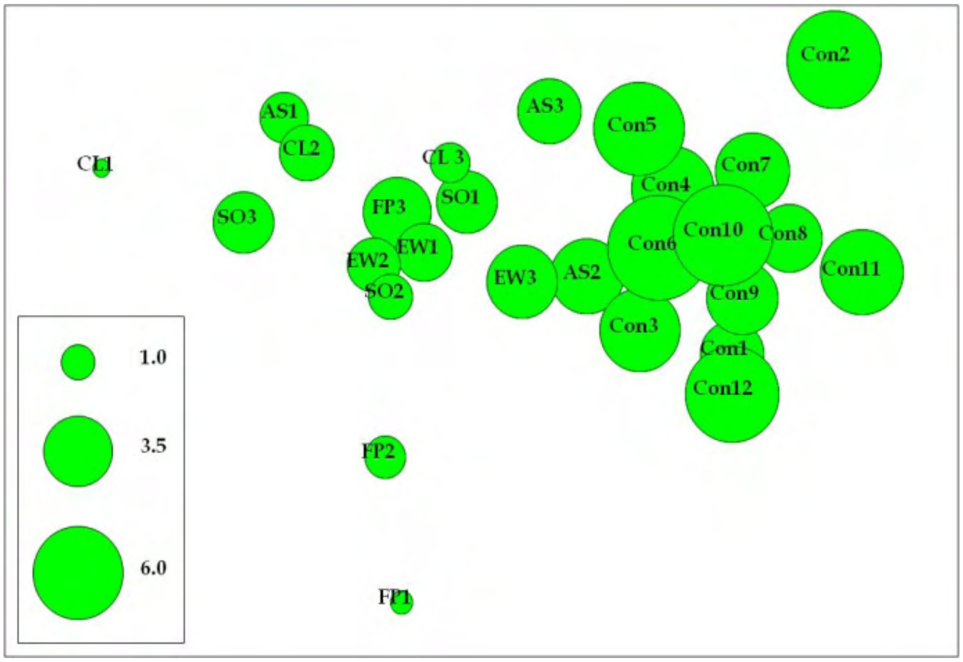

Figure 20. The Inner Reef MDS as shown in Figure 18 with superimposed bubbles over each sample. Each bubble represents the gorgonian percent cover. The bubble scale box in each plot represents the approximate percent cover for each size bubble.

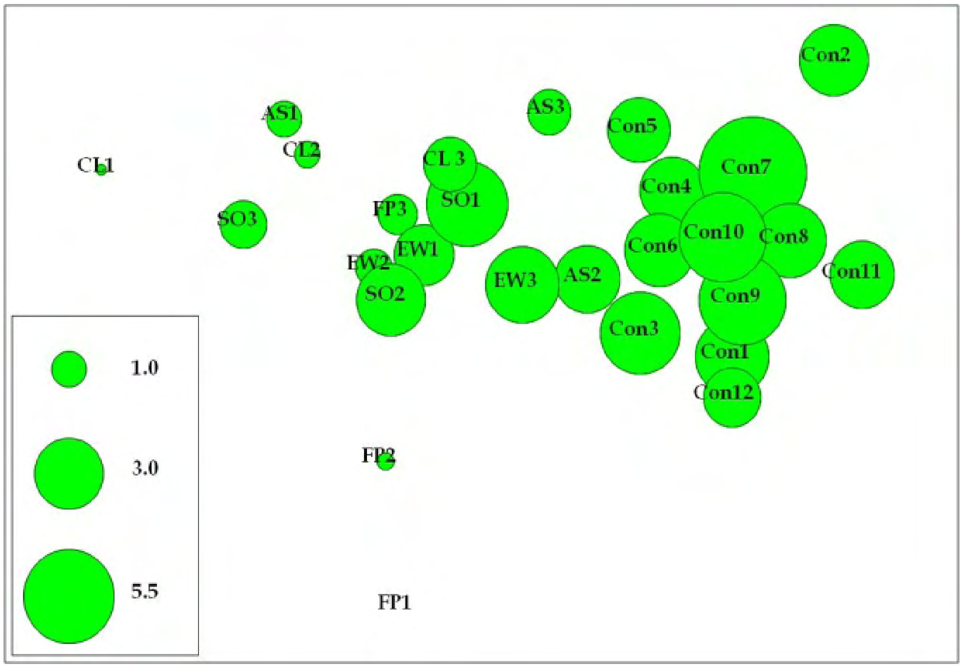

Figure 21. The Inner Reef MDS as shown in Figure 18 with superimposed bubbles over each sample. Each bubble represents the sponge percent cover. The bubble scale box in each plot represents the approximate percent cover for each size bubble.

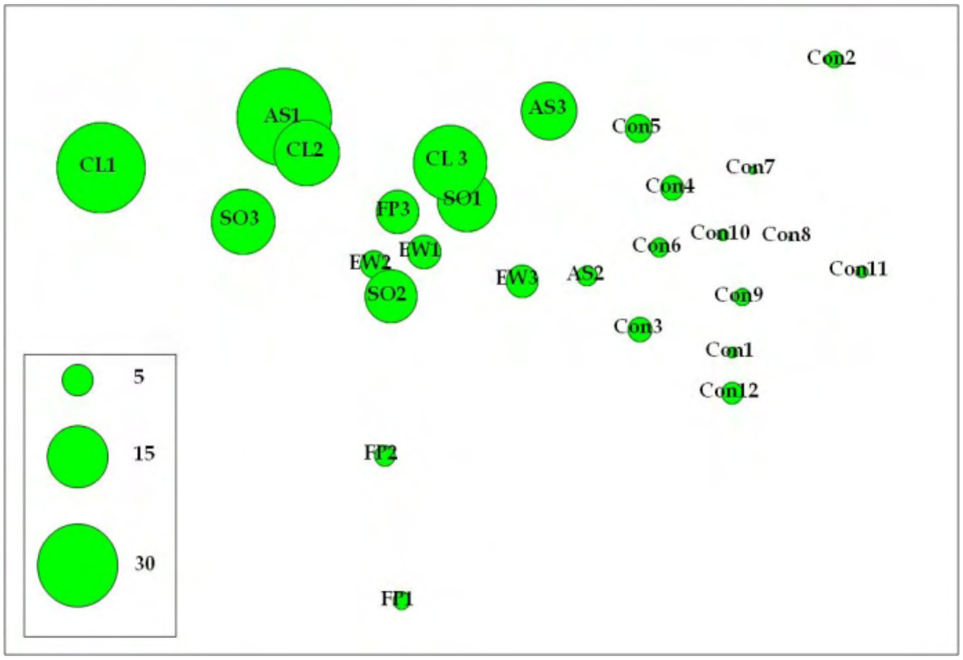

Figure 22. The Inner Reef MDS as shown in Figure 18 with superimposed bubbles over each sample. Each bubble represents the rubble percent cover. The bubble scale box in each plot represents the approximate percent cover for each size bubble.

Stony coral recruit (colonies <5cm diameter) species were identified within the belt transects. Figure 23 is the MDS ordination of recruit species contribution (proportion of each species to the total number of recruits) for all grounding and control samples. A significant difference was determined among sites (ANOSIM, Global R = 0.663, p = 0.1%). Significant groupings (SIMPROF procedure) are also superimposed over the samples in the recruit MDS plot (Figure 23). All control sites group within two 60% similarity groups, and the grounding sites also grouped within a 60% similarity group except the Spar Orion samples which grouped with one of the control groups. SIMPER analyses were run to examine which stony coral recruit species contributed most to the dissimilarity among sites. For each pair-wise comparison (grounding site to control except Spar Orion), the greater contribution of *S. siderea* recruits at the groundings sites and the greater contribution of *M. cavernosa* at the control sample sites accounted for most of the dissimilarity. Figure 25 is the same MDS plot as shown in Figure 23, but the greater contribution of *S. siderea* (Figure 24) at the grounding sites and the greater contribution of *M. cavernosa* (Figure 24) at the control are shown as bubbles superimposed over the sample name.

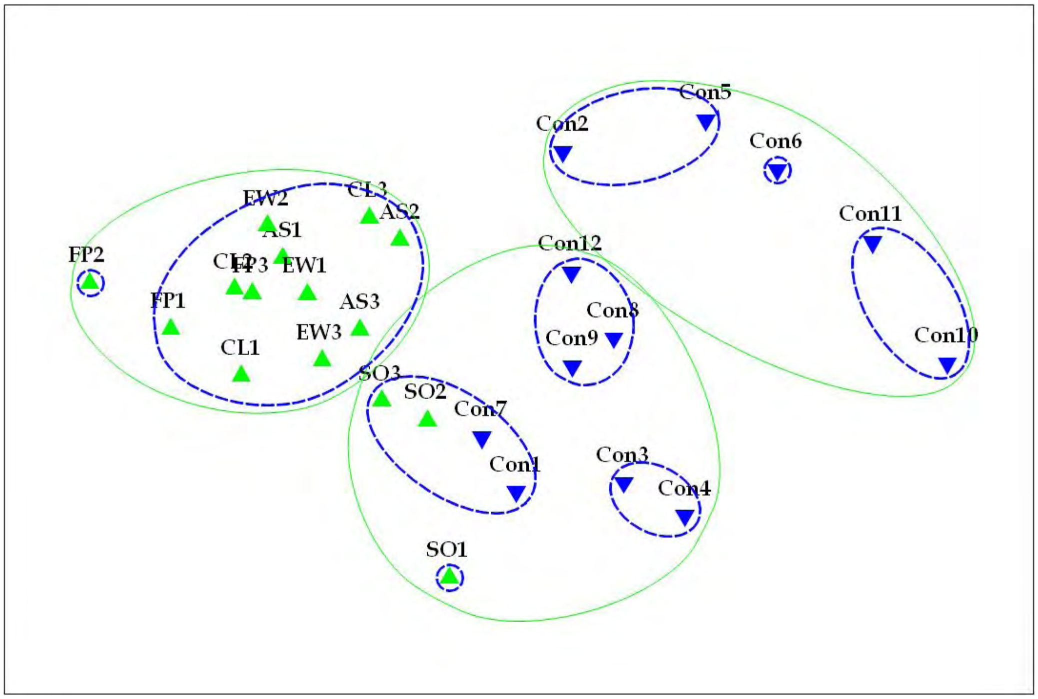

Figure 23. MDS plot of Inner Reef grounding and control sample stony coral recruit data (stress = 0.1) (SO = Spar Orion, FP = Federal Pescadores, EW = Eastwind, AS = Alam Senang, CL = Clipper Lasco, and Con = Control). The green solid line represents Bray-Curtis similarity at 60% and the blue dashed line 70%.

