CLOUDS IN MY COFFEE: THE MISCONCEPTIONS OF TURBID PLUMES FROM DREDGING OPERATIONS AT PORT MIAMI

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ABSTRACT

During cutter and hopper dredging operations turbid plumes are produced that can have a deleterious impact on benthic resources. This is a particular concern in areas where coral reefs lie adjacent to dredging projects. It is therefore important to understand the potential environmental impacts of different dredging methods. This understanding includes both theoretical and practical elements that can help predict impacts prior to construction, reduce impacts through adaptive management during construction, and can inform best practices for future projects. Here we address some of the major issues encountered during the Port Miami Dredge Project, which was widely – but incorrectly - cited as an environmental disaster. In particular, we discuss negative claims made by government agencies and project opponents that can be dismissed based on their selective use of data, incorrect interpretations, and misunderstanding of dredging operations. Getting the facts straight is a prerequisite for science-based management of the resources under the collective stewardship of various management agencies on behalf of the public. We hope that the lessons learned from Port Miami will serve as a guide for implementing best management practices for upcoming projects in the region.

Keywords: Coral Reefs, Adaptive Management, Turbidity, Sediment, Monitoring.

INTRODUCTION

There is often conflict among stakeholders when dredging projects have the potential to negatively impact environmental resources, especially when projects are performed near coral reefs. Unfortunately, disagreements and conflict are typically played out in the press before conclusions arise that are science-based. This was especially true in the highly contentious Port Miami Deep Dredge Project (PMDP) conducted from November 20, 2013 to March 16, 2015 (Alverez 2015, 2016, Gomez 2015, Nelson 2015).

Numerous articles and commentaries have been published about dredging in Florida since the 1970s and the view that these projects are deleterious to the marine environment have proliferated (see Straughan 1972, but see comments in Griffin 1974). Project opponents pit dredging projects (and their contractors) against the environment. However, these views are often based on weak inferences, suppositions, and anecdotes. Ideological approaches to resource management, whether proffered by non-governmental organizations (NGO's) or regulatory personnel, have strong emotional appeal, but they ultimately

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undermine the credibility of conservation science (Finkl and Kruempel 2005). Further, they hinder, not advance, our ability to protect these resources (Precht 2021). Thus, it is incumbent on those who conduct these projects to adopt best management practices (BMPs) that can be employed to minimize potential impacts to valuable resources (MICCI 2008). In the case of the PMDP, BMPs are informed by a detailed understanding of the dredging methodologies employed and outcomes from a science-based approach to resource monitoring and management. In addition, understanding the impacts of past dredging projects allows us to establish the scientific foundation from which we can compare and contrast current projects (Griffin 1974, Marszalek 1982, Spring 2011, Adjeroud et al. 2016, Stoddart 2019).

Best Management Practices

During construction, it is generally required that quantitative monitoring of key biotic and abiotic parameters be performed, allowing for the implementation of corrective and adaptive management measures as needed. For example, if turbidity from dredging operations exceeds predicted thresholds, modifications to BMPs can be made to reduce these impacts in real-time (Foster et al. 2011). Similarly, if dredge-related sediments are causing excessive stress to the living coral reef biota, swift action can and should be taken before long-term impacts are realized (Foster et al. 2018, Suedel et al. 2024). Thus, an adaptive approach to environmental monitoring is implicit to the successful implementation of BMPs. Specifically, management decisions should be treated as hypotheses regarding ecosystem responses, and scientific monitoring programs should be designed as experiments to test the hypotheses. This approach allows real-time management decisions to be revised (adapted) to meet project goals as necessary (Precht and Robbart 2006). In Port Miami, the Florida Department of Environmental Protection (FDEP) required a detailed, comprehensive, repeated-measures environmental monitoring program associated with the permit issued for the PMDP (see FDEP 2012). This program was designed so adaptive management decisions could be reactive to the needs of the project in a timely manner. Unfortunately, in the case of the PMDP, there were numerous instances where the regulatory review of the contractor's weekly compliance monitoring reports was often delayed, sometimes by several months, making it difficult to get timely approval of recommendations made by the project team to reduce project-related impacts.

Coral Reef Protection

Concerns related to coastal dredging projects can dramatically arise when coral reefs are involved (Maragos 1994, PIANC-UNEP 2010, Foster et al. 2011, Erftemeijer et al. 2012). Public interest increases when a potential outcome of a dredging project is significant environmental destruction (Bailey et al. 2023). On the other hand, navigation dredging is a vital infrastructure activity for national security, enabling access to ports by commercial, deep-draft ocean-going vessels. Dredge projects that expand shipping channels are important because they significantly enhance local and regional commerce, yielding substantial economic benefits to communities (Padgett and Hudson 2016, Fulfillment Hub 2024). For instance, Port Miami is Miami-Dade County's second most important economic driver, contributing $61 billion annually to the local economy and supporting more than 340,000 jobs throughout the region (Miami-Dade County 2024a, 2024b).

Therefore, the intention of conducting scientific monitoring projects for coral reef protection on federal projects requires careful documentation of the status and trends of the environmental resources present. Fortunately, in the case of the PMDP, the multiple agency mandated monitoring programs that were conducted before, during, and after construction provide a rich data set to help understand impacts caused by dredging and other factors, including the various causes of coral mortality (DCA 2010, 2012, 2014a, 2014b, 2015a, 2015b, 2015c, 2015d, 2017a, 2017b).

The Port Miami Deep Dredge Project

The Miami Harbor Phase III Federal Channel Expansion Project was the most extensive dredging project conducted in the southeast United States over the past quarter century (USACE 2024a), so assessing environmental impact was paramount (FDEP 2012). To accept post-Panamax class vessels in Port Miami, the goal of the PMDP was to deepen and widen the Entrance Channel, deepen portions of Government Cut, deepen and widen the Fisher Island Turning Basin, and deepen and widen Fisherman's Channel and the Lummus Island Turning Basins (Figure 1). The USACE provided oversight for the project in partnership with Port Miami, Miami-Dade County. The dredging contractor (Great Lakes Dredge and Dock, LLC [GLDD]) removed more than five million cubic yards of limestone rock and sand, deepening the existing channel from -12.8 m to -15.9 m mean sea level (MSL). Specifically, some 2,199,500 cubic yards of material were removed from Cut 1 and Cut 2 of the outer Entrance Channel (GLDD survey records and USACE daily project reports). Maintenance dredging to remove a thin veneer of overlying sand within the existing shipping channel began on November 20, 2013, while the construction dredging phase started on December 17, 2013. Dredging progressed from west (Cut 2) to east (Cut 1), with construction of the outer Entrance Channel being completed on March 16, 2015.

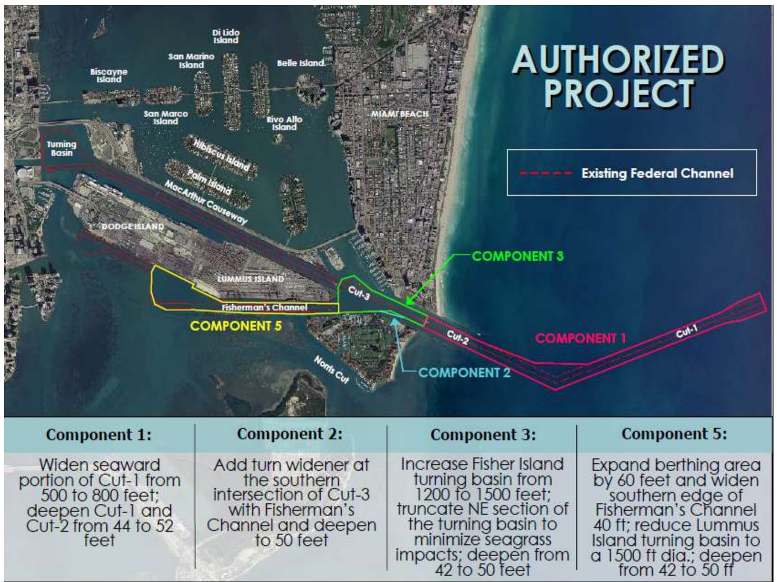

Figure 1. Authorized project components for the Miami Harbor Phase III Federal Channel 'Deep-Dredge' Expansion Project. This manuscript focuses on the outer Entrance Channel (Cut 1 and Cut 2) which comprised Component 1 of the project.

The Role of Dredging: Turbidity and Sedimentation

It is well known that marine dredging operations can create turbid plumes in the surrounding water column, which in turn can impact benthic resources (Wilber et al. 2005, Stark et al. 2017). During the PMDP, rocks and sediments dredged and removed from the channel bottom were loaded into material transport dump scows and towed to approved offshore dredged material placement sites (Tsai et al. 1992, McArthur et al. 2002) or used as beneficial fill for habitat creation and restoration (Jordan-Sellers et al. 2016). Turbidity plumes were a consequence of this activity, but it was not the only cause of turbidity plumes. Therefore, understanding the sources and characterizing the impacts of turbidity plumes present during the PMDP is crucial if lessons learned from the project are to accurately inform future projects in the region. Additionally, a thorough understanding of turbidity and its measurement is also required.

