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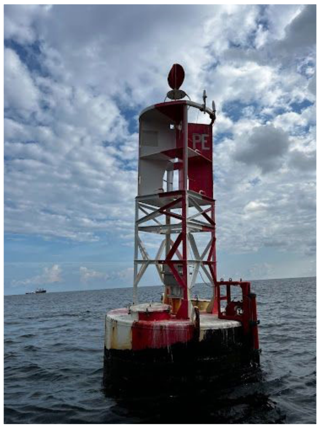

Authors

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Potential Impact of Dredging Activities at Port Everglades (Florida) on Coral Reef Communities: Assessment of the Threat of Sediment Associated Contaminants

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Gina M. Raimondo Secretary	Rick Spinrad, PhD Under Secretary	Nicole LeBoeuf Assistant Administrator

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Abstract

Port Everglades is a major port on Atlantic Coast of Florida that is adjacent to significant and ecologically important coral reef ecosystems. Heavy ship traffic (including container, military and cruise ships) has the potential to chronically impact ecosystem health through potential discharges, anti-fouling paints and physical damage, but periodic acute dredging events, i.e., to improve or maintain the ship channels, may also be major stressors to the ecosystem. In addition to the potential for increased sedimentation and decreased water clarity, contaminants associated with sediment particles from dredging can be transported from the relatively polluted port area to the adjacent reef ecosystem. Dredging operations to maintain and/or expand active ports have the potential to be extremely disruptive to nearby ecosystems, including coral reef ecosystems, which are particularly sensitive to changes in water clarity, sediment deposition and contaminants. This study investigates the pollutant component of this maintenance dredging stress, examining changes in surficial sediment chemistry from the period immediately before dredging to just after the dredging had taken place in Port Everglades. Chemical constituents measured for this study included a wide range of organic compounds (PAHs, PCBs, pesticides, etc.), as well as trace elements, including heavy metals. This study found that while levels of contamination were generally low both pre- and post- dredging, there were significant differences in both the chemical and physical characteristics of the sediments following maintenance dredging. This has potential implications for ecosystem health, including impacting benthic infauna, important fish species and coral reefs themselves, and reinforces the potential impacts that larger dredging operations could have.

Introduction

Contaminant Stressors in Coral Reef Ecosystems

The ecological health of coral reef systems can be adversely impacted by a variety of stressors, including overfishing, thermal stress, disease, ocean acidification and pollution. Types of pollution include nutrients, pathogens, metals, legacy organic pollutants (e.g., PCBs), legacy and current use pesticides, hydrocarbons, flame retardant compounds (PBDEs), personal care products and pharmaceuticals. A number of National Oceanic and Atmospheric Administration (NOAA) studies have previously quantified baseline pollution in coral reef ecosystems in US waters (e.g., Pait et al. 2008, Mason and Whitall 2019), including in sediments (Whitall et al. 2015), in the water column (Whitall et al. 2019), in coral tissues (Pait et al. 2010) and in motile benthic reef organisms (Whitall et al. 2016). However, these baseline studies do not capture the impact of acute or extreme events such as hurricanes or marine construction/dredging. Port Everglades is a major port on the east coast of Florida, operating for almost a century. Both cargo and passenger ships (cruise liners) utilize the port. The harbor itself is highly engineered, with a depth of 13 m (Stauble, 1993), and has a sizeable footprint (295 m in width and 641m in length). In 2016, authorization was granted for the Port Everglades Deepening Project (PEDP), to be overseen by the U.S. Army Corps of Engineers. This project will deepen (up to 17.4 m at the Outer Entrance Channel) and widen the channels as part of the Water Infrastructure Improvements for the Nation (WIIN) Act (Army Corps of Engineers, 2022). An Environmental Impact Statement (EIS) was submitted for public comment in 2016 (Final EIS), 2020 (Supplemental Draft EIS), and 2022 (Revised Supplemental Draft EIS; Army Corps of Engineers, 2022). In addition to potential contaminants due to port activities, the drainage area to Port Everglades Inlet contains significant urban areas (85% of land use by area), with associated point and non-point pollution sources, with minimal agriculture (less than 1%; Pickering and Baker, 2015, Whitall et al. 2019).

The reef ecosystems adjacent to the study sites fall within the Kristen Jacobs Coral Reef Ecosystem Conservation Area and provide habitat to important fisheries (Ferro et al. 2005, SAFMC 2009, Kilfoyle et al. 2015). The impacts from port expansion described in the Recommended Plan include up to 14.5 acres of seagrass, 1.2 acres of mangrove, and 564 acres of coral habitats (to varying degrees of severity due to sedimentation; USACE 2022), which the South Atlantic Fishery Management Council designates as essential fish habitat and Habitat Areas of Particular Concern. Coral listed as threatened under the Endangered Species Act are also present in the project area, in addition to their designated critical habitat. The benthic habitat consists of a mix of contiguous coral reefs, soft substrates (e.g. tidal sand flats and mud flats), seagrass, oyster reefs, mangroves, and offshore/