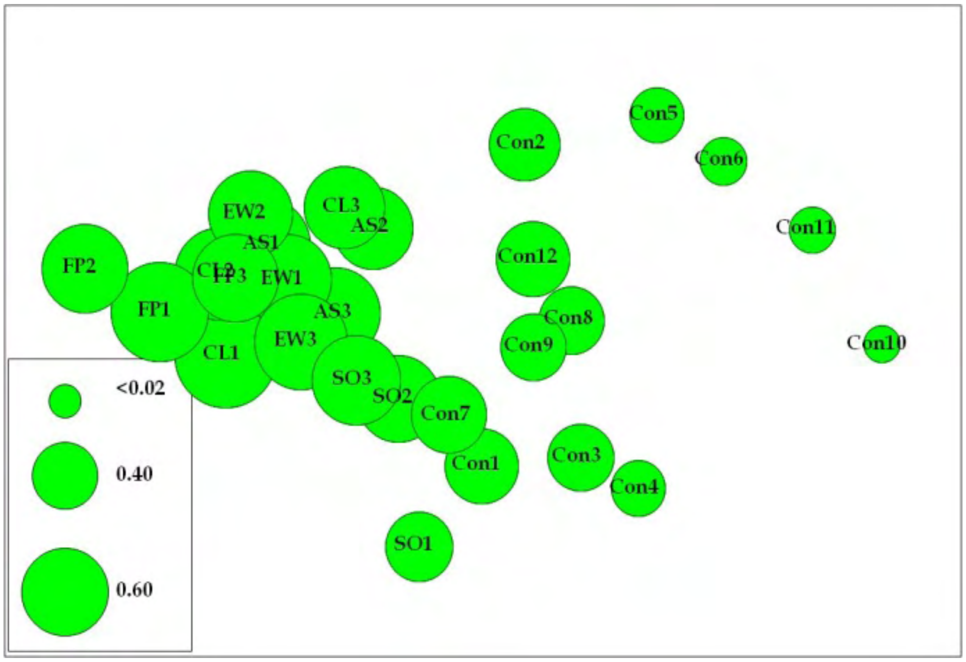

Figure 24. The Inner Reef MDS as shown in Figure 23 with superimposed bubbles over each sample. Each bubble represents the *S. siderea* percent cover. The bubble scale box in each plot represents the approximate percent cover for each size bubble.

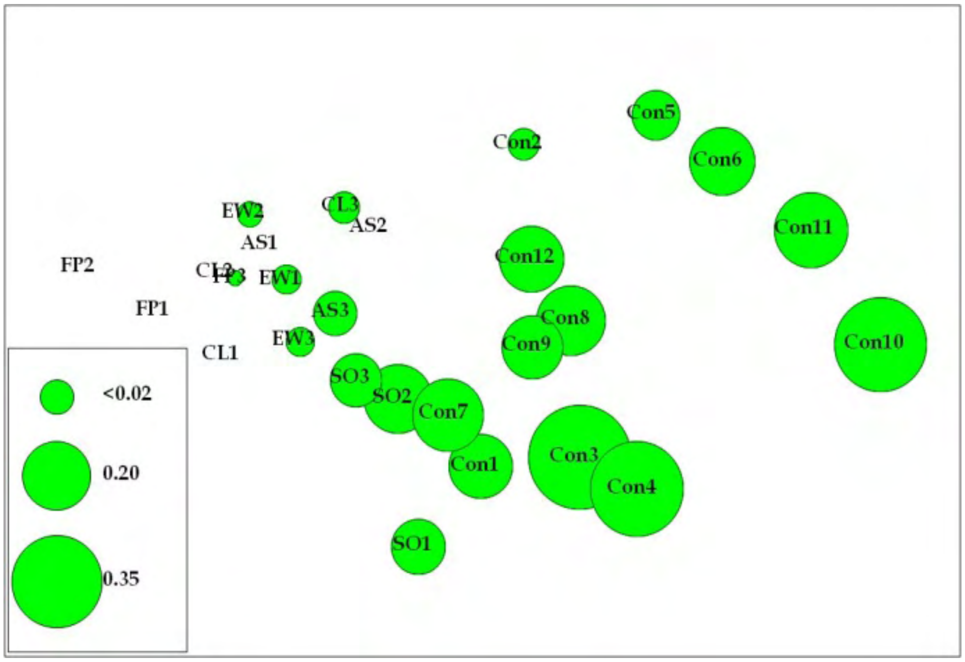

Figure 25. The Inner Reef MDS as shown in Figure 23 with superimposed bubbles over each sample. Each bubble represents the *M. cavernosa* percent cover. The bubble scale box in each plot represents the approximate percent cover for each size bubble.

Table 7 summarizes the densities of colonies greater than 20cm diameter identified within the four, 4m x 30m transects sampled within the control site. All twelve sites had colonies >50cm diameter, ten sites had colonies >75cm, and four sites had colonies >100cm. *M. cavernosa, M. faveolata,* and *M. annularis* colonies were the largest species identified in eight of the twelve sites. The largest colony (290cm diameter) was a *M. faveolata* colony identified in control site 8.

Table 8 summarizes number of colonies greater than 20cm diameter estimated to have been present within each grounding site. These estimates indicate that it is likely that the grounding sites had numerous colonies at least 50cm diameter.

Table 7. Density (colonies/m²) of stony coral colonies by size (cm) class identified within the control site large coral transects. The max and species columns represent the largest colony identified within the four transects in each site.

Site	Total	20 – 50	≥ 50	≥ 75	≥ 100	Max	Species
Crtl 1	0.140	0.127	0.013	0.002	0.000	86	*M. cavernosa*
Crtl 2	0.308	0.267	0.042	0.004	0.000	95	*M. cavernosa*
Crtl 3	0.115	0.106	0.008	0.004	0.000	95	*M. meandrites*
Crtl 4	0.240	0.215	0.025	0.002	0.002	120	*M. faveolata*
Crtl 5	0.294	0.260	0.033	0.010	0.006	170	*M. faveolata*
Crtl 6	0.131	0.117	0.015	0.004	0.000	75	*M. meandrites*
Crtl 7	0.050	0.048	0.002	0.000	0.000	60	*M. cavernosa*
Crtl 8	0.156	0.142	0.015	0.002	0.002	290	*M. faveolata*
Crtl 9	0.167	0.140	0.027	0.006	0.000	85	*C. natans*
Crtl 10	0.138	0.117	0.021	0.004	0.000	88	*M. annularis*
Crtl 11	0.156	0.138	0.019	0.002	0.002	115	*M. annularis*
Crtl 12	0.081	0.069	0.013	0.000	0.000	66	*M. meandrites*
Mean ± SE	0.164± .039	0.145± .034	0.019± .006	0.003 ±.002	0.001± .001		

Table 8. Estimated number of colonies >20cm diameter within each grounding site prior to the injury event. The injury area for each site is multiplied by the corresponding size class density in Table 7.

Grounding Site	Injury Area (m^2)	Total	20 – 50cm	≥ 50cm	≥ 75cm	≥ 100cm
Alam Senang	216	35	31	4	1	1
Eastwind	10,995	1803	1594	209	33	11
Federal Pescadores	23,399	3837	3393	445	70	23
Spar Orion	546	90	79	10	2	1
Clipper Lasco	558	92	81	11	2	1

Firat Grounding

Three Firat grounding and three control samples were surveyed on the nearshore ridge in Broward County. Table 2 and Figure 2 show the sample dates and locations for the Firat grounding sites. Table 3 and Figure 9 show the sample dates and locations of the three control sites.

For stony coral colonies >5cm diameter, neither mean percent cover (belt transect data) nor density (colonies/m^2) were significantly different between the grounding and control samples (t-test, $p>0.05$) (Table 9). Although stony coral mean diameter was larger and the mean largest colony was greater in the control samples, neither was significantly greater than the Firat samples (Table 9). Colony size distribution was examined by pooling all control colonies and all colonies within the Firat samples and assigning them to size (diameter) classes (5-10cm, 11-20cm, 21-30cm, 31-40cm, 41-50cm, and >50cm). The Firat samples were more heavily right-skewed towards the smallest size classes (Figure 26), and the control samples had a greater contribution from colonies in the four largest size classes (21-30cm, 31-40cm, 41-50cm, and >50cm).

There was no significant difference in the mean number of stony coral species (colonies >5cm diameter) identified between the Firat and control samples (Table 9). Eleven total species were identified in the six samples with six species identified in at least five of the six samples (Table 10). *P. astreoides* and *Dichocoenia stokesii* appear to have a greater contribution to the stony coral assemblage in the Firat samples versus the control samples (Table 10), and *Acropora cervicornis* may have a greater contribution in the control samples.

Stony coral recruits were defined as colonies <5cm diameter. There was no significant difference in recruit density (colonies/m^2) or numbers of recruit species (t-test, $p>0.05$) (Table 9). Recruit density was low in both the Firat samples and control samples with a mean less than 2/m^2.

Table 9. Summary data [mean (SE)] for the Firat grounding samples and the Firat control sites. Significantly different means are bolded.

