Miami Harbor Phase III
Federal Channel Expansion Project
Permit No. 0305721-001-BI

Quantitative Post-Construction Analysis for Hardbottom Benthic Communities

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LIST OF FIGURES

Functional group data, analyzed from collected video transect footage, including octocorals, scleractinians, and sponges changed little between baseline and post-construction, although groups varied over time during compliance monitoring. Due to the low cover of living functional groups as documented in baseline investigations (most <5% cover), *in situ* colony counts are recommended for a more accurate and precise measurement of organismal change at the level of the transect and site. Functional group data including crustose coralline algae, turf, and bare rock (CTB) and sand varied widely throughout the compliance period and these trends can be attributed to both natural and project related variability. Increases in sand were documented at channel-side sites during construction monitoring, however, based on the post-construction video dataset analysis, CTB appeared to be increasing at HBN3 and all southern channel-side sites since January 2015, which would be expected as any local increases in sediment are assimilated into the benthos over time.

Sedimentation flux was calculated (daily rates) using sediments collected in traps at all hardbottom stations. These rates reflected seasonal variation in sediment transport as well as proximal sources of sedimentation (i.e. location relative to active dredging equipment). Sedimentation rates for post-construction were lower for all grain sizes when compared to baseline data. These changes in sedimentation rates may represent a seasonal difference, as baseline data were collected in the fall/winter when winds and waves re-suspended sediments (but before any dredging activity), compared with summer conditions, which were relatively calm and had lower suspended solids.

Both natural and project related impacts were observed to be important to benthic communities in the vicinity of the project area. However, the greatest impacts associated with coral mortality over time appear to be related to a catastrophic, regional-scale coral bleaching/disease outbreak that started in the fall of 2014 and continues to deleteriously affect coral populations at the time of this writing (fall 2015). The results of this study led to a rejection of the null hypothesis, as benthic communities were changed between the pre- and post-dredging periods due to natural and project related factors.

1.0 INTRODUCTION

1.1 Study Context and Objectives

The Miami Harbor Deepening Project was designed to widen and deepen the outer entrance channel to increase safe access to the Port of Miami by larger ships, including post-Panamax class ships. To accommodate these larger vessels, the outer entrance channel has been widened at the outer reef and deepened to 52 (±1) feet Mean Lower Low Water (MLLW) (15.6 ± 0.3 m). Avoidance and minimization of impacts to natural resources (hardbottom and seagrasses) was conducted by the U. S. Army Corps of Engineers (USACE) as the lead Federal agency through the NEPA process and a Record of Decision was signed on May 22, 2006. The project was permitted through the Florida Department of Protection (FDEP), under Permit No. 0305721-001-BI. Permit conditions provide a number of protective measures to ensure the preservation of natural resources, such as hardbottom, reef, and seagrass communities, including methods on environmental monitoring required before, during, and after dredging activities.

Great Lakes Dredge and Dock (GLDD) was responsible for implementing the required environmental monitoring program during the immediate pre-, during, and immediate post-construction time periods associated with the Miami Harbor Phase III project.

Dial Cordy and Associates Inc. (DCA) was contracted by GLDD to conduct baseline, compliance and post-construction monitoring of hardbottom, reef, and seagrass habitats in the project area. Specifically, DCA was contracted to (1) conduct baseline, compliance, and post-construction surveys at hardbottom, middle and outer reef monitoring sites, and their control sites, (2) conduct baseline, compliance, and post-construction surveys at Fisherman’s Channel seagrass sites, and (3) conduct baseline, compliance and post-construction surveys at Julia Tuttle Seagrass Mitigation Site (JTSMS).

This post-construction report characterizes the benthic communities within those channel-side areas of the nearshore hardbottom required to be monitored in compliance with the FDEP permit before, during and following completion of the project. Since hardbottom and outer reef baseline monitoring reports were submitted separately at the beginning of the project, the separate presentation has been preserved for the post-construction reports. The FDEP mandated monitoring study was designed to compare pre- and post-construction results to detect effects of dredging on adjacent benthic resources. The study also compared channel-side sites to control sites in the post-construction period. A number of parameters including benthic organism density, cover, and condition, as well as quantitative sedimentation rates were measured to test the null hypothesis (H_o):

> H_o: Benthic communities in the indirect effect (channel-side) sites will remain unchanged between the pre and post-dredging surveys.

1.2 Study Area

The study area is located in central Miami–Dade County, within hardbottom and relict reef habitats east of the Port of Miami entrance channel (Figure 1). The relict reefs of southeast Florida extend from Miami–Dade to Palm Beach County and were accretional reefs during the early-to-middle Holocene Epoch, approximately 10,000 – 6,000 years ago (Banks et al. 2007). Today, nearshore hardbottom areas (patch reefs) and parallel ridges or reefs lie offshore in a shore-parallel position, and are dominated by macroalgae, octocorals, sponges, and to a lesser extent hard corals (Blair and Flynn 1989, Moyer et al. 2003, Gilliam 2007). Throughout this report, these reef areas will be referred to as nearshore hardbottom or hardbottom, second or middle reef, and third or outer reef (after Moyer et al. 2003, but see Walker 2012).

The Holocene reefs in Miami–Dade County run almost continuously in a generally north-to-south trend along the coast to approximately 55th Street, Miami Beach. A break in the reef ridges occurs at approximately 55th street. South of 55th Street, only two reefs lines run parallel to the coast and are commonly referred to as the second (middle) and third (outer) reefs, with patchy nearshore hardbottom areas lying west of the second reef tract (Figure 1).

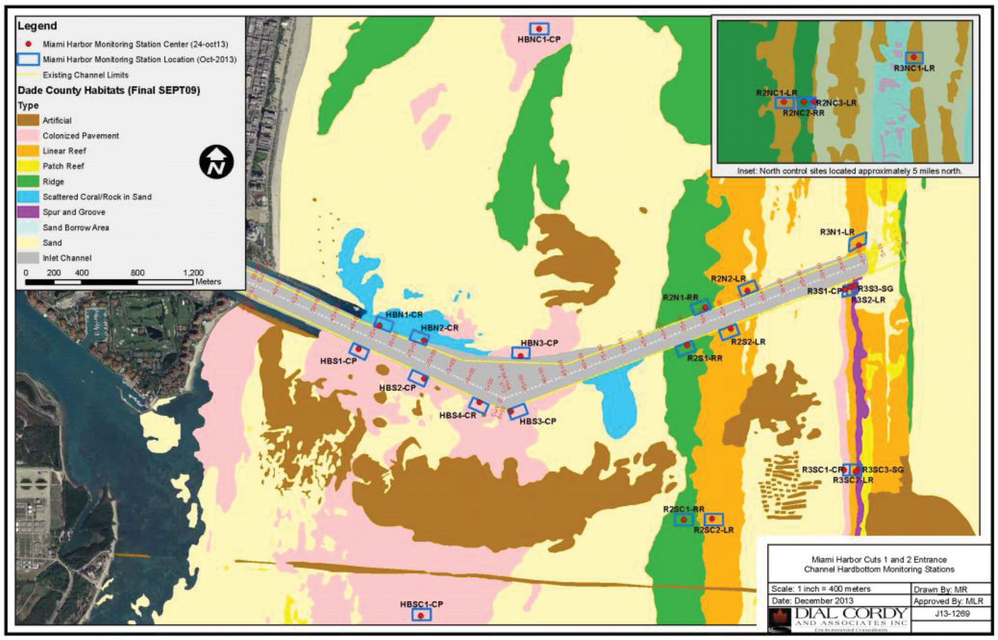

Figure 1. Miami Harbor Cuts 1 and 2 Entrance Channel hardbottom, middle, and outer reef monitoring stations. Habitat maps used were developed by Walker et al. 2008.

1.3 Previous Studies

A number of USACE studies have been conducted to support the project, starting with the Environmental Impact Statement (EIS), which was finalized by signature of the Record of Decision in 2006. Moreover, a Pilot Study was conducted in October 2009 to determine the level of effort required to adequately sample the hardbottom and reef habitats surrounding the Miami channel in order to detect a level of change in functional group cover of 5% (see Dial Cordy and Associates [DCA] 2010).

Indirect-effect sites and control sites sampled during the Pilot Study were similar to other reef areas in southeastern Florida that have been characterized by Gilliam (2007), Moyer et al. (2003), and others. In general, these areas are dominated by macroalgae (45–82% cover across sites), with lower cover of other biological groups, including corals (scleractinians and *Millepora*; 0.05–4.62% cover), sponges (0.54–6% cover), and octocorals (1 to 15% cover). The rubble, sand, and pavement group (4–71% cover) was the second most dominant cover type after macroalgae.

1.3.1 Pilot Study Results

The 2009 Miami Harbor Pilot Study documented that an analysis of variance (ANOVA) based approach would not provide sufficient statistical power to detect change at the level of 5% across groups (octocorals, macroalgae, corals, and sponges). The sample sizes required to detect a 5% change in macroalgal cover at $P = 0.05$ with a power of 0.80 ranged from 275 to 450 transects per site. Octocoral variances were also high. The sample sizes required to detect a 5% change at $P = 0.05$ with a power of 0.80 for octocorals would start at 2,200 transects per sample site. These results showed that an ANOVA approach is not practical for sampling in this variable and patchy environment. Thus, a regression based study design was recommended for quantitatively comparing before and after dredging results.

1.3.2 Quantitative Study Results 2010

Due to the low cover and sporadic occurrence of hard corals and octocorals at the Pilot Study sites, a regression-based approach on the middle and outer reefs, beginning adjacent to the channel, was conducted for the Quantitative Study Plan in 2010. For nearshore hardbottom communities west of the middle reef, a stratified random approach was implemented, based upon octocoral and scleractinian colony density within treatment and control sites identified during the Pilot Study. The report also recommended that all areas be sampled using colony counts rather than estimates of cover, due to the low cover of benthic organisms.

By following this recommended design, post-construction surveys conducted after the dredging operation would have allowed direct comparison with the pre-dredging data. Potential effects of the dredging operation on the hardbottom habitat would have been detectable as a significant difference between the pre- and post-dredging conditions in the relationship between distance from the channel and the magnitude of change. Effects on hardbottom sites would be detectable as significant interaction terms of ANOVA between time (before *versus* after dredging) and treatment (indirect-effect *versus* control).

1.3.3 Baseline Quantitative Study 2013

The Project monitoring study design, permitted by FDEP, was developed using a repeated measures design, with three permanent transects established at each of 26 sites; this was contrary to the recommended approach outlined in the 2009 Miami Harbor Pilot Study and the methods employed for the 2010 Quantitative Study (DCA 2010 and DCA 2012). The current study required a pre-dredging survey and a post-dredging survey, which are compared here to detect project effects. This document reports and compares the pre- and post-dredging survey results for hardbottom environments.

1.3.4 Corps Survey Results

The USACE pre-bid and pre-dredge hydrographic surveys documented differences in sediment accumulation across Cuts 1 and 2 of the federal channel. The nearshore hardbottom habitat, where seven project monitoring survey sites are located, had an 18% increase in sedimentation between August 2010 and October 2013, whereas other locations in Cuts 1 and 2 had a 2-3% increase in sedimentation (personal communication Steven Conger, USACE, April 3, 2015).

1.4 Dredging Activity

General dredging activity is described here, with beginning and ending dates for dredges. For more information on adaptive management strategies used during construction, see Weekly Compliance reports. The hopper dredge Terrapin Island began dredging on November 20, 2013 adjacent to hardbottom monitoring sites. The dredge Texas and the Spider barge began chopping rock and offloading dredged material to scows for the ocean dredged material disposal site (ODMDS) and Julia Tuttle seagrass mitigation site (JTSMS) disposal on December 17, 2013. Terrapin Island left the job site on December 27, 2013, but the Texas and Spider barge continued working offshore from west to east. The hopper dredge Liberty Island arrived at the Project site on May 14, 2014 and worked offshore until July 3, 2014. Dredging operations in the channel flare (easternmost portion of Cut 1) commenced on August 6, 2014. On August 24, 2014, the Texas and Spider barge moved inshore for repairs. The Texas and Spider barge dredged in Cut 2 for seventeen days before returning to Cut 1 on September 12, 2014. The Dredge Texas and Spider barge completed offshore dredging operations on December 23, 2014. The Dredge 55 operated intermittently offshore, when weather permitted until March 16, 2015. All Cut 1 and Cut 2 dredging (offshore) was accepted and therefore deemed complete, by the USACE on April 8, 2015. Dredging inshore continued until September 16, 2015. The USACE accepted the project as complete on September 17, 2015.

2.0 METHODS

2.1 Study Site Description

The hardbottom baseline survey established information on the population dynamics, condition and sedimentation environment of the benthic communities adjacent to the Port of Miami Phase III project area. These baseline results are used as a point of comparison for the post-construction survey to document changes attributable to dredging while considering other environmental or anthropogenic factors that influenced hardbottom resources in the area. The following section describes the materials and methods used to collect post-construction data on the benthic organisms and sedimentation rates at hardbottom sites. Raw photo, video and scanned data sheets were submitted to the USACE under separate submission in accordance with contract specification on September 2, 2015.

In 2013 site selection was conducted on a desktop computer, using ArcView™. FDEP permit site establishment polygons were imported into ArcView™. A smaller polygon, fitting within the FDEP polygon, was generated in ArcView™. The ArcView™ random point generator was used to establish a center point for the monitoring site within that smaller polygon. Site selection was conducted per FDEP Permit # 0305721-001-BI and based on habitat descriptiondescriptions by Walker et al. 2008.

In the field, HYPACK Navigational™ software was used to locate and mark the center point defined in ArcView™. Scientific divers qualitatively assessed the potential site for the appropriated habitat, hardbottom with hard corals and octocorals. The buoy location was adjusted by divers to optimize the amount of reef and/or hardbottom habitat. Thus, transect placement was not random, instead transects were intentionally placed in areas devoid of sand where possible. This was done in order to maximize sampling hardbottom or reef habitat, as this was the defined goal of the monitoring program mandated by the FDEP permit. Three monitoring transects were established approximately 5 m apart from each other.

In the fall of 2013, during site installation, 202 scleractinians were permanently marked at hardbottom sites (channel-side and control; Table 1). During the two years of compliance monitoring sixteen (8%) out of 202 were documented as missing, and were never found. Fourteen of these corals were at channel-side sites. The cause of missing corals was presumed to be due to physical disturbance or strong storms, but no obvious signs of impact were documented. The channel-side environment is active with boat traffic and has greater velocity of currents, when compared to control sites, which may explain the missing colonies. Other coral monitoring programs in southeast Florida have commonly noted tagged corals as missing (see Gilliam 2012). Analysis in the results section has been conducted using the 186 coral colony count, unless otherwise stated.

Table 1. Hardbottom sites and the number of permanently marked corals established in fall 2013 before baseline surveys.

Area	Site	Permanently Marked Hardbottom Corals
		N
North	HBN1-CR	23
	HBN2-CR	15
	HBN3-CP	27
	HBNC1-CP	14
South	HBS1-CP	18
	HBS2-CP	21
	HBS3-CP	29
	HBS4-CR	25
	HBSC1-CP	30
Total		202

2.1.1 Control Sites

Two control sites were established in the colonized pavement (CP) habitat type within a similar depth range, and are located a considerable distance from the project area for comparison purposes to account for larger scale non-dredging (natural) conditions which may affect hardbottom resources. Similar methods have been used in previous studies to characterize hardbottom communities off Broward and Palm Beach counties (Walker et al. 2008). HBNC1-CP is located 2.35 km north of the harbor entrance (Government Cut), and is characterized by relatively high density of octocorals and scleractinians. Both control sites are classified as colonized pavement habitat (Walker 2009). HBSC1-CP is 1.65 km south of Government Cut and characterized by a benthic assemblage dominated by *Montastrea cavernosa* colonies and numerous large sea plumes (~2m).

2.1.2 Channel-side sites

Seven channel-side or compliance sites are located approximately 10 m from the edge of the existing channel edge. The three northern channel-side sites were placed in numerical order from west to east with HBN1-CR being the site closest to the jetties and HBN3-CR located closest to the middle reef. HBN1-CR and HBN2-CR represent the coral rock/rubble (CR) habitat type, while HBN3-CP was considered to represent colonized pavement (CP) (Walker 2009). The four southern channel-side sites were not placed in numerical order from west to east. HBS1-CP is the site closest to the jetties, followed by HBS2-CP, HBS4-CR and HBS3-CR located closest to the middle reef. HBS4-CR was originally planned for coral rock (CR) habitat, east of HBS3-CP.

During the establishment of the monitoring stations and before baseline surveys began in 2013, scientific divers documented no hardbottom habitat at six separate locations associated with FDEP proposed site location for HBS4-CR. In order to search for hardbottom at this proposed location, divers used a 30 m transect tape radius, with one diver holding the fully extended transect tape, and the second diver swimming to the edge of visibility (~5-10 m) from the first diver. Divers then swam around each location in a circular search pattern, looking in both directions for hardbottom or signs of hardbottom. Divers covered roughly a 100 m diameter area around the proposed station location. Divers took photos at each location documenting mostly sand, as well as some attached algae and gorgonians. The buried gorgonians suggested this area may experience seasonal burial and exposure, however, in the fall of 2013 before the commencement of dredging operations; the area was completely buried in sand (Figure 2). Therefore, HBS4-CR was established in colonized pavement habitat, west of HBS3-CP, where hardbottom existed.

Figure 2. No hardbottom area at the suggested HBS4 location was found during site set-up. HBS4 had to be established in a different area.

2.1.3 Site Layout

At each monitoring site, three permanent 20 m transects were established during baseline, parallel to each other in a north (0 m) to south (20m) direction. Transect number increases from east to west (1-3) at each site. Stainless steel eyebolts (3/8-in. by 8-in.) were drilled into the bottom at 0, 10, and 20 m locations along each transect. Small closed-cell foam floats coated with anti-fouling paint were attached to each eyebolt with a short length of nylon braided line to aid in transect relocation. Two floats marked the beginning of each transect, while mid and end points were marked with a single float (Figure 3). This provided the diver with an orientation while laying out transect tapes during each monitoring dive. Sediment blocks were positioned at the center of the site, between Transect 1 and 2. Adjustments to exact transect placement in the field were conducted based on avoiding sand areas, maximizing hardbottom, and maximizing the number of hard corals on a single transect.

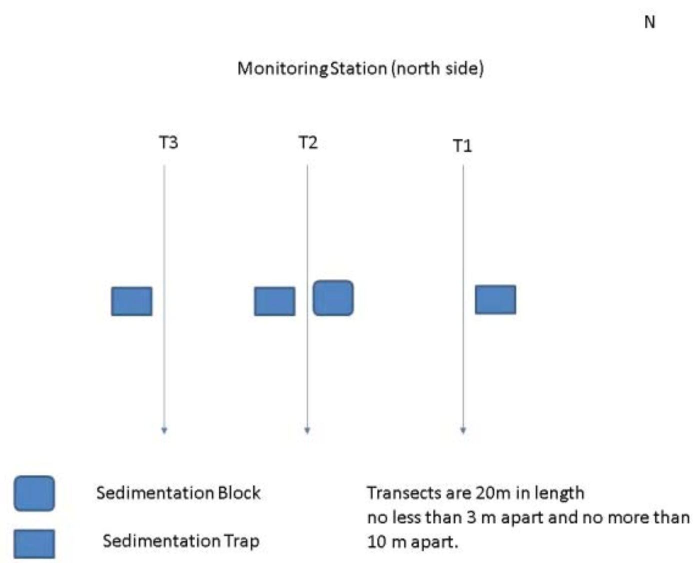

Figure 3. Hardbottom monitoring site layout.

2.1.4 Sedimentation Traps

Three sediment traps (Figure 4) were placed during baseline at each of the hardbottom monitoring sites (including control sites) to allow the comparison of net sediment trap accumulation among monitoring stations and between construction monitoring sites and control monitoring sites. The sediment traps were constructed of 1 in. interior diameter x 8 in. interior length polyvinyl chloride (PVC) pipe and a 500 ml Nalgene collection jar, or similar, making modifications to best sample sedimentation within the environment, based on hydrodynamics, currents and particle size (Storlazzi et al. 2011; Figure 3). Both trap necks and jars were coated with anti-fouling paint to minimize epibiotic growth. The PVC traps with the attached jar lids were fastened to the steel sediment trap frame with hose clamps. The frames were drilled and cemented into the substrate at all hardbottom sites, and were installed to collect sediment from the water column approximately 18 inches off the bottom. Sediment traps were removed at 28-day intervals by unscrewing the Nalgene trap jars from the PVC collars and capping the jars *in situ*. New jars were installed when collections were made and a new 28-day sediment monitoring period started. Following completion of the post-construction monitoring program, all sediment traps and frames were removed.

Figure 4. Sediment traps installed at all offshore sites for environmental monitoring of hardbottom resources in Cuts 1 and 2.

2.1.5 Sedimentation Blocks

A net sediment accumulation block was placed during baseline at each site at the 10 m mark on Transect 2 (Figure 5). This block served as the center point of the monitoring site for underwater navigational purposes. The sediment accumulation block consisted of an 8 in. x 8 in. x 8 in. concrete block attached to the bottom with hydraulic cement. The block had one side coated with antifouling paint, which was oriented as the upper surface. The antifouling paint minimized the bioaccumulation on the upper surface of the block which could interfere with sediment accumulation. The blocks were designed as an abiotic proxy for hard corals, to be used to measure an accumulation of sediment. Due to high rates of water flow associated with tidal and north to south currents, sediment blocks did not accumulate sediment during the monitoring period. Blocks were attached to exposed rock surfaces devoid of benthic fauna and no closer than 30 cm to any coral colony to assure no impact to living marine resources from the antifouling paint. Following completion of the post-construction monitoring program, all blocks were removed.

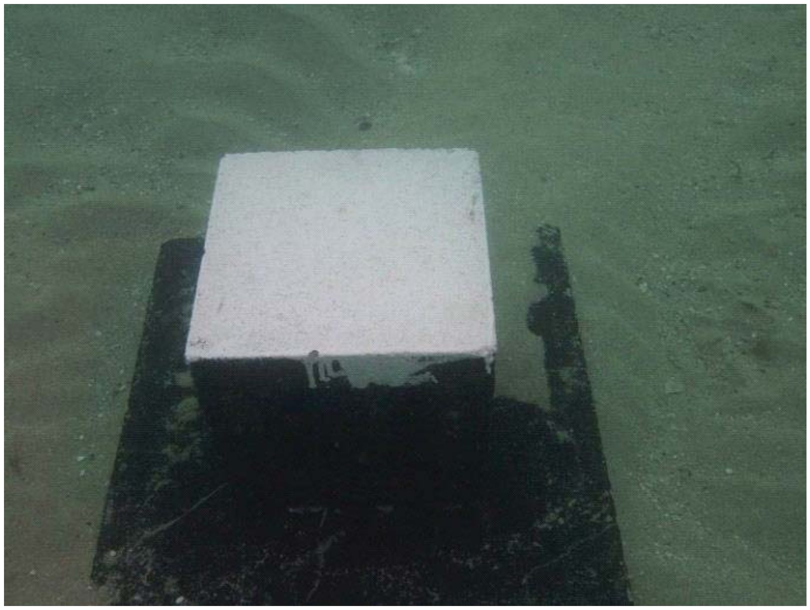

Figure 5. Sediment Block used to monitor sediment accumulation at hardbottom sites.

2.2 Data Collection

All scientific divers were trained and qualified to conduct benthic surveys in hardbottom environments, per the FDEP permit specifications. During Week 1 of baseline and post-construction surveys, all scientific divers responsible for collecting *in situ* data participated in quality assurance and quality control (QA/QC) training and exercises, with periodic follow-up throughout the monitoring period to maintain QA/QC standards over the life of the survey period. Project specific training materials were developed and included coral species identification and coral stress indicator guides. These training tools were provided to all project personnel. Previous studies have documented difficulty in finding and differentiating coral colony species smaller than 4 cm (Edmunds et al. 1998). As a result of inter-observer variability, data on corals smaller than 3 cm were not collected in this study. As mentioned above, a site specific identification manual was developed and used as a training tool and reference in addition to standard references including but not limited to the Humann (2002) Caribbean reef identification guidebook and on-line AGRRA coral identification keys (Atlantic Gulf Reef Rapid Assessment 2013.).

Post-construction surveys of the hardbottom sites were conducted over four weeks between June 22, 2015 and July 15, 2015. Hardbottom sediment samples were collected on July 20, 2015. Each site was surveyed once per week, during the four weeks of post-construction study as required by FDEP permit (Table 2). Adverse weather conditions affected the ability to conduct scientific diving on 4 of 29 days during the post-construction monitoring period. Safe diving conditions are described in EM-385 (EM-385 is the safety regulation document that guides all USACE scientific diving operations) as current speed of <1 knot and visibility >3 feet; additionally best professional judgment of wind and wave conditions was used to determine whether or not scientific dive operations may be conducted safely. Accordingly, no operations were conducted during small-craft boating advisories.

Surveys were conducted in order to ensure four distinct sampling periods were completed for each site. A sampling week was defined as a 7-day period in which each site was planned to be sampled. Due to unsafe diving conditions, sites may have been sampled four, five or six days apart or more than seven days apart (Table 2).

Post-construction sediment trap samples (28 days) were placed at all hardbottom sites on June 22, 2015. Sediment trap samples were collected at all hardbottom sites on July 20, 2015.

Table 2. Post-construction surveys were conducted at hardbottom sites between June 22, 2015 and July 15, 2015.

Site	Post-construction Survey Dates			
	Week 1	Week 2	Week 3	Week 4
HBN1-CR	06/23/2015	06/30/2015	07/09/2015	07/13/2015
HBN2-CR	06/23/2015	06/30/2015	07/09/2015	07/14/2015
HBN3-CP	06/23/2015	06/29/2015	07/09/2015	07/14/2015
HBNC1-CP	06/22/2015	06/29/2015	07/09/2015	07/15/2015
HBS1-CP	06/23/2015	06/30/2015	07/08/2015	07/13/2015
HBS2-CP	06/23/2015	06/30/2015	07/08/2015	07/13/2015
HBS3-CP	06/22/2015	06/29/2015	07/10/2015	07/14/2015
HBS4-CR	06/22/2015	06/29/2015	07/10/2015	07/14/2015
HBSC1-CP	06/22/2015	06/29/2015	07/08/2015	07/14/2015

2.2.1 Abiotic Characteristics

Abiotic data were collected to describe the general conditions of each monitoring site. The presence of hardbottom, rock, rubble, sand, sedimentation, bare substrate, maximum water depth and rugosity were documented at hardbottom sites. Rugosity (topographic complexity) data were collected along each transect, and calculated as $(1–d/l)$, where d is the geometric distance of each transect measured using a weighted line and l = the length of each transect (after Aronson et al. 1994). Rugosity measurements were used as a means of characterizing hardbottom habitats surfaces, with a value of 0 being a completely flat surface.

2.2.2 *In Situ* Data

In situ data were collected along three 20 m x 1 m belt transects at each hardbottom monitoring site, each week for four weeks during the post-construction survey period (June 22 – July 15, 2015; see Table 2. Scientific divers placed transect tapes, marked in metric and standard along the pre-established transects, securing the tape at the beginning, mid, and end points. *In situ* post-construction data were collected using underwater data sheets and clipboards and all *in situ* data are provided in Appendix A. Scleractinian abundance (counts) and condition data were collected for all colonies greater than 3 cm within the 20m x 1m belt transect, during all four weeks of post-construction surveys. Photographs of all tagged colonies during baseline, construction, and post-construction surveys are provided in Appendix B. Landscape site photos of each compliance monitoring site during baseline and post-construction monitoring periods are provided in Appendix C. During Week 3, the maximum diameter was measured for all scleractinians (>3 cm), and the abundance (count) of encrusting and erect octocorals (genera) was recorded within each belt transect. Individual erect octocorals were counted if holdfasts fell within the belt transect. Maximum diameter for erect octocorals was the measured maximum height. In Weeks 1, 2 and 4, transects were visually assessed for changes, but no counting of individual octocorals or maximum diameter measurements were conducted during those weeks (Table 3). Qualitative sedimentation observations were also collected during all four weeks. Summary tables of the total numbers of scleractinian and octocorals recorded during baseline and post-construction surveys are provided in Appendix D.

Table 3. Quantitative *in situ* data collected at all hardbottom permanent transects during post-construction surveys at hardbottom sites, June and July 2015.

	Week 1	Week 2	Week 3	Week 4
All non-marked scleractinian species within 20m x 1m transect (colonies > 3cm)	Abundance (counts) and condition	Abundance (counts) and condition	Abundance (counts), condition, and maximum diameter (*north side only baseline – both sides post-construction*)	Abundance (counts), condition
Permanently marked scleractinian species	Condition	Condition	Condition and maximum diameter	Condition
Encrusting and Erect Octocorals (genera)	-	-	Abundance (counts)	-

2.2.3 Scleractinian Condition Surveys

Scleractinian corals are sensitive to environmental changes and therefore coral condition is commonly used as an indicator of reef "health" (Vargas-Angel et al. 2007). Coral condition is one of the metrics required by the FDEP permit, and coral health assessment parameters include any condition that may be expected to adversely affect coral "health". Coral conditions included bleaching, excess mucus production, polyp extension, disease, and sediment accumulation (Bruckner 2001, Dial Cordy Training PPT 2013, Table 4). Examples of corals with conditions captured during compliance monitoring and post-construction surveys are provided in Figures 6-10. Each permanently marked coral colony was assessed for each of the health parameters and assigned a condition of either "0" or "1" for each parameter. A score of "0" indicated no observed bleaching, excess mucus production, polyp extension, disease, or other adverse condition, while a "1" would be assigned if one or more condition was present. Conditions were not additive, if a coral exhibited more than one condition (i.e. mucus and polyps extension), the coral received a score of "1".

Table 4. Coral stress indicator categories for *in situ* data collection which were observed during baseline, construction, and post-construction surveys at hardbottom sites (adapted from FRRP (Florida Reef Resilience Program) and DCA 2012). * designates conditions categories that were not present during baseline, but were added during compliance monitoring as needed.