Turbidity is a simple measurement of light scattering and is used for water quality purposes - it should not be used alone as a surrogate for sedimentation impacts. Anyone who has poured cream into a cup of coffee understands the difference between turbidity and sedimentation. Clarke and Wilber (2008) warned that because turbidity is a relative index of water clarity, it only has ecological relevance once it is related to an environmentally important parameter such as total suspended sediment concentrations (TSS) or percent surface irradiance. When turbidity is measured and used to estimate TSS, it is typically done by empirically calibrating turbidity to TSS. Importantly, the calibrations are site-specific and subject to significant errors (Puckette 1998). In many instances, establishing a reliable relationship between TSS and turbidity is not possible due to variations in the characteristics of the suspended material in the turbid plume (Puckette 1998). While nephelometric turbidity observations can be successfully used in quantitative sediment studies (see Fearns et al. 2018), these data can only be obtained if the relevant turbidity versus in situ TSS data are collected simultaneously and a regression equation is established (Ouillon et al. 2004). Additionally, when satellite images are used as a proxy to estimate sediment concentration and the potential impact a dredge plume might have on benthic organisms, any algorithmic approach used must be ground-truthed (Evans et al. 2012, Gramer and Hendee 2018). For the PMDP, the corresponding ground-truth data were not collected. Further, the frequency, magnitude and duration in determining the impact to corals from turbidity plumes (and potentially elevated TSSs) is poorly constrained by limited quantitative measurements. This is relevant because several studies related to the PMDP used satellite images as a proxy for sedimentation, reaching flawed conclusions, discussed below (Barnes et al. 2015, Cunning et al. 2019, Dobbelaere et al. 2024).

The interpretation of turbidity plumes present during the PMDP is further complicated because of the uncertainty of attributing causes (Gramer and Hendee 2018), especially where multiple plumes exist from multiple sources. Puckette (1998) described attempts to use remote imagery to track plumes associated with dredging in the Cape Fear River near Wilmington, North Carolina. He noted they were unsuccessful because the naturally turbid waters in the vicinity of the dredge obscured the plume. At Port Miami, visually extensive turbidity plumes are regularly observed passing through the inlet at Government Cut from Biscayne Bay (which includes the outfall of the Miami River) out into the Atlantic Ocean (Figure 2). These extensive plumes were found to periodically comingle with dredge-related plumes during the PMDP making it difficult, if not impossible, to differentiate between the two (Figure 3). While visually spectacular, satellite and aerial images offer limited quantitative information of total sediment load carried by turbid

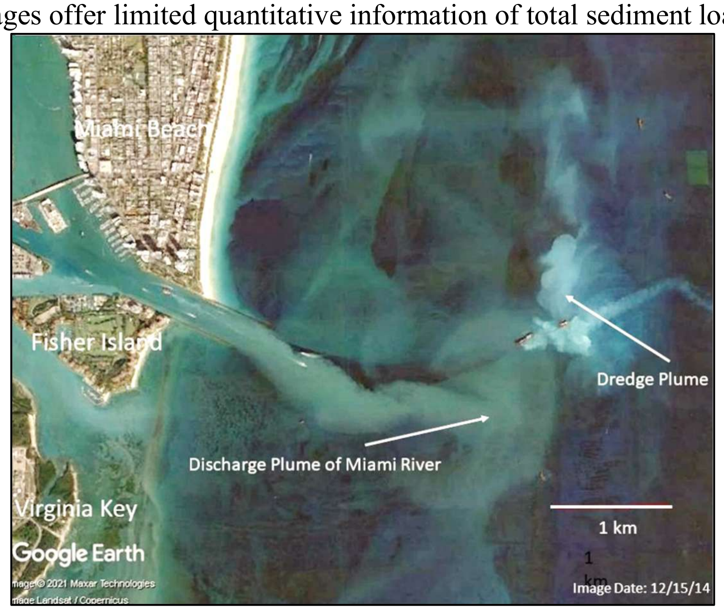

Figure 2. Google Earth Pro Image of the shipping channel entrance to Port Miami. (Government Cut). Image taken on December 15, 2014 during active offshore dredge operations. Turbid dredge plume showing highly reflective (white) optical characteristics of suspended carbonate sediments created by cutterhead dredge operations. Note fine-grained sediments being transported to the north by the prevailing currents. Also note the large plume of turbid water being discharged through the inlet between Miami Beach and Fisher Island. This plume includes a mixture of sediment-laden, nutrient-rich, and highly polluted discharge of the Miami River into the Atlantic Ocean.

Figure 3. Landsat-8 image of the Port Miami and surrounding waters from April 24, 2014. Note how the sediment laden discharge plume passing through Government Cut has comingled with the dredge plume making it impossible to distinguish one from another. Photo Credit: Brian Barnes / Univ. South Florida.

plumes (Orpin and Ridd 2012). The idea that simply digitizing a satellite image of a turbidity plume and being able to determine an area (polygon) of sediment impacts associated with the PMDP with any accuracy, as calculated by Barnes et al. (2015) is problematic.

Further confounding an understanding of turbid plumes present during the PMDP are oceanographic conditions such as wave height and current flow. Both can resuspend sediment in the water column leading to increased turbidity as well as sedimentation on the benthic organisms (Storlazzi et al. 2011, Jones et al. 2016, Evans et al. 2018). For instance, Hanes and Dompe (1995) measured turbidity concurrently with waves and currents at depths of 5 m and 10 m offshore Hollywood, Florida (Broward County) from January 1990 to April 1992. They found a significant correlation between wave height and turbidity. They also noted that long-period swells associated with winter cold fronts resulted in increased sediment suspension and turbidity in nearshore waters. Similar comments can be found in Voss and Voss (1955), Gordon and Dera (1969), and Griffin (1974) linking storms to increased turbidity in southeast Florida, turning the water column milky white. Using satellite data from southeast Florida, Gramer and Hendee (2018) found linear relationships between relative turbidity and wave action with measured wave heights being greatest from October-April. In addition to turbidity, mean wave heights have been positively correlated with total sediment accumulation, particularly fine sediments, in unprotected marine environments (Larcombe et al 1995, Biggs et al. 2016).

Regional wave height data, collected from the NOAA Fort Pierce oceanographic buoy (NOAA 2021a), were compared with corresponding wind data collected from the NOAA Fowey Rocks Station (2021b) to evaluate the linkage between synoptic, regional weather patterns and wave height (Figure 4). Based on a post hoc analyses of coral colonies affected by sediment accumulation, daily sedimentation rates, and percent cover of sediment on the substrate at the Port Miami channel and control monitoring sites, we determined that wave driven sediment resuspension was the major factor in the number of colonies experiencing sediment stress (see Figures 5 – 7).

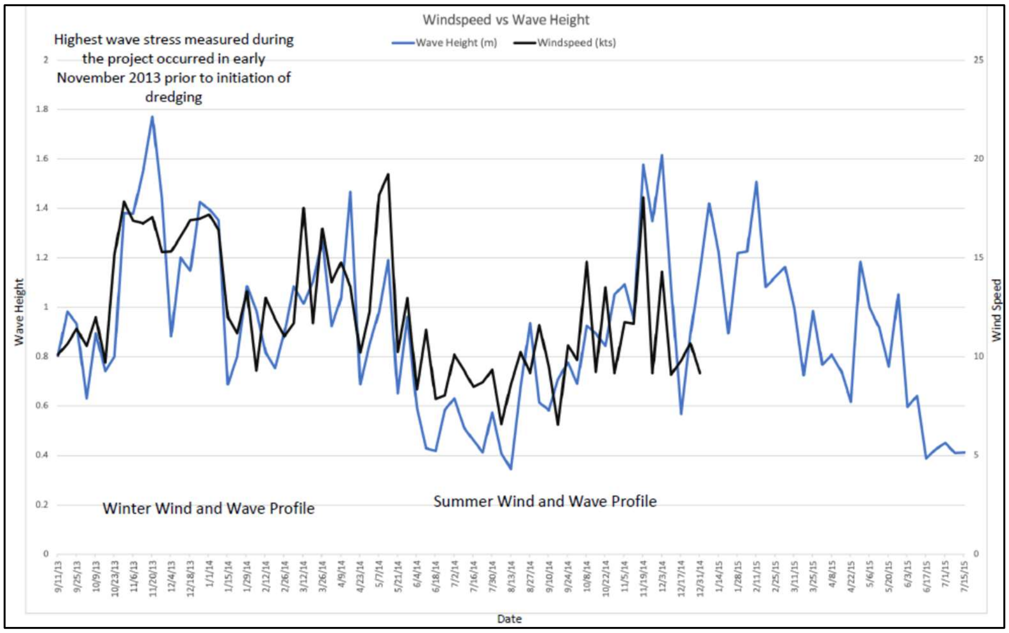

Figure 4. Mean wave heights recorded from a NOAA Wave-Rider Buoy (Station 41114) offshore of Fort Pierce, Florida from September 13, 2013 through July 15, 2015. Water depth under buoy was -16.8 m MSL (NOAA 2021a). Wind speed data was downloaded from NOAA National Data Buoy Center, Fowey Rock Station (FWYF1) located due east of Soldier Key (2021b). These were the closest available offshore data to Port Miami. Although these two stations are located approximately 130miles (210 km) from each other. Notice the remarkable correspondence between wave height and wind speed. **Also note the marked seasonal variation in wave heights.**

As part of the FDEP permit, the environmental contractor was required to collect sediment data in sediment traps. Three sediment traps were deployed at each of 26 monitoring sites during baseline surveys and collected approximately every 28 days for the duration of the project. These data were used to calculate daily sedimentation rates of fine grained (< #230 sieve) and coarse grained (> #230 sieve) sediments. The sediment that accumulates in the traps is a primary flux of particles that settle for the first time, and a secondary flux of resuspended particles that can settle a multiple number of times (Thomas and Ridd 2004). Thus, the sediment collected in sediment traps is the net sum of both. Sediment traps cannot distinguish or isolate 'new' from 'resuspended' sediment. In high energy reef settings, due to resuspension, the sediment flux is generally much greater than the new sediment entering the system. Biggs et al. (2016) found that most sediment that accumulated in their traps was from benthic material (reef sediment) surrounding the trap that had been resuspended by wave action. Storlazzi et al. (2011) noted "*In energetic environments that typically characterize coral reefs, resuspension is common resulting in inferred 'sedimentation rates' that may greatly exceed those from the influx of new particles actually depositing and remaining on the seabed*…" For instance, on fore-reef habitats in Hawaii, Bothner et al. (2006) found that during storms, sediment collection rates in traps were > 1000 times higher than during non-storm periods, primarily because of sediment resuspension by waves.

