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Acute and Chronic Effects of Large-Vessel Anchoring on Coral Reef Communities Inside a Designated Commercial Anchorage

Lauren Waters
Nova Southeastern University Oceanographic Center, Swng1grl@gmail.com

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NOVA SOUTHEASTERN UNIVERISTY OCEANOGRAPHIC CENTER

Acute and chronic effects of large-vessel anchoring on coral reef communities inside a designated commercial anchorage.

By
Lauren Waters

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Lauren Waters

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Approved:

Thesis Committee

Major Professor:______________________________
Brian Walker, Ph.D.

Committee Member:____________________________
David Gilliam, Ph.D.

Committee Member:____________________________

Kenneth Banks, Ph.D.

Abstract

Coral reefs provide economic and environmental services to millions of people as areas for recreation, sources of food, jobs, and shoreline protection; and are now under threat from multiple stresses (NOAA 2002). Anthropogenic impact from acute physical events such as commercial vessel grounding and anchor drags have been well documented throughout the world and southeast Florida. However little data exist on the chronic effects of large commercial vessels anchoring on reef resources. The Port Miami commercial anchorage was designated circa 1927 and was delineated over approximately 700 acres of reef resources. Anchorage use, benthic resources, and substrate composition were surveyed to understand the impact commercial vessel anchoring activities have had. Survey sites included both random sites within the anchorage to understand the cumulative chronic effect of anchoring activity, as well as targeted surveys at recently anchored sites to understand the immediate impacts of those anchoring events. Survey data were also compared to anchorage use data to understand how vessel traffic patterns influenced impact. Results indicated that there was both significant differences at acute recent impact sites and chronic impact sites. Generally, Outer Reef chronic impact sites had more evidence of chronic impacts both in the benthic community and substrate composition than Inner Reef sites. Significant differences on Outer Reef included an increase in the percent cover of small rubble, a decrease in octocoral percent cover, and a decrease in the density of larger octocoral size classes. Significant differences on Inner Reef included a decrease in the number of scleractinian species present compared to control sites.

Key Words: coral reef, anchoring, anchorage, vessel impact

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1. Introduction

Coral reefs are among the most diverse and biologically complex ecosystems on Earth; providing economic and environmental services to millions of people as areas for recreation, sources of food, jobs, chemicals, pharmaceuticals, and shoreline protection; and are now under threat from multiple stresses (NOAA 2002). These stresses range from global climate change to local indirect impacts such as overfishing and land based sources of pollution, and direct impacts such as recreational anchoring and coastal construction. It has been shown that of three possible anthropogenic impacts during recreational activities, anchoring, diver contact, and effects of antifouling paint on coral reefs, anchoring can have the greatest impact over time (Saphier & Hoffmann 2005). The northernmost tropical reef system in the United States runs along the southeast coast of Florida; where commercial and recreational anchor damage and groundings have impacted the State's natural resource.

Studies have looked at acute (short-term, singular occurrences) reef impact incidents such as ship groundings, and chronic (long-term, repetitive occurrences) impacts such as recreational anchoring near popular fishing and diving locations (Dinsdale & Harriott 2004, Saphier & Hoffmann 2005, Rogers & Garrison 2001, Behringer et.al. 2011). Many chronic studies have shown that reefs with high intensity recreational boating activities have higher incidences of physically damaged corals (Dustan & Halas 1987, Jameson et. al. 1999). Additionally these impacted areas have less relative coral cover and increased algal cover (Jameson et. al. 2007). During acute physical impact, reef biota may be injured or removed from the substrate and the reef framework fractured, leaving denuded limestone pavement or rubble, indicating reef damage. If physical damage is chronic or repeated, the reef framework could decline further to produce more, smaller rubble and sand. Those reefs with continuous disturbances have a decrease in potential coral recovery rates compared to areas free of disturbances (Dinsdale & Harriott 2004, McManus et. al. 1997). This disturbance effects not only the coral community itself but the entire reef community including fish assemblages. More complex reef substrate supports more species of fish than those that are less rugose (Emslie et. al. 2008).

Variables that qualify injury to corals (such as scrapes or colony fractures), have been shown to be more efficient in distinguishing sites with different chronic recreational anchoring intensities than coral cover alone (Dinsdale & Harriott 2004). In one recreational anchor impact study, it was found that measures of injury to coral colonies were generally more efficient than measures of coral cover in describing the effects of, and indicating coral reef condition associated with, anchoring intensities (Dinsdale & Harriott 2004).

Examples of acute anchoring events from commercial vessels that have been documented include the cruise ship *Wind Spirit*, which with a single anchor and chain impacted 251 m^2 of reef near the island of St. John, USVI, the MV *Starward* which impacted 2100 m^2 on a sloped reef near Grand Cayman (Allen 1992); and the MV *Albarella* which impacted 64 m^2 (Walczak 2007) the MV *Afra* which impacted 350 m^2 (Beaver 2006) and the *UAL Gabon* which impacted 744 m^2 (Sansgaard 2012) all in Broward County, Florida. Within the impact area of the MV *Afra*, MV *Albarella*, and the UAL *Gabon* the substrate was documented as scraped while damaged biota included sheared *Xestospongia muta* and dislodged octocorals and scleractinia. Many of these incidents also reported fractured substrate or varying amounts of rubble. Within the impact scar from the *Wind Spirit*, live coral cover had not increased significantly 10 years post-event, reflecting poor survival and growth of newly settled corals. It was suggested that the relatively planar aspect of the scar increased the vulnerability of the recruits to abrasion and mortality from shifting sediments (Rogers & Garrison 2001). While these acute events help shed light on impacts to relatively unimpacted reef communities, none have focused on the chronic impacts from commercial vessel anchoring.

1.1 Historical Background

In Southeast Florida there are three commercial ports with designated commercial anchorages, Port of Palm Beach in Palm Beach County, Port Everglades in Broward County, and Port Miami in Miami-Dade County. Between 1994 and 2006 Broward County had many vessel anchoring and grounding incidents on reef resources adjacent to the Port Everglades commercial anchorage which resulted in an evaluation of the safety of that anchorage configuration (Collier et al. 2008). The United States Coast Guard (USCG) led a group of local, state, and federal agencies, port personnel, and local stakeholders in an effort to modify the anchorage configuration to decrease hazardous situations and avoid reef impacts. In 2007, an emergency rule change in the Federal Register by the USCG modified the anchorage, requiring ships to anchor further offshore. While resource trustees were investigating the reef injuries associated with anchoring near Port Everglades, it was noted that the reef had been impacted, possibly from anchors or anchor chains (Walker 2010). It was reasoned that because these injuries were observed on the reefs near the Port Everglades anchorage, other anchorages in a similar proximity to reefs could be causing similar impacts. In 2008, the Southeast Florida Coral Reef Initiative (SEFCRI) initiated a project, “A Study to Minimize or Eliminate Hardbottom and Reef Impacts from Anchoring Activities in Designated Anchorages at the Ports of Miami and Palm Beach,” to determine if the current location of other U.S. Coast Guard (USCG) designated commercial vessel anchorages were located near or over reefs resources, and if so, to develop, through a stakeholder process, alternative anchorage locations. That study found that approximately 700 acres of State protected reef resources and Federally protected critical habitat and Essential Fish Habitat (EFH), as well as potential colonies of Endangered Species Act (ESA) listed coral species, were located within the Port Miami Anchorage (Walker 2010) (Figure 1).

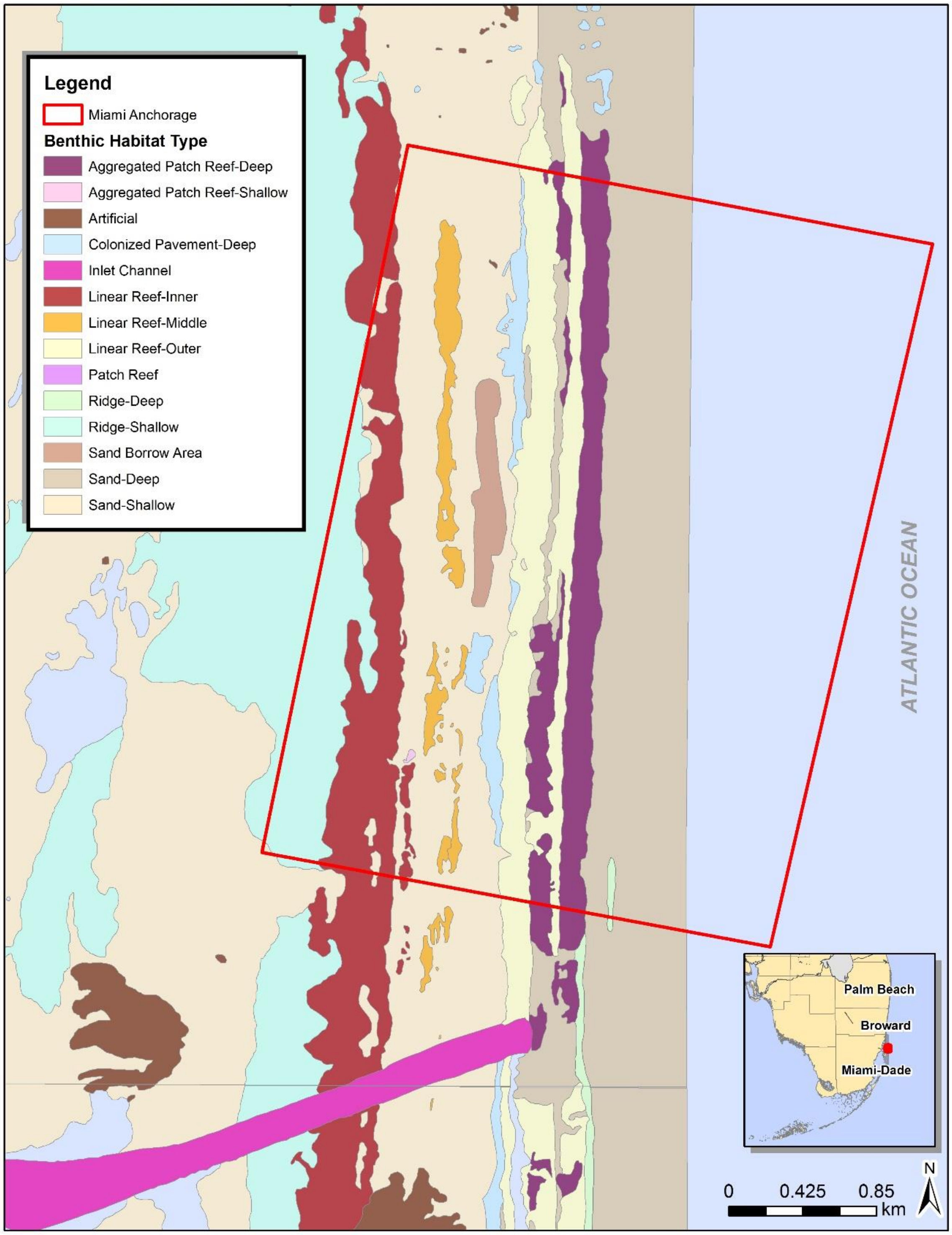


Figure 1. Current Port Miami anchorage location overlain on benthic habitat maps created by Walker (2010).

The establishment of the current Port Miami facility began on April 5, 1960 when the Dade County Board of Commissioners approved Resolution No. 4830, "Joint Resolution Providing for Construction of Modern Seaport Facilities at Dodge Island Site" (Port of Miami 2011). However, well before the modern day Port, there was a need for a nearby staging area for vessels waiting to enter the Port. By February 1927 a 10 km^2 (2495 acre) area north of the Port entrance channel was officially designated as Port Miami Anchorage (PMA) (Figure 2) (US Coast and Geodetic Survey 1927). Since 1960 vessels using Port Miami include passenger ships, large tankers and cargo vessels (>75m in length), and smaller cargo vessels that navigate the Miami River (<75m in length). In 2010, PM reported the transiting of 4,150,000 passengers on 778 cruise ships, 7,389,165 million tons of cargo on 1663 docked vessels, and generating $104,084,719.00 in revenue (Miami Dade Seaport Department, 2010).

After the report by Walker 2010, the Port Miami Anchorage Working Group (AWG) was formed to discuss the potential impacts of vessel activity in the PMA and options to reduce or eliminate those impacts to reef resources. The AWG consists of local, state, and federal agency representatives, as well as local stakeholders (e.g. Port Miami Pilots, Miami River Association, USCG etc.) who are working together to ensure all stakeholder concerns are addressed.

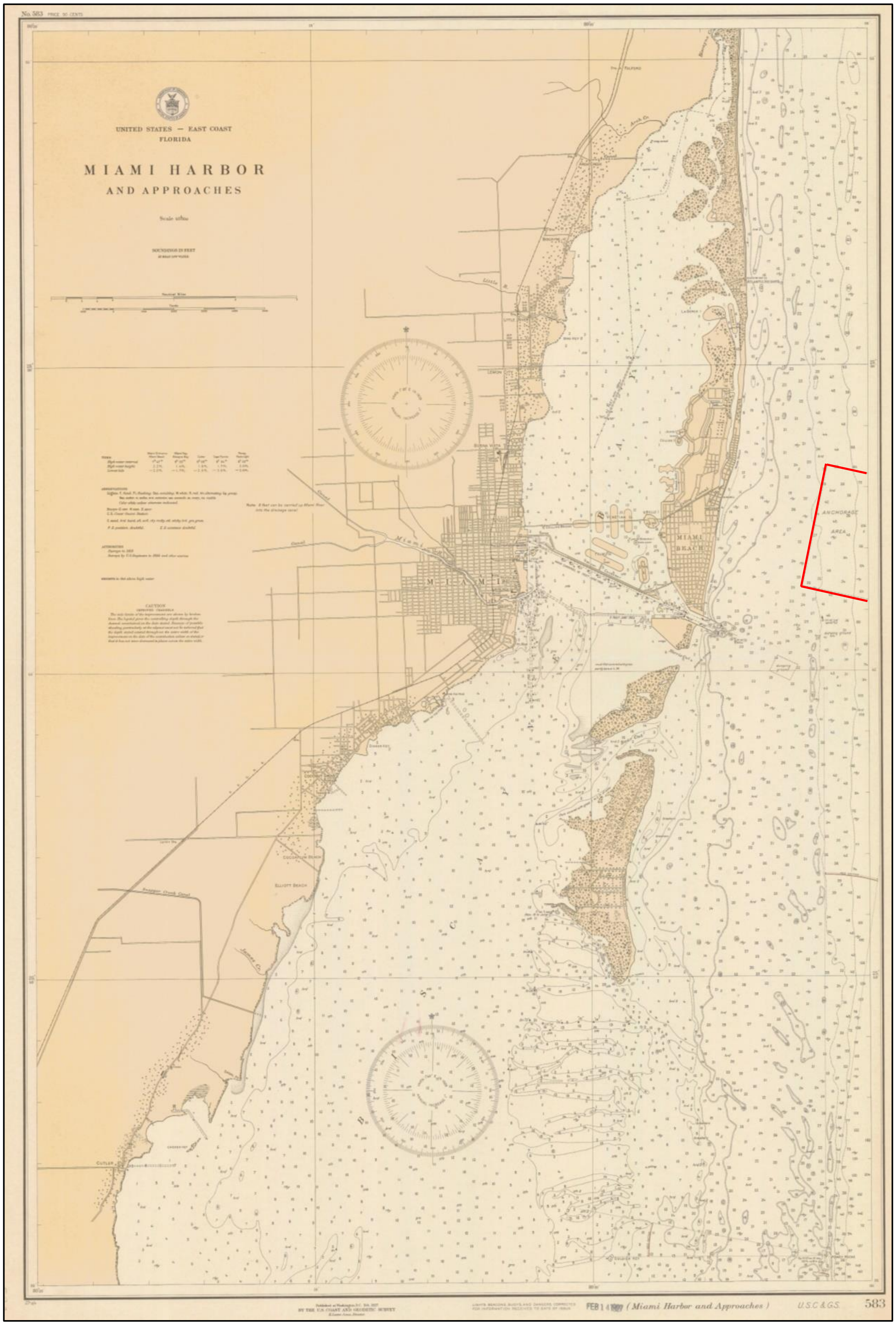


Figure 2. Historic chart of Miami Harbors and Approaches showing the Miami Anchorage (highlighted in red for ease of viewing) (US Coast and Geodetic Survey 1927).

1.2 Applicable Rules

There are several federal and one State rule which may apply to the current Port Miami Anchorage (PMA) or any future reconfigurations of the anchorage.

1.2.1 Endangered Species Act and Critical Habitat

In 2006 the elkhorn coral, *Acropora palmata*, and the staghorn coral, *Acropora cervicornis*, were listed as threatened by the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) under the Endangered Species Act (ESA). The northern extension of the Florida reef tract running parallel and offshore of Miami-Dade County provides approximately 71 km^2 (17,544 acres) of designated Critical Habitat for these species (National Marine Fisheries Service 2008, Walker 2010). Essential Fish Habitat (EFH) for many federally managed fish species is provided by these reef and hardbottom resources, which are also designated Habitat Areas of Particular Concern (HAPC) by the South Atlantic Fishery Management Council (SAFMC) for many commercially important species such as *Panulirus argus* (spiny lobster) and *Mycteroperca* spp. (groupers) (SAFMC 1982a, 1982b, 1983, and 2009).

At the time the critical habitat was defined for *Acropora cervicornis* and *Acropora palmata*, pursuant to ESA section 3(5)(A)(i), all waters identified as existing (already constructed) federally authorized channels and harbors including Miami Harbor, were excluded from the critical habitat designation. The PMA was not. According to the ESA Under Section 7, Federal agencies must consult with the U.S. Fish and Wildlife Service (FWS) or the NMFS when any action the agency carries out, funds, or authorizes (such as through a permit) may affect a listed, endangered, or threatened species. This process usually begins as informal consultation. If the USCG, after discussions with the NMFS, determines that the proposed action is not likely to affect any listed species or its designated critical habitat in the project area, and if the NMFS concurs, the informal consultation is complete and the proposed project moves ahead. If it appears that the agency's action may affect a listed species, that agency may then prepare a Biological Assessment to assist in its determination of the project's effect on a species. The Biological Assessment is then analyzed against the jeopardy of the species in question. Under the ESA, jeopardy occurs when an action is reasonably expected, directly or indirectly, to diminish a species numbers, reproduction, or distribution so that the likelihood of survival and recovery in the wild is appreciably reduced.

1.2.2 Essential Fish Habitat

The multitude of EFH designations affecting southeast Florida contained no exclusions for any present, future, or existing actions at the time they were adopted, but no consultation is required for completed actions. The Magnuson-Stevens Fisheries Conservation and Management Act (MSA), as amended through October 11, 1996, requires federal agencies to consult with NMFS on actions that may adversely affect EFH. The EFH rule defines an adverse effect as "...any impact which reduces the quality and/or quantity of essential fish habitat...may include direct or indirect physical, chemical, or biological alterations of the waters or substrate and loss of, or injury to...their habitat. Adverse effects to EFH may result from actions occurring within EFH or outside of EFH and may include site-specific or habitat-wide impacts, including individual, cumulative, or synergistic consequences of actions", (50 CFR 600.810). If a federal agency's authorized, funded, or undertaken, or proposed to be authorized, funded, or undertaken action may adversely impact EFH, that federal agency is required to enter into the process of satisfying the federal agency consultation requirements of section 305(b)(2) and 305(b)(4)(B) of the MSA, and the EFH Conservation Recommendation requirement of section 305(b)(4)(A) of that Act. Once NMFS learns of a Federal or State activity that may have an adverse effect on EFH NMFS is required to develop EFH conservation recommendations for the activity, even if consultation has not been initiated by the action agency (Magnuson-Stevens Fishery Conservation and Management Act 1976).

1.2.3 Coral Reef Protection Act

In 2009, the State of Florida enacted the Coral Reef Protection Act (CRPA) which authorizes the Florida Department of Environmental Protection (FDEP) to "...protect coral reefs through timely and efficient recovery of monetary damages resulting from vessel groundings and anchoring-related injuries..." and collect compensation "For any anchoring of a vessel on a coral reef or for any other damage to a coral reef" (FDEP 2010). Florida Statues (F.S.), Chapter 403, Part IIV authorizes the Coral Reef Protection Act which applies to the sovereign submerged lands that contain coral reefs off the coasts of Monroe, Miami-Dade, Broward, Palm Beach, and Martin counties. The CRPA had no exclusions included at the time it was adopted, nor did it exclude any impacts that would occur after its adoption. The act requires "the responsible party who knows or should know that their vessel has run aground, struck, or otherwise damaged coral reefs must notify the department of such an event..." and that "... The responsible party must cooperate with the department to undertake damage assessment and primary restoration of the coral reef in a timely fashion (Section 403.93345, F.S.).

2. Purpose

The purpose of this thesis is to determine if there is a measurable effect of chronic or recent acute commercial vessel anchoring impacts on benthic reef communities within the PMA. The following *a priori* null hypotheses for both chronic and acute impact were tested.

H0: There is no significant difference in substratum type between the anchorage and control sites.

H1: There is no significant difference in algae percent cover between anchorage sites and control sites.

H2: There is no significant difference in scleractinian percent cover between anchorage sites and control sites.

H3: There is no significant difference in scleractinian species richness between anchorage sites and control sites.

H4: There is no significant difference in scleractinian live tissue cover between anchorage sites and control sites.

H5: There is no significant difference in octocoral percent cover between the anchorage and control sites.

H6: There is no significant difference in octocoral size distribution between anchorage sites and control sites.

H7: There is no significant difference in *Xestospongia muta* size distribution between anchorage sites and control sites.

3. Methods

3.1 Survey Site Selection and Control Selection

All three shore-parallel reef lines as defined by previous studies (Figure 1) (Duane & Meisburger 1969, Walker 2009) are within the PMA. The Linear Inner Reef and Linear Outer Reef were surveyed (Figure 3). Surveys were only conducted within FDEP SCUBA diving limits (< 30 m).The Middle Reef is a discontinuous less pronounced feature north of the anchorage and disappears all together just south of the anchorage (Walker 2010). Due to the Middle Reef's discontinuous nature and lack of nearby unimpacted habitat for control samples, it was excluded from this study.

Reconnaissance dives were conducted to understand potential spillover effects of vessels anchoring outside of the designated anchorage. It was discovered that there were visual indicators of spillover such as denuded substrate. Also there was a general decrease in typical benthic cover on reef habitat that lie south of the anchorage but north of the existing Port Miami entrance channel, potentially from vessel traffic or the influence of the entrance channel inlet waters (Joanna Walczak, personal communication 2011). Reef habitat south of the Port Miami Channel are considered to be in a different biogeographic region than the anchorage itself (Walker 2012). Therefore no control sites were located south of the anchorage. All control sites were to the north and randomly selected a minimum of 200 m away from the existing anchorage in order to reduce chances of sampling spillover effects;

and south of the next coastal inlet to avoid potential inlet water quality influence (Figure 3).

3.1.1 Anchorage Chronic Impact Site Selection

In order to understand the impacts to reef resources and substrate from the chronic anchoring activity that has occurred over the past 80 years within the anchorage, five survey sites were randomly chosen on Linear Inner and Linear Outer Reef habitats within the anchorage and control areas for a total of ten chronic impact survey sites and ten control sites in unaffected adjacent habitat.