Site	Firat	Control
Number of Samples	3	3
Stony Corals		
No. of Species	7.33 (1.20)	7.67 (0.88)
Cover (%)	2.04 (0.44)	6.51 (2.31)
Density (col./m²)	1.65 (0.15)	1.34 (0.21)
Mean colony size (dia cm)	12.91 (0.70)	23.85 (1.65)
Max colony size (dia cm)	55.00 (12.09)	75.00 (14.43)
No. of Recruit Species	2.67 (0.67)	2.67 (0.67)
Recruit Density (col./m²)	1.90 (0.29)	1.03 (0.38)
Gorgonians		
No. of Species	11.33 (0.33)	9.67 (0.33)
Cover (%)	**24.23 (0.93)**	**17.70 (0.69)**
Density (col./m²)	26.87 (5.83)	26.23 (5.54)
Recruit Density (col./m²)	1.30 (0.25)	0.70 (0.25)
Substrate		
Pavement Cover (%)	98.53 (0.37)	97.76 (0.41)
Rubble Cover (%)	1.25 (0.25)	2.14 (0.39)
Sand Cover (%)	0.22 (0.15)	0.10 (0.07)
Rugosity	**1.06 (0.01)**	**1.11 (.01)**

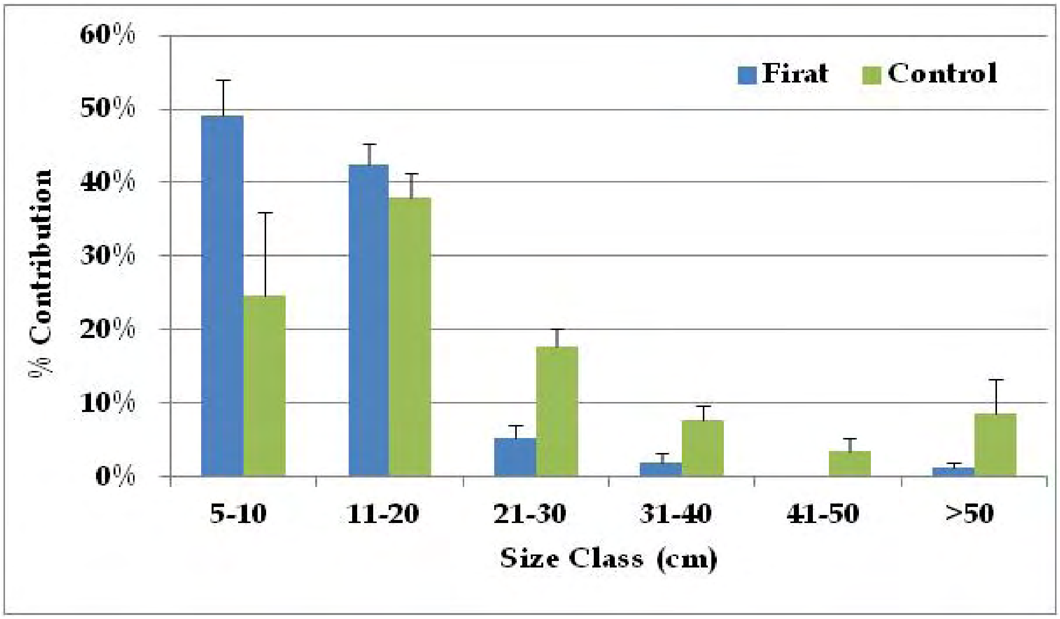

Figure 26. Mean (SE) stony coral size class contribution (percent).

Table 10. Stony coral (colonies ≥5cm dia) species contribution (%) within each sample.

Species	Firat 1	Firat 2	Firat 3	Control 1	Control 2	Control 3
Acropora cervicornis	22.7%	1.8%	0.0%	92.5%	77.4%	15.3%
Colpophyllia natans	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%
Dichocoenia stokesii	4.3%	3.0%	1.6%	1.4%	0.0%	3.6%
Diploria clivosa	12.7%	23.9%	16.4%	0.3%	9.9%	1.0%
Meandrina meandrites	0.0%	0.0%	0.0%	1.3%	0.0%	0.0%
Montastraea cavernosa	5.6%	27.8%	0.0%	0.1%	1.4%	10.6%
Porites astreoides	43.9%	37.5%	67.5%	1.4%	7.1%	17.4%
Porites porites	0.5%	0.6%	5.7%	0.0%	0.0%	0.6%
Siderastrea siderea	2.7%	1.1%	0.0%	1.3%	3.4%	9.3%
Solenastrea bournoni	5.2%	4.4%	8.8%	1.6%	0.0%	40.1%
Stephanocoenia intersepta	2.4%	0.0%	0.0%	0.0%	0.0%	2.1%

Only five recruit species were identified in the six samples (*P. astreoides*, *S. siderea*, *D. stokesii*, *S. intersepta*, and *Montastraea cavernosa*), and *P. astreoides* and *S. siderea* were the most common in abundance and were present in all samples.

Mean percent gorgonian cover was significantly greater in the Firat samples than in the control samples (Table 9) (t-test, $p<0.05$), but mean gorgonian density (colonies/m^2) was not significantly different among the samples (Table 9) (t-test, $p>0.05$). Size (height) class distribution also appeared similar between the control and Firat samples (Figure 27).

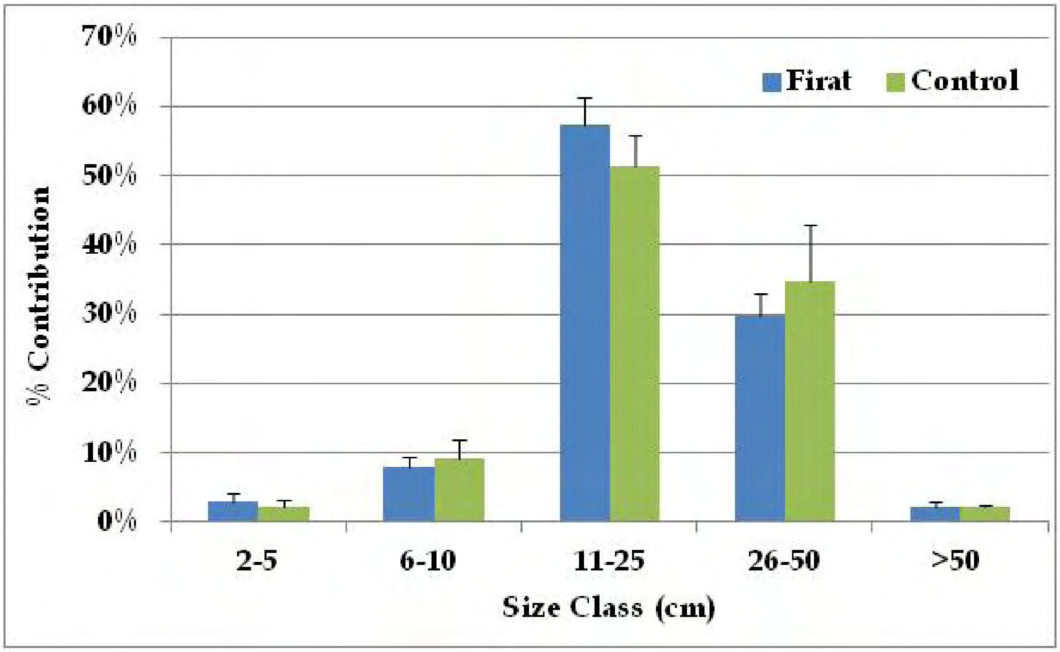

Figure 27. Mean (SE) gorgonian size (height cm) class contribution (percent).

There was no significant difference (t-test, p>0.05) in the mean number of gorgonian species identified in the control samples and Firat samples (Table 9). The gorgonian species identified in each of the six samples were very similar with nine of the eleven species identified in all six samples (Table 11). *Eunicea succinea* was the most common species identified in all six samples. There was no significant difference in gorgonian recruit (height <2cm) density between the control samples and Firat samples (Table 9).

Table 11. Gorgonian species contribution (percent) within each sample.

SPECIES	Firat 1	Firat 2	Firat 3	Control 1	Control 2	Control 3
Eunicea flexuosa	3.7%	3.2%	3.3%	0.0%	7.5%	5.0%
Eunicea fusca	6.9%	0.5%	5.9%	6.6%	3.1%	5.5%
Eunicea succinea	73.2%	78.1%	69.0%	67.0%	74.8%	75.5%
Eunicea spp.	2.4%	4.1%	5.4%	4.0%	0.3%	1.8%
Gorgonia ventalina	2.0%	3.0%	2.9%	3.3%	6.0%	2.7%
Muricea sp.	3.7%	3.7%	2.5%	4.6%	3.8%	5.2%
Plexaura homomalla	0.2%	0.7%	0.8%	6.3%	0.0%	0.0%
Plexaurella sp.	1.5%	2.3%	0.8%	3.0%	1.6%	0.2%
Pseudoplexaura spp.	2.0%	1.8%	1.3%	2.3%	0.6%	1.4%
Pseudopterogorgia spp.	1.5%	0.9%	7.5%	3.0%	1.6%	1.8%
Pterogorgia citrina	2.8%	1.6%	0.4%	0.0%	0.6%	0.9%

No barrel sponges were identified in any of the Firat or control samples.

Percent substrate type cover (pavement, rubble, and sand) within each site was estimated from the transect videos (Table 9). Percent coverage of pavement (consolidated substrate) was greater than 97% at all control and Firat samples. There was no significant difference (t-test, p>0.05) in percent cover of any of the substrate types (pavement, rubble, or sand) between the control samples and Firat samples (Table 9).

The functional group percent cover was estimated from the video transects. Figure 28 is the MDS ordination plot of percent functional group cover the three Firat and three control samples. A significant difference was determined among sites (ANOSIM, Global R = 0.889, p = 0.10%) (with three samples only a significance level to 10% is possible). Significant groupings at 80% (SIMPROF procedure on Bray Curtis similarity indices) are superimposed over the samples in the MDS plot (Figure 28).