Despite the caveats about the potential sources of sediment that end up in traps, we used the PMDP datasets to calculate mean daily sedimentation rates for the nearshore hardbottoms, as well as the inner and outer reefs (DCA 2015c, 2015d). Our a priori expectation was that we would see a greater concentration of sediments (especially fine-grained) in traps closest to active dredge operations. Because the dredge moved from west to east (Cut 2 into Cut 1), there should have been more sediment observed in traps adjacent to the nearshore hardbottoms in the early phases of dredging, on the inner reef sites during the middle phases,

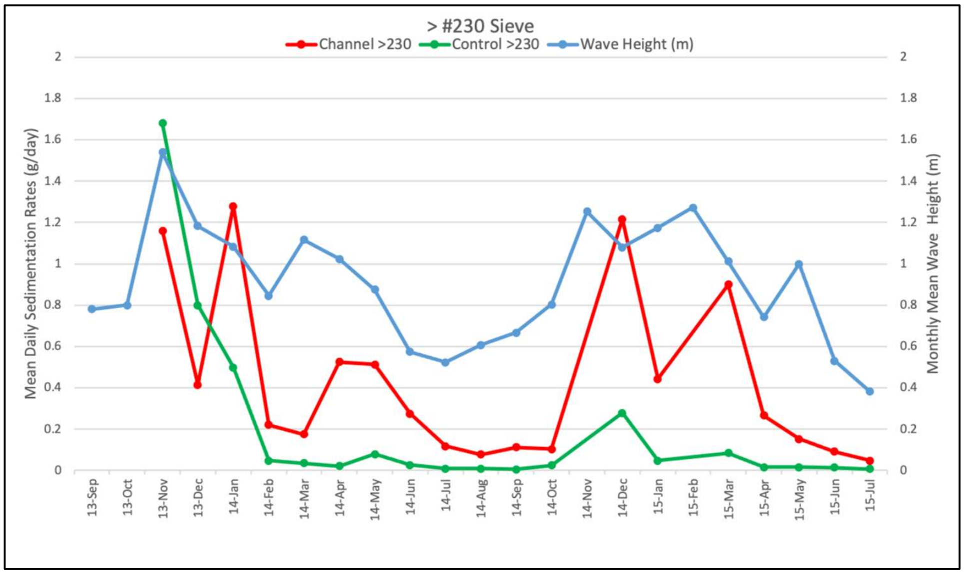

Figure 5. Mean average daily sedimentation rates at all project monitoring sites for coarse-grain sediment (> #230 sieve) from baseline through post-construction surveys. Red graph denotes channel-side sites, Green denotes control sites. Blue graph represents monthly averaged wave heights from the NOAA Ft. Pierce Buoy Station (2021a). Note the strong correlation between wave heights and sediment deposition. Sediment measured in sediment traps correlates with seasonal weather/wave dynamics and not the position of dredge.

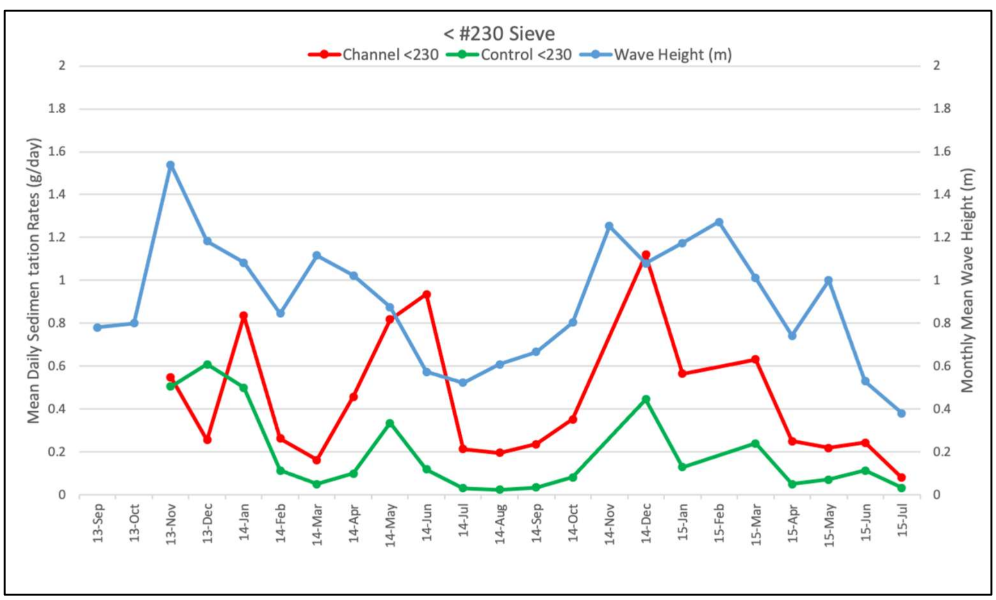

Figure 6. Mean average daily sedimentation rates measured at all project monitoring sites for fine-grain sediment (< #230 sieve) from baseline through post-construction surveys. Red graph denotes channel-side sites, Green denotes control sites. Blue graph represents monthly averaged wave heights from the NOAA Ft. Pierce Buoy Station (NOAA 2021a). Note temporal lag between maximum wave heights and peak sedimentation events. Fine sediments are deposited on decreasing wave profiles.

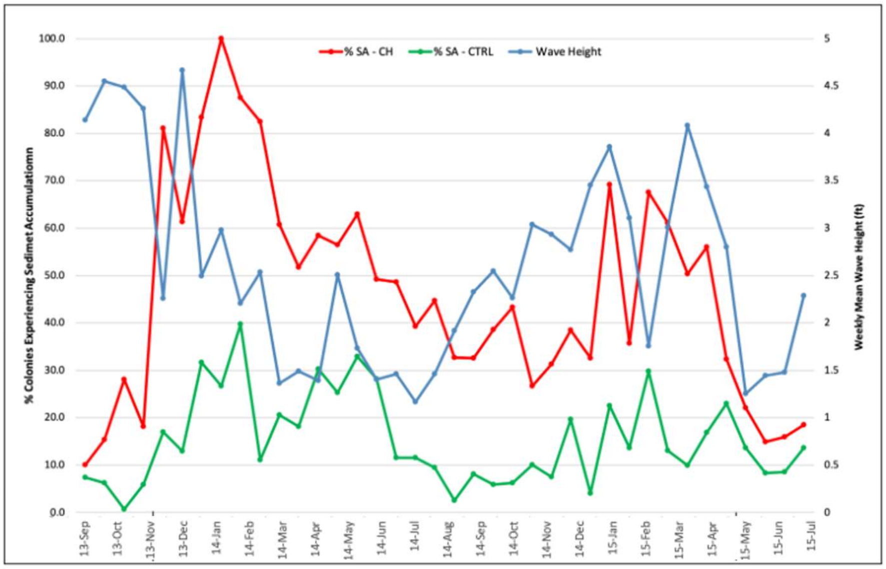

Figure 7. Average bi-weekly sediment accumulation observed on tagged corals at all project monitoring sites from baseline through post-construction surveys. Red graph denotes channel-side sites, Green denotes control sites. Blue graph represents bi-weekly averaged wave heights from the NOAA Ft. Pierce Buoy Station (NOAA 2021a). Note the correlation between wave height and sediment accumulation.

and on the outer reef in the final phases. Also, if dredge activity was the primary influence on the flux of sediment measured in the traps, the greatest totals should have occurred during the summer months when resuspension from wave activity was minimal and accumulation rates should have been high. This, however, was opposite of the pattern observed. Comparing sediment trap data from both channel and control sites with mean monthly regional wave heights (Figures 5 and 6), the highest sediment accumulation rates occurred during the fall, winter, and spring, and was lowest during the summer months. While there was a greater flux of sediment close to the channel, the sediment accumulation data are strongly correlated with wave regime and not the position of the dredge. This is likely due to wave heights and associated bottom currents being sufficient to exceed a critical bed shear stress of the sediments, releasing sediment into the overlying column as a suspended load (Ogston et al. 2004), particularly during the passage of winter storms when sea states are elevated (Hanes and Dompe 1995). Specifically, the measured increases in fine-grained sediments in the traps (Figure 6) are associated with deposition during the waning periods following storms (Verspecht and Pattiaratchi 2010).

Cunning et al. (2019) also used the same sediment data sets (DCA 2015c, 2015d), and recognized the same temporal pattern. Specifically, they stated "*Fine sediment accumulation rates showed peaks in late 2013, spring 2014, and late 2014, and began to decline after dredging ended*." However, in their analysis they only compared the daily sediment accumulation rates with distance from the channel. Failure to consider resuspension and deposition due to seasonal variation in wave heights is a critical flaw in both their analysis and conclusions (see Figure 6).

