Examination of Sedimentation Impacts to Coral Reef along the Port of Miami Entrance Channel, December 2015

NOAA's National Marine Fisheries Service
Final Report, April 2016

Executive Summary

The NOAA's National Marine Fisheries Service (NMFS) assessed the damage from sedimentation to coral reefs adjacent to the Port of Miami Entrance Channel[1] during December 2015. This work was conducted to assist development of a compensatory mitigation plan for offsetting impacts to coral reefs from the dredging necessary to expand navigation channels for the Port of Miami. The NMFS focused its fieldwork on the Middle Reef north of the Entrance Channel, assessing sites as far as 700 meters north of the channel in addition to control (or reference) sites the USACE established for this portion of the project. The NMFS surveyed both the Ridge-shallow (western, and referred to in this report as low-relief or LR) and Linear Reef (eastern, and referred to in this report as high-relief or HR) portions of the Middle Reef, including areas not assessed previously for sedimentation impacts by the USACE, its contractors, the Florida Department of Environmental Protection (FDEP), the Miami Dade Department of Regulatory and Economic Resources Division of Environmental Resources Management (DERM), and groups sharing their information. The NMFS determined the severity and extent of sedimentation impacts and associated lost services based on the presence of sediment layers over reef habitat, depth of the sediment over reef habitat, partial mortality, and presence of sediment-associated stressors on corals (e.g., accumulation of sediment and a ring of dead tissue at the base of a colony referred to as a "halo"). The NMFS observed sedimentation impacts to coral reef at all survey sites on the Middle Reef. The severity of the damage was generally more severe at sites closer to the channel and along the high-relief portions of the reef. The NMFS developed assessment areas based on trends in partial mortality and sediment-associated mortality. The level of severity in each assessment area was determined by examining sediment depth measured at each site and observations of surface sediment type. The NMFS estimates very severe impacts to approximately 6.6 acres, severe impacts to 12.6 acres, significant impacts to approximately 11.8 acres, moderate impacts to approximately 96.0 acres, and low impacts to 31.5 acres of the Middle Reef north. For the impact areas characterized as very severe, reef habitat has transitioned to sand bottom and recovery will not begin until the sand is removed. For other areas, the NMFS estimates the start of natural recovery will begin once the sediment is removed from the system, which may require several years. Once recovery begins, it is expected to take years before the species richness, densities, and size class distributions comprising a resilient reef community are reached.

Section 1: Introduction

In November 2015, the NMFS agreed to assist the U.S. Army Corps of Engineers Jacksonville District (USACE) with development of a compensatory plan to offset sedimentation impacts to coral reef and hardbottom[2] adjacent to and several hundred meters surrounding the Entrance Channel to the Port of Miami. To inform development of a general mitigation strategy, the NMFS determined an in-water

[1] NOAA nautical charts refer to the Entrance Channel as the Bar Cut and Outer Bar Cut; reports from USACE contractors often refer to the Entrance Channel as Cut 1 and Cut 2.

[2] This report uses the terms *hardbottom, reef,* and *coral reef* interchangeably.

assessment was needed to assess potential impact gradients affecting likelihood of recovery. Results from the impact assessment will inform a Habitat Equivalency Analysis used to scale compensatory mitigation requirements. The general strategy will be based on the mitigation plan the NMFS and USACE developed for expanding the Outer Entrance Channel to Port Everglades (Fort Lauderdale, Florida), which is summarized in the final Environmental Impact Statement for that project (2015).

The NMFS focused its field efforts on the coral reef feature referred to as *Middle Reef north*[3] (Figure 1) in USACE project reports. Although Dial Cordy and Associates, Inc. [DCA] (2015a), a USACE contractor, reported dredge-induced sedimentation impacts to the Outer Reef north (8.3 acres), Outer Reef south (1.6 acres), and Middle Reef south (64.4 acres) and DCA (2014a) and FDEP (2014) reported impacts to the Nearshore Ridge Complex north and south (39.0 acres) near the "elbow" of the Entrance Channel, these earlier assessments suggested Middle Reef north had the more severe sedimentation impacts and contained the largest impact area (FDEP 2014; DCA 2015a; DCA 2015b; Miami Waterkeeper 2015a; Miami Waterkeeper 2015b) with approximately 130 acres of impacts to coral reef from sedimentation (DCA 2015a).

[3] Walker (2009) refers to the Middle Reef as the "Inner Reef." This portion of the Florida Reef Tract lacks a Middle Reef, and reports often misidentify the Inner Reef as Middle Reef or Reef 2. For consistency with the USACE and DCA reports, the NMFS will refer to this feature as the Middle Reef.

Figure 1. Coral reef features surrounding the Port of Miami Entrance Channel.

Section 2: Field Methods

Site Selection

Survey sites selected included both Ridge-shallow (referred to as low-relief or LR in this report) and Linear Reef-Inner (referred to as high-relief or HR in this report) habitats within the western and eastern portions, respectively, of Middle Reef north as characterized by Walker (2009)[4]. Using Google Earth Pro, channel-parallel bands were drawn 100, 200, 300, 500, and 700 meters from the channel yielding nine potential assessment areas (Figure 2)[5]. To account for habitat transitions (e.g., from LR to HR, from LR to sand, or from HR into the mapped sand channel within the Middle Reef), a 60-meter buffer was

[4] Walker (2009) is the base map used in DCA (2015a) and DCA (2015b).

[5] A survey site was identified in the low-relief reef at 700 meters north of the channel, but it was not surveyed due to time limitations. Therefore 9 out of the 10 originally selected assessment areas were surveyed.

applied in each assessment area to ensure transect placement was entirely within the targeted reef habitat based on the maps in Walker (2009). Sixty meters was determined to be the minimum buffer needed because maximum transect length is 50 meters; however, actual buffer distances ranged from 71 meters at R2N-300-LR (the distance between the dive site and HR) to 293 meters at R2N-100-LR (the difference between the dive site and the sand/reef edge to the west). Each assessment area was divided into four channel-perpendicular cells, and a dive site was randomly selected, using the random number generator in MicroSoft Excel, within one of the four cells, with the exception of three dive sites: R2N-100-LR, R2N-200-LR, and R2N-300-LR (Figure 3). For these three sites, the NMFS used the center points of transects surveyed by DCA (2010 fieldwork, 2011 report). The six other dive sites (R2N-500-LR, R2N-100-HR, R2N-200-HR, R2N-300-HR, R2N-500-HR, and R2N-700-HR) were selected to be at or near the 100-meter interval mark. The NMFS visually inspected aerial imagery collected in March 2013 (before expansion dredging began) with a one-foot resolution [supplied by Dr. Brian Walker, Nova Southeastern University, and described in Walker and Klug (2014) and Klug (2015)], to ensure previously unmapped sand channels were not present near the dive sites.

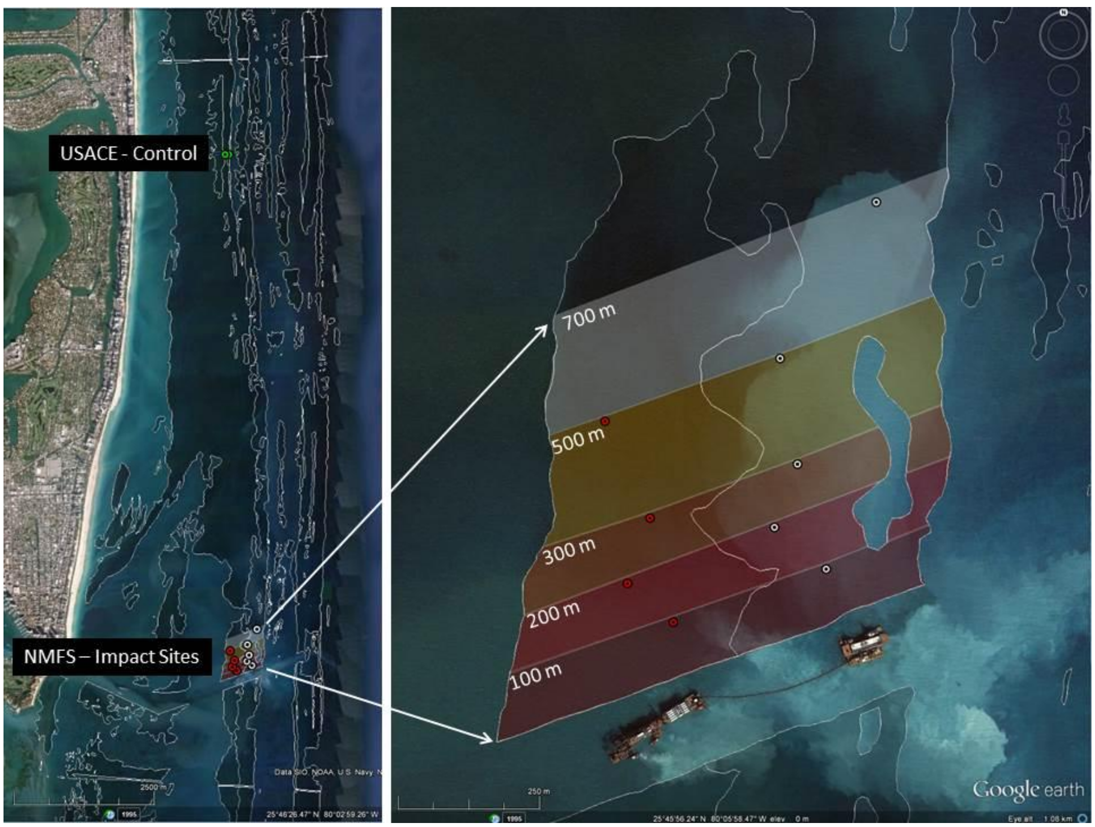

Figure 2. Location of the eleven dive sites the NMFS assessed during December 2015. Green points (top of left panel) represent the USACE control sites the NMFS also surveyed during December 2015. In the right panel, the red points show the NMFS dive sites within the low-relief (LR) reef and white points are the NMFS dive sites within the high-relief (HR) reef.

The two control sites are the controls the FDEP specified for Middle Reef north in Permit #0305721-001-BI, issued in 2014. This report will refer to these sites as the “USACE control sites” or “USACE” in figures and tables. These sites are approximately 5.5 miles north of the federal channel. Dial Cordy and Associates, Inc. (DCA), refer to these sites as R2N-C1-LR and R2N-C2-RR in project compliance monitoring reports[6]. The NMFS used shapefiles obtained from the USACE to determine the location of the NMFS dive sites in these areas, which represent the center point of each site.

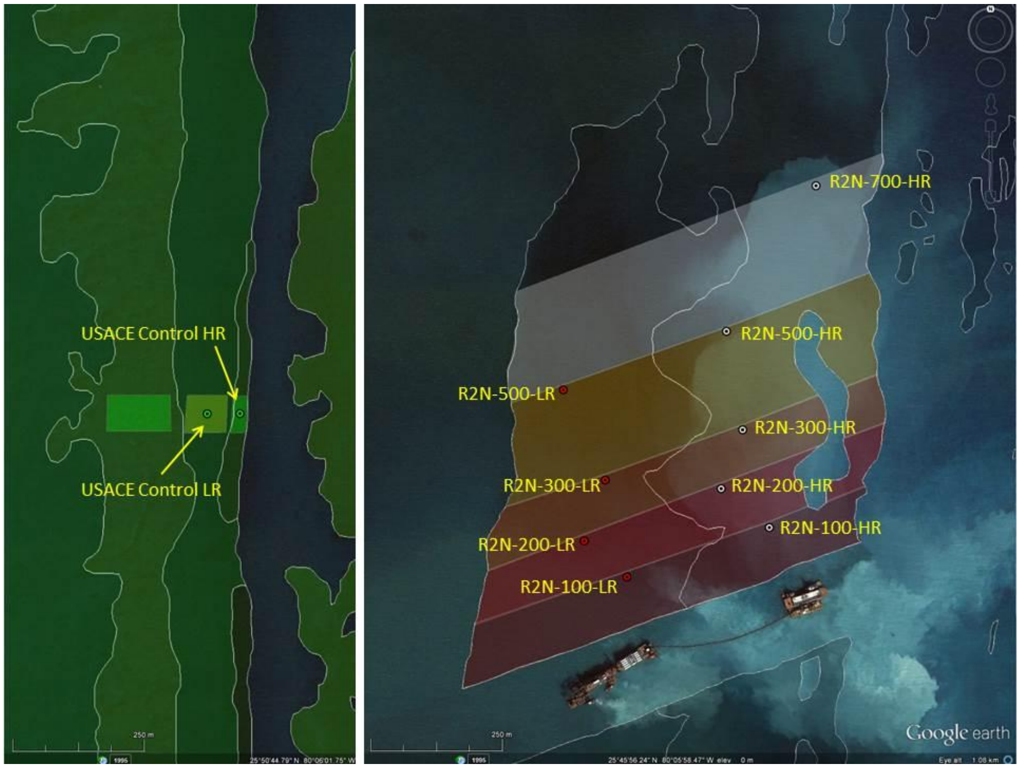

Figure 3. Left: The USACE control sites. The USACE had one additional HR control site to the west, which the NMFS did not survey due to the shallow depth compared to the Middle Reef north sites; this site was not surveyed during all compliance monitoring events (DCA 2015c). Right: The NMFS survey sites. The Middle Reef north is referred to as R2N in project monitoring reports, the number is the approximate distance in meters from the federal channel, and LR and HR refer to low-relief and high-relief areas, respectively, with high-relief habitat generally having more than 1.0 meter of vertical elevation off the seafloor.

Assessment Methods

Six belt transects (10 meters by 1 meter) and two 50-meter-long line-intercept transects were surveyed at each site[7]. In general, the belt transects were oriented east-west, with the exception of the USACE

[6] This report uses the acronym "LR" differently compared to project compliance monitoring reports prepared by DCA. In the DCA reports, "LR" refers to "linear reef" and "RR" refers to "ridge reef." In the NMFS assessment, "LR" refers to "low-relief" and "HR" refers to "high-relief" habitat. Sites DCA refers to as LR are sites the NMFS refers to as HR.

[7] At R2N-300-HR seven belt transects were completed.

control sites where the bearing was north-south due to the narrow reef[8]. The two line-intercept transects were run directly from the buoy, which was dropped from the boat according to the dive location. Due to time constraints, only scleractinian corals (number, species, size class, and condition) were recorded at four of the belt transects that were run in parallel and adjacent (approximately 10 meters away from the line-intercept transect). The number of scleractinian corals (species and size class), octocorals (genera and size class), sponges (morphotype and size class)[9], and condition of each organism were recorded at the other two belt transects. Conditions assessed included disease, dead[10], bleaching, sediment "halo," percent mortality, sediment accumulation[11], and healthy if there was no noticeable signs of stress present. A sediment "halo" refers to a concentric ring of dead coral tissue at the base of the coral colony. This distinct pattern of mortality results from a coral colony not being able to keep up with sediment removal. Sediment accumulates in the lower portion of the coral colony which smothers and eventually kills coral tissue at the base of the colony (Figure 4).

Figure 4. Example of a great star coral (*Montastraea cavernosa*) colony with a sediment halo at R2N-200-LR. Note the margins (or halo) surrounding the live coral tissue are covered in sediment. Left: The colony before a diver removed the sediment. Right: The colony after a diver fanned away sediment. Note the margins (or halo) surrounding the live coral tissue indicate dead coral calyx (or the cups within the scleractinian corals that hold polyps).

The line-intercept transects recorded bottom type every meter. Bottom type classifications included sand channel, hardbottom, or hardbottom with coral, dead coral, sponge, dead sponge, turf, macroalgae, palythoa, cyanobacteria, crustose coralline algae (CCA), and sediment over hardbottom. If there was a visible depth of sediment over hardbottom, this was labelled as "sediment over hardbottom." For example, turf normally has sediment embedded within the algae, but if the turfs were completely buried by sediment and not visible, this would be labelled as "sediment over hardbottom." If the depth of this sediment was 4.0 centimeters or more, it was labelled as "deep sediment over hardbottom." Every 5.0

[8] The east-west length of the USACE Control sites is 77 meters (LR) and 28 meters (HR) and the buffer rules for avoiding a transition into a different habitat could not be applied.

[9] All sponges were counted, however, in some cases only in a 5-square-meter area due to dive-time constraints. A subset of *Xestospongia muta* barrel sponges were identified to the species level.

[10] Not all dead corals were counted.