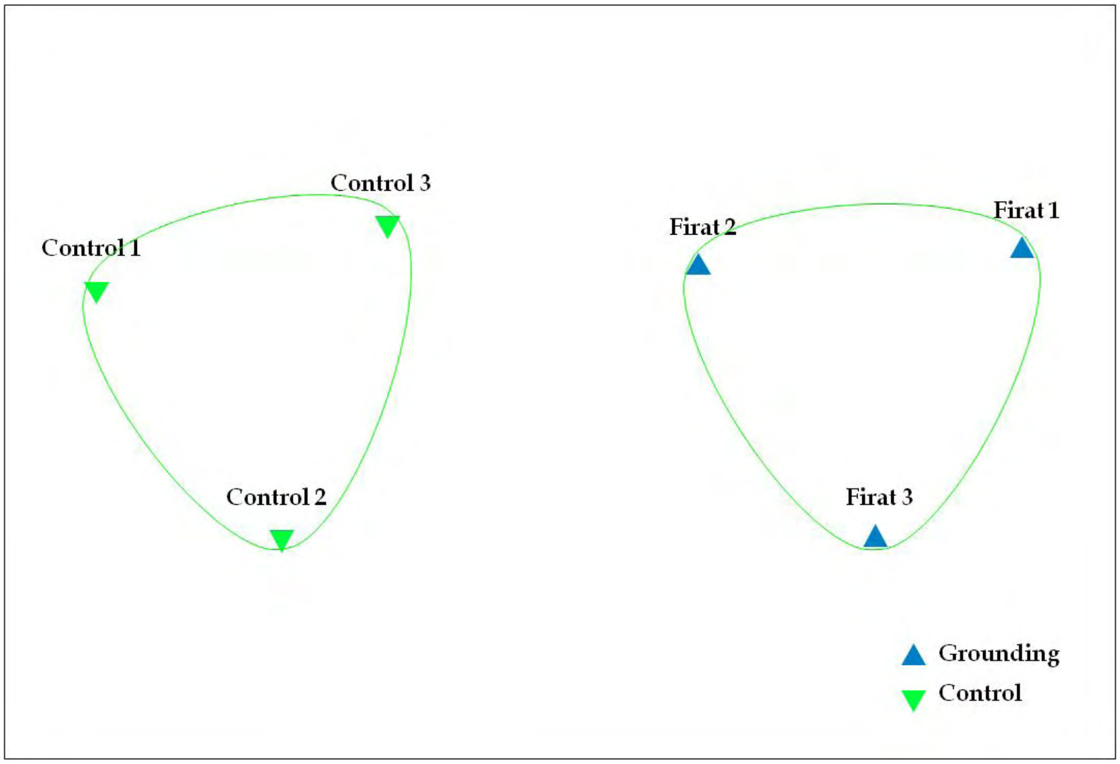

Figure 28. MDS plot of the Firat and control samples percent functional group cover data (stress 0.02). The green solid line represents Bray-Curtis similarity at 80%.

A SIMPER analysis was run to examine which functional groups contributed the most to the dissimilarity between the Firat and control samples. Increased percent cover of macroalgae (Figure 29) and turf algae on pavement in the Firat samples and greater percent cover of *Diploria clivosa* (Figure 30) in the control samples were the top functional groups contributing to the dissimilarity.

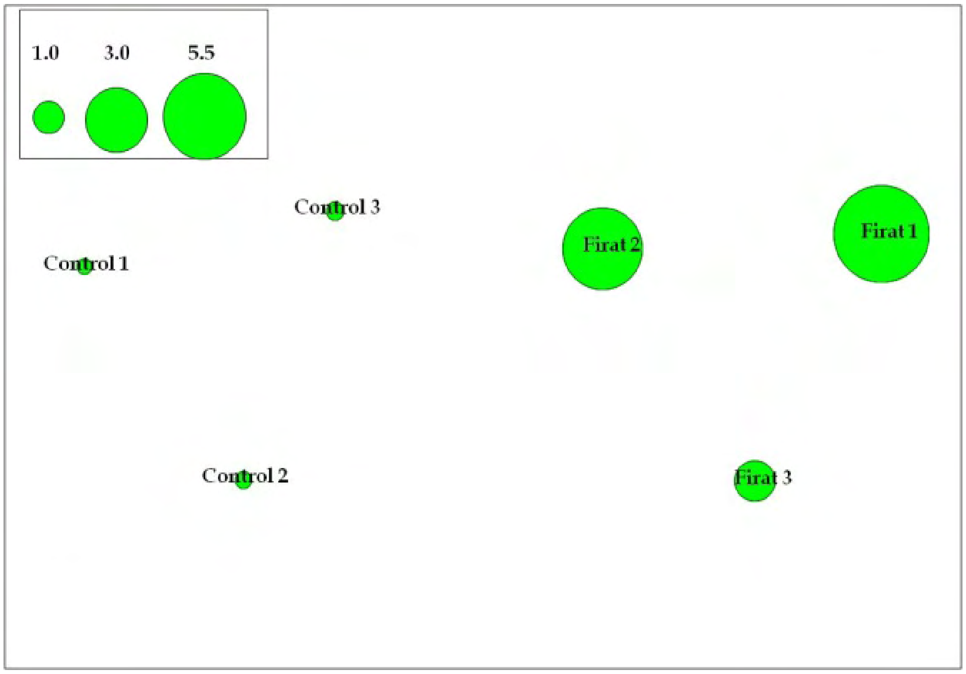

Figure 29. The Inner Reef MDS as shown in Figure 28 with superimposed bubbles over each sample. Each bubble represents the macroalgae percent cover. The bubble scale box in each plot represents the approximate percent cover for each size bubble.

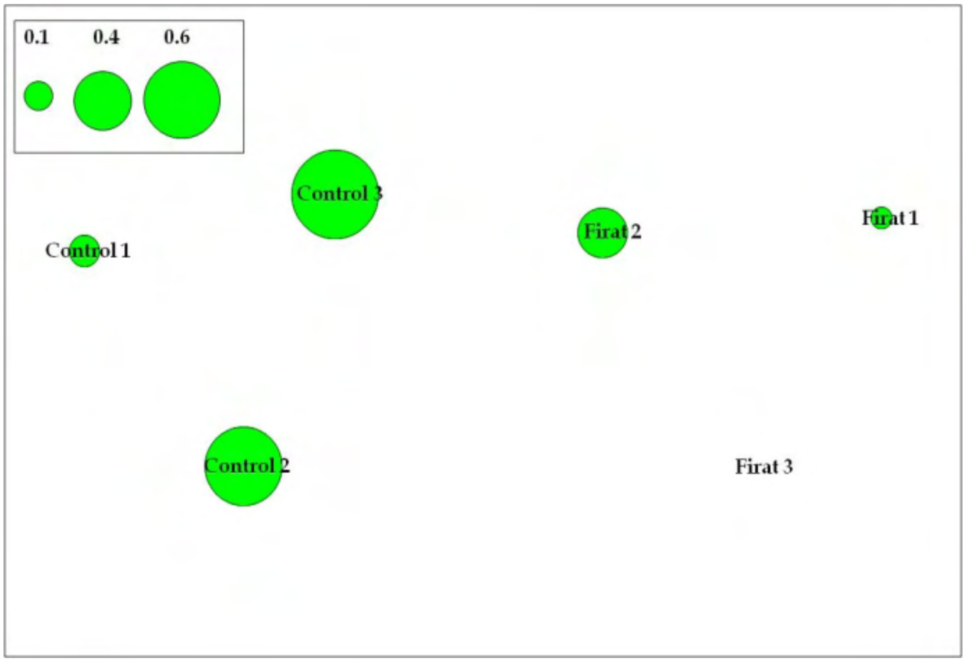

Figure 30. The Inner Reef MDS as shown in Figure 28 with superimposed bubbles over each sample. Each bubble represents the *D. clivosa* percent cover. The bubble scale box in each plot represents the approximate percent cover for each size bubble.

Anzhela Explorer Grounding

Three Anzhela Explorer grounding and control samples were surveyed. Table 1 lists the date of the grounding event, and Tables 2 and 3 list the sample dates and locations for the grounding and control samples. Figure 8 show the locations of each sample within the Anzhela Explorer grounding site and the location of the 3 control samples.

The three Anzhela Explorer samples combined only had five stony coral colonies ≥5cm diameter as compared to 38 colonies identified in the control samples. This dissimilarity lead to a significant difference (t-test, $p<0.05$) in mean percent cover (from belt transect data) and density (colonies/m^2) between the control samples and the Anzhela Explorer samples (Table 12). Of the five Anzhela Explorer colonies, the largest were two 10cm *S. intersepta* colonies. In contrast, the control samples had four colonies >40cm diameter and two colonies ≥60cm (one *D. clivosa* colony was 60cm and one *M. cavernosa* colony was 120cm). This difference in colony size distribution is illustrated in Figure 31 (pooled control colonies and pooled Anzhela Explorer colonies assigned to size classes).

Table 12. Summary data [mean (SE)] for the Anzhela Explorer (AE) grounding site and the control. Means which are significantly different than the controls are bolded.