It also needs to be emphasized that these sediment trap data are not a proxy for amount of dredge sediment deposited on the reef (see Storlazzi et al. 2011). For instance, Cunning et al. (2019) presumed that the cumulative amount of fine-grained sediment measured in the traps during the project was all dredge related. This led to some highly exaggerated claims. For instance, Andrew Baker, a co-author on the Cunning et al. (2019) manuscript stated the following "*840 kilograms per square meter of sediment were dumped onto the reef in the course of the dredging project. That's like 23 bags of 88 pounds of cement onto every square* *meter of that reef*" (Baker 2018). While there certainly was input of dredge-related sediment at the channel-side sites during the course of the PMDP, the amount cannot be isolated or quantified with the available data. A key takeaway from our analysis is resuspension of sediments was the driving factor in the observed sedimentation rates at both the channel and control sites and not the position of the dredge (see Figures 5 and 6).

We also compared the percentage of tagged corals that had observed sediment on their living surfaces at the channel and control environmental compliance monitoring sites (DCA 2015b, 2015c) with the regional wave height data (NOAA 2021a). These data are a useful proxy for determining levels of sediment stress on the corals through time. Sediment accumulation was elevated at the channel-side sites, but the increases and decreases in sediment accumulation through time at both the channel and control sites also corresponds to the seasonal wave dynamics and not the position of the dredge (Figure 7). It is also unknown whether the fine-grained sediments observed on the channel-side coral colonies were a product of dredging, the outfall of material passing through the Government Cut inlet, or the natural breakdown (both physical or biological) of locally derived reef sediments. More than likely, it was a combination of all three. As with the sediment accumulation rates for fine-grained sediments measured in the traps (see Figure 6), there is a temporal lag between maximum wave heights and peak sediment accumulation observed on the living coral colonies (Figure 7).

Bak and Meesters (2000) showed that resuspension of sediment due to storms was also important in preventing sediment from permanently settling and accumulating on the coral surface, thereby reducing the direct negative effects (long-term burial) of sediments on the corals in areas regularly subjected to high levels of turbidity and sedimentation. Species composition of coral communities in these environments demonstrate that species that are tolerant of, and adapted to high turbidity and high sediment stress, also commonly suffer from substantial partial mortality (Marszalek 1982). Bak and Meesters (2000), suggested that partial mortality may be a key aspect of such adjustment.

The FDEP (2012) permit also required that a sediment accumulation block be placed in the center at each of the 26 compliance monitoring sites. The intent was that "*The sediment accumulation blocks may provide sedimentation data more similar to accumulation of sediments on corals when resuspension due to wave actions and water flow is allowed to occur, may provide information more quickly to allow an immediate response should conditions warrant*" (FDEP 2012). Similar sediment blocks were deployed on a previous project in south Florida with viable results (see CSA 2007). The sediment accumulation block consisted of an 8 in x 8 in x 8 in concrete block which was attached to a 16 in x 16 in x 4 in concrete slab and affixed to exposed limestone hardbottom using hydraulic cement (Figure 8). During block deployment, depressional areas or areas with previous sediment accumulation were avoided. The block's upper side was coated with antifouling paint. The paint minimized the accumulation of epibionts on the block which could interfere with sediment accumulation. Blocks were attached to the substrate no closer than 30 cm to any living coral colony to assure there was no impact to existing coral resources. The blocks were observed and photographed each time a site was monitored (about 40 x each for the duration of the project). The blocks were cleaned at the end of each site visit. As noted, the blocks were designed as an abiotic proxy for hard corals, used to measure punctuated sediment accumulation events that might result in stress to the corals. Due to high rates of water flow associated with both tidal and wave generated currents, the sediment blocks did not accumulate measurable amounts of sediment during the monitoring period. While some agency personnel and project opponents regarded the paucity of sediment accumulation as a deficiency in block design, the lack of sediment accumulation was in and of itself an important result. This result illustrated that currents regularly swept the blocks clean throughout the survey period (DCA 2015c, 2015d), similar to the way corals passively remove sediments from their surfaces (Stafford-Smith and Ormond 1992, see also Bak and Meesters 2000).

Figure 8. Underwater photo of deployed sediment accumulation block attached to exposed hardbottom. Photo taken on November 12, 2014 during active dredge operations. A colony of the large star coral, *Montastraea cavernosa* can be seen in the upper left corner of photograph. Note dusting (< 1 mm) of fine sediment deposited on the upper surface of both the block and slab. Photo by RF.

In combination, all these results contrast dramatically with the previously described erroneous assumptions that linked dredging to catastrophic turbidity plumes and sedimentation at PMDP (Barnes et al. 2015, Miller et al. 2016, Cunning et al. 2019, NOAA 2023, Dobbleaere et al. 2024).

The Effects of Dredging on Reefs and Hardbottom Resources

One of the goals of the monitoring program for the PMDP was to distinguish between non-project related impacts and impacts, both direct and indirect, associated with marine dredging operations (FDEP 2012). Why is this important? Because failure to differentiate between the two will ultimately result in developing a cure plan for the wrong ailment. In addition to the FDEP permit-related monitoring programs, a number of sampling efforts were conducted by agency personnel well after the project was completed (NMFS 2016, 2023). Unfortunately, claims made using data collected in these post hoc sampling programs created substantial controversy about the causes of coral mortality during the project, and in our view were unwarranted because of fatal flaws in their design and interpretation.

On May 19, 2015 two NMFS personnel shadowed the environmental contractor's scientific divers while performing permit compliance inspections on the inner reef. Following these dives, the NMFS concluded that the cumulative impacts of the PMDP were worse than expected (NMFS 2015a). This conclusion was based on one day of diving and without performing any quantitative analysis. Precht et al. (2019) addressed many of the problems associated with the NMFS (2015a) field report. Even so, the NMFS doubled down on their claims and on September 11, 2015 the Regional Administrator of NMFS wrote a letter to the Commander of the USACE Jacksonville District and stated that the 'damage' to the reef "*greatly exceeds projections, perhaps more than ten times over*" and "*there is no indication the effects will be temporary*" (NMFS 2015b), while at the same time accusing the environmental contractor of underestimating the impacts caused by the dredging operation. This letter was then used by local project opponents as direct evidence that the PMDP was killing the reef. It is important to note that the one-day diving conducted by NMFS contrasts with over 10,000 dives conducted during the mandated FDEP monitoring program by the environmental contractor. How one day of diving was considered legitimate when conclusions from the formal monitoring program for the project were dismissed is one of the tragedies of the project. We analyze this in more detail, below.

After the initial one day of NMFS diving, in December 2015 and April 2016, staff from the NMFS performed additional field studies at Port Miami. Their field report (NMFS 2016) also directly contradicted project reports produced by the environmental contractor (DCA 2015c, 2015d). Then, in 2023, NMFS released a field report that summarized data they collected in 2015 and 2016 (NMFS 2023). The report included conclusions about the areal extent of project-related impacts of the PMDP. However, numerous problems exist with their work that conclusively undermine their interpretations. For example: (1) they selected field sites that, based on the DCA reports (2015b, 2015d), were known to have the greatest project impacts while disregarding all others; (2) performed one-off field surveys to measure project impacts without having any pre-project baseline data for comparison; (3) assumed that far-field sites were the same as the channel side sites (spatial replicates); (4) used only one transect per site that limited their ability to make statistical comparisons both within and between sites; (5) used variable point count totals per transect that were an outcome of incorrectly implementing a commonly used Linear Point Intercept transect methodology (i.e. double counting of some points); (6) lumped key functional groups into single a category (corals and octocorals) that are not comparable to any other previously reported studies from the region; (7) misidentified causes of coral stress or mortality in field photographs; (8) failed to address potentially confounding covariates in coral stress and mortality; (9) they biased sediment depth measurements along their transects (making multiple measurements and only recording the deepest; see Miller et al. 2016); (10) assumed that all sediments in their measurements were project related; (11) performed their site visits well after dredging activities had ceased; and (12) performed their field surveys immediately following the passage of winter storms that greatly reduced underwater visibility and increased the amount of sediment covering the seafloor, impacting their results. Many similar sampling issues and problems have been identified in evaluating the impacts of logging in tropical forests, often leading to biased and incorrect interpretations and conclusions (Laufer et al. 2013). While it is not our intent to belabor these individual issues in this manuscript (but see Precht et al. 2019 for a commentary on many of the problems raised), they do matter because the interpretations and conclusions in these reports are being used as the main evidence to require that specific dredging methodologies and restrictions be imposed on future projects (Vazquez 2023).

The Creation of Turbid Plumes from Dredging Operations

Multiple dredging methods were used during the PMDP and each has specific advantages and disadvantages related to the amount of turbidity created and potential resulting environmental damage. Unfortunately, misunderstandings about the consequences of the different dredging methods resulted in seriously flawed recommendations for future dredging projects. Therefore, a detailed history and description of dredging at PMDP is needed to set the record straight.

During the PMDP, rocks, sand and gravel-sized sediments were removed from the channel bottom and transported by dump scows to approved offshore dredged material disposal/placement sites (Tsai et al. 1992, McArthur et al. 2002, FDEP 2012). In the offshore entrance channel (Cuts 1 and 2), a majority of the construction dredging was performed using a Cutter Suction Dredge (CSD). CSDs are commonly used for deepening navigable waterways. The CSD employs a rotating cutterhead with pick point teeth mounted to a shaft. The cutterhead rotates around a suction mouth which is connected to a centrifugal pump by a steel pipeline. The cutterhead is essentially a large drill bit with teeth (pick points) attached to the six arms of the cutterhead. By rotating the cutterhead and moving it across the channel, the pick points impact the seabed rock formation, cutting it into fragments small enough to pass between the cutterhead arms and into the suction mouth. The CSD can be employed with or without its suction pumps being engaged. The suction mouth, piping, and cutterhead are attached to a 700-ton structure known as the 'ladder.' The ladder with its cutterhead is attached to the bow-end of the dredge in the ladder well. The ladder is lowered in the water column to the seabed and the cutterhead begins rotating. The dredge and ladder are then swung across the channel, engaging the cutterhead against the rock face. In the case of the PMDP, the cutterhead fractured the rock floor of the existing, previously dredged channel. Step-by-step, the layers of rock are cut and drawn into the suction mouth. With each swing, the ladder is lowered several feet until the cutterhead reaches its target depth.