nearshore hardbottom habitat (Walker and Klug 2014). The reefs include limestone ridges colonized by typical Caribbean fauna, including reef organisms such as sponges, octocorals, macroalgae and stony corals (Goldberg 1973; Moyer et al. 2003; Banks et al. 2007), and generally occur within ~30 meters to up to 3 to 4 km from shore in the Port Everglades area (Goldberg 1973; Moyer et al. 2003; Banks et al. 2007; Walker and Klug 2014, Gilliam 2010). Nearshore hardbottom habitats, located between the shoreline and offshore reefs, range from patch reef-like vertical mounds in depths of 0 to 4 m to flat expanses of exposed rock with little vertical structure. These nearshore hardbottom areas, inhabited by octocoral, macroalgae, sponges and stony corals, can support a diverse assemblage of fish primarily represented by juveniles indicating their importance as nursery habitat for reef fish (Lindeman & Snyder 1999; Gilliam 2010).

Previous research around a similar dredging project at another port in close proximity (the Port of Miami) after its most recent expansion (2013-2015) demonstrated higher prevalence of partial mortality of corals up to 700 m from the channel as a result of dredging-induced sedimentation (Miller et al 2016), although impacts likely extended over 5-10 km from the dredge area (Cunning et al. 2019). Recent work looking at the effects of dredging on corals also suggest that effects may vary depending on the grain size and composition of the suspended sediments, as well as the sensitivity of the coral species (reviewed in Erftemeijer et al. 2012; Jones et al. 2016; Jones et al. 2019). Finer suspended sediments tend to attenuate more light, thus causing a greater net reduction in light essential for photosynthesis (Storlazzi et al. 2015). Finer suspended sediments also have a clay-like texture that is more resistant to bioturbation, can lead to a change in the bacterial community (Erftemeijer et al. 2012), and are more likely to become anoxic (Weber et al. 2006; Piniak, 2007). Finally, sediments can also harbor contaminants (Su et al. 2002; Eggleton and Thomas, 2004; Giarikos et al. 2023) and microbial pathogens (Weber et al. 2012) which may potentially transmit coral disease, including Stony Coral Tissue Loss Disease (Studivan et al. 2022).

Approach

Concentrations of contaminants in coastal waters are constantly changing with tides, currents and precipitation and it is difficult to obtain representative samples without collecting a large number of samples over time. For this reason, water column grab samples for analytical chemistry have their drawbacks. Sediments tend to accumulate contaminants, including both inorganic (metals) and organic, and they act as a natural integrator over time. Sampling sediments, rather than using a water column grab sample, gives a more temporally representative assessment of contamination in a system. This study used a “before and after” (pre- and post-dredging) temporal sampling design to assess changes in surface sediment chemistry following a maintenance dredging project in Port Everglades. The final USACE Environmental Assessment describes dredging approximately 100,000 cubic yards of material and discharging beach quality material along the shoreline south of the federal channel with the remaining material discharged at the EPA-designated Ocean Dredge Material Disposal Site, located approximately 4 miles offshore (USACE 2020). The dredge project was executed in two phases, with clamshell (mechanical) dredging occurring between November 24, 2020 to January 8, 2021 and hopper dredging occurring between February 11 and March 5, 2021.

Study Site

Port Everglades is located adjacent to the cities of Hollywood and Fort Lauderdale, Florida. It is a man-made harbor that is a key port for container ships, petroleum shipping, and cruise lines; it also supports military activities (US Navy and US Coast Guard). Navigation in the port is challenged by insufficient channel depths and widths. Dredging projects are aimed to alleviate these issues allowing for fewer, larger and more efficient ships, as well as maintaining a navigable channel. Natural habitats around the port include coral reefs, mangroves and seagrasses. Protected and listed species under the Endangered Species Act that are found in the area include: manatees, sawfish, sea turtles, crocodiles, as well as multiple coral species (USACE 2020), and the recently listed queen conch (NOAA 2024).

Methods

Sediments were collected by divers at eighteen sites, plus two reference sites located within the harbor itself (Figure 1; Table 1). Site nomenclature (see Table 1) includes a prefix (number, e.g., 2000) that shows the longshore