3.1.2 Anchorage Acute Impact Site Selection

In order to understand the immediate acute impacts to reef resources and substrate that may be more pronounced (e.g. denuded areas, bright white scraped or fractured substrate) than chronic impacts, five targeted, recently anchored sites were surveyed. The AIS data were reviewed for vessels at anchor and plotted against benthic habitat maps to determine if the anchors were located over Linear Inner or Linear Outer Reef habitat. If they were, dives were conducted to verify the anchor location and compass bearing of the chain. The site was revisited within one week of the vessel's departure for surveying. Two recent impact sites on Linear Inner Reef, and three recent impact sites on Linear Outer Reef were surveyed for a total of five recent impact sites to investigate acute impacts (Table 1).

Table 1. Location of anchorage Inner Reef (AI), anchroage Outer Reef (AO), control Inner Reef (CI), control Outer Reef (CO), recent impact Inner Reef (RI), and recent impact Outer Reef (RO) sites in decimal minutes.

Treatment				Depth (m)	Site Name	Latitude	Longitude
Zone	Reef	Selection	Impact Type				
Control	Inner	Random	Control	12.5	CI1	25.80736	-80.0969
Control	Inner	Random	Control	12.0	CI2	25.81065	-80.0977
Control	Inner	Random	Control	13.7	CI3	25.81824	-80.0973
Control	Inner	Random	Control	11.0	CI4	25.8333	-80.0991
Control	Inner	Random	Control	10.4	CI5	25.83581	-80.0993
Control	Outer	Random	Control	16.0	CO1	25.80665	-80.0866
Control	Outer	Random	Control	18.3	CO2	25.8354	-80.089
Control	Outer	Random	Control	17.1	CO3	25.837	-80.0885
Control	Outer	Random	Control	16.8	CO4	25.83836	-80.0883
Control	Outer	Random	Control	17.7	CO5	25.83973	-80.0881
Anchorage	Inner	Random	Chronic	12.8	AI1	25.7993	-80.0961
Anchorage	Inner	Random	Chronic	11.0	AI2	25.79665	-80.0963
Anchorage	Inner	Random	Chronic	11.3	AI3	25.78769	-80.0965
Anchorage	Inner	Random	Chronic	11.9	AI4	25.78411	-80.0961
Anchorage	Inner	Random	Chronic	12.8	AI5	25.7786	-80.0961
Anchorage	Outer	Random	Chronic	17.7	AO1	25.80098	-80.0876
Anchorage	Outer	Random	Chronic	12.8	AO2	25.78928	-80.0884
Anchorage	Outer	Random	Chronic	15.2	AO3	25.78131	-80.0893
Anchorage	Outer	Random	Chronic	13.4	AO4	25.77478	-80.0895
Anchorage	Outer	Random	Chronic	12.5	AO5	25.77151	-80.0894
Anchorage	Outer	Targeted	Acute	14.9	RO1	25.78817	-80.0891
Anchorage	Inner	Targeted	Acute	13.7	RI2	25.78938	-80.096
Anchorage	Outer	Targeted	Acute	13.0	RO3	25.79594	-80.089
Anchorage	Inner	Targeted	Acute	12.5	RI4	25.773	-80.0966
Anchorage	Outer	Targeted	Acute	15.2	RO5	25.78814	-80.0881

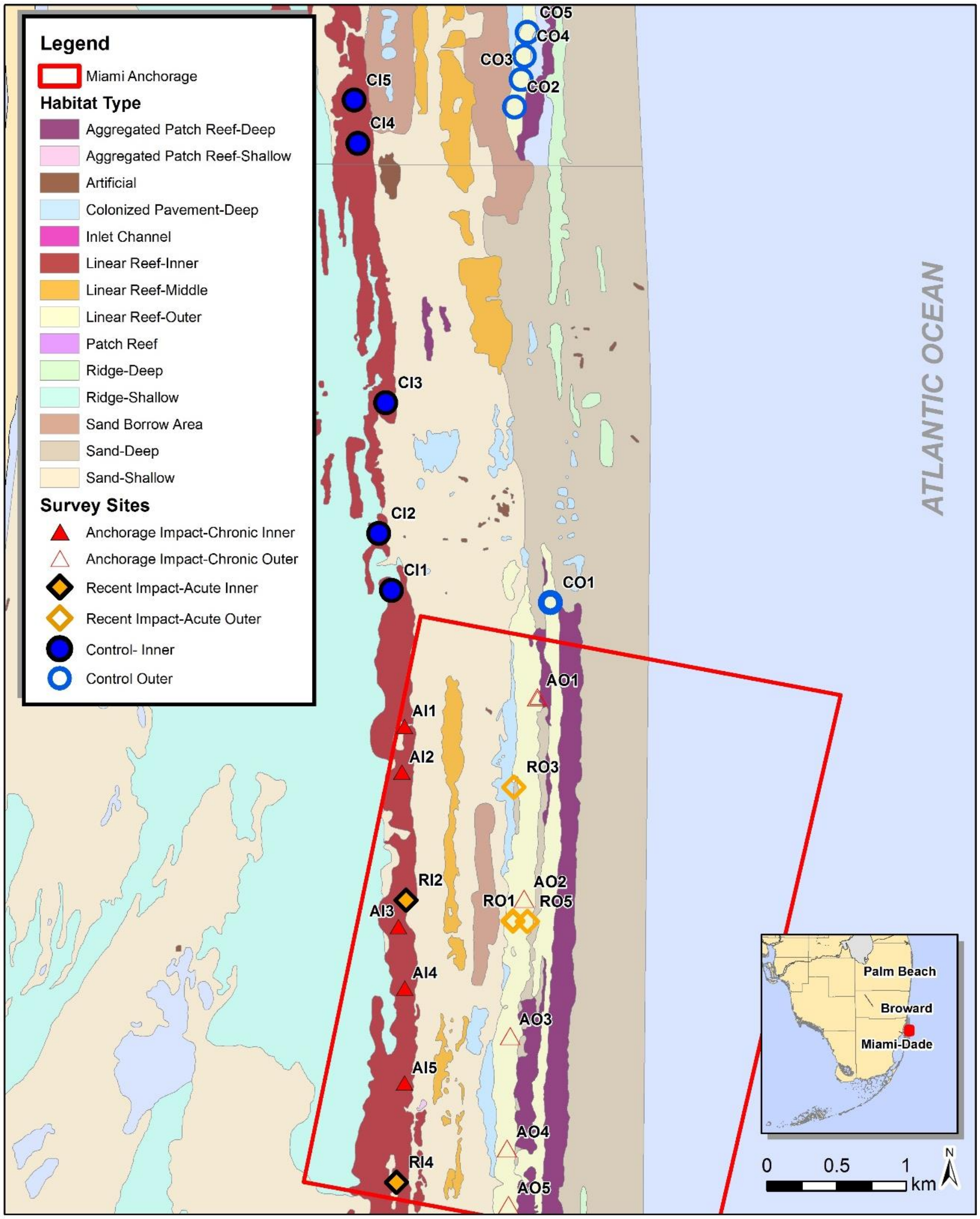


Figure 3. Map of benthic habitats and the PMA and anchorage Inner Reef (AI), anchorage Outer Reef (AO), control Inner Reef (CI), control Outer Reef (CO), recent acute impact Inner Reef (RI), and recent acute impact Outer Reef (RO) survey sites.

3.2 Protocol

At each site, six non-overlapping point-intercept transects were surveyed to characterize both the type of benthic substrate and benthic community percent cover. A small weighted buoy was deployed upon arrival at the site. Each of the six point-intercept transects were conducted along a 20 m line. Along each transect line, reef community functional group and the substrate present was recorded every 20 cm, for a total of 600 points. The functional groups included the biota scleractinia, octocoral, porifera, algae, bryozoa, hydrozoa, or zoanthid. Further classification included identifying all scleractinian corals (≥ 4 cm in diameter) to species except for the following; *Scolymia* spp., *Madracis* spp. and *Mycetophyllia* spp. to genus, and *Porites porites* did not include the various growth forms. Only the sponge *Xestospongia muta* was identified to species because of its relatively large contribution to overall benthic composition and it can be noticeably damaged or show evidence of impact relative to other sponge species. Hydrozoans were only identified for the genus *Millepora* sp. A subset of benthic organisms within the octocoral phylum were surveyed for this study and when referring to that community will be referred to as octocorals. Octocorals (≥ 4 cm in vertical height or horizontal length depending on growth form) were identified to species for the encrusting *Erythropodium caribaeorum,* and *Briareum asbestinum;* whips *Pterogorgia anceps, Pterogorgia citrine,* and *Pterogorgia guadalupensis;* and the fans *Gorgonia ventelana* and *Iciligorgia schrammi*, all others were classified by the morphotype (e.g. rod, plume).

Studies on the Great Barrier Reef showed certain substrates to be most indicative of impacted sites versus non impacted sites and, as such, substrate at each point was classified as sand, consolidated hardbottom, small rubble (≤ 0.5 m), or large rubble (> 0.51 m) (Dinsdale & Harriott 2004). In the event a functional group overlapped, such as an octocoral over a scleractinian, the bottommost group was recorded. In the event a point fell upon a portion of a partially living coral that was dead, it was recorded as rubble if loose, or consolidated hardbottom if attached.

In addition to functional group cover, demographic data within 20 one- square- meter quadrats, was collected. In the 20 square meter quadrats, all live scleractinian, octocorals, and *Xestospongia muta* were counted. All scleractinian, octocorals, and *Xestospongia muta* < 4 cm were not identified to species. Scleractinian corals (≥ 4 cm in diameter) were identified to species except for the following which were identified to genus; *Scolymia* spp., *Madracis* spp. and *Mycetophyllia* spp., and *Porites porites* did not include the various growth forms. Octocorals (≥ 4 cm in vertical height or horizontal length depending on growth form) were identified to species for the encrusting *Erythropodium caribaeorum,* and *Briareum asbestinum;* whips *Pterogorgia anceps, Pterogorgia citrine,* and *Pterogorgia guadalupensis;* and the fans *Gorgonia ventelana* and *Iciligorgia schrammi*, all others were classified by the morphotype (i.e. rod, plume).

For stony corals ≥4 cm diameter, colony live tissue area (colony live tissue length x width to the nearest 1 cm) was calculated using the formula for an ellipse. All octocorals ≥4 cm in height were assigned to bins based on their height if a vertically growing morphotype or width if an encrusting morphotype (4 cm-10 cm, 11 cm- 0.5 m, 0.51 m-1 m, and >1 m). For *Xestospongia muta,* sponge height and base width were recorded.

Physical injury on live scleractinian, octocoral, and *Xestospongia muta* in the point intercept transects and quadrats was recorded in the following categories: crushed and abraded. Crushed included species that were obviously split open or in many pieces, abraded included obvious signs of anchor chain scraping or slicing. Additionally, it was noted how many barrels were present for *Xestospongia muta*, since it is believed this species may create several barrels when recovering from severe impact (Gilliam et al. 2008).

In order to provide information in the event of a Section 7 consultation between the USCG and NOAA, at each anchorage site the recommended protocol for Tier 1 site surveying for *Acropora* spp. colonies was followed. That is, if none were within the surveyed area, a 10 minute haphazard site swim was completed to ensure colonies outside of transects were not missed (Technical Memo "*Recommended Survey Protocol for Acropora* spp. *in Support of Section 7 Consultation Revised October 2007*").

3.2.1 Anchorage Chronic Impact and Control Survey Protocol

For chronic impact and control sites, divers ensured the weighted buoy was in the appropriate habitat by visually characterizing the site based on descriptions from Walker 2009; and then began all transect sampling radiating out from that weighted buoy. Transects were laid along a compass bearing that was randomly generated prior to the dive. Data was collected every 20 cm as stated above. Ten one- square- meter quadrat samples were collected along two of the point intercept transect lines, chosen at random, for a total sample area of 20 square meters.

3.2.2 Anchorage Acute Impact Survey Protocol

For recent impact sites, in order to survey the acute impact, transects and quadrats were placed specifically to capture the visible impact. The weighted buoy was placed in the greatest impact area and transect tapes were laid along the path of where the anchor chain had been. When a commercial vessel anchors, a reasonable assumption is that they deploy enough anchor chain to equal approximately seven times the depth of water they are anchoring in (House 2007). This means in waters from 12.5 m to 15.0 m, the length of chain would be 87.5 m to 105 m. Since the total length of the point intercept transects was 120 m (6 x 20 m if laid end to end), at some sites not all 600 points were collected. Twenty one m^2 quadrat samples were collected along both sides of the transect, within the most heavily impacted area.

3.3 Vessel Traffic

In order to investigate vessel use of the anchorage and frequency of anchor impacts, information from vessel's automatic information system (AIS) was gathered from online sources freely available to the public. In navigable waters of the United States (with certain exceptions in the St. Lawrence Seaway) all domestic and foreign self-propelled vessels over 1600 tons (excluding US government military vessels) and any foreign vessels in commercial service over 65ft in length (excluding passenger or fishing vessels) must have an AIS installed (Code of Federal Regulation title 33 in §164). The AIS reports the speed, location of the stern, and name of the vessel, with additional information that can include the length and draught of the vessel, as well as the position of the AIS on the vessel. In general AIS instruments are located in the aft quarter of the vessel. The anchorage was monitored once a day on most week days (Monday-Friday) from March 2011 through November 2013 and any vessels in the anchorage at that time were recorded. The data were filtered to include only singular anchoring events, that is, if a vessel was in the anchorage for several days in a row, only the day it dropped anchor was recorded. The data were also filtered for any faulty information such as missing vessel lengths, when analyzing by vessel length; or other missing information which called into question the validity of the information.

3.4 Statistical Analysis

The reef lines of south Florida are different habitats with subtle differences in species present and size classes of those species. These habitats covary with depth which effects factors controlling species distributions such as water temperature, wave energy interacting with the substrate, light attenuation, etc (Walker et al. 2009). As such, for analysis of chronic impact data, Inner Reef control survey sites were compared to Inner Reef Anchorage; and Outer Reef control survey sites were compared to Outer Reef anchorage. The data sets were not combined to compare all control sites to all anchorage sites. Because of the small number of acute impact survey sites, results were analyzed by comparing acute impact Inner Reef to control Inner Reef, acute impact Outer Reef to control Outer Reef, and by combining all acute impact sites and comparing them to combined control sites.

3.4.1 Point Intercept Data

Point intercept data were analyzed to understand benthic community percent cover and substrate composition. Data were analyzed into nine functional groups, scleractinia, octocoral, porifera, hydrozoa, zoanthus, bryozoa, algae, cyanobacteria, and tunicata. Because *Xestospongia muta* is unique among the sponges in northern reef tract for its contribution to the benthic community by volume compared to other sponges and can show visible signs of impact, it was placed in its own group for analysis. Additionally the lack of benthic community, or conversely the presence of bare substrate, can indicate impact and therefore bare substrate was given its own category.

Primer v6 statistical software was used to perform a cluster analysis and corresponding non-metric multi-dimensional scaling (MDS) plot. These were constructed using Bray-Curtis similarity indices of the point intercept data to evaluate differences in benthic cover and substrate composition. That is, to understand the contribution of each variable (e.g. percent cover of each benthic phylogenetic group) to the observed similarity or dissimilarity between control and anchorage site communities. In order to reduce this test being misleading from analysis of non-normally distributed data or data with standard deviations that are not homogeneous, a square-root transformation was performed on all data. A one-way analysis of similarity (ANOSIM) was performed to statistically determine differences between groups of (multivariate) samples from different experimental treatments. ANOSIM is a permutation-based hypothesis test analogous to univariate analyses of variance (ANOVAs) that tests for differences between groups of (multivariate) samples from different experimental treatments, in this case the anchorage chronic or acute impact sites and the control sites. The closer the R statistic is to 1, the stronger the categorical groups (Clarke & Gorley 2006). Data were then analyzed separately for the overall benthic community and substrate, octocoral, scleractinian, and *Xestospongia muta* populations. Univariate ANOVA was used to examine differences in the density of major phylogenetic groups as well as differences in the percent cover of sand, rubble, and consolidated substrate between anchorage and control sites.

3.4.2 Quadrat Data

Quadrat data were analyzed to understand demographic cover of scleractinians, octocorals, and *Xestospongia muta*; and differences in species or morphotype composition; as well as differences in size classes, live tissue area, and injury to biota. Univariate ANOVA was used to examine differences in species or morphotype composition, in size classes, live tissue area of scleractinians, and recorded damage or injury to biota. For octocoral size class analysis, *Briareum asbestinum* was analyzed separately due to its encrusting horizontal growth form being fundamentally different than the other octocorals with a vertical growth structure.

Primer v6 statistical software was used to evaluate for differences in scleractinian species richness, octocoral community composition of different morphotypes, and octocoral size class densities between treatments.

3.4.3 Vessel Data

Using Esri ArcGIS Spatial Analysis Extension software the vessel location data were analyzed to evaluate if there were any areas in the anchorage more heavily used or anchoring patterns by vessel size. This was accomplished using the calculate distance band from neareast neighbor tool, incremental spatial autocorellation tool, and then joining the anchoring point data to the benthic habitat layer. A hot spot analysis was performed using the Getis-Ord Gi and Anselin Moran I with the input field being vessel length.

4. Results

4.1 Chronic Impacts

4.1.1 Inner Reef

4.1.1.1 Overall Benthic Community and Substrate

Mean major benthic community percent cover showed control and anchorage chronic impact Inner Reef sites were dominated by macroalgae with 75.9% and 79.8% respectively; followed by porifera with 6.5% and 5.8%, bare substrate with 5.4% and 4.4%, and octocoral with 4.9% and 4.2% (Figure 4 and Table 2). Both the control and anchorage chronic impact Inner Reef sites were predominately consolidated substrate with percent cover means of 82.3% and 86.6% respectively; followed by small rubble at 9.7% and 8.7%, sand at 6.7% and 4.2%, and large rubble 1.2% and 0.5% (Figure 5 and Table 3). ANOSIM showed no significant difference in benthic community or substrate composition percent cover between control and anchorage chronic impact Inner Reef sites (R=0.06, p=0.59 and R=0.132, p=0.18, respectively) (Figure 6 and Figure *7*) ANOVA showed no significant difference in benthic community or substrate composition percent cover between treatments.

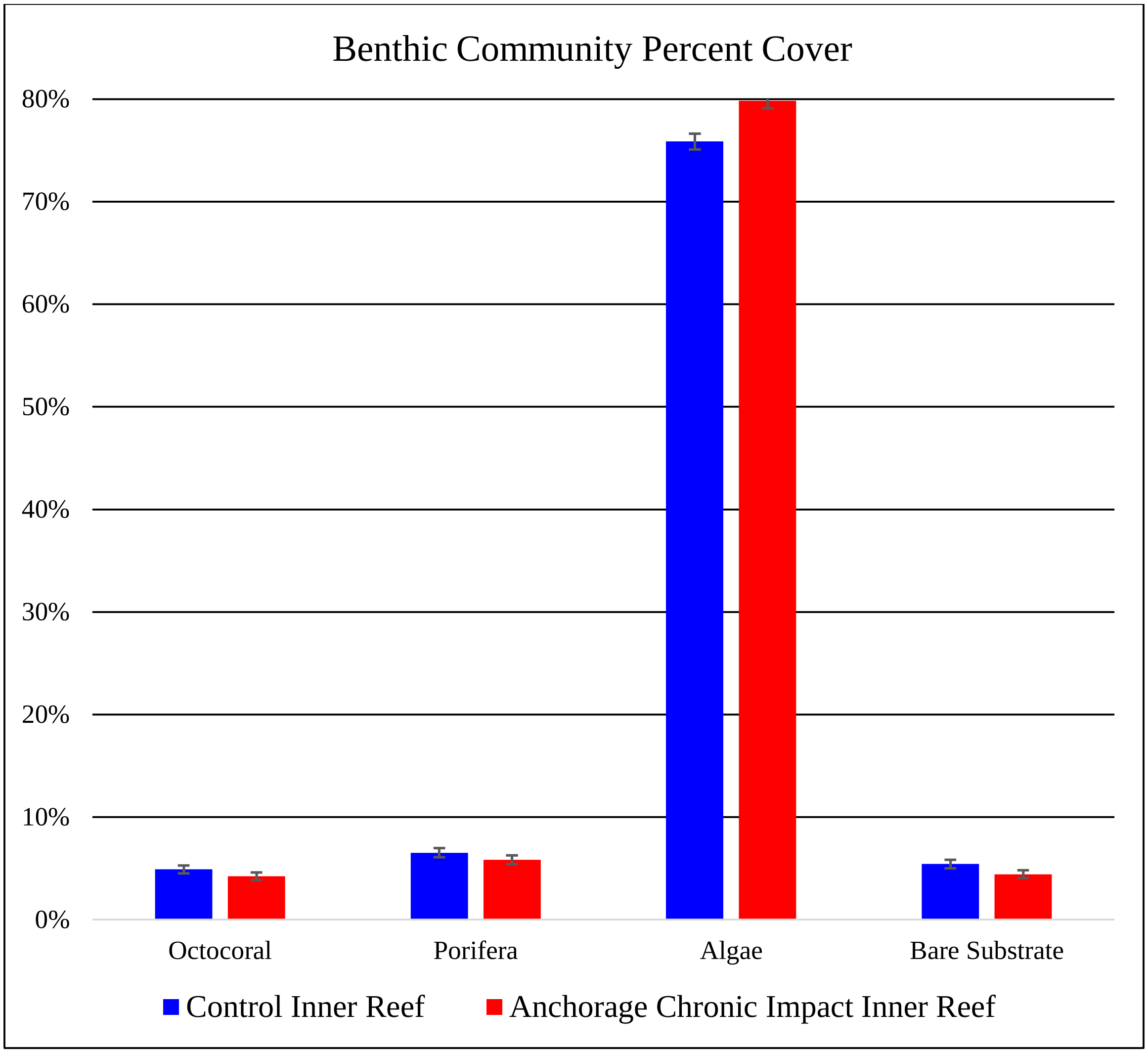


Figure 4. Major contributors to the benthic community percent cover at Inner Reef control and anchorage chronic impact sites with standard error bars.