When the suction pumps of the CSD are engaged, the rock fragments and sea water combine to form a slurry which enter the suction mouth and are hydraulically transported through the dredge pumps and its floating pipeline to a trailing spider barge which directs the slurry into material transport dump scows for eventual towing by tug to the pre-approved material disposal site(s) (Figures 9a and 10). The rock fragments created by the CSD must be smaller than 33 cm (13 in) in its longest dimension to fit through the cutterhead arms, into the suction mouth, and pass through the inboard pumps. Therefore, the swing rate of the ladder across the channel must be slow enough to ensure breakage (cutting) of the rock into fragments < 33 cm. The hydraulic dredging of the limestone initially breaks the rock apart, then exposes the material to intense hydraulic mixing (mix is roughly 90% water and 10% solids), theoretically breaking apart its matrix into smaller, mud-sized particles. Due to their size, this fine-grained carbonate mud would tend to not settle out inside the scow and would exit in the slurry along with the scow overflow. This overflow exits the scows below the hull at – 7 m MSL below the surface. The spillage (material that falls behind the suction mouth and is not drawn into the suction inside the cutterhead) has generally been estimated at < 10 %. Some of the material from the spillage is resuspended while the rest is usually deposited on the seabed near the cutterhead (Hayes et al. 2000, Hayes and Wu 2001). However, when dredging hard rock with a CSD the amount of loss can approach 13% (Kemps and Masini 2017). The USACE - Engineering Research and Development Center (ERDC) suggests 1% as an estimate of spillage at the cutterhead (USACE 2022). While there is some spillage of fine material that occurs at the suction mouth, the majority of turbidity and greatest source of fine-grained sediments created during the PMDP was caused by the allowed (permitted), decanting or overflow of seawater and fines through the skimmers in the dump scows.

Figure 9. Photos of dredge material being loaded into scows. (a) During CSD operations with suction engaged, the dredge slurry contains a mixture of water (90%) and cut rock (10%). The rock fragments are all < 33 cm in their longest dimension. Note the turbid (opaque) nature of the water in the scow due to high volumes of fine sediment in the slurry. As the scow fills with rock fragments the turbid water exits the scow as overflow. (b) Rock placed in the scow with clamshell dredge following CSD rock cutting with the suction turned off (rock chopping). Most rock fragments created during the rock chopping method are large (> 33 cm).

Economic loading of dump scows is achieved by pumping the rock material slurry from the CSD into the bin of the dump scows and allowing the turbid water to over-flow the bin through two skimmer tubes so that more consolidated, larger material (rock fragments) may be transported to the disposal site(s). This process can result in a large turbidity plume of decanted water from the dump scow, which depending upon the sediment composition can have significant, negative, local environmental impacts (Figures 10 and 11). Sediment resuspension generated from this overflow is generally about 10 – 15 % of the total material load according to a range of available estimates from the literature (Mills and Kemps 2016, Kemps and Masini 2017). Florida policy requires that dump scows cannot overflow (economic loading) while dredging hazardous or toxic materials, or clay and silt-sized sediments.

Figure 10. Aerial view of the Cutterhead Dredge Texas working in the offshore channel during the PMDP. Spider-barge loading dredge material into transport scow for disposal shown in the foreground. Note the plume of turbid water discharge from the overflow valves on the scow. Dredge plume is being carried north by prevailing surface currents. At the top of the photo is the cutterhead dredge swinging across the channel. Note the much smaller turbidity plume created by the cutterhead that is confined within the channel boundaries. Plume movement within the channel is dominated by east-west tidal currents. View is looking west. Photo courtesy of Great Lakes Dredge and Dock.

As previously noted, the discharge from the overflow skimmers below the dump scow hull contains a significant concentration of predominantly fine-grained sediment whose bulk density exceeds that of seawater. Therefore, the overflow discharge generates a negatively buoyant, dynamic plume which descends rapidly through the water column while being advected by the ambient current flow (Dankers 2002, Spearman et al. 2007). The settling and resuspension rates of sediment in this overflow are directly proportional to the grain size of the sediment contained within the discharge plume and the flow characteristics and water depth of the receiving water body. The sediment fall speed is dependent on the grain size diameter and is calculated with the equations derived by Hallermeier (1981), with coarser sands in the mixture sinking almost immediately to the seabed being deposited near the dredge operation. As this dynamic plume mixes with and entrains surrounding seawater as it descends, it also reduces the sediment concentration, density, and rate of descent of the plume. This results in a rapid diminution of sediment as one moves away from the point of origin of the plume with sediment concentrations decreasing logarithmically with time and distance (Jones et al. 2016, see also USACE 2022). Modeling exercises have revealed that > 90% of the material is deposited within the first 150 m of the operation (Henriksen 2009). This is almost identical with the field observations made by the environmental contractor at the PMDP that revealed most of the sediment impacts related to the project were observed directly adjacent to the dredge channel and diminished as one moved away from the project area (DCA 2015b, Figure 11). There were

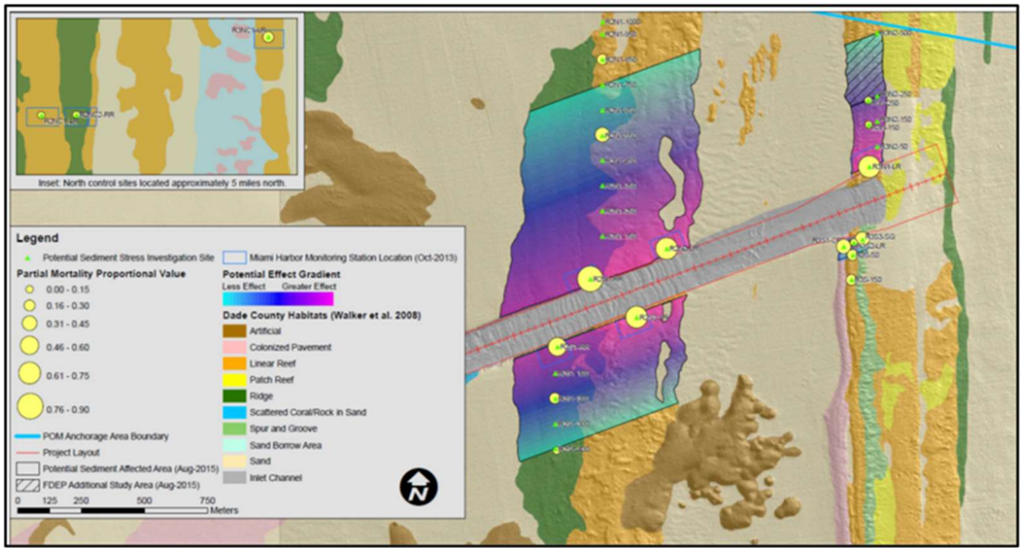

Figure 11. Total area of dredge impact for the inner and outer reefs assessed in situ by scientific divers using a combination of qualitative and quantitative observations (DCA 2015b). Data collected from April 25 to May 22, 2015 following completion of active dredging in Cuts 1 and 2. Yellow circles represent the proportional value of corals observed with partial mortality around their bases that was likely associated with acute sediment burial. Total area of impact is 213.7 acres (0.86 km^2). Note decreasing impacts with increasing distance from channel.

also greater impacts on the north side of the channel due to the direction of the prevailing currents (McLeish and Maul 1991, see Figures 10 and 11). The distance and intensity of impacts shown in Figure 11 are also similar with previous published reports showing the rapid diminution of sediment moving away from the source (Griffin 1974, Newell et al. 1998, Wilber and Clarke 2001). The dispersion of sediment within the dynamic plume suggest that sedimentation is rapid and is generally confined to the immediate vicinity of the discharge (within the authorized 150 m mixing zone), with most of the remainder of the fine-grained material settling out within 750 m.

If the current flow is strong and the water deep enough, then the dynamic plume mixes with the surrounding water and its dilution transitions into a diffusive passive plume that can travel great distances without ever reaching the seabed. Thus, the area of the visual turbid plume does not equate with the area of sediment impact. This is because in open ocean environments, even under relatively calm conditions, the turbulent flow is not low enough to allow the smallest particles to settle (dilute turbulent suspension) (Hjulstrom 1939). Hence, depending on the surrounding surface conditions and water clarity, these turbid plumes may travel as much as several kilometers or more away from the dredging location before it is no longer visible (Newell et al. 1998, Dankers 2002, de Wit et al. 2015). This helps to explain some of the plume observations described in Barnes et al. (2015) and Dobbelaere et al. (2024) for the PMDP.