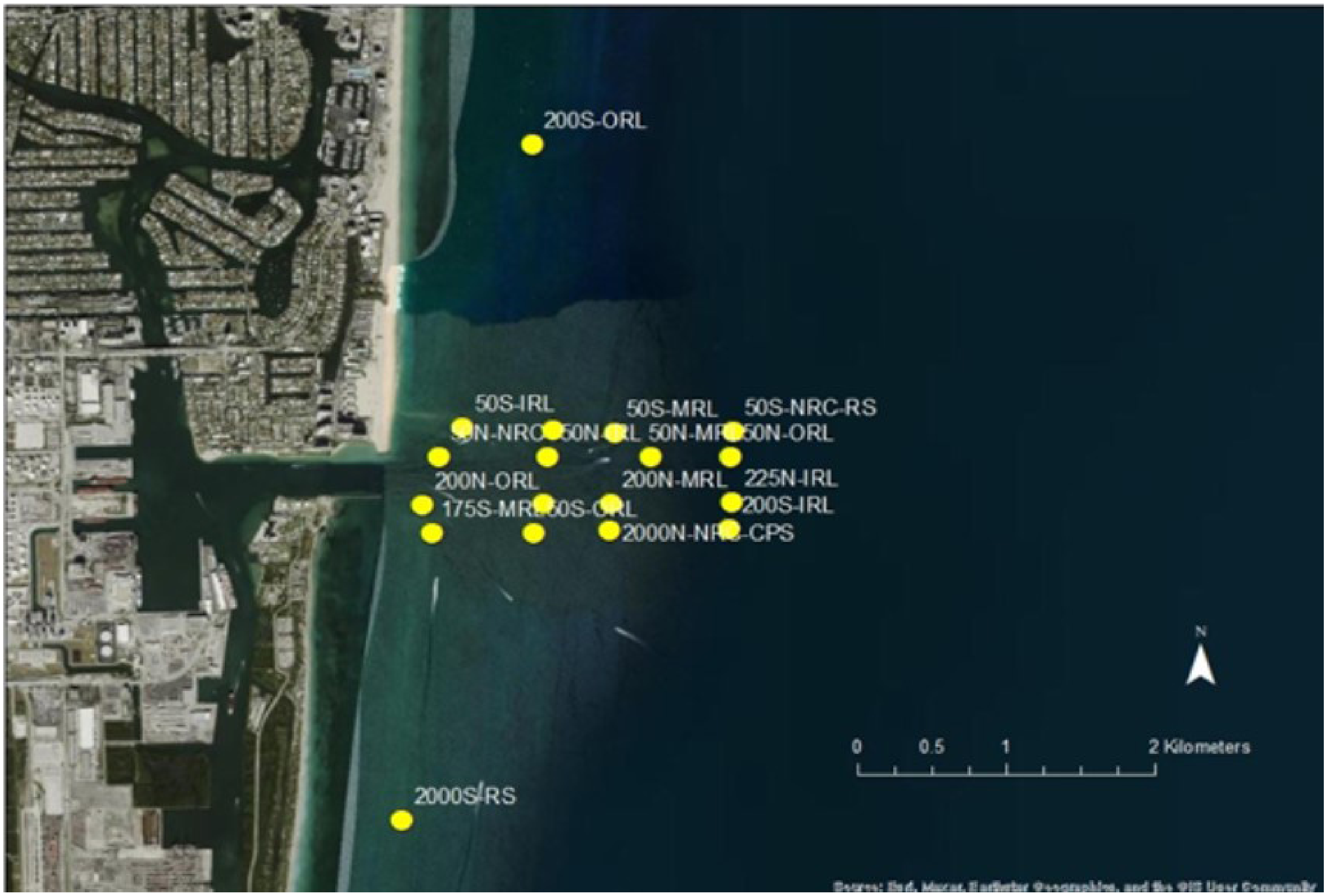

Figure 1: Sediment sampling sites.

distance from the port, then the coral reef feature followed by the habitat type (for example, Nearshore Ridge Complex Colonized Pavement Shallow or NRC-CPS). Divers collected samples directly into pre-cleaned i-Chem certified glass jars. Nitrile gloves were worn to minimize the potential for cross-contamination between sites. All samples were stored cold in the dark until returning to the lab, where they were frozen for shipment to the analytical laboratory. Samples for grain size analysis were stored refrigerated so as not to alter grain size through freezing and thawing. All sediment samples for grain size and TOC were dried at 80° C for 24 hours to ensure complete water loss and sub-samples were taken for subsequent percent total organic carbon (TOC) and grain size. Laboratory analyses were conducted following the protocols of the National Status and Trends Program (Kimbrough et al. 2006, Kimbrough and Lauenstein et al. 2006, McDonald et al. 2006) using a NOAA contract lab (TDI Brooks International). Briefly, PAHs were analyzed in the laboratory using gas chromatography/mass spectrometry in the selected ion monitoring (SIM) mode. Selected chlorinated organics (PCBs and pesticides) were analyzed using gas chromatography/electron capture detection. Method detection limits (MDL) for organic compounds are shown in Appendix Table A1.

Silver, cadmium, copper, lead, antimony, and tin were analyzed using inductively coupled plasma- mass spectrometry. Aluminum, arsenic, chromium, iron, manganese, nickel, silicon and zinc were analyzed using inductively coupled plasma- optical emission spectrometry. Mercury was analyzed using cold vapor- atomic absorption spectrometry. Selenium was analyzed using atomic fluorescence spectrometry. For each element, total elemental concentration (i.e., sum of all oxidation states) was measured and reported. It should be noted that there were minor deviations from acceptable QA standards (Kimbrough and Lauenstein, 2006) specifically differences between duplicates for Si, Mn, Fe, and in the blanks for silica; these were attributed to high levels of calcium carbonate (likely coral or shell derived) in the samples that can confound analyses. These deviations do not invalidate these data, but less certainty exists about the absolute values for those analytes. Method detection limits for trace and major elements are shown in Appendix Table A2. For graphical presentation purposes, values below the MDL are plotted as "zero" but it should be noted that the true value is between zero and the MDL.