[11] Defined as the presence of sediment on live coral tissue.

meters along the transect, qualitative observations were recorded on surface sediment type (e.g., sand or fine mud-like sediment) and the depth of the sediment over hardbottom was measured in centimeters[12]. If a point fell on hardbottom where a diver was unable to discern one individual organism at the point, all organisms at that point were recorded. Video was recorded of each line-intercept transect. Still photos of representative individual organisms and landscape conditions were made at each site. The line-intercept transects were generally oriented east-west. In addition, general environmental observations were made on the presence or absence of fish species and signatures of sediment stress, including burial of erect forms of octocoral and sponge holdfasts, signs of necrosis at the attachment parts of excavated octocorals, and direct accumulation of mud-like material in low-lying pockets.

Section 3: Results

Dives Completed

Fieldwork occurred December 7, 9, 10, and 11, 2015, on the Middle Reef north (field conditions were not suitable for diving on December 8). Each day the dive team was composed of four divers from the NMFS Restoration Center, Southeast Fisheries Science Center, and Southeast Regional Office. To ensure consistency in data collection between dives, individual divers were assigned the same task. The dive platform was a 25-foot Parker supplied by Calloway Marine Technologies through the NMFS Southeast and Caribbean Coral Support Contract. A reef site near the coral reef referred to as Emerald Reef, approximately six miles south of the federal channel, was visited on the first day to allow the divers to calibrate methods for collecting data along belt and line-intercept transects and observations. This site was also visited by another NOAA dive team during October 2014 (findings described in NMFS 2015a), allowing the NMFS dive team to qualitatively assess change at the reef that may have occurred over the 14-month interval and after the White Plague disease outbreak during spring to fall 2015.

Nine potential impact sites were assessed in water depths ranging from 23 to 30 feet of water on the Middle Reef north, in addition to the two USACE control sites (Table 1). Impact sites were assessed at low-relief and high-relief portions of the reef at 100, 200, 300, and 500 meters from the channel. In addition, the high-relief reef was assessed at 700 meters from the channel (Figure 3). The USACE control sites also included one low-relief and one high-relief coral reef.

[12] In 0.25-centimeter increments for measurements less than 2.00 centimeters; however, there was one measurement of 0.30 centimeters at USACE-HR. Measurements were made to the nearest whole number if depth was greater than 2.0 centimeters, with the exception of R2N-100-HR and R2N-200-LR where measurements of 3.5 and 2.5 centimeters were recorded, respectively.

Table 1. The NMFS Dive Sites, date surveyed, and water depth recorded on line-intercept and belt transects.			
NMFS Dive Site	Survey Date	Water Depth (feet) Line-intercept Transects	Water Depth (feet) Belt Transects
R2N-100-LR	12/10/2015	28	27 to 30
R2N-100-HR	12/10/2015	30	30
R2N-200-LR	12/11/2015	29	24 to 27
R2N-200-HR	12/11/2015	28	28 to 30
R2N-300-LR	12/09/2015	27	27 to 28
R2N-300-HR	12/09/2015	29	27 to 28
R2N-500-LR	12/09/2015	30	27 to 28
R2N-500-HR	12/09/2015	30	28 to 30
R2N-700-HR	12/11/2015	30	29
USACE-LR	12/10/2015	23	23 to 28
USACE-HR	12/10/2015	23 to 25	28

Qualitative Observations

Overall observations

Sedimentation impacts, such as accumulations of fine white sediments, partial mortality of scleractinian corals, burial of octocoral holdfasts, and burial of sponges, tunicates, and turf algae was observed at all survey sites on the Middle Reef. Variation in the extent of these impacts was based on distance from the channel with sites closest to the channel and sites within the high-relief reef generally having greater levels of impact from sedimentation. While the HR sites exhibited the highest relief observed, the changes in relief were more subtle than expected between HR and LR sites. Sedimentation impacts extended beyond 700 meters north of the channel based on NMFS dive observation at site R2N-700-HR. Similar observations indicative of sedimentation impacts were not seen at the USACE control sites five miles northward (Figure 2).

High-relief reef components of the Middle Reef north (greater than one meter of vertical relief) seemed to be more susceptible to sedimentation impacts due to concentration of sediments at the reef's base and interstitial spaces resulting in a reduction of habitat complexity and rugosity. Occurrence of deep sediment, filling of interstitial spaces of the reef, and downslope movement of sediments was observed primarily in the high-relief reef. Organisms in downslope locations of the high-relief reef were observed to be stressed by sediments deposited directly on the colonies and had moved downwards from the upslope areas of the reef. Partial mortality of scleractinian colonies, in particular, appeared to increase in these areas. At sites with deep sediment, such as R2N-200-HR, when divers would excavate buried holdfasts of octocorals, necrosis of the tissue was apparent and dead/buried scleractinian corals were also present.

Sediment depth at the two USACE control sites ranged from 0.3 to 1.0 centimeters with most observations being 0.5 centimeters of sediment visually characterized as sand. Coral paling was commonly observed, in addition to some bleaching and disease. The high-relief reef control sites had numerous interstitial spaces with greater reef fish abundance and reef fish species diversity than any other transect location in the Middle Reef north assessment area. When divers descended at the high-relief control site, a large nurse shark swam up to the anchor. Three spiny lobsters were observed in one crevice (Figure 22). A large stoplight parrotfish was observed at a cleaning station with gobies providing the services. In contrast, the high-relief reefs affected by sediment within the Middle Reef north have effectively lost their habitat complexity when these spaces are filled with sediment. No parrotfish or gobies were observed in the high-relief reef in the impact areas the NMFS assessed.

R2N-100-LR

Sedimentation was apparent on all horizontal surfaces of low-relief reef (less than one meter of vertical relief) (Figure 5). Accumulations of fine white sediment and coarse sediments were observed generally ranging from 1 to 5 centimeters over hardbottom and throughout the reef. Greater sediment depths (including coarser sediments and sand waves) over hardbottom were observed within low-lying reef areas. Scleractinian colonies had sediment accumulations at their bases with partial mortality of the colonies apparent. Numerous scleractinian colonies observed with recent mortality (i.e., polyps were empty and the coral skeleton was white with little to no algal colonization and with sharp edges on the coral calyx and septa). Nearly all octocoral holdfasts were buried by sediments. Numerous octocorals and sponges had partial or complete mortality.

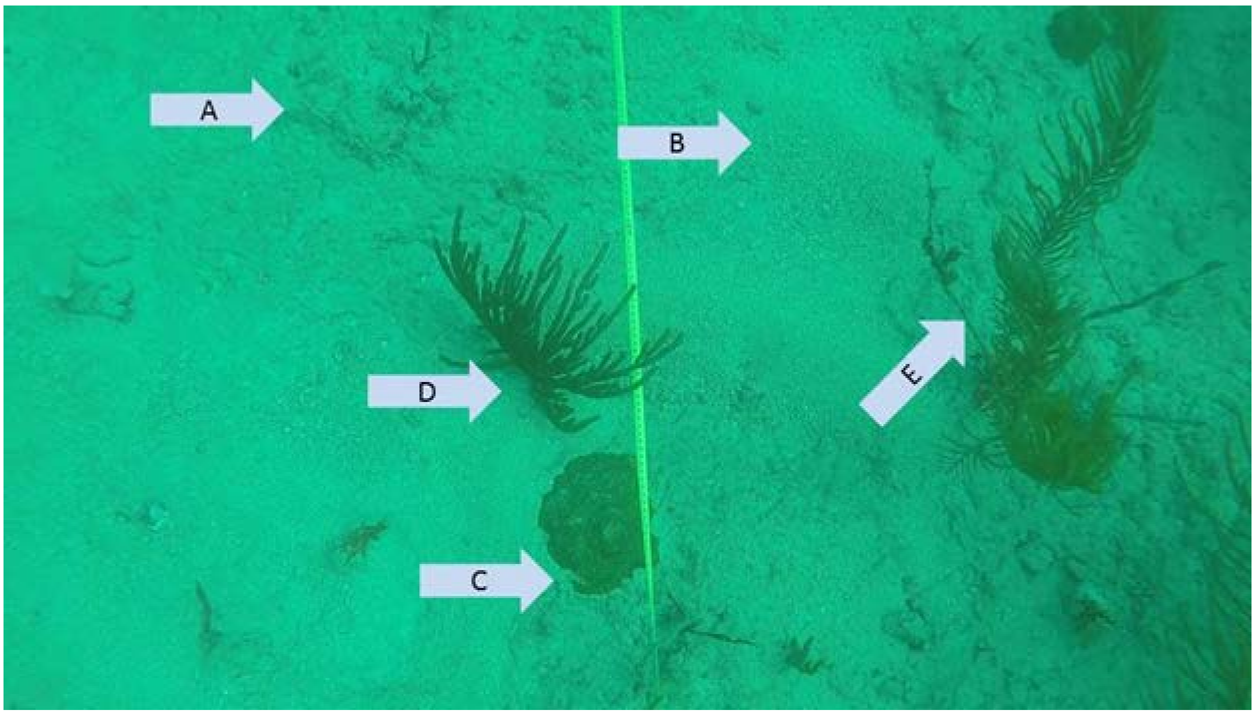

Figure 5. Sedimentation impacts at transect R2N-100-LR. Fine white sediments adhere to and smother the algal turf, benthic animals, and rock framework of the reef (A). Sorted sediments with greater depth in depressions within the reef (B). Most scleractinian corals show a sediment halo with partial mortality at the base of the colony (C). Almost all octocoral holdfasts are buried by sediments (D). Numerous octocorals and sponges also have partial or complete mortality (E).

R2N-100-HR

Sedimentation was apparent on the upper surfaces of the high-relief reef (1 to 2.5 meters of vertical relief). Accumulation of deep sediment (at least 4.0 centimeters) over reef was observed at the base of reef structures and in depressions within the reef (Figures 6 and 7). Nearly all scleractinian corals exhibited partial or complete mortality. Turf algae and small animals (e.g., sponges and scleractinian corals) covered beneath 1 to 7 centimeters of fine, grayish white sediment over hardbottom.

Figure 6. Extensive burial of octocorals and other reef animals was observed on the R2N-200-HR transect. Deep sediment (more than 4.0 centimeters) with sand waves in the fine white sediments over hardbottom was observed throughout this dive.

Figure 7. Sedimentation impacts at transect R2N-100-HR. Sediment observed on most horizontal surfaces of this high-relief reef. Accumulation of deep sediment over hardbottom, often more than 10 centimeters, at the base of the reef structure has smothered scleractinian corals, sponges, octocorals, and other benthic organisms.

R2N-200-LR

Sedimentation apparent on all horizontal surfaces of the low-relief reef (less than one meter of vertical relief) (Figure 8). Accumulations of fine white sediment and more coarse sediments observed generally ranging from 1 to 5 centimeters over hardbottom throughout the reef. Greater sediment depths (including coarser sediments and sand waves) observed in low-lying hardbottom areas within the reef. Most living scleractinian colonies had sediment accumulations at the bases with partial mortality of the colonies apparent (e.g., Figure 9). Numerous scleractinian colonies observed with recent mortality (i.e., polyps were empty and the coral skeleton was white with little to no algal colonization and with sharp edges on the coral calyx and septa). Almost all octocoral holdfasts buried by sediments. Numerous octocorals and sponges show partial or complete mortality.

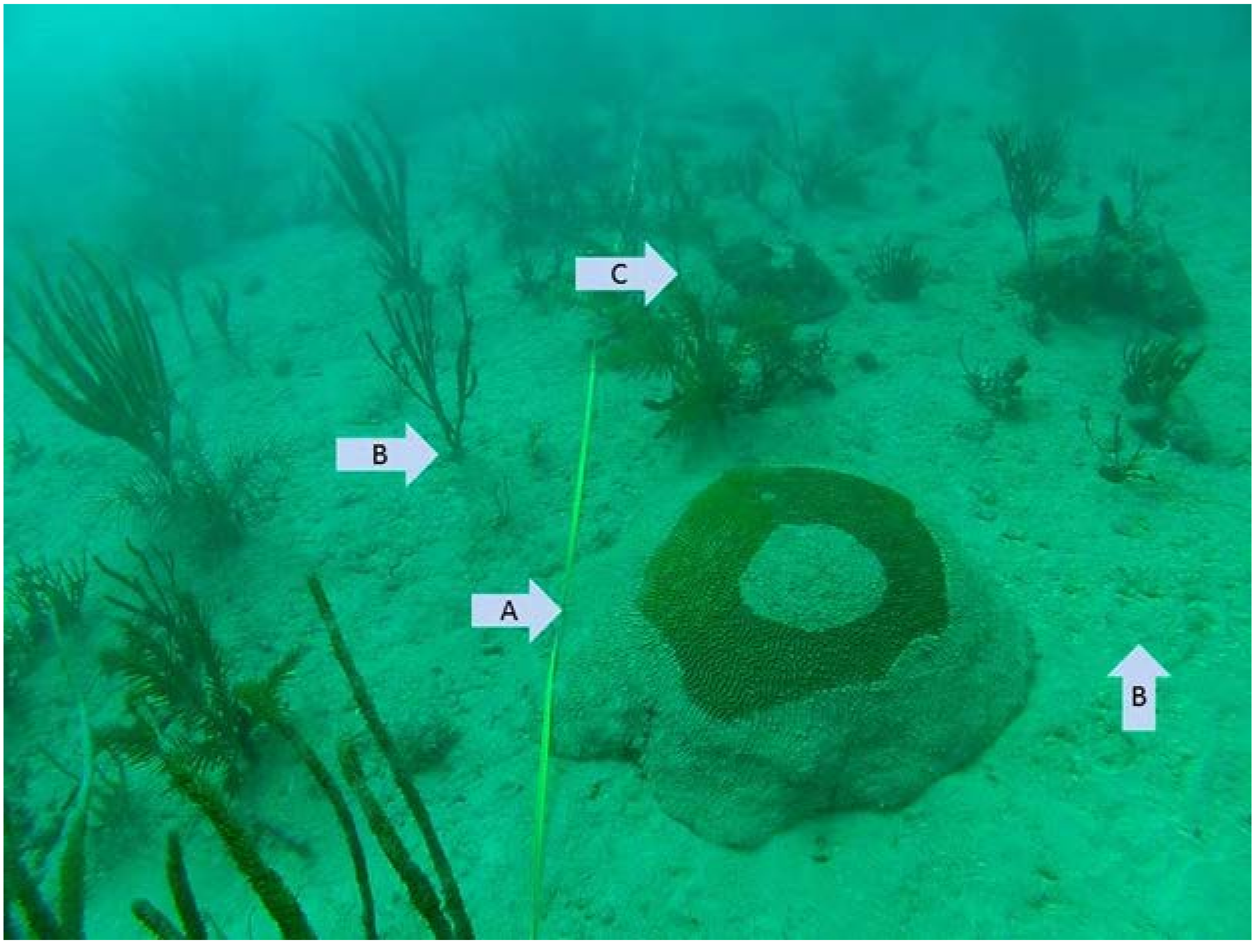

Figure 8. Sedimentation impacts observed on transect R2N-200-LR. *Psuedodiploria strigosa* shows partial mortality with a sediment halo in contrast to the same species shown in Figure 20 from the control site USACE-LR. Fine white sediments adhere to the reef and cover the holdfasts of octocorals (B). The *Orbicella faveolata* colony in the background (shown in detail in Figure 9) has a halo of mortality consistent with sediment burial at the base (C).