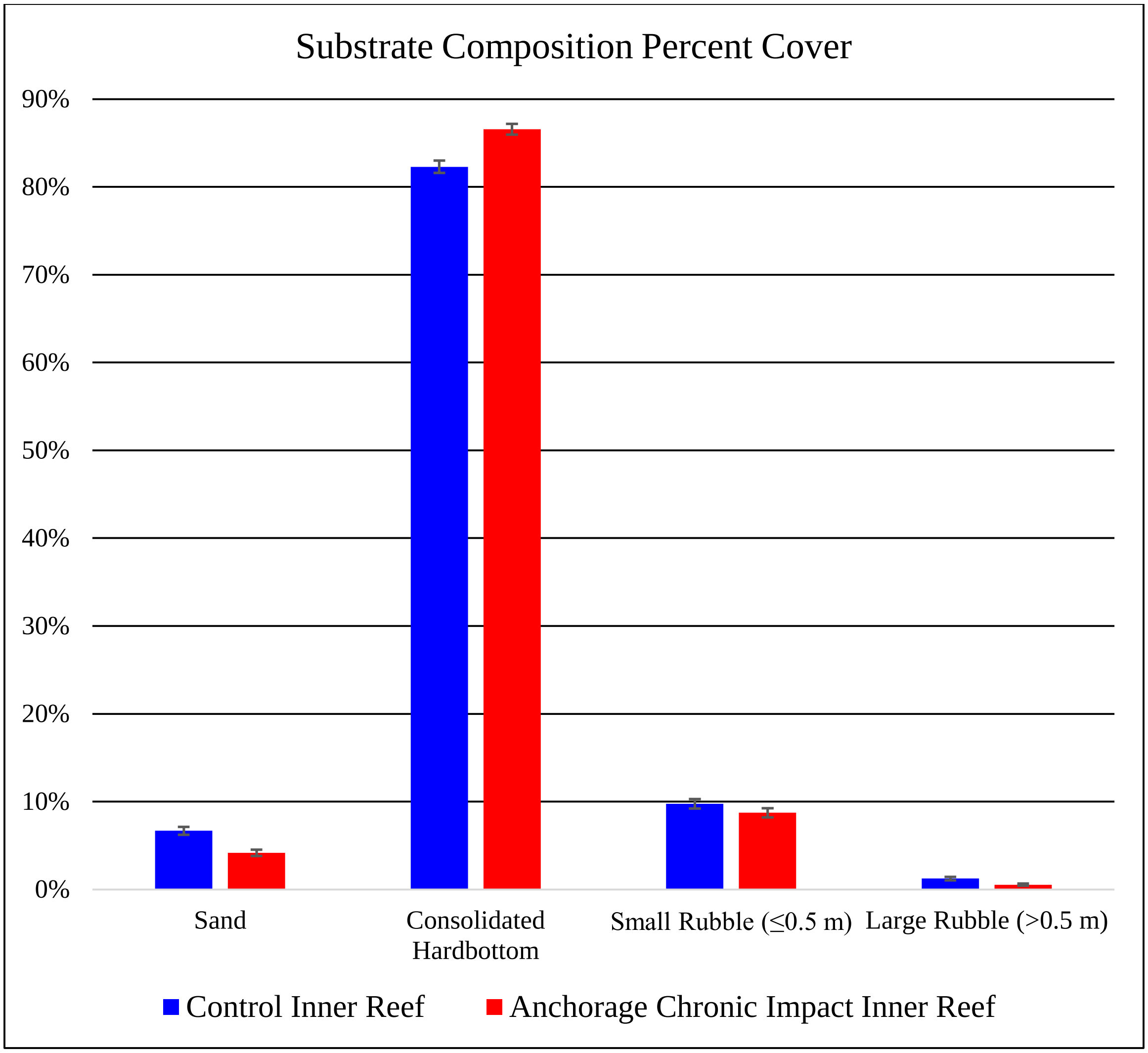


Figure 5. Substrate composition percent cover at Inner Reef control and anchorage chronic impact sites with standard error bars.

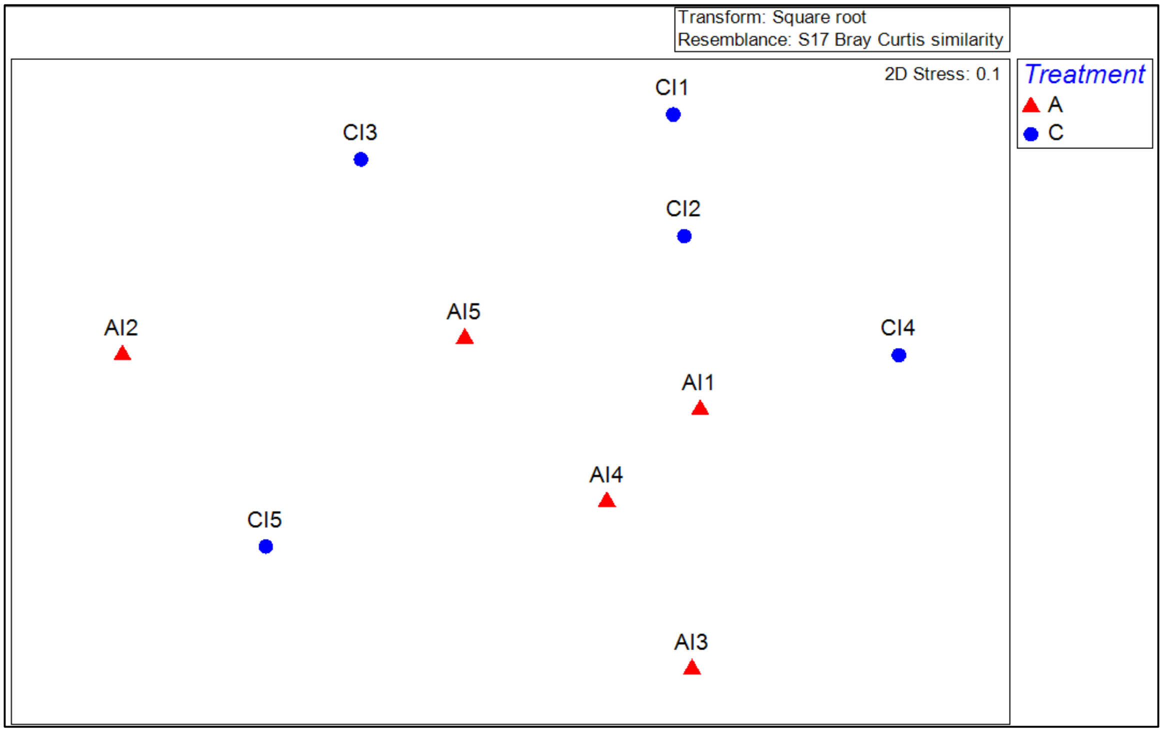


Figure 6. Two-dimensional MDS plot illustrating the dissimilarity of benthic community percent cover at Inner Reef control (CI) and anchorage (AI) chronic impact sites. ANOSIM R = 0.132 (p=0.18).

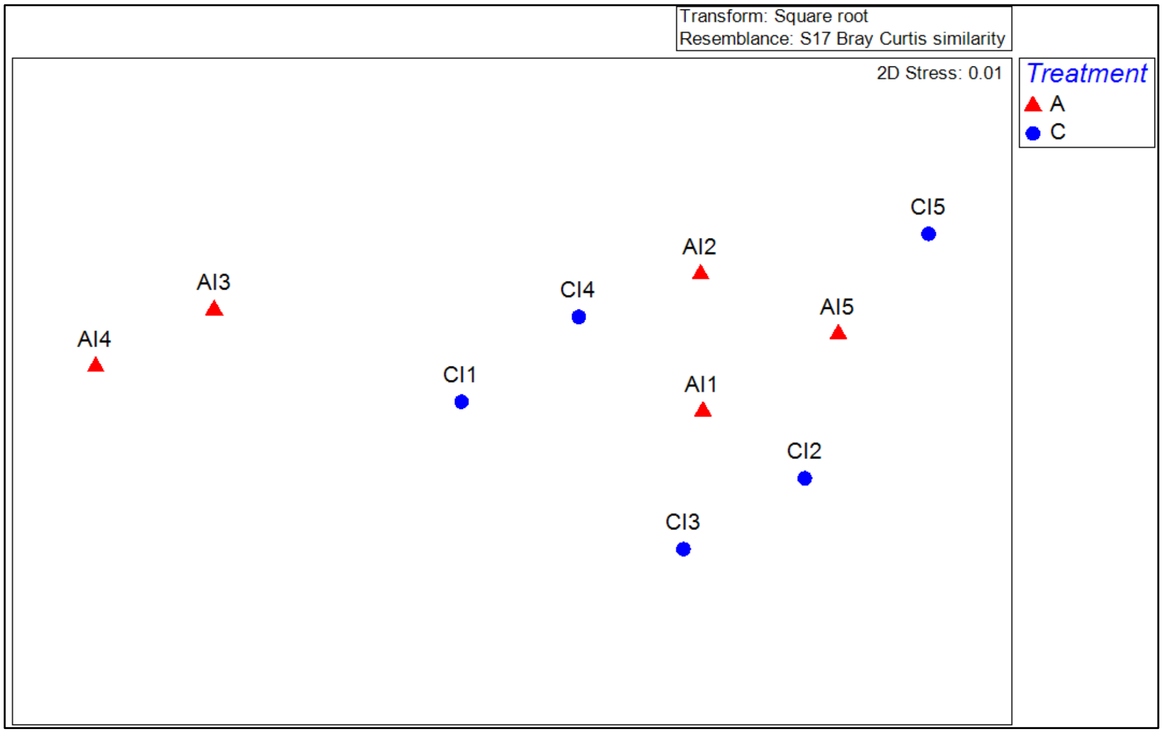


Figure 7. Two-dimensional MDS plot illustrating the dissimilarity of substrate composition percent cover at Inner Reef control (CI) and anchorage (AI) chronic impact sites. ANOSIM R=0.06 (p=0.59).

Table 2. Mean percent cover and standard error of major benthic communities at control, chronic impact within the anchorage, and acute impact within the anchorage sites. Control and chronic impacts had five samples sites each, while acute impacts had two Inner Reef and three Outer Reef survey sites.

	Scleractinia	Octocral	Porifera	*X. muta*	Hydrozoa	Zoanthus	Bryozoa	Algae	Cyanobacteria	Tunicata	Bare Substrate
Control Inner Reef	1.7 (± 0.2)	4.9 (± 0.4)	6.5 (± 0.5)	0.5 (± 0.1)	0.8 (± 0.2)	0.6 (± 0.1)	0.9 (± 0.2)	75.9 (± 0.9)	2.6 (± 0.4)	0.1 (± 0.1)	5.4 (± 0.4)
Anchorage Chronic Impact Inner Reef	0.8 (± 0.2)	4.2 (± 0.4)	5.8 (± 0.4)	0.5 (± 0.1)	0.2 (± 0.1)	0.1 (± 0.1)	0.2 (± 0.1)	79.8 (± 0.7)	3.7 (± 0.3)	0.1 (± 0.1)	4.4 (± 0.4)
Anchorage Acute Impact Inner Reef	0.3 (± 0.2)	1.7 (± 0.4)	6.3 (± 0.8)	0.4 (± 0.2)	0.3 (± 0.1)	0.2 (± 0.1)	0.2 (± 0.1)	76.5 (± 1.4)	5.5 (± 0.7)	0.1 (± 0.1)	8.4 (± 0.9)
Control Outer Reef	0.9 (± 0.2)	9.1 (± 0.5)	8.4 (± 0.5)	1.3 (± 0.2)	1.1 (± 0.2)	0.2 (± 0.1)	0.3 (± 0.1)	67.0 (± 0.9)	5.2 (± 0.4)	0.1 (± 0.1)	6.3 (±0)
Anchorage Chronic Impact Outer Reef	0.8 (± 0.2)	2.4 (± 0.3)	4.7 (± 0.4)	0.6 (± 0.1)	0.2 (± 0.1)	0.2 (± 0.1)	0.4 (± 0.1)	78.9 (± 0.7)	6.3 (± 0.4)	0.1 (± 0)	5.4 (± 0.4)
Anchorage Acute Impact Outer Reef	0.5 (± 0.2)	2.3 (± 0.4)	4.7 (± 0.6)	0.7 (± 0.2)	0.1 (± 0.1)	0.3 (± 0.1)	1.6 (± 0.3)	68.9 (±1.2)	3.6 (± 0.5)	0.1 (± 0.1)	17.1(± 0.9)

Table 3. Mean percent cover and standard error of substrate type at control, chronic impact within the anchorage, and acute impact within the anchorage sites. Control and chronic impact had five samples sites each, while acute impact had two Inner Reef and three Outer Reef survey sites.

	Sand	Small Rubble (≤0.5 m)	Large Rubble (>0.5 m)	Consolidated Hardbottom	Manmade Object
Control Inner Reef	6.7 (± 0.5)	9.7 (± 0.5)	1.2 (± 0.2)	82.3 (± 0.7)	0.1 (± .05)
Anchorage Chronic Impact Inner Reef	4.2 (± 0.4)	8.7 (± 0.5)	0.5 (± 0.1)	86.6 (± 0.6)	0.0 (± 0)
Anchorage Acute Impact Inner Reef	4.0 (± 0.6)	23.5 (± 1.4)	4.2 (± 0.6)	68.0 (± 1.5)	0.3 (± 0.6)
Control Outer Reef	10.7 (± 0.6)	3.0 (± 0.3)	0.1 (± 0.1)	86.1 (± 0.6)	0.1 (± 0)
Anchorage Chronic Impact Outer Reef	6.1 (± 0.4)	9.4 (± 0.5)	1.0 (± 0.2)	83.4 (± 0.7)	0.2 (± 0.1)
Anchorage Acute Impact Outer Reef	6.1 (± 0.6)	21.5 (± 1.1)	5.1 (± 0.6)	67.3 (± 1.2)	0.0 (± 0)

4.1.1.2 Octocoral Community

Summary data for the octocoral densities surveyed on Inner Reef within quadrats is provided in appendix A 1. Analysis showed no significant difference in the total density of octocorals per square meter between control and chronic anchorage impact sites. Analysis of octocorals showed a weak difference (ANOSIM R = 0.42, p = 0.04) between control and anchorage sites driven primarily by *Briareum asbestinum* contributing to 33.96% of the difference (Figure 8). A one-way ANOVA of the quadrat data confirmed that there was significantly more *Briareum asbestinum* at control Inner Reef sites than at anchorage Inner Reef sites experiencing chronic impact (p = 0.02).

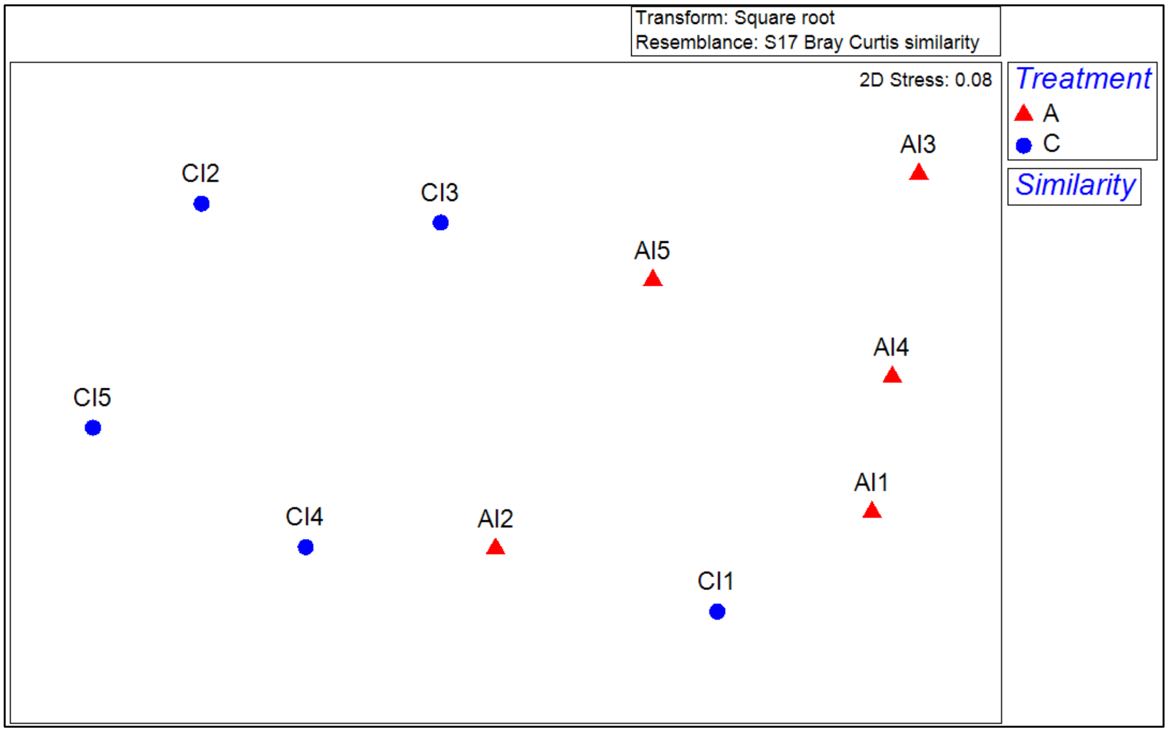


Figure 8. Two-dimensional MDS plot illustrating octocoral densities at Inner Reef control (CI) sites and anchorage (AI) chronic impact sites. ANOSIM R=0.42 (p=0.04).

Analysis of size class distribution of vertically growing octocorals within quadrats showed no significant differences between the total octocoral community at control sites and chronic impact anchorage sites. However, at control sites the encrusting class had significantly more individuals in both the 4 cm - 10 cm and 11 cm - 0.5 m size class bins (ANOVA p=0.04 and p=0.02 respectively).

Analysis of total octocorals < 4 cm showed no significant difference. When analyzed separately, there were significantly more encrusting recruits at control sites than anchorage sites (ANOVA, p=0.05).

The differences in total octocoral density on Inner Reef was driven by higher densities of *Briareum asbestinum* at control sites, and this may have contributed to some of the differences seen in the vertically growing octocoral community. While not significant, there were more vertically growing octocorals at anchorage chronic impact sites on Inner Reef than at control sites. It was this difference which was driving CI1, which had the most vertically growing octocorals per square meter, and AI2, which had the fewest vertically growing octocorals per square meter, to be more similar to anchorage or control sites respectively (Figure 8).

4.1.1.3 Scleractinian Community

Summary data for the scleractinian communities surveyed on Inner Reef within quadrats is provided in appendix A 2. Total scleractinians were significantly denser at control sites (ANOVA, p = 0.001). Analysis of scleractinian species cover indicated moderate differences between treatments existed (ANOSIM, R = 0.61, p = 0.08) and that it was driven primarily by *Siderastrea siderea* (Figure 9). Indeed there were significantly more *Siderastrea siderea* at control Inner Reef sites than chronic impact anchorage sites (Wilcoxon Rank Sums, p = 0.01). In addition there were significantly more coral species found at control sites (Wilcoxon Rank Sums, p = 0.02) with nine species not observed in the anchorage (*Pseudodiploria clivosa*, *Pseudodiploria strigosa*, *Madracis* spp., *Meandrina meandrites*, *Orbicella annularis*, *Orbicella faveolata*, *Orbicella franksi*, *Scolymia* spp., and *Solenastrea bournoni).*

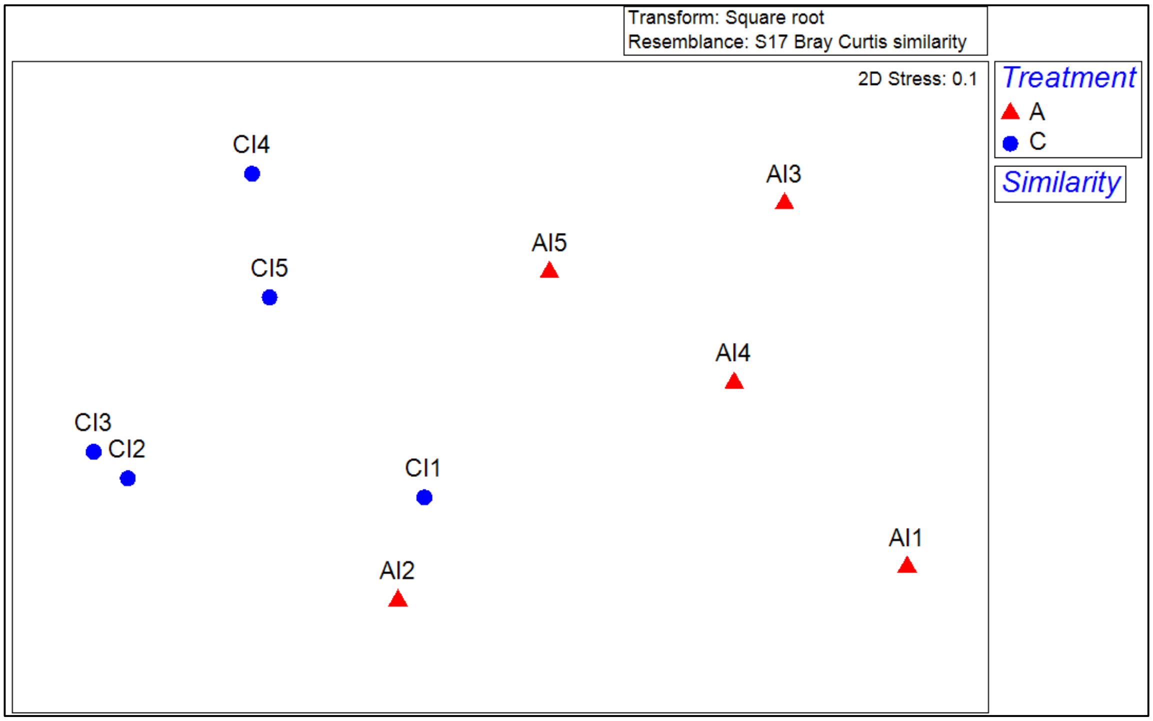


Figure 9. Two-dimensional MDS plot illustrating scleractinian density (individuals per square meter) at Inner Reef control (CI) sites and anchorage (AI) chronic impact sites. ANOSIM R = 0.61 (p = 0.08).

Not only were *Siderastrea siderea* densities significantly greater at control sites on Inner Reef, the species was found at every site, as opposed to impact sites of which only AI2 and AI5 had the species present. The highest density of *S. siderea* was at AI2 which also had the least percentage of quadrats with no scleractinians present of all the impact sites. It was the high density of *S. siderea* and low number of quadrats with no corals that was driving AI2 to be more similar to control sites. While it was not significant (ANOVA, p = .11) every control site except CI1 had *Agaricia agaricites* present. The absence of *A. agaricites* and having the second lowest densities of *S. siderea* may be driving CI1 to be more similar to anchorage chronic impact sites.

Coincident with coral density, there was also significantly more live coral tissue per square meter at control sites than chronic impact Inner Reef (ANOVA, p = 0.02). Mean live tissue per individual coral was significantly greater at control sites (ANOVA, p = 0.02). Total density of scleractinian corals ≤4 cm showed no significant difference between control and chronic impact Inner Reef (ANOVA, p = 0.06).

4.1.1.4 Xestospongia muta

Summary data for *Xestospongia muta* surveyed on Inner Reef within quadrats is provided in appendix A 3. There was no significant difference in *X. muta* density between control and anchor impact Inner Reef sites. There was also no significant difference in the width, height, or number of barrels per individual.

4.1.1.5 Colony Injury

Comparisons between Inner Reef control and chronic impact sites showed no significant difference in the amount of visible damage or reduced health to octocorals, scleractinians, or *Xestospongia muta*. There was no injury observed on scleractinians or octocorals at control sites, while there was minor to minimal paling, abrasion, and disease at anchorage sites.