Site	AE	Control
Number of Samples	3	3
Stony Corals		
No. of Species	**1.00 (0.57)**	5.00 (0.58)
Cover (%)	**0.01 (0.01)**	1.48 (0.39)
Density (col./m^2)	**0.06 (0.03)**	0.42 (0.06)
Mean colony size (dia cm)	**8.40 (0.68)**	18.39 (3.39)
Max colony size (dia cm)	**10.00 (0.00)**	75.00 (22.91)
No. of Recruit Species	5.33 (1.33)	4.67 (1.20)
Recruit Density (col./m^2)	3.87 (0.44)	7.07 (2.05)
Gorgonians		
No. of Species	4.00 (0.00)	5.33 (0.88)
Cover (%)	**0.94 (0.19)**	5.09 (2.09)
Density (col./m^2)	**1.25 (0.13)**	5.27 (1.28)
Recruit Density (col./m^2)	0.33 (0.12)	0.50 (0.06)
Substrate		
Pavement Cover (%)	**46.32 (10.57)**	92.44 (3.29)
Rubble Cover (%)	**42.19 (8.83)**	4.37 (0.21)
Sand Cover (%)	**11.49 (8.97)**	3.17 (3.17)
Rugosity	**1.07 (0.01)**	1.15 (0.01)

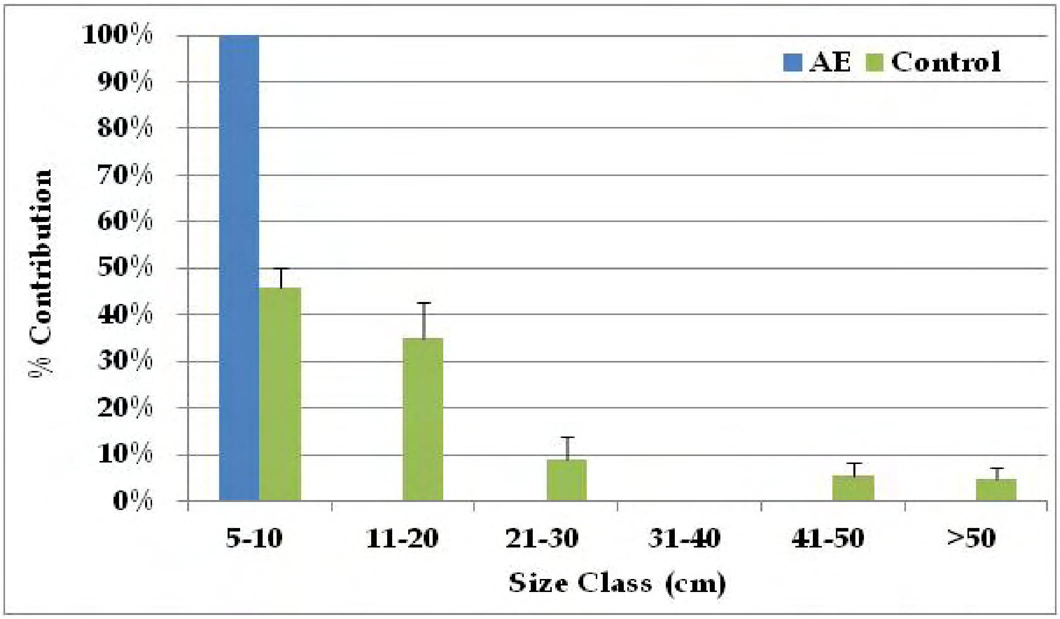

Figure 31. Mean (SE) stony coral size class (cm) contribution (percent). AE= Anzhela Explorer grounding site.

The mean number of stony coral species (colonies ≥5cm diameter) identified in the control samples was more than twice that identified in the Anzhela Explorer (Table 12). In fact, only two species (one colony of *A. cervicornis* and four colonies of *S. intersepta*) were identified in the Anzhela Explorer as compared to seven species identified in the control samples (Table 13). *S. intersepta* was identified in all three control samples and two Anzhela Explorer samples.

Table 13. Stony coral (colonies ≥5cm dia.) species contribution (%) within each sample.

Species	AE 1	AE 2	AE 3	Control 1	Control 2	Control 3
Acropora cervicornis	0.0%	50.0%	0.0%	0.0%	0.0%	0.0%
Dichocoenia stokesii	0.0%	0.0%	0.0%	20.0%	37.5%	16.7%
Diploria clivosa	0.0%	0.0%	0.0%	40.0%	6.3%	0.0%
Montastraea cavernosa	0.0%	0.0%	0.0%	0.0%	0.0%	8.3%
Montastraea faveolata	0.0%	0.0%	0.0%	0.0%	6.3%	0.0%
Siderastrea siderea	0.0%	0.0%	0.0%	20.0%	18.8%	8.3%
Solenastrea bournoni	0.0%	0.0%	0.0%	0.0%	18.8%	41.7%
Stephanocoenia intersepta	0.0%	50.0%	100.0%	20.0%	12.5%	25.0%

Stony coral recruits were defined as colonies < 5cm diameter. Although the mean control sample recruit density (colonies/m^2) was greater than the Anzhela Explorer samples (Table 12), there was no significant difference in density among the sites (t-test, p>0.05). *S. siderea* dominated the juvenile population contributing more than 70% in all six samples.

Mean percent gorgonian cover and mean gorgonian density (colonies/m^2) were significantly greater in the control samples than in the Anzhela Explorer samples (Table 12) (t-test, p<0.05). Size (height) class distribution was different between the control and Anzhela Explorer samples (Figure 32) with colonies 25-50cm contributing a greater proportion in the control samples and colonies >50cm not present in the Anzhela Explorer samples.

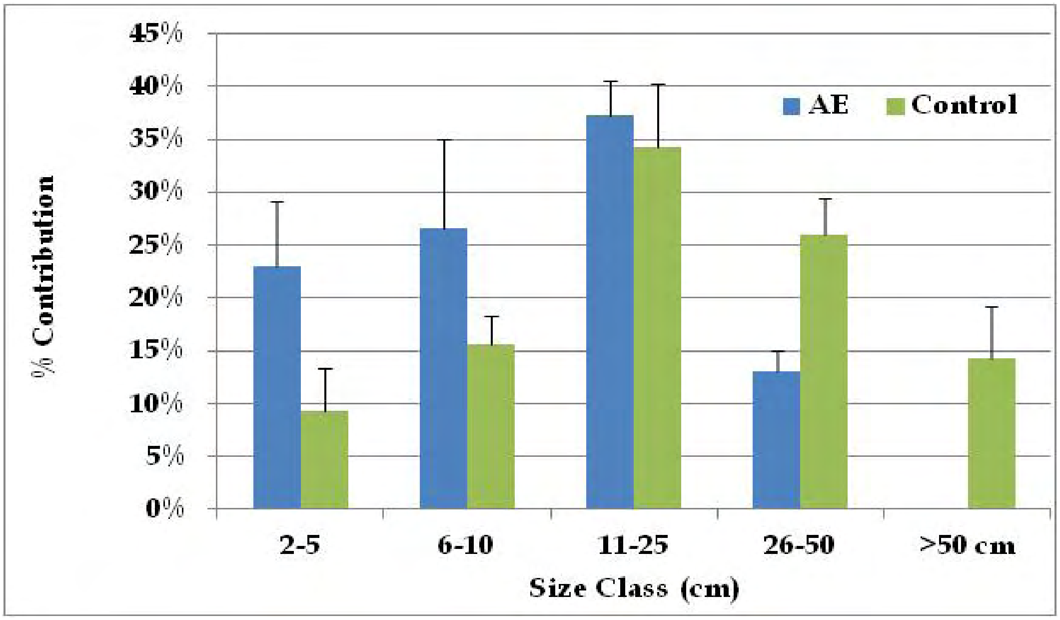

Figure 32. Mean (SE) gorgonian size (height) class contribution (percent).

Most gorgonians in the Anzhela Explorer samples were identified to genus. There was no significant difference (t-test, p>0.5) in the mean number of gorgonian genera identified in the control and Anzhela Explorer samples (Table 12). Gorgonians in the genera *Eunicea*, *Pseudopterogorgia*, and *Pseudoplexaura* were common in all six samples (Table 14).

Table 14. Gorgonian species contribution (percent) within each sample.

Genus	AE 1	AE 2	AE 3	Control 1	Control 2	Control 3
Eunicea spp.	36.7%	47.6%	26.8%	32.6%	55.7%	32.6%
Gorgonia ventalina	3.3%	2.4%	0.0%	3.5%	1.4%	0.0%
Muricea muricata	0.0%	0.0%	0.0%	0.0%	0.9%	0.0%
Plexaura spp.	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%
Plexaurella spp.	0.0%	0.0%	2.4%	0.0%	5.5%	0.0%
Pseudoplexaura spp.	26.7%	16.7%	34.1%	34.8%	23.4%	26.7%
Pseudopterogorgia spp.	33.3%	33.3%	36.6%	29.1%	12.9%	39.5%

No barrel sponges were identified in any of the Anzhela Explorer or control samples.

Percent substrate type cover (pavement, rubble, and sand) within each site was estimated from the transect videos. Percent coverage of pavement (consolidated substrate) was significantly greater (t-test, p<0.05) at the control samples while percent cover of rubble and sand was significantly greater (t-test, p<0.05) at the Anzhela Explorer samples (Table 12) (Figure 33).

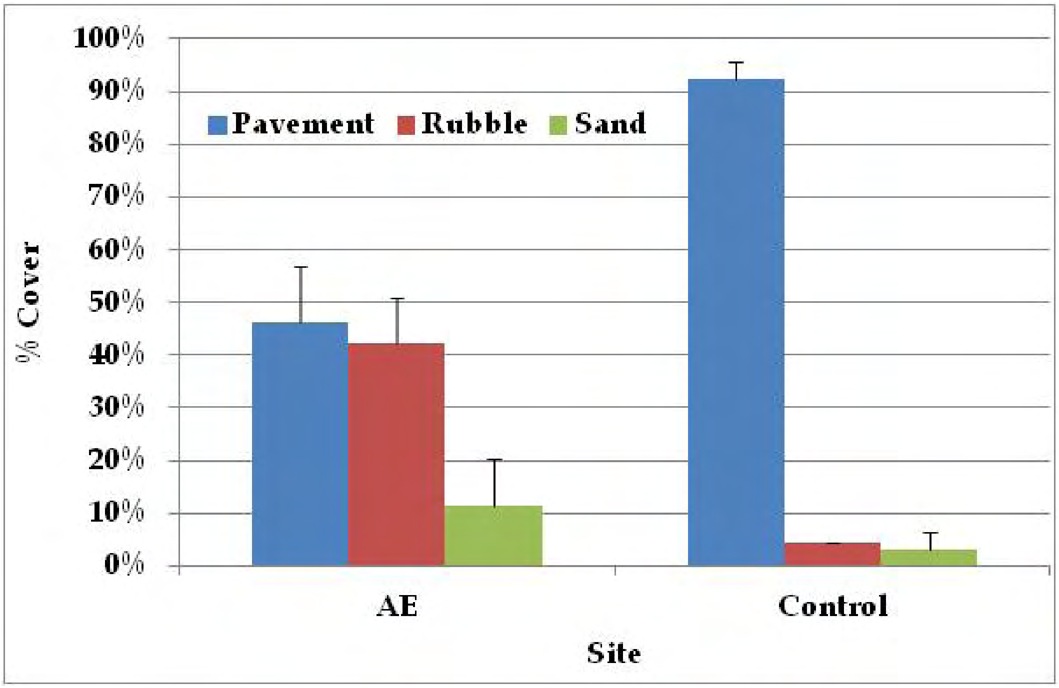

Figure 33. Mean (SE) percent substrate (pavement, rubble, and sand) for each site. All three substrate types were significantly different (t-test, p<0.05) between the sites.