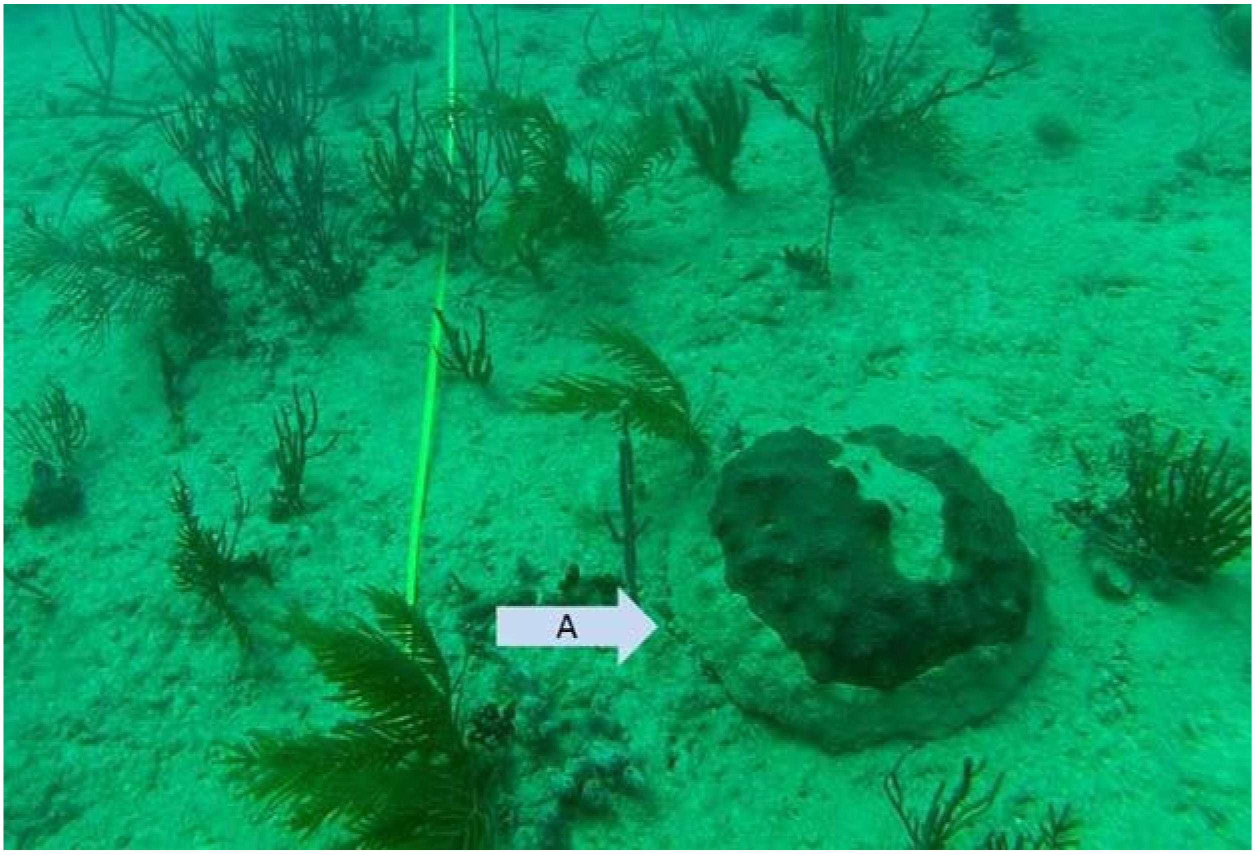

Figure 9. Sedimentation impacts at transect R2N-200-LR. This *Orbicella faveolata* colony has partial mortality from the sediment halo (A) and what appears to be old mortality of unknown origin on top that is collecting sediment.

R2N-200-HR

Sedimentation common on the upper surfaces and interstices of the high-relief reef (1 to 2 meters in vertical relief). Sediment depths of 2 to 7 centimeters over hardbottom observed along the transect. Sediment movement downslope has filled interstitial spaces of the reef, reducing habitat complexity and rugosity. Accumulation of deep sediment observed at the base of reef structures and in low-lying depressions within the reef (Figure 10). Buried scleractinian corals and octocorals observed (Figure 11). Partial mortality of corals and sponges apparent throughout the transect. This transect has the greatest impacts observed during the survey due to accumulations of sediment observed on all horizontal, sloping, and interstitial spaces within this high-relief reef (Figure 12).

Figure 10. Deep sediment at transect R2N-200-HR. Extensive burial of the high-relief reef is observed. Note sand waves indicating continued movement of sediments. Habitat complexity and rugosity was reduced or eliminated due to the presence of deep sediment. Reef was converted from a hard substrate to a predominantly soft substrate.

Figure 11. Sedimentation impacts at transect R2N-200-HR. Burial of octocoral holdfasts and branches resulted in partial or complete mortality of the colony (left). Sand filled low-lying reef, covering scleractinian (A) and octocoral (B) colonies.

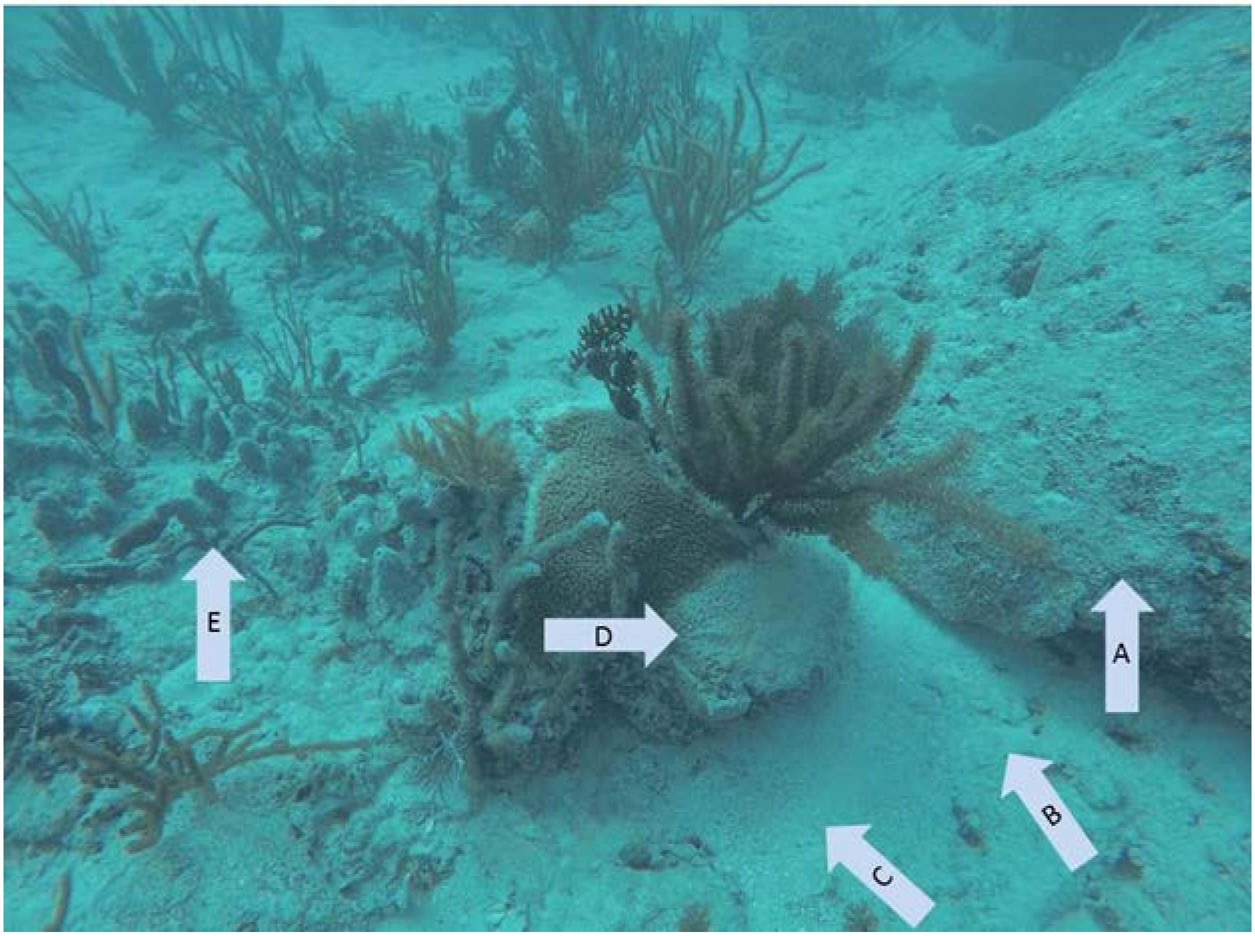

Figure 12. Sedimentation impacts at R2N-200-HR. Accumulations of sediment observed on all horizontal, sloping, and interstitial spaces within this high-relief reef. Sediments on sloping surfaces move down slope (A). Accumulation of deep sediment fills the natural low-lying areas within the reef (B). Sorting of sediments occurs during movement down slope resulting in coarser sediments at the base (C) and finer sediments adhering to surfaces like this *Montastrea cavernosa* colony (D). Sponges, octocorals, and turf algae are adversely affected (E).

R2N-300-LR

Sedimentation was apparent on all horizontal surfaces of the low-relief portion of the reef (less than one meter of vertical relief) (Figure 13). Accumulations of fine white sediment and coarse sediments observed 0.5 to 2 centimeters depth over hardbottom. Greater sediment depths (including coarse sediments and sand waves) observed in low-lying depressions within the reef. Most living scleractinian colonies have sediment accumulations at the bases with partial mortality of the colonies apparent. Numerous scleractinian colonies observed with recent mortality (i.e., polyps were empty and the coral skeleton was white with little to no algal colonization and with sharp edges on the coral calyx and septa).

Figure 13. Sedimentation impacts at R2N-300-LR. A layer of fine white sediments (0.5 to 2 centimeters thick) covering the reef (A) and coral colony (B). Sediment coating the turf algae covered with sediments qualitatively describes as fine and medium grain sediments (C).

R2N-300-HR

Sedimentation on the upper surfaces and interstices of the high-relief reef (1 to 2 meters in vertical relief) is apparent. Accumulation of deep sediment (at least 4.0 centimeters) over hardbottom observed at the base of reef structures and in depressions on the reef (Figure 14). Turf algae, small animals (e.g., sponges and scleractinian corals), and the bases of octocorals are covered with 0.5 to 1 centimeter of fine white sediment over hardbottom. Sponge and octocoral mortality observed at a reduced frequency compared to transects closer to the channel.

Figure 14. Sedimentation impacts at R2N-300-HR. Deep sediment accumulation fills the natural hardbottom channels in the reef framework (A).

R2N-500-LR

Sedimentation apparent on horizontal surfaces and interstices of the low-relief reef (less than one meter of vertical relief). Color of encrusting sponges and other epibenthos more apparent than on transects closer to the channel. Accumulations of fine white sediment observed generally ranging from 0.5 to 3.0 centimeters deep over hardbottom and throughout the low-relief reef (Figure 15). Greater sediment depths observed in low-lying depressions within the reef. Sediment accumulation was apparent at the base of scleractinian colonies with partial mortality of the colonies also apparent Figure 16). Many octocoral holdfasts were partially buried by sediments. Partial mortality of octocorals and sponges observed at this transect.

Figure 15. Sedimentation impacts at R2N-500-LR. Fine white sediments adhere to and smother the algal turf, benthic animals and rock framework of the reef (A). Most octocoral holdfasts partially or completely buried by sediment (B).

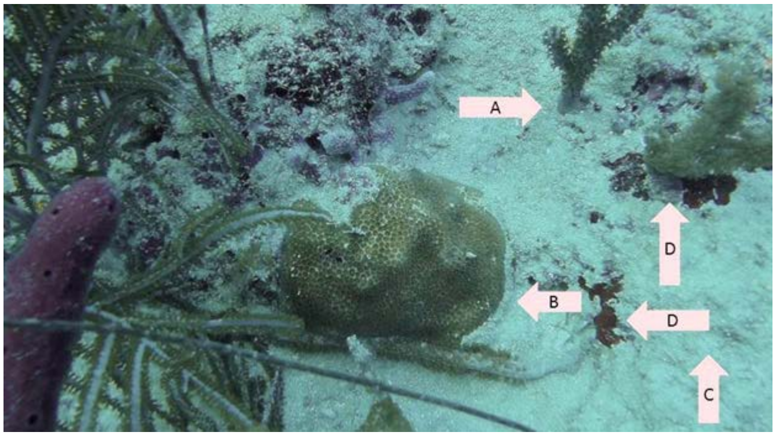

Figure 16. Sedimentation impacts at R2N-500-LR. Octocoral holdfasts partially buried 500 meters from the channel (A). A halo of dead coral tissue observed at the base of this *Stephanocoenia intercepta* colony (B). Fine white

sediment on the reef smothers turf algae and inhibits recruitment of benthic animals (C). Color of sponges and other epibenthos was more apparent on this transect than at transects closer to the channel (D).

R2N-500-HR

Sedimentation apparent on the high-relief reef (1 to 2 meters of vertical relief). Color of encrusting sponges and other epibenthos more apparent than on transects closer to the channel. Accumulations observed of fine white sediment generally ranging from 0.5 to 4.0 centimeters deep over the hardbottom and throughout the low-lying components of the reef (Figure 17). Greater sediment depths observed over hardbottom and in depressions within the reef. Sediment accumulation at the base of scleractinian colonies with partial mortality of the colonies was apparent. Many octocoral holdfasts partially buried by sediments. Partial mortality of octocorals and sponges also observed at this transect. Sediment halos on scleractinian colonies and fine white sediment covering the reef framework observed. Federally managed fishery species, including mutton snapper (Figure 18), gray triggerfish, and yellowtail snapper observed on this transect. Federally managed species were not observed closer to the channel. Abundance and species diversity of reef fish species was higher at the two control sites than at any of the impact sites.

Figure 17. Sedimentation impacts at R2N-500-HR. Fine white sediments on the outside of this sponge colony are easily re-suspended with fanning. Native sediments on the reef are larger grain size and less susceptible to resuspension.

Figure 18. Mutton snapper observed at R2N-500-HR.

R2N-700-HR

Sedimentation apparent on the high-relief reef (1 to 2 meters of vertical relief). Color of encrusting sponges and other epibenthos obscured by grayish white sediment. Accumulations of fine white sediment covering all the reef surfaces observed ranging from 1 to 6 centimeters deep throughout the high-relief reef (Figure 19). Greater sediment depths observed in hardbottom depressions within the reef. Interstitial spaces of the high-relief reef filled with sediment smothering benthic animals and reducing the complexity and rugosity of the reef. Sediment accumulation at the base of scleractinian colonies with partial mortality of the colonies apparent. Many octocoral holdfasts partially buried by sediments. Partial mortality of octocorals and sponges also observed at this transect.

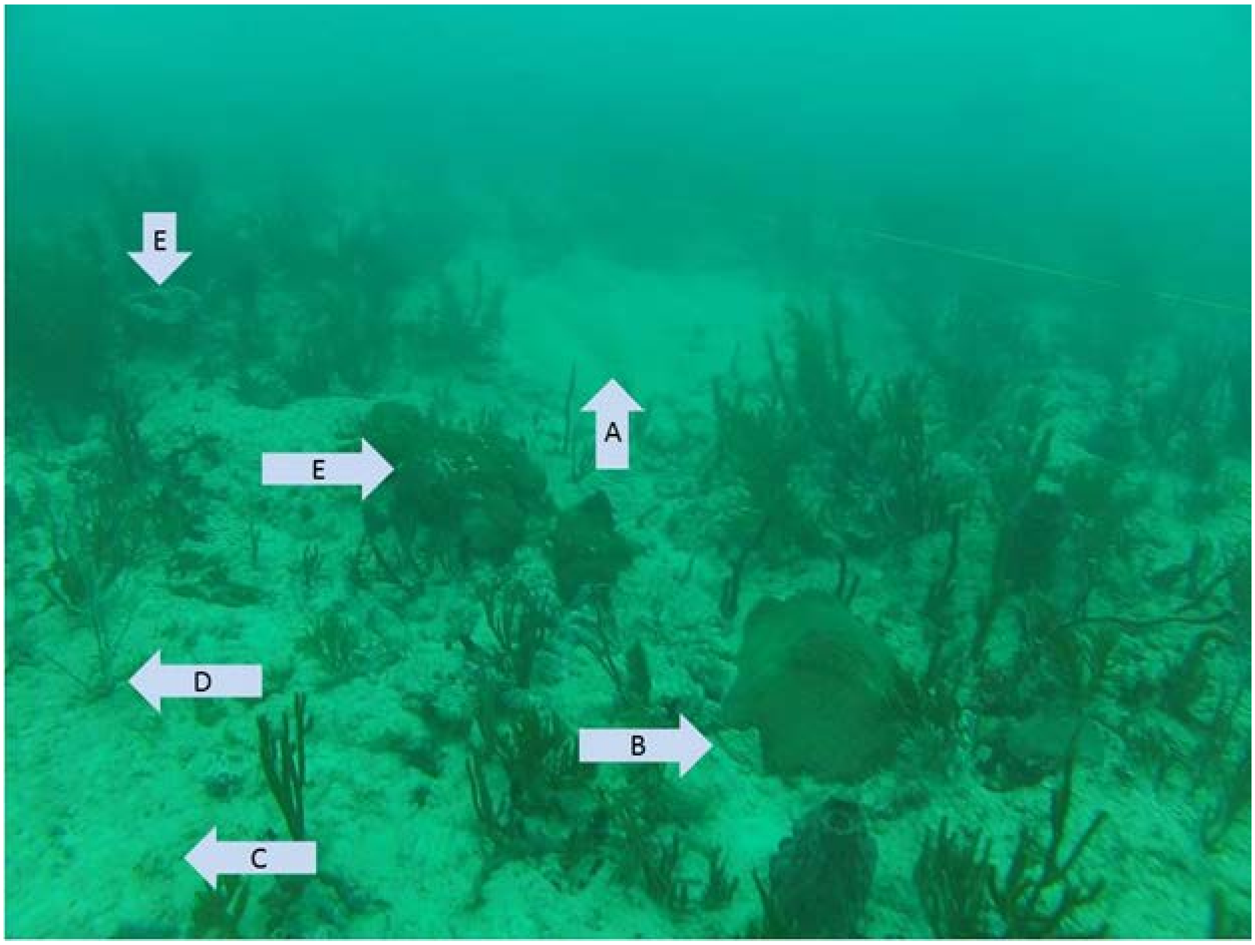

Figure 19. Sedimentation impacts at R2N-700-HR. Low-lying depressions within the reef filled with deep accumulations of sediment (A). Sediment halos on scleractinian colonies (B) and fine white sediment covering the reef framework observed (C). Burial of octocoral hold fasts and partial mortality of octocoral colonies is apparent (D). Recently deposited, highly-mobile fine-white sediments on scleractinian coral and sponge colonies (E).