4.1.2 Outer Reef

4.1.2.1 Overall Benthic Community and Substrate

Outer Reef major benthic community percent cover at control and anchorage chronic impact sites indicated algae was the most prevalent benthic functional group cover with control sites having 67.0% and chronic impact sites having 78.9%. At control sites, octocorals (9.1%) were the next most abundant benthic cover followed by porifera (8.4%); whereas at chronic impact sites the second most abundant benthic cover was cyanobacteria (6.3%) followed by bare substrate (5.4%) (Figure 10 and Table 2). Major benthic functional group cover between Outer Reef control and chronic impact sites were weakly dissimilar (ANOSIM, R = 0.33, p = 0.04), which was driven by octocorals (Figure 11). Percent cover was significantly higher for octocorals (ANOVA, p = 0.01), *Xestospongia muta* (ANOVA, p = 0.02), and poriferans (not including *X. muta*) (ANOVA, p = 0.04) at the Outer Reef control sites. High algal cover as well as low poriferan cover was responsible for driving control Outer Reef site CO4 to be more similar to impact sites. While the chronic impact site AO5 had the lowest algal cover, it also had the lowest octocoral cover, which caused it to separate from other anchorage and control sites.

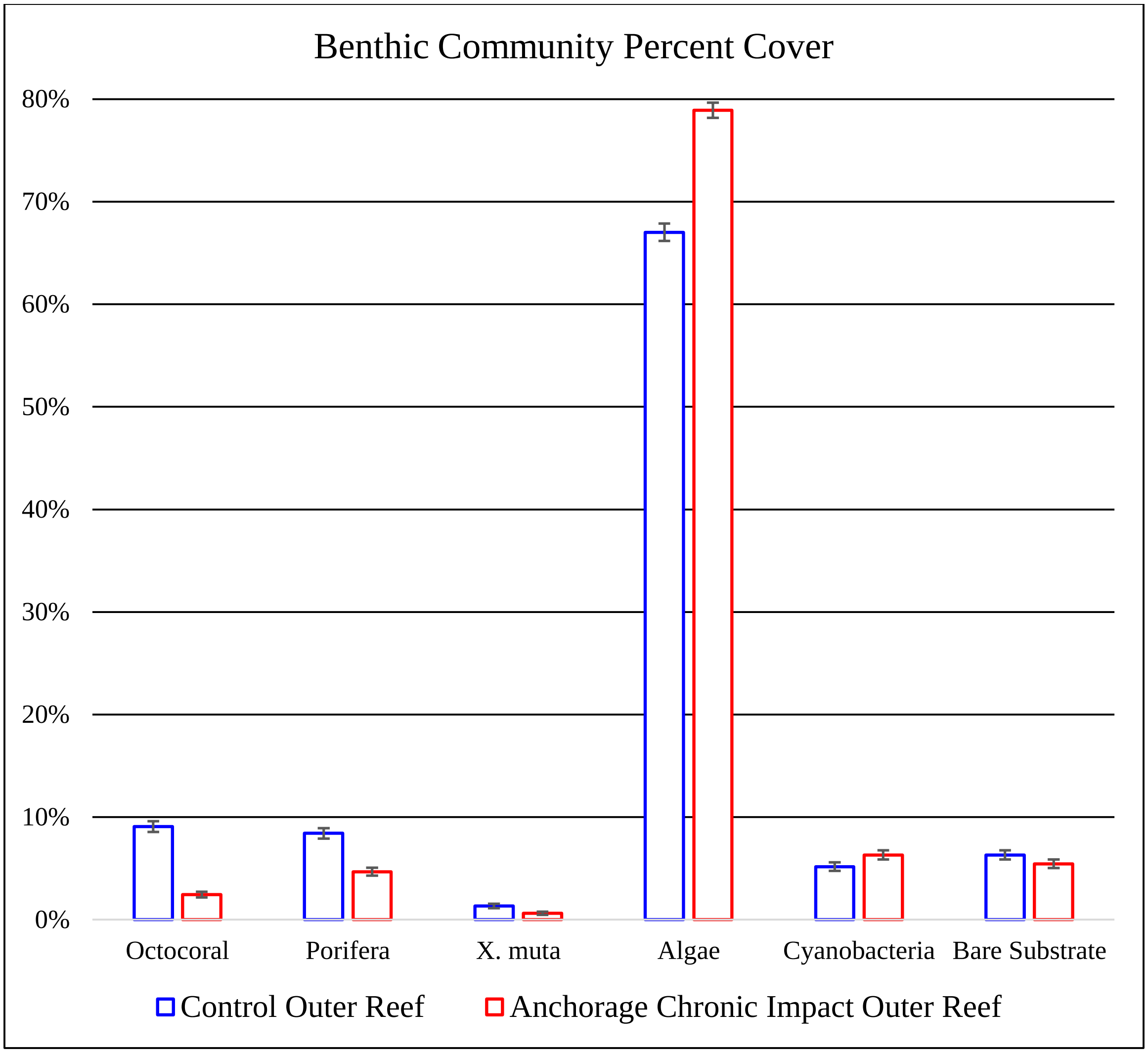


Figure 10. Major contributors to benthic community percent cover at Outer Reef control and anchorage chronic impact sites with standard error bars.

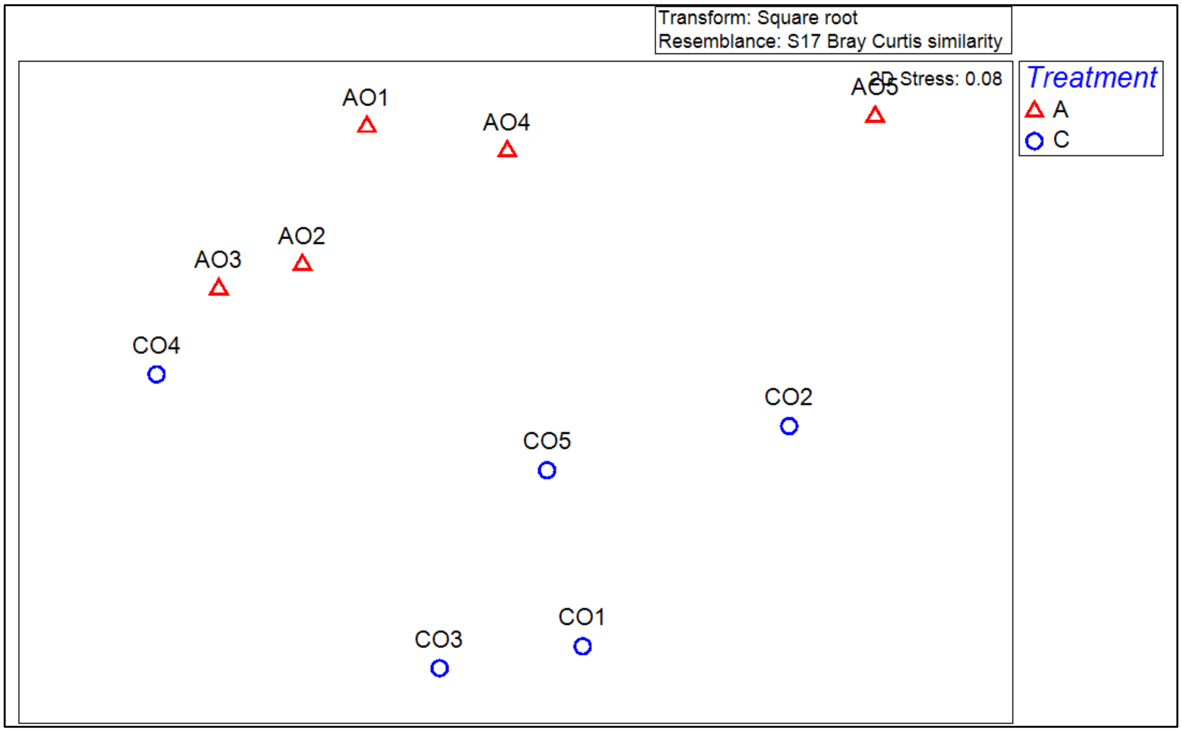


Figure 11. Two-dimensional MDS plot illustrating benthic community percent cover at Outer Reef control (CO) sites and anchorage (AO) chronic impact sites. ANOSIM R = 0.33 (p = 0.04).

Both control and chronic impact Outer Reef sites were dominated by consolidated substrate cover (86.1% and 83.4%), followed by sand (10.7% and 6.1%), small rubble (3.0% and 9.4%), and large rubble (0.1% and 1.0%) (Figure 12 and Table 3). Substrate composition cover was moderately dissimilar between Outer Reef control and chronic impact sites (ANOSIM R = 0.436, p = 0.02) and further SIMPER analysis suggested that small rubble was contributing to 36.3% of the dissimilarity between control and anchorage sites (Figure 13). Indeed there was significantly more small rubble at the Outer Reef anchorage chronic impact than control sites (ANOVA, p = 0.003).

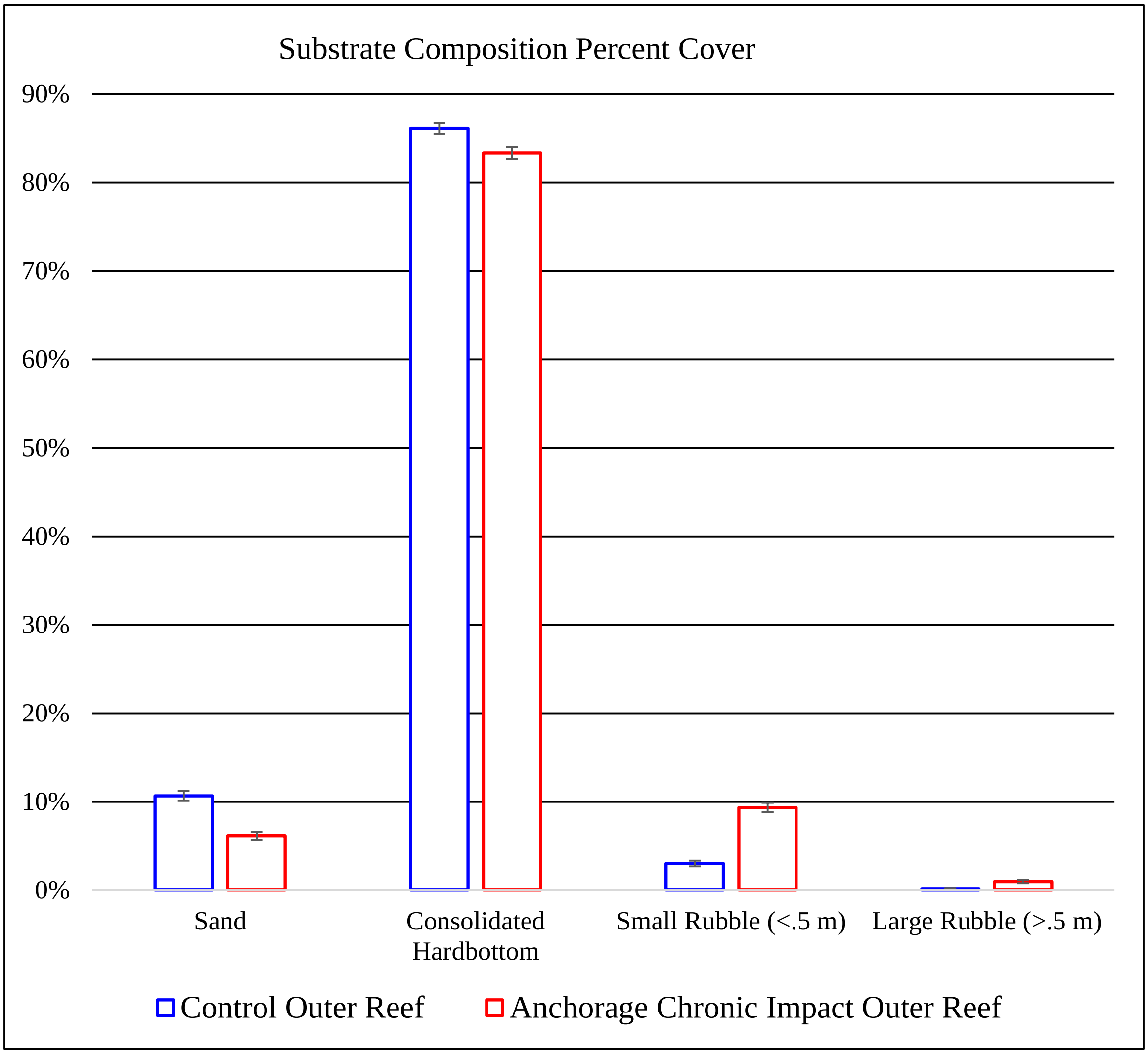


Figure 12. Substrate composition percent cover at Outer Reef anchorage chronic impact sites and control sites with standard error bars.

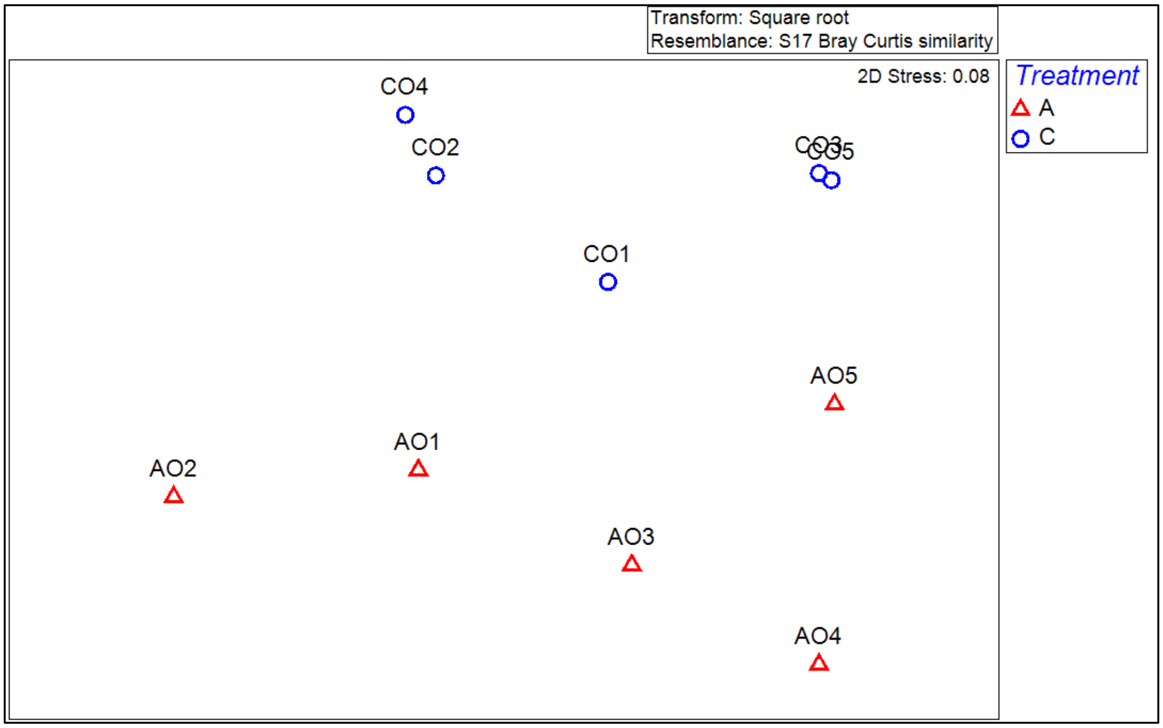


Figure 13. Two-dimensional MDS plot illustrating the dissimilarity of substrate composition cover at Outer Reef control (CO) and anchorage (AO) chronic impact sites. ANOSIM R=0.436, (p = 0.02).

4.1.2.2 Octocoral Community

Summary data for the octocoral densities surveyed on Outer Reef within quadrats is provided in appendix A 4. Total octocoral density was significantly higher at Outer Reef control sites (ANOVA, p = 0.004). The MDS plot showed moderate clustering in octocoral community composition between Outer Reef treatments (ANOSIM, R = 0.62, p = 0.01) driven primarily between differences in rod and *Briareum asbestinum* densities (41.88% and 25.55% of the difference respectively) (Figure 14). A Wilcoxon Rank-Sums analysis confirmed there were significantly more rods (z = 0.012) and a one-way ANOVA confirmed that there was significantly more *Briareum asbestinum* at control sites (p =

0.001). *Gorgonia ventalina*, was significantly more dense at control sites as well (Wilcoxon Rank-Sums, z = 0.57).

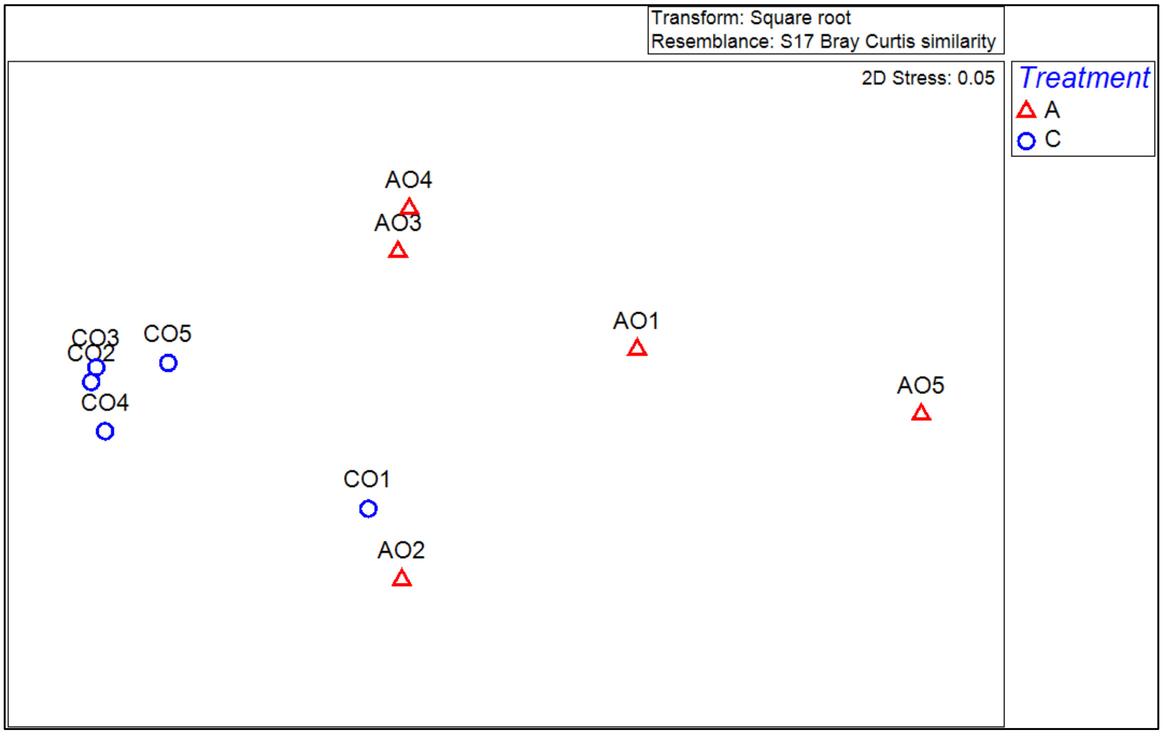


Figure 14. Two-dimensional MDS plot illustrating the dissimilarity of octocoral community composition at Outer reef control (CO) and anchorage (AO) chronic impact sites. ANOSIM R=0.616, (p = 0.01).

Analysis of size class distribution of vertically growing octocorals within quadrats suggested a moderate difference between the total octocoral community at control sites and anchorage site (ANOSIM R=0.616, p = 0.03) (Figure 15). When analyzed independently it was found that there were significantly more vertically growing octocorals within the 4 cm - 10 cm, 11 cm – 0.5 m, and 0.51 m - 1 m size class bins at Outer Reef control sites than anchorage chronic impact sites (ANOVA, p=0.031, p=0.020, and Wilcoxon Rank-

Sums z = 0.020 respectively). There were no rods recorded in the 0.5 m – 1 m size class and only one rod recorded in the >1 m size class at anchorage chronic impact Outer reef sites; compared to 26 and 7 at control sites, respectively. Also only eight plumes were recorded in the 0.51 m – 1 m size class and none in the >1 m size class at anchorage chronic impact Outer Reef sites; compared to 17 and 1 at control sites, respectively. *Briareum asbestinum* had significantly more individuals in the 11 cm – 0.5 m size class bins at control sites (p = 0.007).

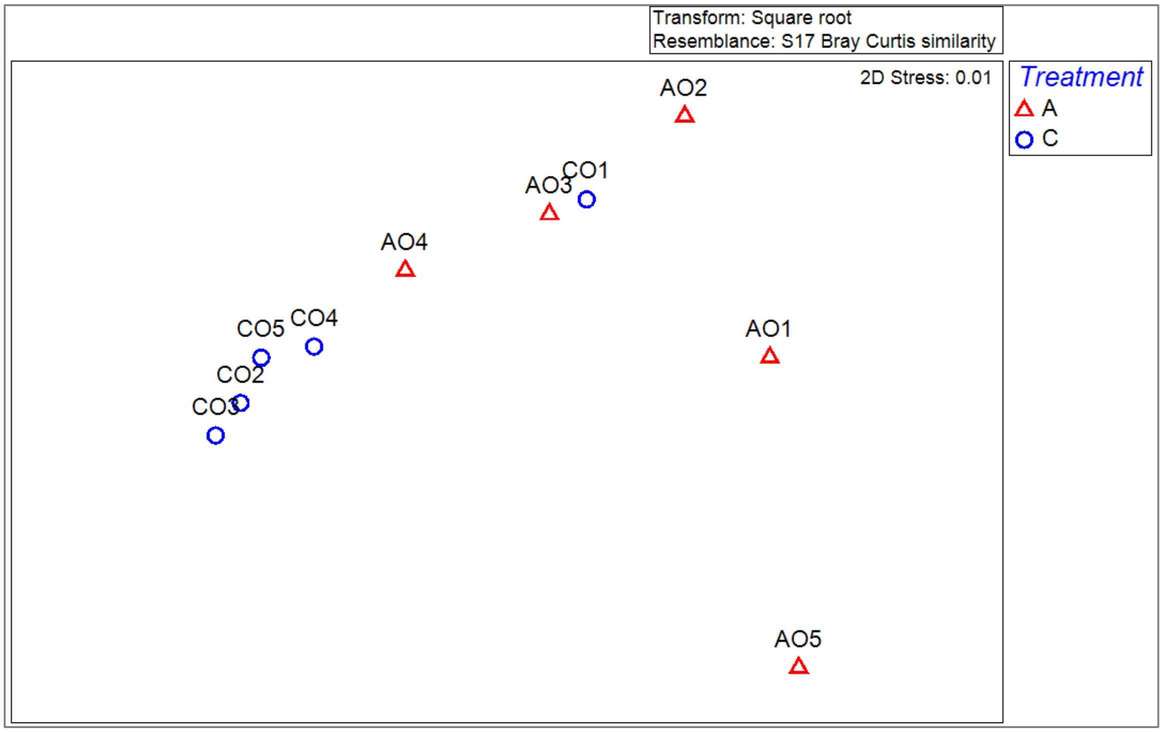


Figure 15. Two-dimensional MDS plot illustrating the dissimilarity between octocoral size class contribution at Outer Reef control (CO) and anchorage (AO) chronic impact sites. ANOSIM R = 0.36, (p = 0.03).

Analysis of total octocoral density of the smallest class (<4 cm) showed moderately significant differences between treatments (ANOSIM, R=0.564, p = 0.01) with small encrusting and rod contributing the most to the difference (43.24% and 35.38% of the difference respectively). There were significantly more small (< 4 cm) encrusting (ANOVA, p = 0.001) and rod octocorals (ANOVA, p = 0.04) at control sites.