The functional group percent cover was estimated from the video transects. Figure 34 is the MDS ordination plot of percent functional group cover for the Anzhela Explorer and control samples. A significant difference was determined among sites (ANOSIM, Global R = 0.926, p = 10%) (with three samples only a significance level to 10% is possible). Significant groupings (SIMPROF procedure on Bray Curtis similarity indices) are superimposed over the sites in the MDS plot (Figure 34). Both control samples and Anzhela Explorer samples group at 70% similarity.

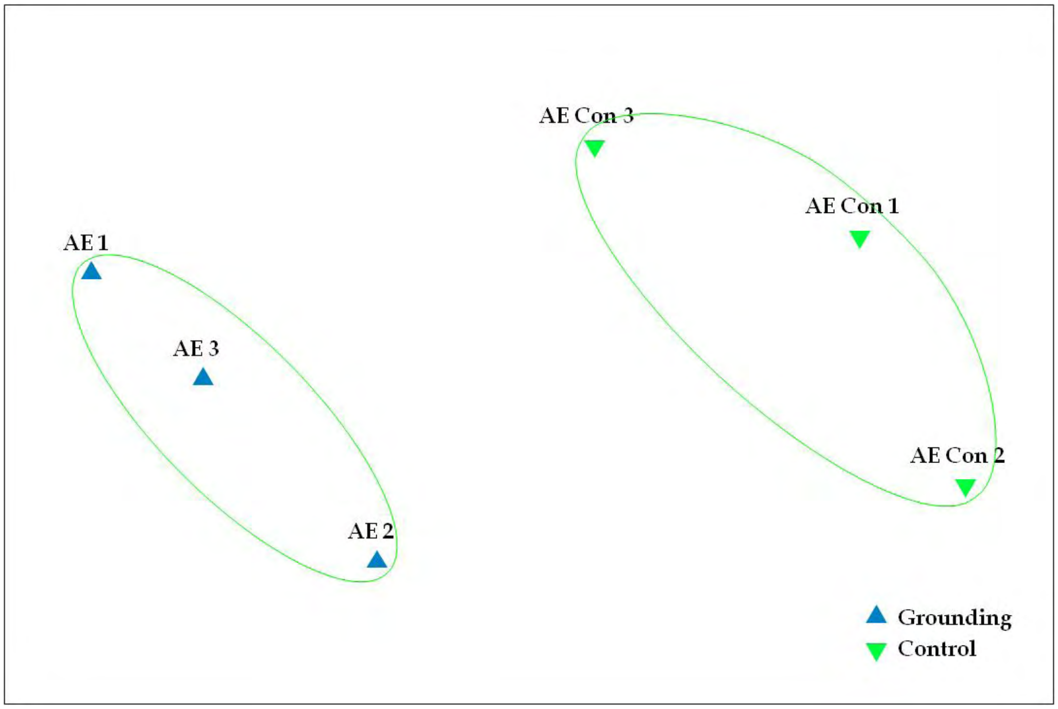

Figure 34. MDS plot of the Anzhela Explorer and control samples (stress 0.0). The green solid line represents Bray-Curtis similarity at 70%.

An analysis was run to examine which functional groups contributed the most to the dissimilarity between the Anzhela Explorer and control samples. Increased percent cover of rubble substrate (35) in the Anzhela Explorer samples and greater percent cover of gorgonians (36) in the control samples were two of the top functional groups contributing to the dissimilarity.

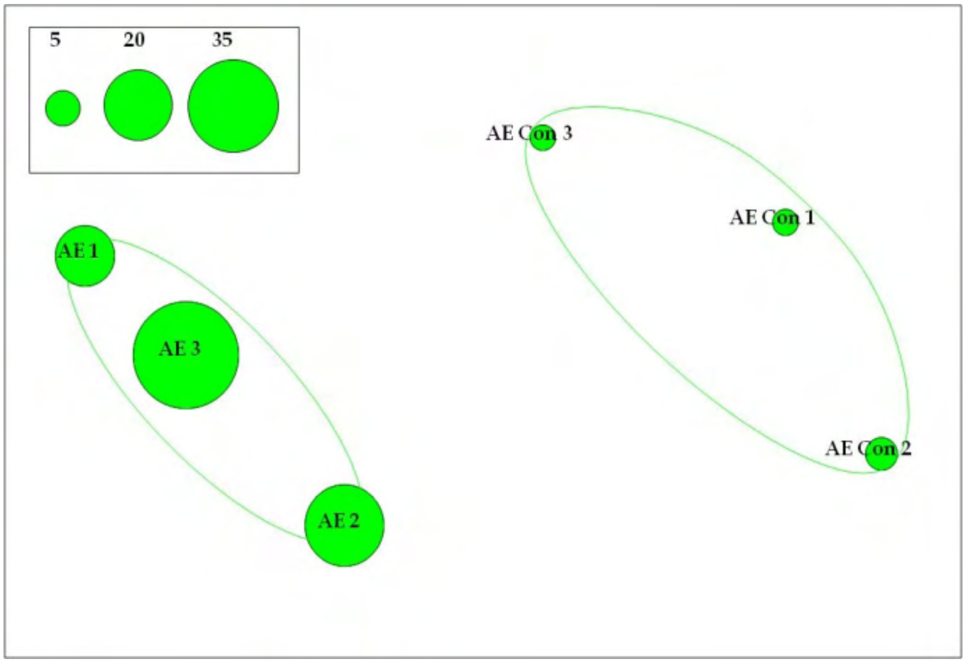

Figure 35. The Anzhela Explorer MDS as shown in Figure 35 with superimposed bubbles over each sample (stress 0.0). Each bubble represents the rubble percent cover. The bubble scale box in each plot represents the approximate cover for each size bubble. The green solid line represents Bray-Curtis similarity at 70%.

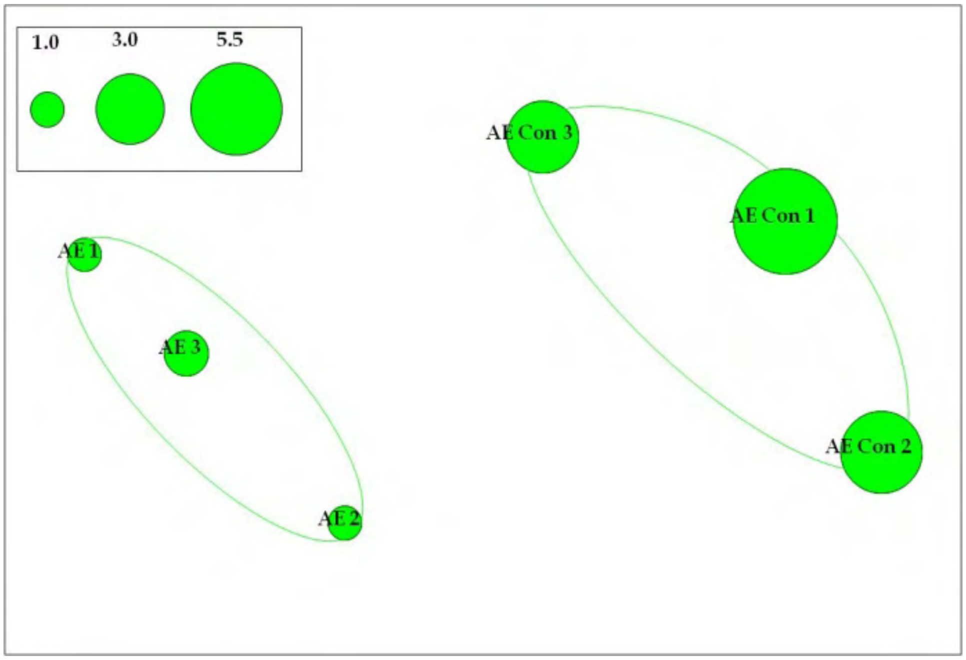

Figure 36. The Anzhela Explorer MDS as shown in Figure 35 with superimposed bubbles over each sample (stress 0.0). Each bubble represents the gorgonian percent cover. The bubble scale box in each plot represents the approximate cover for each size bubble. The green solid line represents Bray-Curtis similarity at 70%.

DISCUSSION

Phase I of Maritime Industry and Coastal Construction Impacts (MICCI) Combined Project 14, 15, and 16 was designed to compare the current condition of reef sites in Broward and Miami-Dade counties that had been impacted by ship groundings against the condition of control (un-injured reference) samples to determine if differences exist in: 1) benthic community structure, 2) density and size of corals, gorgonians, and barrel sponges, and 3) physical characteristics such as rugosity and amount of unconsolidated substrate such as rubble and sand. The basic null hypotheses tested were as follows:

- H1: There is no difference in density of stony corals, gorgonians, or barrel sponges between grounding and control sites.
- H2: There is no difference in size of stony corals, gorgonians, or barrel sponges between grounding and control sites.
- H3: There is no difference in cover of stony coral, gorgonians, pavement, sand, or unconsolidated substrate (rubble) between grounding and control sites.
- H4: There is no difference in rugosity between grounding and control sites.
- H5: There is no difference in benthic community composition (functional group percent cover and coral species percent cover) between grounding and control sites.

The grounding sites surveyed offshore Broward County included the *Firat*, the *Alam Senang, the Federal Pescadores*, the Eastwind, the *Spar Orion*, and the *Clipper Lasco*. These groundings occurred on the Inner Reef west of the Port Everglades anchorage with the exception of the Firat which grounded on the Nearshore Ridge Complex (NRC) west of the anchorage. The Anzhela Explorer grounding occurred on a much closer to shore on the NRC in Miami-Dade County.