USACE-LR

Minimal sediment accumulation apparent on the low-relief reef (less than one meter of vertical relief). Medium-grained to large-grained calcareous sediments with a small amount of fine sediment. Sediment depth ranging from 0.3 to 0.5 centimeters deep was observed mixed with the turf algae throughout the low-relief reef. Color of encrusting sponges and other epibenthos more apparent at the control site than on transects in the impact areas. Absence of sediment accumulation and partial mortality at the base of scleractinian colonies (halo), compared to the impact sites, noted (Figure 20). Federally managed fishery species frequently observed at this control site compared to few or none observed at survey sites (Figure 21).

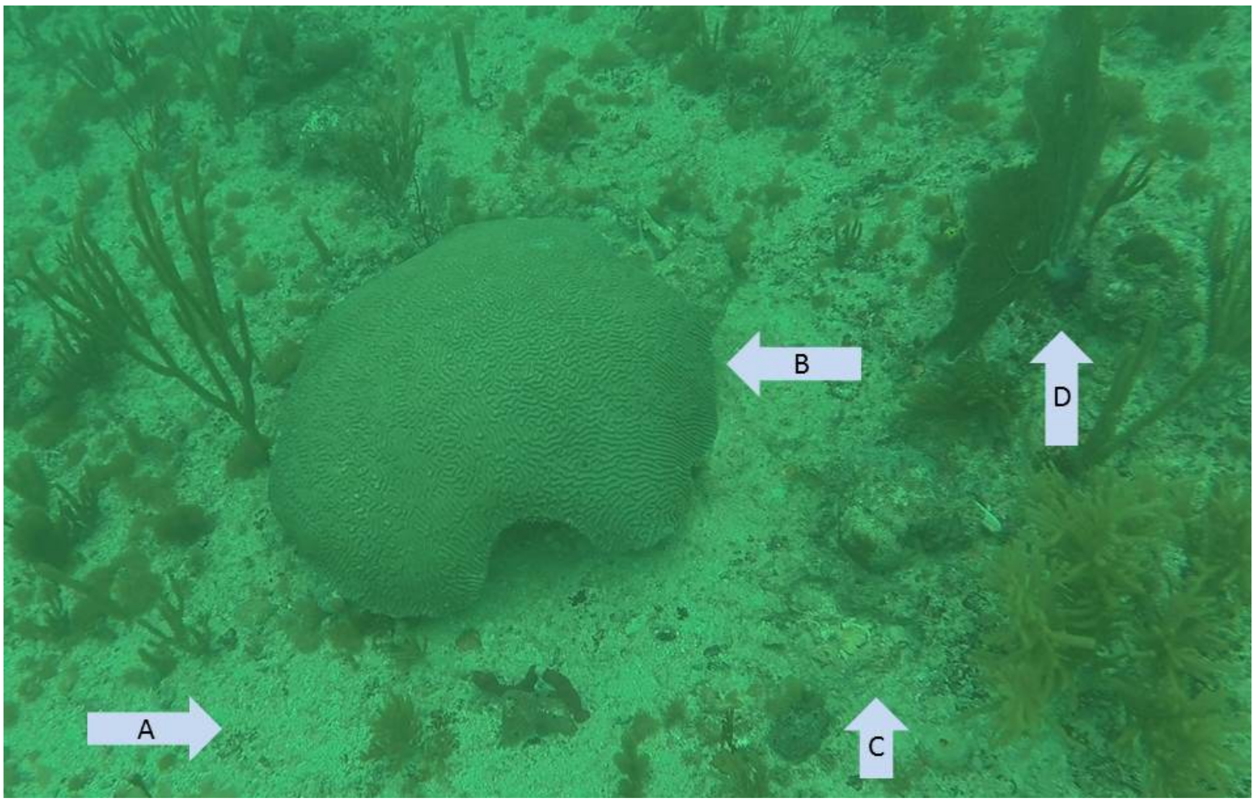

Figure 20. Sediment depth measurements and observations of sediment accumulation are considerably lower at the USACE control site (USACE-LR) than observed at all impact sites (A). This *Psuedodiploria strigosa* is not showing signs of partial mortality or sediment-associated stress (B). Color of benthic organisms (e.g. encrusting sponges, macroalgae and encrusting octocoral) is more apparent than the grayish white sediments covering the benthos at the impact sites (C). Burial of octocoral holdfasts seldom observed (D).

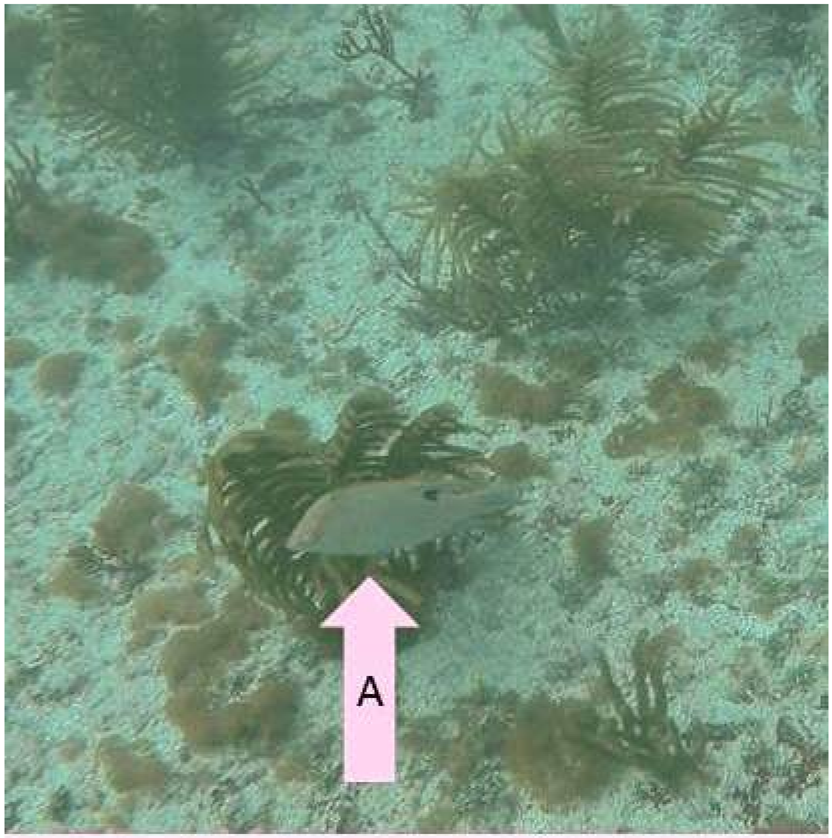

Figure 21. Numerous hogfish (A) and hogfish prey (crustaceans) observed at the USACE-LR and HR transects. Very few reef fish or crustaceans were observed in the impact areas.

<u>USACE-HR</u>

Minimal sediment accumulation apparent on the high-relief reef (1 to 1.5 meters of vertical relief). Medium-grained to large-grained calcareous sand sediments ranging from 0.3 to 1 centimeter deep observed mixed with the turf algae throughout the transect. Color of encrusting sponges and other epibenthos more apparent than on transects near the channel. No sediment accumulation or partial mortality at the base of scleractinian colonies (halo) observed. Burial of octocoral holdfasts on the control site not observed. Federally managed fishery species frequently observed at this control site compared to few or none observed at survey sites (Figure 22).

Figure 22. Interstitial spaces in the high-relief reef were observed with greater frequency at the USACE control site (USACE-HR) (A). Interstitial spaces utilized by spiny lobsters as shelter (B) and by cryptic reef fish like this high hat (C).

Line-Intercept Transect Results

Sediment over Hardbottom

Points along survey transects characterized as “sediment over hardbottom” and “deep sediment over hardbottom” were more common along the Middle Reef north transects than the USACE control site transects (Figures 23 and 24). Less than 5 percent of the survey points at the USACE control sites exhibited sediment over hardbottom. In contrast at Middle Reef north, the percentage ranged from 27 to 63 percent in the low-relief areas and from 43 to 81 percent in the high-relief areas. Notably over 80 percent of the points at R2N-200-HR were characterized as “sediment over hardbottom” compared to one percent at the USACE high-relief control. R2N-200-HR also had the highest prevalence of points characterized as “deep sediment over hardbottom” (a subset of sediment over hardbottom) with 43 percent of the points exhibiting 4.0 centimeters or greater sediment over reef (Figure 24). Along the transects 100, 200, 500, and 700 meters north of the channel, the percentage of points characterized as “deep sediment over hardbottom” were higher at the high-relief areas compared to the matching low-relief areas (Figure 24).

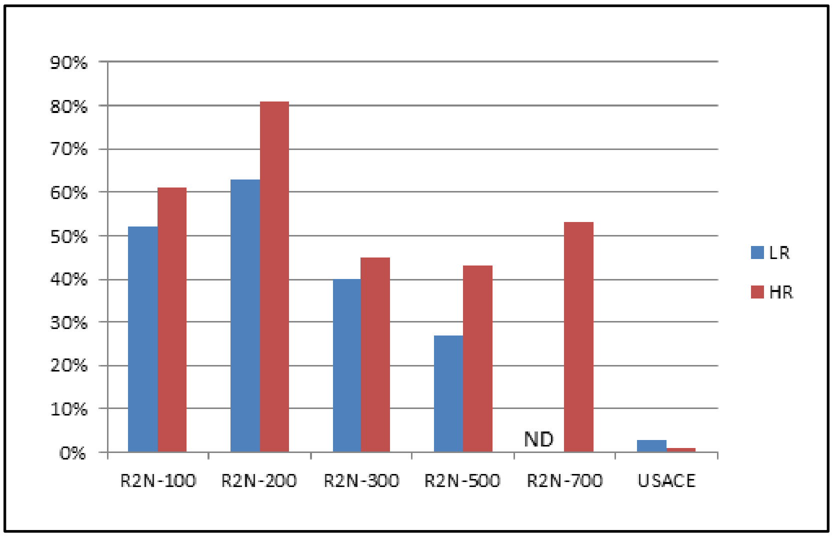

Figure 23. Percentage of points characterized as “sediment over hardbottom” from the two pooled line-intercept transects at the indicated distances from the Entrance Channel edge. The USACE control transects were approximately five miles northward. ND = No data (i.e., the NMFS did not survey the low-relief portion of Middle Reef north 700 meters from the channel edge)

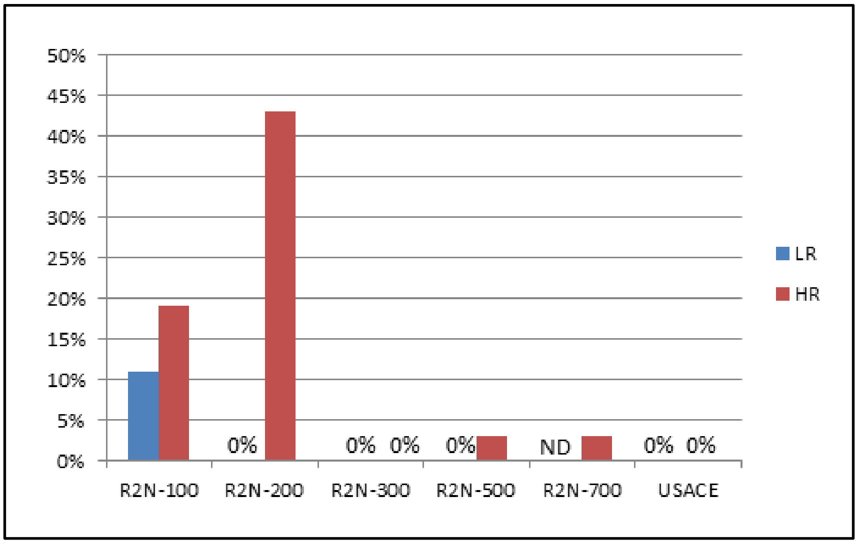

Figure 24. Percentage of points characterized as “deep sediment over hardbottom,” which is a subset of “sediment over hardbottom,” from the two pooled line-intercept transects at the indicated distances from the Entrance Channel edge. The USACE control transects were approximately five miles northward. ND = No data (i.e., the NMFS did not survey the low-relief portion of Middle Reef north 700 meters from the channel edge)

Sediment Depth

The average and maximum depth of the sediment layers over hardbottom at Middle Reef north were higher than at the USACE control sites (Figures 25 and 26). The average depth of the sediment layer ranged from 0.7 to 4.2 centimeters along transects in the high-relief areas and 0.9 to 1.8 centimeters in the low-relief areas. In contrast, the average sediment layer depth at the USACE control sites was 0.3 at both the HR and LR areas. The highest measured maximum sediment depth was 10 centimeters at R2N-200-HR and the lowest maximum sediment depth measurement was 0.5 centimeters at USACE-LR.

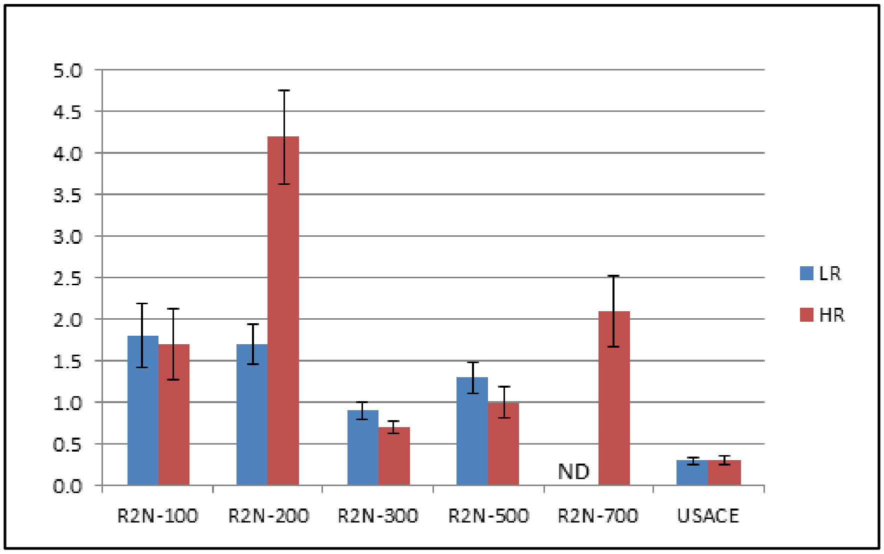

Figure 25. Mean sediment depth over hardbottom and +/- one standard error recorded from the line-intercept transects. Sediment depth was recorded every five meters along the transect for a total of 10 measurements per transect and 20 measurement total per site. Sediment measurements were independent of where sediment over hardbottom was recorded (Figure 23). ND = No data (i.e., the NMFS did not survey the low-relief portion of Middle Reef north 700 meters from the channel edge)

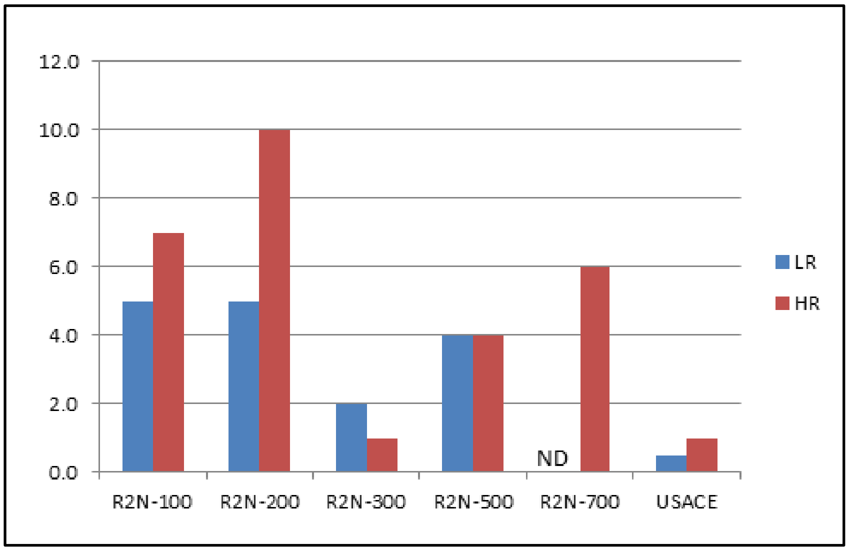

Figure 26. Maximum sediment depth recorded from the line-intercept transects. ND = No data (i.e., the NMFS did not survey the low-relief portion of Middle Reef north 700 meters from the channel edge)

Belt Transect Results

The frequency of scleractinian corals showing signs of stress at Middle Reef north were higher than observed at the USACE control sites (Table 2). There was up to a 2.5 to 4.1 fold increase in the prevalence of corals with partial mortality at treatment sites when compared to controls (Figure 27). The occurrence of sediment accumulation on corals ranged from 4.8 to 21.3 times higher at treatment sites when compared to control sites (Figure 28). Sediment halos (mortality at the base of colonies due to elevated levels of sedimentation) on scleractinian corals ranged from 3 to 26 times more frequent at treatment sites when compared to control sites (Figure 29).