Condition	Cause	Appearance	Field Code	Presence	
Bleaching				Baseline	Post-Construction
Paling	Stressed/Elevated Irradiance/Temperature	Live tissue with some loss of color.	P	•	•
Partial Bleaching	Stressed/Elevated Irradiance/Temperature	Patches of fully bleached or white tissue.	PB	•	•

Condition	Cause	Appearance	Field Code	Presence	
Bleaching	Stressed/Elevated Irradiance/Temperature	Live tissue with complete loss of color across the entire colony.	BL	•	•
Disease					
Black Band	Stress	Black band surrounds dead patch.	BB	•	
Yellow Band	Stress	Yellow band surrounds dead patch.	YB		
White Band (*Acropora* only)	Stress	White lines or bands of recently dead coral tissue found in species of the genus *Acropora.*	WB		
White-plague	Stress	White lines or bands of recently dead coral tissue affecting non-*Acroporid* corals.	WP	•	•
Unknown band	Stress	Unknown band-like mortality around the base of the colony, later presumed to be white-plague on *Dichocoenia stokesi*	UB	•	
Unknown *Solenastrea* disease	Stress	Patchy discoloration of living tissue resulting in a mottled bleached appearance. Only noted for *Solenastrea* spp.	UD	•	•
Stress indicators					
Polyps extended	Stress and feeding	Tentacles are extended on 100% of polyps on the colony.	PE	•	•
Fish bites	Grazing	Bites of live tissue removed.	FB	•	•
Mucus production	Sediment stress/Lunar cycle	Excessive mucus production results in a mucus film and/or sediment balled up in mucus.	M	•	•
Cliona delitrix	Competition	Red boring sponge present on colony. Typically accompanied by tissue mortality radiating outward from the point of sponge emergence.	CD	•	•
Unknown partial mortality	Stress	Tissue mortality from an unknown cause.	UPM	•	•

Condition	Cause	Appearance	Field Code	Presence	
Physical disturbance	Abrasion	Abrasion or physical disturbance such as a gouge or a nick, not in a discernable pattern like fish bites.	PD	•	•
Competitive mortality *	Competition	Recent partial mortality from a competition event. Typically the result of sponge or zoanthid overgrowth.	CM		•
Dark Spot *	Stress	Dark spots on otherwise normal *Siderastrea* spp.	DS		•
Unknown condition *	Stress	Discoloration of living tissue from an unknown cause. Not related to known bleaching or disease indicators.	UC		•
Sedimentation indicators					
Sediment	Sedimentation	Low amount, a “dusting”, of sediment on top of the coral.	SED	•	•
Sediment accumulation	Sedimentation	Moderate sediment accumulation on top of colony (more than dusting). Accumulation in grooves and/or between polyps.	SA	•	•
Partial burial	Sedimentation	Portion(s) of the colony buried by sediment.	PBUR	•	•
Burial	Sedimentation	Entire colony buried by sediment.	BUR	•	•
Partial mortality *	Sedimentation	Partial mortality of coral colony appears white with no live polyps visible. Generally, occurs around the margin of the colony. Visible when sediment recedes.	PM		•
Complete Mortality Indicator					
Complete mortality *	Any	Death of the entire colony; no live tissue remaining on the skeleton.	DEAD		•

Figure 6. **Photographs of bleaching conditions documented during compliance and post-construction surveys.**

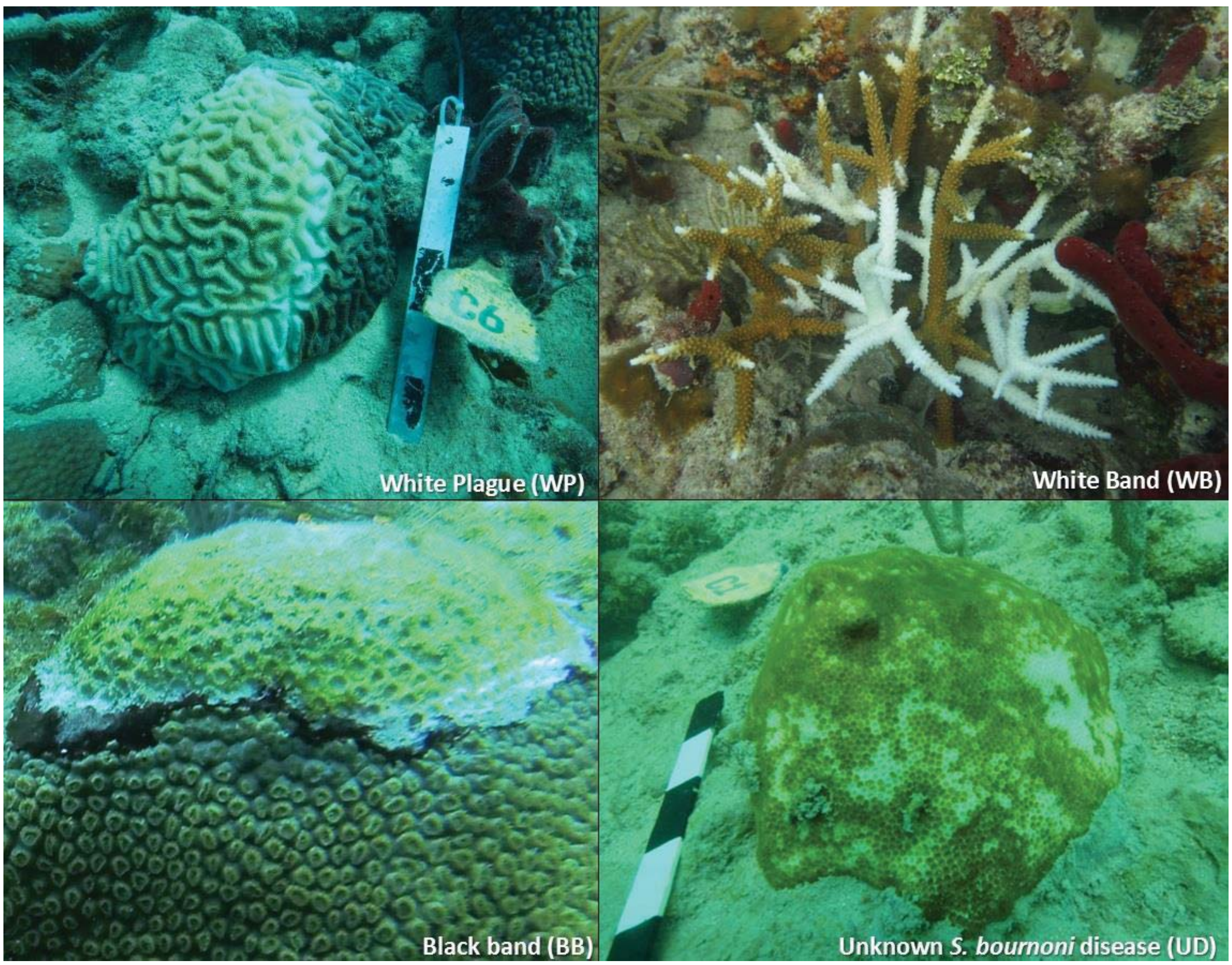

Figure 7. **Photographs of disease conditions documented during baseline through post-construction surveys.**

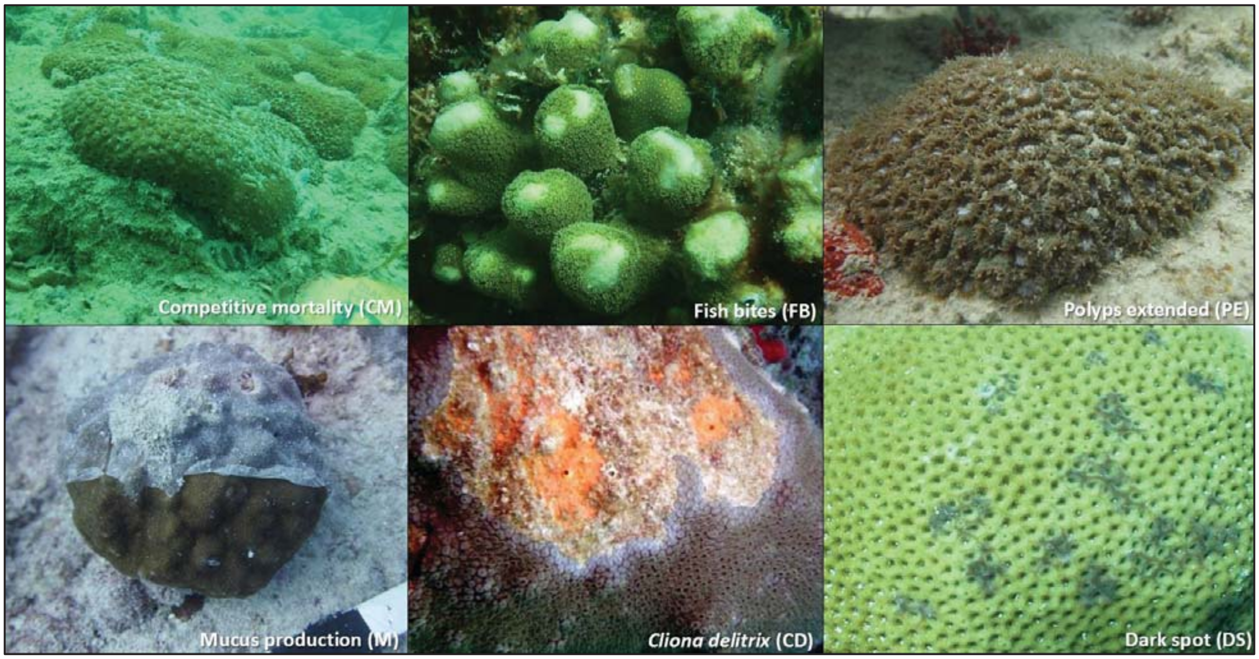

Figure 8. **Photographs of stress indicators documented during compliance and post-construction surveys.**

Figure 9. **Photographs of stress indicators documented during compliance and post-construction surveys.**

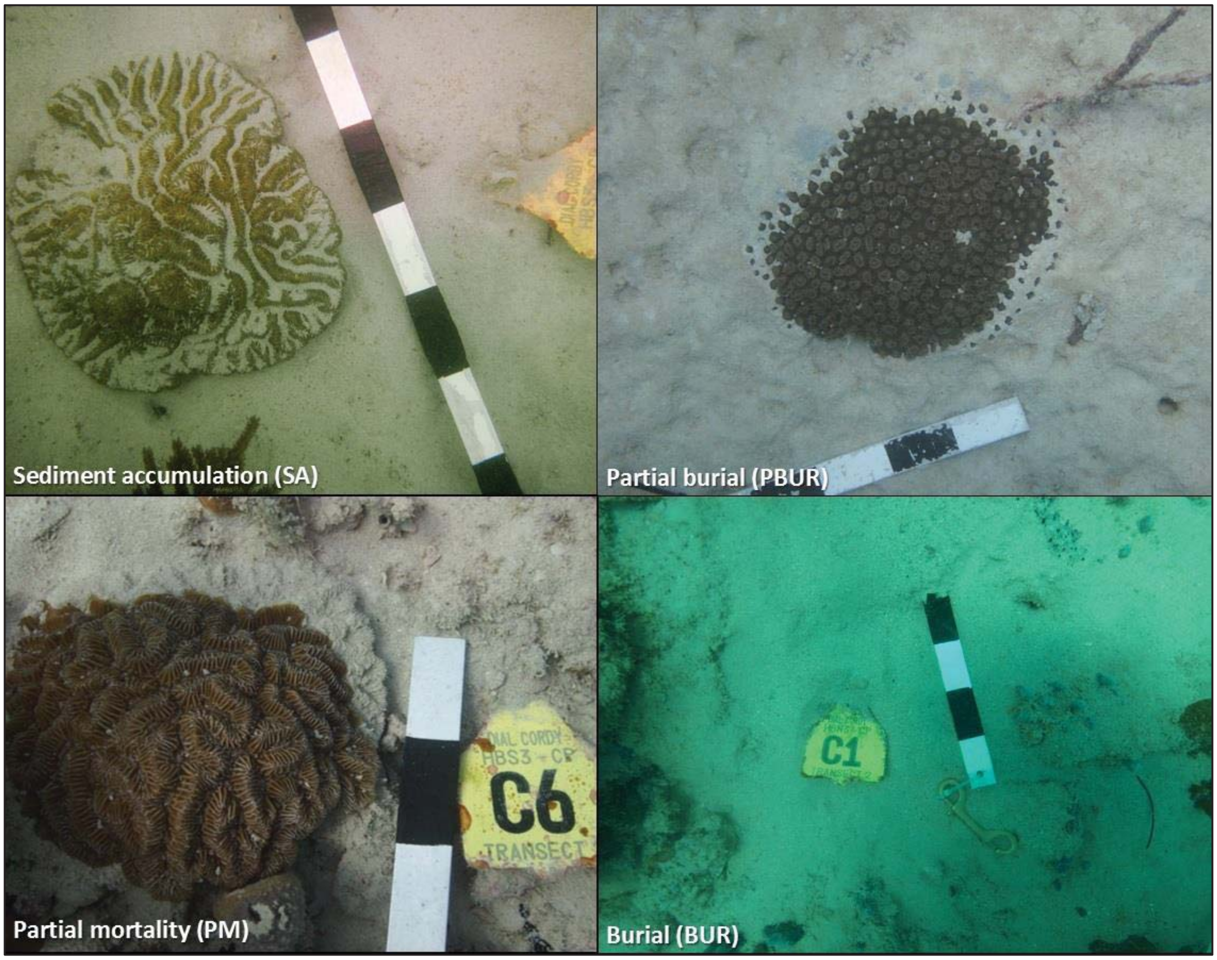

Figure 10. Photographs of sedimentation indicators documented during compliance and post-construction surveys.

2.2.4 Photo and Video

Scientific divers collected still photographs of permanently marked corals from a horizontal perspective, so that the maximum diameter of the colony was present within a single photo frame along with the permanent marker and scale bar in each of the four weeks of post-construction monitoring. Additional photographs were collected at the center of the site, adjacent to the sediment block, facing four directions at approximately 1.5 m above the bottom from an oblique angle so that the water column and general site characteristics were captured in the photographs.

Quantitative digital video data were collected along each transect with the camera positioned 40 cm above the substrate in a vertical orientation to produce birds-eye view digital video of each transect (20 m x 0.4 m), during each compliance monitoring week and each of four weeks of post-construction surveys (Aronson et al. 1994). The video camera was equipped with a measuring bar to ensure the camera remains at 40 cm above the bottom and a scale bar was visible at the bottom of the video record at all times (Figure 11). The diver swam the camera along each transect at a speed of ~5 m per minute to insure quality still images could be extracted for point count analysis using Coral Point Count with extensions (CPCe®; Kohler and Gill 2006). This method was used to evaluate both the coral health and potential sedimentation stress during post-construction as well as functional group cover at both the channel-side sites and the control sites.

Figure 11. Scientific diver collecting video data of transects during baseline surveys. Photo taken October 24, 2013.

2.2.5 Sedimentation Traps

Quantitative sediment samples were collected during baseline, construction and post-construction periods. A sediment trap at each transect held three replicate 500 mL Nalgene bottles. Replicates were combined for analysis so a single estimate per transect was calculated. Sediment samples were collected to determine daily sedimentation rates, and to evaluate the fraction of sediment withheld by a #230 sieve (coarse grain) and the fraction of sediment that passed through the #230 sieve (fine grain).

Post-construction monitoring sediment trap bottles were set on June 22, 2015 at all hardbottom sites and picked up 28-days later on July 20, 2015, as specified in the FDEP permit. Infrequently during the study period one or more bottles were lost or the stand was tipped over due to weather, waves or human interaction. When the sediment traps were disturbed, the sample was discarded and a note made in the sample record to alert the sediment sample analysis team.

2.2.6 Sediment Blocks

Sediment blocks were generally located on high points at each site, above the benthos and were subject to strong currents. As a result, no sediment accumulated on the blocks during baseline, compliance or post-construction periods. Photos of the blocks were collected during monitoring surveys.

2.3 Data Analysis

2.3.1 *In Situ* Data

After *in situ* data collection, scientific divers reviewed their results and discussed issues with the on-site scientific Data Manager. Underwater data sheets were washed, dried and quality controlled by the Data Manager, after which post-construction data were entered into an Excel based spreadsheet program. QA/QC of data input was conducted by another scientist to insure accurate data entry for analysis.

Parametric and non-parametric statistical methods were used to describe the scleractinian and octocoral abundance, density, diversity (H'), and evenness (J'). All statistical analysis results are provided in Appendix E. Condition values were calculated from raw data and are presented in the results section of this report. Abundance, density, diversity (H'), and evenness (J') were calculated as follows (p_i represents the proportion of individuals, and S represents species richness):

$$\text{Relative Species Abundance} = \frac{Total\ number\ of\ individuals\ for\ a\ species}{Total\ number\ of\ species\ at\ a\ given\ site}$$

$$\text{Density} = \frac{Total\ number\ of\ individuals\ for\ a\ group}{Total\ area\ of\ a\ transect}$$

$$\text{Diversity (H}') = \sum_{j=1}^{\%} p_i\ ln\ p_i$$

$$\text{Evenness (J}') = \frac{H'}{\ln S}$$

2.3.2 Coral Condition Data

Coral condition data were collected and analyzed for all scleractinian corals at the study sites through all four weeks of baseline and post-construction surveys. Only permanently marked scleractinian corals were photographed which provided a visual record and comparison between baseline and post-construction datasets. QA/QC was conducted on permanently marked scleractinian photos for all coral conditions in the laboratory.

2.3.3 Baseline Data Revisions

Transcription and calculation errors were identified in baseline graphs and tables during the post-construction data analysis time period. These errors or miscalculations are identified in the figure or table caption in this post-construction report. If an error was not noted, then no changes have been made to the baseline figure or table. All comparisons within this post-construction report were made with the updated and corrected baseline data. No error or miscalculation changed any of the trends for baseline data.

2.3.4 Functional Group Percent Cover Analysis

Video analysts conducted quality control exercises prior to evaluating transect still images. A training dataset of 30 hardbottom images, with 10 random points/image was compiled by two expert analysts. All video analysts independently performed a functional group analysis of the training dataset. Image-scoring from each analyst was compared on a per-image basis to the expert results. If an analyst diverged from the expert assessment by more than one point per benthic category, the images were reviewed with the analyst; the difference was discussed and corrected.

Video transect footage from Week 3 of post-construction was analyzed for the post-construction report, as these files provided the clearest still images from the post-construction period. Video transect footage was segmented (frame grab) into non-overlapping still images using GOM Player™ software. For each 20 m transect, 40 individual still images were generated. Each image was analyzed by using Coral Point Count with extensions™ (CPCe), and overlaying 10 randomly generated points (Somerfield et al. 2008). The organism or feature underneath each random point on the image was characterized by functional group. Functional groups were as follows: macroalgae (rhodophyta, phaeophyta, chlorophyta, and cyanobacteria) (MACA); crustose coralline algae, turf, and bare (CTB); sediment/sand (S); zoanthids (Z); hard coral (CORAL); octocoral/gorgonian (GORG); sponge (SPO); and tape, wand, shadow (TWS).

Coralline algae, turf, and bare substrate are difficult to differentiate using video techniques and therefore were grouped together for analysis (Aronson & Precht 2000). CTB and sand were the largest cover components for most sites, from baseline through post-construction periods. In order to most accurately and precisely classify these categories over the entire duration of the project, project specific definitions were developed to insure continuity of results. For visual analysis purposes, CTB was defined as rough substrate, or bottom with a textural component. In contrast, sand was visually defined for analysis as textureless and appeared as though it would obscure the tip of a pencil. All compliance sites were covered with a varying amount of sand during baseline, but was only identified as such when it would have been possible to stick a pencil into it. Figure 12 is an image from baseline at R3NC1-LR, and shows the difference between CTB and sand functional groups. Cyanobacteria periodically covered substrate and complicated analysis, as cyanobacterial mats on top of sand appeared to have texture, similar to CTB. Periodically, during the course of compliance monitoring, cyanobacteria would colonize sediment and was visually indistinguishable from CTB. In these cases, the estimation of CTB was higher than actual CTB because of limitations of this method. TWS designates points that cannot be identified from photographs because either benthos is obscured by survey tape or the camera measuring pole, or because image quality was too poor. These points are automatically excluded from the total sum of the means of each categories.

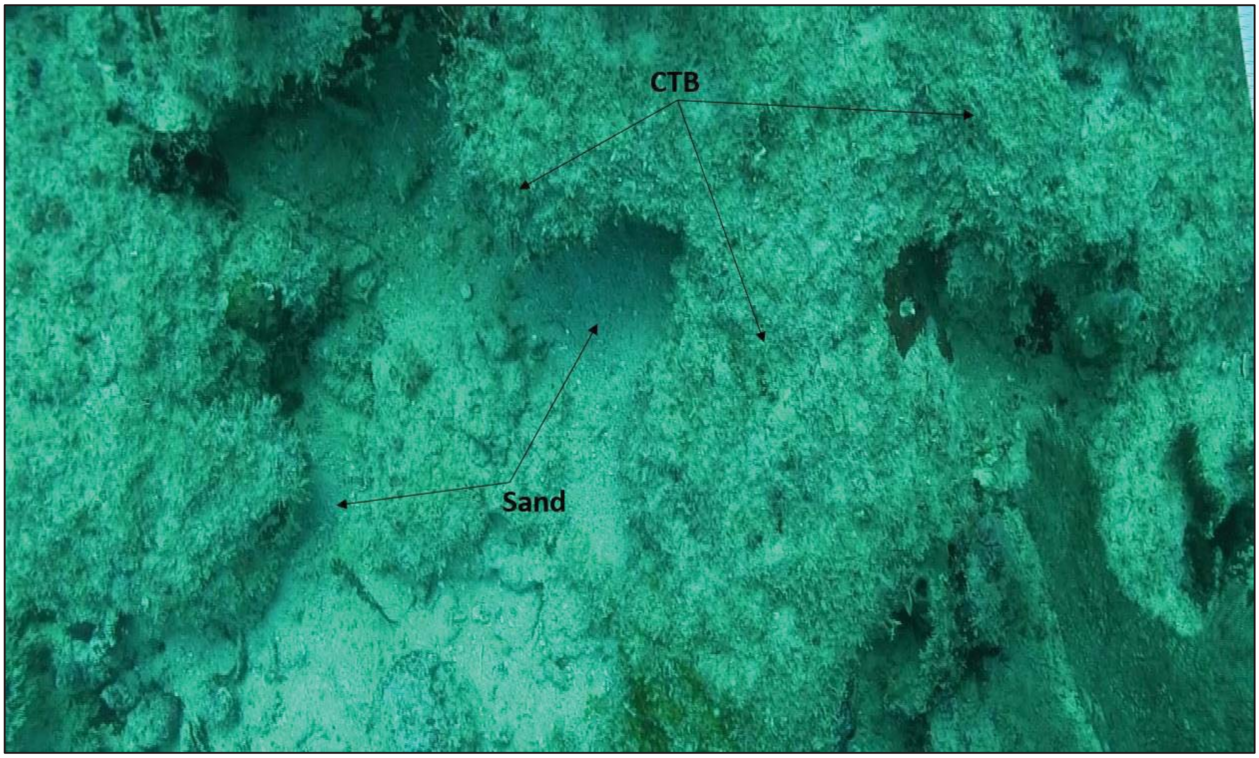

Figure 12. Still image from R3NC1-LR during baseline showing the distinction between sand and the CTB category.

In addition to analysis, all evaluated transects underwent QA/QC screening. For each transect that was analyzed for relative abundance of functional groups by a trained analyst, a second analyst reviews 10% of the resulting frames. If disagreement of more than 20% exists between analysts the site is re-analyzed and is subjected to a second round of QA/QC evaluation. Significant disagreement between analysts is discussed until a consensus is reached.

Although no comparison between channel-side and control sites were required for the 5% change special condition (FDEP permit (SC32aiid), control site data may be used as a general point of comparison to describe regional trends. Weekly video data collected at control sites were analyzed throughout compliance monitoring when corresponding channel-side site data were collected.

2.3.5 Sediment Accumulation Assessment

As described above, all three transects within a monitoring site had an associated sediment trap installation that contained three collection bottles. A total of nine bottles collected sediment accumulation data at each monitoring site. For analysis, three replicates (bottles) from the sediment traps were combined to produce an aggregate sample per transect. These three samples were then averaged to create a site mean sedimentation rate.

The mass of the specimen in each bottle was measured. The sediment samples were washed from the collection bottles through a U.S. Standard #230 sieve until water flowed freely through the fraction retained on the sieve. All wash water and sediment passing the #230 sieve was collected. Organisms that may have grown or crawled (i.e., fish, crabs, worms, algae) into the sediment collection bottle, if visibly retained on the sieve, were removed during the wash process and noted. None were observed for the post-construction samples. Sand retained on the #230 sieve was washed into a labeled tare. Some of the water was aspirated off the sand fraction and the tare was placed in a forced-draft oven at 66°C (150°F) until dry and for a minimum of 24 hours. Containers with the fraction passing the #230 sieve were allowed to settle for a minimum of 48 hours. After settling, the water was aspirated off the settled sample and the fine fraction was consolidated using additional wash water into the appropriate size labeled and weighed container and allowed to settle another 48 hours. The conductivity of the water was measured after the second settling phase. The water was aspirated off and the fraction of sample finer than the #230 sieve was placed in the oven until dry and for a minimum of 24 hours. The samples were removed from the oven and placed in the desiccator until cooled. The masses of the fractions retained and passing the #230 sieve were determined and recorded to the nearest 0.01 gram. All the data were entered into an Excel spreadsheet.

Sedimentation rates were calculated by dividing the sample dry weight value by the number of days the sediment collection bottles were in the water, with the first day being the day after the bottles were installed. Transect values were averaged to calculate a site mean.

3.0 RESULTS AND DISCUSSION

Post-construction biological monitoring results are compared with baseline monitoring results and provided below. Data collected during compliance monitoring of tagged coral colonies related to effects of sedimentation, bleaching and disease are also presented below. A thermally induced coral bleaching event during the summer of 2014 preceded a white-plague disease outbreak in the study area that directly affected coral health at control and channel-side sites, causing total mortality of many of the tagged corals associated with the project. The loss of these colonies had a direct bearing on the post-construction data set as presented below. All *in situ* post-construction monitoring data is provided in Appendix A.

3.1 Tagged Scleractinian Mortality and Conditions

A total of 186 scleractinian corals (not including missing corals) were tagged and monitored between baseline and post-construction surveys at the hardbottom habitat sites (Table 5) in compliance with the FDEP mandated monitoring program. Other long-term coral monitoring programs have documented dislodged or disappeared colonies over time (Gilliam 2012). Of the 186 corals surveyed, 52 died between baseline and post-construction surveys representing a total mortality rate of 27.96% over all hardbottom monitoring sites. When possible, causes of mortality were recorded in the field and are tallied in Table 5. Patterns of mortality were similar between channel-side and control sites.

The greatest cause of mortality was related to a white-plague disease epizootic that resulted in the total mortality of 33 corals and represented 17.74% of all tagged hardbottom corals (Table 5). Combined, *Solenastrea* unknown disease and *Oculina* unknown disease killed 12 corals and represented 7.5% of all tagged hardbottom corals. Sediment related mortality occurred in 3 corals and represents 1.6% of all tagged hardbottom corals (Table 5). Photographs of all tagged corals during each baseline, construction and post-construction monitoring survey are provided for reference in Appendix B.

Table 5. Total Scleractinian mortality from baseline through post-construction as measured at each hardbottom monitoring site. Mortality has been broken into categories based on cause of coral mortality and include: sediment, disease and bleaching (white-plague not included), and white-plague disease. The white-plague disease category includes colonies photographed with definitive signs of white-plague disease and those consistent with white-plague due to the resulting mortality patterns, timing, location, and species involved. Corals showing active white-plague have also been included. The N is all tagged colonies except missing colonies.

Survey Zone	Area	Site	Scleractinian Mortality (Baseline through Post-construction)											
			N	Sediment	Bleaching	Oculina Unknown Disease	Solenastrea Unknown Disease	Unknown Cause	WP Mortality	WP Active	% Sediment Mortality	% WP Mortality	Total Mortality	% of Tagged Dead
Hardbottom	North	HBN1-CR	22	0	0	0	0	0	0	0	0.00	0.00	0	0.00
		HBN2-CR	12	1	0	0	0	0	0	2	8.33	0.00	1	8.33
		HBN3- CP	24	1	1	2	0	1	0	0	4.17	0.00	5	20.83
		HBNC1- CP	12	0	0	0	1	0	2	0	0.00	16.67	3	25.00
	South	HBS1 -CP	18	0	0	1	0	0	0	0	0.00	0.00	1	5.56
		HBS2-CP	18	0	0	0	2	0	2	4	0.00	11.11	4	22.22
		HBS3-CP	26	0	0	1	0	1	16	0	0.00	61.54	18	69.23
		HBS4-CR	24	1	0	1	3	0	8	4	4.17	33.33	13	54.17
		HBSC1-CP	30	0	0	0	1	1	5	5	0.00	16.67	7	23.33
Totals			186	3	1	5	7	3	33	15	1.61	17.74	52	27.96

3.1.1 Causes of Mortality at Channel-side Sites

Patterns of mortality were similar between channel-side and control sites. From baseline surveys through post-construction surveys at all hardbottom channel-side sites, approximately 29% of all tagged corals died (Table 5). When considering all causes of scleractinian mortality at channel-side sites, white-plague disease was responsible for 62% of all mortality at the channel-side sites, followed by *Solenastrea* unknown disease (12%), *Oculina* unknown disease (12%), and sediment related total colony mortality was 7% (Figure 13). There is a strong possibility that all coral diseases recorded may be related.

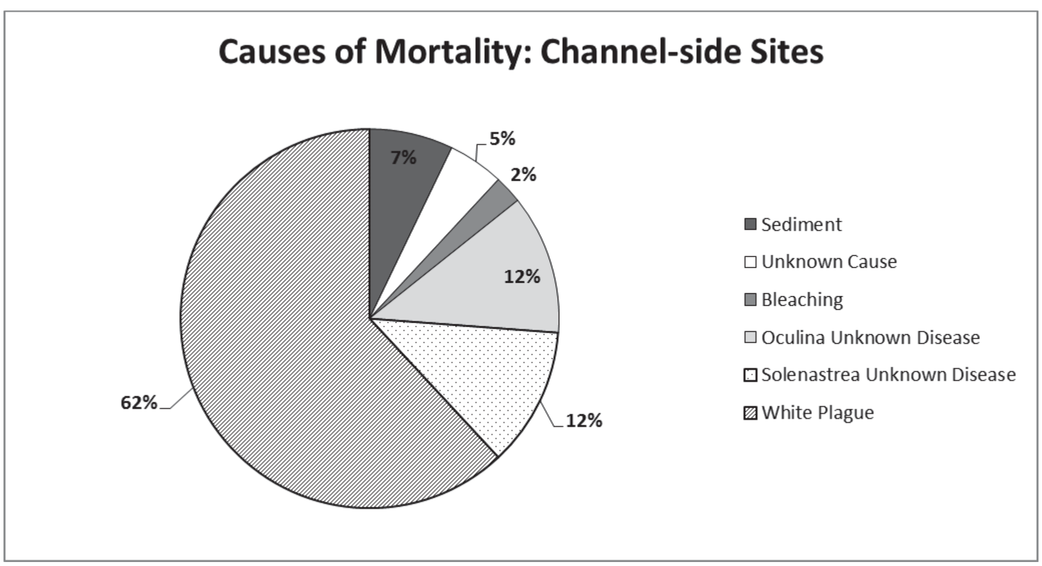

Figure 13. Percentage of causes of total scleractinian mortality across all hardbottom channel-side sites from baseline to post-construction surveys.

3.1.2 Causes of Mortality at Control Sites

From baseline through post-construction surveys at all hardbottom control sites, approximately 24% of all tagged corals died. When considering causes of mortality, white-plague disease was the greatest cause of mortality (70%), while *S. bournoni* unknown disease was responsible for 20% of mortality and 10% of mortality occurred due to unknown causes (Figure 14). No total colony mortality was attributed to sediment stress at hardbottom control sites. The major sources of coral mortality at hardbottom monitoring sites are discussed individually in the following sections.

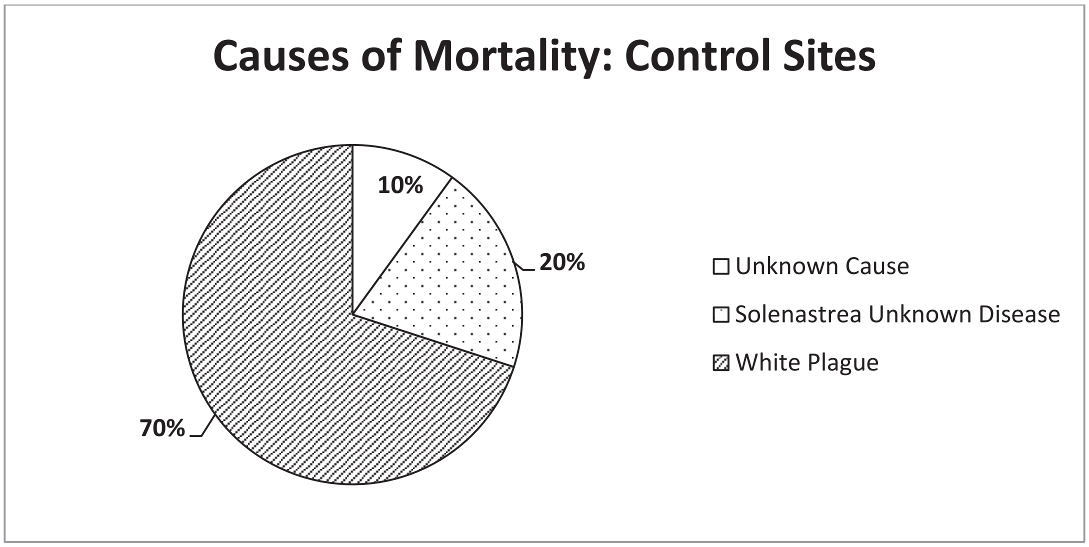

Figure 14. Percentage of causes of total scleractinian mortality across all hardbottom control sites from baseline to post-construction surveys.

3.1.3 White-plague Disease and Total Colony Mortality Related to Sediment

3.1.3.1 White Plague Disease

All three types of white-plague disease (WPL I, II, and III), are characterized by a sharp line between apparently healthy coral tissue and recently dead coral skeleton (Sutherland et al. 2004). The migrating disease line associated with white-plague diseases can progress rapidly, as fast as 2cm/day, and often results in total colony mortality (Richardson et al. 1998). Forty two Caribbean coral species are susceptible to white-plague disease (Harvell et al. 2007), and outbreaks following summer bleaching events have caused significant declines in total coral cover (Brandt & McManus 2009; Miller et al. 2009).

Between Compliance Week 52 (mid-November 2014), when the mortality of several corals with white-plague disease was first reported within the project study area, and the post-construction surveys (June 2015), white-plague disease had spread from primarily affecting middle reef sites, to both the outer reef and hardbottom habitats. White-plague was still active on a number of colonies at hardbottom sites during Week 4 of post-construction surveys.