When the suction pumps on the CSD are turned off, this allows the cutter dredge to break up the rock into larger pieces that remain in place on the seabed and are removed at a later date, generally using a mechanical clamshell dredge with an 18-cy bucket. This operation is often referred to as 'rock chopping.' On the PMDP, GLDD used both the CSD method loading dump scows and rock chopping in the offshore area (Cuts 1 and 2). However, there appears to be considerable misunderstanding of why the rock chopping method was used during the PMDP and what the differences are when it comes to the creation and spillage of fine sediments using the CSD. For instance, Dekker et al. (2003) in modeling flows from the dredging of soils using a CSD noted that the least spillage occurs at high flow numbers, where the suction flow dominates, and an inward flow exists around the entire contour of the cutterhead. Based on their results, it was assumed that when there is no suction, there must be extremely high spillage rates leading to excessive turbidity and transport of fine-grained sediments (Water & Air 2017).

The assumption that rock chopping was the cause of excessive turbidity plumes at the PMDP (Water & Air 2017) led to unsubstantiated comments by the NMFS (see NMFS 2023). They stated "*Rather than conducting confined underwater blasting prior to dredging to pre-treat hard rock as described in the EIS (e.g., three blasts per day for up to 1,333 days), an alternative method, not considered in the EIS, referred to as "rock chopping" (or "roller chopping"), was implemented to pre-treat the rock. Rock chopping is the practice of using the draghead of the Cutterhead Suction Dredge (CSD) to grind, pulverize, or pound the rock without the suction function engaged. Rock chopping results in the introduction and re-suspension of 'rock flour,' the clay-like material that caused the most concern during the Phase Ill dredging*." However, the EIS (USACE 2004) specifically stated the following directly contradicting the claims in the NMFS (2023) report, "*Geotechnical analysis has identified areas from Cut 1, Sta. 0+00 to 90+00 and Cut 2, Sta. 13+00 to Cut 3, Sta. 5+00, where moderately hard to hard rock is present but fractured and exhibits frequent layers of weaker rock or sand. Rock similar to this was previously dredged in Phase I of the deepening in the same area using a large cutterhead dredge. Based on existing Geotechnical data, this area exhibits potential for deepening with minimum or no blasting based on proposed equipment use.*"

One of the likely reasons that GLDD was selected by the USACE for the PMDP was they proposed using a large CSD for a majority of the rock removal and also committed to not blasting any rock prior to dredging. The major rationale for avoiding blasting was to reduce risk to ESA-listed species, especially marine mammals and turtles, and to avoid conflict with local stakeholders (Miller 2011, NMFS 2012). The idea that rock chopping was not considered in the EIS is also directly contrary to statements in the study (USACE 2004). Specifically, the EIS stressed "*Drilling and blasting will be required of most rock prior to dredging with the exception of the majority of Cuts 1 –2 which might be dredged with a cutterhead dredge having rock cutting capability.*" For the record, no confined blasting occurred on any components of the PMDP.

The 'rock chopping' comments in the unpublished Water & Air (2017) and NMFS (2023) studies were further entrenched by statements in Dobbelaere et al. (2024) that reiterated the same incorrect assumptions, specifically that "*Certain dredging operations, referred to as 'non-conventional' were not covered in the Environmental Impact Statement (EIS). These involved "rock chopping" – a process where the draghead of a Cutterhead Suction Dredge (CSD) grinds or pulverizes rock without suction. This technique creates "rock flour", a very fine, clay-like material that settles slowly and can disperse over large distances. Most of these non-conventional operations occurred between December 2013 and May 2014 to pre-treat hard rock.*"

The dredge process referenced above is actually termed 'milling', not rock chopping, where the cutterhead dredge turns a special-purpose 9-arm cutterhead (not 6-arm) that is swung very slowly across the channel, grinding or milling very hard rock into fine sediment. Milling is used when very hard rock pinnacles are present and pretreating the rock with drilling and blasting is not acceptable. Milling was never used as a method to pre-treat very hard rock on the PMDP because in this portion of the project (Cuts 1 and 2) pretreatment was unnecessary because of the nature of the limestone rocks present (see below). In addition, rock chopping is not a 'non-conventional' dredging methodology as purported, it is simply the same rock cutting process using the same CSD equipment only with the suction pumps turned off. Further, we are not sure how a 'drag head' was used to grind and pulverize the rock as stated in NMFS (2023) and Dobbleaere et al. (2024), since a drag head is not a component of a CSD. The drag head is a steel structure with a visor that is dragged across the seabed to loosen and collect sediment during trailing suction hopper dredging operations (TSHD) (Mills and Kemps 2016). TSHD's are primarily used for dredging sand, silt, and gravel. Lastly, Water & Air (2017) used the term 'roller chopping' in lieu of 'rock chopping' to describe the method of using the CSD without suction (see also NMFS 2023). This too is incorrect. Roller chopping is a method that uses a rolling mechanism, not a CSD, to pulverize (crush) the rock rather than cutting (breaking) it into discrete pieces. These gross mischaracterizations of the dredging methods used during the PMDP resulted in numerous incorrect assumptions regarding the potential impacts from their operation.

Rock chopping in this instance is not a method used to grind or pulverize the rock into rock flour or fine clay-like sediments. In fact, it is a method used to do exactly the opposite. Because the rock does not have to be < 33 cm in diameter to fit through the cutterhead arms and into the suction mouth, the cut rock can be left in larger pieces on the seabed at the point of the cutterhead's contact with the rock face. When the cutterhead is operated with no suction, the cut material (large pieces of limestone rock) is left on the seabed directly behind the cutter and as stated earlier is then picked up at a later time by a mechanical clamshell bucket (Figure 9b). With no dredge material going through the suction line, nearly all the cut material from the CSD is left on the seabed compared to a similar cutterhead operation with suction engaged. In this case, however, the overall potential for the generation of fines and their release as a turbid plume is reduced because material attrition occurs only at the cutterhead (Mills and Kemps 2016). When the suction pumps are turned off the dredge operator can increase the rate of swing of the dredge and cutterhead across the channel, cutting the rock into much larger pieces. Less rock is being cut results in fewer fines being created at the cutterhead. So, while spillage may be high, the resulting resuspension of fines is low. This also results in an increased production rate in rock cutting by almost 30% (GLDD, personal communication).

During the PMDP, GLDD used the rock chopping method described above in two instances. First, was when the CSD was working in the narrow, confined shipping channel area between the jetties of south Miami Beach and Fisher Island. This was due to the need to frequently move the CSD out of the channel to facilitate the safe navigation of large commercial vessels entering and exiting Port Miami that would have resulted in significant downtime in dredge operations. When the CSD was set for rock chopping, the dredge discharge pipeline, spider barge, scows and tugs were removed from the area allowing the dredge to continue working while commercial port traffic was able to transit the project corridor safely. Second, they used rock chopping as an approved adaptive management strategy on the PMDP (starting on February 9, 2014) to reduce the amount of turbidity and sediment fallout that resulted from continuous dredging, which as stated earlier, was generally caused by resuspension from permitted scow skimmer overflows and not from the point of cutterhead impact on the seabed. While the very coarse fractions of the spillage (cut rocks > 33 cm) were deposited directly on the seabed behind the cutterhead, small amounts of finer fractions were resuspended and mixed over a localized zone of highly turbulent flow generated around the rotating cutterhead. Finally, because the plume created at the cutterhead is also denser than the surrounding seawater, a large portion will stay low in the water column. Thus, the turbidity plume created at the cutterhead's contact with the rock floor, with or without suction, was generally confined within the deep box cut (at depths between -12.8 and -15.8 m MSL) of the previously dredged channel while the overflow from the loading of scows was not (see Figure 10).

The most egregious error in the Water & Air (2017) report pertains to the amount of sediment resuspension associated with rock chopping at Port Miami. Specifically they state "*Note: Very crudely, considering a dredge volume of approximately 2 million yd^3 (assuming approximately only 33% was broken apart by CSD/roller-chopping into fines in the vicinity of the Middle Reef, rather than the total estimated volume of 5.8M yd^3) spread over an estimated 216 acres (the area assessed by DCA to indicate sedimentation) at an average of 20% stripping losses, this would approximately equate to a deposition on the hardbottom communities of 13 inches or 33 cm…*" However, every term used in their calculation is incorrect, yet this calculation has been uncritically accepted by the NMFS (2016, 2023), the USACE (2023), and Dobbelaere et al. (2024) as evidence for significant sediment impacts to the resources both near and far from the dredging operation. For instance, Dobbleaere et al. (2024) quoting the USACE (2023), who in turn were quoting Water & Air (2017) stated the following "*The use of rock chopping was estimated to cause up to 33 cm of sediment deposition over 874,121 m^2 of reef around the outer entrance channel.*"

We will address this calculation, point-by-point. First, the total of 5.8 million cubic yards of material used in the Water & Air calculation was the total amount of material removed for the entire PMDP (all components; see Figure 1). Water & Air assumed that 33% of the total volume was rock chopped in the offshore 'reef' area which reduced the 5.8 million cubic yards amount to 1,914,000 cubic yards. As noted earlier, the total volume of material removed from the outer Entrance Channel was actually 2,199,500 cubic yards using all dredging methods combined, just slightly more than Water & Air's claim of material that was rock chopped for just the Entrance Channel. The total amount of material rock chopped in the PMDP (all components) was 1,614,417 cubic yards, however, the actual quantity of material that was rock chopped in the outer Entrance Channel (Cuts 1 and 2) was 483,650 cubic yards (GLDD survey records and USACE daily project reports). The amount of material rock chopped for the outer channel is equivalent to 30% of the total volume of material rock chopped and only 8% of the total material removed for the entire project. Water & Air further assumed a stripping loss of 20%. Water & Air used the term 'stripping losses' to represent the percentage of material converted into fines during the rock chopping process. Thus, the total amount of material used in Water & Air's calculation was 382,800 cubic yards. Comparing Water & Air's calculation of 382,800 cubic yards with the actual amount of material rock chopped (483,650 cubic yards) would have required a 79% stripping loss in the offshore area. Water & Air also assumed that all the liberated material from the rock chopping operation was fine-grained and would be spread equally over an area of 216 acres (the actual area of impact was 213.7, not 216 acres; see Figure 11). Neither of these two assumptions are accurate.