Because of potential habitat and reef community differences among the reef habitats injured, there were essentially three studies using control samples for each reef type; the five Inner Reef grounding sites were compared to Inner Reef controls, the Firat nearshore ridge grounding site was compared to adjacent NRC controls, and Anzhela Explorer NRC grounding site was compared to its own adjacent nearshore ridge controls.

The time period from the date of the grounding event to the date of the project sample surveys was used to define the period of time the injury area has had to recover (i.e., age). Table 15 lists the grounding sites sampled, their grounding date, and age. For this project, recovery is defined as the complete return of ecological services back to the pre-injured condition (Edwards and Gomez, 2007) which includes a complete recovery of the reef biotic community and restoration of the reef structure and physical environment (substrate types and complexity).

Table 15. The grounding date and age of the sites sampled. Age is the number of years from the grounding date to the current assessment.

Vessel	Grounding Date	Age (Years)
Firat	Nov 1994	15
Alam Senang	Jun 2003	6
Eastwind	Apr 2004	5
Federal Pescadores	Oct 2004	5
Spar Orion	May 2006	3
Clipper Lasco	Sept 2006	4
Anzhela Explorer	Mar 2007	3

Each of the three grounding studies is discussed separately followed by overall project conclusions and recommendations.

Inner Reef

The current condition of the coral reef community within all five of the Inner Reef groundings sites did not indicate recovery. Null hypotheses 1-4 for the stony coral and barrel sponge communities were all rejected. Stony coral cover, density, and colony size did not differ among the grounding sites but did differ from the control (Table 4). Stony coral (colonies >5cm diameter) species richness was also lower in the grounding sites. There were also important differences in the common species recorded within the grounding and control samples. Species such as *Siderastrea siderea* and *Stephanocoenia intersepta* that tend to contribute greatly to colony abundance but also tend to be smaller in size (Gilliam et al., 2009) were common in all grounding and control samples, but *Montastraea cavernosa* which is a species that was common in the control samples was nearly absent in the grounding sites. *M. cavernosa* is one of the more common species throughout southeast Florida that grows to larger (>1m diameter) colony sizes (Gilliam et al., 2009). In fact, within the control samples (large colony transects), colonies >50cm diameter were recorded in four samples, >75cm in two samples, and the largest colony recorded was 95cm. *M. cavernosa* was also determined to be a species contributing to the dissimilarity between the grounding and control samples (MDS plot, Figure 18), and the slow recovery of this larger colony species is also supported by the limited recruitment of this species into the grounding sites (stony coral recruit MDS plot, Figure 23).

For the gorgonian community some indication of recovery was seen. Gorgonian cover was lower in the groundings sites (rejection of hypothesis 3), but density was not different from the controls (acceptance of hypothesis 1). Gorgonian community recovery is not complete as shown by differences in colony size class distribution (rejection of hypothesis 2) (Figure 15). The contribution from the larger gorgonian size classes (25–50cm and >50cm) was reduced in the grounding sites compared to the control sites. Although not significant, the gorgonian species richness was reduced in the groundings sites (Table 4) and species dominance was not consistent between the grounding sites and the control. Faster growing and early colonizing species such as *Pseudopterogorgia* spp. dominated the grounding samples. The grounding samples also had reduced abundances of other common gorgonian species such as *Gorgonia ventalina*. As expected, the gorgonian community appears to be recovering quicker than the stony coral community. Gorgonians have been recorded as early colonizers in other disturbed habitats and tend to have higher recruitment rates and growth rates (Lasker et al., 2003; Gutierrez-Rodriguez and Lasker, 2004) than most stony corals. The greater contribution of *Pseudopterogorgia* spp. in the grounding sites was also seen in other injured areas (Hudson and Diaz, 1988; Jaap, 2000).

The multivariate analyses determined that the five grounding sites were more similar to each other than they were to the control, and ANISOM results indicated that the grounding sites were significantly different than the control (rejection of hypothesis 5). In addition to determining difference between the grounding and control, a SIMPER analysis was able to illustrate that stony coral cover and gorgonian cover were two important groups in defining the dissimilarity between the grounding sites and the control (Figures 19 and 20). Another major functional group defining the dissimilarity between the grounding sites and the control was greater percent cover of rubble in the grounding sites (Figure 22). This was also supported by significantly greater rubble cover determined in the grounding sites (Table 4 and Figure 16) (rejection of hypothesis 3). Rubble may be a substrate capable of supporting small stony coral colonies, the density of stony coral recruits was not significantly different among the grounding sites and the control (Table 4 and Figure 14), but rubble is not a suitable substrate for continued colony growth allowing the stony coral community to recover the size class distribution comparable to a non-injured reef. The greater percent rubble cover in the groundings sites is a key factor which will likely slow and possibly inhibit full recovery. The production of rubble from ship grounding events has been frequently recorded (Curtis, 1985;

Hudson and Diaz, 1988; Gittings et al., 1994; Jaap, 2000; Jaap and Hudson, 2001) and the continued presence of mobile rubble in the injured area can be turned-over from storm events potentially killing recruits which have settled on the rubble and potentially injuring other adjacent areas (Gittings et al., 1990; Cook et al., 1994; Rogers, 1994; Rogers and Garrison, 2001).

Defining recovery and estimating a recovery trajectory (time it would take an injured area to recover back to its non-injured state) is a difficult task. The five grounding sites show limited recovery and with all five sites having grounded within three years of each other there is not sufficient spread in age, and therefore recovery state, to estimate a trajectory. The MDS plot (Figure 18) illustrates some greater recovery of the oldest Inner Reef site (Alam Senang, 6 years old) with two of its samples (AS2 and AS3) having a greater similarity to the control samples than the other grounding samples. This is weakly supported by the position of the Eastwind samples (five years old) in the same MDS plot (Figure 18). The samples in the two youngest sites (Spar Orion and Clipper Lasco, three and four years old, respectively) were more dissimilar to the control samples than the two Alam Senang and Eastwind samples. This trend is not seen with the other five year old site, Federal Pescadores, which had two samples (FP1 and FP2) which were quite dissimilar to any of the grounding or control samples. This dissimilarity was driven by reduced stony coral cover, which was similar to the other grounding sites, but also reduced rubble cover, which was similar to the control samples. This weak trend in older sites being more similar to the non-injured condition (control samples) is shown in Figure 37 which is an MDS ordination plot of the average functional group cover within each grounding site and the control samples. Although the Alam Senang site is closer to the control followed by the Eastwind, this trend is weak as illustrated by the superimposed 80% similarity group superimposed over all the grounding sites.

There are a number of possible processes and conditions which are limiting recovery. The assessment data showed that the grounding sites had significantly fewer and smaller stony corals. The SIMPER analysis also showed that stony corals, such as *M. cavernosa*, contribute greatly to the dissimilarly between the grounding sites and the control samples. Stony corals are slow growing with many of the common southeast Florida species growing less than 1 cm/year (linear extension) (Gladfelter et al., 1978; Bak and Engel, 1979; Dodge, 1981; Highsmith et al., 1983; Rogers et al., 1984; Hughhes and Jackson, 1985; van Moorsel, 1988; Edmunds, 2000; Gilliam et al., 2010). The largest stony coral colony measured in the control samples (belt transects) was a 95cm diameter *M. cavernosa* which is arguable over 100 years old. Six control samples had *M. cavernosa*, *M. faveolata*, *Colpophyllia natans*, or *Meandrina meandrites* colonies >50cm diameter.

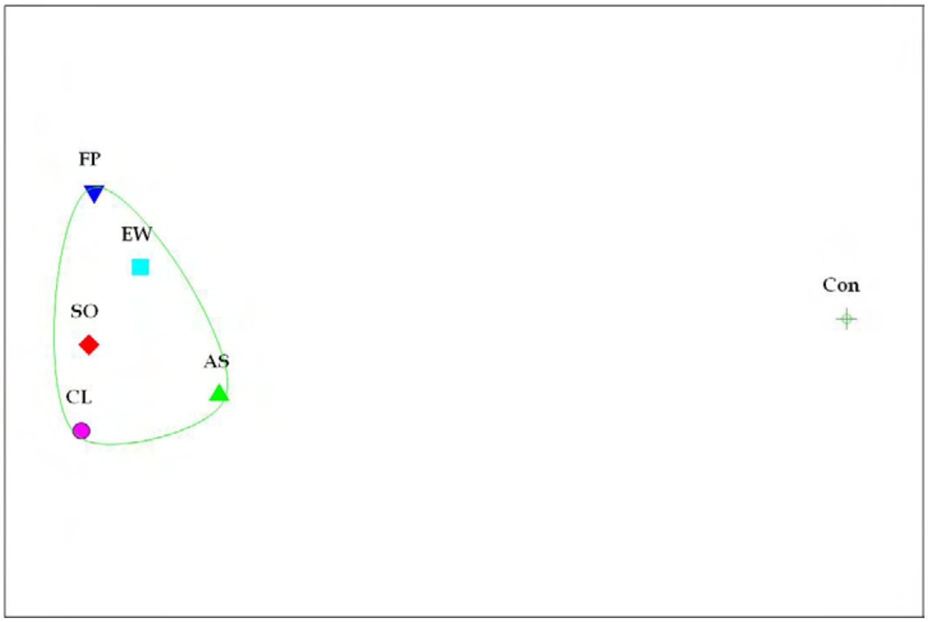

Figure 37. An average MDS plot (stress = 0.01) of all five grounding sites and the control samples. The green solid represents Bray-Curtis similarity at 80%.

If a conservative approach is taken by using the average size of the largest colony recorded in each control sample, this is still equal to a 50cm diameter colony (Table 4). The multivariate analyses showed that stony coral cover was an important group contributing to the dissimilarity between grounding and control samples. The slow growth of stony corals would define long recovery times.