While the ANOSIM for octocoral size class was weak, both the octocoral community and size class MDS plots showed tight clustering of the control sites except for CO1. On Outer Reef sites, it was the extremely low density of rods and plumes that was driving CO1 to be more similar to anchorage chronic impact sites and a higher density of *Briareum asbestinum* at AO2 that may be driving it to be more similar to control sites. The CO1 site, also had the lowest densities in each size class bin (A 4). Specifically CO1 was the only control Outer Reef site with no octocorals greater than 1 m. This resulted in CO1 being more similar to anchorage chronic impact sites. Anchorage chronic impact site AO5 had the lowest total octocoral density of all control or anchorage chronic impact Outer Reef sites, making it least similar to all other sites.

4.1.2.3 Scleractinian Community

Summary data for scleractinian densities surveyed on the Outer Reef is provided in appendix A 5. There were no significant differences in the mean number of species or mean density of scleractinians between control and anchorage chronic impact Outer Reef sites, however the MDS of scleractinian density by species showed clear separation between treatments although the ANOSIM was weak (R = 0.392, p = 0.01) (Figure 16). A SIMPER analysis indicated the differences were driven primarily by *Porites astreoides* and *Montastrea cavernosa*. A Wilcoxson Rank-Sums test showed that *M. cavernosa* and *P. astreoides* (z = 0.017 and z = 0.013, respectively) were significantly more dense at anchorage chronic impact sites.

Anchorage chronic impact sites on Outer Reef actually had total scleractinian densities greater or equal to all but one control site. While this wasn’t significant, of note was that even though the total densities were not significantly different, the impact sites had an average of 42% of quadrats with no corals as opposed to control sites which had an average of 25% of quadrats with no corals present. There was no significant difference between small scleractinian density (<4 cm) by treatments.

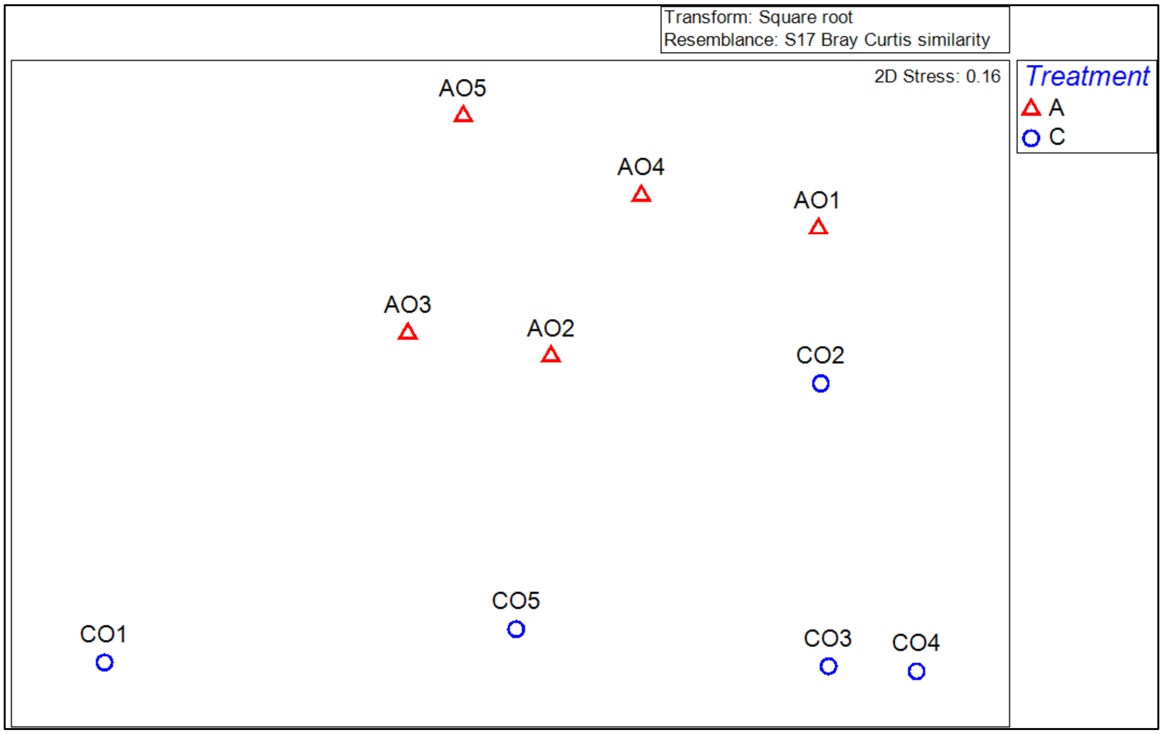


Figure 16. Two-dimensional MDS plot illustrating the dissimilarity between scleractinian density (individuals per m^2) at Outer Reef control (CO) and anchorage (AO) chronic impact sites. ANOSIM R = 0.392, (p = 0.01).

4.1.2.4 Xestospongia muta

Summary data for the *Xestospongia muta* surveyed on Outer Reef within quadrats is provided in appendix A 6. There was no significant difference in *X. muta* density between Outer Reef treatments. There was also no significant difference in the width, height, or number of barrels per individual.

4.1.2.5 Colony Injury

Comparisons between control and anchorage chronic impact Inner Reef showed no significant difference in the amount of visible damage to octocorals, scleractinians, or

Xestospongia muta. At control sites, there was no visible injury to scleractinians and minimal injury to octocorals. Conversely, at impact sites there was minimal scleractinian injury and no observed octocoral injury.

4.2 Acute Impacts

4.2.1 Inner and Outer Reef Combined Comparison

Due to low sample sizes within reef types (two Inner and three Outer), differences within reef types were not tested. It was necessary to combine all control sites and compare them to all acute impact sites to investigate acute impacts.

4.2.1.1 Overall Benthic Community and Substrate

Both control and anchorage acute impact sites were dominated by algae cover (71.4% and 71%.9). Bare substrate was the next dominant cover type at acute impact sites (13.7%) followed by porifera (5.3%) and cyanobacteria (4.4%), whereas control sites were dominated by porifera (7.5%), octocorals (7.0%), and bare substrate (5.9%) (Figure 17 and Table 4). The MDS plot of benthic community cover data showed weak separation between treatments (ANOSIM, R = 0.39, p = 0.01) (Figure 19). However the clustering amongst controls was tighter, indicating less variability amongst controls and anchorage acute impact sites. Further SIMPER analysis showed that cyanobacteria, bare substrate, and the octocoral community contributed most to the dissimilarity (Figure 19). Mean bare substrate cover was significantly higher at acute impact sites (ANOVA, p = 0.05). Conversely, both scleractinian and octocoral cover were significantly higher at control sites (ANOVA, p = 0.029 and ANOVA, p = 0.008, respectively).

Both the control and acute impact sites were predominately consolidated substrate (84.2% and 67.6%), followed by small rubble (6.4% and 22.3%), sand (8.7% and 5.2%), and large rubble (0.7% and 4.8%) (Figure 18 and Table 5). Substrate composition drove the differences between control and acute impact site dissimilarity (ANOSIM, R = 0.656, p = .001) with SIMPER analysis showing that small rubble (39.19%) and large rubble (23.2%) contributed most to the dissimilarity (Figure 20). There was significantly more small rubble and large rubble at the acute impact sites than control site (ANOVA, p = 0.002).

The high prevalence of cyanobacteria and bare substrate at acute impact sites was driving most of the benthic community differences compared to control sites. Acute impact site RI2 had the least percent of bare substrate (2.3%) and the highest percentage of poriferans (8.4%), driving it to be more similar to control sites than the other acute impact sites. Similarly RI2 had the most consolidated substrate and least amount of small or large rubble of any of the recent impact sites, which lead it to be more similar to control sites. Site CI5 had the higher cyanobacteria and lower poriferan percent cover relative to impact sites, driving that site to be more similar to recent acute impact sites.

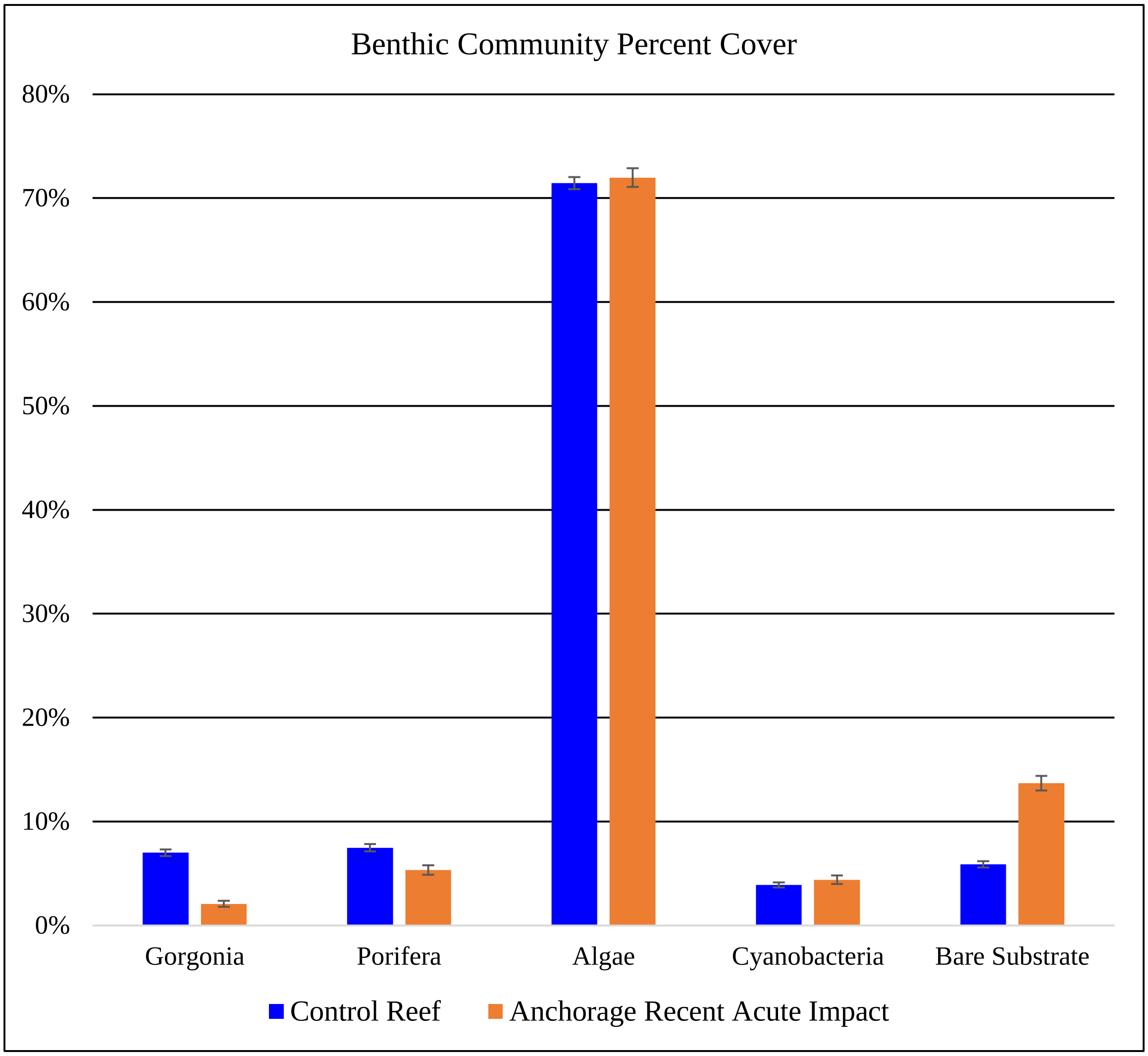


Figure 17. Major contributors to benthic community percent cover at anchorage acute impact and control sites with standard error bars.

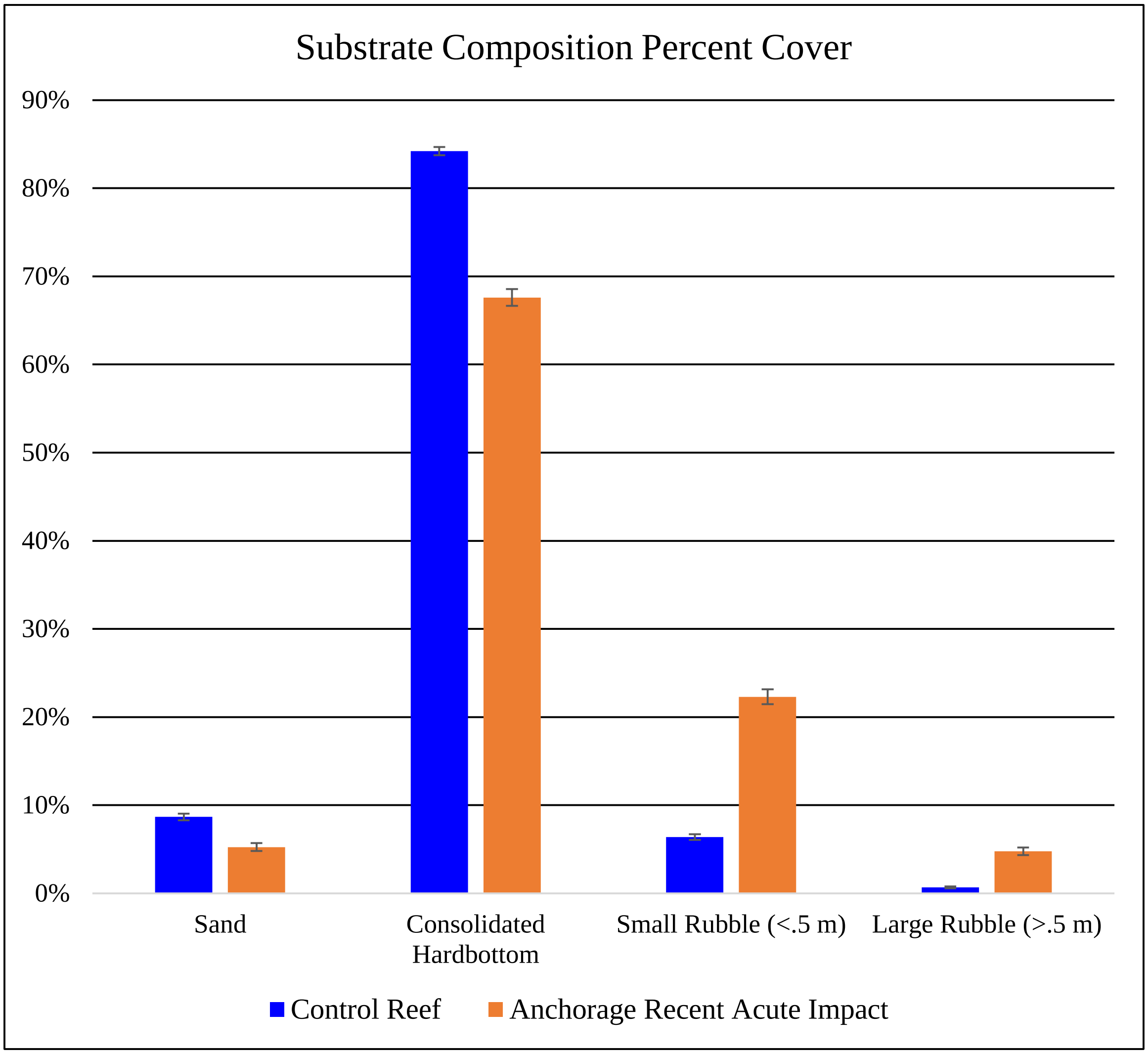


Figure 18. Substrate composition percent cover at anchorage acute impact sites and control sites with standard error bars.

Table 4. Mean percent cover of major benthic communities at all control sites (Inner and Outer Reef) and acute impact sites within the anchorage. Combined control sites resulted in ten samples total, while acute impacts had five.

	Scleractinia	Octocoral	Porifera	*X. muta*	Hydrozoa	Zoanthus	Bryozoa	Algae	Cyanobacteria	Tunicata	Bare Substrate
Control Sites	1.3 (± 0.1)	7.0 (± 0.3)	7.5 (± 0.4)	0.9 (± 0.1)	0.5 (± 0.1)	0.2 (± 0.1)	0.6 (± 0.1)	71.4 (± 0.6)	3.9 (± 0.2)	0.1 (± 0)	5.9 (± 0.3)
Anchorage Acute Impact Sites	0.4 (± 0.1)	2.1 (± 0.3)	5.3 (± 0.5)	0.6 (± 0.2)	0.2 (± 0.1)	0.1 (± 0.1)	1.1 (± 0.2)	71.9 (± 0.9)	4.4 (± 0.4)	0.1 (± 0)	13.7 (± 0.7)

Table 5. Mean percent cover of substrate types at all control sites (Inner and Outer Reef) and acute impact sites within the anchorage. Combined control sites resulted in ten samples total, while acute impacts had five.

	Sand	Small Rubble (< 0.5 m)	Large Rubble (>.5m)	Consolidated Hardbottom	Manmade Object
Control Sites	8.7 (± 0.4)	6.4 (± 0.3)	0.7 (± 0.1)	84.2 (± 0.5)	0.1 (± 0)
Anchorage Acute Impact Sites	5.2 (± 0.4)	22.3 (± 0.8)	4.8 (± 0.4)	67.6 (± 0.9)	0.1 (± 0.1)

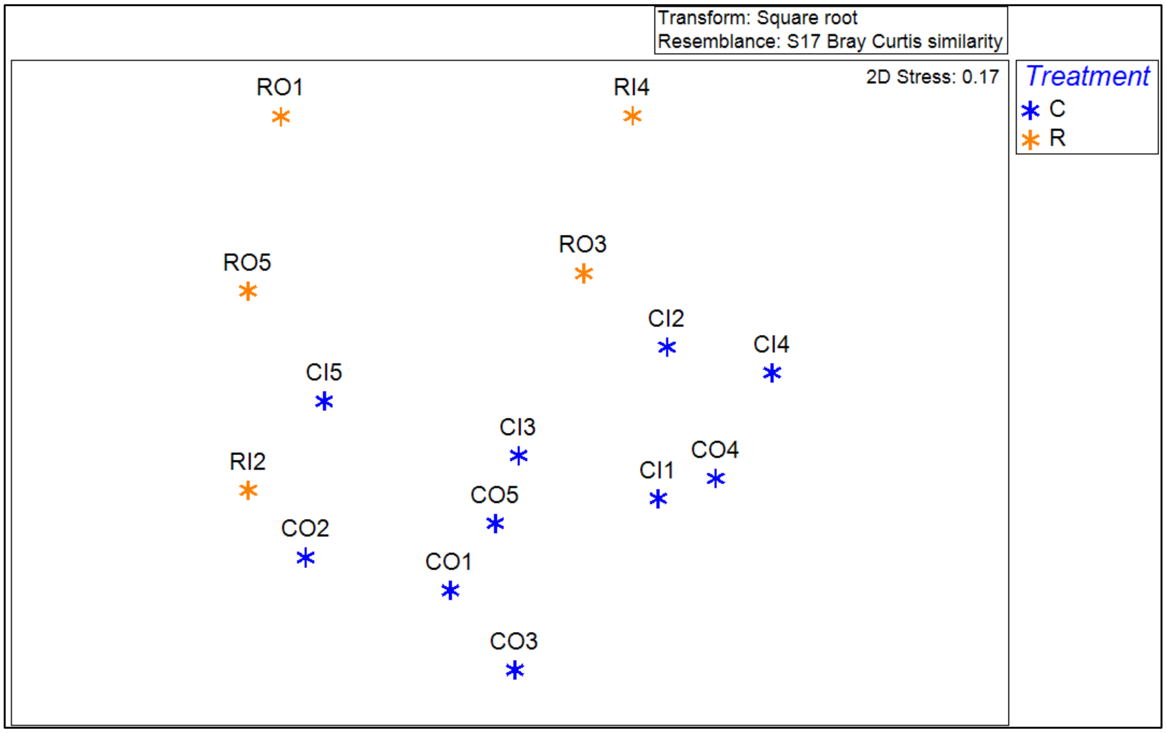


Figure 19. Two-dimensional MDS plot illustrating the dissimilarity between benthic community composition at control (C) and recent anchorage acute (R) impact sites. ANOSIM R = 0.39, (p = 0.01).

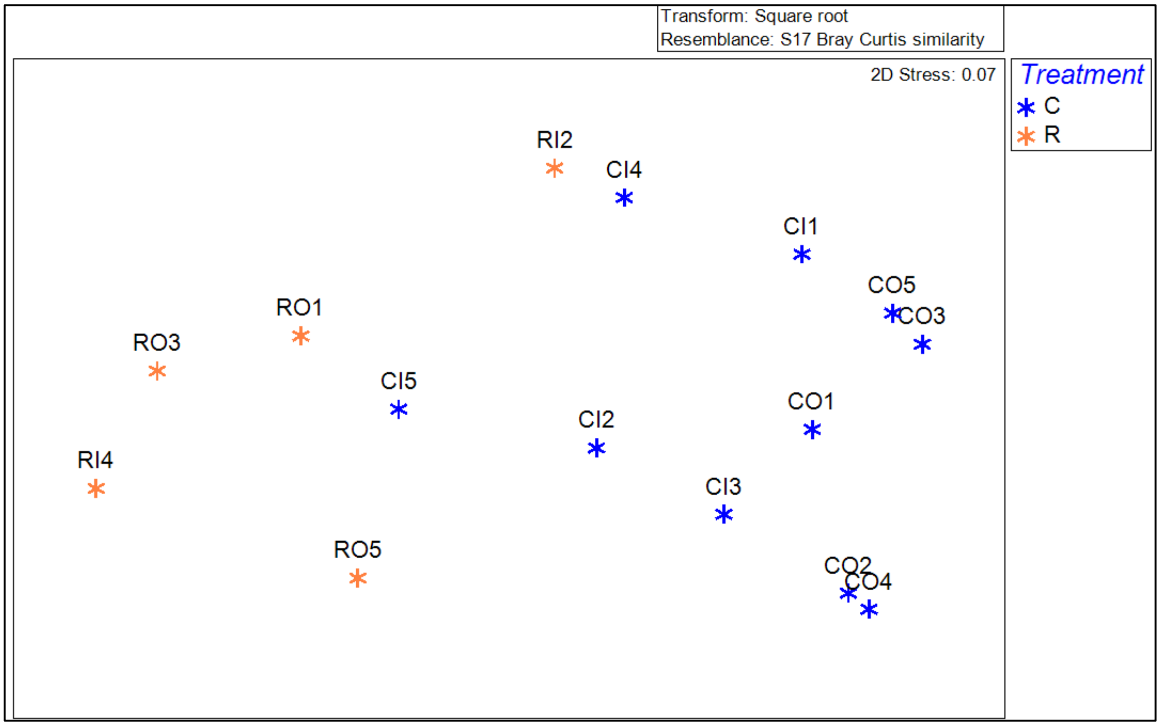


Figure 20. Two-dimensional MDS plot illustrating the dissimilarity between substrate composition at control (C) sites and recent anchorage acute (R) impact sites. ANOSIM R=0.656 (p = 0.001).