Table 1: List of sampling sites with latitude and longitude. Naming convention for each reef feature and habitat type is denoted as NRC-CPS = Nearshore Ridge Complex Colonized Pavement Shallow, NRC-RS = Nearshore Ridge Complex Ridge Shallow, IR = Inner Reef, MR = Middle Reef, OR = Outer Reef, ABW = Artificial Breakwater).

Site ID	Latitude	Longitude
2000N-NRC-CPS	26.11233	-80.096
200N-ABW	26.09645	-80.1002
225N-IRL	26.09633	-80.0947
200N-ORL	26.09622	-80.0838
200N-MRL	26.09617	-80.091
50N-IRL	26.09483	-80.095
50N-MRL	26.09483	-80.0888
50N-NRC	26.09483	-80.1016
50N-ORL	26.09483	−80.08400
50S-ORL	26.09225	-80.0839
50S-MRL	26.09223	-80.0912
50S-IRL	26.0922	-80.0953
50S-NRC-RS	26.09212	-80.1026
200S-ORL	26.09077	-80.084
175S-MRL	26.09073	-80.0913
200S-IRL	26.09057	-80.0959
200S-NRC-RS	26.09057	-80.102
2000S-RS	26.07447	-80.1038

Total organic carbon (TOC) was quantified via high temperature combustion and subsequent quantification of the CO_2 produced (Hedges and Stern 1984). Grain size analysis was carried out using a series of sieving and settling techniques (Plumb 1981). Grain size classes reported are clay (< 4 mm), silt (4 mm to 62.5 mm), sand (62.5 mm to 2 mm) and gravel (> 2 mm).

Statistical Analysis

Because these data were not normally distributed (Shapiro-Wilk test), non-parametric statistics were applied to the dataset. The lack of replication at a given site prevented comparison of pre- and post-dredge concentrations at individual sites. However, the differences between pre- and post-dredging were examined globally (i.e., across all sites) using a Wilcoxon test (α=0.05).

Results and Discussion

All chemistry data and metadata are available for public download via NOAA's National Centers for Environmental Information. (https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0282807).

Sediment Organics

Unexpectedly, other than PAHs, all organic contaminants were at concentrations below levels of detection. This is surprising because of the level of urbanization surrounding the port and the extent to which organic contaminants have been detected in other similar tropical and sub-tropical systems (Pait et al. 2010, Apeti et al. 2012, Whitall

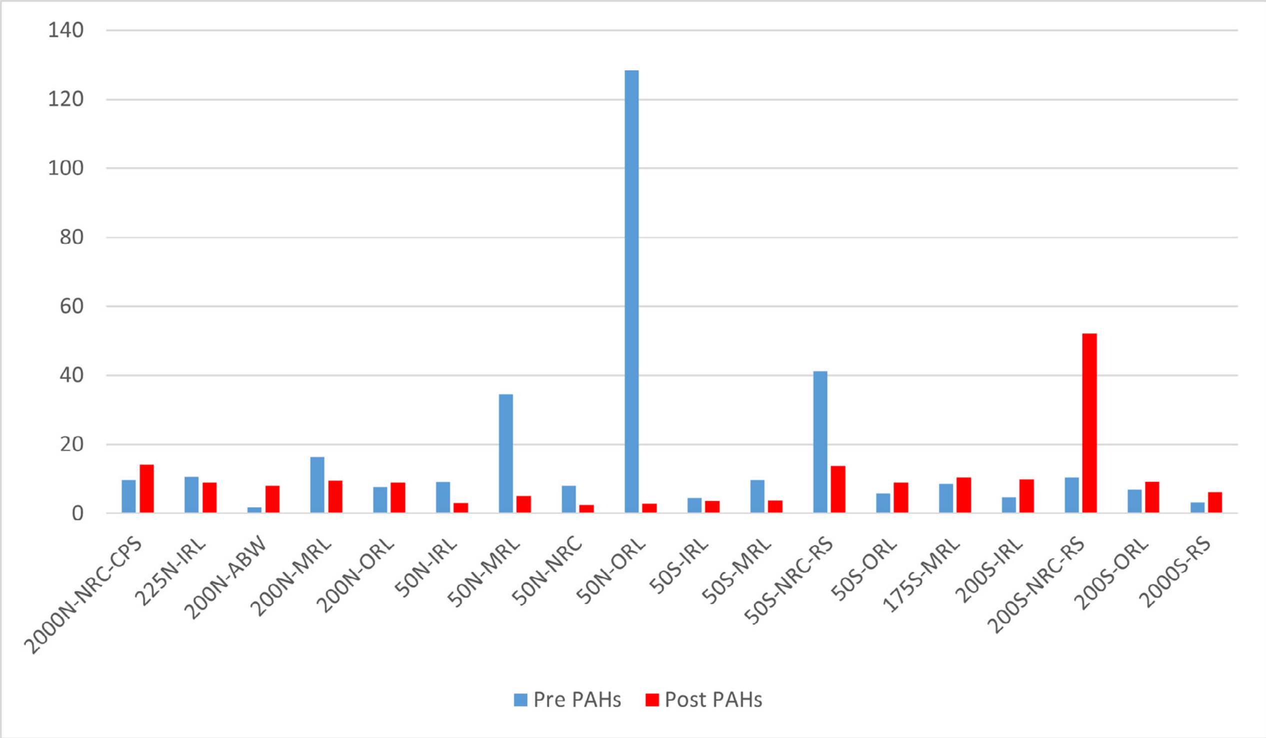

Figure 2: Sediment concentrations of total PAHs, pre- and post dredging.