Table 2. Percentage of scleractinian corals showing signs of stress in the belt transects at each site.

Site	Total Number of Colonies Observed	Percent of Corals With One or More Observed Signs of Stress
R2N-100-LR	191	37%
R2N-100-HR	81	89%
R2N-200-LR	140	66%
R2N-200-HR	93	73%
R2N-300-LR	135	42%
R2N-300-HR	76	62%
R2N-500-LR	73	40%
R2N-500-HR	76	58%
R2N-700-HR	82	52%
USACE-LR	135	19%
USACE-HR	156	21%

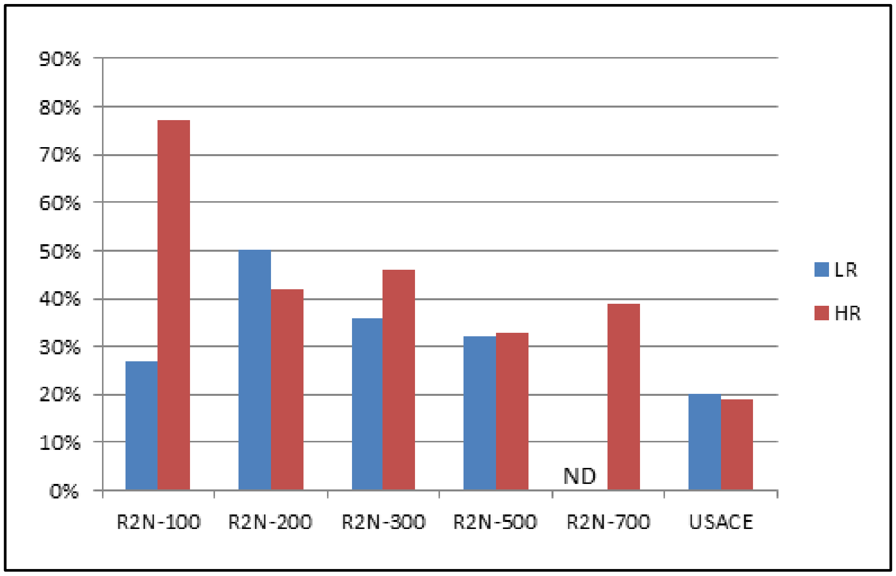

Figure 27. Proportion of scleractinian corals with partial mortality at Middle Reef north and USACE control sites. ND = No data (i.e., the NMFS did not survey the low-relief portion of Middle Reef north 700 meters from the channel edge)

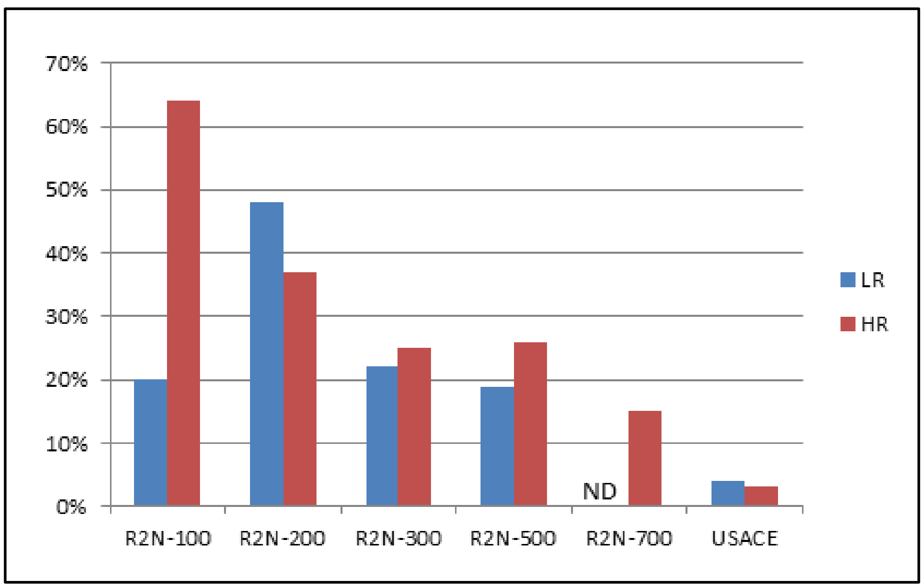

Figure 28. Proportion of scleractinian corals with sediment accumulation at Middle Reef north and USACE control sites. ND = No data (i.e., the NMFS did not survey the low-relief portion of Middle Reef north 700 meters from the channel edge). Findings at R2N-100-LR are discussed in the Conclusions Section.

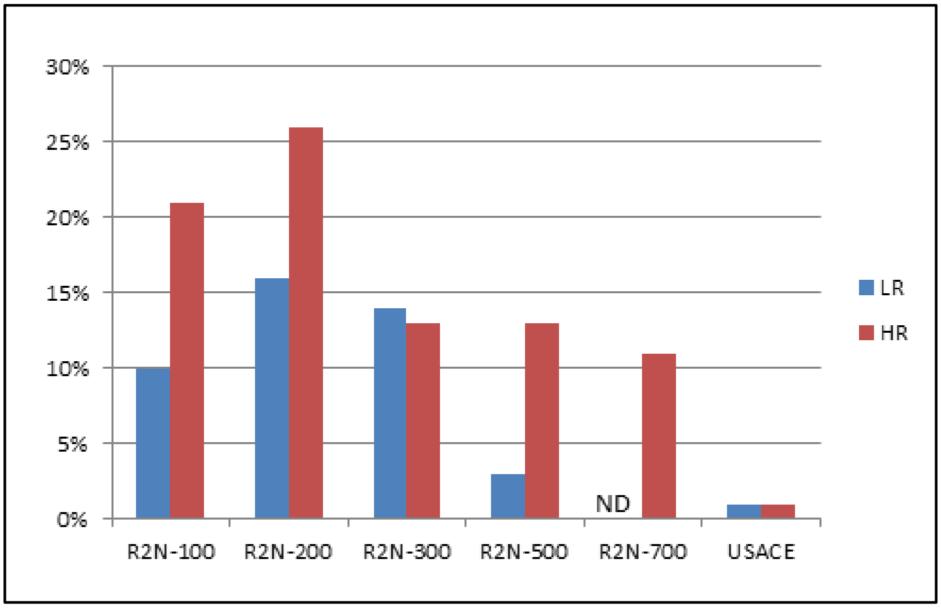

Figure 29. Proportion of scleractinian corals with sediment halos (dead coral tissue at the base of a colony caused by sedimentation) at Middle Reef north and USACE control sites. Findings at R2N-100-LR are discussed in the Conclusions Section. ND = No data (i.e., the NMFS did not survey the low-relief portion of Middle Reef north 700 meters from the channel edge)

Table 3 summarizes the partial mortality, sediment accumulation, sediment halo, sediment over hardbottom, and deep sediment over hardbottom results from the Line and Belt Transects performed in the impact sites and the USACE control areas.

Table 3. Percentage of scleractinian corals at each site with partial mortality, sediment accumulation, or sediment halo and number of corals from the belt transects. Percentage of survey points with sediment over hardbottom and deep sediment from line-intercept transects.

Site	Number of Scleractinian Corals	Percent Corals with Partial Mortality	Percent Corals with Sediment Accumulation	Percent Corals with Sediment Halo	Percent Survey Points Characterized Sediment over Hardbottom	Percent Survey Points Characterized Deep Sediment over Hardbottom
R2N-100-LR	191	27%	20%	10%	52%	11%
R2N-200-LR	140	50%	48%	16%	63%	0%
R2N-300-LR	135	36%	22%	14%	40%	0%
R2N-500-LR	73	32%	19%	3%	27%	0%
R2N-100-HR	81	77%	64%	21%	61%	19%
R2N-200-HR	93	42%	37%	26%	81%	43%
R2N-300-HR	76	46%	25%	13%	45%	0%
R2N-500-HR	76	33%	26%	13%	43%	3%
R2N-700-HR	82	39%	15%	11%	53%	3%
USACE-LR	135	20%	4%	1%	3%	0%
USACE-HR	156	19%	3%	1%	1%	0%

Octocorals

The percentages of octocorals showing partial mortality at Middle Reef north were higher than observed at the USACE control sites, with the exception of R2N-300-LR, R2N-200-HR, and R2N-700-HR where there was no obvious difference when comparing to the respective control (Figure 30). There was up to a three fold increase in the prevalence of octocorals with partial mortality at HR survey sites when compared to the HR control (Figure 30). Colonies from the genus *Antillogorgia* (formerly *Pseudopterogorgia*) appear to be particularly susceptible to sedimentation as up to 29 percent of the colonies exhibited partial mortality at (R2N-300-HR), whereas 11 percent of colonies showed partial mortality at the respective control site (Figure 31).

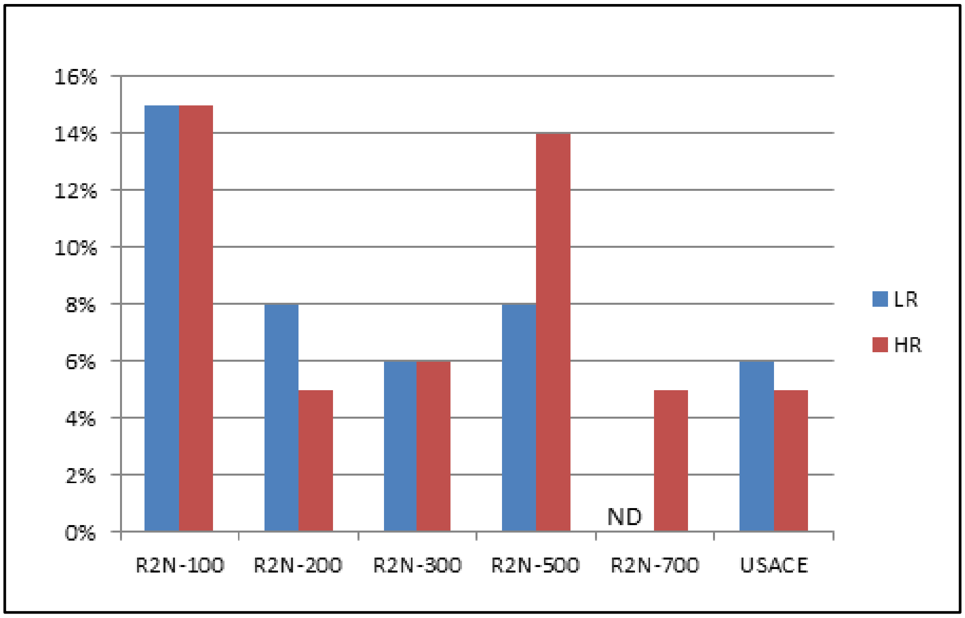

Figure 30. Percentage of octocorals with partial mortality. ND = No data (i.e., the NMFS did not survey the low-relief portion of Middle Reef north 700 meters from the channel edge).

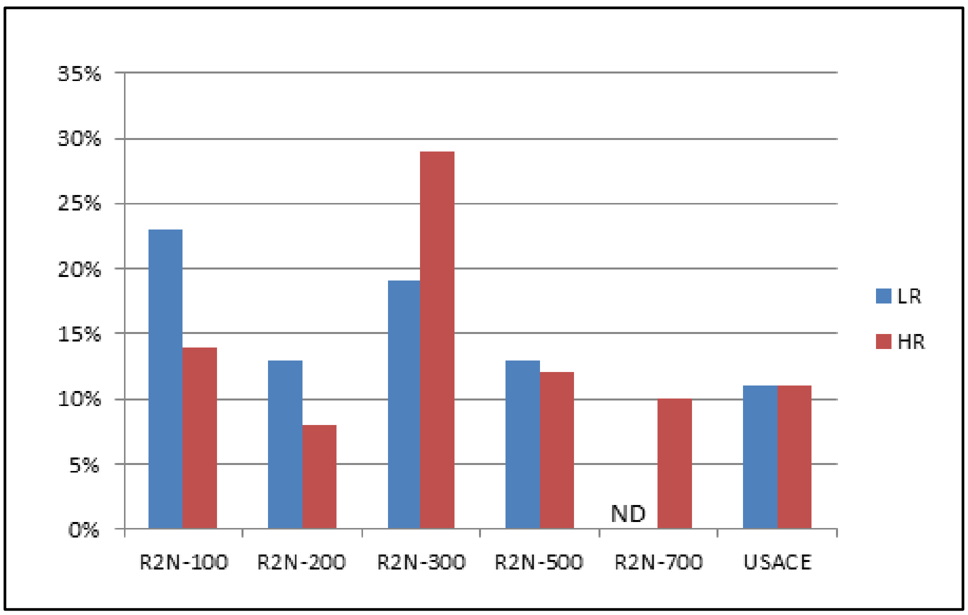

Figure 31. Percentage of *Antillogorgia* spp. (genus formerly named *Pseudopterogorgia*) with partial mortality. ND = No data (i.e., the NMFS did not survey the low-relief portion of Middle Reef north 700 meters from the channel edge).

Sponges

The percentage of sponges with sediment accumulation was considerably higher 100 meters and 200 meters from the channel when compared to control sites (Figure 32). Notably, 46 percent of sponges had sediment accumulation at R2N-200-HR, compared to 2 percent at USACE-HR (Figure 32) and 100 percent of barrel sponges had sediment accumulation at R2N-100-LR and R2N-200-LR (Figure 33). Barrel, ball, and vase sponge morphologies appeared particularly susceptible to sediment accumulation with 86 percent exhibiting sediment accumulation at R2N-200-HR compared to zero at the respective control site (Figure 34).

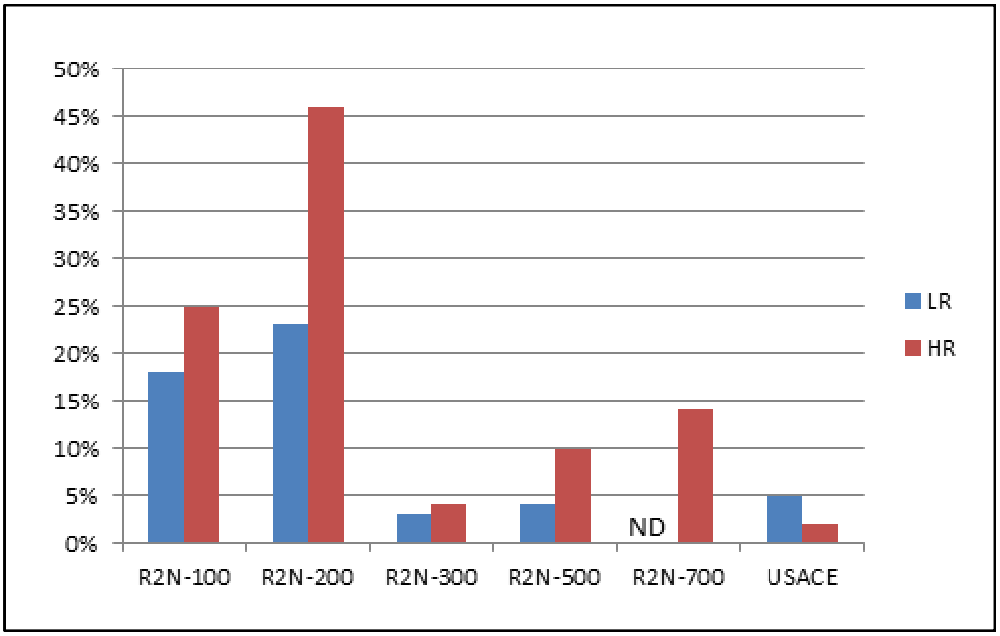

Figure 32. Percentage of sponges with sediment accumulation. ND = No data (i.e., the NMFS did not survey the low-relief portion of Middle Reef north 700 meters from the channel edge).