Using the correct terms in the calculation we find that using Water & Air's stripping loss estimate of 20% on 483,650 cubic yards of material that was rock chopped in the offshore area would equate to 96,730 cubic yards of total material being spread over an area of 1,045,440 yds^2 (874,121 m^2) which translates to a depth of approximately 8.23 cm (3.24 in). This depth is 75% less than the Water & Air (2017) calculation of 33 cm (13 in). If we now apply the conservative loss estimates of 10% for cutting hard sandstone (see Kemp and Masini 2017), the resulting loss would be 48,375 cubic yards of material which equals a sediment depth of 4.6 cm (1.8 in). If we apply the 2% estimate of Kemp and Masini (2017) for dredging limestone, the resulting loss would only be 9,674 cubic yards of material which equals a sediment depth of 0.92 cm (0.36 in). However, Kemps and Masini (2017) noted that only 30 – 50% of this material would be fine-grained further reducing the sediment depth to 0.46 cm (0.18 in). The latter amount is remarkably similar to channel-side observations routinely made by scientific divers during the project (Figure 12) and is in-line with model predictions for sediment deposition associated with CSD's (see Williams et al. 2024).

In any case, the sediment depth calculation in Water & Air (2017) was inflated by at least 75% and likely much more. A significant take home message from both the assumptions and conclusions made in the Water & Air (2017) report is that we should all be more cautious about accepting asserted statements as facts. Thus, the suggestion by Water & Air (2017, 2018), NMFS (2023), and Dobbelaere et al. (2024) that rock chopping was the cause of the large, areally extensive, south-to-north oriented turbidity plumes observed in satellite images and accumulation of fine, clay-like materials found on the seabed is patently incorrect. Why is this important? First, since it was not the cause of the consequential turbidity plumes observed during the project, then focusing on that as 'the problem' diverts attention from ameliorating the real issue – reducing the permitted overflow of fine-grained sediment contained within the slurry from dump scow loading and transport. Second, the inaccurate claim that rock chopping was responsible for the generation of clay-like, neutrally buoyant sediments led to the development of post hoc, sediment transport simulation models (Water & Air 2018, Dobbelaere et al. 2024) that showed far greater project impacts both in the amount and areal extent of sediments, than those observed in situ by trained scientific divers. The scientific dive team performed more than 10,000 dives from baseline through post-construction and were in the water daily (weather permitting), documenting project-related stress on the resources surrounding the PMDP.

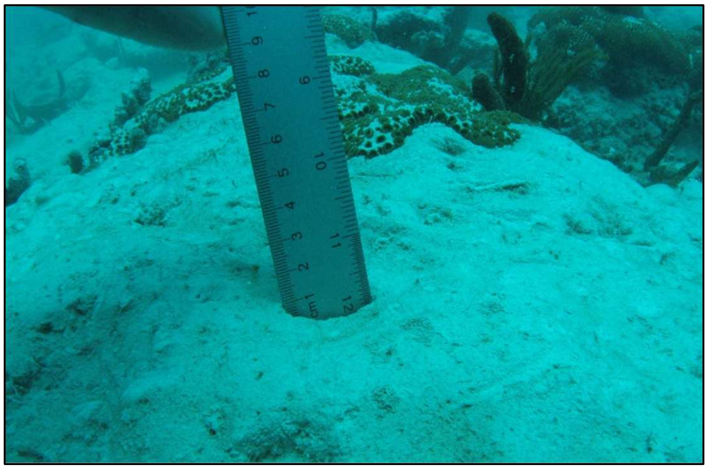

Figure 12. Underwater photograph of typical depth measurement of fine-grained sediment over hardbottom. Photo taken on the inner reef located approximately 50 m north of the dredge channel during active dredge operations on November 7, 2014. Photo taken by RF.

Importantly, no project related sediment was ever observed at any of the southern control monitoring sites, directly contrary to the model predictions and claims in Dobbelaere et al. (2024). Thus, the incorrect assumptions underlying the Water & Air (2018) and Dobbelaere et al. (2024) simulation models ultimately resulted in flawed conclusions of project impacts (NMFS 2023). Third, based on recommendations in the Water & Air (2017) report, NMFS has recently stipulated that the rock chopping method be prohibited in future dredging projects adjacent to coral reefs (see also Dobbelaere et al. 2024), including at Port Everglades and Port Miami (Vazquez 2023). This restriction is counterproductive to agency goals and public interests because it will result in greater impacts to corals. Rock chopping, as described above, is an important adaptive tool used to reduce the amount of fine sediment and turbidity created during dredge operations.

Sources of fine-grained sediments during the PMDP

Baseline studies to characterize the mineralogical and stable isotope characteristics of sediment present in an area can help to identify the potential sources or origin of those sediments. Unfortunately, at Port Miami this analysis was not performed. If they had, comparison of pre-project baseline data with data collected after a dredging could elaborate as to whether the overlying sediment was derived from dredging - outflow from the port due to tides and the Miami River - or if were they naturally produced in situ by the surrounding reef.

Numerous authors have cited an unpublished lab report by Peter Swart from the University of Miami (Swart 2016) as prima facie evidence that the PMDP deposited fine-grained sediments throughout the region and the sediments were still present more than a year after the cessation of dredging activities (NMFS 2016, 2023, Cunning et al. 2019, May et al. 2023). Unfortunately, misunderstandings about the underlying geology presented in Swart (2016) invalidate his results and, consequently, the conclusions of the studies that cite his report (NMFS 2016, 2023, Cunning et al. 2019, May et al. 2023). Along with Water & Air (2017), this is the second example of incorrect conclusions from a non-peer-reviewed report being accepted as fact by NMFS (2023) in the canon of PMDP-related literature.

Swart (2016) specifically tested the hypothesis that sediments were introduced to the area by the PMDP using a combination of mineralogical and stable isotopic techniques. The analyses were performed on unconsolidated, fine-grained sediments collected post hoc from hardbottom and reef habitats in and around the vicinity of Port Miami. Sediments for this study were collected by NMFS contract divers in April 2016, more than a year after dredging was completed. Sampling methodology consisted of divers scraping turf algae with a knife, releasing the fine-grained sediments that were bound by the algal filaments, and then placing these sediments in a collection vile. In total, 20 samples were collected; 15 from purportedly 'impacted' sites that were in close proximity to the dredge channel, and five (5) from "pristine" sites located approximately 9 km to the north.

By comparing the carbonate minerology, isotopic concentrations (carbon and oxygen), and quartz abundances of the samples, Swart (2016) attempted to distinguish autochthonous (locally produced) from allochthonous (introduced) reef sediments. The results in Swart (2016) showed that the sites closest to the channel had higher concentrations of low-magnesium calcite (LMC) (as high as 27%), higher concentrations of quartz, and lower concentrations of aragonite and high-magnesium calcite (HCM). In contrast, the reference sites had higher aragonite and HMC, and lower LMC. The sites closest to the channel also had lower carbon and oxygen isotope concentrations compared to the reference sites. LMC content was inversely correlated to both d13C and d18O. Sediments with higher concentrations of LMC and lower carbon and oxygen isotope signatures were likely diagenetically altered limestones that were originally aragonite (Saller and Moore 1991). Aragonite neomorphism is commonly observed in limestones that are exposed to freshwater and is typical for the Pleistocene-age limestone formations found throughout south Florida (see Martin et al. 1986, Evans and Ginsburg 1987, Harris and Purkis 2020).

Based on these lab results, Swart (2016) concluded that the higher LMC and lower carbon and oxygen isotope concentrations in these surface sediments likely originated from the underlying Pleistocene age Anastasia and Fort Thompson formations and were therefore introduced. Swart (2016) asserted that these sediments were produced by dredging activities that occurred more than a year earlier during the PMDP. But what if the underlying geologic formations encountered during the dredging operation were not the same as those described in the Swart (2016) report? The Anastasia and Fort Thompson Formations were never encountered while dredging Cut 1 or Cut 2 during the PMDP. Locally, the Fort Thompson Formation underlies (subcrops) the Miami Limestone (Johnson 1992, Cunningham et al. 2006), while the nearest known occurrence of the Anastasia Formation is some 35 - 40 miles north in Broward County (Williams et al. 2022). The Anastasia Formation is comprised of a coarse mixture of carbonate shell hash (coquina) mixed with quartz sands (Missimer and Maliva 2005) and is stratigraphically equivalent with and grades into the Miami Limestone (Missimer 1984, Scott 1991, Johnson 1992, Purkis and Harris 2017, Williams et al. 2022).

During the PMDP, the main rock formation encountered in Cut 2 was the Pleistocene (Marine Isotope Stage 5e) Miami Limestone (Oolite) which underlies and locally forms the foundation of the nearshore ridge complex. Specifically, the highly burrowed, mottled facies of the Miami Oolite was pervasive throughout the westernmost segment of the offshore portion of the dredge project (Figures 13a and 13b). Rock samples of the Miami Oolite collected from the base of the wall by one of us (WFP) during the PMDP were comprised primarily of *Ophiomorpha* (Callianassid ghost shrimp) burrows and had related inter-burrow and intra-burrow macropores in a cemented matrix comprised primarily of small ooids and peloids (Figure 13c). This sample was stained using Feigl's Solution (Kato et al. 2003) and revealed a rock with a nearly 70/30 mixture of aragonite and diagenetically altered (LMC) oolitic/peloidal sand.