et al 2014, Mason and Whitall 2019, Whitall et al 2022). One possible explanation for this is the relatively coarse nature (sand and gravel) of these sediments. These low organic matter sediments also have lower surface area for sorption (i.e., compared to a silt or a clay sediment) and tend to not sequester organic contaminants as well as other finer sediment types (Horowitz 1991). Total PAH concentrations ranged from 1.86 ng/g to 129 ng/g before dredging and 2.52 ng/g to 52.5 ng/g after dredging (Figure 2; Appendix Table A3). While there was no global difference (i.e., across all sites), between pre- and post-dredging total PAH concentrations (Wilcoxon test, $\alpha=0.05$, $p=0.51$), sites nearest to the port seem to be qualitatively lower after dredging. If only these nearest sites (sites less than or equal to 175 meters from the port) are considered for statistical comparison, there is a significant difference ($p=0.038$) with the pre-dredge samples having higher concentrations than the post-dredge samples. This is perhaps somewhat counterintuitive as it might be expected that dredging resuspends relatively polluted sediments, which would raise the ambient sediment concentrations. One potential hypothesis that could explain this would be lower concentrations at depth, either due to possible lower historical pollution rates or degradation of older PAHs at depth, (i.e., biodegradation over time in the deeper sediments). Exposing/re-suspending these deeper/cleaner sediments could have the overall effect of diluting the overall sediment concentration. It should be noted that some previous studies have reported down core decreases (e.g., Wu et al. 2022), but others have reported relatively steady concentrations with depth (e.g., Yan et al. 2009). Additional research, including sediment coring in the study area, would be required to further explore this hypothesis. It should be noted that these concentrations are relatively low; for context, the Effect Range Low (ERL) sediment quality guideline for total PAHs is 4,022 ng/g (Long et al. 1995;), meaning that these observed concentrations are unlikely to result in toxicity to benthic infauna. It should be noted, however, that relatively lower water column concentrations of PAHs have been shown to have adverse effects on corals (May et al. 2020) and that coral tissues have been shown to accumulate PAHs at higher rates than sediments (Menezes et al. 2023). PAH pollution in this system and its effects on corals in this system may warrant further study.

Spatially, there are no clear patterns in total PAH concentrations (Figure 3). Two reference sites from within the port area itself had relatively higher concentrations: 139 and 935 ng/g, which is not surprising based on the ship traffic through the port. This also suggests limited transport of PAHs from the port area to the reefs themselves.