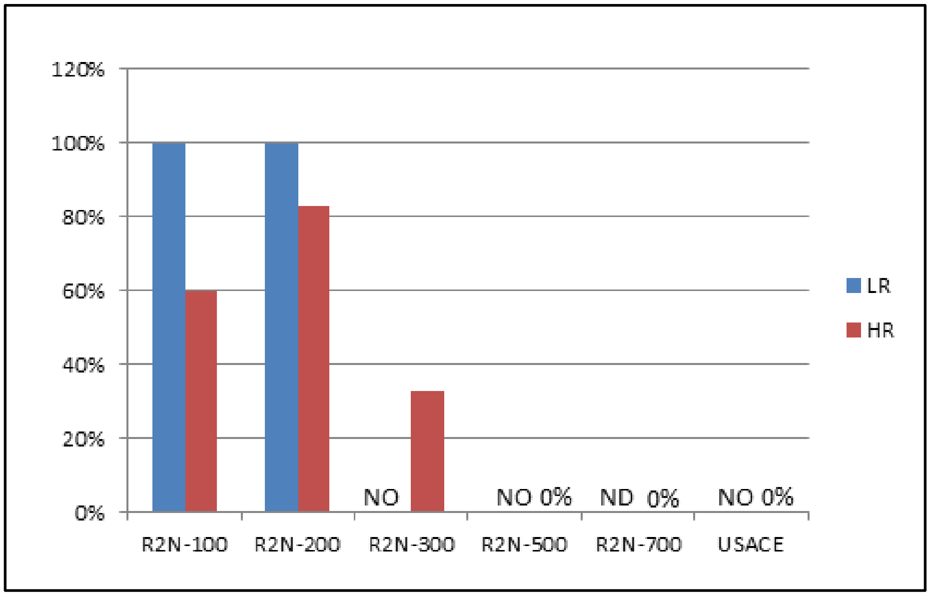

Figure 33. Percentage of barrel sponges, including the giant barrel sponge (*Xestospongia muta*), with sediment accumulation. NO = No barrel sponges observed within the transects at the site. No barrel sponges were recorded at R2N-300-LR, R2N-500-LR, and USACE-LR. None of the barrel sponges observed at R2N-500-HR, R2N-700-HR, and USACE-HR exhibited sediment accumulation. ND = No data (i.e., the NMFS did not survey the low-relief portion of Middle Reef north 700 meters from the channel edge).

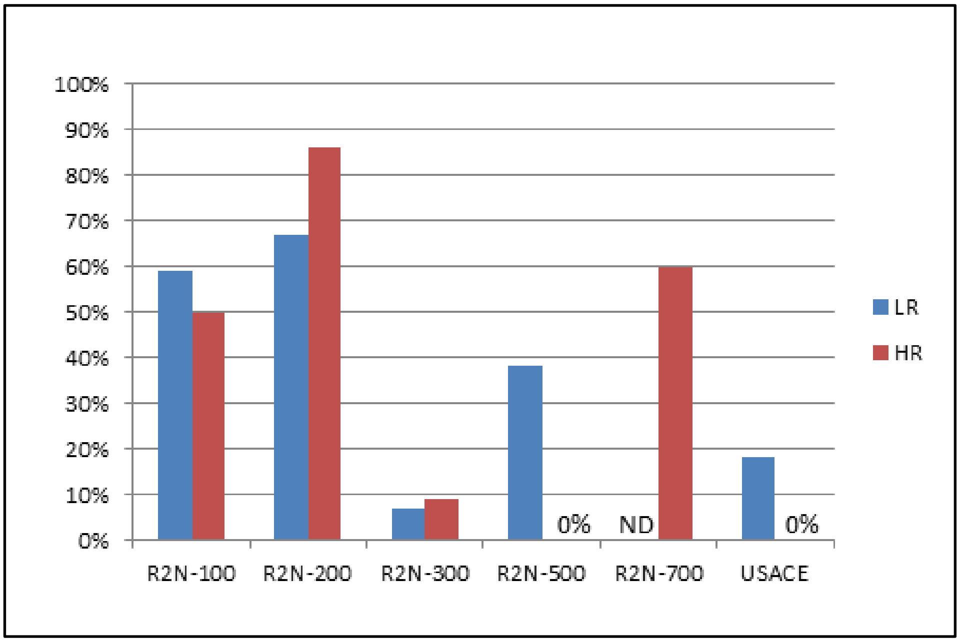

Figure 34. Percentage of barrel, vase, and ball sponges with sediment accumulation. No sediment accumulation on sponges was observed at R2N-500-HR or USACE-HR. ND = No data (i.e., the NMFS did not survey the low-relief portion of Middle Reef north 700 meters from the channel edge).

Section 4: Other Available Data Sets

As detailed below, several groups are examining how the Port of Miami dredging and natural events (such as White Plague Disease) affected coral reef along the Entrance Channel. The NMFS and USACE agree each survey provides valuable information and should be considered appropriately to develop a comprehensive assessment. This section reviews all surveys the NMFS is aware of from the area to help clarify the extent of coral disease mortality relative to sedimentation mortality and to better understand the chronology and location of each observation.

Discerning Disease versus Sedimentation Impacts to Scleractinian Corals

Although disease is cited as the primary cause of project-wide colony mortality (DCA 2015a), within the Middle Reef north, disease was recorded on up to 40 percent of the scleractinian corals at LR channel-side compliance site, with the USACE Middle Reef control sites exhibiting 6.7 percent white plague mortality (from Table 5 in DCA 2015b) (Figure 35). This pattern is consistent with the highest plume exposure area showing increased disease impacts (Pollock et al. 2014; and Barnes et al. 2015).

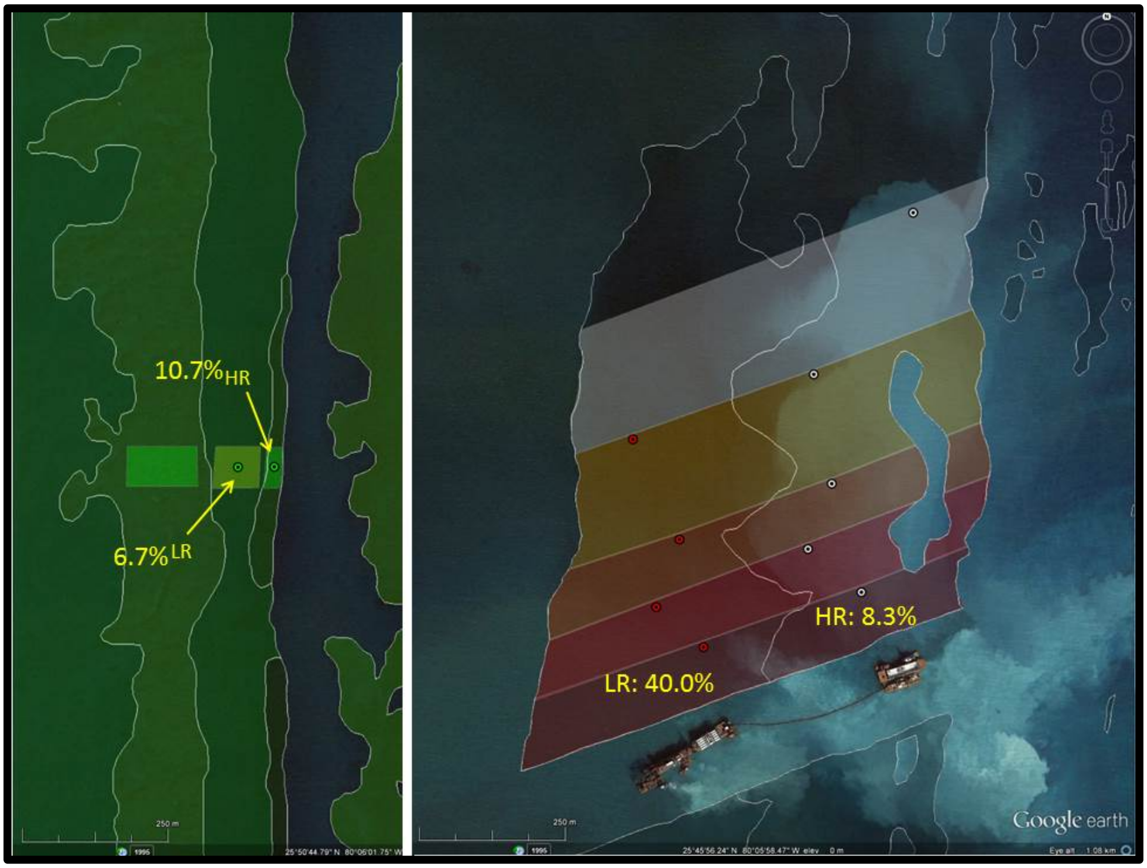

Figure 35. Percentage of White Plague mortality documented along the Middle Reef north (data from DCA 2015a, Table 5). Yellow numbers indicate the percentage of corals with White Plague mortality at the USACE control sites (left) and at channel-side compliance sites (right).

The disproportionate decline in scleractinian coral species richness (Table 4) at the channel-side sites is not consistent with the notion that region-wide disease (independent of interacting dredge stress) accounts for all scleractinian coral mortality in the project impact area. DCA (2015b, Table 13) presents a significant decline in scleractinian richness (41 percent compared decline in Middle Reef north compliance sites compared to a 13 percent decline at USACE control sites based on averages of impact and control sites).

Table 4. Differences in scleractinian coral species richness at the USACE channel-side compliance and control sites between baseline (data collected in 2013) and post-construction (data collected in 2015). Data from DCA (2015b).			
Impact Sites	Baseline (2013)	Post (2015)	Percent Difference
USACE R2N-RR	13	7	46%
USACE R2N-LR	17	11	35%
Reference Sites			
USACE R2N-C1-LR	13	12	8%
USACE R2N-C1-RR	11	9	18%

The disproportionate increase in sediment-associated partial mortality (Figure 36) at the channel-side sites is not consistent with the notion that region-wide disease (independent of interacting sediment/plume stress) accounts for all scleractinian coral mortality in the project impact area.

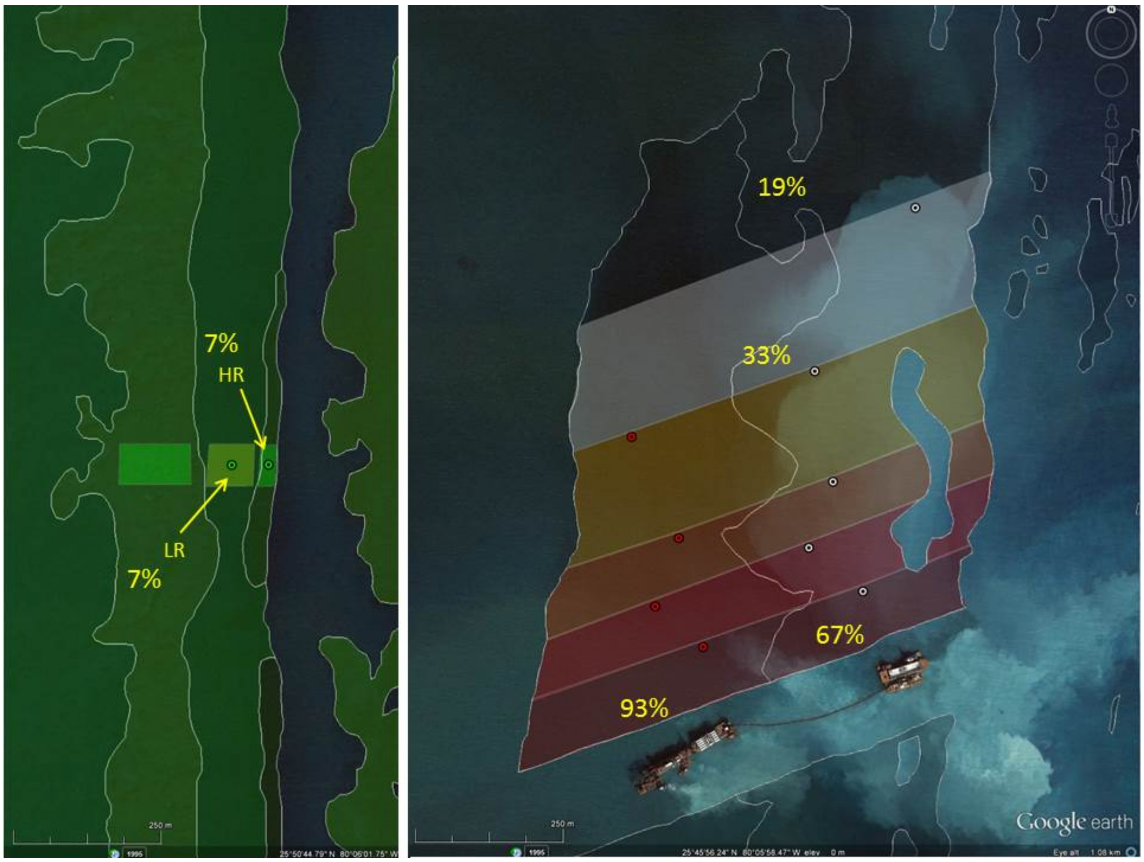

Figure 36. Prevalence of partial mortality from sediment stress using data from DCA (2015b) Table 4. Note the low prevalence of partial mortality at the USACE control sites compared to the channel-side compliance sites and sites referred to as R2N1-550 (33 percent) and R2N1-850 (19 percent) in DCA (2015a).

Ten Additional Survey Reports from the Middle Reef North

Between July 2014 and December 2015, three government agencies including DERM, the FDEP, and NMFS, and one non-governmental organization (Miami Waterkeeper) produced ten dive reports characterizing sedimentation impacts on the Middle Reef north. Locations of all observations conducted pre-, during, and post-construction[13], including areas assessed by DCA, have been mapped (Figure 37) and the majority of the observations within these reports are portions of Middle Reef north that have not been assessed as part of the compliance monitoring required by the FDEP permit.

Pre-dredging surveys were conducted in 2010 (DCA 2011) and 2013 (DCA 2014b) (Figure 38). Pre-dredging sites surveyed were limited to the low-relief component of the Middle Reef north and did not include potential impact sites further than 450 meters (DCA 2011) or 70 meters (DCA 2014b) north of the channel. During construction surveys were completed by the NMFS (2015a); Miami Dade County DERM in 2014 (DERM 2014) and 2015 (DERM 2015); FDEP in 2014 (FDEP 2014) and 2015 (FDEP 2015); Miami Waterkeeper in 2014 (Miami Waterkeeper 2014a, 2014b) and in 2015 (Miami Waterkeeper 2015a, 2015b, 2015c); and DCA (multiple compliance surveys conducted within two channel-side compliance sites on the Middle Reef north that extend approximately 70 meters north of the channel) (Figure 39). Post-dredging surveys have been completed in 2015 by NMFS (NMFS 2015b; and described in this report) and DCA (2015a, 2015b) (Figure 40).

Notably, for the post-dredging surveys, quantitative data collection by DCA is limited to channel-side compliance sites and at 550 and 750 meters away from the channel. The NMFS is the only entity reporting quantitative data between the northern edge of channel-side sites (approximately 70 meters north of the channel, the center point of the compliance site is used on the map) and 500 meters away from the channel in both low- and high-relief components of the reef. The sites DCA surveyed at 550 and 750 meters north of the channel did not use buffers (discussed in Methods Section) to ensure dive sites did not include transitions between reef type (i.e., low- versus high-relief). DCA had one dive site location where quantitative data were collected on the high-relief portion of the Middle Reef north (the part of the reef the NMFS identifies as most severely impacted) and this site did not include a buffer during site selection. Other sites DCA surveyed are limited to qualitative data and would not meet the buffer rules NMFS applied. Quantitative data have been collected at 13 sedimentation assessment sites post-construction (Figure 41) and 9 of the 13 sites were surveyed by NMFS.

[13] Post-construction refers to the dredging that was occurring in the outer entrance channel. Additional dredging may have been occurring in the inner harbor during this time.