The present outbreak has affected both channel-side and control sites, with *Meandrina meandrites* and *Dichocoenia stokesi* being the most affected species. Total colony mortality of *Pseudodiploria strigosa, Pseudodiploria clivosa, Solenastrea bournoni, Montastrea cavernosa* and *Colpophyllia natans* have also been documented as a result of white-plague disease across most compliance and all control sites, including hardbottom, middle and outer reefs.

To date, white-plague disease has caused the total mortality of 17.7% (33 out of 186 marked corals, excluding missing) and has affected (either killed or is actively causing mortality) 25.8% of marked corals within all hardbottom monitoring sites (Table 5). Compliance monitoring sites that were affected by white-plague mortality and/or active white-plague disease were: HBN2-CR, HBNC1-CP, HBS2-CP, HBS3-CR, HBS4-CR, and HBSC1-CP.

The southern hardbottom sites were the most impacted by white-plague disease (Table 5), particularly channel-side sites, where 26 out of 86 colonies died from the disease, and 8 colonies were showing active white-plague disease signs during post-construction surveys. The southern sites have a higher occurrence of species that have been documented as highly affected by white-plague disease, such as *M. meandrites*, *D. stokesi* and *M. cavernosa* when compared with the northern hardbottom monitoring sites. Only a few *D. stokesi* are found across northern sites, and no *M. meandrites* and *M. cavernosa* colonies were identified for tagging at northern monitoring sites during installation.

The white-plague disease outbreak documented above followed a period of bleaching (Summer/Fall 2014) due to thermal stress across the region. Figure 15 displays the proportion of corals surveyed that exhibited bleaching and white-plague disease during compliance monitoring. The proportion of bleached coral was highest during the summer of 2014, starting in late August 2014 and continuing through October 2014. The proportion of bleached coral was highest during the summer of 2014, starting in late August 2014 through October 2014. The proportion of bleached corals was highest in September 2014, when approximately 28% of corals surveyed were bleached. White-plague disease started to appear across most monitoring sites and all control sites, as early as November 2014, when 4% of surveyed corals showed signs of white-plague. This percentage kept increasing to reach its highest documented level in March 2015, when 15% of tagged corals surveyed had white-plague disease.

Post-construction surveys of hardbottom sites ended in July 2015, when the sea surface temperature had increased again to 31°C. The increased sea surface temperatures were also accompanied by an increase in the proportions of bleached corals by the end of post-construction surveys. These data indicate that corals of the hardbottom habitat are experiencing a second year of coral bleaching, bleaching watches and warnings issued by NOAA confirm this (NOAA 2015a). The result of this 2015 bleaching event on the mortality of tagged corals is currently unknown. The increased water temperatures and bleaching at the end of post-construction surveys and the large number of corals with active white-plague disease suggests that the total mortality attributed to bleaching and white-plague disease may increase beyond what is reported here due to the ongoing nature of these stressors.

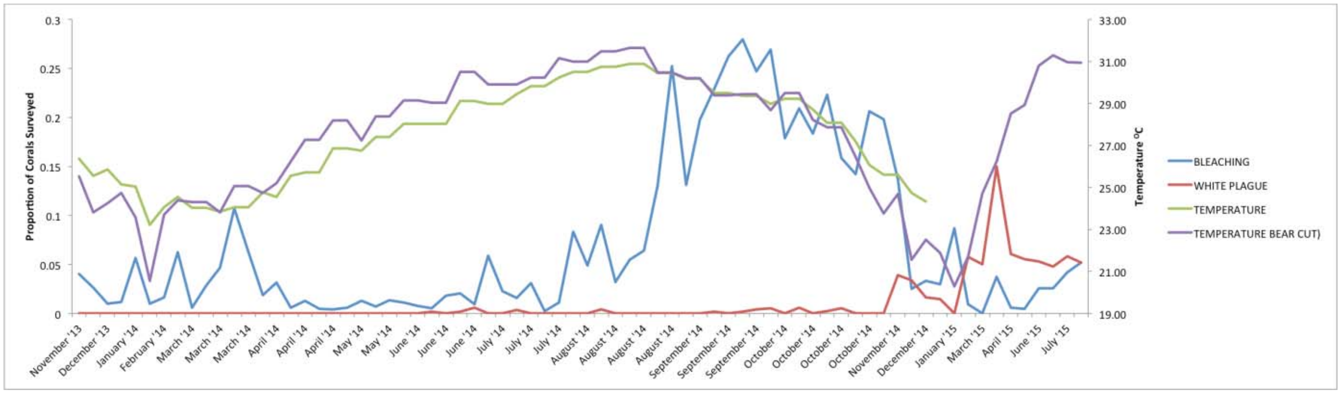

Figure 15. Proportion of corals surveyed across all compliance monitoring sites (hardbottom, middle and outer reef sites) showing signs of bleaching or white-plague disease across all monitoring weeks.

3.1.3.2 Total Colony Mortality Related to Sediment

Sediment related mortality at the channel-side sites was due to a combination of factors, including sedimentation, topography of the site, and spatial location of individual colonies in relation to topographic low areas. In total, 3 corals across the hardbottom monitoring sites died from sediment. A *Dichocoenia stokesi* experienced total colony mortality due to burial at HBN2-CR (Table 5). The colony was first documented as buried by coarse sediment during Week 4 compliance surveys (December 11, 2013), and reported as dead in Compliance Week 13 (February 17, 2014). The complete burial and death of this colony was likely due to the natural sand wave that affected the area of HBN1-CR and HBN2-CR.

A second *D. stokesi* was documented as dead due to burial during Compliance Week 22 (April 17, 2014). The colony was first documented as buried in Week 18 (March 20, 2014). Conditions documented, prior to the burial, included sediment accumulation, polyps extended, and mucus production. The burial and associated mortality of this colony was likely due to a combination of project-related and natural factors.

A *Siderastrea siderea* colony was documented as dead during the second week of post-construction surveys (June 29, 2015). The colony was located in a depressed area of the site and experienced complete burial twice during compliance surveys (Week 16 – March 6, 2014, and Week 43 – September 11, 2014). The colony was documented as buried for a third time during Week 1 of post-construction surveys (June 23, 2015), and then identified as dead the following week (June 29, 2015).

3.1.4 *Oculina* Unknown Disease

An unknown disease caused total mortality of five *Oculina diffusa* colonies at hardbottom monitoring sites (Table 5). Four colonies were documented as dead during the first week of post-construction surveys, while mortality of the fifth colony was recorded in Week 2 of post-construction surveys. This *Oculina* disease may be related to the regional white-plague disease outbreak, as the timing and locations of the disease coincide with the outbreak of white-plague. *Oculina diffusa* colonies survived through compliance monitoring and then appeared to be affected by this disease that caused patchy mortality over the entire colony during post-construction monitoring. However, due to the unique morphology of the species, it was not possible to confirm the presence of the sharp line between apparent healthy coral tissue and recently dead skeleton that is characteristic of white-plague disease on the tagged colonies. It should be noted that corals with differing morphology often show disease symptoms that are unique to that species. The patchy mortality observed on *Oculina diffusa* (Figure 16) was therefore labeled as '*Oculina* unknown disease'. The *Oculina* unknown disease was responsible for 12% of all coral mortality at hardbottom channel-side sites between baseline and post-construction surveys (Figure 13).

Figure 16. Image of *Oculina diffusa* "unknown" disease.

3.1.5 Unidentified Coral Disease (UD)

The coral *Solenastrea bournoni* is one of the most common corals in the waters of Miami-Dade County. It has long been thought to be one of the most eurytopic of the Atlantic corals, being able to sustain great variations in temperature, light, and salinity (Macintyre & Pilkey 1969). Throughout the project area, numerous colonies of *S. bournoni* started to show outward signs of distress in the fall of 2013. This unknown disease (UD) included disease-like symptoms with mottled coloration and necrotic tissues (Figure 17). Corals in the control areas as well as channel-side corals were similarly affected. During baseline surveys, as many as 14% of *S. bournoni* colonies at hardbottom survey sites were affected by this unknown disease.

Figure 17. *S. bournoni* exhibiting unknown disease condition during compliance monitoring surveys. This colony was recorded as dead during post-construction surveys.

This unknown disease was variable over time but affected *S. bournoni* during compliance monitoring at all hardbottom sites. Approximately 98% (44 out of 45) of tagged *S. bournoni* colonies at hardbottom sites exhibited signs of this unknown disease at one time or another (compliance and/or post-construction). Out of the 45 colonies noted with the disease, 7 died. During post-construction the unknown disease was variable over time but affected *S. bournoni* at HBN1-CR, HBN3-CR, HBNC1-CR, HBS2-CR, HBS3-CR, HBS4-CR and HBSC1-CR.

The etiology of the unknown disease affecting *S. bournoni* is unknown and further research may reveal a pathogen or group of pathogens.

3.1.6 Unknown Cause of Mortality

The term “unknown cause” was used to represent the mortality of a coral colony where the cause of mortality was not documented. In the hardbottom channel-side sites one *D. stokesi* coral died of unknown cause. The coral colony was observed alive in Compliance week 69/70 (March 2015) where it appeared healthy and was not surveyed again until Week 1 (June 2015) of post-construction where it had recently died. Due to the timing and susceptibility of *D. stokesi* corals to white-plague disease it is likely that this coral died of white-plague but it is counted as “unknown” because the signs of the disease were never observed. At HBS3-CP, a *M. meandrites* also died of unknown cause. The coral was last documented as alive in Week 69/70, and was dead in Post-construction Week 1. At hardbottom control sites only one *P. clivosa* colony died from unknown causes at HBSC1-CP during Compliance Week 29 (June 2014) surveys. The last conditions recorded for this colony were partial mortality (PM), physical disturbance (PD) and partial bleaching (PB) during Week 28 (June 2014).

3.1.7 Bleaching and Paling

A single *Porites astreoides* colony was reported dead at HBN3-CP due to bleaching in Compliance Week 51 (November 2014). The colony first showed signs of thermal stress during Compliance Week 41and 42 (August 2014), when it was pale. In Week 43 it exhibited paling and was also partially bleached. The next survey was not until Week 51 (November 2015) when the coral was documented as dead. Two other *P. astreoides* colonies that were present at HBN3-CP exhibited paling and bleaching, but recovered over the same time period. Although bleaching was widespread in the summer of 2014 and was again showing increasing prevalence during post-construction surveys in the summer of 2015, only one coral colony was noted to have died as a direct result of bleaching throughout the hardbottom monitoring sites (Table 5).

In the summer of 2014, a NOAA coral watch bleaching alert was issued for the south Florida region. Regional bleaching was documented in south Florida during the summer of 2014 by a number of observers in the Florida Keys (NOAA 2014a; 2014b; NOAA 2015a), and the event was described for hard corals in the Florida Keys and Miami-Dade County. By the late summer and early fall of 2014, many of the corals off southeast Florida expelled their zooxanthellae in response to prolonged warm sea surface temperature (SST) resulting in the worst bleaching episode since 1997-1998 with corals, zoanthids, and octocorals all showing outward signs of stress (NOAA 2015b). In June 2015, NOAA released a bleaching event update, and noted that warming had begun in the Caribbean, with extensive bleaching watches and some warnings for Florida coasts (NOAA 2015a).

Bleaching and paling are primarily attributed to seasonally warm water temperatures and elevated levels of irradiance (e.g., Baker et al. 2008), but have also been documented as a stress response to cold water temperatures (Lirman et al. 2011). Pale or partially bleached corals were recorded at all hardbottom sites during post-construction. The percentage of corals exhibiting paling ranged from 0- 20%% per site during Week 1 and 11% - 43% per site during Week 4 (July 2015) of post-construction surveys (Table 6; Figure 18). This increase was likely due to the slow increase of sea surface temperatures, and the prolonged exposure of the colonies to warm waters, triggering a stress reaction and a reduction in concentration of zooxanthellae, thus causing paling in more colonies across all hardbottom sites. Week 1 surveys started on June, 22 2015, and Week 4 surveys ended on July, 15, 2015. During that time, water temperatures ranged from 29.8C to 32.1C (NOAA National Data Buoy Center 2015). Corals start to become stressed when the SST is 1°C warmer than the highest monthly mean temperature (Glynn and D'Croz 1990). From July 2015 to September 2015, sea surface temperatures remained above the maximum monthly sea surface temperature mean in Biscayne Bay, rising above the NOAA bleaching threshold during the month of September (NOAA 2015c). *S. siderea, S. intersepta* and *S. bournoni* were the species most affected by paling throughout post-construction.

Only two tagged colonies were documented as entirely bleached during the four weeks of post-construction surveys, one at HBS1-CP (*S. siderea*) and the other at HBS3-CP (*O. diffusa)* (Table 6). High sea surface temperatures (SSTs) have persisted in South Florida waters through the summer and fall of 2015, bleaching corals throughout the region (NOAA 2015c). The result of this bleaching event on the survivorship of tagged coral colonies is unknown due to the ongoing nature of the event.

Table 6. Proportion of all tagged scleractinian corals exhibiting paling (P), partial bleaching (PB), and complete bleaching (BL) across hardbottom compliance sites during the four weeks of post-construction surveys.

	Week 1			Week 2			Week 3			Week 4		
	P	PB	BL	P	PB	BL	P	PB	BL	P	PB	BL
HBN1-CR	0.14	0.00	0.00	0.14	0.00	0.00	0.27	0.00	0.00	0.23	0.00	0.00
HBN2-CR	0.08	0.00	0.00	0.17	0.00	0.00	0.45	0.09	0.00	0.27	0.00	0.00
HBN3-CP	0.00	0.00	0.00	0.05	0.00	0.00	0.11	0.00	0.00	0.32	0.00	0.00
HBNC1-CP	0.00	0.00	0.00	0.00	0.11	0.00	0.22	0.00	0.00	0.11	0.00	0.00
HBS1-CP	0.00	0.13	0.00	0.24	0.06	0.00	0.18	0.06	0.06	0.18	0.06	0.06
HBS2-CP	0.07	0.36	0.00	0.07	0.07	0.00	0.27	0.13	0.00	0.43	0.21	0.00
HBS3-CP	0.20	0.00	0.00	0.20	0.00	0.00	0.10	0.00	0.00	0.33	0.00	0.11
HBS4-CR	0.07	0.07	0.00	0.00	0.08	0.00	0.17	0.00	0.00	0.18	0.00	0.00
HBSC1-CP	0.04	0.00	0.00	0.17	0.00	0.00	0.26	0.04	0.00	0.39	0.04	0.00

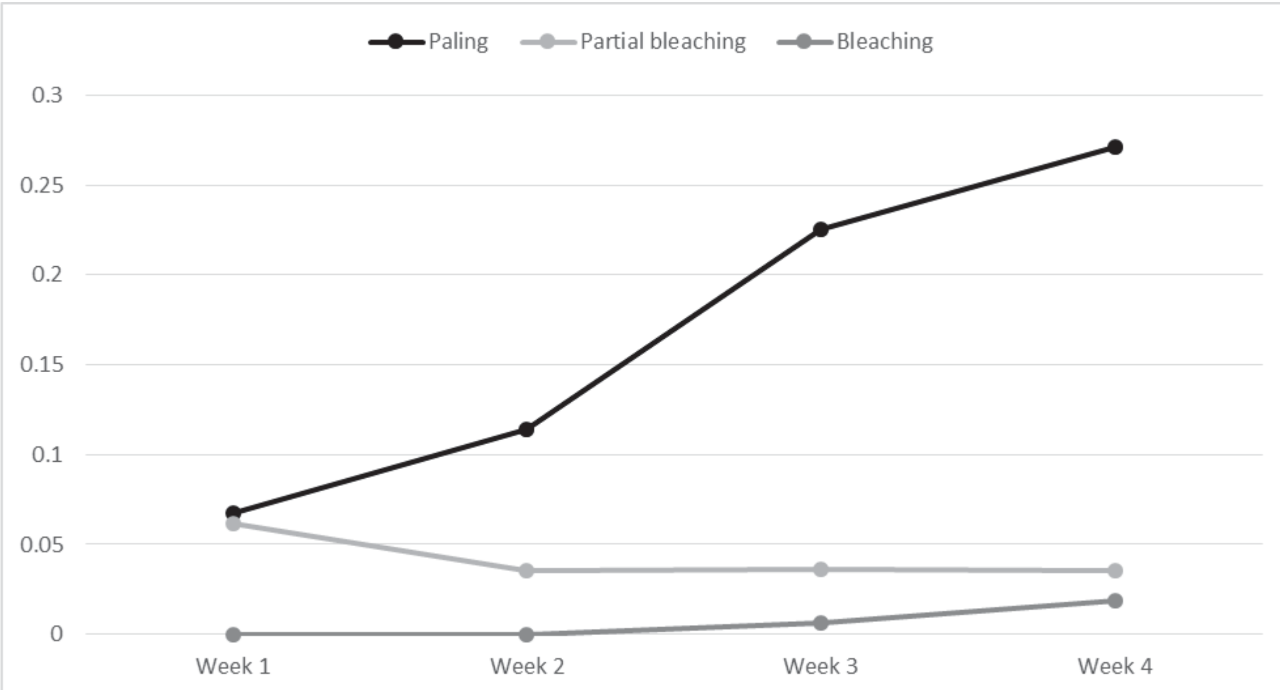

Figure 18. Mean proportion of all corals exhibiting paling, partial bleaching, or complete bleaching at all hardbottom sites over the four weeks of post-construction assessment.

3.1.8 Sediment Stress and Partial Mortality

Sediment stress was documented as the source of mortality for 3 corals across the hardbottom monitoring sites between the baseline and post-construction surveys (Table 5). In addition, partial mortality due to sedimentation was noted throughout the compliance monitoring period and is quantified by site in Table 7.

Of the coral stress indicators evaluated during compliance monitoring, several were specifically identified to evaluate the effect of sedimentation on corals. Sediment dusting (SED) was defined as a low amount, a "dusting", of sediment on top of the coral. SED was not considered a "stress" indicator and was given a condition score of zero. Sediment accumulation (SA), was an accumulation of sediment on top of the coral, between polyps, or within grooves and was qualitatively more than a dusting of sediment. Partial burial (PBUR) was the accumulation of sediment around the base of the coral, sometimes in the form of a berm, and burial (BUR) was the complete burial of the coral colony by sediment (Figure 10 and Table 4). Recent partial mortality (PM) was the observation of dead coral skeleton where sediment had previously accumulated on or around a coral colony. Of these sediment stress indicators, sediment dusting, sediment accumulation, partial burial, and complete burial by sediment were ephemeral indicators of coral stress that could be alleviated by water movement and/or physical removal of sediment by the coral. Partial mortality (PM), however, was an indicator of permanent impacts of sediment stress to coral colonies.

Scleractinian partial mortality (PM) due to sediment stress data were collected *in situ* for all compliance monitoring sites and by compiling partial mortality data from compliance and post-construction monitoring periods at all compliance monitoring sites. Partial mortality due to sediment was documented throughout the hardbottom habitats including reference sites where natural sedimentation has caused partial mortality. Rates of partial mortality due to sediment were patchy throughout the hardbottom habitats with the highest rates documented at the southern channel-side sites. Table 7 details measured rates of partial mortality due to sediment throughout the hardbottom habitats.

Due to the high rates of white-plague disease-related mortality documented across hardbottom reefs (DCA 2015), all sediment-related partial mortality data is presented in Table 7 in two formats: one that includes all tagged corals at compliance monitoring sites, and again with all dead corals removed from the total number of corals sampled. The removal of dead corals from the sediment-related partial mortality values changed the total number of corals sampled at some compliance monitoring sites.

Partial mortality (PM) was recorded on 57% of all scleractinian corals at hardbottom sites (106 out of 186) at one time or another (compliance and/or post-construction). 16 tagged coral colonies disappeared during compliance monitoring, and are excluded from both of the above calculations. Out of the 16 missing colonies, 3 were documented as having PM during compliance monitoring.

Partial mortality occurred across channel-side sites and control sites (Table 7). HBS2-CP recorded the highest percentage of corals affected by partial mortality (89%), while HBN1-CR had the lowest (5%). Of the 106 colonies affected by PM, 34 died during compliance. Of the 34 colonies that died, 20 died from white-plague disease, 1 died from bleaching, 2 died from burial, and 10 died from unknown disease (*S. bournoni* 4 and *O. diffusa*-5) or an unknown cause (*P. clivosa*).

The one colony at HBN1-CR that showed PM is a *S. bournoni* colony, and PM was noted in Week 43. However, the site had not been surveyed since baseline, suggesting that this PM mortality was likely due to the natural sand wave covering the site that was documented as moving into the area prior to the commencement of dredging operations (see Section 3.2.1).

The unknown disease exhibited by *S. bournoni* and *O. diffusa* colonies often made it difficult to confirm the PM condition code in these species.

Table 7. Mean sediment related partial mortality as measured throughout compliance and post-construction monitoring. Scleractinians at compliance monitoring sites were assigned a "0" or "1" depending on the presence/absence of sediment- related partial mortality. Corals with no evidence of sediment-related partial mortality were assigned a "0", while corals exhibiting sediment-related partial mortality (PM) were assigned a "1". Data are presented both for the total number of corals marked at a given site "All corals" and with dead corals removed "without dead corals". "All Corals" does not include 16 colonies that disappeared during the project. Partial mortality on an individual coral colony is defined as any portion of a coral colony with mortality consistent in appearance with sedimentation related partial mortality.

Survey Zone	Area	Site	Partial Mortality Related to Sediment Stress							
			All Corals				Without Dead Corals			
			#PM	N	Prop.	SD	#PM	N	Prop.	SD
North		HBN1-CR	1	22	0.05	0.21	1	22	0.05	0.21
		HBN2-CR	7	12	0.58	0.51	7	11	0.64	0.48
		HBN3-CP	19	24	0.79	0.41	15	19	0.50	0.42
		HBNC1-CP	7	12	0.58	0.51	6	9	0.67	0.50
South		HBS1-CP	11	18	0.61	0.50	10	17	0.59	0.51
		HBS2-CP	17	18	0.89	0.32	14	16	0.88	0.34
		HBS3-CP	21	26	0.81	0.40	7	8	0.88	0.35
		HBS4-CR	16	24	0.67	0.48	9	11	0.82	0.40
		HBSC1-CP	7	30	0.23	0.43	5	23	0.22	0.42
Total			106	186			74	136		

3.2 Quantitative Benthic Sampling: Scleractinians

Nearshore hardbottom sites consisted of seven treatment sites (HBN1-CR, HBN2-CR, HBN3-CP, HBS1-CP, HBS2-CP, HBS3-CP, and HBS4-CR) and two control sites (HBNC1-CP and HBSC1-CP). Three transects were sampled within each site, for a total of 27 transects covering 540 m^2 of nearshore hardbottom habitat for *in situ* data collection. Abiotic characteristics (e.g., substrate type, rugosity, and maximum depth), colony counts of scleractinian (by species) and octocorals (by genus) were collected from all transects, as well as condition of scleractinian corals. Photos of all permanently marked corals and video of each transect were also collected. Parametric and non-parametric statistics were used to analyze the abundance and density of scleractinians and octocorals, as well as condition of corals. Raw data including photos, video and data sheets were submitted under separate cover to the USACE on September 2, 2015.

3.2.1 Natural Sand Transport Event – Northern Channel-side Sites

During the baseline survey period (October 17, 2013 to November 18, 2013) at the hardbottom sites, a natural sand transport event was documented on the north side of the channel, close to the north jetty. A sand wave moved from north to south following the general movement of the regional longshore drift in the vicinity of HBN1. At HBN1 all marked corals documented in Weeks 1 and 2 were buried by Week 3 of baseline, as documented in photos and video collected at the site on November 1, 2013 (Figure 19). Photos from HBN2 and HBN3 show turbid water and sedimentation during baseline surveys, although no corals were buried at these sites, it was apparent that natural sand transport influenced the sediment dynamics of these nearshore hardbottom communities. The last full monitoring of HBN1 was conducted on December 4, 2013. HBN1 was visited periodically when the site was within the 750m compliance monitoring zone, and weather and sea conditions allowed, but it appeared to be buried from the surface during those periodic visits and therefore no monitoring was conducted. In Week 43 (September 12, 2014) of compliance monitoring, scientific divers determined the site was no longer buried by sediment. On this visit *in situ*, photo, and video data were collected. The site was sampled again on September 22, 2014 and November 7, 2014. On December 12, 2014 and January 22, 2015, HBN1 was again buried, as observed by scientific divers. Two western most transects of HBN2 were also buried under coarse sand on January 22, 2015. On March 21, 2015 HBN1 permanently marked corals were unburied, while most permanently marked corals were still buried across all transects at HBN2. This was the first visit to these sites, since January 22, 2015.

Figure 19. HBN1-CR in Week 1 of baseline and in Week 4 of baseline after burial event.

This natural sand transport has been documented as an annual winter event and was not documented during the four weeks of post-construction surveys, which occurred during the summer months (June and July 2015).

Despite such strong, seasonal sediment movements and periodic burial episodes, all tagged coral colonies at the site, with the exception of one that was documented as missing during Post-construction Week 1 (likely toppled over), were alive and apparently healthy as of the last surveys of post-construction.

3.2.2 Abiotic Characteristics

All sampling was conducted in areas of hardbottom habitat in 6 to 9 m (21 to 29 feet) of water. Hard substrate was typically interspersed with sand pockets (Table 8). Nearshore hardbottom sites were topographically low in rugosity, ranging from 0.00 to 0.06 during baseline, and from 0.02 to 0.17 during post-construction. Rugosity was not collected at HBN1-CR, HBNC1-CP, and HBN3-CP due to environmental conditions. Rubble was present at four sites (i.e., HBN1-CR, HBN1-CP, HBS2-CP, and HBS3-CP). Average daily sedimentation rate data, computed from monthly sediment trap data, were graphed for the entire project (baseline through post-construction) and are reported in Section 3.5.2.

Table 8. Abiotic characteristics for all hardbottom survey sites during baseline and post-construction. Baseline surveys are designated by a circle, while post-construction surveys are designated by a square.

Abiotic Characteristics	Site								
	HBN1-CR	HBN2-CR	HBN3-CP	HBNC1-CP	HBS1-CP	HBS2-CP	HBS3-CP	HBS4-CR	HBSC1-CP
Hardbottom	• □	• □	• □	• □	• □	• □	• □	• □	• □
Bare Substrate	• □	• □	• □	• □	• □	• □	• □	• □	• □
Rubble	• □		• □			• □	• □		• □
Sand	• □	• □	• □	• □	• □	• □	• □	• □	• □
Sedimentation	• □	• □	• □	• □	• □	• □	• □	• □	• □
Rugosity (baseline)	N/A	0	0.02	N/A	0.06	0.02	N/A	0	0.04
Rugosity (post-construction)	0.17	0.07	0.09	0.02	0.02	0.08	0.05	0.06	0.03
Max Depth (baseline)(m)	26	24	25	27	24	26	28	27	24
Max Depth (post-construction)(m)	26	26	24	29	23	26	27	27	23

3.2.3 Scleractinian Occurrence

During the four weeks of baseline and post-construction surveys all scleractinian corals 3 cm and larger (tagged and untagged) within the one meter belt transect (20 m) were recorded to species level and assessed for condition. Eighteen scleractinian coral species were documented across the nearshore hardbottom sites during baseline and fourteen species were documented during post-construction surveys, which included one additional species that was not documented in baseline (*Madracis decactis*) (Tables 9 and 10). *Colpophyllia natans, Eusmilia fastigiata, Favia fragum,* and *Siderastrea radians* were documented during baseline surveys but were absent from the hardbottom sites during post-construction (Table 9). Of the four species that were documented in baseline but absent in post-construction surveys, *F. fragum* was represented by a single individual at HBN3-CP during the baseline Week 1 survey. Similarly, three colonies of *E. fastigiata* were observed during baseline Week 2 survey at HBN1-CR. Four *C. natans* were identified during baseline. A single colony of *C. natans* at HBSC1-CP was later reclassified as *Pseudodiploria strigosa*. The other three colonies of *C. natans* were documented at HBS3-CP, two were tagged corals and the other colony was observed once during the baseline Week 4 survey. Of the tagged *C. natans* at HBS3-CP, one tagged colony was reported missing during Compliance Week 18 surveys (March 2014), and the other was reported dead due to white-plague disease during Week 1 of post-construction surveys.

The differences in species presence between baseline and post-construction surveys are likely due to the presence/absence of a few representative colonies that can be influenced by changes in sample area, mortality, and identification accuracy. Since untagged corals were not monitored through compliance, it is not possible to attribute a cause for the loss of those individual species that were untagged colonies. Although we cannot assign causality to the loss of un-monitored corals, mortality at hardbottom monitoring sites among tagged corals was primarily due to white-plague disease, *Solenastrea* and *Oculina* unknown disease, sedimentation, unknown cause, and bleaching (Table 5).

It also should be noted that other long-term coral monitoring studies have documented losses of corals over time. As Gilliam (2012) has noted "Of the original 49 colonies mapped in 2006, 23 were found alive in 2011, two were found dead, and *24 were not found*. During this six year period, greater than 50% of the *O. diffusa*, *S. siderea*, and *D clivosa* colonies became missing (dislodged) and were categorized as not found (NF). *Montastrea cavernosa* appears to be much more stable with 10 of the original colonies still attached and alive" (Gilliam 2012).

During baseline *Siderastrea siderea* and *S. radians* were differentiated where possible. In some cases, colonies were identified as *S. siderea/radians* when the identity was unclear, usually in smaller colonies (<5 cm). Accurate differentiation of these two species is difficult when individuals are small (Edmunds et al. 1998). During compliance monitoring and post-construction surveys, all *Siderastrea* colonies were documented as *Siderastrea* species (sp.). The more general identification carried out through compliance and post-construction monitoring is the reason that no *Siderastrea radians* colonies were recorded during post-construction surveys. For analysis purposes, all *Siderastrea* species have been combined.

HBN1-CR had the lowest number of scleractinian species during both survey periods, while HBS1-CP, HBN3-CP, and HBSC1-CP had the greatest number of species during baseline surveys (11), and HBS1 (11) had the greatest number of species during post-construction. A decline in scleractinian species occurrence occurred at 8 out of 9 sites. One site (HBS1-CP) had the same number of documented species in baseline and post-construction surveys.

Only one coral documented in the hardbottom monitoring sites has been listed as threatened under the Endangered Species Act. A single colony of *Orbicella faveolata* was recorded during post-construction monitoring at HBS1-CP. The colony was a tagged colony and measured approximately 36 cm in diameter in baseline and 37cm in post-construction. This colony is the only coral species across all hardbottom sites that has been listed as threatened under the Endangered Species Act. No other species currently listed under ESA occurred within surveyed hardbottom habitat. Summary tables of all scleractinian species surveyed during each week of baseline and post-construction surveys are provided in Appendix D.

Table 9. Scleractinian species present at each nearshore hardbottom site for all baseline and post-construction weeks. Baseline surveys are designated by a circle and post-construction surveys are designated by a square.

Scleractinian Species	Site								
	HBN1-CR	HBN2-CR	HBN3-CP	HBNC1-CP	HBS1-CP	HBS2-CP	HBS3-CP	HBS4-CR	HBSC1-CP
Colpohyllia natans							•		•
Dichocoenia stokesii		•	• □	• □	• □	• □	• □	• □	• □
Eusmilia fastigiata	•								
Favia fragum			•						
Madracis decactis									□
Meandrina meandrites					□	••	•	□	
Montastrea cavernosa			•		• □		• □		• □
Oculina diffusa		•	• □	••	•	□	• □	• □	
Orbicella faveolata					• □				
Porites astreoides		• □	• □	•	• □	•	•	•	• □
Porites porites			•	• □				•	• □
Pseudodiploria clivosa			• □		• □				•
Pseudodiploria strigosa			□		• □			□	• □
Siderastrea sp.	• □	• □	□	□	□	□	□		
Siderastrea radians	•		•	•	•	•		•	•
Siderastrea siderea	• □	• □	• □	• □	• □	• □	• □	• □	• □
Solenastrea bournoni	• □	• □	• □	• □	• □	• □	• □	• □	• □
Stephanocoenia intersepta		• □	• □	• □	• □	• □	• □	• □	• □

3.2.4 Scleractinian Abundance

Mean scleractinian colony abundance declined at seven out of nine hardbottom sites between baseline and post-construction surveys (Table 10). Abundance data are reported from tagged and non-tagged scleractinian data collected during baseline and post-construction periods within three one meter (1 m) belt transects at all sites. Two sites (HBN1 and HBN2) increased in mean colony abundance, while at HBS1 mean abundance remained relatively unchanged (Table 10).