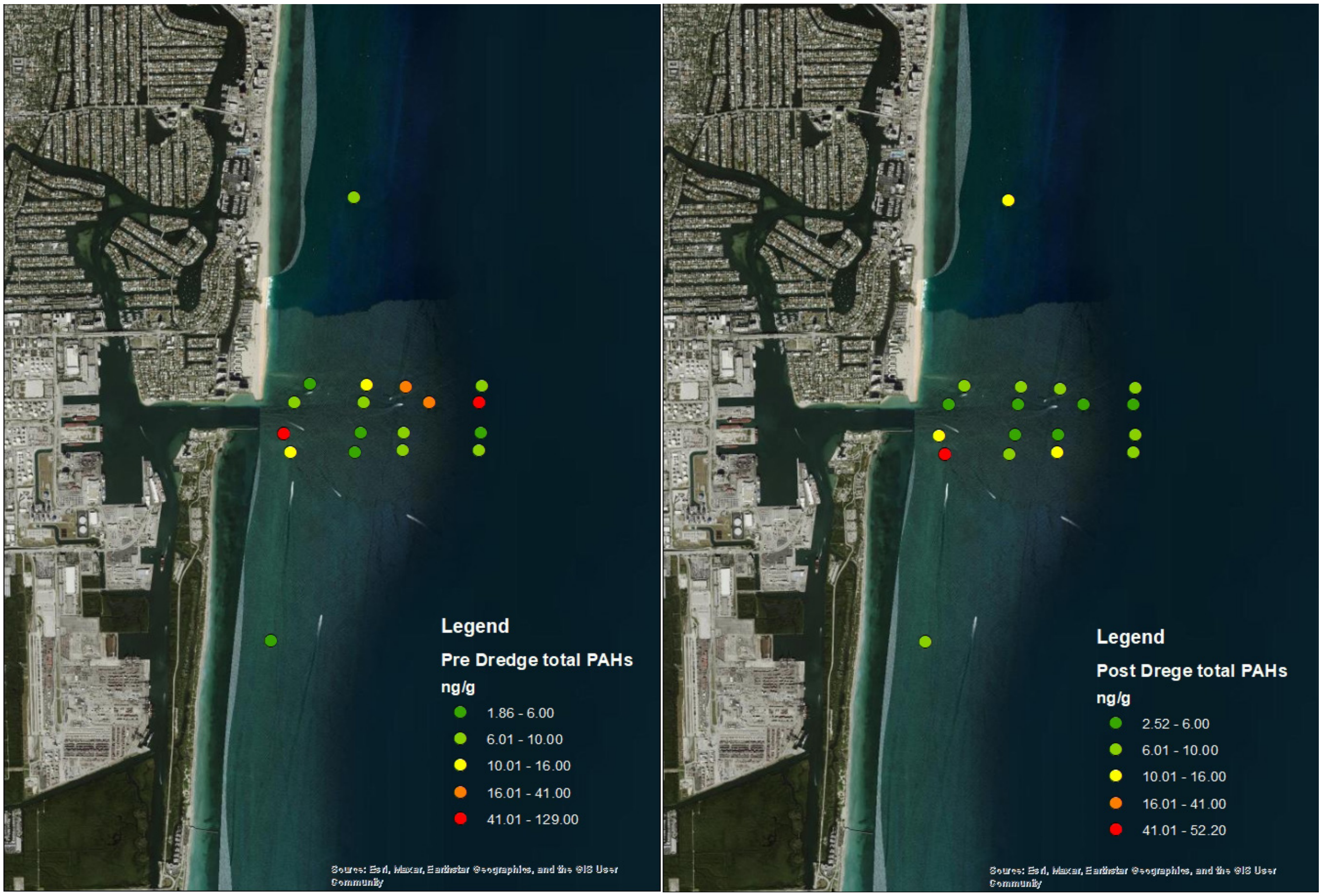

Figure 3: Map of sediment concentrations of total PAHs, pre- and post dredging.

Sediment Metals

There were statistically significant differences (Wilcoxon test, α=0.05) in concentrations for the following metals: iron, nickel and zinc (Figures 4-6; Figure A1 and A2). However, there were not obvious spatial patterns in the distribution of these three metals (Figures 8-10). For each of these three metals, the mean post-dredge concentrations were higher than the pre-dredge concentrations. Reference sites from inside the port area were generally similar to the concentrations observed near the reef sites. While these data cannot definitively link these patterns to the dredging activity, the pattern and timing is consistent with a disturbance like dredging. Furthermore, unlike PAHs, which degrade over time, metals are stable in the environment. Therefore any "historical" (i.e., previously deposited) metals pollution at depth has the opportunity to be re-introduced to the system during dredging.

In general, concentrations of sediment metals (Figures 4-6, Appendix Figures A1-A9 and Table A4) did not exceed previously published Sediment Quality Guidelines (SQG; Long et al. 1995; Table 2) above which toxicity to benthic organisms might be expected. The exception to this was arsenic, which exceeded the Effect Range Low (ERL, indicating possible sediment toxicity) at one site pre-dredge and three sites post-dredge. Metals in these samples, including arsenic, likely represent a combination of natural (crustal erosion) and anthropogenic sources (Perumal et al. 2021). Anthropogenic sources of arsenic include treated wood products (e.g., lumber for construction) and agricultural chemicals (WHO 2022). While neither of these are specifically associated with the port, there is significant urbanization and some agriculture in this watershed (Pickering and Baker, 2015, Whitall et al. 2019). Arsenic is known to be a mutagen, carcinogen, and teratogen. Effects of arsenic have been studied in fish and mammals (including humans) as well as in invertebrates and plants (Eisler 1988, Novellini et al. 2003, McCloskey 2009). Arsenic toxicity to corals is less well studied, but previous research has documented that arsenic does accumulate in coral tissues (Whitall et al. 2014).