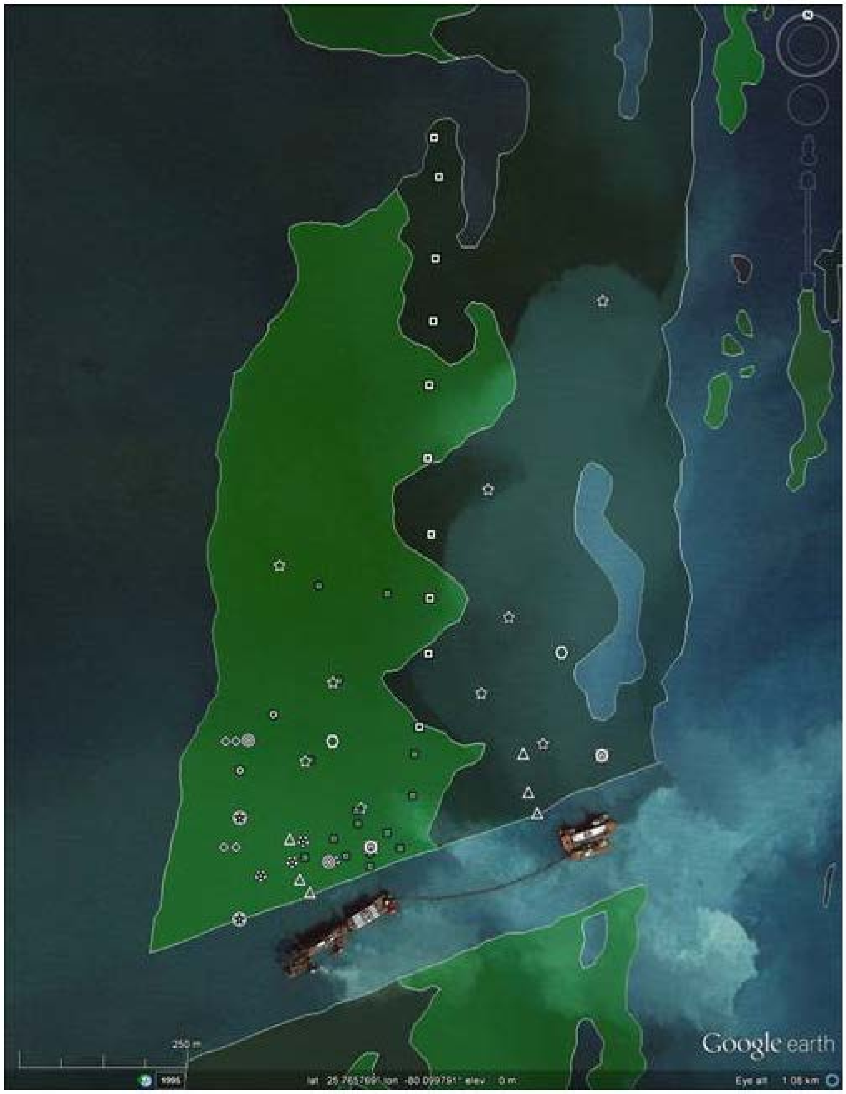

Figure 37. Locations of pre-construction, during construction, and post-construction surveys completed by DERM, FDEP, DCA, and the NMFS. Each symbol is a dive site or a start/stop location of a transect (100 meters or longer). Symbols overlap when sites were visited more than once (i.e., channel-side compliance sites).

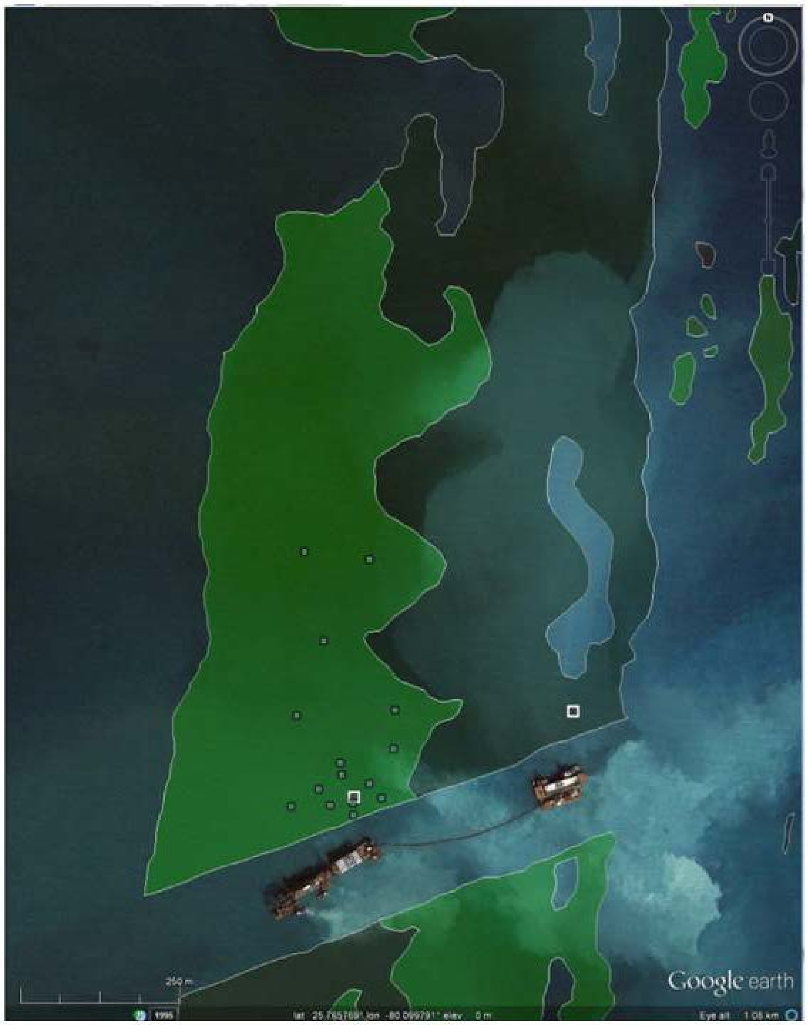

Figure 38. Locations of pre-dredging surveys on the Middle Reef north. Small squares are locations of the first DCA baseline survey dive sites in 2010. Larger squares are the channel-side compliance sites surveyed in 2013 by DCA.

Figure 39. Locations of during dredging surveys on the Middle Reef north by DCA, FDEP, NMFS, and DERM.

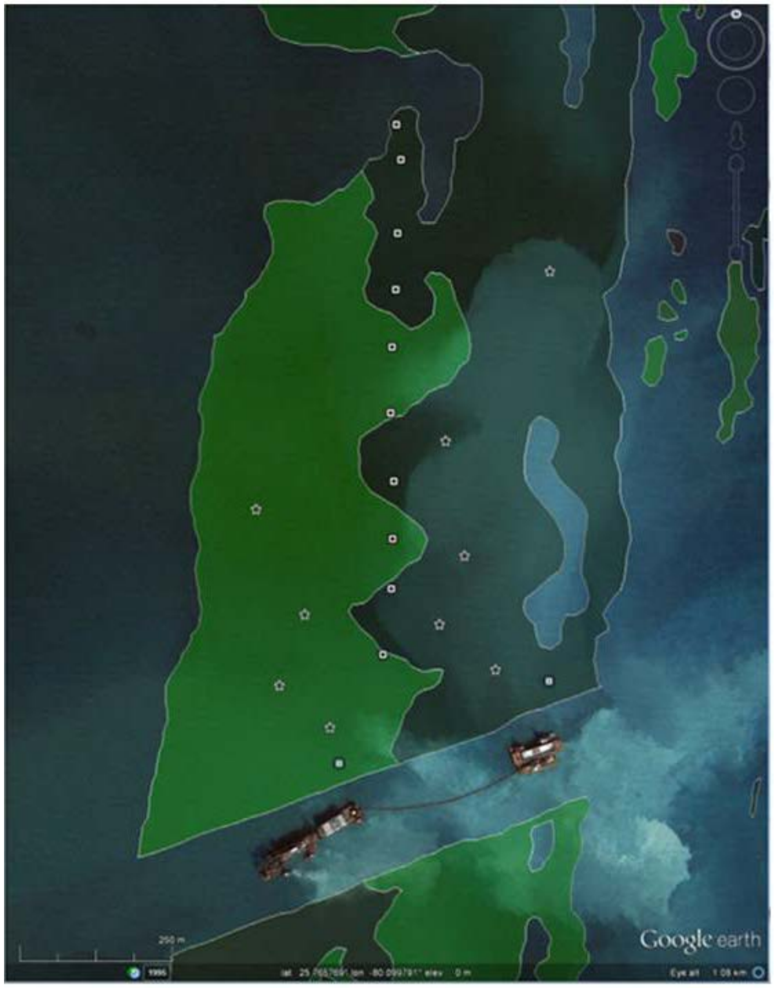

Figure 40. Approximate locations of post-dredging surveys on the Middle Reef north by DCA and the NMFS. Squares are locations DCA surveyed during the sediment delineation survey and immediate post-construction (channel-side compliance sites). Stars represent the NMFS sites.

Figure 41. Locations of dive sites that included in quantitative data collection post-construction. Sites the NMFS assessed represented by stars and sites DCA assessed represented by squares.

In the ten reports reviewed, sediment accumulation is consistently described as recent on the reef (DERM 2014; FDEP 2014; DERM 2015; FDEP 2015) and distinguishable from natural sediment (DERM 2014; DERM 2015). Sedimentation on the Middle Reef north is referred to as heavy (DERM 2014), profound (FDEP 2014), severe (NMFS 2015a), and of variable thickness (FDEP 2014; Miami Waterkeeper 2015a), with the spatial extent spreading over 200 meters north of the channel on the Middle Reef with no evidence of the sedimentation receding at this distance away from the channel (FDEP 2014; Miami Waterkeeper 2015a). The type of sediment is consistently described as "clay-like" in texture (DERM 2014; DERM 2015; FDEP 2015; NMFS 2015a; Miami Waterkeeper 2015a; NMFS 2015a; NMFS 2015b) and observed to be very mobile (Miami Waterkeeper 2015a). In addition, fish are conspicuously absent from surveys (FDEP 2015; NMFS 2015b).

The sedimentation "halo" of mortality around the base of the colony (depicted in Figure 29) has been consistently observed on the Middle Reef north in the last 21 months (FDEP 2014; Miami Waterkeeper 2014a; DERM 2015; Miami Waterkeeper 2015a; Miami Waterkeeper 2015c; NMFS 2015a, NMFS 2015b). The sediment-associated coral stress signatures that ultimately result in the halo of dead tissue at the base of the colony, such as clay-like sediment on the coral tissue forcing the corals to expend energy to remove the sediment either through polyp distension, tentacular action, or mucus production has also been reported (NMFS 2015a; NMFS 2015b). Notably, this type of halo mortality is absent at sites located several miles south of the channel (NMFS 2015a). Scleractinian coral colonies with 100% mortality attributed to sedimentation have been observed (DERM 2015) and burial of the base of octocorals is commonly reported (Miami Waterkeeper 2015a; Miami Waterkeeper 2015c; NMFS 2015b). Only scleractinian corals growing on steep sides of larger boulders appear to be able to successfully remove sediments from their surface without accumulation on lower parts of colonies (FDEP 2015; NMFS 2015b).

Images of impacts to staghorn coral (*Acropora cervicornis*), which is listed as threatened under the Endangered Species Act, show partial mortality or complete mortality from sedimentation (Miami Waterkeeper 2014b; Miami Waterkeeper 2015a; NMFS 2015a; FDEP 2015; CSI 2015). Images also show staghorn coral branch tips dipping into sediment (Miami Waterkeeper 2015a; Miami Waterkeeper 2015c; NMFS 2015a), which is not a normal pattern of growth for staghorn coral. In addition, reports depict and provide images of sediment covering the base of the staghorn coral colonies (Miami Waterkeeper 2014b; Miami Waterkeeper 2015c; NMFS 2015a). The Miami Waterkeeper (2015a) reported little to no exposed hardbottom and little to no visible crustose coralline algae, which could be relevant observations for determining the amount of suitable recruitment habitat present and the time it may take for the reef to return to suitable staghorn coral recruitment habitat.

There is relatively little information available for true pre-dredging conditions. Exceptions include the first baseline assessment conducted by DCA in 2010 and FDEP pre-dredging observations (summarized in FDEP 2014). From DCA (2011): "Sedimentation was documented at all sites but R3N [Outer Reef north] and coincided with an outgoing tide (page 16)." The sediment cover FDEP staff observed in 2014 was noted to be one to 14 centimeters deep and "not characteristic" for the reef surveyed during pre-dredging surveys completed by FDEP staff (FDEP 2014, page 38). The FDEP (2014) concludes the lost reproductive output and recruitment resulting from the sedimentation impact will have long-lasting effects on the impacted areas of reefs and hardbottom and the cohesive nature of fine sediments suggests that the sediment cover may persist for some time and have even more profound effects on the ecological function of the communities (FDEP 2014).

The Quality of "Baseline" Data

The baseline survey data collected in 2010 (described in DCA 2011) is useful in that it assessed sites up to 450 meters north of the channel. However, the survey was limited to the low-relief reef and the amount of area surveyed further than 100 meters north of the channel is low. A total of 15 transects, each 20 square meters, were surveyed in the Middle Reef north; however, 10 of the transects (200 square meters) were between the channel and 100 meters north of the channel and 5 of the transects were used for surveying the area between 100 meters and 450 meters. In addition, the video collected from this survey is generally low in light and resolution and may not be sufficient for analysis.

Use of baseline survey data collected in 2013 (described in DCA 2014a; DCA 2014b) as true pre-project conditions is problematic. Maintenance dredging was occurring prior to the expansion dredging thereby transporting sediment-laden waters to the reefs located along the channel twice per day on out-going tides. It is possible that impacts to the coral reefs positioned outside the channel may have occurred prior to the commencement of expansion dredging and continued throughout the duration of the project. In addition, the baseline data collection was not completed until at least 40 days after the expansion dredging began. Expansion dredging commenced on November 20, 2013, in Cut 2 (USACE, personal communication via email dated November 19, 2013). Baseline surveys were conducted on the Middle and Outer Reefs between October 23, 2015, and December 30, 2013 (DCA 2014b, Table 1). The location of the cuts are depicted in the Port of Miami Final Environmental Impact Statement and show Cut 2 as located seaward of the Inner Entrance Channel, near the elbow region of the channel within the nearshore ridge complex, and possibly extending towards the Middle Reef (USACE 2004, Figures 5 and 6). Therefore, it is likely that impacts to the coral reefs positioned outside the channel may have occurred during the baseline data collection and continued throughout the duration of the project.

Section 5: Conclusions

Overall, the assessed impact sites on Middle Reef north showed considerably more scleractinian partial mortality, sediment accumulation, and mortality from the halo effect when compared to the USACE control sites (Figure 42). Of all corals surveyed in the belt transects (n=949), 41 percent exhibited partial mortality. Partial mortality includes both sediment-associated and other types of mortality. Halo mortality is a subset of partial mortality. Of all the corals surveyed at the control sites (n=291), 19 percent exhibited partial mortality. Thirty-one percent of the corals in impact sites exhibited sediment accumulation, compared to three percent at control sites. Fourteen percent of corals at impact sites exhibited the sediment halo (mortality at the base of the colony indicative of sedimentation impact), compared to one percent at control sites.

The effects of sedimentation on octocorals is not well-studied. The lower prevalence of partial mortality among octocoral colonies (Figures 30 and 31) when compared to scleractinian coral colonies (Figure 27) may be attributed to the ability of octocorals to heal faster after injury. However, healing can only occur when healthy tissue adjacent to the wound is available to help regeneration (Mezaros and Bigger 1999). Similar to scleractinian corals, if a portion of the octocoral colony remains buried, it will not be able to heal. The burial of octocoral holdfasts under a thick layer of sediment can result in the death of tissue over the holdfast. Without this live tissue, new axis material will not be deposited as the octocoral grows, and it will not provide the stability necessary to support the colony. In the absence of the live tissue, the holdfast and axis material, called gorgonin, will erode away and the live portion of the colony will eventually break off or become dislodged, which results in colony death, especially during normal storm activity (personal communication, January 29, 2016, Ms. Vanessa Brinkhuis, Florida Fish and Wildlife Research Institute, Coral Reef Research Group). Similar to scleractinian corals, a healthy octocoral colony does not have portions of the colony buried in sediment.

Like octocorals, sponges can heal relatively quickly after damage if there is enough remaining healthy tissue to contribute to regeneration. Sponges heal much faster than their normal rate of growth, and healing could represent a significant expenditure of energy (Hoppe 1988). Sponges are also unable to tolerate being buried for extended periods of time. Long-term burial of sponges will lead to mortality. Greater amounts of sediments trapped among algae on the more horizontal substrata may contribute to the smothering of young or adult sponges and increased sedimentation rates increase the chances of young sponges being smothered (Zea 1993). To capture the effects of sedimentation stress on sponges, the population would need to be surveyed immediately after an event. When sponges die, their tissue quickly disintegrates, so later monitoring may not detect dead sponges. For the sponges surviving sedimentation, later monitoring would show sponges having already undergone regeneration to the best of their ability in the altered environment (personal communication, January 29, 2016, Ms. Vanessa Brinkhuis, Florida Fish and Wildlife Research Institute, Coral Reef Research Group).

The NMFS used sediment depth and type to determine the level of impact severity from sedimentation and this information will also help inform recovery lag time for the Habitat Equivalency Analysis. Assessment areas were then developed based on trends in the partial mortality and sediment-associated stressors. Each assessment area can have all levels of severity, and this approach is further described below.