During baseline, scleractinian colony abundance ranged from 1 (HBN1-CR baseline Week 4) to 63 (HBN3-CP baseline Week 3) colonies across nearshore hardbottom sites. During post-construction assessment period, scleractinian colony abundance ranged from 19 (HBS4-CR post-construction Week 4) to 66 (HBN1-CP post-construction Week 2 and 3) colonies across nearshore hardbottom sites. The increase in scleractinian abundance documented at HBN1 and HBN2 may be attributed to the sand wave that affected HBN1-CP and HBN2-CR during baseline surveys in October-November 2014. During post-construction surveys in June-July of 2015, the sand wave was not present at either site, and more coral colonies were visible when compared to baseline surveys. The change in relative abundance of *S. bournoni* at HBN1-CR between baseline and post-construction surveys is due to the movement of this sand wave. During Week 4 of baseline, one *S. bournoni* at HBN1-CR was the only coral documented, whereas 66 colonies of various species were found in post-construction surveys (Figures 20 and 21).

Table 10. Mean number of scleractinian colonies and species richness for four weeks of baseline and post-construction surveys at nearshore hardbottom sites. The number of species reported below has been revised for baseline values.

Site	Baseline				Post-Construction			
	Number of Colonies		Number of Species	*N*	Number of Colonies		Number of Species	*N*
	Mean	SE			Mean	SE		
HBN1-CR	32.5	10.9	5	4	63.0	1.9	3	4
HBN2-CR	24.3	5.3	6	4	28.8	1.5	5	4
HBN3-CP	53.5	3.8	11	4	40.5	1.0	9	4
HBNC1-CP	47.5	4.8	8	4	25.3	4.4	6	4
HBS1-CP	24.5	0.5	11	4	24.3	2.1	11	4
HBS2-CP	32.0	2.2	8	4	25.0	2.0	6	4
HBS3-CP	51.8	1.8	9	4	29.5	0.3	7	4
HBS4-CR	44.3	1.0	9	4	21.5	1.9	7	4
HBSC1-CP	51.5	2.3	11	4	41.3	1.5	9	4

The decrease in mean number of colonies at all southern sites, particularly at HBS3-CP and HBS4-CR, may be attributed to multiple factors including white-plague disease, sedimentation and bleaching, which affected these sites between baseline and post-construction survey periods (Table 5). At HBS3-CP and HBS4-CR alone, white-plague caused mortality of 58% of all tagged corals. Other unknown diseases affecting *S. bournoni* and *O. diffusa* colonies have also caused mortality of these scleractinians in the southern hardbottom sites. Northern hardbottom sites were not as affected by white-plague because the species composition of northern hardbottom sites (except for HBNC1-CP) had fewer colonies of white-plague disease susceptible species.

A small proportion of species made up the majority of scleractinian colonies at nearshore hardbottom sites. Relative species abundance data are reported from tagged and non-tagged scleractinian data collected during baseline and post-construction periods along one meter belt transects (3) and reported by site (Figures 20-23). Across all sites during both baseline and post-construction, four species predominated: *S. siderea*, *S. intersepta, D. stokesi* and *S. bournoni*. *P. astreoides* contributed as the fifth most abundant species at one or more sites during baseline only. In post-construction, *Siderastrea sp.* replaced *P. astreoides* in the top five most abundant species at the hardbottom sites.

The five most abundant scleractinians during hardbottom baseline surveys constituted 94% of colonies documented at northern channel-side sites (i.e., HBN1-CR, HBN2-CR, and HBN1-CP), and 95% of colonies at the northern control site. The five most abundant scleractinians made up 76% of those documented at the southern channel-side sites (i.e., HBS1-CP, HBS2-CP, HBS3-CP, and HBS4-CR) and 66% of colonies documented at the southern control site (i.e., HBSC1-CP). During post-construction, the five most abundant species constituted 92% of colonies documented at northern channel-side sites, and 96% of colonies at the northern control site. The five most abundant scleractinians made up 82% of those documented at the southern channel-side sites, and 54% of colonies documented at the southern control site.

The southern channel-side sites five most abundant species remained the same between baseline and post-construction, and there was little variation in the relative abundance between these two survey periods (Figures 22 and 23).

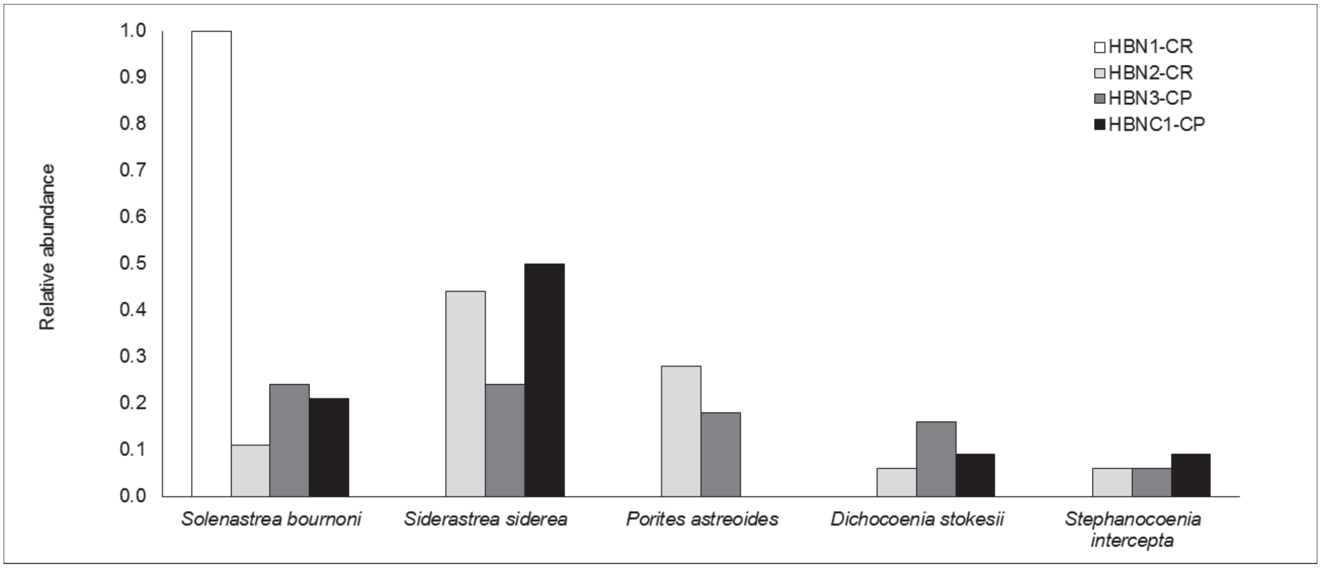

Figure 20. Relative abundance of the five most abundant scleractinian corals at the northern nearshore hardbottom sites in Week 4 of baseline surveys.

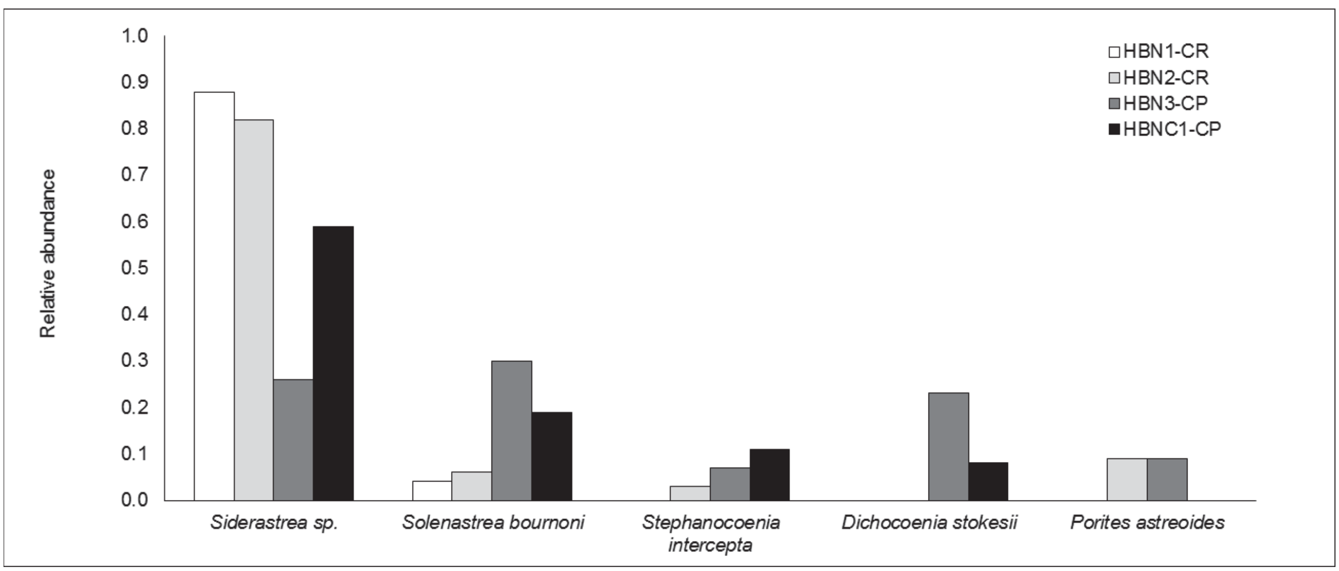

Figure 21. Relative abundance of the five most abundant scleractinian corals at the northern nearshore hardbottom sites in Week 4 of post-construction surveys.

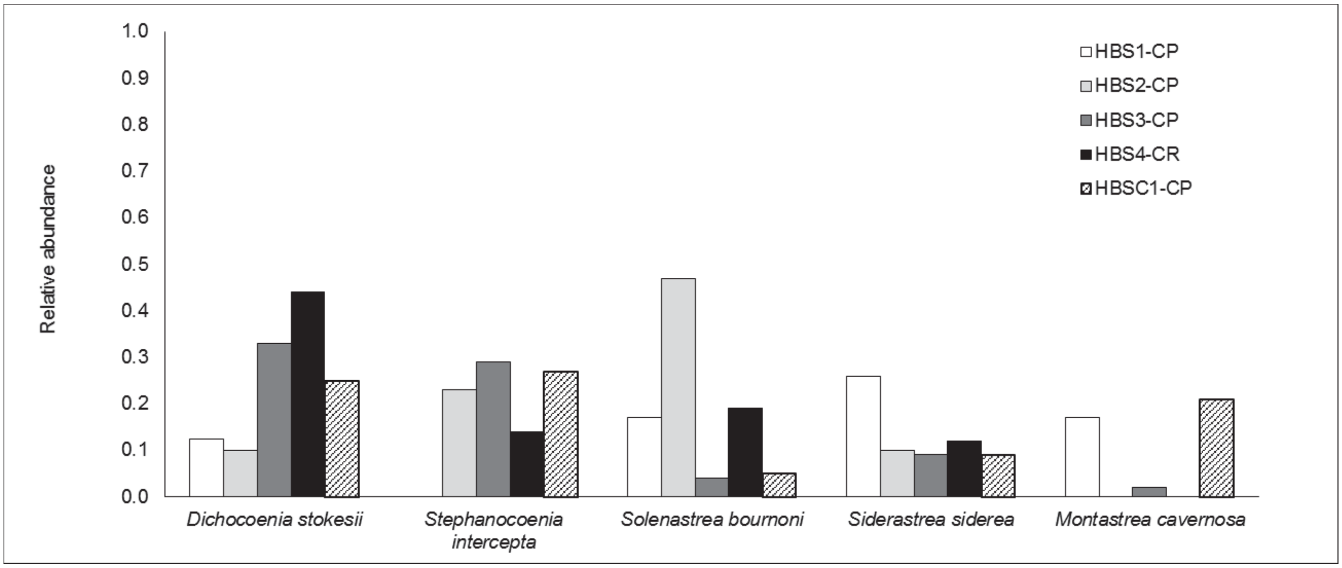

Figure 22. Relative abundance of the five most abundant scleractinian corals at the southern nearshore hardbottom sites in Week 4 of baseline surveys. Baseline calculations were revised for this graph due to transcription errors.

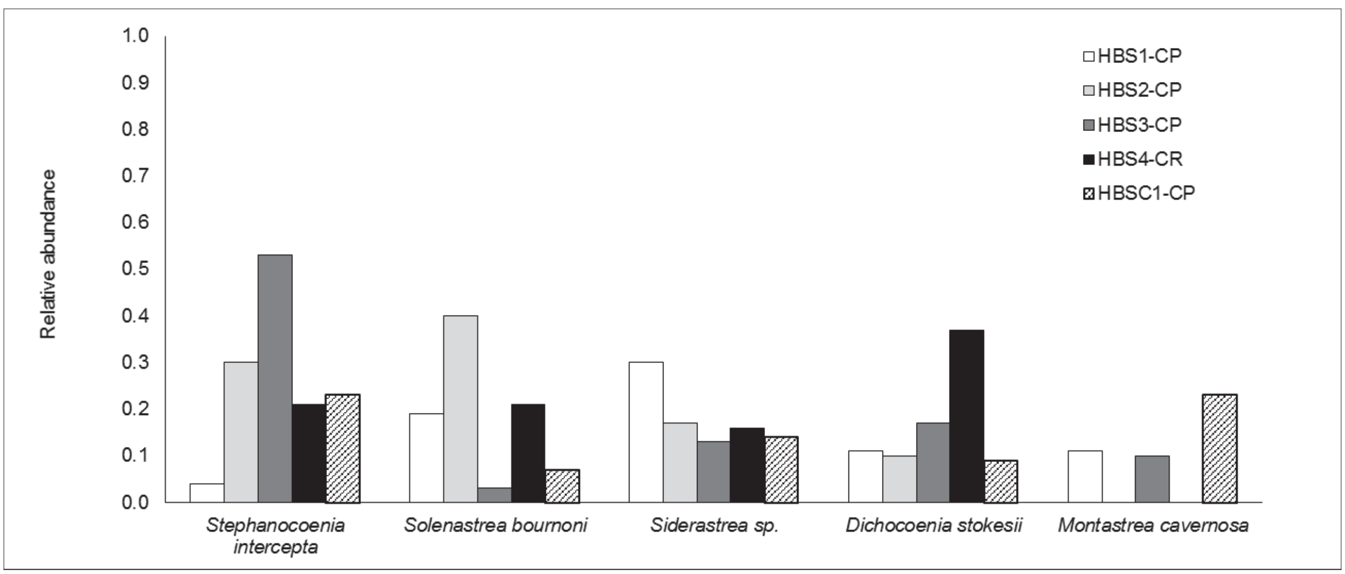

Figure 23. Relative abundance of the five most abundant scleractinian corals at the southern nearshore hardbottom sites in Week 4 of post-construction surveys.

3.2.5 Scleractinian Density

Mean scleractinian site density ranged from 0.36 to 1.05 colonies/m^2across all hardbottom sites in four weeks of post-construction surveys (Table 11). Scleractinian density data are reported from tagged and non-tagged scleractinian data collected during baseline (4 weeks) and post-construction periods (4 weeks) at one meter (1 m) belt transects (3) and reported by site (Figure 24). Mean scleractinian density was lowest at HBS4-CR (0.36 colonies/m^2) and highest at HBN1-CR (1.05 colonies/m^2) (Figure 24, Table 11).

Table 11. Mean scleractinian density (with standard deviation and standard error) among nine hardbottom sites across three permanent transects.

Site	Baseline			Post-Construction		
	Mean Density	SD	SE	Mean Density	SD	SE
HBN1-CR	0.54	0.32	0.09	1.05	0.21	0.06
HBN2-CR	0.41	0.18	0.05	0.48	0.11	0.03
HBN3-CP	0.89	0.19	0.05	0.68	0.12	0.03
HBNC1-CP	0.79	0.22	0.06	0.42	0.22	0.06
HBS1-CP	0.42	0.16	0.05	0.40	0.15	0.04
HBS2-CP	0.53	0.17	0.05	0.42	0.11	0.03
HBS3-CP	0.86	0.13	0.04	0.49	0.11	0.03
HBS4-CR	0.74	0.11	0.03	0.36	0.09	0.03
HBSC1-CP	0.86	0.20	0.06	0.69	0.12	0.03

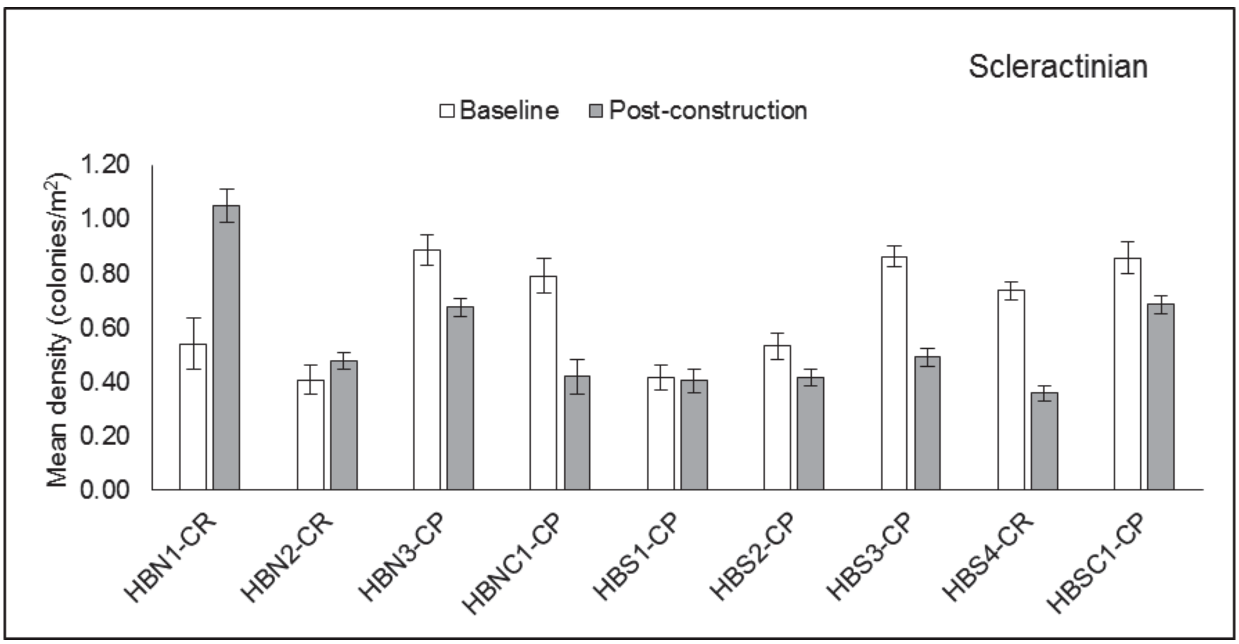

Figure 24. Mean density of scleractinian colonies at nearshore hardbottom sites across all four weeks of baseline and post-construction surveys. Error bars represent the standard error for each site. Baseline calculations were revised for this graph due to a transcription error.

In baseline surveys, a one-way ANOVA was used to determine if mean coral density was different over the nine sites of the hardbottom survey area. Mean site density, expressed as the mean number of coral colonies per square meter over the four weeks of baseline assessment, were normally distributed (Anderson–Darling tests, $P > 0.05$ in all cases) and the variances were heterogeneous (Levene's test, *P* =.258). Significant effects of site were detected (F = 5.962, P =.001; Table 12). Tukey HSD post-hoc analysis revealed that there was a significant increase in coral density from HBN2 (mean density 0.40 corals/m^2) and HBS1 (mean density 0.41 corals/m^2) to HBN3 (mean density 0.89 corals/m^2), HBS3 (mean density 0.86 corals/m^2), and HBSC1 (mean density 0.86 corals/m^2). These sites represented the lowest and highest coral density sites respectively. Although the previous site groupings were the only significant differences among the nine survey sites, there was a general trend of lower coral densities (mean density ≤ 0.53 corals/m^2) near the channel jetty (sites HBN1, HBN2, HBS1 and HBS2) than further away (mean density ≥ 0.74 corals/m^2 at HBN3, HBNC1, HBS3, HBS4, and HBSC1). Increased tidal currents and land-based influences may limit coral density at the near-jetty sites.

Table 12. One-way ANOVA results testing the difference in scleractinian density over the nine hardbottom sites during the baseline surveys.

Source of variation	df	MS	*F*	*P*-value
Between Sites	8	0.111	5.962	0.001
Within Sites	18	0.019		
Error	260			

In the post-construction period, a two-way repeat measures ANOVA was used to determine if mean coral density was different among the nine hardbottom sites between the baseline and post-construction assessment periods. Data were collected over four weeks for each assessment period. Mean site densities were normally distributed (Anderson-Darling test, P>0.05), in all cases except HBS3-CP, (Anderson-Darling test, P=0.0473). LOG and square-root transformations were applied to HBS3-CP densities, however even with these transformations, the results did not deviate from the original p-value, and therefore the ANOVA was performed using non-transformed data. Significant effects among the sites between the assessment periods were detected (F = 12.40, P < 0.0001; Table 13). Significant differences were detected in mean coral density between assessment periods (F = 17.25, P = 0.001), sites (F = 12.89, P < 0.0001), and a significant effect was detected based on the interaction of period and site (F = 11.30, P < 0.0001) (Table 14). A Bonferroni adjustment was used to create a pairwise comparison of the interaction effect.

Table 13. Two-way ANOVA results testing the difference in scleractinian density among and between the nine hardbottom sites between the two assessment periods.

Source of variation	DF	Sum of Squares	Mean Square	F Value	Pr > F
Between Sites	17	3.01603781	0.17741399	12.40	<.0001
Within Sites	54	0.77284722	0.01431199		
Corrected Total	71	3.78888503			

Table 14. Two-way ANOVA results testing the effects of the two assessment periods (baseline and post-construction), the effects of coral locations, and the interaction between the two effects on scleractinian density among the nine hardbottom survey areas.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Period	1	0.24694830	0.24694830	17.25	0.0001
Site	8	1.47537809	0.18442226	12.89	<.0001
Period*Site	8	1.29371142	0.16171393	11.30	<.0001

Additional Tukey post-hoc comparisons were performed on non-transformed and transformed data to determine significant differences of mean coral density between sites during the post-construction assessment period and among individual sites between the baseline and post-construction assessment periods. Significant differences were detected between the sites during the post-construction period (F = 37.91, P < 0.001, Table 15). Mean coral density was significantly different at HBN1-CR (mean density 1.05) from all other sites, HBSC1-CP (mean density 0.69) and HBN3-CP (mean density 0.68) were significantly different from all other sites (mean densities ≤ 0.49, Table 11), but were not significantly different from each other (Table 15, Figure 24).

Table 15. Tukey post-hoc comparisons of mean coral density differences among sites for the post-construction assessment period.

Data type	Test statistic (p-value)	**Tukey post-hoc comparison** (sites with same letter indicated in superscript are not statistically significant)		
Non-transformed	F=37.91 (p<0.0001)	HBN1-CR^{A}	HBSC1-CP^{B} HBN3-CP^{B}	HBS3-CP^{C} HBN2-CR^{C} HBNC1-CP^{C} HBS2-CP^{C} HBS1-CP^{C} HBS4-CR^{C}

The Tukey post-hoc comparisons of mean density among individual sites between baseline and post-construction were performed on non-transformed data. Significant differences were detected at six of the nine sites. A significant increase in mean density occurred at HBN1-CR, where mean density nearly doubled from 0.54 to 1.05 colonies/m^2 (F = 8.17, P = 0.0289, Table 16, Figure 24). Significant decreases were detected at HBN3-CP (F = 10.39, P = 0.0181), HBNC1-CP (F = 11.47, P = 0.0147), HBS3-CP (F = 149.45, P < 0.0001), HBS4-CR (F = 111.40, P < 0.0001), and HBSC1-CP (F = 13.45, P = 0.0105) (Table16, Figure 24). HBS4-CR experienced the greatest decrease from 0.74 to 0.36 colonies/m^2.

The increased density at HBN1-CR may be explained by the lack of sand cover at this site during the post-construction period, when almost twice as many coral colonies were documented at the site. As discussed in Section 3.1, the decrease in scleractinian density at the other hardbottom sites is likely due to the combined effects of, in order of severity, white-plague disease, other coral diseases, sediment related mortality, unknown causes, and coral bleaching (Table 5).

Table 16. Tukey post-hoc comparisons of mean coral density within individual sites from baseline and post-construction assessment periods (superscripts indicate a significant difference between survey periods).

Site	Test statistic (p-value)	Tukey post-hoc comparison
HBN1-CR	F=8.17(p=0.0289)	Post-construction^{A}, Baseline^{B}
HBN2-CR	NS	(trend) Post-construction > Baseline
HBN3-CP	F=10.39 (p=0.0181)	Baseline^{A}, Post-construction^{B}
HBNC1-CP	F=11.47 (p=0.0147)	Baseline^{A}, Post-construction^{B}
HBS1-CP	NS	(trend) Baseline > Post-construction
HBS2-CP	NS	(trend) Baseline > Post-construction
HBS3-CP	F=149.45 (p<0.0001)	Baseline^{A}, Post-construction^{B}
HBS4-CR	F=111.40 (p<0.0001)	Baseline^{A}, Post-construction^{B}
HBSC1-CP	F=13.45 (p=0.0105)	Baseline^{A}, Post-construction^{B}

3.2.6 Scleractinian Colony Size

During baseline surveys maximum diameter measurements (cm) were collected for northern hardbottom site scleractinians only. During post-construction maximum diameter data were collected for all hardbottom sites, north and south. Measurements for scleractinians were grouped according to size class for comparison purposes (Figure 25-27). Maximum diameter of each scleractinian colony was collected at all hardbottom sites during post-construction. Summary tables of coral size class data from baseline and post-construction surveys are provided in Appendix F.

The majority of scleractinian corals at northern hardbottom sites, including control sites were 15 cm or less in maximum diameter during baseline and post-construction surveys. When comparing northern hardbottom baseline and post-construction survey results, the group of corals within the smallest size class, increased in the post-construction period, across sites, while the corals within the 6-15 cm size class declined slightly. The larger size classes (16 cm and above) declined slightly (HBN2-CR) or were similar to baseline values. An explanation for the increase in small size class corals at northern hardbottom sites may be due to sampling timing. Baseline surveys were conducted in the fall/winter when northern hardbottom sites were under the influence of the natural sand wave and may have obscured or buried scleractinians that were exposed in post-construction surveys (summer of 2015).

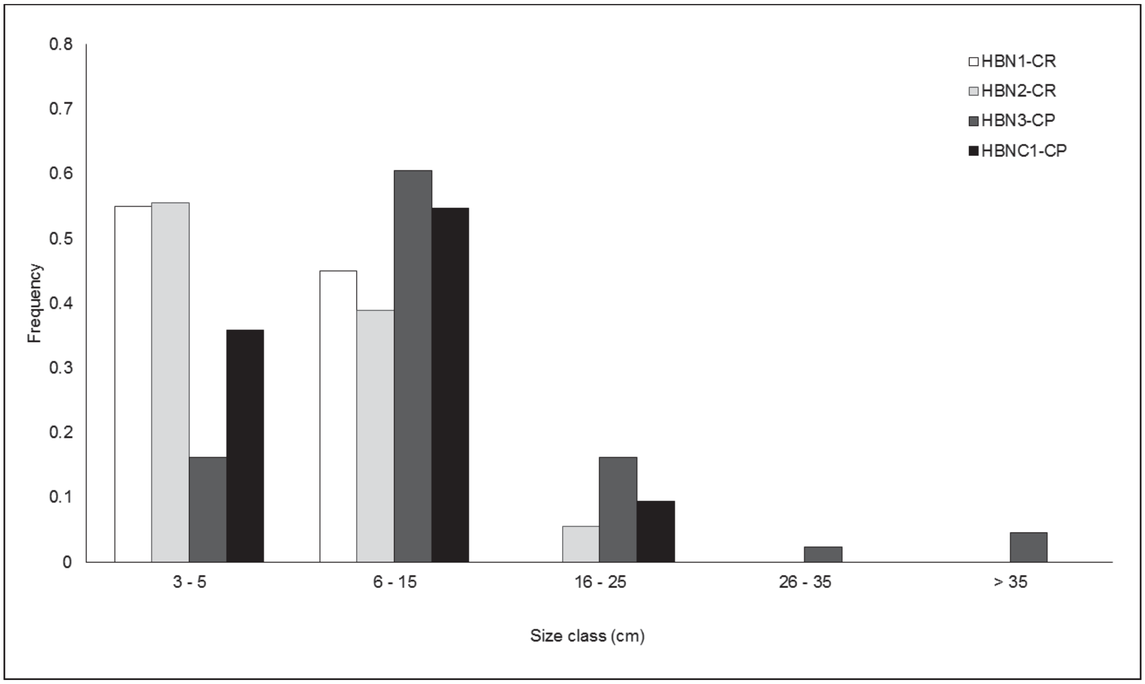

Figure 25. **Proportion of scleractinian coral colonies by size class at northern hardbottom sites during baseline surveys.**

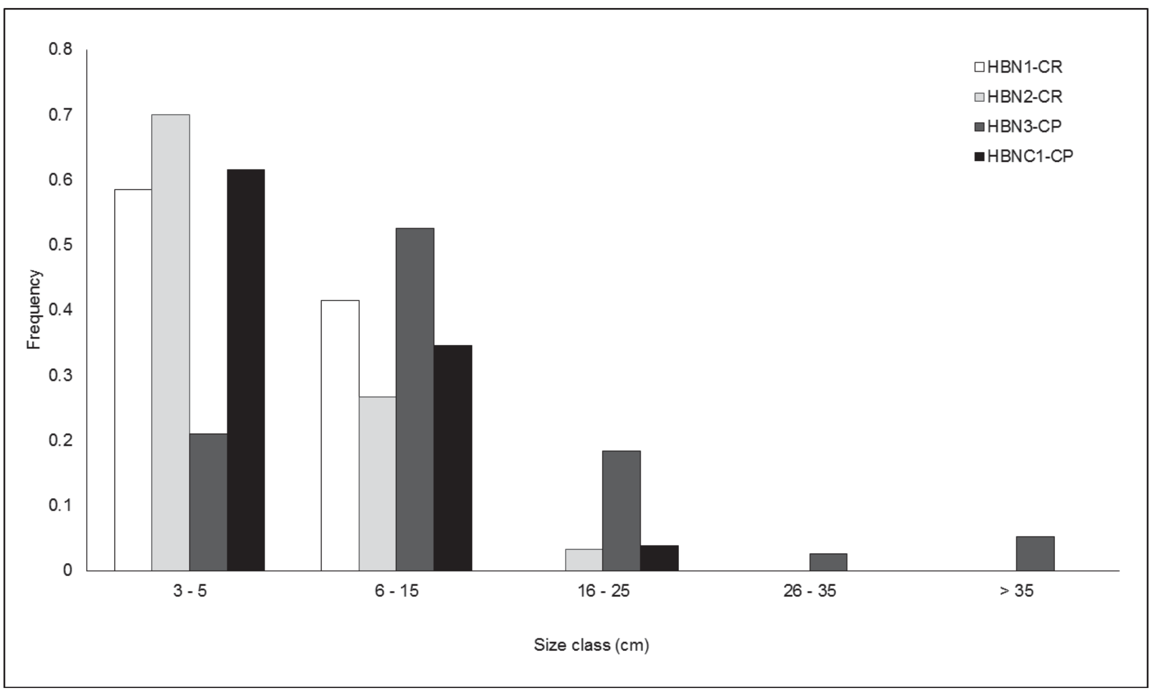

Figure 26. **Proportion of scleractinian coral colonies by size class at northern hardbottom sites during post-construction surveys.**

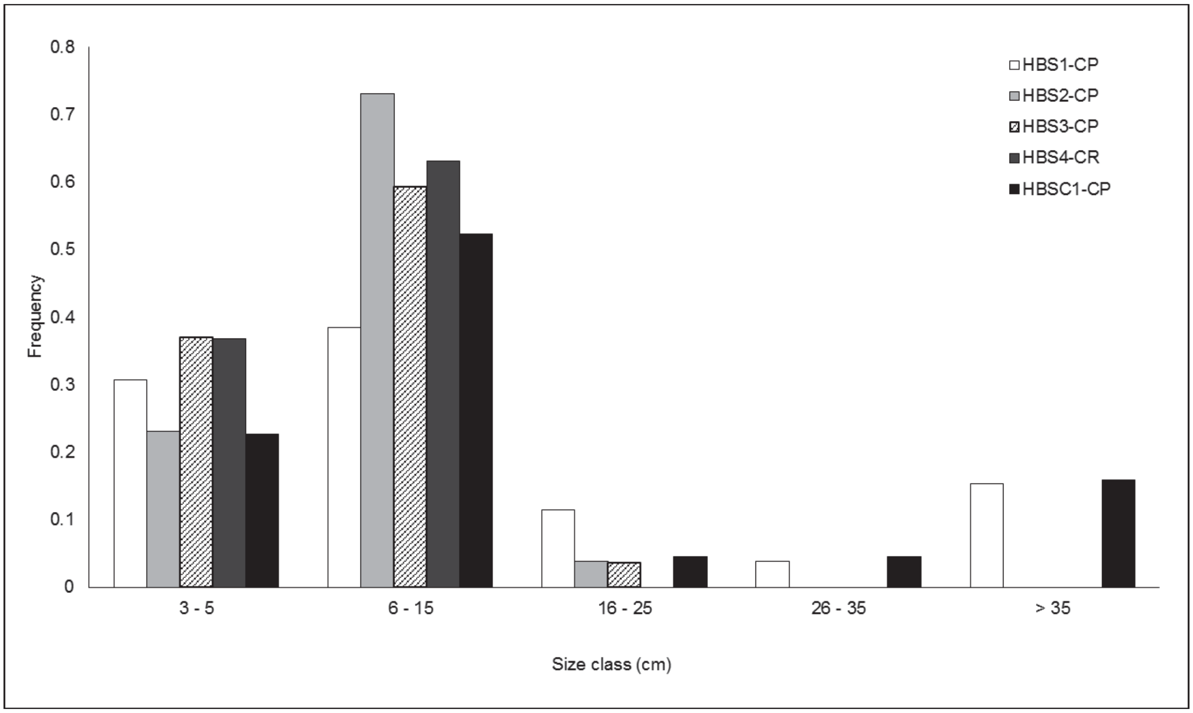

Figure 27. Proportion of scleractinian coral colonies by size class at southern hardbottom sites during post-construction surveys.