A change in the physical structure of the habitat is arguably the greatest factor limiting recovery. The grounding sites had more rubble and sand and were flatter (less complex) than the control samples (Table 4 and Figures 16 and 17). This change in habitat affects biological recovery processes such as recruitment and survival. Although the density of stony coral recruits was not significantly different, there was significant dissimilarity in recruit species contribution (Figures 24 and 25). *M. cavernosa* was shown to be an important contributor to the stony coral recruit assemblage but the contribution of *M. cavernosa* in the grounding sites was much less than in the control samples. This altering of the habitat substrate affecting recruitment further inhibits recovery as defined by a return of diversity in the injured reef site. The reduced gorgonian species richness and greater dominance of *Pseudopterogorgia* spp. in the grounding sites provide additional evidence of a reduction of diversity which would slow and limit recovery. Other studies have shown that habitats with rubble or that are flat have reduced diversity and potentially slower recovery (Aronson and Swanson, 1997).

The natural variability in the southeast Florida coral reef community (Gilliam et al., 2009; Moyer et al., 2003) also contributes to the difficulty in measuring recovery and estimating a recovery trajectory. The MDS plots show that that although most of the grounding samples grouped together and most of the control samples group together there was still dissimilarity within each site.

It was assumed that the areas which were sampled within each grounding site had 100% loss of the biological community (i.e., all stony corals, gorgonians, and sponges were lost). The actual severity and injury type (fractured substrate creating rubble versus scarified substrate without fractured substrate) within each sample area may have been variable. An example of this are Federal Pescadores samples 1 and 2 (FP1 and FP2) which showed very little recovery (low stony coral and gorgonian densities) but also had very low cover of rubble.

The presence and density of larger (>20cm diameter) stony corals that may have been present in an area prior to the injury event may be used as a metric to assist with determining lost ecological services and recovery times. The larger colony transects in the Inner Reef control sites permitted densities of colonies larger (>50cm) to be estimated, which in turn was used to estimate the numbers of colonies potentially lost during each grounding event (Table 8). With all control sites having colonies greater than 50cm diameter and ten of twelve sites having colonies >75cm, it appears very likely that all of the Inner Reef groundings sites had colonies greater than 50cm diameter present in the injury area prior to the injury event. Growth rates for the common larger species (*M. cavernosa, M. faveolata, M. meandrites*, and *C. natans*) are all in the range of less than 1cm growth per year (Gladfelter et al., 1978; Dodge, 1981; Highsmith et al., 1983; Hughes and Jackson, 1985). This growth rate would even conservatively indicate that stony corals approaching and most likely greater than, 100 years old were lost during the grounding events. Four of the sites had colonies greater than 100cm with the largest colony identified being a 290cm *M. faveolata* colony. This argues that there may have been colonies much older than 100 years present.

<u>Firat</u>

Unlike the Inner Reef grounding sites, there was no significant difference determined between the Firat samples and the Firat control samples for stony coral cover, density, or colony size (general acceptance of hypotheses 1 and 3). Gorgonian cover was actually greater in the Firat samples.

There was evidence that the Firat site was still not fully recovered. The Firat samples had a reduced contribution of >50cm (height) gorgonians than the control samples (partial rejection of hypothesis 2). The Firat samples were also flatter (rejection of hypothesis 4).

The Firat grounding occurred in 1994 and was surveyed 15 years after the event. It is not surprising that this grounding site showed greater recover (was more similar to the control samples) than the younger Inner Reef grounding sites. The NRC habitat where the Firat grounded is also more dominated by gorgonians (see cover and density values for the Inner Reef controls in Table 4 and the Firat control cover and density values in Table 9). A habitat dominated more by gorgonians is likely to show partial recovery sooner than habitats less dominated by gorgonians (Hudson et al., 2008).

The type and severity of the injury from the Firat grounding may have been different than that at the Inner Reef groundings. The percent cover of rubble in the Firat samples was not greater than the Firat control samples (Table 9). This may have been due to the rubble being dispersed over the 15 years since the grounding date, or less rubble was created during the grounding event. If less rubble was created during the event, recovery may be quicker at this site. The percent cover of rubble in the Firat control was also much less than the percent cover of rubble in the Inner Reef controls, suggesting that rubble contributes less to the substrate type in the NRC habitat in this area than in the Inner Reef control area. This difference in habitat would also support a quicker recovery time in the nearshore habitat.

An issue which may have overestimated the similarity in the Firat samples and the control samples was the uncertainty in the sample location choice for the Firat grounding samples. The grounding event injury assessment effort and reporting did not provide enough injury area and injury severity information to confidently target sample locations which should include only 100% injury area. The injury assessment reports (Beak Consultants Inc., 1996) did not provide a map of the injury area or the distribution of injury types. The sample locations were based on locations which were defined as stony coral reattachment zones. These zones were stated as being in the recovery area. This was essentially as much information that was available. The reconnaissance dives located reattached stony corals providing some evidence that the location was within the injured area and visual inspection noted flatter substrate and some signs of scraped substrate. However, unlike the Inner Reef grounding sites which had more detailed habitat maps and more visually obvious injured areas, it was very possible that not all of the area within each Firat grounding sample was injured during the grounding and not all was severely injured.

The sample size, only three samples for the grounding and control, also potentially limited the ability of the study to capture differences between the grounding and control samples.

Even with all these caveats, differences were still identified between the Firat samples and the control samples. Recovery was not 100%. The multivariate analysis determined a significant difference between the grounding and control samples (Figure 28). A difference in stony coral size class distribution was also still evident (Figure 26) and a significant difference in rugosity (Table 9) showed that the injured area has not fully recovered.

Anzhela Explorer

The Anzhela Explorer grounded on nearshore ridge habitat offshore Miami-Dade County in 2007 and was surveyed three years after the injury event. This time period is very similar to the time period for the Inner Reef grounding surveys.

Similar to the Inner Reef grounding sites, very limited recovery was determined for the Anzhela Explorer site. The current status of the injured area remained very different than the adjacent non-injured control samples. Stony coral and gorgonian cover, density, colony sizes and species richness were significantly different between the Anzhela Explore samples and the control samples (rejection of hypotheses 1, 2, and 3).

Also much like the Inner Reef grounding sites, the multivariate analysis also showed significant differences between the grounding and control samples. The grounding samples had significantly greater rubble coverage (Table 12) which was supported by the SIMPER analysis which indicated that the greater percent cover of rubble in the Anzhela Explorer samples was a major contributor to the dissimilarity between the grounding and control samples (Figure 37).

The current status of the injured area clearly indicates that limited recovery has occurred and a much greater time period than three years will be required for full recovery. However, like the Inner Reef sites, actually estimating a recovery time and a trajectory are difficult. As illustrated with the Inner Reef samples, the nearshore habitat shows some of the same variability issues illustrated in the Anzhela Explore MDS plot (Figure 34). Although the grounding samples and control samples clearly group, they have only a within group similarity of 70%.

Identifying the injury area and knowing the severity of the injury was not an issue for the Anzhela Explorer. The injury evaluation effort conducted by the Florida Department of Environmental Protection (FDEP) and Miami-Dade County Department of Environmental Resource Management (DERM) (Thanner et al., 2007) provided appropriate information to choose grounding sample locations and know the severity of the injury with confidence (Sea Byte Inc, 2008). After three years, the injury area was very visually obvious and choosing appropriate locations for the grounding samples was accomplished with great confidence much like the Inner Reef sites, but unlike the Firat.

The processes limiting recovery at the Anzhela Explorer site are much like the Inner Reef sites, the presence of rubble, stochastic recruitment events, and the slow growing nature of stony corals which greatly define recovery.

Conclusions

1. Measuring the current status of the grounding sites showed that recovery will take much more time than has currently elapsed between the oldest grounding event (Firat at 15 years) and the assessment date.

2. Grounding sites have greater percent coverage of unconsolidated rubble substrates and are less rugose (flatter) than control (non-injured) areas. The increased presence of rubble is likely limiting recovery by providing poor habitat for survival and growth of stony corals and gorgonians.

3. Simply estimating stony coral and gorgonian densities and percent cover is not adequate for documenting the current status of a grounding site or evaluating recovery. For stony corals, data on colony size and condition need to be evaluated at the species level and for gorgonians at the genera level. Barrel sponge data (at a minimum sponge height and condition) should also be included in reef habitats where they are important components of the community (i.e., south Florida).

4. Size class distribution for stony corals and gorgonians, and where possible barrel sponges, should include juveniles (<2cm diameter) as well as adults. This project provided data which suggests there is a stony coral size class bottleneck associated with the presence of rubble. This supports the need to not only determine juvenile densities but also record the substrate types the juveniles are growing on.

5. Even in the southeast Florida reef habitats which have lower stony coral cover relative to other coral reef systems (Gilliam et al., 2010), stony corals were shown to be an important functional group influencing recovery. The presence of large (>75cm diameter and up to 95cm) stony coral colonies in the control samples and the absence of these colonies in the grounding samples supports a long recovery period. Based on published *Montastrea* growth rates (linear extension) (Dullo, 2005) of less than 2cm/year and expected lag periods between successful larval settlement, juvenile survival, and growth to mature sizes, restoration of normal size class distribution could conservatively equal 100 years or more.

6. Estimating recovery times and a recovery trajectory are difficult. The close ages of these grounding events did not allow for separation in the recovery status of the sites. There is some indication of older grounding sites (Alam Senang) being more similar (more recovered) than the younger sites (Clipper Lasco) but variability within the grounding sites and within the control samples does not permit a clear trend or timeline. A longer term grounding study, in the order of decades, that involves repeated sampling of replicate permanent monitoring sites in several grounding areas would provide the quantitative data required to determine a recovery trajectory.

7. Variability in the severity and type of the injury among and within grounding sites also makes measuring recovery difficult. This highlights the importance of requiring detailed assessments of all future grounding events. These assessments need to include a detailed description of each injury type, maps of location and extent of each injury type, and quantitative data on lost or injured resources.

8. Primary restoration of future grounding events must include appropriate rubble stabilization and removal efforts. Rubble and boulders produced during the event should not only be stabilized but when possible used to restore the natural rugosity and the physical structure of the injured area.

9. An assessment similar to the effort conducted for this study should be conducted within injured areas immediately after the event. The sample locations should also be permanently marked to facilitate future assessments and document recovery. Conducting an assessment immediately after the injury event will also reduce the uncertainty in defining the severity and type of injury within each sample.

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