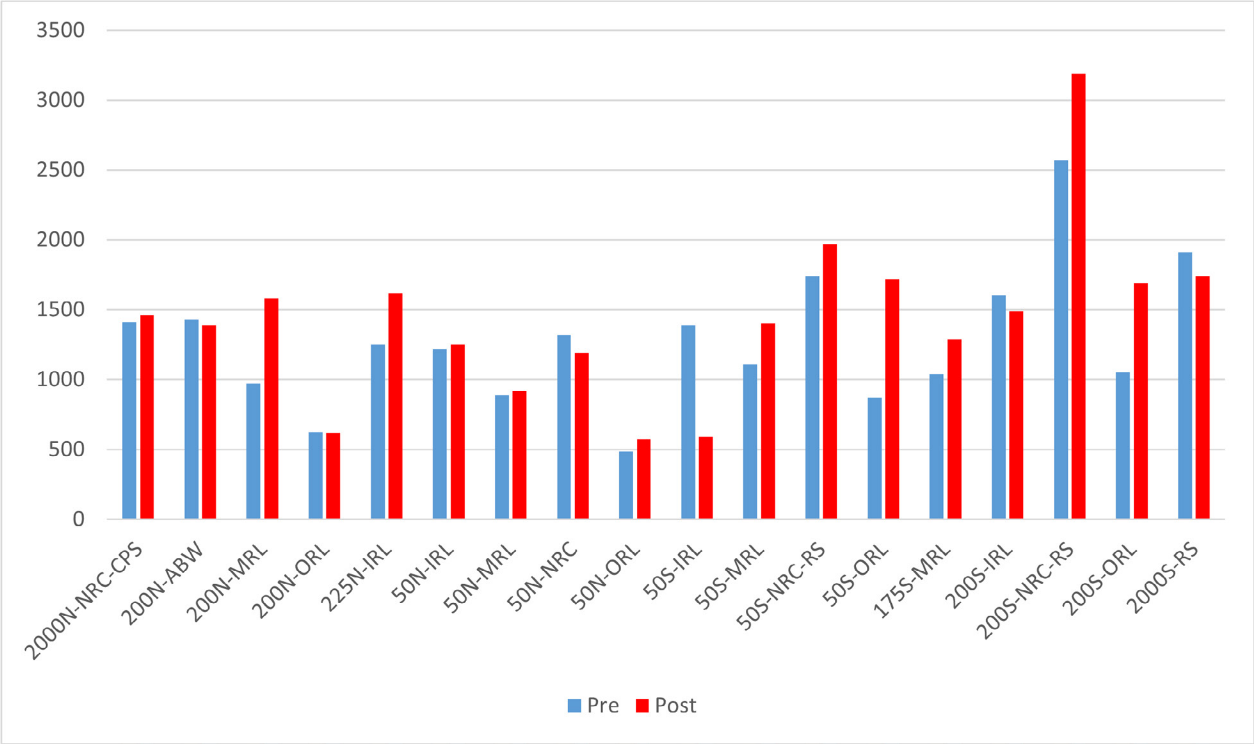

Figure 4: Total sediment iron concentrations in surface sediments pre- and post-dredging.

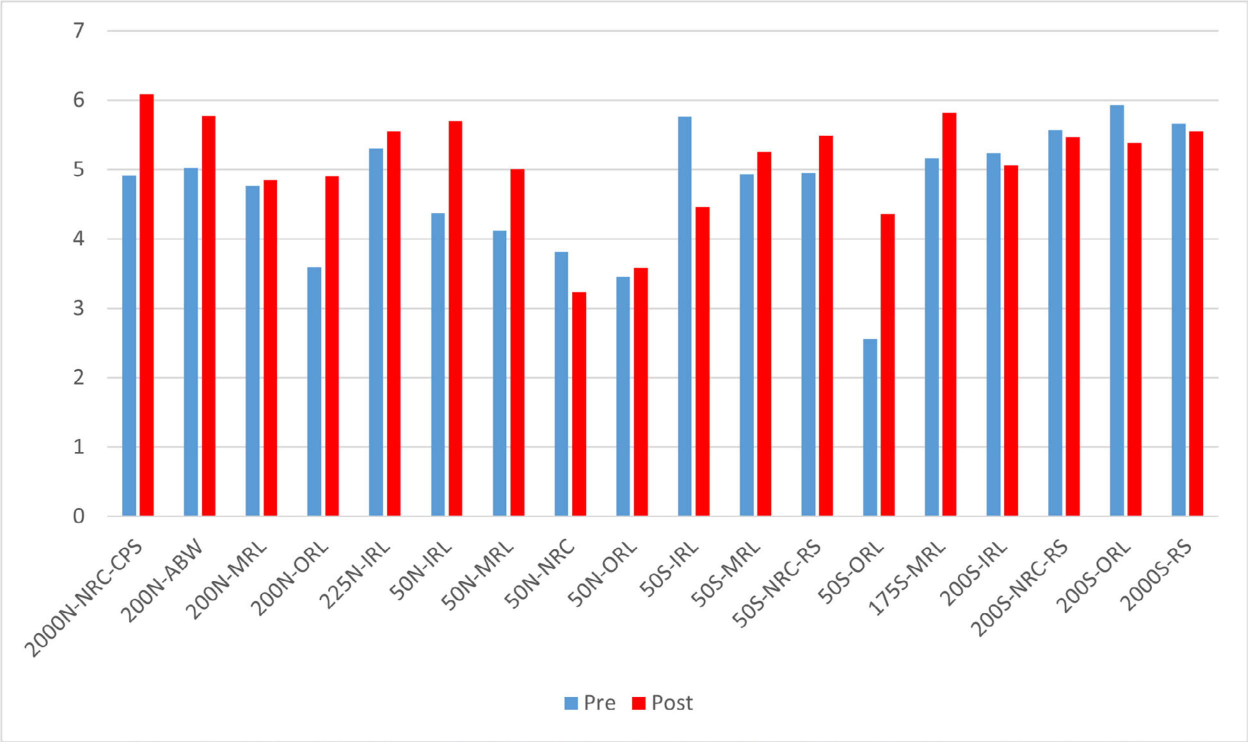

Figure 5: Total sediment nickel concentrations in surface sediments pre- and post-dredging.