Southern hardbottom sites were similar to northern hardbottom sites in that corals in the two smallest size class represented the greatest number of individual coral colonies.

3.2.7 Scleractinian Diversity and Evenness

The Shannon–Wiener diversity Index (H') was used to calculate species diversity. Diversity (H') values ranged from 0.31 to 2.11 across hardbottom sites during post-construction. The HBN1-CR diversity value (0.69) remained low when compared to the rest of the hardbottom sites, and between baseline and post-construction, because this site is colonized mostly by *Siderastrea* species. Evenness (J') ranged from 0.05 to 0.41 across nearshore hardbottom sites and was also lowest at HBN1-CR during both baseline and post-construction surveys (Table 7). Five out of nine sites declined in diversity, while evenness changed at only three compliance sites between baseline and post-construction. Changes in diversity may be explained by the loss of rare species at hardbottom monitoring sites and the species-specific nature of the white-plague disease event discussed previously (Section 3.1).

Table 17. Shannon–Wiener Diversity Index (H') and Evenness (J') calculated for observed scleractinian species present at nearshore hardbottom sites during baseline and post-construction surveys.

Site	H'		J'	
	Baseline	Post-construction	Baseline	Post-construction
HBN1-CR	0.69	0.31	0.13	0.05
HBN2-CR	1.21	1.58	0.26	0.31
HBN3-CP	1.91	1.75	0.31	0.31
HBNC1-CP	1.74	1.64	0.31	0.32
HBS1-CP	2.02	2.11	0.44	0.42
HBS2-CP	1.60	1.30	0.33	0.25
HBS3-CP	1.66	1.67	0.29	0.31
HBS4-CR	1.59	1.55	0.31	0.31
HBSC1-CP	1.94	2.01	0.36	0.37

3.2.8 Scleractinian Condition

Scleractinian colony-condition data were collected for all tagged and non-tagged scleractinians (3 cm and greater in maximum diameter) surveyed during baseline and post-construction surveys, within each one meter (1 m) belt transect (3), at each site. Condition categories were described in the methods (Section 2.2.3) and included in the evaluative criteria defined in the FDEP permit. An average of 37% of scleractinians surveyed in baseline exhibited one or more conditions, while 73% of scleractinians surveyed in post-construction showed one or more conditions. The five dominant conditions at northern and southern hardbottom sites for baseline and post-construction are below described in Section 3.2.9.

During post-construction surveys, the same diseases observed in baseline were reported in the hardbottom areas – white-plague disease and the unidentified disease in colonies of *S. bournoni*. White-plague disease only occurred in one colony of *D. stokesi* at HBS3-CR during baseline. During post-construction surveys, active white-plague was recorded at five different sites (HBN3-CP, HBS2-CP, HBS3-CP, HBS4-CR, and HBSC1-CP), affecting 7.7% of all surveyed coral colonies, among four different species (*M. cavernosa, S. intersepta, S. bournoni* and *D. stokesi)*.

The unknown disease only occurred in *S. bournoni,* and was recorded on 36% of tagged *S. bournoni* colonies across all four weeks of post-construction surveys.

3.2.9 Spatial Analysis of Coral Condition

Coral condition, as measured by the proportion of stressed corals present at hardbottom sites, was affected by sampling location. The five predominant scleractinian stress indicators were different between baseline and post-construction, and were different between northern sites and southern sites (Figures 28-31). During the baseline period, the top five stress conditions overall were sediment stress, polyps extended, mucus production, unknown disease and fish bites (Figure 28), and these five stressors were originally present at both northern and southern sites. A reporting error was identified from the baseline report and Figure 30 (southern sites – baseline) was revised in this report due to transcription errors, as the five predominant stressors at southern sites were different from the ones at northern sites during baseline. The five most dominant stressors at southern sites during baseline were physical disturbance, polyps extended, unknown partial mortality, sediment stress, and fish bites (Figure 30).

During the post-construction period, the top five stress conditions at northern hardbottom sites were sediment stress, polyps extended, paling, physical disturbance, and unknown partial mortality (Figure 29). At the southern hardbottom sites, the five predominant stress conditions were sediment stress, polyps extended, paling, unknown partial mortality and white-plague disease. These categories are presented here for comparison. “Sediment stress” included sediment accumulation, partial burial and/or burial during baseline and post-construction surveys. During baseline surveys, partial burial and burial conditions were only witnessed at HBN1-CR due to the natural sand wave event.

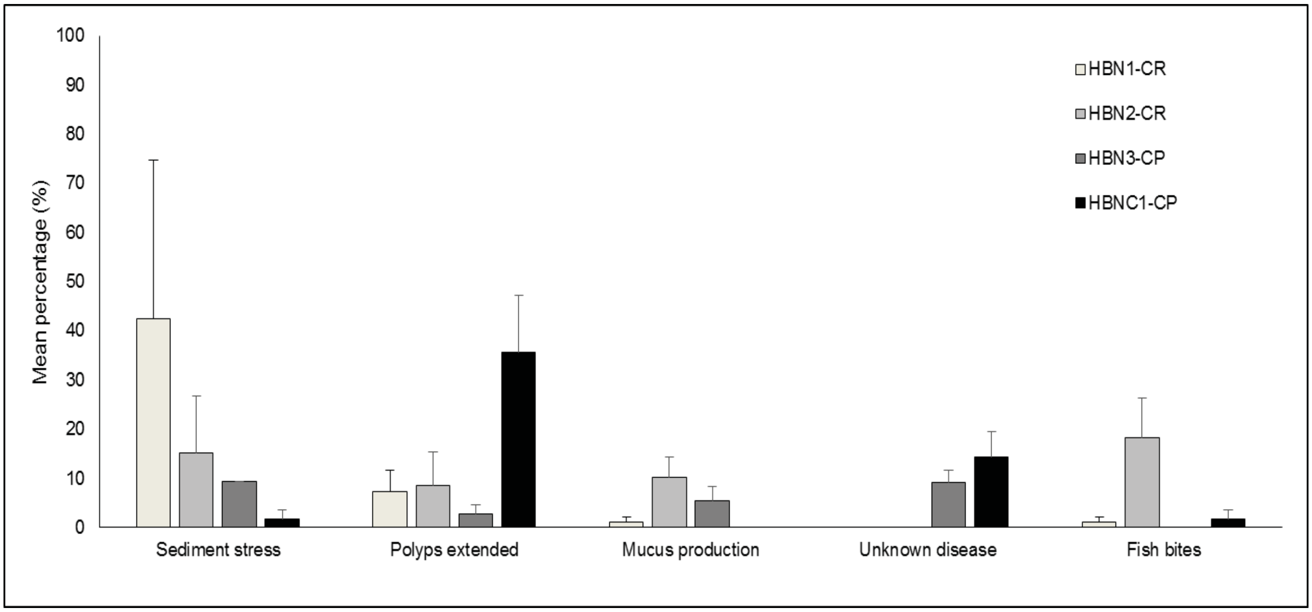

Figure 28. Mean percentage of the five most predominant scleractinian stress indicators across all four weeks of baseline surveys in the northern hardbottom sites amongst tagged coral colonies. Error bars represent the standard error for each site mean.

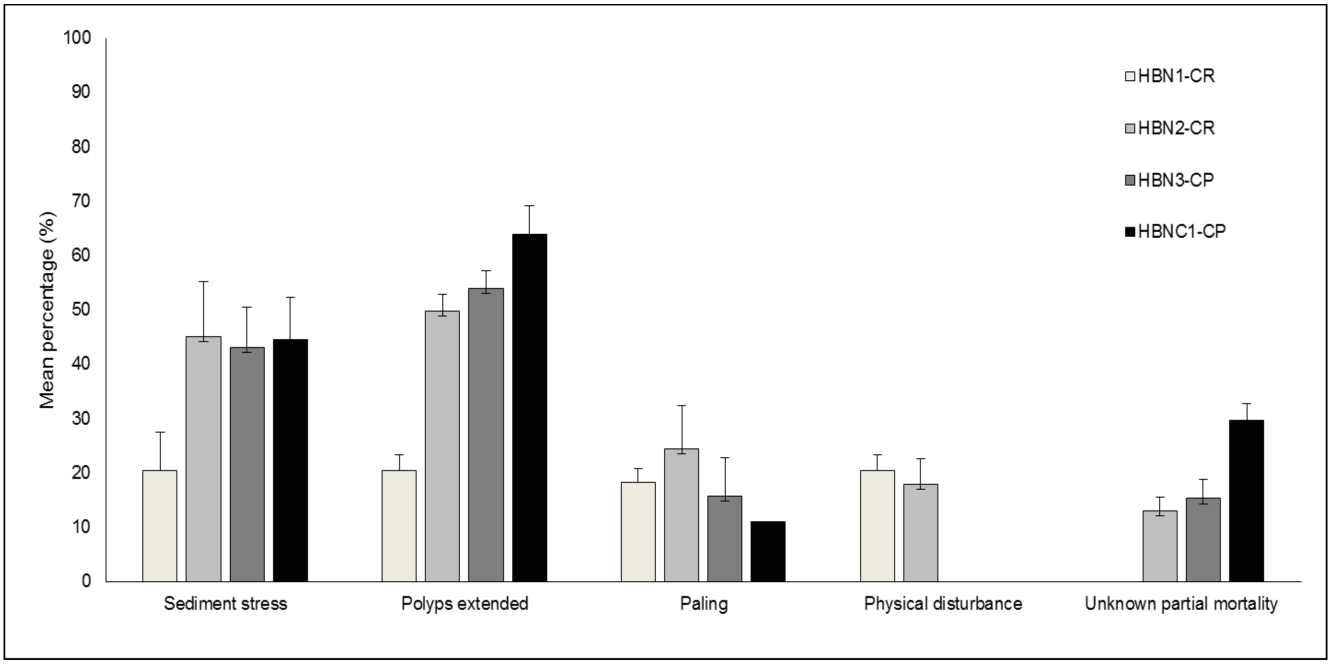

Figure 29. Mean percentage of the five most predominant scleractinian stress indicators across all four weeks of post-construction surveys in the northern hardbottom sites amongst tagged coral colonies. Error bars represent the standard error for each site mean.

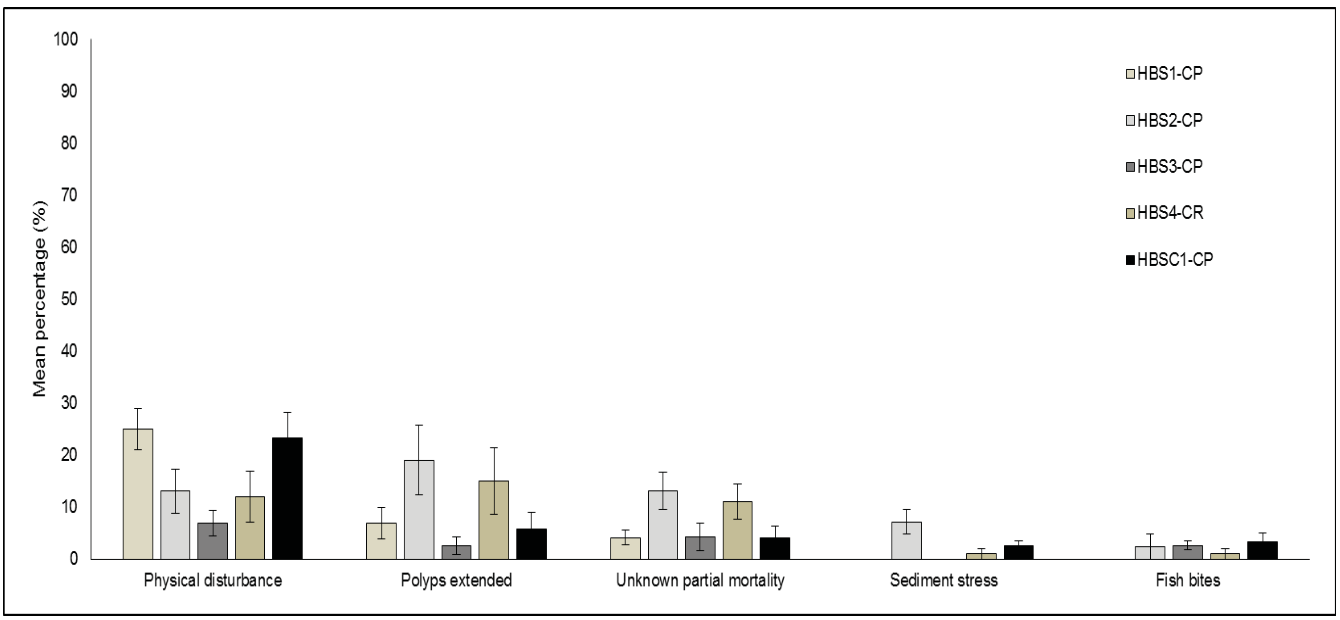

Figure 30. Mean percentage of the five most predominant scleractinian stress indicators across all four weeks of baseline surveys in the southern hardbottom sites amongst tagged coral colonies. Error bars represent the standard error for each site mean. Baseline calculations were revised for this graph due to transcription errors (top 5 stressors for south sites were different from north).

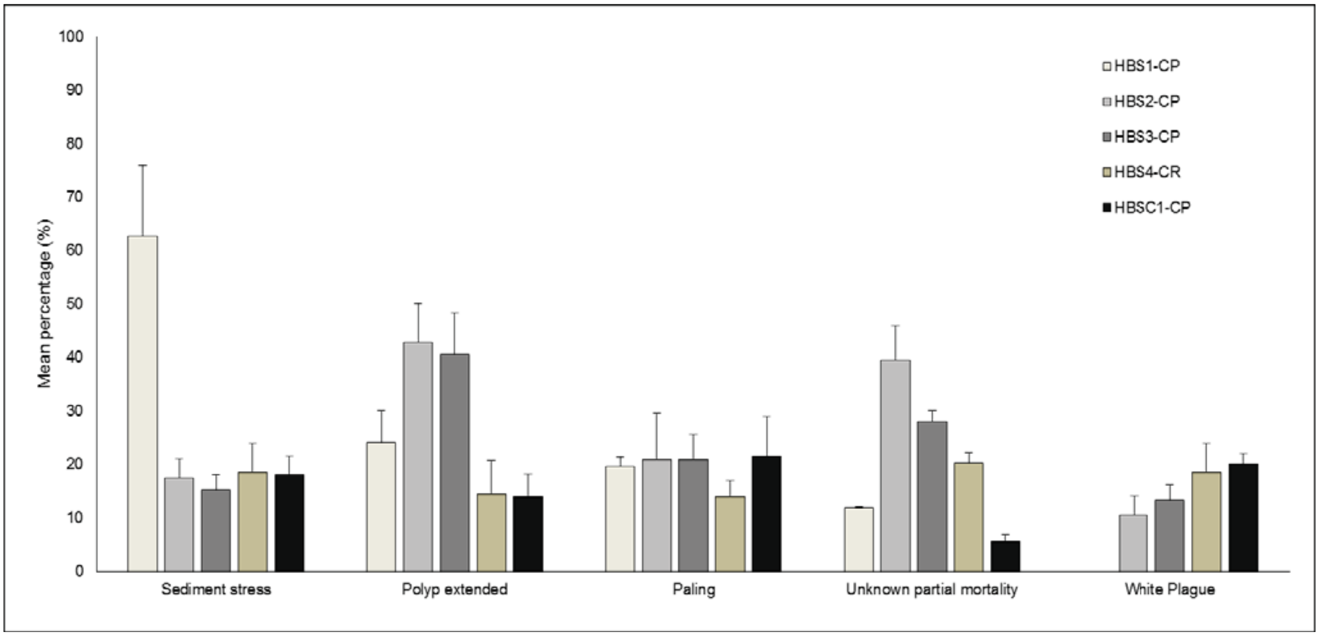

Figure 31. Mean percentage of the five most predominant scleractinian stress indicators across all four weeks of post-construction surveys in the southern hardbottom sites amongst tagged coral colonies. Error bars represent the standard error for each site mean.

During post-construction in the northern hardbottom sites, sediment stress, polyps extended and paling were the majority of stress conditions at northern hardbottom sites. Interestingly, HBN1-CR levels of all top five conditions were lower when compared to other channel-side and control sites, except for "physical disturbance" (Figure 29).

June and July 2015 were the hottest months on record (NOAA 2015c), and increased sea surface temperatures likely caused coral colonies to become pale during this time.

During post-construction in the southern hardbottom sites, paling, unknown partial mortality and white-plague disease were part of the five most dominant stress indicators (Figure 31). Active white-plague disease and white-plague associated mortality were most prevalent in the southern sites, particularly at HBS3-CP, HBS4-CR and HBSC1-CP, where more than half of the tagged colonies at each site died from white-plague disease, or showed signs of active white-plague disease (see Section 3.1.2).

Sediment stress was elevated at HBS1-CP during the post-construction study period, when compared to baseline surveys. While this site was not buried by the natural sand wave similar to HBN1-CR and HBN2-CR, it is likely the site was affected by littoral drift resulting from nearshore tidal influences. HBS1-CP is located close to the jetties at the opening of Government Cut, and is susceptible to strong currents and coarse-sediment movement and turbidity during outgoing tides (DCA personal observations).

3.2.10 Temporal Analysis of Coral Condition

In addition to spatial patterns, temporal trends in condition metrics over the four weeks of baseline and post-construction sampling were also tested. The mean proportion of stressed corals at each site is presented for all four weeks of baseline sampling in Table 18, and all four weeks of post-construction in Tables 19 and 20.

During baseline, coral condition as expressed as the proportion of stressed corals in each hardbottom transect, changed significantly over the four weeks of data collection (Friedman's Test, $\chi^2(3) = 10.69$, $P = .013$). Post-hoc pairwise tests indicated that proportion of stressed corals at hardbottom sites in Week 1 surveys were significantly less than in Week 4, and that the proportion of stressed corals at hardbottom sites in Week 2 was significantly less than in Week 3 and Week 4 (Table 20). These significant differences in condition were due to winter storm events that affected the area in the second half of baseline surveys.

The recently documented high levels of scleractinian coral mortality attributed to the white-plague disease event created a confounding factor when examining total coral stress data from compliance monitoring sites. As part of the field survey method, tagged colonies which have documented total colony mortality are scored as a "1" to indicate coral stress. As a result, sites with high coral mortality continue to have high stress values, regardless of other stressors acting on living corals (i.e. sediment stress, disease). Prior to the white-plague disease event, no compliance monitoring site contained more than 4 tagged colonies that had undergone total colony mortality. As a result, the confounding effect of coral mortality was limited to a small proportion of all coral stress data. With the emergence of the white-plague disease event, as many as 17 tagged colonies per compliance monitoring site have experienced total colony mortality. In order to clearly present these data, mean colony condition score is presented for post-construction in two forms, first with dead colonies given a stress score of "1" (Table 19), and then with dead colonies removed from total scleractinian stress results (Table 20). The intent of the FDEP mandated monitoring program was to determine the nature and extent of project related permanent impact associated with dredging activities. Therefore, removal of the dead colonies, especially those that died as a result of white-plague disease, from this assessment allows for a clearer representation of stress and impacts associated with the project.

In post-construction surveys, a Friedman's Test ($\chi^2(3) = 2.69$, $p = 0.44$) indicated that coral condition did not change significantly over the post-construction period of four weeks.

Temporal comparisons between baseline and post-construction survey sites were made using a ranked one-way ANOVA. Tukey's post-hoc comparison revealed all sites except HBN1-CR had significantly higher levels of coral stress during the post-construction period, when compared to the baseline period (Table 21). At HBN1-CR coral stress was lower during post-construction than during baseline surveys. The reduction in coral stress at HBN1-CR is attributable to the sand wave that greatly affected this site during baseline surveys. Since coral condition was significantly higher during post-construction at all channel-side and control sites (with the exception of HBN1-CR), the increase is likely the result of the ongoing regional stressors related to the bleaching and disease events.

Table 18. Mean (and standard deviation) of colony condition score over four weeks of baseline data collection at all hardbottom sites.

	Week 1		Week 2		Week 3		Week 4		Baseline	
Site	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
HBN1-CR	0.35	0.49	0.43	0.51	0.52	0.51	1.00	0.00	0.58	0.29
HBN2-CR	0.53	0.52	0.60	0.51	0.67	0.49	0.43	0.51	0.56	0.10
HBN3-CP	0.41	0.50	0.22	0.42	0.52	0.51	0.52	0.51	0.42	0.14
HBNC1-CP	0.57	0.51	0.43	0.51	0.43	0.51	0.64	0.50	0.52	0.11
HBS1-CP	0.33	0.49	0.33	0.49	0.28	0.46	0.33	0.49	0.32	0.03
HBS2-CP	0.33	0.48	0.29	0.46	0.48	0.51	0.48	0.51	0.39	0.10
HBS3-CP	0.10	0.31	0.17	0.38	0.28	0.45	0.24	0.44	0.20	0.08
HBS4-CR	0.24	0.44	0.20	0.41	0.32	0.48	0.32	0.48	0.27	0.06
HBSC1-CP	0.20	0.41	0.33	0.48	0.43	0.50	0.33	0.48	0.33	0.10

Table 19. Mean (and standard deviation) of colony condition score over four weeks of post-construction data collection at all hardbottom sites, including dead colonies.

	Week 1		Week 2		Week 3		Week 4		Post-Construction	
Site	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
HBN1-CR	0.59	0.50	0.55	0.51	0.68	0.48	0.59	0.50	0.60	0.06
HBN2-CR	0.92	0.28	1.00	0.00	0.92	0.29	0.92	0.29	0.94	0.04
HBN3-CP	0.88	0.34	0.88	0.34	0.96	0.20	0.96	0.20	0.92	0.05
HBNC1-CP	0.92	0.29	0.83	0.39	0.83	0.39	0.92	0.29	0.88	0.05
HBS1-CP	0.76	0.44	0.89	0.32	0.67	0.49	1.00	0.00	0.83	0.15
HBS2-CP	1.00	0.00	1.00	0.00	1.00	0.00	0.94	0.24	0.99	0.03
HBS3-CP	0.92	0.27	0.92	0.27	1.00	0.00	0.92	0.27	0.94	0.04
HBS4-CR	0.83	0.38	0.92	0.28	0.96	0.20	0.92	0.28	0.91	0.05
HBSC1-CP	0.67	0.48	0.77	0.43	0.80	0.41	0.90	0.31	0.78	0.10

Table 20. Mean (and standard deviation) of colony condition score over four weeks of post-construction data collection at all hardbottom sites, excluding dead colonies.

	Week 1		Week 2		Week 3		Week 4		Post-Construction	
Site	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
HBN1-CR	0.59	0.50	0.55	0.51	0.68	0.48	0.59	0.50	0.60	0.06
HBN2-CR	0.92	0.29	1.00	0.00	0.91	0.30	0.91	0.30	0.93	0.04
HBN3-CP	0.86	0.36	0.84	0.37	0.95	0.23	0.95	0.23	0.90	0.06
HBNC1-CP	0.89	0.33	0.78	0.44	0.78	0.44	0.89	0.33	0.83	0.06
HBS1-CP	0.75	0.45	0.88	0.33	0.65	0.49	1.00	0.00	0.82	0.15
HBS2-CP	1.00	0.00	1.00	0.00	1.00	0.00	0.93	0.27	0.98	0.04
HBS3-CP	0.80	0.42	0.80	0.42	1.00	0.00	0.78	0.44	0.84	0.10
HBS4-CR	0.71	0.47	0.83	0.39	0.92	0.29	0.82	0.40	0.82	0.08
HBSC1-CP	0.58	0.50	0.71	0.46	0.74	0.45	0.87	0.34	0.73	0.12

Table 21. Baseline and post-construction comparison of scleractinian density using a ranked one way ANOVA with a Tukey's post-hoc comparison (superscripts indicate a significant difference between survey periods).

Site	Test statistic (p-value)	Tukey post-hoc comparison
HBN1-CR	NS	(trend) Baseline > Post-construction
HBN2-CR	F=13.68, p=0.0101	Post-construction^{A}, Baseline^{B}
HBN3-CP	F=35.58, p=0.0010	Post-construction^{A}, Baseline^{B}
HBNC1-CP	F=18.88, p=0.0048	Post-construction^{A}, Baseline^{B}
HBS1-CP	F=34.51, p=0.0011	Post-construction^{A}, Baseline^{B}
HBS2-CP	F=91.42, p<0.0001	Post-construction^{A}, Baseline^{B}
HBS3-CP	F=99.85, p<0.0001	Post-construction^{A}, Baseline^{B}
HBS4-CR	F=97.71, p<0.0001	Post-construction^{A}, Baseline^{B}
HBSC1-CP	F=25.25, p=0.0024	Post-construction^{A}, Baseline^{B}

3.2.11 Temporal Analysis of Individual Condition Metrics

Sediment accumulation, polyp extension, unknown disease, excess mucus and fish bites were the top five coral stress indicators during the four weeks of baseline assessment. The relative proportion of corals exhibiting each of these stress indicators in a given week for baseline and post-construction is shown in Figure 32 and 33. Only sediment accumulation is reported in Figure 32 (baseline), since HBN1-CR data were removed from the analysis and was the only site where partial burial and burial were recorded. Sediment stress for post-construction data were calculated by combining sediment accumulation, partial burial, and burial values (Figure 33).

The significant increase in sediment accumulation scores following the second week of baseline sampling demonstrated that this metric was sensitive enough to respond to the winter storm events of Week 3 and Week 4.

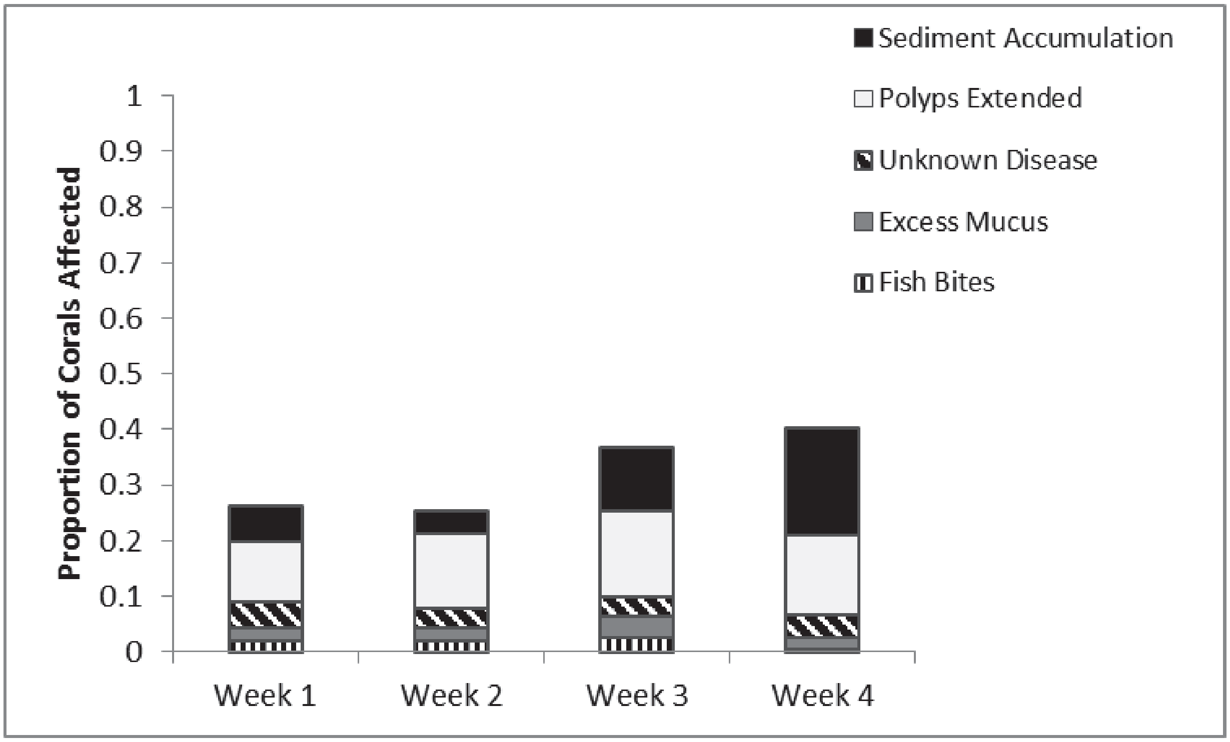

Figure 32. Weekly proportion of tagged corals exhibiting the top five stress indicators over the four weeks of baseline assessment. HBN1 was not included due to complete burial by the natural sand wave event in Week 4. Only sediment accumulation is reported here since HBN1-CR data were removed from the analysis and was the only site where partial burial and burial were recorded

During post-construction surveys, the top five stress indicators at the northern-side sites were sediment stress (sediment accumulation, partial burial and burial), polyps extended, paling, physical disturbance and unknown partial mortality. The relative proportion of corals exhibiting each of these stress indicators in a given week is shown in Figure 33.

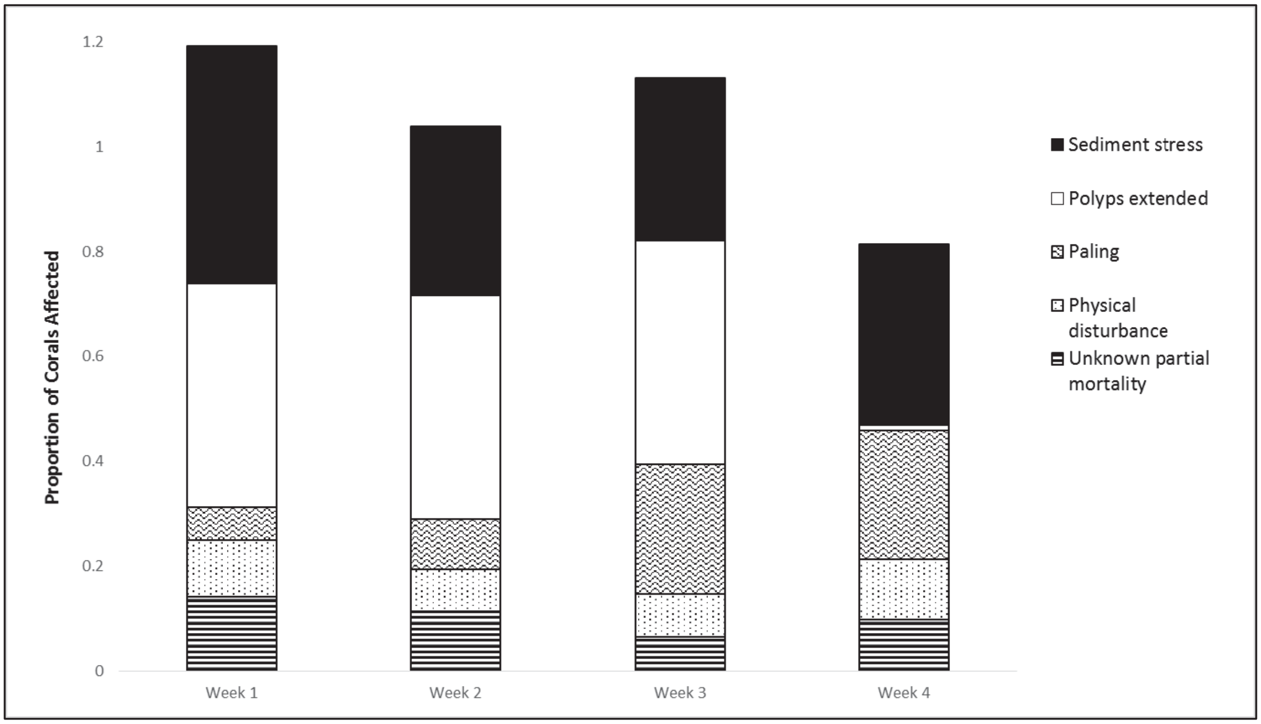

Figure 33. Weekly proportion of tagged corals exhibiting the top five stress indicators at the northern hardbottom sites over the four weeks of post-construction assessment.