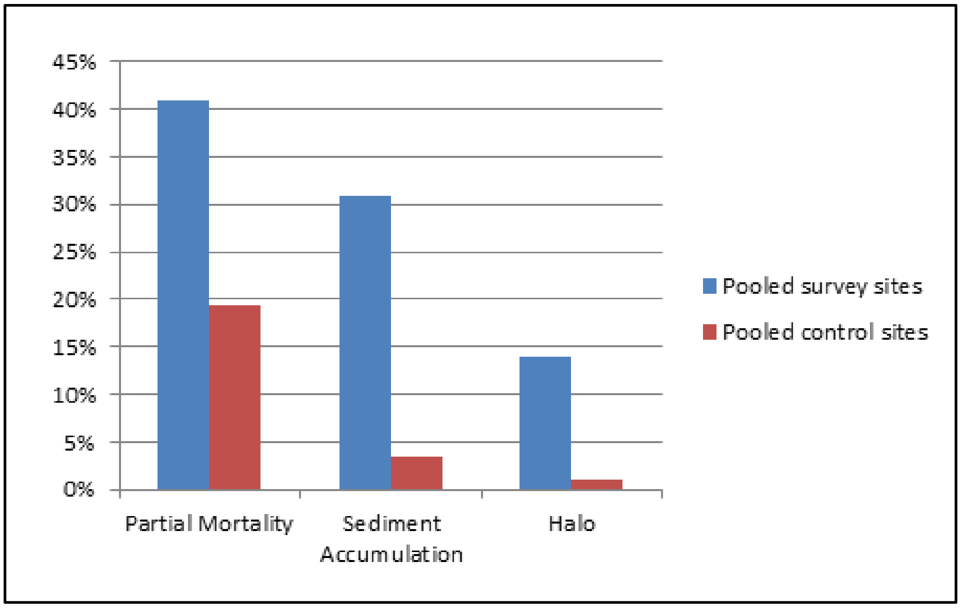

Figure 42. Percent of scleractinian corals with partial mortality or sediment-associated stress at pooled impact and control sites.

Methods for Determining the Severity of Sedimentation Impact Categories and Recovery

While sediment movement and deposition is a normal process in a coral reef ecosystem, offshore coral reefs are not capable of developing or sustaining ecological functions when covered by sediment over prolonged periods when measuring in centimeters or greater. Sedimentation on reefs can reduce coral recruitment, survival, and settlement of coral larval (Erftemeijer et al. 2012) and suppress colony growth (Bak 1978). The increased prevalence of indicators of sedimentation stress and partial mortality at the Port of Miami sedimentation assessment areas (Figures 27, 28, 29, and 42) suggests the frequency, intensity, and duration of sedimentation was much greater at sedimentation assessment sites when compared to controls and mortality and loss of function of reef organisms resulted. Sediment deposition from dredging activities at Port of Miami is the most plausible explanation for how the increment of sediment deposition (i.e., above control) accumulated on the reef.

Sediment deposition threshold criteria have recently been proposed for classifying sediment impacts to reef habitats based on threshold values in peer-reviewed studies and new modelling approaches (Nelson et al. 2016). The sediment threshold criteria, termed "stoplight indicators", are based on active sedimentation onto reef surfaces and corals during a prescribed period of time (18 to 30 days within a 90 day timeframe). Sediment depth in excess of 1.0 centimeter is classified as *red*, and corresponds to severe colony stress resulting in mortality. If depth is less than 1.0 centimeters, but greater than 0.5 centimeters it is classified as *yellow*, corresponding to moderate colony stress with some coral colonies expected to recover. If sediment depth was less than 0.5 centimeters it is classified as *green*, meaning negligible or limited impacts to coral colonies (Table 5; Nelson et al. 2016). The standing sediment levels measured at Port of Miami are cumulative standing sediment levels over a much longer time period than is considered in Nelson et al. (2016), likely commenced with the beginning of dredging, and are therefore conservative values when compared to the sediment threshold criteria stoplight indicators.

The presence, type, and depth of sediment over the hardbottom is intended to serve as the proxy for the severity of sedimentation, and in a parallel effort, to determine the recovery delay in a Habitat Equivalency Analysis. For the purposes of this assessment, indicators of sedimentation impacts were evaluated by qualitatively examining the type of sediment at the surface and and measured depths of sediment over reef in each assessment area (Table 5). The highest level of severity, *very severe*, is where deep sediment is present within the HR reef. Based on basic sediment transport principles, observations in the field, and sediment depth measurements, the sediment in areas characterized as deep sediment over HR is least likely to dissipate due to natural processes and will take the longest time to dissipate compared to other categories of severity. Hardbottom in the area characterized as very severe is not functioning as recruitment habitat for corals, including staghorn corals.

The *severe* impact category is where 3 to 4 centimeters of sediment was measured over the reef (LR or HR) and when deep sediment was present in the LR reef. Based on observations in the field and sediment depth measurements, it appears fast currents from extreme weather events may be able to remove the deep sediment layers from the LR reef, when compared to the HR reef, but these fast currents and extreme weather events are relatively uncommon. Hardbottom in the area characterized as severe is not functioning as recruitment habitat for corals, including staghorn corals.

The *significant* level of severity is where 2 to 3 centimeters of sediment was measured on LR or HR reef. Hardbottom in the area characterized as significant is not functioning as recruitment habitat for corals, including staghorn corals.

The *moderate* impact category is where 1 to 2 centimeters of sediment was measured on the reef in both LR and HR reef. Most coral species are sensitive to this range of sedimentation which adversely affects the structure and function of the coral reef ecosystem by altering both physical and biological processes (Rogers 1990). Sediment deposition on the reef within this depth range is ecologically relevant, especially considering none of the sediment depth measurements at the USACE control sites exceeded 1 centimeter. Hardbottom in the area characterized as moderate is not functioning as recruitment habitat for corals, including staghorn corals.

The method to characterize the different levels of severity in *low* and *no* impact categories focuses on sediment type (i.e., fine sediment versus sand) to differentiate level of severity. Sand sediment measures up to 0.5 centimeters of sand is considered *no* severity or absence of impact. Hardbottom within the sedimentation areas characterized as *no* severity remains potential recruitment habitat for corals, including staghorn corals. Any measurable amount of fine sediment up to 0.5 centimeters is considered *low* severity impact. Hardbottom in the area characterized as *low* is not functioning as recruitment habitat for corals, including staghorn corals.

Table 5. Levels of sedimentation impact severity on the Middle Reef north. The hardbottom habitat with sediment severity levels characterized as "Low" through "Very Severe" is not suitable substrate for coral recruitment.

Severity Level	Sediment Description	Stoplight Indicators from Nelson et al. (2016)
Very Severe	HR reef: >4 centimeters LR reef: not applied	Red: Severe stress resulting in mortality
Severe	HR reef: 3.01 to 4 centimeters LR reef: >4 centimeters	
Significant	HR and LR reef: 2.01 to 3 centimeters	
Moderate	HR and LR reef: 1.01 to 2 centimeters	
Low	HR and LR reef: 0.6 to 1 centimeters of sand or mixed sand and fines or <1 centimeter of fine sediment	Yellow: Moderate, but expected to recover
No	HR and LR reef: no measurable sand to <0.5 centimeters of sand	Green: Negligible or limited

Based on the characterization for no and low severity, the line-intercept data from the USACE control sites for LR and HR control sites, respectively, exhibited 85 percent and 80 percent of sites measured falling into the no category; and 15 and 20 percent that would fall into the low category. The line-intercept points in the USACE control sites that fall within the low category include 0.5 centimeters of fines or mixed sand and fines (n=7), and the remaining points were all zero to 1.0 centimeter of sand and therefore classified in the no category (n=33). None of the Middle Reef north sedimentation assessment survey areas exhibited a sediment depth measurement of zero.

Sediment Impact Area Delineation

To delineate sedimentation impact assessment areas, general trends or obvious groupings were examined for the frequencies of partial mortality, sediment accumulation, and sediment halo. Where a shift or visual break point in the data appeared (summarized in Table 6), a cut-point was drawn between survey areas. A cut-point was drawn 250 meters beyond the channel in the LR habitat because partial mortality decreased and there was also a decrease in points characterized as sediment over hardbottom at R2N-300-LR when compared to R2N-100-LR and R2N-200-LR. Another cut-point was drawn at R2N-400-LR because the prevalence of sediment halo decreased from 14 percent at R2N-300-LR to 3 percent at R2N-500-LR and partial mortality also decreased. In the HR area, a cut-point was drawn at R2N-250-HR because the prevalence of sediment halo decreased from 21 and 26 percent at R2N-100-HR and R2N-200-HR to 13, 13, and 11 percent at R2N-300-HR, R2N-500-HR, and R2N-700-HR, respectively. Another cut-point was drawn at R2N-800 because, while sediment accumulation decreased from 26 percent at R2N-500-HR to 15 percent at R2N-700-HR, the prevalence of partial mortality (33 and 39 percent) increased between R2N-500-HR and R2N-700-HR, and sediment halo (13 and 11 percent) remained similar, yet higher than controls. It is important to note all levels of sedimentation impact severity can be present within an assessment area.

Table 6. Groupings of partial mortality and sediment associated stress at sedimentation assessment sites. Data from Table 3.						
Assessment Area	Site	Percent Corals with Partial Mortality	Percent Corals with Sediment Accumulation	Percent Corals with Sediment Halo	Percent Survey Points Characterized Sediment over Hardbottom	Percent Survey Points Characterized Deep Sediment over Hardbottom
1	R2N-100-HR	77%	64%	21%	61%	19%
	R2N-200-HR	42%	37%	26%	81%	43%
2	R2N-100-LR	27%	20%	10%	52%	11%
	R2N-200-LR	50%	48%	16%	63%	0%
3	R2N-300-HR	46%	25%	13%	45%	0%
	R2N-500-HR	33%	26%	13%	43%	3%
	R2N-700-HR	39%	15%	11%	53%	3%
4	R2N-300-LR	36%	22%	14%	40%	0%
5	R2N-500-LR	32%	19%	3%	27%	0%
6	North of R2N-800-HR. No data, but since impacts persisted at 700-HR, it was assumed impacts continued north of this assessment area.					

Characterization of Assessment Areas

Delineations of impact assessment areas are based on the groupings of the sedimentation assessment sites presented in Table 6. The cut-points between impact areas (depicted in Figure 43) are at the midpoint between assessment sites (e.g., the line drawn at R2N-250-HR is midway between R2N-200-HR and R2N-300-HR).

<u>Sedimentation Impact Area 1: Channel-side to R2N-250-HR</u>
This area is closest to the channel out to approximately 250 meters north of the channel in the high-relief reef (Figure 43). The areas assessed in this part of the reef had the highest prevalence of partial mortality at R2N-100-HR (Figure 27) and high halo mortality (Figure 29), and high sediment accumulation (Figure 28). This area is 21 acres with 4.2 acres characterized as very severe, 3.2 acres of severe, 4.2 acres of significant, 7.9 acres of moderate, and 1.6 acres of low impact to the Middle Reef north (Table 7).

Table 7. Acreage and percent (%) of the level of severity in each assessment area. The level of severity percentages are based on the sum of the number of sediment depth measurements in each category of severity as described in Table 5, divided by the total number of line-intercept points for that transect. Area Number 6 was not assessed by the NMFS (it is from DCA 2015a) and input parameters are based on trends observed in the data.						
Area	Very Severe	Severe	Significant	Moderate	Low	No
Area #1	4.2 (20%)	3.2 (15%)	4.2 (20%)	7.9 (38%)	1.6 (8%)	0.0 (0)
Area #2	0.0 (0)	4.0 (16%)	4.6 (18%)	11.3 (44%)	4.8 (18%)	1.3 (5%)
Area #3	2.4 (5%)	3.4 (7%)	1.0 (2%)	17.3 (36%)	16.8 (35%)	7.2 (15%)
Area #4	0.0 (0)	0.0 (0)	0.0 (0)	10.5 (75%)	3.5 (25%)	0.0 (0)
Area #5	0.0 (0)	2.0 (5%)	2.0 (5%)	34.7 (89%)	0.0 (0)	0.0 (0)
Area #6	0.0 (0)	0.0 (0)	0.0 (0)	14.3 (75%)	4.8 (25%)	0.0 (0)
Total acres	**6.6 acres**	**12.6 acres**	**11.8 acres**	**96.0 acres**	**31.5 acres**	**8.5 acres**

Sedimentation Impact Area 2: Channel-side to R2N-250-LR

This area is closest to the channel out to approximately 250 meters north of the channel in the low-relief reef (Figure 43). This area also experienced high prevalence of partial mortality, sediment halo, and sediment accumulation, but not as high as impact area 1. R2N-100-LR requires further examination as the partial mortality NMFS recorded (27 percent) is notably lower than what was reported in the immediate post-construction monitoring report for the channel-side site located between 10 and 70 meters north of the channel (93 of corals had sediment-associated partial mortality; DCA 2015b). NMFS estimates of partial mortality should be viewed as conservative because methods did not include counting all dead corals. This area is 26 acres with 4.0 acres characterized as severe, 4.6 acres of significant, 11.3 acres of moderate, 4.8 acres of low, and 1.3 acres of no impact to the Middle Reef north (Table 7).

Sedimentation Impact Area 3: R2N-250-HR to R2N-800-HR

This area is within the high-relief reef between 250 and 800 meters north of the channel (Figure 43). Partial mortality is consistently higher at R2N-300-HR, R2N-500-HR, and R2N-700-HR, compared to USACE-HR (Figure 27). The prevalence of partial mortality, sediment halo, and sediment accumulation is lower than impact areas 1 and 2, but still considerably higher than USACE-HR (Figures 27, 28, and 29). This area is 48 acres with 2.4 acres characterized as very severe, 3.4 acres of severe, 1.0 acres of significant impact, and 17.3 acres of moderate, 16.8 acres of low, and 7.2 acres of no impact to the Middle Reef north (Table 7).

Sedimentation Impact Area 4: R2N-250-LR to R2N-400-LR

This area 250 meters north of the channel and approximately 400 meters north of the channel in the low-relief reef (Figure 43). The prevalence of partial mortality, sediment halo, and sediment accumulation is similar to Impact Area 3, but still considerably higher than USACE-LR (Figures 27, 28, and 29). This area is 14 acres with 10.5 acres of moderate and 3.5 acres of low impact to the Middle Reef north (Table 7).

Sedimentation Impact Area 5: R2N-400-LR to the northern edge of low-relief portion of the Middle Reef
This area is between 400 meters north of the channel to the northern edge of the low-relief reef in this area (Figure 43). The prevalence of partial mortality, sediment halo, and sediment accumulation is lower than Impact Areas 3 and 4, but still higher than USACE-LR (Figures 27, 28, and 29). This area is 39 acres with 2.0 acres characterized as severe, 2.0 acres of significant impact, and 34.7 acres of moderate impact to the Middle Reef north (Table 7).

Sedimentation Impact Area 6: R2N-800-HR to one kilometer north of the channel
This area is high-relief reef located between 800 meters and 1,000 meters north of the channel (Figure 43). While NMFS did not assess this area, the characterization of this site in an earlier report (DCA 2015a) is more consistent with a description of a site impacted by sedimentation and inconsistent with visual inspection of aerial imagery available for this site from 2013 (pre-dredging). Dial Cordy and Associates Inc., (2015a) describes numerous large sand patches and "many of the corals larger than 10 centimeters in diameter were located in large sand patches" (page 50). This finding warrants discussion as sand does not have the appropriate substrate that is suitable for corals to recruit. Based on NMFS field observations, the initial appearance of corals within a sand channel was later determined to be buried reef (e.g. Figure 11A). In addition, the prevalence of partial mortality reported at this site is over 2-fold the partial mortality reported at controls (DCA 2015a; partial mortality is 0.19 at R2N1-850 and 0.08 at the respective control R2N1-LR; Table 4). This area is 19 acres with 14.3 acres characterized as moderate, 4.8 acres of low impact to the Middle Reef north (Table 7).

Figure 43. Sedimentation assessment areas, cut-points, and acreages.

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Additional Example Photographs

Photos of two colonies of *Montasraea cavernosa* showing “Halo” effects, mortality at the base of the colony due to sedimentation from the dredging. Both corals have mortality from sedimentation. The colony on the left in also is showing mortality from disease. The photo on the left is before sediment was removed from the base of the colony. The photo on the right is after the sediment was brushed away, showing white skeleton with clean septae and calices showing that this mortality was recent.

Photos from R2N-200-HR. Image on the right is of the buried corals in the left image after the NMFS diver used his hand to winnow away the sediment revealing the buried octocoral holdfast, dead coral halo, and buried reef.

Photos from R2N-200-HR. Image on the left is the normal pattern of growth of octocorals on a high-relief portion of the reef with moderate to low sedimentation impacts. Image on the right shows octocorals buried by a deep layer of sediment at a location characterized as very severe to severe sedimentation impacts.