4.2.1.2 Octocoral Community

Summary data for octocoral community density surveyed on Inner Reef within quadrats is provided in appendix A 7. Analysis showed significantly higher total density of octocorals per square meter at control sites than acute impact sites (ANOVA, p = 0.002). Analysis of the octocoral community showed strong dissimilarity between anchorage and control sites (ANOSIM R = 0.728, p =0.001). This was driven primarily by rod and *Briareum asbestinum* contributing to 37.88% and 32.42% of the difference (Figure 21). A one-way ANOVA of the quadrat data confirmed that there was significantly more *Briareum* *asbestinum* at control sites than at anchorage acute impact sites (p = 0.001); however, rods were not significantly different (p = 0.084).

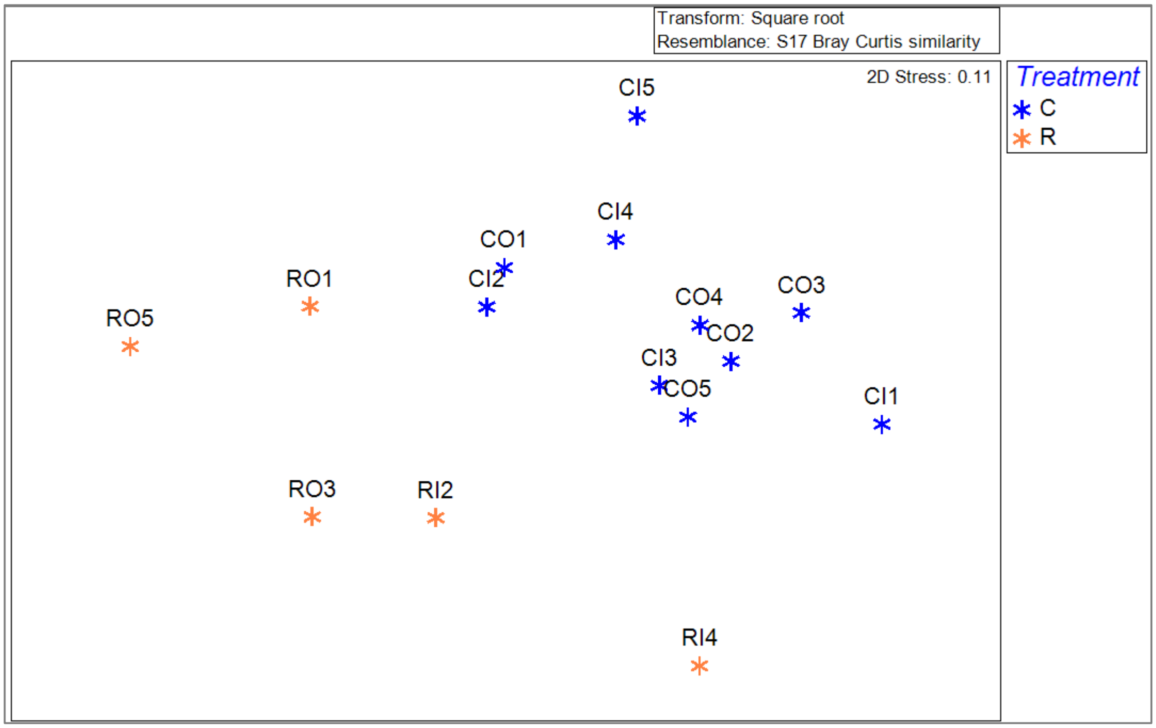


Figure 21. Two-dimensional MDS plot illustrating octocoral community composition at control (C) and recent anchorage acute (R) impact sites. ANOSIM R=0.728, (p= 0.001).

Analysis of size class distribution of vertically growing octocorals within quadrats showed a weak dissimilarity between the total octocoral community at control sites and anchorage acute impact site (R = 0.364, p = 0.01) (Figure 22). However, at control sites, there were significantly more vertically growing octocorals within the 0.51m – 1m size class (p = 0.041) and encrusting had significantly more individuals in both the 4 cm - 10 cm and 11 cm - 0.5 m size class bins (ANOVA p = 0.005 and p = 0.001 respectively).

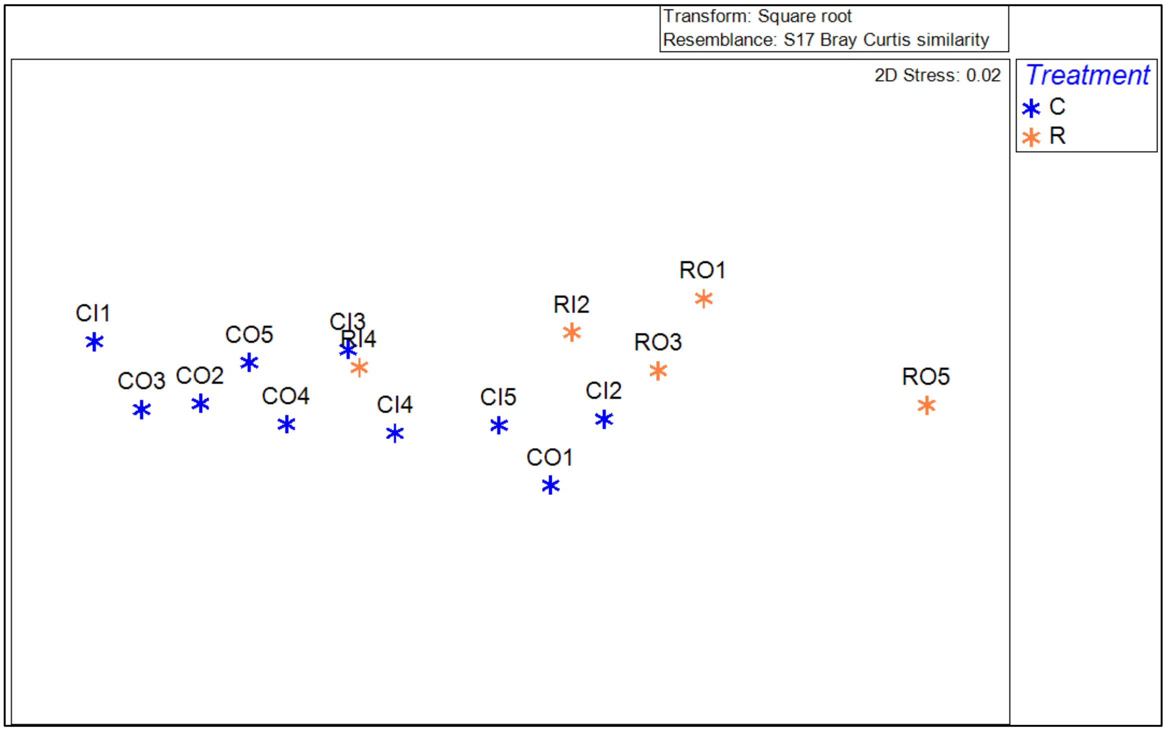


Figure 22. Two-dimensional MDS plot illustrating the dissimilarity between octocoral size classes contributing to the community at control (C) sites and acute (R) anchor impact sites. (ANOSIM R=0.364, p = 0.01).

Analysis of total octocorals < 4 cm showed a weak dissimilarity (R = 0.400, p = 0.001) with encrusting and rod contributing the most to that difference (47.7% and 34.98%, respectively). When analyzed separately, there were significantly more *Briareum asbestinum* at control sites than anchorage acute impact sites (ANOVA, p = 0.02). Acute impact sites had the least amount of *Briareum asbestinum*. Recent impact site RI4 had the highest rod densities of impact sites leading it to be more similar to control sites in size class bins. It was also noted that acute impact sites had an average of 22% of quadrats devoid of octocorals; whereas control sites had an average of 6% of quadrats with no octocorals present.

4.2.1.3 Scleractinian Community

Summary data for the scleractinian communities surveyed at acute impact sites is provided in appendix A 8. Mean scleractinian density was significantly higher at control sites (ANOVA, $p = 0.05$). Analyses showed no distinct patterns of scleractinian community density between treatments (ANOSIM, $R = 0.262$, $p = 0.02$) (Figure 23). However there were significantly more *Stephanocoenia intercepta* at control sites than acute impact sites (ANOVA, $p = 0.04$). There was no significant difference in the number of species recorded between treatments.

Analysis of similarity of total small scleractinian (< 4 cm) density showed no significant difference between control and acute impact.

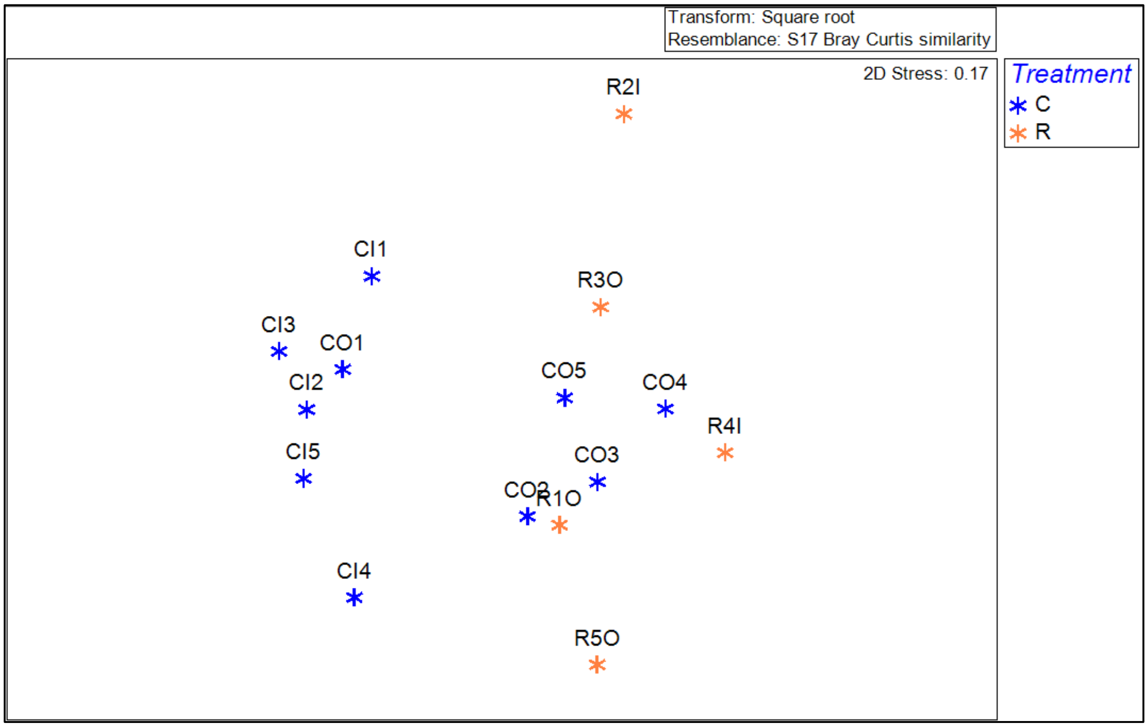


Figure 23. Two-dimensional MDS plot illustrating the dissimilarity between scleractinian community density at control (C) sites and acute (R) anchor impact sites. (ANOSIM R = 0.262, p = 0.02).

4.2.1.4 Colony Injury

Physical injury recorded on live octocorals included scrapes, and on live scleractinians included scrapes, fractures, and dislodging. Evidence of scleractinian colonies being secondarily impacted included bleaching and paling. Additionally, it was noted how many barrels were present for *Xestospongia muta*. Comparisons between control and acute impact sites showed there were significantly more octocorals with scrapes per square meter at acute impact sites (0.32 ±0.02) than control sites which had none. Scleractinians had significantly more occurrences of scrapes per square meter at acute impact sites (0.12 ±0.01) than control sites which had none, and had significantly more bleaching per square meter at acute impact sites (0.14 ±0.02) than control sites which had none. The summary of *Xestospongia muta* quadrat data at actue impact sites is given in appendix A 9. The number of *X. muta* barrels was not significantly different between treatments (ANOVA, p = 0.446).

4.3 Vessel Use

A total of 371 singular anchoring events were recorded over 389 days and 21 events were removed due to incomplete AIS data (Figure 24). The longest vessel recorded was 294 m while the shortest was 25 m (Figure 25). The most common occurring length of a vessel was 90 m (7% of anchoring event (Table 6). The larger vessels (>75 m) accounted for 81% of anchoring events. Many of the ships recorded did not report their draught in the AIS data leaving a total of 293 vessels with data to be analyzed. The draught can change depending on how loaded the vessel is; therefore, the draughts reported here are not necessarily the minimum or maximum draught of the vessel. The deepest draught was recorded as 12.4 m and the shallowest as 1.1 m. The most common draught was 3.0 m (8% of anchoring events) (Table 6).

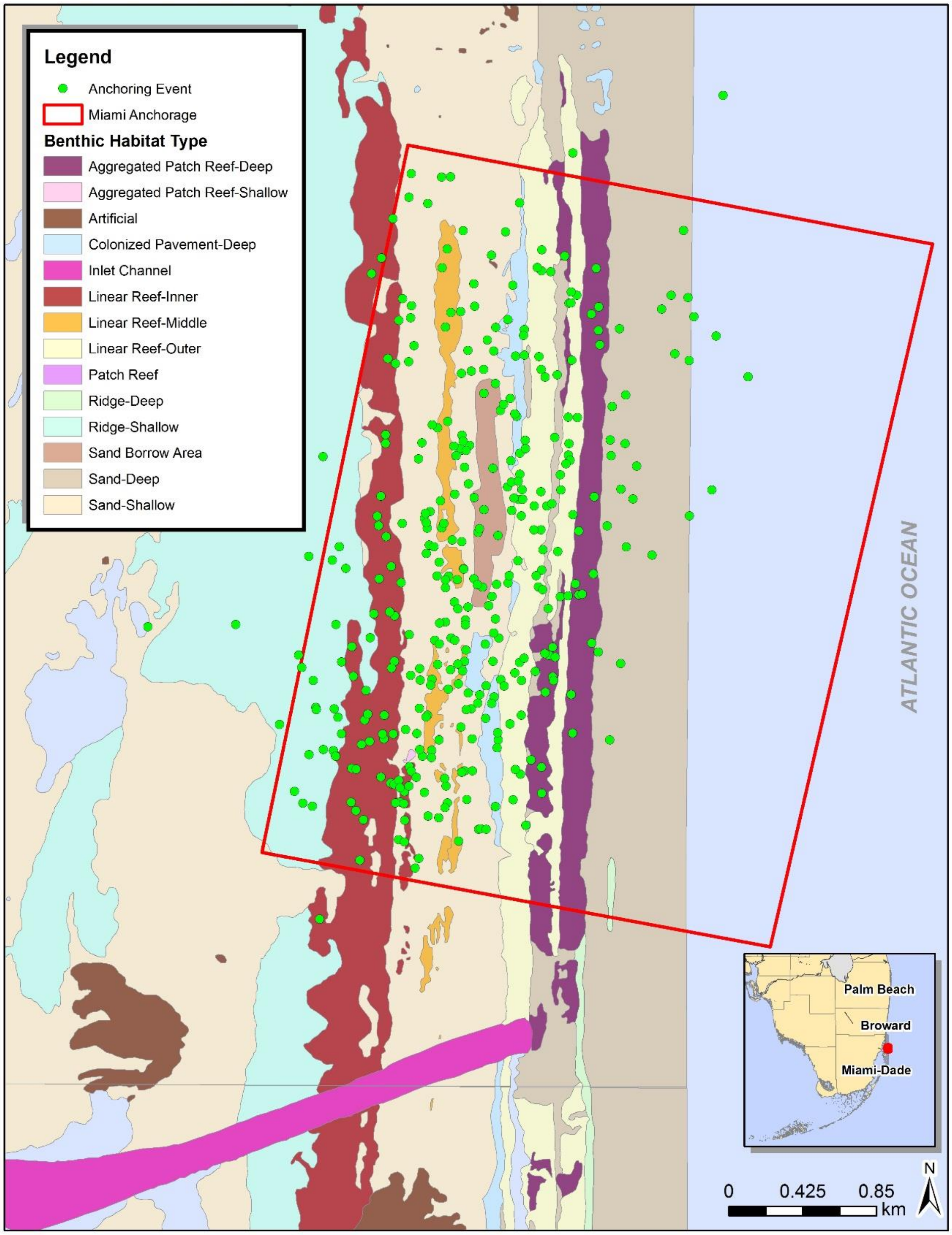


Figure 24. Current anchorage location (red box) with 371 vessel anchoring events data from March 2011 through November 2013.

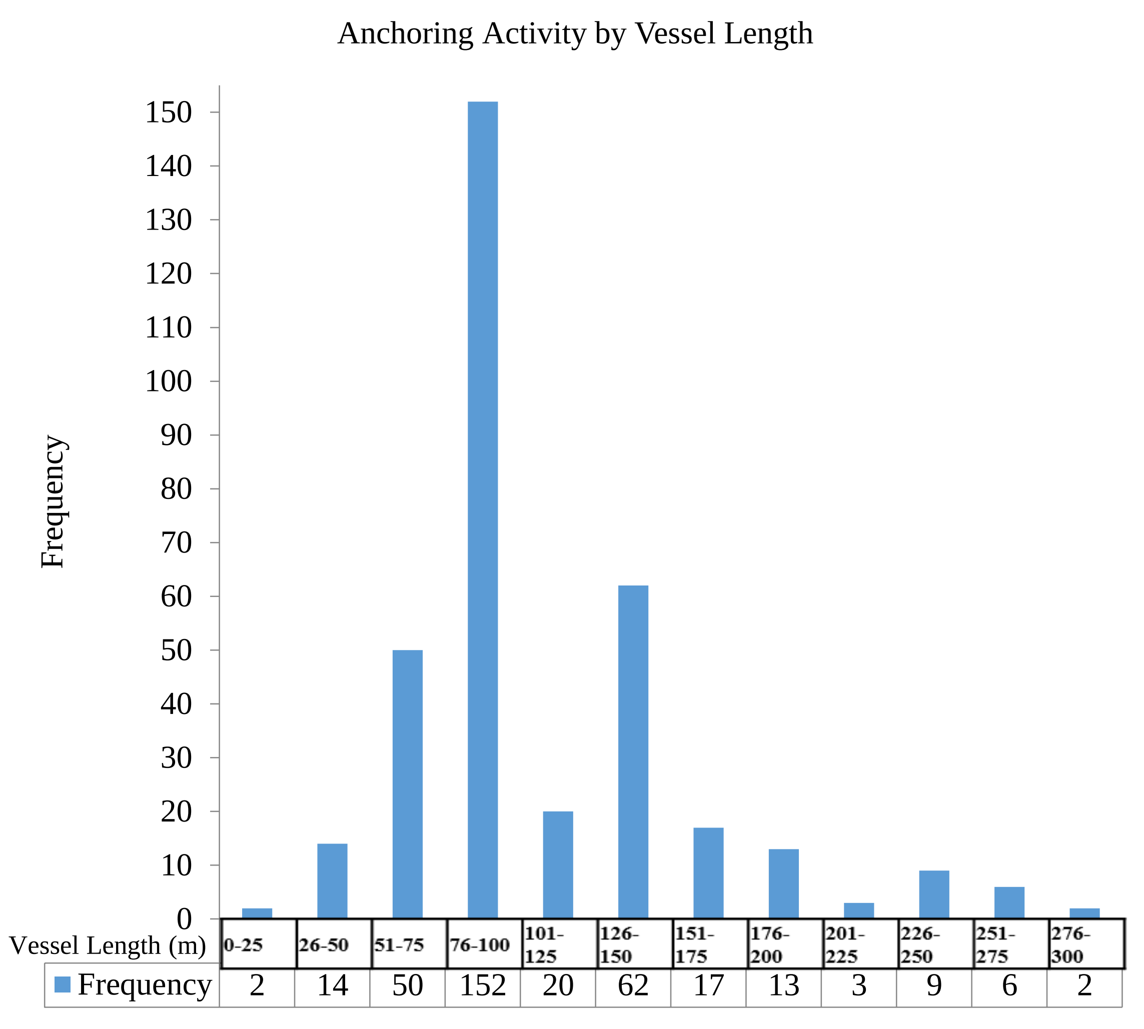


Figure 25. Frequency of vessels at anchor in the Miami Anchorage by vessel length.

Table 6. Most frequent occurrences of vessel lengths and draughts recorded anchored in the Miami Anchorage.

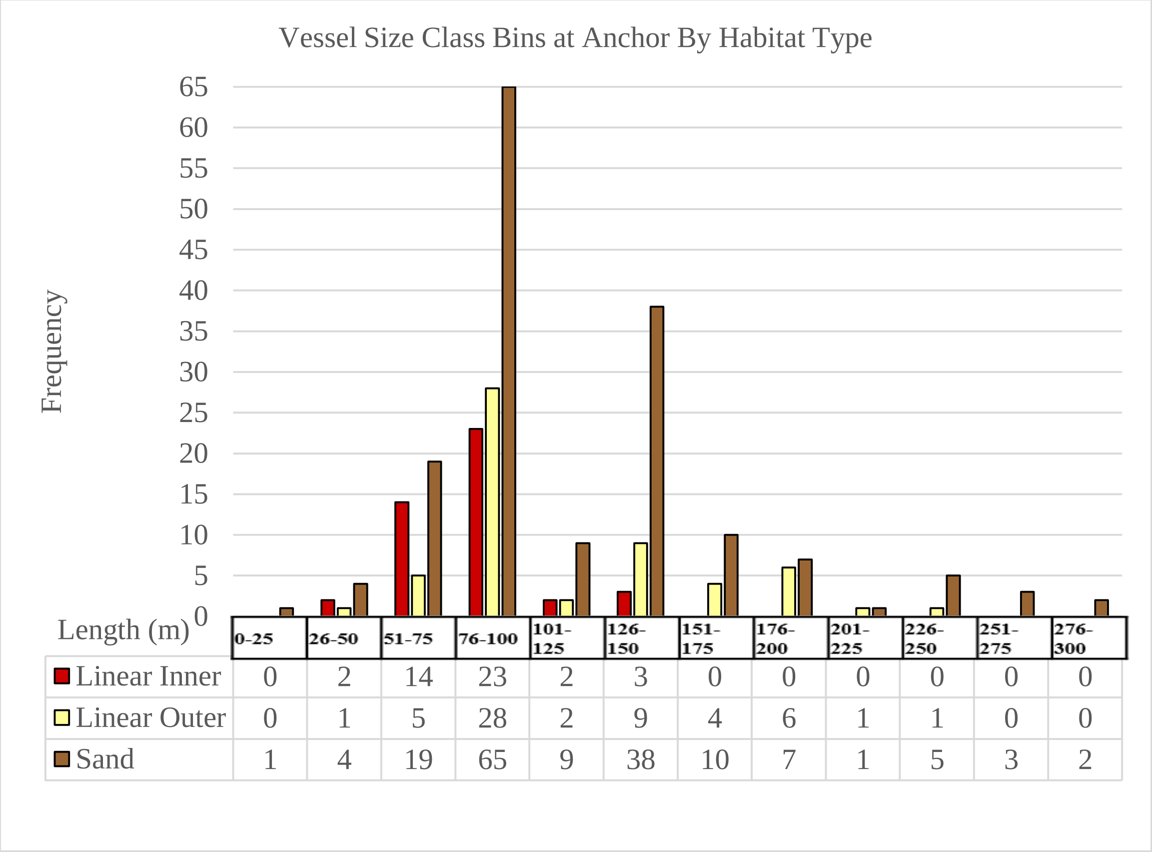
Vessel Length (m)	% of Anchoring Events
90	7%
84	6%
100	5%
76	5%
83	4%

Vessel Draught (m)	% of Anchoring Events
3.0	8%
4.0	7%
3.6	5%
4.6	5%
5.6	5%

All vessel positions reported were from the stern of the ship, not the location of the anchor. This created a margin of error when associating the GPS point with where the vessel's anchor was contacting the substrate. Safe anchoring practices suggest having a length of chain seven times the depth deployed (House, 2008), but it is uncertain how much chain was deployed for any given vessel. The margin of error varied around these points, but could have ranged from 0 m to 190m. Because the vessel locations did not significantly differ from a random distribution, it was assumed that the GPS location was equally likely to be over reef when the anchor was not as over sand when the anchor was not; and therefore location of anchoring relative to habitat type could be examined assuming equal chances of error. Based on this assumption, anchoring on reef habitats (64%) was more frequent than sand habitats (46%) (Table 7). Linear Outer Reef had 16.6% anchoring events while Linear Inner Reef had 12.8%. The most frequent vessel size class was the 100 m – 124 m in both habitats; however, smaller vessels tended to anchor on the Linear Inner Reef, while the larger vessels (>150 m) were only found in deeper habitats like Linear Outer Reef (Figure 26).