The southern-side sites (channel-side and control) exhibited different top five stress indicators from the northern side sites (channel-side and control). Sediment stress, polyps extended, paling, unknown partial mortality and white-plague disease were the most recorded stressors over the four weeks of post-construction surveys. The relative proportion of corals exhibiting each of these stress indicators in a given week is shown in Figure 34. While the top five stress indicators differed between the northern and southern sites, the proportion of paling increased over the four week survey period for both northern and southern hardbottom sites (Section 3.1.6).

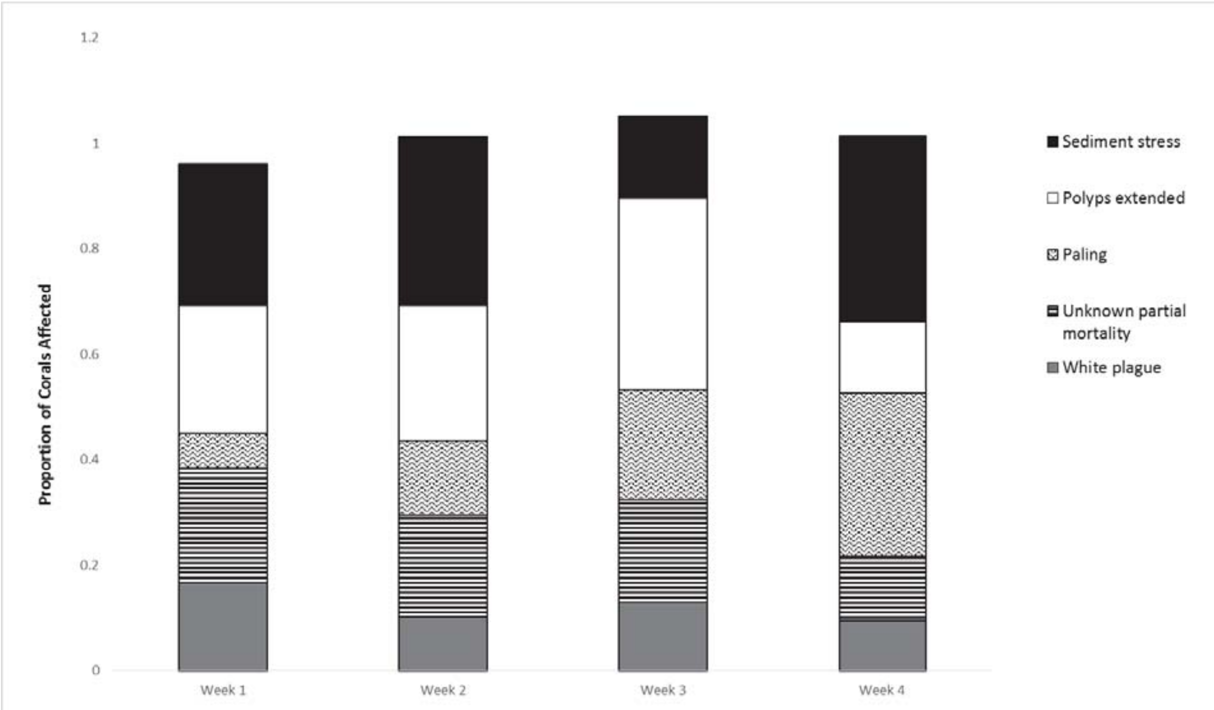

Figure 34. Weekly proportion of tagged corals exhibiting the top five stress indicators at the southern hardbottom sites over the four weeks of post-construction assessment.

3.3 Quantitative Benthic Sampling Comparison: Octocorals

3.3.1 Octocoral Occurrence

Nearshore hardbottom sites included four to ten octocoral genera (Table 22) depending on location. HBSC1-CP had the highest number of genera during both baseline and post-construction surveys (9 and 10 genera, respectively). HBNC1-CP also had the highest number of genera during baseline surveys. HBN1-CR had no octocorals in baseline or post-construction surveys, while HBN2-CR had the fewest number of octocoral genera of any site with octocorals (Table 22). Summary tables of octocoral counts for each week of baseline and post-construction surveys are provided in Appendix D.

Briareum occurred at HBN2-CR during baseline surveys but was not documented during post-construction surveys. *Pterogorgia* was documented at HBS3-CP during baseline but was not documented in post-construction surveys. *Erythropodium* was documented at HBN3-CP and HBSC1-CP during post-construction only. These changes are likely due to the presence of a few representative colonies that are highly susceptible to changes in sampling area, mortality, and identification accuracy. Since individual octocorals were not tagged and monitored over time causation for the presence or absence of these individual genera cannot be assigned.

Table 22. Octocoral genera present at each hardbottom site in Week 1 of baseline, and Week 3 of post-construction surveys. Baseline surveys are designated by a circle, while post-construction surveys are designated by a square.

Octocoral Genera	Site								
	HBN1-CR	HBN2-CR	HBN3-CP	HBNC1-CP	HBS1-CP	HBS2-CP	HBS3-CP	HBS4-CR	HBSC1-CP
Briaerium		•		• □					• □
Erythropodium			□	• □					□
Eunicea		• □	• □	• □	• □	• □	• □	• □	• □
Gorgonia			• □		• □	□	• □	• □	• □
Muricea		• □	• □	• □	• □	• □	• □	• □	• □
Muriceopsis									• □
Plexaura			• □	• □	• □	• □	• □	• □	• □
Plexaurella				• □		• □	• □	• □	• □
Pseudoplexaura		• □	• □	• □	• □	• □	• □	• □	• □
Pseudopterogorgia			• □	• □	• □	• □	• □	• □	• □
Pterogorgia				• □		• □	•		• □

3.3.2 Octocoral Abundance

Patterns of generic relative abundance varied across sites in both baseline and post-construction, but *Eunicea* was the predominant octocoral genus across all hardbottom sites between both baseline and post-construction surveys (Figures 35-38). HBNC1-CP had the greatest number of colonies during both baseline and post-construction (1352 and 1680, respectively, Table 23). No octocorals were present at HBN1-CR during baseline or post-construction surveys (Table 23).

Table 23. Number of octocoral colonies and generic richness of octocoral colonies at nearshore hardbottom sites. Data was collected during Week 1 of baseline surveys, and Week 3 of post-construction surveys.

Site	Baseline		Post-Construction	
	Number of colonies	Number of genera	Number of colonies	Number of genera
HBN1-CR	0	0	0	0
HBN2-CR	13	4	9	3
HBN3-CP	130	6	105	7
HBNC1-CP	1352	9	1680	9
HBS1-CP	207	6	175	6
HBS2-CP	58	7	61	8
HBS3-CP	597	8	510	7
HBS4-CR	331	7	244	7
HBSC1-CP	434	10	577	10

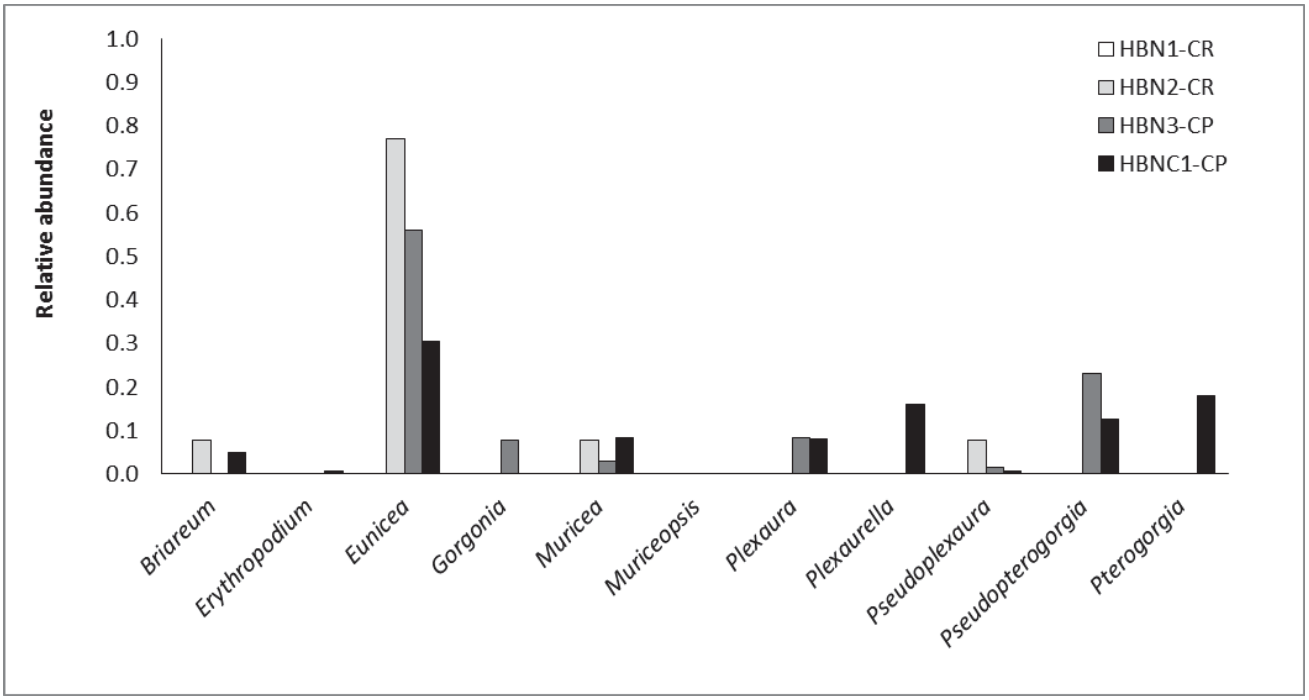

Figure 35. **Relative abundance of octocorals at northern nearshore hardbottom sites in Week 1 of baseline.**

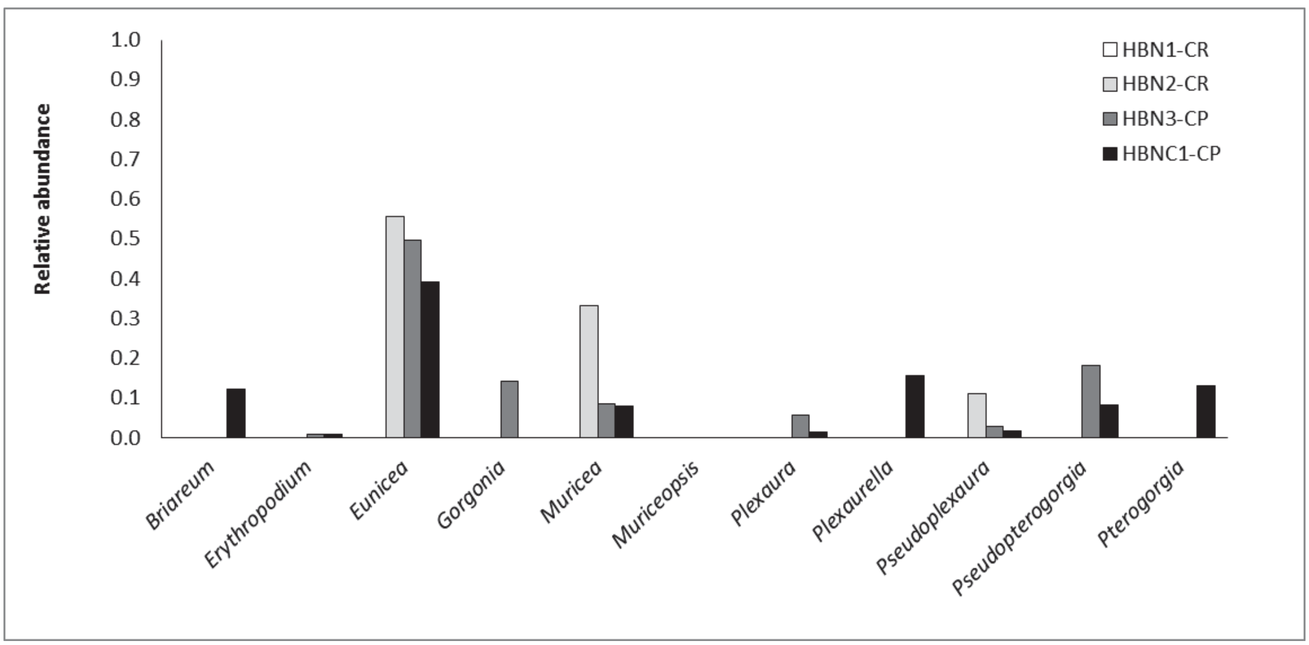

Figure 36. **Relative abundance of octocorals at northern nearshore hardbottom sites in Week 3 of post-construction.**

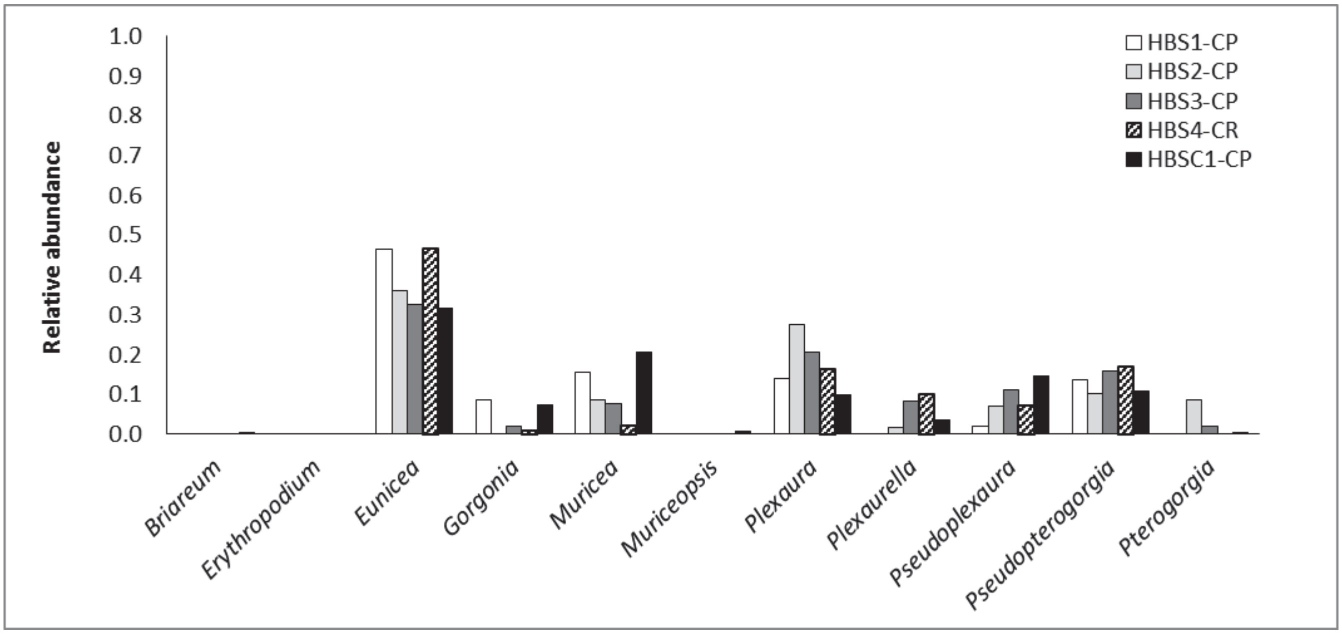

Figure 37. Relative abundance of octocorals at the southern nearshore hardbottom sites in Week 1 of baseline.

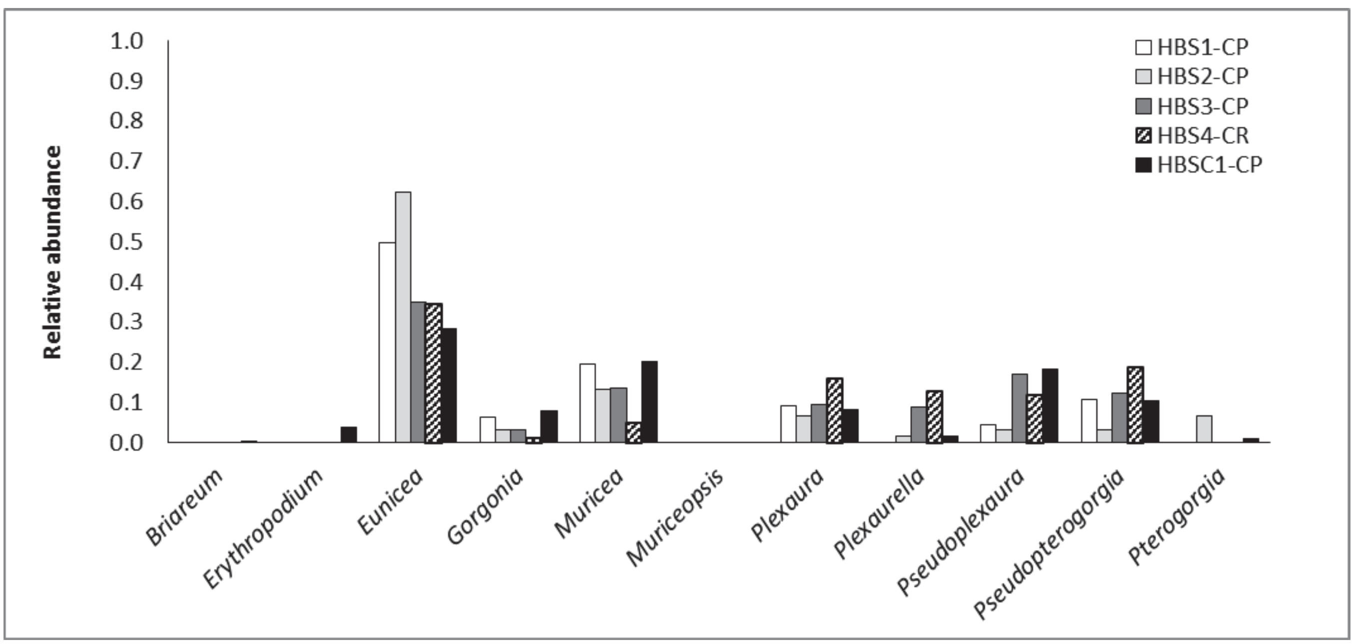

Figure 38. Relative abundance of octocorals at the southern nearshore hardbottom sites in Week 3 of post-construction.

3.3.3 Octocoral Density

During baseline surveys octocoral densities were lower channel-side when compared to the control sites. There was a general trend of lower octocoral densities at the four sites closest to the channel jetty (HBN1-CR, HBN2-CR, HBS1-CP, and HBS2-CP octocoral density ≤3.5 colonies/m^2, Table 24) in baseline and post-construction surveys, possibly a function of stronger currents closer to the jetties. This trend was also noted for scleractinian corals. The FDEP mandated monitoring program did not require tagging and monitoring of octocorals with the same methods (tagging and photo documentation) as scleractinians, and therefore trend analysis is not possible with the limited available data. Accordingly, with only a before and after snapshot of octocoral densities it is difficult to assign causality to these changes.

Table 24. Mean octocoral density (with standard deviation and standard error) among eight hardbottom sites across three permanent transects.

Site	Baseline			Post-Construction		
	Mean Density	SD	SE	Mean Density	SD	SE
HBN1-CR	0.0	0.0	0	0.0	0.0	0.00
HBN2-CR	0.2	0.1	0.066667	0.2	0.1	0.06
HBN3-CP	2.2	0.6	0.337062	1.8	0.2	0.10
HBNC1-CP	22.5	4.0	2.313247	28.0	0.7	0.42
HBS1-CP	3.5	0.3	0.152753	2.9	0.3	0.16
HBS2-CP	1.0	0.5	0.294863	1.0	0.1	0.07
HBS3-CP	10.0	0.3	0.160728	8.5	1.0	0.60
HBS4-CR	5.5	0.7	0.381153	4.1	0.2	0.14
HBSC1-CP	7.2	1.1	0.622718	9.6	1.6	0.94

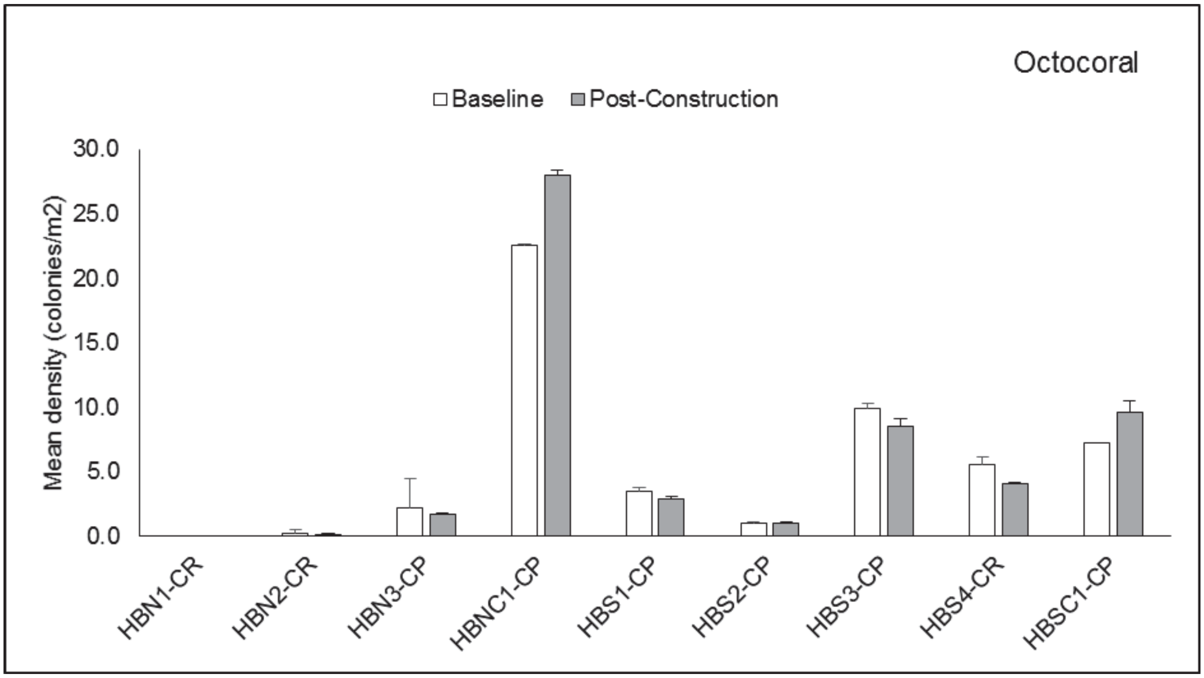

Figure 39. Mean density of octocoral colonies at nearshore hardbottom sites, collected in Week 1 of baseline and Week 3 of post-construction surveys. Error bars represent the standard error.

A two-way repeat measures ANOVA was used to determine if mean octocoral density was different among the eight hardbottom sites between the baseline and post-construction assessment periods. As with the previous baseline report, HBN1-CR was excluded from analysis due to a lack of octocoral presence. Data were collected one time for both the baseline and post-construction assessment periods. Data were square-root transformed to meet the assumptions of normality (Anderson-Darling $P > 0.05$, in all cases). Significant effects among the sites between the assessment periods were detected ($F = 182.48$, $P < 0.0001$; Table 25). Significant effects were detected between sites ($F = 386.40$, $P < 0.001$), and a significant effect was detected based on the interaction between period and site ($F = 4.62$, $P = 0.0012$) (Table 26). A Bonferroni adjustment was used to create a pairwise comparison of the interaction effect.

Table 25. Two-way ANOVA results testing the difference in octocoral density among and between the eight hardbottom sites between the two assessment periods.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Between sites	15	88.50617737	5.90041182	182.48	<.0001
Within sites	32	1.03471505	0.03233485		
Corrected Total	47	89.54089243			

Table 26. Two-way ANOVA results testing the effects of the two assessment periods (baseline and post-construction), the effects of coral locations, and the interaction between the two effects on the mean density of octocorals among the eight hardbottom survey areas.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Period	1	0.00074198	0.00074198	0.02	0.8805
Site	7	87.46011112	12.49430159	386.40	<.0001
Period*Site	7	1.04532426	0.14933204	4.62	0.0012

Additional Tukey post-hoc comparisons were performed on the square-root transformed data to determine significant differences of mean octocoral density between sites during the post-construction assessment period and among individual sites between the baseline and post-construction assessment periods. For the post-construction assessment period mean octocoral density ranged from 0.2 colonies/m^2 (HBN2-CR) to 28.0 colonies/m^2 (HBNC1-CR) (Table 24). Significant differences were detected between the sites during the post-construction period (F = 391.65, P < 0.001; Table 27). Mean octocoral densities were significantly different from all sites at HBNC1-CP and HBN2-CR, the remaining six sites were significantly different based on three pairs; HBS3-CP and HBSC1-CP (respective densities 8.5 colonies/m^2, 9.6 colonies/m^2), HBS1-CP and HBS4-CR (respective densities 2.9 colonies/m^2, 4.1 colonies/m^2), and HBS2-CP and HBN3-CP (respective densities 1.0 colonies/m^2,1.2 colonies/m^2) with no significant differences between the sites within the pairs (Table 27, Figure 39).

Table 27. Tukey post-hoc comparisons of mean octocoral density differences eight hardbottom among sites for the post-construction assessment period.

Data type	Test statistic (p-value)	**Tukey post-hoc comparison** (sites with same letters not statistically significant, indicated in superscript)				
SQRT transformed	F=391.65 (p<0.0001)	HBNC1-CP^A	HBS3-CP^B, HBSC1-CP^B	HBS4-CR^C, HBS1-CP^C	HBN3-CP^D, HBS2-CP^D	HBN2-CR^E

During post-construction surveys octocoral density ranged from 0 to 28 colonies/m^2 across all nearshore hardbottom sites during post-construction (Table 24). No octocorals were documented at HBN1-CP during baseline or post-construction surveys. Of the sites where octocorals occurred, mean octocoral density was lowest for HBN2-CR (0.22 colonies/m^2) and highest at HBNC1-CP (28 colonies/m^2) (Table 24 and Figure 39). In general, octocoral density at channel-side sites declined or stayed the same, while octocoral density at control sites increased (Figure 39).

The Tukey post-hoc comparisons of mean density among individual sites between baseline and post-construction were performed on square-root transformed data. HBS4-CR was the only site that showed a significant difference in octocoral density between the baseline and post-construction assessment (F = 13.80, P = 0.0206) (Table 28), with a decrease from 5.5 octocorals/m^2 to 4.1 octocorals/m^2 (Table 24, Figure 39). The two control areas, HBNC1-CP and HBSC1-CP, as well as HBS2-CR, exhibited a general trend of increasing octocoral density, while the remaining survey areas showed a decreasing trend of octocoral density between the baseline and post-construction surveys.

Table 28. Baseline and post-construction comparison of octocoral density using a ranked one way ANOVA with a Tukey's post-hoc comparison (superscripts indicate a significant difference between survey periods). HBN1-CR is excluded from the analysis due to an absence of octocorals.

Site	Test statistic (p-value)	Tukey post-hoc comparison
HBN2-CR	NS	(trend) Baseline > Post-construction
HBN3-CP	NS	(trend) Baseline > Post-construction
HBNC1-CP	NS	(trend) Post-construction > Baseline
HBS1-CP	NS	(trend) Baseline > Post-construction
HBS2-CP	NS	(trend) Post-construction > Baseline
HBS3-CP	NS	(trend) Baseline > Post-construction
HBS4-CR	F=13.80 (p=0.0206)	Baseline^{A}, Post-construction^{B}
HBSC1-CP	NS	(trend) Post-construction > Baseline

3.3.4 Octocoral Diversity and Evenness

Octocoral generic diversity (H') ranged from 0 to 1.88 across nearshore hardbottom sites during post-construction surveys and from 0 to 1.86 during baseline surveys. Evenness (J') ranged from 0 to 0.43 across all sites during post-construction and between 0 and 0.40 during baseline surveys (Table 29).

Table 29. Shannon–Wiener Diversity Index (H') and Evenness (J') calculated for octocoral genera at nearshore hardbottom sites during baseline and post-construction.

Site	H'		J'	
	Baseline	Post-construction	Baseline	Post-construction
HBN1-CR	0	0	0	0
HBN2-CR	0.79	0.94	0.31	0.43
HBN3-CR	1.24	1.46	0.25	0.31
HBNC1-CR	1.86	1.73	0.26	0.23
HBS1-CR	1.48	1.44	0.28	0.28
HBS2-CR	1.63	1.32	0.40	0.32
HBS3-CR	1.78	1.75	0.28	0.28
HBS4-CR	1.50	1.69	0.26	0.31
HBSC1-CR	1.83	1.88	0.30	0.30

3.4 Functional Group Percent Cover

3.4.1 Baseline and Post-construction Comparison

Functional group percent cover data were highly variable across monitoring sites in the hardbottom areas from baseline through post-construction. This variability was due to the low cover of biotic benthic functional groups (scleractinians, octocorals and sponges). The north and south sides of the channel exhibited different functional group assemblage patterns over time.

During the baseline study period, the benthic composition of the northern sites consisted of predominantly crustose coralline algae, turf, and/or bare substrate (CTB) and sand. In addition to CTB, octocorals accounted for a large percentage of the benthic cover at the northern control site (HBNC1-CP). Sandy substrate was the predominant feature of HBN1-CR (Section 3.2.1) and HBN3-CP exhibited the highest percentage of coral cover (1.4%) for the northern survey sites (Figure 40). Octocoral and sponge coverage were greatest furthest east, at HBN3-CP (5.1% and 7.2%).

During post-construction surveys, sand decreased at all northern hardbottom sites, except HBNC1-CP, which increased in sand by 6%. CTB increased at northern sites and became the predominant cover category at all northern channel-side sites. HBN1-CR had the highest percentage (68.2%), followed by HBN2-CR (64.8%) and HBN3-CP (54.9%) (Figure 41). The change in sand cover between baseline and post-construction time periods may be attributed to the sand wave influence in baseline and lack of influence during the post-construction survey period. Post-construction functional group percent cover data is provided in Appendix G.

Of the macrofauna at northern hardbottom sites, no group declined by more than 3% when compared between baseline and post-construction surveys. Scleractinian cover transitioned from 0.44% to 0 at HBNC1-CP, but this decline to zero may be due to the already low cover (<1%) or increased sand cover at this site during the post-construction period.

Seasonal differences appear to affect sand and CTB cover at northern channel-side hardbottom sites and may be responsible for the low cover in octocorals.

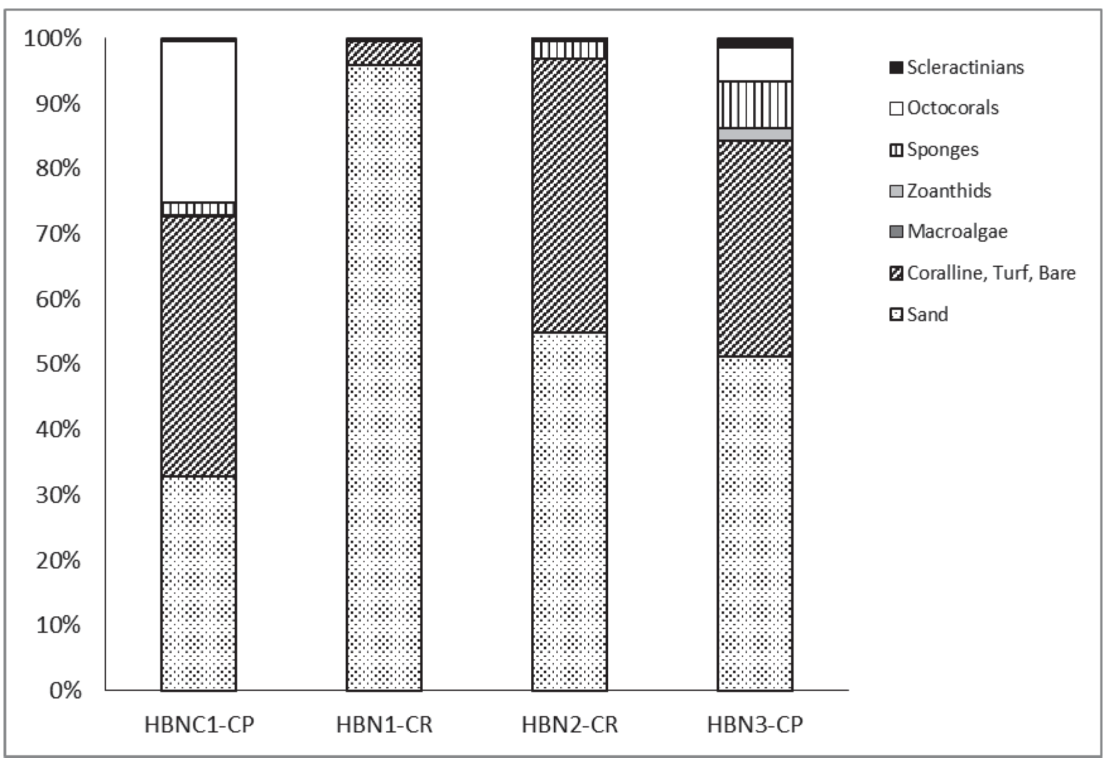

Figure 40. Functional group percent cover for the northern hardbottom survey sites in Week 4 of baseline.