Moving from west to east, from Cut 2 into Cut 1, the Miami Limestone pinches out in a seaward direction and is replaced by early-to-middle Holocene age deposits comprised primarily of aragonitic beach rocks which are in turn, overlain by massive aragonitic reef deposits (Figures 14a, 14b and 14c; Toth et al. 2021). These Holocene-age relict reefs are locally known as the inner and outer reefs (Walker and Klug 2014). These Holocene reef deposits formed a nearly continuous barrier reef complex that stretched from Fowey Rocks in southern Miami-Dade County to northern Palm Beach County, a distance of almost 120 km (Toth et al. 2021). In places, these reef deposits are greater than 10 m thick (Lighty et al. 1978, Lighty 1985, Stathakopoulos and Riegl 2015).

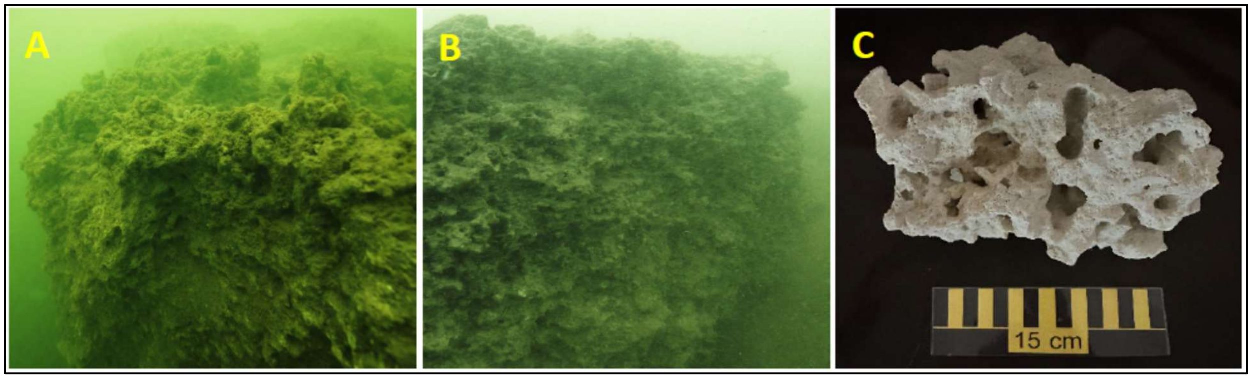

Figure 13. Underwater photographs of exposed outcrops of the Miami Limestone. (a) Section along south wall of channel in Cut 2 at -7.1 m MSL. The predominant facies present include cross-bedded, oolitic grainstones which are overlain by the bioturbated facies. (b) Section of the Miami Limestone along the north wall of Cut 2 in -8.6 m MSL. This section represents the bioturbated facies of the Miami Oolite. The rock is poorly indurated, extremely friable, and easily broken with a rock hammer. (c) Close-up of hand specimen of bioturbated facies collected at the base of the north wall in -15.7 m MSL. Rock is comprised of a vuggy, burrow-mottled, ooid-peloid dominated grainstone. The large vugs are formed by an open network of *Ophiomorpha* (ghost shrimp) burrows. Photos taken by WFP.

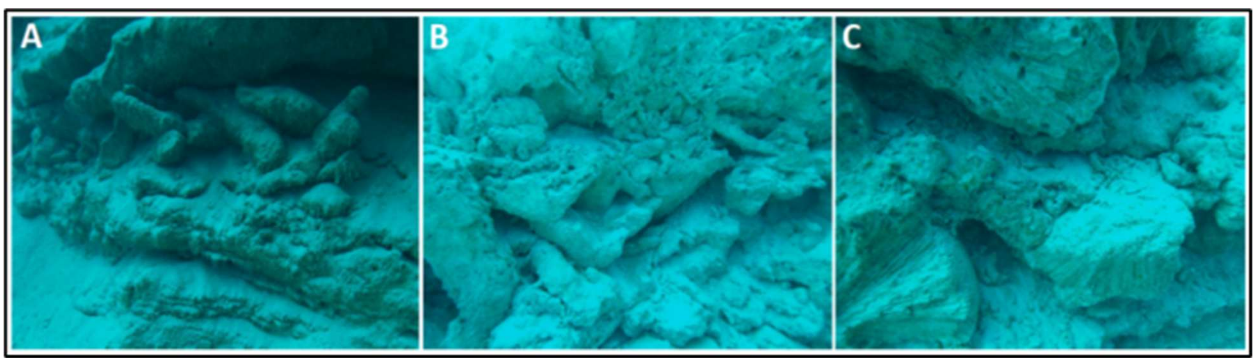

Figure 14. Underwater photographs of freshly exposed Holocene reef framework taken along the recently dredged channel edge on September 17, 2014. (a) Holocene carbonate (aragonitic) beachrock disconformably overlain by transgressive *Acropora palmata*-dominated Holocene reef facies at the base of the outer reef dredge cut exposure at -16.2 m mean sea level (MSL). The beachrock is poorly indurated and dips in a seaward direction. (b) In situ, cemented *A. palmata* reef framework mixed with broken fragments of *A. cervicornis* and loose sand on the outer reef at -14.6 m MSL. (c) Exposed Holocene reef facies comprised of massive corals on the inner reef dredge cut at -10.4 MSL. Photos taken by WFP.

If the bulk of the rock dredged from Cut 1 was predominantly aragonitic in composition, why would there be an abundance of LMC with quartz found in the surface fine-grained sediments collected more than a year after the dredge project was completed? And why would this be an indicator of dredge-produced sediment? In fact, based on the local geology, these data show exactly the opposite of what Swart (2016) contends. The surface sediment should have had an aragonite content similar to that of the recent surface sediments if it was the result of sediment fallout from the dredging of Holocene-age aragonitic reef deposits

(Toth et al. 2021). While we agree with Swart (2016) that non-indigenous (allochthonous) sediments were introduced to the area, it is highly unlikely that these sediments are the product of the PMDP.

Based on the data run in Swart's x-ray diffractometer and mass spectrometer – where does the fine-grained LMC sediment in the NMFS samples originate? One possibility is that some of these fine sediments may come from the constant winnowing of natural and renourished beach sands from Miami Beach moving in a seaward direction away from the coast, especially during winter wave conditions (DeWall and Richter 1977, Wanless and Maier 2007, Warrick 2013, Precht et al. 2021). However, based on the distribution of the LMC and aragonitic sediment samples in Swart (2016), the most parsimonious explanation is that the fine-grained LMC and quartz sediments likely originated from the highly turbid plumes associated with the relentless discharge of Biscayne Bay and the Miami River that pass through the Government Cut inlet on the outgoing phase of semidiurnal astronomical tides. These turbid plumes which can be readily observed in aerial images have a large areal footprint, and have been documented since at least 1916 (Figure 15). The turbid discharge plumes that pass-through Government Cut and visible in the satellite images (see Figures 2 and 3), also correlate spatially with the maps provided in Swart (2016). This outfall plume is comprised of fine-grained sediments that originated from the weathering and erosion of Pleistocene age rocks found throughout the south Florida peninsula (including the Miami Limestone, Anastasia, Pamlico Sand, and Fort Thompson Formations) that drain into the greater Miami Canal, Miami River, and Biscayne Bay watershed(s). In addition to fine-grained sediments, this low salinity turbid water mass is replete in nutrients (Sinigalliano et al. 2019), various pollutants (Futch et al. 2011, Symonds et al. 2016, Staley et al. 2017), and has elevated levels of pCO2 and dissolved inorganic carbon (Enochs et al. 2019), none of which are good for corals.

Figure 15. Aerial photograph of sediment-laden turbid plume discharging into the Atlantic Ocean through the jetties along Government Cut. View is to the east. Miami Beach on left side of photo, Fisher Island is on the right. Photo taken in 1916.

CONCLUSIONS

Through the FDEP permit-mandated monitoring program established for the deepening of Port Miami (FDEP 2012), it was possible to empirically evaluate both the short-term and long-term impacts of the project and other concurrent stressors on the resources within and adjacent to the PMDP (DCA 2017a, 2017b). While there clearly were project-related impacts – some significant – these paled in comparison with the highly exaggerated and inaccurate claims alleged by some (Water & Air 2017, Cunning et al. 2019, NMFS 2023, Dobbleaere et al. 2024). These claims also obscured the relative merits of using different dredging methods to reduce project impacts through adaptive management practices. However, many of these false claims resulted in the NMFS recommending that draconian measures be implemented on future projects, specifically related to dredging methodology. These measures (restrictions) will significantly increase project costs, ultimately adding significant time to the proposed project schedules, while doing little to address or ameliorate the real environmental concerns identified as problematic in the PMDP. Specifically, the reduction of turbidity and sediment fallout from scow loading, transport, and disposal.

Utilizing the accurate lessons learned from the PMDP and other previous projects, and implementing BMPs through targeted environmental monitoring and adaptive management programs will ultimately result in the best possible project outcomes. To that end, we have addressed some of the major incorrect claims made by project opponents, especially with regard to the origin and impacts of the turbid plumes generated by the PMDP. It is hoped that these clarifications provide a clear framework for the future environmental management of construction projects when corals and coral reefs are at risk. This is especially relevant, given future dredging projects such as the expansion and deepening of Port Everglades, as well as safety improvements planned at Port Miami potentially being just around the corner.

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