Table 7. Percentage of anchoring events within the Miami Anchorage by benthic habitat type. Seven events were in the deeper portions of the Anchorage that does not have a ground truthed habitat description.

Benthic Habitat Type	Percent of Vessel Anchoring Events
Aggregated Patch Reef-Deep	7.3%
Colonized Pavement-Deep	4.1%
Colonized Pavement-Shallow	0.3%
Linear Reef-Inner	12.8%
Linear Reef-Middle	5.2%
Linear Reef-Outer	16.6%
Ridge-Shallow	7.9%
Sand Borrow Area	2.6%
Sand-Deep	7.6%
Sand-Shallow	35.6%



Length (m)	0-25	26-50	51-75	76-100	101-125	126-150	151-175	176-200	201-225	226-250	251-275	276-300
🟥 Linear Inner	0	2	14	23	2	3	0	0	0	0	0	0
🟨 Linear Outer	0	1	5	28	2	9	4	6	1	1	0	0
🟫 Sand	1	4	19	65	9	38	10	7	1	5	3	2

Figure 26. Frequency and lengths of vessels anchoring on Linear Inner Reef, Linear Outer Reef, or sand benthic habitats within the Miami Anchorage.

There were no significant differences in the overall use of the anchorage with the entire area being likely an area a vessel would anchor (i.e., no spatial clustering for all anchor sites). The Getis-Ord Gi* spatial cluster analysis indicated there was significant spatial clustering based on vessel length (Figure 27). These results were general and did not fully illustrate the data, therefore an inverse distance weighted interpolated surface of vessel size was created to visualize existing variations within the data. Additionally, an Anselin Local Moran's I cluster and outlier analysis was performed to identify where high and low values of vessel length clustered spatially, and where vessels with lengths significantly different from surrounding values occurred. This helps to illustrate where smaller vessels may have been anchoring in areas that were primarily large vessel areas and vice versa (Figure 28). A result of High High was where significantly larger vessels were anchoring near other significantly larger vessels, and a result of Low Low was where significantly smaller vessels were anchoring near other significantly smaller vessels. A result of High Low was where significantly larger vessels were anchored near significantly smaller vessels, and a result of Low High was where significantly smaller vessels were anchored near significantly larger vessels. This showed that while there is a general separation in larger vessels using the northern portion of the anchorage and smaller vessels using the southern portion of the anchorage, that it is not mutually exclusive.

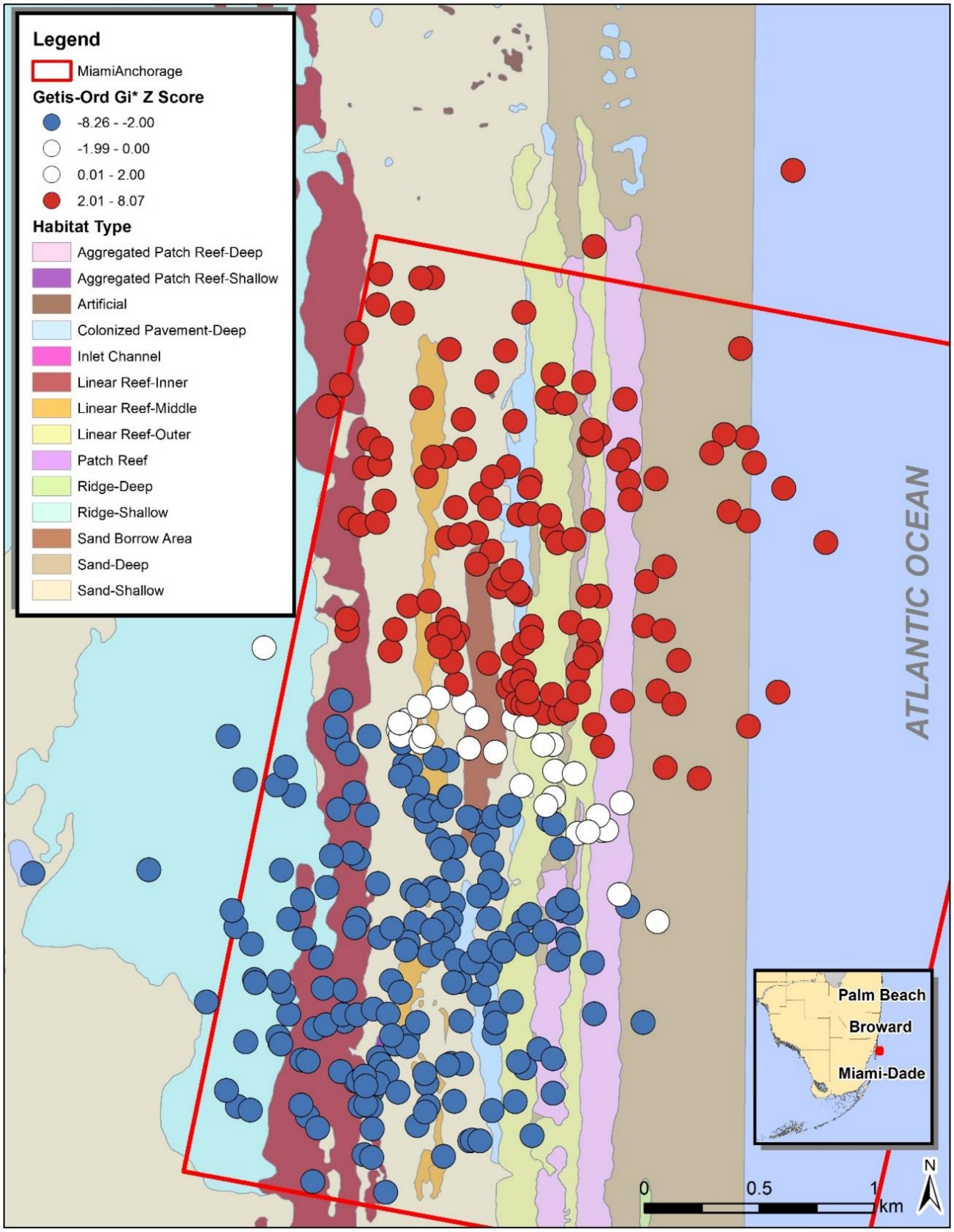


Figure 27. The Port Miami Anchorage with an analysis of anchorage use by vessel length using hot spot analysis Getis-Ord Gi*. Those above or below a Z score of 2 are significantly different.

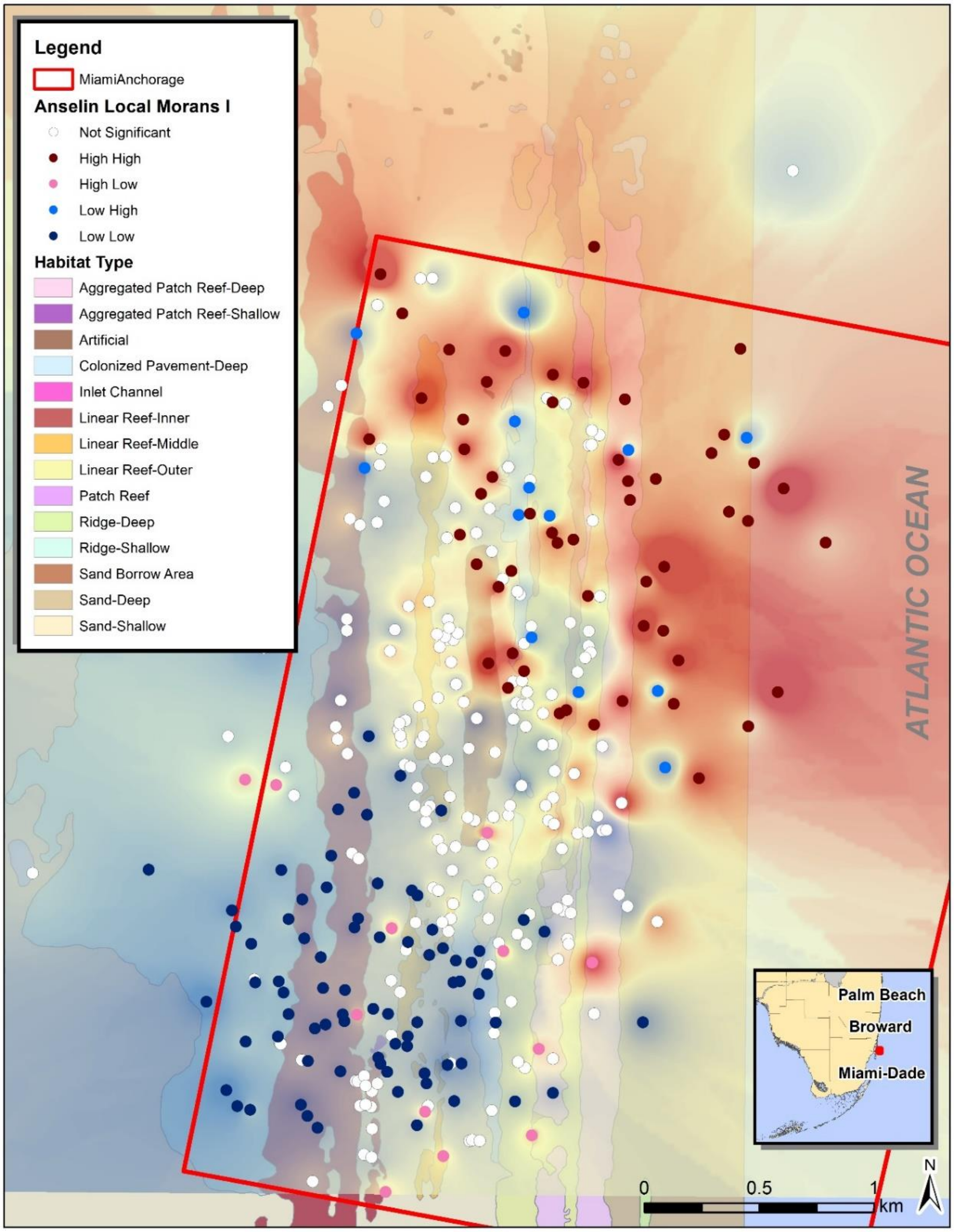


Figure 28. The Port Miami Anchorage overlain with an Inverse Distance Weighted (IDW) surface to provide a visual of where smaller and larger vessel sizes tend to anchor. Anchoring events were then analyzed for outliers using Anselin Moran's I and the results are projected on top of the IDW.

5. Discussion

The purpose of this study was first and foremost to determine if the current Port Miami commercial anchorage's anchoring activity was having an effect on the benthic community and critical habitat within it. This study informs the USCG, AWG, NOAA, FDEP, and other stakeholders about anchoring impacts and provides information as the USCG enters into ESA Section 7 consultation with NOAA NMFS regarding those anchoring impacts to federally listed threatened species and their associated critical habitat. Prior to this study, the following was unknown about the Port Miami anchorage:

- Presence of coral species listed as threatened under ESA
- Impacts to coral species listed as threatened under the ESA or their designated critical habitat
- Impact to habitat areas of particular concern designated under the essential fish habitat provisions of the Magnuson-Stevens Act

While surveys were only conducted on a small portion of reef within the anchorage, listed coral species were encountered (*Orbicella faveolata*) and impacts to their designated critical habitat and habitat areas of particular concern was documented. The data indicate that the Port Miami anchorage is negatively affecting the coral reef communities both chronically from the cumulative anchoring pressure, and acutely with each anchoring event on the hardbottom.

As expected, the benthic community varied between the Inner and Outer Reef habitats. This supports results from many previous studies that these coral reef habitats support different communities (Gilliam et. al. 2010; Gilliam & Walker 2012; Goldberg 1973;

Moyer et. al. 2003; Walker et. al. 2008; Walker et. al. 2009; Walker 2012). Because these communities vary, impacts associated with anchoring might also differ. Overall, significant differences were more pronounced on Outer Reef chronic impact sites and at recent acute impact sites. Differences in benthic community composition, substrate composition, and in the population of octocorals and scleractinians were all evident. Acute impact sites visibly showed the impacts expected from a large vessel anchor impacting reef. Substrate with fresh white scrapes, newly broken substrate, and sponges and octocorals loose or in fragments were all visibly present, similar to other documented anchoring impacts in the region (Beaver 2006; Walczak 2007; Sansgaard 2012). These impacts were also demonstrated statistically through the increased amount of rubble, change in the benthic community composition, decreased benthic cover, and increased bare substrate.

5.1 Anchorage Chronic Impacts

While finding anchor damage within one week after an anchoring event (acute impacts) was to be expected, the cumulative effects from this regular, continual, chronic activity over the past 82 years were also evident. Similar to many other studies and assessments of vessel anchoring impacts, the anchorage had increased rubble on Outer Reef (Table 3) (Riegl 2001, Beaver 2006, Jameson et. al. 2007, Sansgaard 2012). While studies have shown that variables that qualify injuries to corals are more efficient at distinguishing anchoring intensity when looking at recreational anchoring, this was not the case when looking at the chronic impacts from large vessel anchoring (Dinsdale & Harriott, 2004; Dustan & Halas 1987; Jameson et. al. 1999). This presumably could be because small recreational anchors may produce small injuries that do not immediately cause colony mortality, while large anchors produce injuries that impact the entire colony effectively causing rapid mortality which would not be captured in my study. However injury to both octocorals and scleractinians proved a useful indicator of recent impact at acute impact sites.

The benthic community and substrate composition were similar between the Inner Reef anchorage and control sites (Figure 6 and 7). This may have been due in part to the smaller commercial vessels (≤ 75 m) anchoring predominantly in Inner Reef areas and having smaller anchors and chain with smaller links (approximately 5 cm - 10 cm). Smaller commercial anchors and chain are probably not as likely to fracture the substrate. Because the chain is relatively lighter, it is also probably less likely to detach vertically growing octocorals from the substrate, many of which are relatively flexible. Lighter vessel chains would still impact the encrusting octocorals, however, which is most likely why there were few significant differences in the octocoral community except significantly less encrusting *Briareum asbestinum* in the anchorage.

The lack of significant differences in benthic community and substrate composition on the Inner Reef may be due in part to the more dynamic nature of that reef habitat in the natural system. Inner reef is shallower and thus experiences greater wave energy and possibly more turbidity than the Outer Reef. Reef communities in more dynamically energetic environments are expected to have a more variable community (CSA International Inc 2009).

Additionally, because the anchorage is aligned at an angle to the reef, i.e. not due north and south, there is more Inner Reef in the southern portion of the anchorage than the north, which is where the smaller vessels tended to anchor. Therefore, three-quarters of the length of Inner Reef is impacted by smaller vessels, which may not have differences as pronounced as those on Outer Reef.

While significant differences were not as apparent in benthic community composition, when examining specific benthic functional groups, scleractinian densities were significantly lower inside the anchorage (Figure 9) on Inner Reef and were significantly less specious. This is expected as scleractinians are among the slowest growing constituents of the community and take longer to repopulate unlike other faster growing species. Other studies have shown that areas continually disturbed by anchoring activity were unable to recover (Dinsdale & Harriott 2004, McManus et. al. 1997).

On the Outer Reef, the differences between anchorage and control sites were more pronounced. The control sites were dominated by algae, octocorals, and sponges; whereas, the chronic impact sites were dominated by algae, cyanobacteria, and bare substrate (Figure 10). Cyanobacteria are a typical primary successor in newly opened substrate and macroalgae often becomes abundant in areas, and indicative of, new disturbance or recently available substrate from coral mortality (Williams et. al. 2001). On the Outer Reef, the increase in algal cover was associated with significantly less octocoral and *Xestospongia muta* cover. High algal cover has been found in other reef impact studies (Jameson et. al. 2007; Rogers & Garrison 2001) as well as known impacted sites in the region such as the grounding site of the vessel *Firat* (Gilliam & Mouldin 2011). This transition makes sense in impacted areas because octocoral and *Xestospongia muta* would take longer to recruit and recover than algae (McMurray et. al. 2008, Mitchell et. al. 1993). Additionally the significant differences in octocoral size classes (few large octocorals within the anchorage) is indicative of event-related mortality (Mitchell et. al. 1993). Overall differences in the octocoral community were the most indicative benthic functional group of chronic impact on Outer Reef.

As with ship groundings, the action of large ship anchors and chains can generate loose unconsolidated substrate (rubble and sand) as parts of the reef are scraped and broken into smaller fragments (Dinsdale & Harriott 2004). Significantly greater rubble cover was found at the Outer Reef chronic impact sites indicating that the long-term effects of anchoring in this habitat may have increased unconsolidated substrate in the anchorage. The significant amount of rubble at chronic impact sites suggests the continuous physical damage is leading to a decline in the reef structure itself (Dinsdale & Harriott 2004, McManus et. al. 1997).

Unconsolidated substrate may be more prominent when generated in deeper habitats where there is less dynamic wave energy. In shallower waters, the substrate is affected more by higher wave energy (CSA International Inc. 2009), mobile substrate would be carried off and deposited elsewhere. This could be why unconsolidated substrate was not significantly different than control sites on the Inner Reef but was on the Outer Reef. Another factor might be that the Outer Reef was impacted by larger anchors and chain from the larger vessels (see 5.3 Vessel Use section).

Finding appropriate control sites for this study was challenging (Figure 3). Control sites were not able to be selected to the south because it is a different biogeographic region (Walker 2012) and by potential other influences from the inlet itself. Northward was constrained by avoiding the influence of the next inlet north. In addition, Linear Outer Reef almost completely disappears north of the anchorage for several miles before reemerging. With these constraints, the area of available Linear Outer Reef to survey was limited, and the area over which control sites were randomly selected was less than the area of reef over which sites were randomly selected within the anchorage. Linear Inner Reef did have available area to survey similar to the anchorage. Control sites were chosen near the northern border of the anchorage, incorporating a 250m buffer which was believed to be sufficient to avoid spillover effect. While significant difference were noted on both Inner and Outer Reef, many times throughout the analysis, CI1 and CO1 (which were closest to the anchorage) clustered more similar to anchorage chronic impact sites than with other control sites (Figure 8, 9, 14, 15) reducing the difference between treatments. Vessel AIS data showed vessels anchoring very near to, and potentially outside of, the anchorage on the northern border, suggesting there was more spillover than anticipated which could have been driving these control sites to be more similar to anchorage sites (Figure 24).

5.2 Anchorage Acute Impacts

The significant amounts of bare substrate and small and large rubble at acute impact sites indicated that large vessel anchoring caused impacts to the anchorage reefs similar to vessel groundings and continuous recreational anchoring in other studies (Dustan & Halas 1987, Gilliam & Moulding 2011, Rogers & Garrison 2001), and to other commercial vessel anchoring incidents in southeast Florida (Sansgaard 2012). Since 2000, the FDEP CRCP has received 125 reports of potential anchoring events on reef resources in southeast Florida, ranging from yachts to commercial vessels; and 2 reports of commercial vessel anchor drag incidents. Of those, most responsible parties were issued educational warning letters. Those that had site assessments which located damage had injury areas from 6 to 1,214 m^2 (personal communication, FDEP CRCP 2015) with impacts similar to those in this study including freshly scraped bright white substrate, sheared *Xestospongia muta*, dislodged octocorals, and abraded or crushed scleractinians.

Direct impacts from large events such as vessel groundings and anchor drags can clear substrate of the benthic community, frequently resulting in total mortality of organisms in the impact zone and the creation of rubble and sand within the impact area (Gittings et. al. 1998, Rogers & Garrison 2001, Sansgaard 2012). It was noted that often times the encrusting octocorals would be peeled off of the substrate, most likely by the vessel chains scraping across the bottom. In this study, recent anchorage acute impacts in the area where the anchor contacted the reef included dislodged sponges and octocorals. Loose octocorals were observed at all sites but were not included in the data since determining where they originate from was not definitively possible. The mean density of corals at acute impact sites was at least three times less than the control sites, and the mean amount of live tissue per square meter was at least 10 times less. This suggests that although anchoring has been occurring in the anchorage for 88 years, new anchor events are causing new reef injuries.

5.3 Vessel Use

Since the original report documenting the presence of reef resources within the anchorage (Walker 2008), there have been discussions about how the anchorage could be repositioned to avoid impacts to reef resources. Those discussions brought to light many concerns voiced by the stakeholders about what a relocation may mean for those that use the anchorage. Many of those concerns were from a lack of information regarding anchorage use including:

- The number of vessels using the anchorage on a given day
- Where within the anchorage area vessels tended to anchor
- It was assumed that smaller Miami River vessels anchor in the shallower areas to the west and larger vessels to the east

Through documentation of vessel use patterns, this study has helped to address many of those concerns. Prior to this study, the number and sizes of vessels using the anchorage and their spatial use patterns were unknown. It was assumed the larger, deeper drawing vessels anchored in the deeper eastern and middle section of the anchorage, and the shallower draught vessels anchored in the shallower western section (Anchorage Working Group personal communication 2012). This study found that both size classes of vessels anchored throughout the anchorage area, but the larger vessels anchored in the northern section more frequently regardless of depth (Figure 28). The smaller shallower draught vessels tended to anchor in the southern half of the anchorage with a slight favoring for the shallow western section (Figure 24). The tendency for these vessels to anchor in the western section is in part due to the fact that the approach to the Port Miami entrance channel currently intersects with the anchorage. Specifically, there is a precautionary area which surrounds the Miami sea buoy “M” with a one mile radius, which overlaps the southeast corner of the anchorage. No vessels were found anchoring in the southeastern corner of the anchorage, to avoid impeding vessels entering and departing the port (Andrew Melick personal communication 2015). This is a flaw in the entrance channel design which was dredged and expanded several times after the anchorage was created.

Upon inspection of the depths along the Outer Reef, there are three small areas that reside in about 10.7 m in depth. This study observed ten vessels drawing over 9.1 m, meaning that in a typical swell of 0.75 m these vessels could impact the reef within the current anchorage. Additionally, ships drawing deeper than 10.7 m were recorded during this study, meaning regardless of wave height, the use of the anchorage in those areas is a danger to those vessels. Evidence of vessels scraping the reef have been photographed and documented (unpublished data). These pictures showed areas recently denuded and with remnants of a red paint, which is commonly used in commercial vessel haul application (Figure 29).