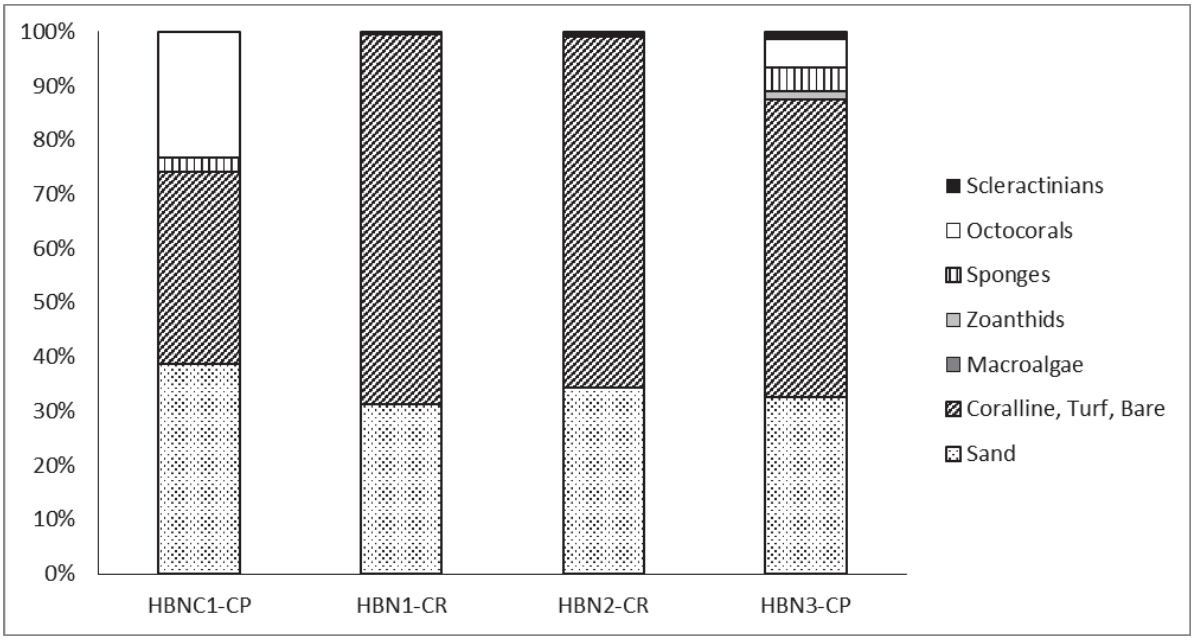

Figure 41. Functional group percent cover for the northern hardbottom survey sites in Week 3 of post-construction.

During baseline documentation at the southern hardbottom sites, sand and CTB were the primary functional groups at all southern monitoring sites. HBSC1-CP had the greatest scleractinian cover (3.1%) across all hardbottom sites. In addition, HBS1-CP showed the highest percent coverage of sponges (6.5%) (Figure 42).

In contrast to the northern sites, sand increased in post-construction analysis, but CTB remained the primary functional group at HBSC1-CP, HBS1-CP, HBS3-CR and HBS4-CR (Figure 43). All sites documented an increase in sand cover when compared to baseline. Furthermore, sand is the most dominant functional group at HBS2-CP (53.1%) during post-construction, but the site also recorded the highest percentage of sand cover during baseline (34%).

Of the macrofauna at southern hardbottom sites, no group declined more than 3.2% (Octocoral group at HBSC1-CP). Similar to baseline, HBSC1-CP saw the highest percentage of scleractinian cover (2.7%), and HBS1-CP showed the highest percent coverage of sponges (5.4%). In addition to CTB, octocorals accounted for a large percentage of the benthic cover at HBS3-CR (16%).

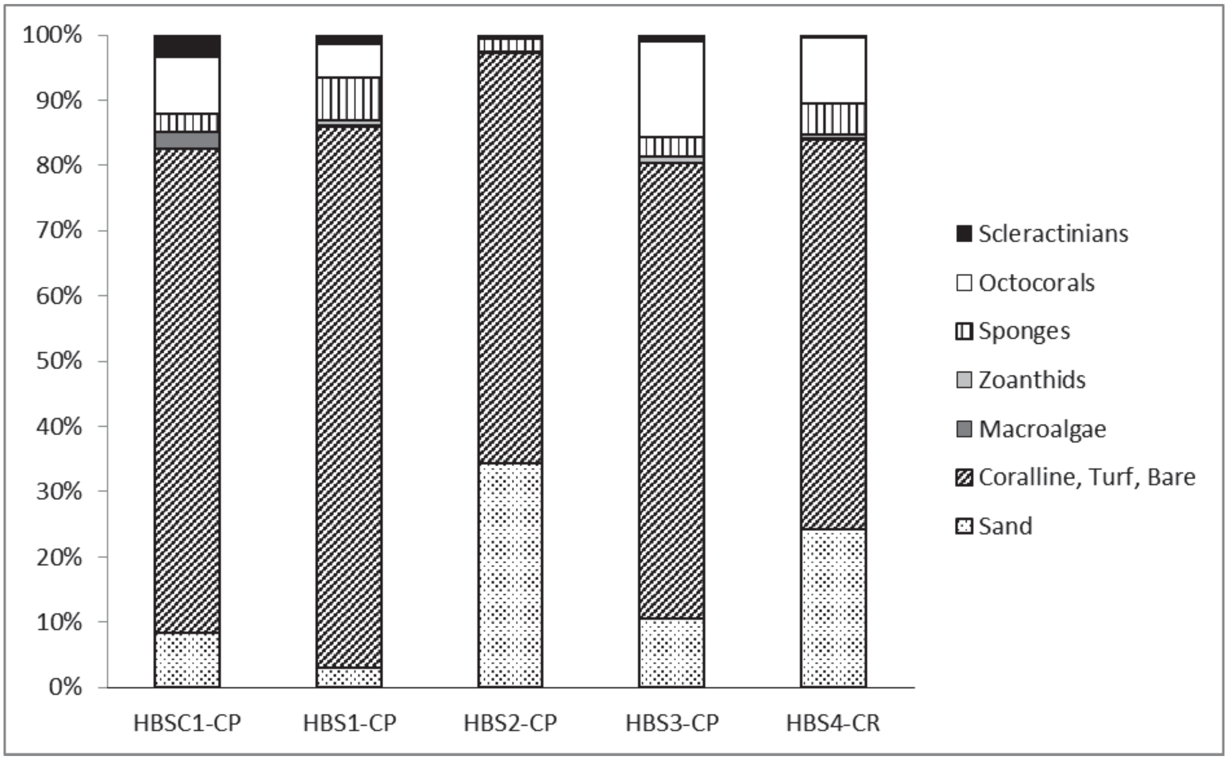

Figure 42. Functional group percent cover for the southern hardbottom survey sites in Week 4 of baseline.

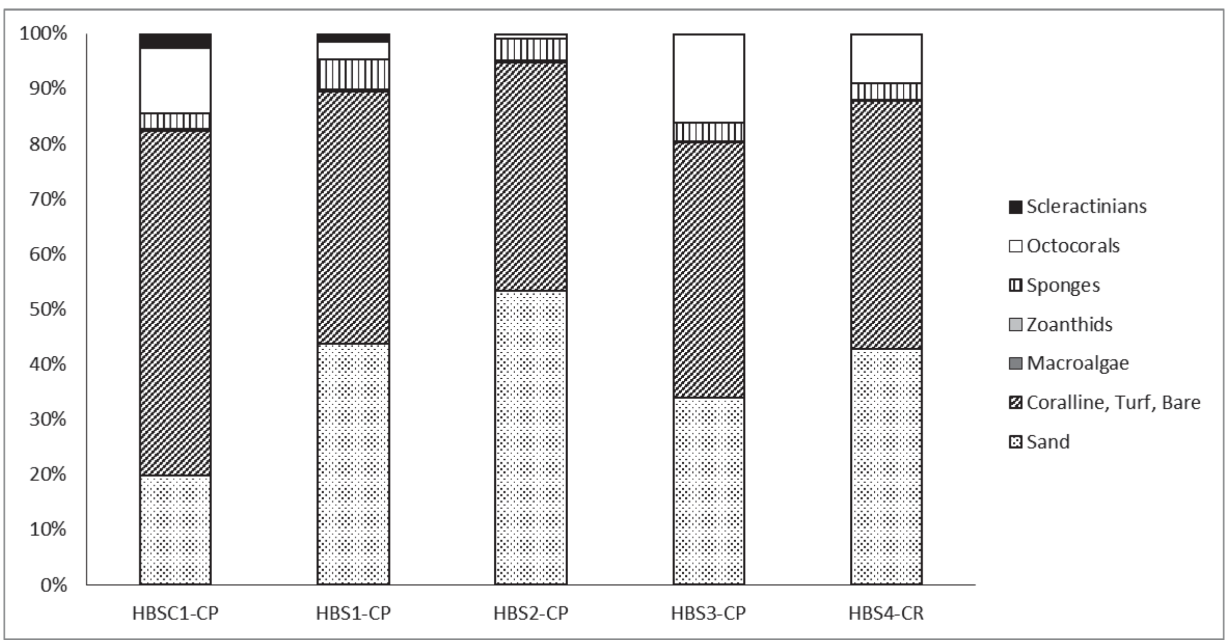

Figure 43. Functional group percent cover for the southern hardbottom survey sites in Week 3 of post-construction.

3.4.2 CTB vs. Sand

Two functional groups – sand and CTB (crustose turf and bare) were used as proxies to measure levels of sediment at outer reef channel-side and control sites from baseline through post-construction. Data were obtained during baseline, compliance and post-construction surveys from video transect data. During compliance, data were collected and analyzed if a site was within 750 m of a dredge and when weather conditions allowed for safe diving practices. If sites were sampled twice in a single week, 1 set of video data were analyzed, the video that was analyzed was chosen based on best available video quality. All video were archived and were submitted to the USACE on September 2, 2015 as part of contract and permit requirements. Data collection time periods vary by site because of the monitoring time frame requirements, but in general late 2013 to late 2014 or early 2015 and July 2015 (post-construction time period) are presented for nearshore hardbottom sites and their controls (Figure 44-52). All functional group percent cover data from baseline through post-construction monitoring are provided in Appendix H.

Northern hardbottom site baseline CTB values ranged from less than 3% to 42%. HBNC1-CP, the control site, had 40% CTB during the baseline period (Figures 44-47, first column of each figure). The northern hardbottom sites ranked in order from greatest cover of CTB to lowest CTB cover as follows: HBN2-CP (42%), HBNC1-CP (40%), HBN3-CP (33%), and HBN1-CR (3%) (Figures 44-47). After the baseline survey period, patterns of CTB cover varied by site over time as a function of seasonal weather conditions, dominant current patterns and spatial relationship to dredging operation (Figures 44-47). While CTB values were highly variable throughout the construction periods, all northern channel-side sites showed an increase in CTB cover during post-construction analysis compared to baseline, HBN1-CR (65%), HBN2-CR (23%), and HBN3-CP (22%) (Figures 44-46, last column of each figure). HBNC1-CP, the northern control site, experienced a 5% decrease in CTB cover compared to baseline values (Figure 47, last column of figure). The considerable increase in CTB values at HBN1-CR is due to the absence of the sand wave that covered the site during baseline monitoring. The increases at HBN2-CR and HBN3-CP are likely due to calmer conditions and onshore movement of sand that occurs seasonally, during non-winter months.

Southern hardbottom site CTB values ranged from 63% to 83% during baseline surveys (Figures 48-52, first column on each figure). The southern hardbottom sites ranked in order from greatest CTB cover to lowest CTB cover, HBS1-CP (83%), HBSC1-CP (74%), HBS3-CP (69%), HBS2-CP (63%), HBS4-CR (59%) (Figures 48-52). Immediately following the baseline survey period, CTB cover declined across all southern hardbottom sites. Throughout compliance monitoring, the relative proportion of CTB and sand at each site varied as a function of seasonal weather conditions (winter v. summer), dominant current patterns and spatial relationship to the dredging operation (Figures 48-52). During post-construction surveys CTB values across all hardbottom sites were less than the values reported during the baseline period, but were on the increase across sites.

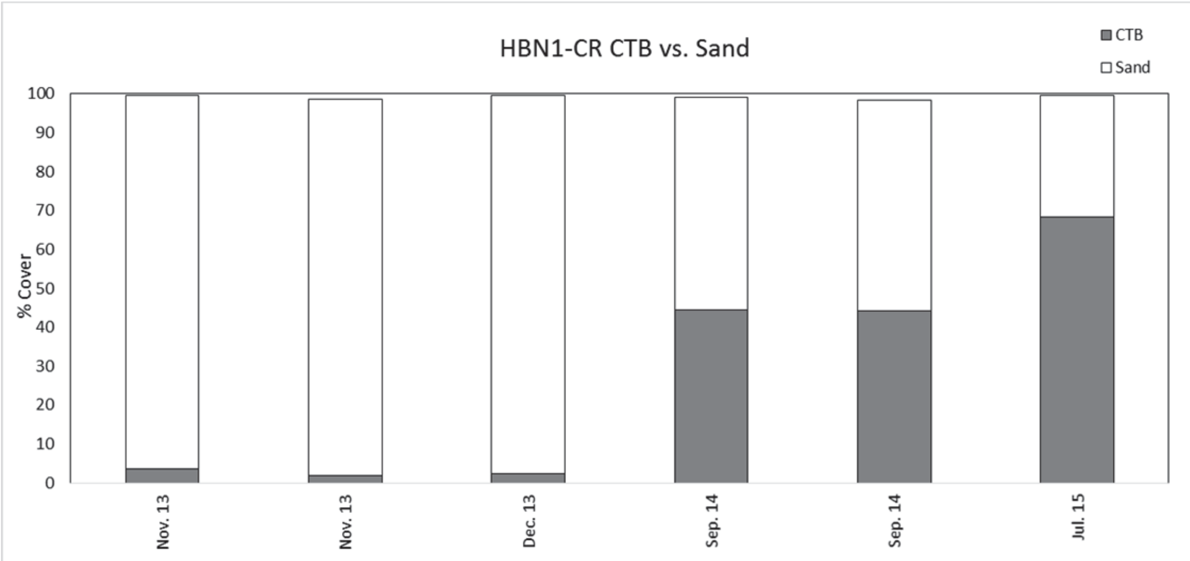

Figure 44. HBN1-CR CTB (crustose, turf, and bare) and sand data analysis based on video transect analysis. Percent cover data are presented from November 2013 through July 2015. First column of the figure represents baseline analysis, and last column represents post-construction analysis.

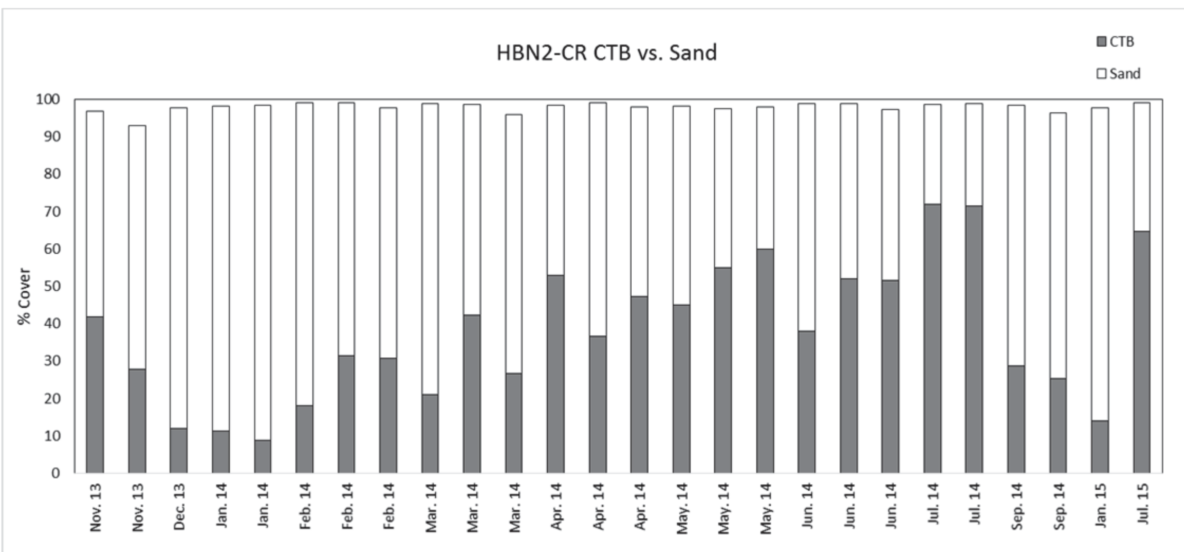

Figure 45. HBN2-CR CTB (crustose, turf, and bare) and sand data analysis based on video transect analysis. Percent cover data are presented from November 2013 through July 2015. First column of the figure represents baseline analysis, and last column represents post-construction analysis.

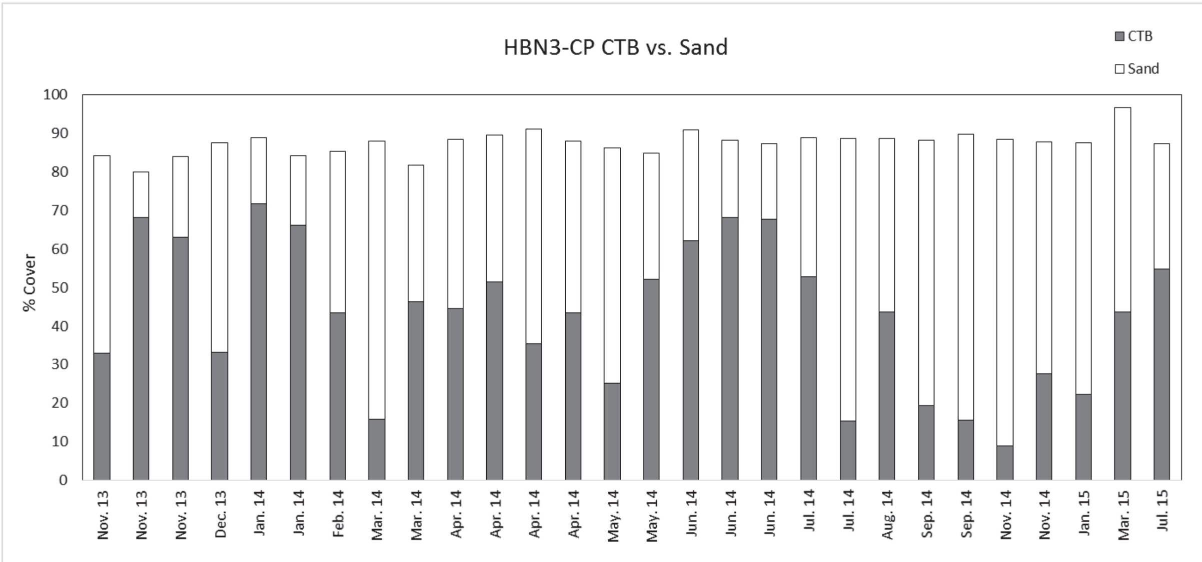

Figure 46. HBN3-CP CTB (crustose, turf, and bare) and sand data analysis based on video transect analysis. Percent cover data are presented from November 2013 through July 2015. First column of the figure represents baseline analysis, and last column represents post-construction analysis.

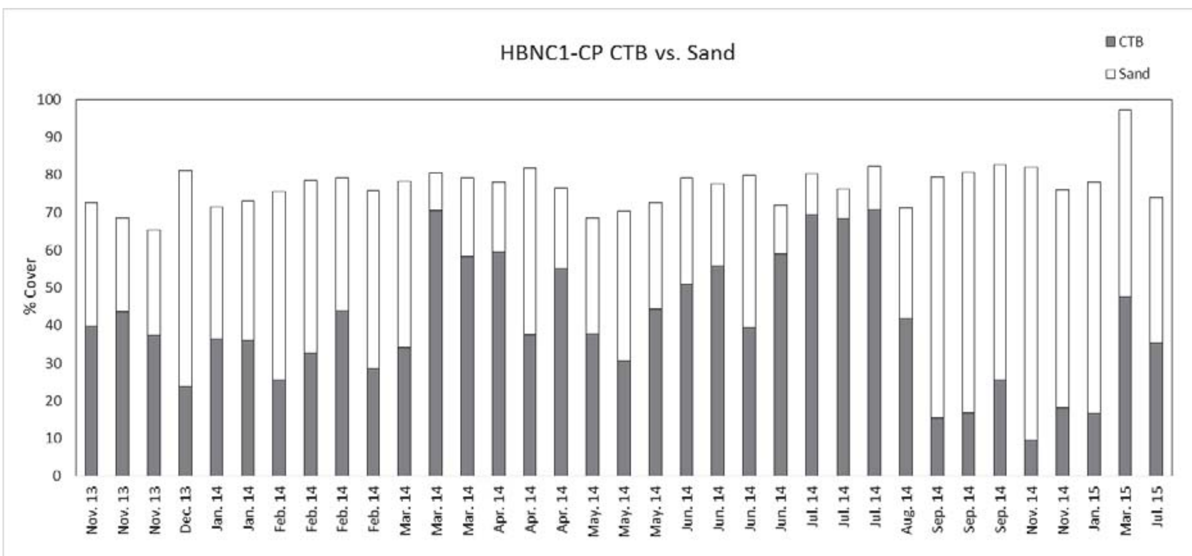

Figure 47. HBNC1-CP CTB (crustose, turf, and bare) and sand data analysis based on video transect analysis. Percent cover data are presented from November 2013 through July 2015. First column of the figure represents baseline analysis, and last column represents post-construction analysis.

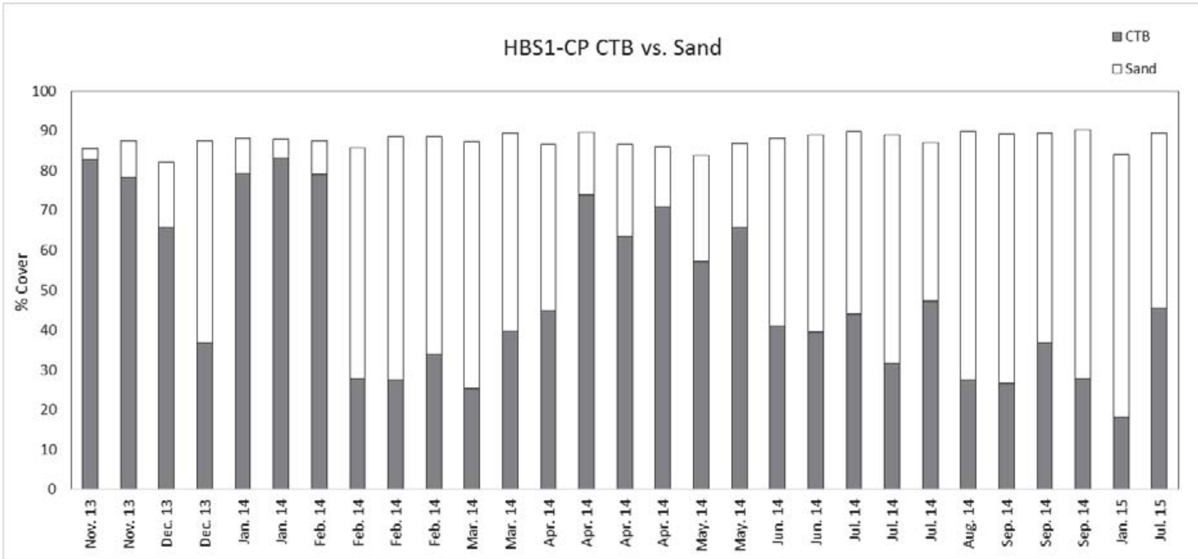

Figure 48. **HBS1-CP CTB (crustose, turf, and bare) and sand data analysis based on video transect analysis. Percent cover data are from November 2013 through July 2015. First column of the figure represents baseline analysis, and last column represents post-construction analysis.**

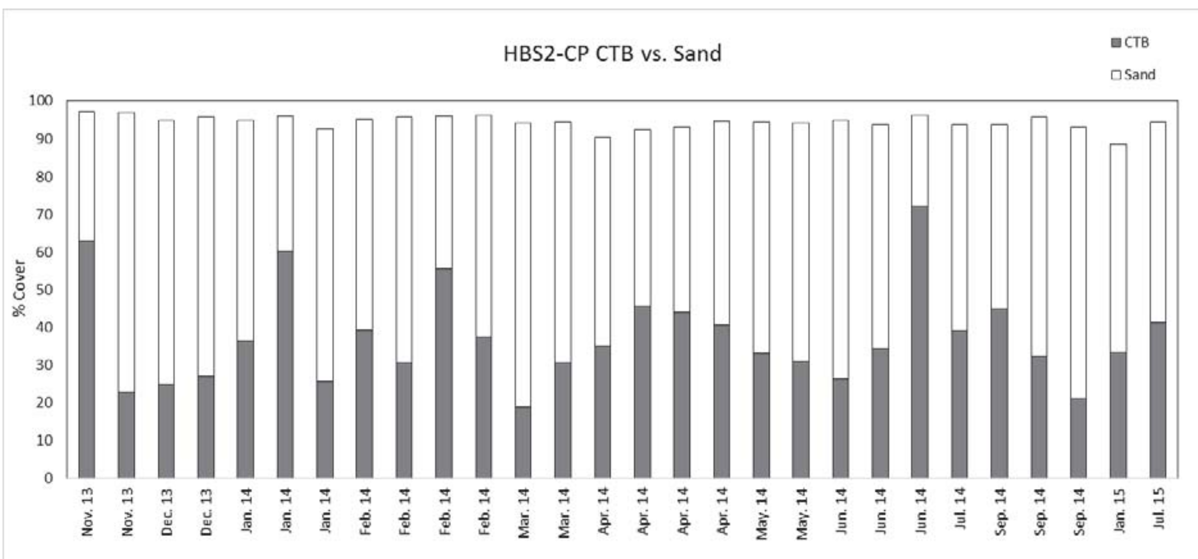

Figure 49. **HBS2-CP CTB (crustose, turf, and bare) and sand data analysis based on video transect analysis. Percent cover data are presented from November 2013 through July 2015. First column of the figure represents baseline analysis, and last column represents post-construction analysis.**

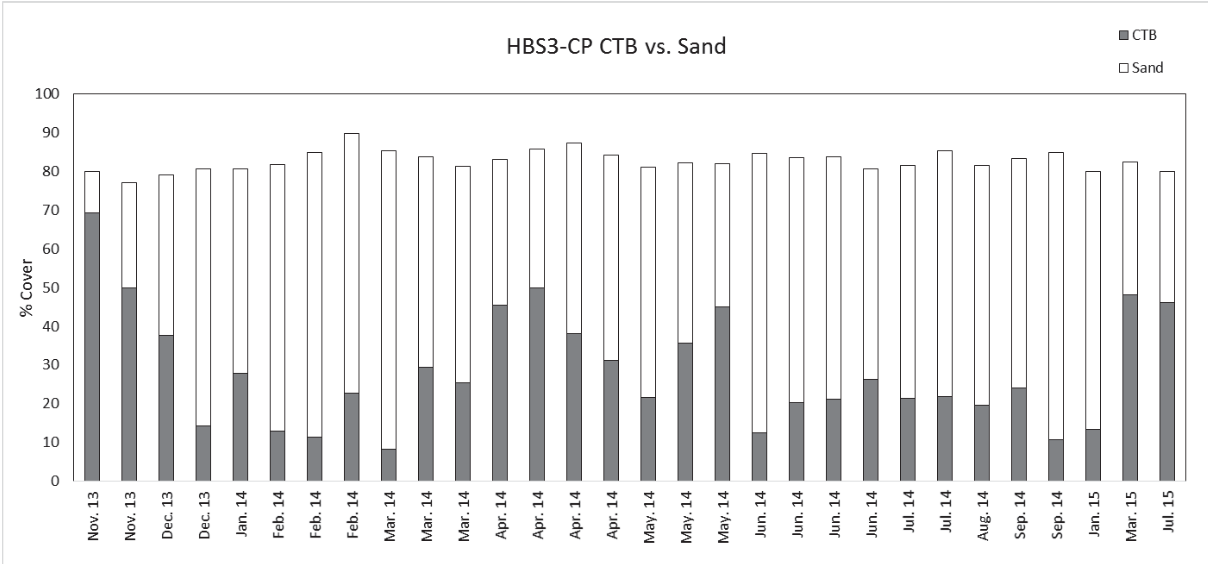

Figure 50. **HBS3-CP CTB (crustose, turf, and bare) and sand data analysis based on video transect analysis. Percent cover data are presented from November 2013 through July 2015. First column of the figure represents baseline analysis, and last column represents post-construction analysis.**

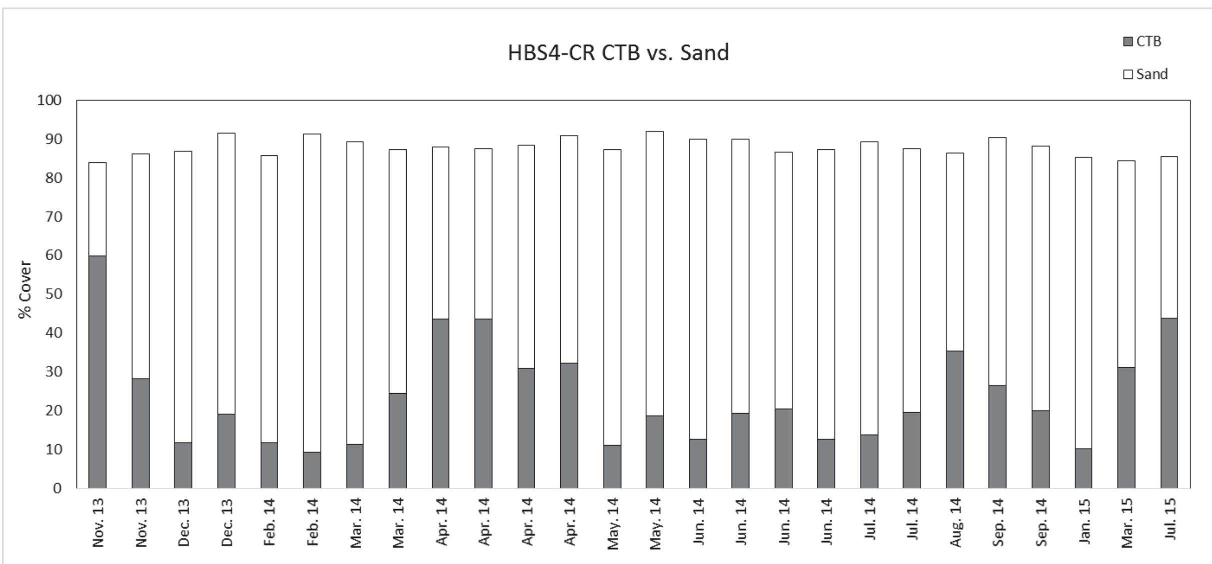

Figure 51. **HBS4-CR CTB (crustose, turf, and bare) and sand data analysis based on video transect analysis. Percent cover data are presented from November 2013 through July 2015. First column of the figure represents baseline analysis, and last column represents post-construction analysis.**

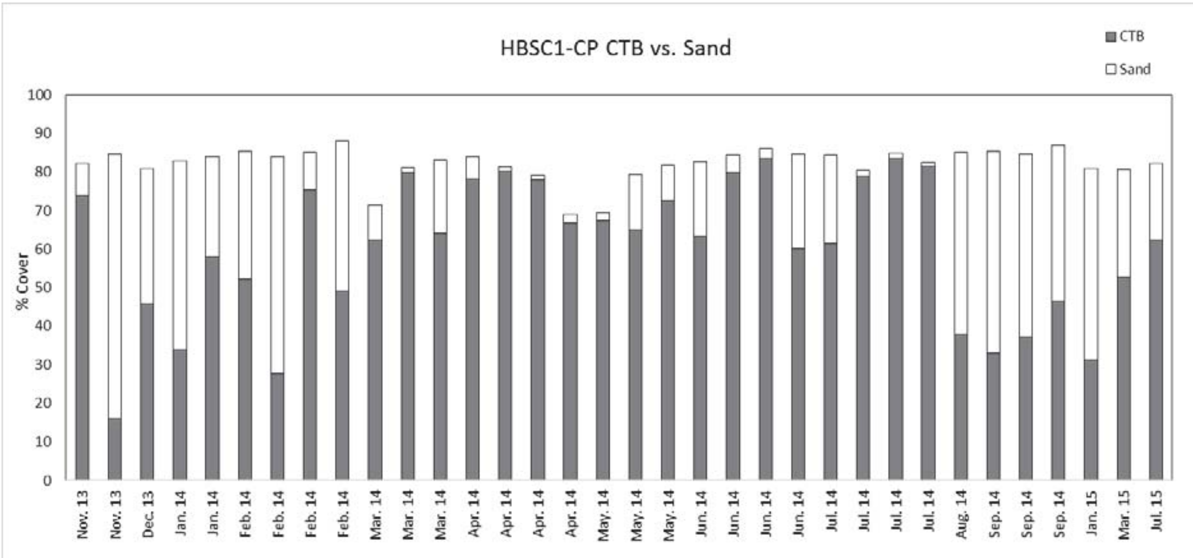

Figure 52. HBSC1-CP CTB (crustose, turf, and bare) and sand data analysis based on video transect analysis. Percent cover data are presented from November 2013 through July 2015. First column of the figure represents baseline analysis, and last column represents post-construction analysis.

3.5 Quantitative Sediment Accumulation Rates

Sedimentation data were collected from the sediment traps (*N* = 27) at each transect at the end of the post-construction survey period (28 days after installation). Three replicates were combined to create a single sample per transect, for a total of three samples per site. A daily sedimentation rate was calculated for each site as an average of the three samples for a single site. Samples were separated into two fractions in the lab, a coarser grain fraction (≥ #230 sieve) and a finer fraction (< #230 sieve). All quantitative sedimentation data from baseline through post-construction surveys is provided in Appendix I.

During baseline, sedimentation rates were greatest for the three northern channel-side sites, with a maximum of 6.98 g/day. Fine-grain sedimentation remained low across sites and ranged from 0.49 to 0.96 g/day (Figures 53 and 54). Daily sedimentation of both coarse and fine grained sediment was significantly higher at sites located to the north of the channel (Kruskal-Wallis test, P=.016 and P=.005 respectively).These data support the observations of sediment accumulation and low water clarity reported by divers during baseline at these sites, which was apparently part of a natural sand transport event (see Section 3.2.1). Continuation of winter-weather conditions during baseline, including high winds and significant sea states, caused re-suspension of sand material and contributed to the elevated levels mean daily sedimentation rate for fine-grain sediments at all hardbottom sites during that time. Dredging operations had not commenced when hardbottom baseline sediment samples were collected, so these results reflect a non-dredging condition that could be characteristic of seasonal winter conditions.

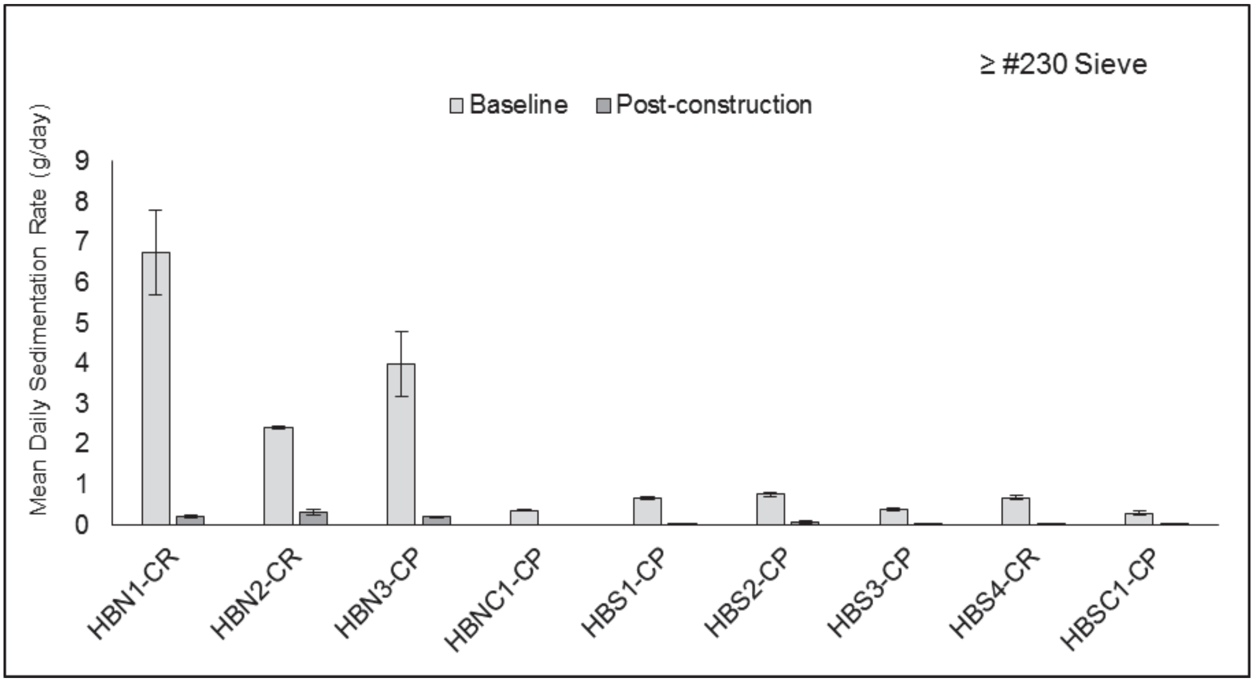

Figure 53. **Daily sedimentation rates at nearshore hardbottom sites for coarse-grain sediment (≥ #230 sieve) during baseline and post-construction. Error bars represent the standard error.**

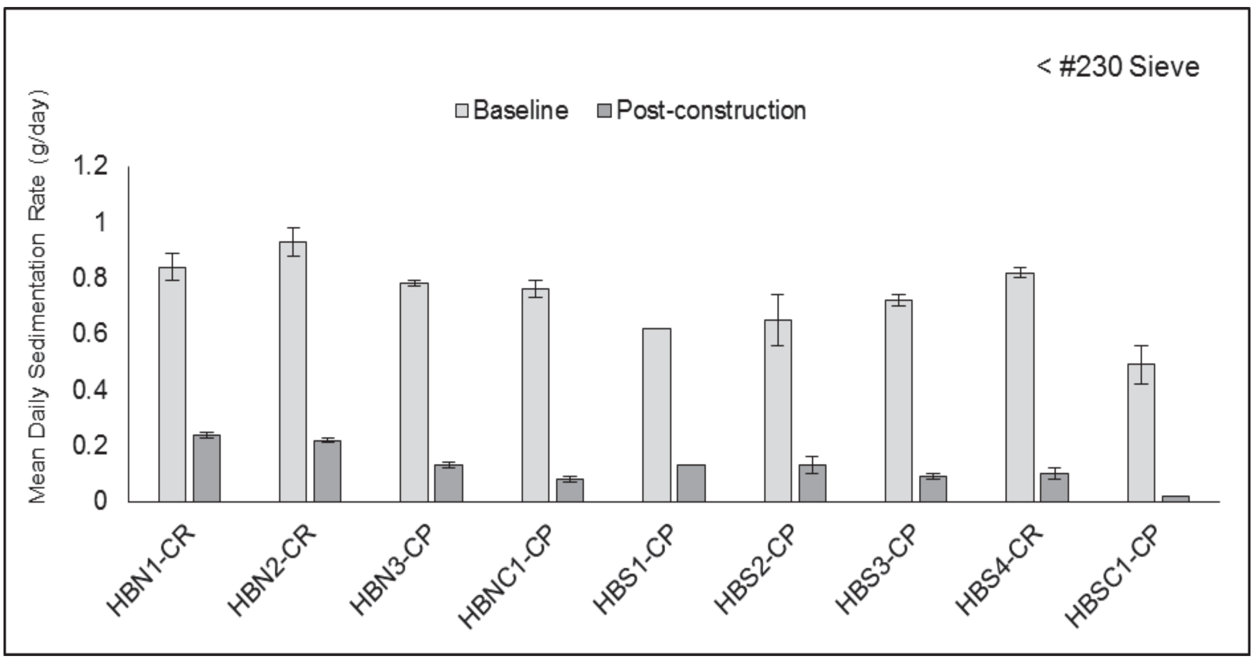

Figure 54. **Daily sedimentation rates at nearshore hardbottom sites for fine-grain sediment (< #230 sieve) during baseline and post-construction. Error bars represent the standard error.**

During post-construction, sedimentation rates were lower for both coarse and fine grained sediments at both north and south sites when compared to baseline results, which is likely a seasonal effect (baseline – fall/winter v. post-construction – summer). Sedimentation rates for coarse-grain sediments were greatest at HBN2-CR (0.32g/day), while the rates for fine-grain sediments were highest at HBN1-CR (0.24 g/day) (Figures 53 & 54).

Average daily sedimentation rates for the project were tabulated and presented here for each site, from baseline through post-construction. Dredges Texas, Terrapin Island and Liberty Island conducted dredging operations offshore from November 2013 to December 2014 (Table 30). The clamshell Dredge 55 dredged by itself, intermittently offshore (spot clean-ups), between January and March 16, 2015. The USACE accepted offshore dredging was complete on April 8, 2015. Commencement and completion dates of all offshore dredging activity are included in Figures 55 – 58, and are indicated by colored vertical lines. Data for HBN1-CR were collected in baseline and again in October 2014, after the site was identified as unburied, all other hardbottom sites have continuous daily sedimentation rate records.

Table 30. Dredge commencement and completion dates are presented for each dredge offshore. Maintenance periods where dredges may not have been working are not represented, but were generally two weeks or less in duration.

Dredge	Type	Start Date	End Date
Texas	Cutterhead	12/17/2013	12/23/2014
Terrapin Island	Hopper	11/20/2013	12/27/2013
Liberty Island	Hopper	5/14/2014	7/3/2014
55	Clamshell	4/5/2014	3/16/2015

Between baseline and post-construction, sedimentation rates differed depending on their relation to the channel (north or south) and depending on grain size (coarse or fine). In general, the northern side of the channel experienced greater sedimentation rates for coarse and fine grain sediment (Figure 55-58). Each site had a unique pattern, the similarities are discussed below.

Sedimentation rates for coarse grain sediment were elevated, prior to dredging, at all northern channel-side sites, with mean daily sedimentation ranging from approximately 2.5 g/day (HBN2-CR) to 7.0 g/day (HBN1-CR) (Figure 55). Mean daily sedimentation rates were less than 0.5 g/day at the corresponding control site (Figure 55). Sedimentation rates at all southern hardbottom sites (channel-side and control), prior to the start of dredging, were less than 1.0 g/day (Figure 56). The elevated sedimentation rates at the northern channel-side sites were likely due to the sand wave that began covering HBN1-CR during the baseline survey period.

Mean daily sedimentation rates for coarse grain sediment remained above approximately 3.5 g/day in late December 2013 (after the commencement of dredge operations) at HBN2-CR and HBN3-CP (Figure 55). No sediment samples were collected from HBN1-CR until November 2014, as the site was not actively surveyed due to burial by the naturally occurring sand wave. Coarse grain sedimentation rates varied throughout the duration of the project along the north side of the hardbottom channel–side sites. The highest sedimentation rates were documented in April 2014 (HBN2-CR, approximately 5 g/day) and December 2014 (HBN1-CR & HBN3-CP, approximately 7 g/day) (Figure 55). Throughout the duration of the project coarse grain sedimentation rates remained below 1.0 g/day at HBNC1-CP (Figure 55). In May 2015 all northern hardbottom site sedimentation rates were below 1.0 g/day and remained at these levels through the post-construction survey period (July 2015).

In the winter of 2013, after the commencement of dredging all southern channel-side hardbottom sites experienced an increase in mean daily sedimentation rates. In late December 2013, all southern channel-side sites experienced the highest documented sedimentation rates for the survey period. All rates of sedimentation had more than doubled at the channel side sites, ranging from approximately 2.0 g/day (HBS3-CP) to 3.1 g/day (HBS2-CP) (Figure 56). Similar, to the northern hardbottom control site (HBNC1-CP), coarse grain sedimentation rates were below 1.0 g/day for the duration of the project. Between May 2015 and July 2015 (end of post-construction surveys), all daily sedimentation rates were less than the documented baseline rates.

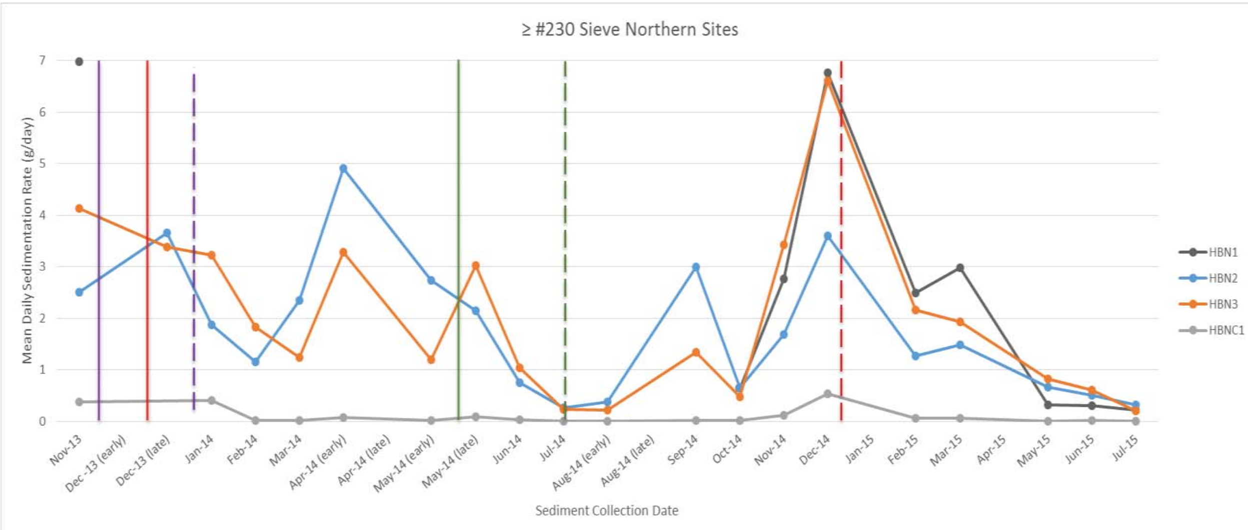

Figure 55. Daily sedimentation rates at northern hardbottom sites for coarse-grain sediment (≥ #230 sieve) from baseline through post-construction surveys. The solid purple line on November 20, 2013 represents the first day of dredging by the hopper dredge Terrapin Island. The solid red line represents the first day of dredging for the Texas. The dotted purple line signifies the departure of the Terrapin Island (12/27/2013). The solid green line represents the first day of dredging for the Liberty Island (05/14/2014), and the green dotted line is the last day of dredging for the Liberty Island (07/03/2014). The red dash line represents the last day offshore of Dredge Texas (12/23/2014).

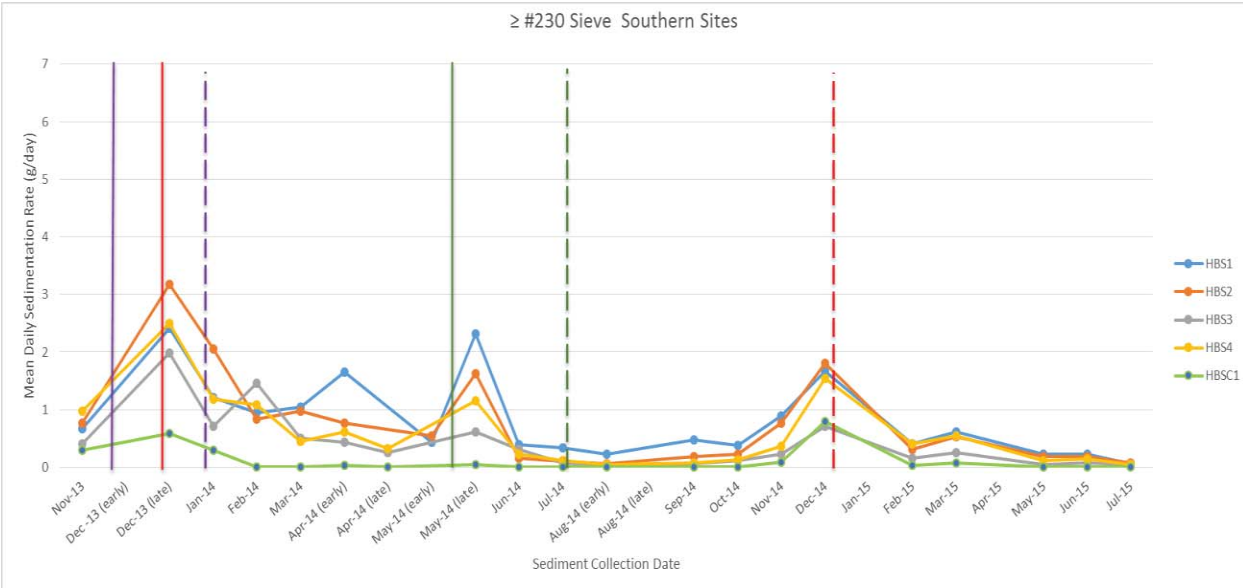

Figure 56. Daily sedimentation rates at southern hardbottom sites for coarse-grain sediment (≥ #230 sieve) from baseline through post-construction surveys. The solid purple line on November 20, 2013 represents the first day of dredging by the hopper dredge Terrapin Island. The solid red line represents the first day of dredging for the Texas. The dotted purple line signifies the departure of the Terrapin Island (12/27/2013). The solid green line represents the first day of dredging for the Liberty Island (05/14/2014), and the green dotted line is the last day of dredging for the Liberty Island (07/03/2014). The red dash line represents the last day offshore of Dredge Texas (12/23/2014).

Fine grain sedimentation rates at the northern hardbottom sites, were near their highest documented values, prior to the commencement of dredging. Mean daily sedimentation rates ranged from approximately 0.75 g/day (HBNC1-CP) to 1.0 g/day (HBN2-CR) (Figure 57). After the commencement of dredging HBNC1-CP and HBN3-CP experienced a slight increase in fine grain sedimentation rates, while HBN2-CR remained steady (Figure 57). Throughout the construction period HBNC1-CP had the highest sedimentation rates when all sites experienced increases. The highest sedimentation rates for fine grain sediment were documented in December 2014, when daily sedimentation rates ranged from approximately 1.0 g/day (HBN1-CR) to 1.3 g/day (HBN3-CP & HBNC1-CP). During the post-construction assessment period fine grain sedimentation rates for all northern hardbottom sites were less than 0.3 g/day (Figure 57).

Mean daily sedimentation rates of fine grain sediment at the southern hardbottom sites were slightly lower than the northern hardbottom sites prior to start of dredging. Sedimentation rates ranged from approximately 0.5 g/ day (HBSC1-CP) to 0.8 g/day (HBS4-CR) (Figure 58). In late December 2013, HBS4-CR, HBS3-CP, and HBS2-CP experienced their highest documented sedimentation rates; 1.7g/day, 1.5 g/day, and 1.3 g/day respectively (Figure 58). The highest documented fine grain sedimentation rates for HBS1-CP and HBSC1-CP were approximately 1.2 g/day and were documented in December 2014 (Figure 58). Fine grain daily sedimentation rates at all southern hardbottom sites decreased throughout early 2015 and at the end of the post-construction period were documented at their lowest rates, when the documented sedimentation rates were less than 0.2 g/day for all sites.

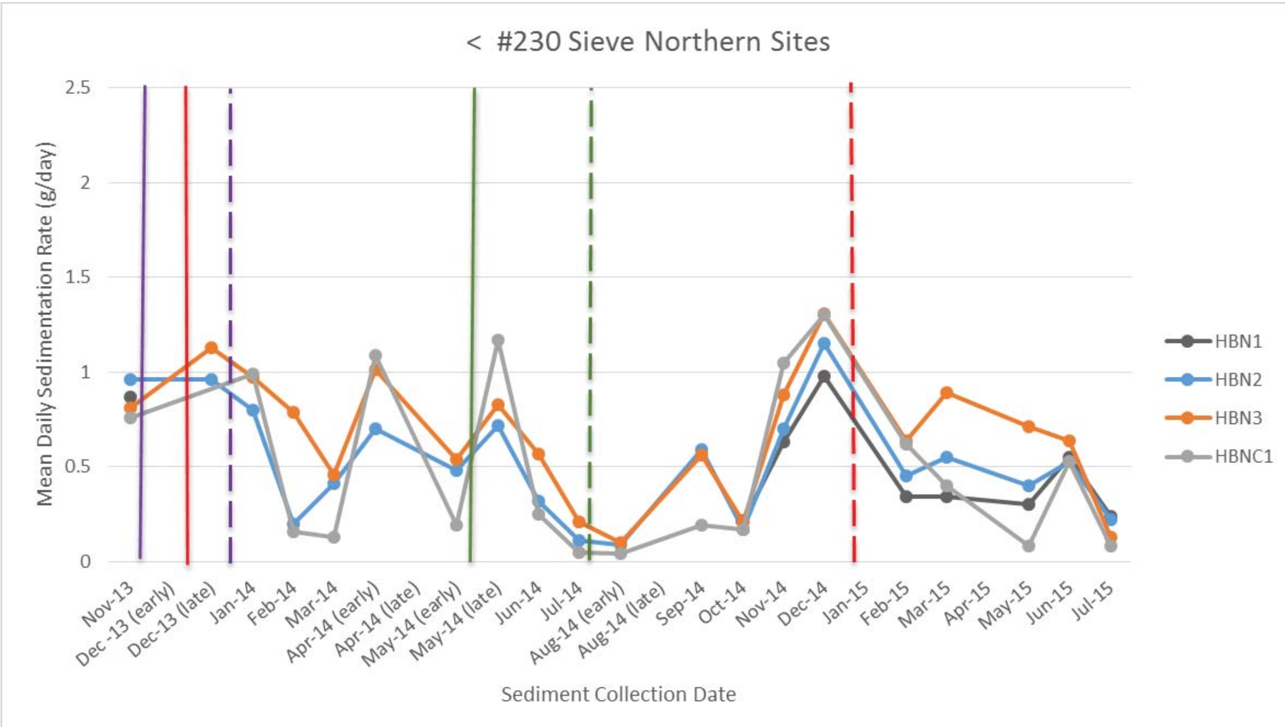

Figure 57. Daily sedimentation rates at northern hardbottom sites for fine-grain sediment (< #230 sieve) from baseline through post-construction surveys. The solid purple line on November 20, 2013 represents the first day of dredging by the hopper dredge Terrapin Island. The solid red line represents the first day of dredging for the Texas. The dotted purple line signifies the departure of the Terrapin Island (12/27/2013). The solid green line represents the first day of dredging for the Liberty Island (05/14/2014), and the green dotted line is the last day of dredging for the Liberty Island (07/03/2014). The red dash line represents the last day offshore of Dredge Texas (12/23/2014).

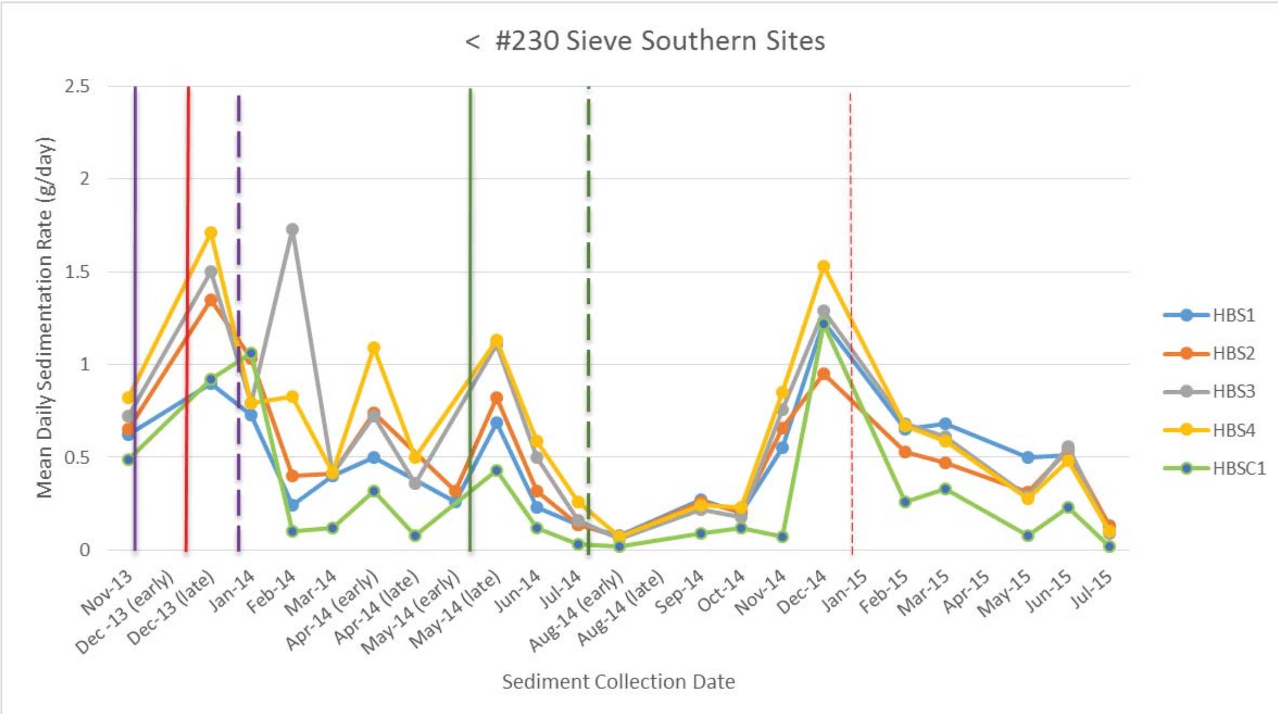

Figure 58. Daily sedimentation rates at southern hardbottom sites for fine-grain sediment (< #230 sieve) from baseline through post-construction surveys. The solid purple line on November 20, 2013 represents the first day of dredging by the hopper dredge Terrapin Island. The solid red line represents the first day of dredging for the Texas. The dotted purple line signifies the departure of the Terrapin Island (12/27/2013). The solid green line represents the first day of dredging for the Liberty Island (05/14/2014), and the green dotted line is the last day of dredging for the Liberty Island (07/03/2014). The red dash line represents the last day offshore of Dredge Texas (12/23/2014).

4.0 SUMMARY

Baseline surveys established information on the population dynamics, condition and sedimentation environment of the benthic communities adjacent to the Federal Navigation Channel. These baseline results were used as a point of comparison for the post-construction survey period to document changes attributable to dredging while considering other environmental or anthropogenic factors that influence hardbottom resources in the area. Comparisons between baseline and post-construction benthic habitats documented changes in nearshore hardbottom benthic habitats. Changes in the benthic habitats were attributable to a number of factors, including both natural environmental perturbations and project related activities.

The greatest project related effects documented at the end of post-construction surveys in the hardbottom habitat were the mortality of 3 tagged coral colonies at channel-side sites, or 1.6% of tagged colonies across all sites. In addition to whole colony mortality related to the effects of sediment stress, partial mortality due to sedimentation of coral colonies was documented over time (compliance through post-construction period) for tagged corals at all hardbottom sites (channel-side and controls). Sediment related partial mortality of coral colonies is due to sediment smothering a portion of the colony for a period of time; corals were affected at both channel-side and control sites by this process. However, patterns of sediment related partial mortality varied by site, with channel-side sites being more greatly affected than control sites. The north control, HBNC1-CP had 58% of corals affected by sediment related partial mortality. Channel-side sites recorded 50% (HBN1-CP), 58% (HBN2-CP) and, 79% (HBN3-CP). When compared against their controls, only HBN3-CP had greater partial mortality when compared to the control site. Partial mortality due to sedimentation at the southern control (HBSC1-CP) occurred on 23% of tagged colonies, while channel-side sites had a greater percentage of colonies affected by sediment related partial mortality for all sites (HBS1-CP [61%], HBS2-[89%], HBS3 [81%], and HBS4 [67%]).

As a result of the FDEP mandated monitoring program natural and project related effects on benthic communities were possible to discern. In the summer of 2014, a significant regional bleaching event was detected at control and channel-side sites. Shortly after the bleaching event, a white-plague disease event began to affect coral colonies (September 2014), starting at southern control sites on the middle reef. The white-plague outbreak continued to affect control and channel-side sites through 2015. These regional influences had a much greater effect on scleractinians within channel-side and control sites, when compared to the project-related impacts. White-plague disease was directly responsible for total scleractinian colony mortality of 18.3% of all tagged colonies from nearshore hardbottom sites (channel-side and control). White-plague mortality affected the greatest number of coral colonies at HBS3-CP (65.4%), followed by HBS4-CR (33.3%), HBSC1-CP (16.7%), HBNC1-CP (16.7%), and HBS2-CP (11.1%). The species most dramatically impacted include *Dichocoenia stokesi* and *Meandrina meandrites*. At the end of post-construction surveys, the white-plague disease outbreak was still active throughout the region and corals within most of the hardbottom monitoring sites were still being impacted by this epizootic. Accordingly, total colony mortality related to this disease can be expected to continue to be a region-wide issue into the future.

According to baseline and post-construction octocoral abundance comparisons, octocoral populations declined slightly, although not significantly at hardbottom channel-side sites (except HBS4-CR). Control site octocoral populations increased, but these results were also not statistically significant. In order to better understand effects on octocorals or any other benthic organism of interest, individuals must be tagged and followed through time in order to separate project related and regional impacts.

Functional group data, analyzed from collected video transect footage, including octocorals, scleractinians, and sponges changed little between baseline and post-construction, although groups varied over time during compliance monitoring. Due to the low cover of living functional groups (most <5% cover), *in situ* colony counts are recommended for a more accurate and precise measurement of organismal change at the level of the transect and site. Functional group data including CTB and sand varied widely throughout the compliance period and these trends can be attributed to both natural and project related variability. Increased sand was documented during construction monitoring, particularly at southern channel-side sites. However, based on the video dataset analysis, since January 2015, CTB appeared to be increasing at most hardbottom sites, which would be expected as any local increases in sediment are assimilated into the benthos over time.

Sedimentation flux was calculated (daily rates) based on analysis of using sediments collected in traps at all hardbottom stations. These rates reflected seasonal variation in sediment transport as well as proximal sources of sedimentation (i.e. location relative to active dredging equipment). Sedimentation rates for post-construction were lower for all grain sizes when compared to baseline data, which may represent a seasonal difference, as baseline data were collected in the fall/winter (but before any dredging activity), compared with summer conditions, which were relatively calm.

Recommendations

Consider regression based study design to document project effects over a greater spatial extent rather than monitoring at only project-adjacent and control sites. This would provide a more complete understanding of project related effects throughout the monitoring time period.

For diver safety consider locating project adjacent sites no closer than 30m to project related activities.

Provide more detailed baseline information for a greater area than 150m away from the project location, so that project related effects can be measured.

Consider repeated measures to look at all representatives of community (i.e. corals, octocorals, and sponges) to differentiate project and regional effects.

Continuous weekly monitoring of resources from baseline through post-construction would provide information on how organism stress abates when construction is not present. In addition, continual monitoring would decrease the number of individuals assigned mortality of unknown cause.

Integration of real-time aerial (satellite) imagery of sediment plumes, in-water turbidity monitoring of these plumes, and *in-situ* sediment deposition monitoring (concentrations of TSS) on the benthic community associated with dredging operations, during construction. This will allow for concentrating field efforts to determine if certain areas are being unduly impacted by sediment fallout above levels that may be considered stressful to the benthic communities in the project area. Real-time adaptive management would be seamless with these data available to both the project team and regulators.

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