Figure 29. Original and color corrected photo of area presumed to have been scraped by the hull of a ship, red paint is within the areas circled in the foreground of the photo (FDEP 2012)

5.4 Recovery

If anchoring activities were to cease, it is uncertain how quickly the area could recover. No significant differences between control and chronic anchorage impact sites in small (<4cm) scleractinians or octocorals suggest larval contribution within the anchorage is similar to that of reefs nearby. However, previous studies have shown that the presence of recruits will not necessarily result in an increase in adult coral cover. At an anchor drag event in St. John, while recruits were present, coral cover did not significantly increase after 10 years, reflecting poor survival and growth of the recruits (Rogers & Garrison 2001). It was suggested this may have been due to vulnerability to abrasion from shifting sediments within the scar. Similar results of a lack of recolonization or change in community structure have been observed at vessel grounding sites in the southeast Florida region where, although the density of scleractinian coral recruits was not significantly different on Inner Reef, there was significant dissimilarity in recruit species contribution (Gilliam & Moulding 2011).

Other studies have shown that impact sites with less rubble could begin to recover, while areas with high rubble cover may require some stabilization or enhancement actions to allow for recovery in a more timely (<10 years) period. If the anchoring activity were to cease, perhaps those areas with less rubble could begin to recover (Gittings et. al. 1990). Sediment removal can enhance recruitment and can increase habitat complexity (Gittings et al. 1998). What is certain is that reefs with continuous disturbances have a decrease in potential coral recovery rates compared to areas free of disturbances. If the anchoring continues at its present rate, it is unlikely that the benthic community will recover (Dinsdale & Harriott 2004, McManus et. al. 1997). If the physical damage continues, the reef structure itself could also decline further to produce more rubble and sand, which may reduce recruit survival and be resuspended during storms, further lessening the chance that the area could recover.

5.5. Management Considerations

During the course of this study nine additional Atlantic scleractinian species were listed as Threatened under the Endangered Species Act. At the time the surveys were conducted, only the two *Acropora* species were listed, and therefore were the only species that were specifically documented if they were present in the survey area, but outside of the transect or quadrat footprint. None were found. However, one of the newly listed species, *Orbicella faveaolata,* was documented within survey quadrats. While only one species of listed coral was encountered during these survey events, many more likely exist throughout the anchorage, and impacts to *Acropora* designated critical habitat was evident. Therefore the present anchorage is likely to impact listed species or their designated critical habitat into the future. Given this study's findings, it is the responsibility of the USCG to enter into consultation with NOAA and prepare a Biological Assessment to assist in the determination of the project's effect on a species. It is reasonable that the USCG may consider permanent moorings to avoid all impacts or alternative anchorage configurations that would minimize impacts to reef resources. Given the vessel use information provided in this study, it is likely an alternative configuration can accommodate current and future vessel traffic, including Post-Panamax vessels, and reduce impacts. In order to provide safe anchoring for the largest vessels using the anchorage it is recommended to keep the deeper eastern section of the anchorage, but with a buffer on the eastern edge of Outer Reef to prevent impacts; similar to the present design Port Everglades. That is, the anchorage would essentially be decreased in half from north to south, just east of Outer Reef. Many concerns have been raised by AWG stakeholders regarding providing shallow areas for the smaller (<75 m) vessels. Permanent moorings could likely be installed within sand areas within the current anchorage footprint for those vessels. Alternatively, a second smaller linear area could be designated within the current anchorage footprint over what is presently Middle Reef. This area has approximately 30 acres of patchily distributed reef, with a majority of the area being sand bottom. This would reduce or eliminate impacts to

Inner and Outer Reef. Dependent upon the alternative configuration, additional surveys to supplement this study will most likely be needed in order to survey those areas and reef communities not included here; and to document currently listed Threatened species and their designated critical habitat.

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Appendix

A 1. Quadrat summary data for the octocoral communities at chronic impact (AI) and control (CI) Inner Reef Sites. The mean number of octocorals, mean number of individuals within designated height bins, mean number of small octocorals (≤ 4cm), and mean number of individuals with visible damage or disease per square meter is given.

	Site	AI1	AI2	AI3	AI4	AI5	CI1	CI2	CI3	CI4	CI5
Mean Number of Octocorals /m^2	*Briareum asbestinum*	0.65	2	0	0.05	1.4	1.1	4.05	4.85	3.85	7.75
	Erythropodium caribaeorum	0	0.05	0	0.1	0	0.40	0	0	0.1	2.1
	Gorgonia ventelana	0	0.05	0	0	0.1	0.25	0	0	0.35	0.1
	Iciligorgia schrammi	0	0	0	0	0	0	0	0	0	0
	Pterogorgia anceps	0	0	0	0	0	0	0	0	0	0
	Pterogorgia citrine	0	0.15	0	0.1	0	0	0	0	0.05	0
	Pterogorgia guadalupensis	0	0.2	0	0	0	0.05	0	0	0.1	0
	Plume	3.15	1.7	1.25	1.85	0.25	1.95	0.4	0.3	1.4	0.5
	Rod	11.6	2.55	4.25	6.95	7.2	13.9	0.8	4.65	1.4	1.35
% of Quadrats with No Octocorals		0%	0%	0%	0%	5%	0%	5%	0%	0%	0%
Mean Number of Octocorals /m^2 within each size bin	4 cm to 10 cm	6.45	2.25	1.05	2.7	3.05	8.6	2.35	2.55	3	6.35
	11 cm to 0.5 m	8	4.15	4.1	5.8	5.8	7.8	2.85	7.1	4	5.3
	0.51 m to 1 m	0.9	0.3	0.35	0.55	0.1	1.15	0.05	0.15	0.2	0.25
	>1 m	0.05	0	0	0	0	0.1	0	0	0.05	0
Mean Number of small Octocoral (≤4cm) /m^2	Rod	0.6	0.15	0.15	0.45	0.9	1.1	0.1	0.35	0.1	0.1
	Plume	0.15	0.1	0.1	0.15	0.1	0.05	0	0.05	0.2	0
	Fan	0	0	0	0	0.05	0	0	0	0.05	0
	Whip	0	0.1	0	0	0	0	0	0	0.05	0
	Encrusting	0.15	0.05	0	0	0.25	0	0.4	0.55	1.35	1.7
Mean Number of Visibly Damaged Octocorals /m^2	Abraded	0	0	0	0	0	0	0	0	0	0
	Bleach/Pale	0.05	0	0	0	0	0	0	0	0	0
	Disease	0	0.05	0	0.05	0.05	0	0	0	0	0

A 2. Quadrat summary data for the scleractinian communities at chronic impact (AI) and control (CI) Inner Reef Sites. The mean number of scleractinians, mean number of small scleractinian (≤ 4cm), the mean amount of total live tissue, and mean number of individuals with visible damage or disease per square meter is given.

	Site	AI1	AI2	AI3	AI4	AI5	CI1	CI2	CI3	CI4	CI5
	Agaricia agaricites	0	0	0	0.05	0	0	0.25	0.1	0.05	0.05
	Agaricia fragilis	0	0.05	0	0	0	0.05	0	0.2	0	0
	Colpophyllia natans	0	0	0	0	0	0	0	0	0	0
	Dichocoenia stokesi	0	0	0.05	0	0.05	0	0	0	0.15	0.15
	Eusmilia fastigiata	0	0.05	0	0	0	0.05	0.05	0.05	0	0.05
	Isophyllia spp	0	0	0	0	0	0	0	0	0	0
	Madracis spp.	0	0	0	0	0	0	0.05	0	0	0
	Meandrina meandrites	0	0	0	0	0	0	0.05	0.05	0.05	0
	Montastraea cavernosa	0	0.1	0	0.05	0.05	0.15	0.15	0.1	0.05	0.2
	Mycetophyllia spp	0	0.05	0	0	0	0	0.05	0	0	0.05
	Orbicella annularis	0	0	0	0	0	0	0	0	0	0.05
	Orbicella faveolata	0	0	0	0	0	0	0	0.1	0.05	0
	Orbicella franksi	0	0	0	0	0	0	0.05	0.05	0	0
	Porites astreoides	0	0.05	0.05	0	0.05	0	0.15	0	0.25	0
	Porites porites	0	0.05	0.55	0.5	0.1	0.4	0	0	0.05	0
	Pseudodiploria clivosa	0	0	0	0	0	0.05	0	0	0	0
	Pseudodiploria strigosa	0	0	0	0	0	0	0	0.05	0	0.05
	Scolymia spp.	0	0	0	0	0	0	0	0.05	0	0
	Siderastrea radians	0.05	0.05	0	0.05	0	0	0	0	0	0
	Siderastrea siderea	0	0.2	0	0	0.1	0.45	1.05	0.95	0.75	0.35
	Solenastrea bournoni	0	0	0	0	0	0	0	0	0.1	0.1
	Stephanocoenia intersepta	0.45	0.05	0.25	0.2	0.4	0.9	1.05	0.6	0.1	0.4
% of Quadrats with No Scleractinians		65%	30%	40%	40%	40%	5%	5%	25%	30%	20%
Mean Number of Individuals/m^2		0.5	0.65	0.9	0.85	0.75	2.05	2.9	2.3	1.6	1.45
Small Scleractinian (≤4cm)/m^2		0.5	0.45	0.55	0.6	1.15	3.15	2.4	1.7	1.15	0.65
Mean Live Tissue Area (cm2)/m^2		13.35	18.30	30.51	12.41	20.85	184.06	326.65	62.42	82.15	148.6
Mean Number of Scleractinian with Visible Damage /m^2	Crushed	0	0	0	0	0	0	0	0	0	0
	Abraded	0	0	0	0	0.1	0	0	0	0	0
	Bleach/Pale	0.15	0.95	0	1.25	1.1	0	0	0	0	0
	Disease	0	0	0.1	0	0	0	0	0	0	0

A 3. Quadrat summary data for *Xestospongia muta* at chronic impact (AI) and control (CI) Inner Reef sites. The mean number, mean width, and mean height of individuals per square meter is given. Also the mean number of individuals with visible damage per square meter and the mean number of barrels per individual is given.

	Site	AI1	AI2	AI3	AI4	AI5	CI1	CI2	CI3	CI4	CI5
Mean *X. muta*/m^2		0.05	0.85	0.0	0.0	0.6	0.05	0.35	0.2	0.45	0.15
Mean *X.muta* Width Per Idividual (cm)		8	16	0	0	11	4	16	32	17	39
Mean *X. muta* Height Per Individual (cm)		4	13	0	0	9	4	19	23	17	20
Mean Number of *X. muta* with Visible Damage/m^2	Abraded	0.0	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Bleach/Pale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Disease	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.0	0.0	0.0
Mean Number of Barrels Per Individual		1.0	1.4	0.0	0.0	1.0	1.0	1.0	1.25	1.0	1.0

A 4. Quadrat summary data for the octocoral communities at chronic impact (AO) and control (CO) Outer Reef sites. The mean number of octocorals, mean number of individuals within designated height bins, mean number of small octocoral (≤4cm), and mean number of individuals with visible damage or disease per square meter is given.

	Site	AO1	AO2	AO3	AO4	AO5	CO1	CO2	CO3	CO4	CO5
Mean Number of Octocorals /m^2	*Briareum asbestinum*	1.15	2.6	1.4	0.9	0.3	4.3	5.05	5.4	5.35	2.65
	Erythropodium caribaeorum	0	0.45	0	0	0.05	0.15	0	0.05	0	0
	Gorgonia ventelana	0	0	0.05	0	0	0	0.05	0.15	0.3	0.2
	Iciligorgia schrammi	0	0	0	0	0	0	0	0.05	0.25	0
	Pterogorgia anceps	0	0.15	0	0	0	0	0	0	0	0
	Pterogorgia citrine	0	0	0	0	0	0	0	0	0	0
	Pterogorgia guadalupensis	0	0.05	0	0	0	0	0	0	0	0
	Plume	0.05	0.8	1.55	2.75	0.05	0.75	1.25	2.4	1.2	2.0
	Rod	0.55	0.1	0.05	0.2	0.1	0.65	8.95	10.6	3.95	4.65
% of Quadrats with No Octocorals		35%	10%	15%	0	75%	15%	10%	0%	15%	10%
Mean Number of Octocorals /m^2 within each size bin	4 cm to 10 cm	1.05	1.95	0.95	1.5	0.3	1.75	4.55	5.7	5.45	3.55
	11 cm to 0.5 m	0.6	2.2	1.85	2.2	0.15	3.9	10.2	12.1	5.15	5.15
	0.51 m to 1 m	0.1	0	0.25	0.1	0.05	0.2	0.5	0.8	0.3	0.65
	>1 m	0	0	0	0.05	0	0	0.05	0.05	0.15	0.15
Mean Number of Small Octocoral (≤4cm) /m^2	Rod	0.1	0.05	0.05	0	0.1	0	0.4	1.05	0.35	1.05
	Plume	0	0.2	0.1	0.25	0	0	0.25	0.05	0	0.05
	Fan	0	0.05	0	0	0	0	0	0	0	0.05
	Whip	0	0	0	0	0	0	0	0	0	0
	Encrusting	0.15	0.25	0.05	0.6	0.3	0.7	1.2	1.35	1.15	1.4
Mean Number of Visibly Damaged Octocorals /m^2	Abraded	0	0	0	0	0	0	0	0	0	0
	Bleach/Pale	0	0	0	0	0	0	0	0	0	0
	Disease	0	0	0	0	0	0	0	0	0.15	0

A 5. Quadrat summary data for the scleractinian communities at chronic impact (AO) and control (CO) Outer Reef sites. The mean number of small scleractinians (≤4cm), mean number of scleractinian recruits, the mean amount of total live tissue, and mean number of individuals with visible damage or disease per square meter is given.

	Site	AO1	AO2	AO3	AO4	AO5	CO1	CO2	CO3	CO4	CO5
	Agaricia agaricites	0	0	0	0	0	0.05	0	0	0	0
	Agaricia fragilis	0	0	0	0.1	0	0	0	0	0	0
	Colpophyllia natans	0	0	0	0	0	0	0	0	0	0
	Dichocoenia stokesi	0.15	0	0.05	0	0	0	0.05	0	0	0
	Eusmilia fastigiata	0	0	0	0	0	0.05	0	0	0	0
	Isophyllia spp	0	0	0	0	0	0	0	0	0	0
	Madracis spp.	0	0.1	0.1	0	0	0	0.05	0	0	0.05
	Meandrina meandrites	0	0.05	0.1	0.05	0.05	0.11	0	0	0	0.05
	Montastraea cavernosa	0.25	0.15	0.2	0.15	0.1	0.11	0.05	0.05	0.05	0.05
	Mycetophyllia spp	0	0	0	0	0	0	0.05	0	0	0
	Orbicella annularis	0	0	0	0	0	0.11	0	0	0	0
	Orbicella faveolata	0	0	0.05	0	0	0.11	0	0	0	0
	Orbicella franksi	0	0	0	0	0	0	0	0	0	0
	Porites astreoides	0.1	0.1	0.05	0.2	0.15	0	0.05	0	0	0
	Porites porites	0	0	0	0	0	0	0	0	0	0
	Pseudodiploria clivosa	0	0	0	0	0	0	0	0	0	0
	Pseudodiploria strigosa	0	0	0	0	0	0	0	0	0	0
	Scolymia spp.	0	0.05	0	0	0	0	0	0.05	0	0
	Siderastrea radians	0	0	0	0	0.05	0	0	0	0	0
	Siderastrea siderea	0.3	0.15	0.15	0.2	0.05	0.32	0.2	0.25	0.1	0.05
	Solenastrea bournoni	0	0	0.05	0	0.05	0	0	0	0	0
	Stephanocoenia intersepta	0.2	0.15	0.15	0.1	0.25	0.42	0.25	0.2	0.1	0.3
% of Quadrats with no Scleractinians		40%	45%	30%	50%	45%	42%	25%	20%	10%	30%
Mean number of Individuals/m^2		1	0.75	0.9	0.8	0.7	1.26	0.7	0.55	0.25	0.5
Small Scleractinian (≤4cm)/m^2		0.9	0.3	1.15	0.3	0.35	0.74	0.2	0.55	0.15	0.5
Mean live tissue area (cm^2)/m^2		32.94	21.28	45.71	42.06	17.94	59.69	20.81	22.70	3.81	17.44
Mean Number of Scleractinians with Visible Damage /m^2	Crushed	0.05	0	0	0	0	0	0	0	0	0
	Abraded	0	0	0	0	0	0	0	0	0	0
	Bleach/Pale	0	0.05	0	0	0	0	0	0	0	0
	Disease	0	0	0	0	0	0	0	0	0	0

A 6. Quadrat summary data for *Xestospongia muta* at anchorage chronic impact (AO) and control (CO) Outer Reef sites. The mean number, mean width, and mean height of individuals per square meter is given. Also the mean number of individuals with visible damage per square meter and the mean number of barrels per individual is given.

	Site	AO1	AO2	AO3	AO4	AO5	CO1	CO2	CO3	CO4	CO5
Mean *X. muta*/m^2		0.05	0.03	0.3	0.15	0.35	0.65	0.05	0.15	0.4	0.3
Mean *X.muta* Width Per Individual (cm)		6	14	24	25	22	19	38	16	23	26
Mean *X. muta* Height Per Individual (cm)		4	12	20	26	17	22	43	17	21	27
Mean number of *X. muta* with Visible	Abraded	0	0.05	0	0.05	0	0	0	0	0	0
	Bleach/Pale	0	0	0	0	0	0	0	0	0	0
	Disease	0	0	0	0	0	0	0	0	0	0
Mean Number of Barrels Per Individual		1	1	2	1	1.1	1	1	1	1	1.3

A 7. Quadrat summary data for the octocoral communities at Anchorage recent acute impact sites on Inner Reef (RI) and Outer Reef (RO). The mean number of octocorals, mean number of individuals within designated height bins, mean number of small octocoral (≤4), and mean number of individuals with visible damage or disease per square meter is given.

	Site	RO1	RO3	RO5	RI2	RI4
Mean Number of Octocorals /m^2	*Briareum asbestinum*	2.00	0.56	0.59	0.10	1.47
	Erythropodium caribaeorum	0.00	0.00	0.00	0.00	0.00
	Gorgonia ventelana	0.00	0.00	0.18	0.05	0.11
	Iciligorgia schrammi	0.00	0.00	0.00	0.00	0.00
	Pterogorgia anceps	0.00	0.00	0.00	0.00	0.00
	Pterogorgia citrine	0.00	0.00	0.00	0.00	0.00
	Pterogorgia guadalupensis	0.20	0.00	0.00	0.00	0.00
	Plume	0.90	0.94	0.88	0.50	0.53
	Rod	0.10	1.06	0.29	6.90	0.11
% of Quadrats with No Octocorals		45%	11%	26%	10%	21%
Mean Number of Octocorals /m^2 within each size bin	4 cm to 10 cm	1.80	0.78	0.59	2.25	1.21
	11 cm to 0.5 m	1.40	1.78	1.35	5.00	1.00
	0.51 m to 1 m	0.00	0.00	0.00	0.30	0.00
	>1 m	0.00	0.00	0.00	0.00	0.00
Mean Number of Small Octocoral (≤4cm) /m^2	Rod	0.00	0.00	0.24	0.45	0.00
	Plume	0.00	0.00	0.00	0.00	0.00
	Fan	0.05	0.00	0.00	0.00	0.00
	Whip	0.00	0.00	0.00	0.00	0.00
	Encrusting	0.25	0.00	0.12	0.10	0.95
Mean Number of Visibly Damaged Octocorals /m^2	Abraded	0.65	0.06	0.18	0.25	0.37
	Bleach/Pale	0.00	0.00	0.00	0.00	0.00
	Disease	0.00	0.00	0.00	0.00	0.00

A 8. Quadrat summary data for the scleractinian communities at Anchorage recent acute impact sites on Inner Reef (RI) and Outer Reef (RO). The mean number of scleractinians, mean number of small scleractinian (≤4cm), the mean amount of total live tissue, and mean number of individuals with visible damage or disease per square meter is given.

	Site	RO1	RI2	RO3	RI4	RO5
Mean Number of Scleractinians /m^2	*Acropora cervicornis*	0	0	0	0	0
	Acropora palmata	0	0	0	0	0
	Agaricia agaricites	0	0.17	0	0	0.05
	Agaricia fragilis	0	0	0.06	0.05	0
	Colpophyllia natans	0	0	0	0.05	0
	Dichocoenia stokesi	0	0	0	0	0
	Eusmilia fastigiata	0	0	0.06	0	0
	Isophyllia spp	0	0	0	0.07	0
	Madracis spp.	0.05	0	0.06	0	0
	Meandrina meandrites	0	0	0	0	0
	Montastraea cavernosa	0.05	0.11	0.18	0	0
	Mycetophyllia spp	0	0	0	0	0
	Orbicella annularis	0	0	0	0	0
	Orbicella faveolata	0	0	0	0	0
	Orbicella franksi	0	0	0	0	0
	Porites astreoides	0.20	0	0.06	0.05	0.21
	Porites porites	0	0	0	0	0
	Pseudodiploria clivosa	0	0	0	0	0
	Pseudodiploria strigosa	0	0	0	0	0
	Scolymia spp.	0	0	0	0	0.05
	Siderastrea radians	0	0	0	0	0
	Siderastrea siderea	0.30	0.06	0.12	0.20	0.16
	Solenastrea bournoni	0	0	0	0	0
	Stephanocoenia intersepta	0.15	0	0.06	0.25	0.10
% of Quadrats with no Scleractinians		60%	78%	70%	55%	58%
Mean number of Individuals/m^2		0.75	0.33	0.59	0.60	0.58
Small Scleractinian (≤4cm)/m^2		0.45	0.44	0.59	0.55	0.16
Mean live tissue area (cm2)/m^2		17.1	6.0	13.2	17.3	13.5
Mean Number of Scleractinians with Visible Damage /m^2	Crushed	0	0	0	0	0
	Abraded	0.15	0.18	0.15	0.10	0.12
	Bleach/Pale	0	0	0.06	0.25	0.5
	Disease	0	0.06	0	0	0.26

A 9. Quadrat summary data for *Xestospongia muta* at anchorage recent impact Inner Reef (RI) and Outer Reef (RO) sites. The mean number, mean width, and mean height of individuals per square meter is given. Also the mean number of individuals with visible damage per square meter and the mean number of barrels per individual is given.

	Site	RO1	RI2	RO3	RI4	RO5
Mean *X. muta*/m^2		0.10	0.28	0.35	0.40	0.16
Mean *X.muta* Width Per Individual (cm)		11.50	18.40	17.17	8.25	8.00
Mean *X. muta* Height Per Individual (cm)		8.50	14.40	7.50	11.75	2.67
Mean number of *X. muta* with Visible	Abraded	0.10	0.22	0.29	0.00	0.05
	Bleach/Pale	0.00	0.00	0.00	0.00	0.05
	Disease	0.00	0.00	0.00	0.00	0.00
Mean Number of Barrels per individual		1.00	1.60	1.00	1.00	1.00