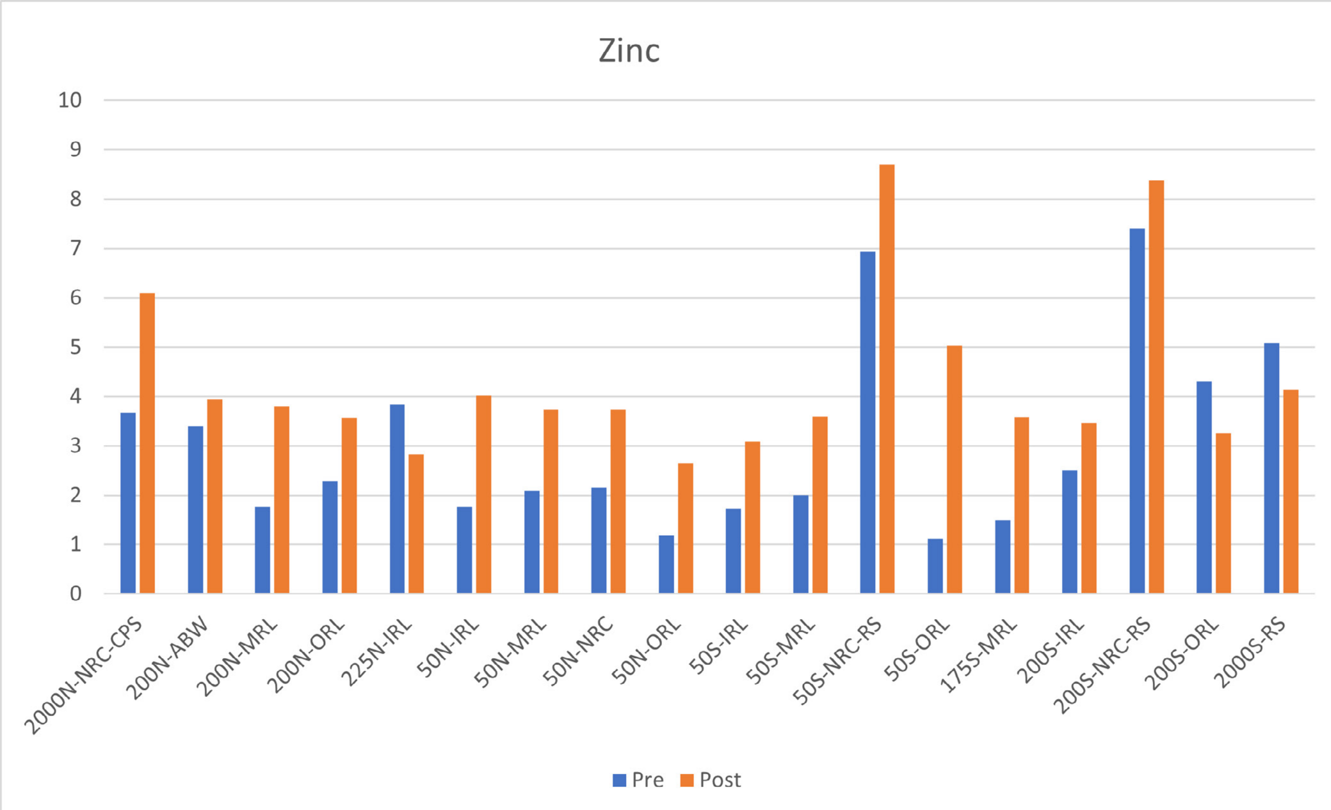

Figure 6: Total sediment zinc concentrations in surface sediments pre- and post-dredging.

Iron is generally not considered to be a pollutant as it is relatively non-toxic. However, it is a micronutrient and can have limiting effects on phytoplankton and bacterial populations. Perturbations in iron concentrations could disrupt biogeochemical cycling in the system. Iron concentrations can be driven by crustal erosion or human uses of iron and steel in construction, cars or boats. In addition to crustal erosion, human sources of nickel include: metal plating, coins, batteries, and alloys such as stainless steel. The adverse effects of nickel have been demonstrated in crustaceans, fish (Hunt 2002) and sea urchins (Novellini et al. 2003). The acute toxicity of nickel for 23 marine species in 20 genera (USEPA 1986) ranged from 152 µg/L for Heteromysis formosa (juveniles) to 1100 mg/L for clams. Previous studies that water column concentrations of 9 mg/L cause mortality in Pocillopora damicornis larvae (Goh 1991) and that nickel accumulates in coral tissues (Whitall et al. 2014).

Table 2. Sediment quality guidelines. Units are µg/g, except for total PAHs which are ng/g.

Analyte	ERL	ERM
Total PAHs	4022	44792
Arsenic	8.2	70
Cadmium	1.2	9.6
Chromium	81	370
Copper	34	270
Lead	46.7	218
Mercury	0.15	0.71
Nickel	20.9	51.6
Silver	1	3.7
Zn	150	410

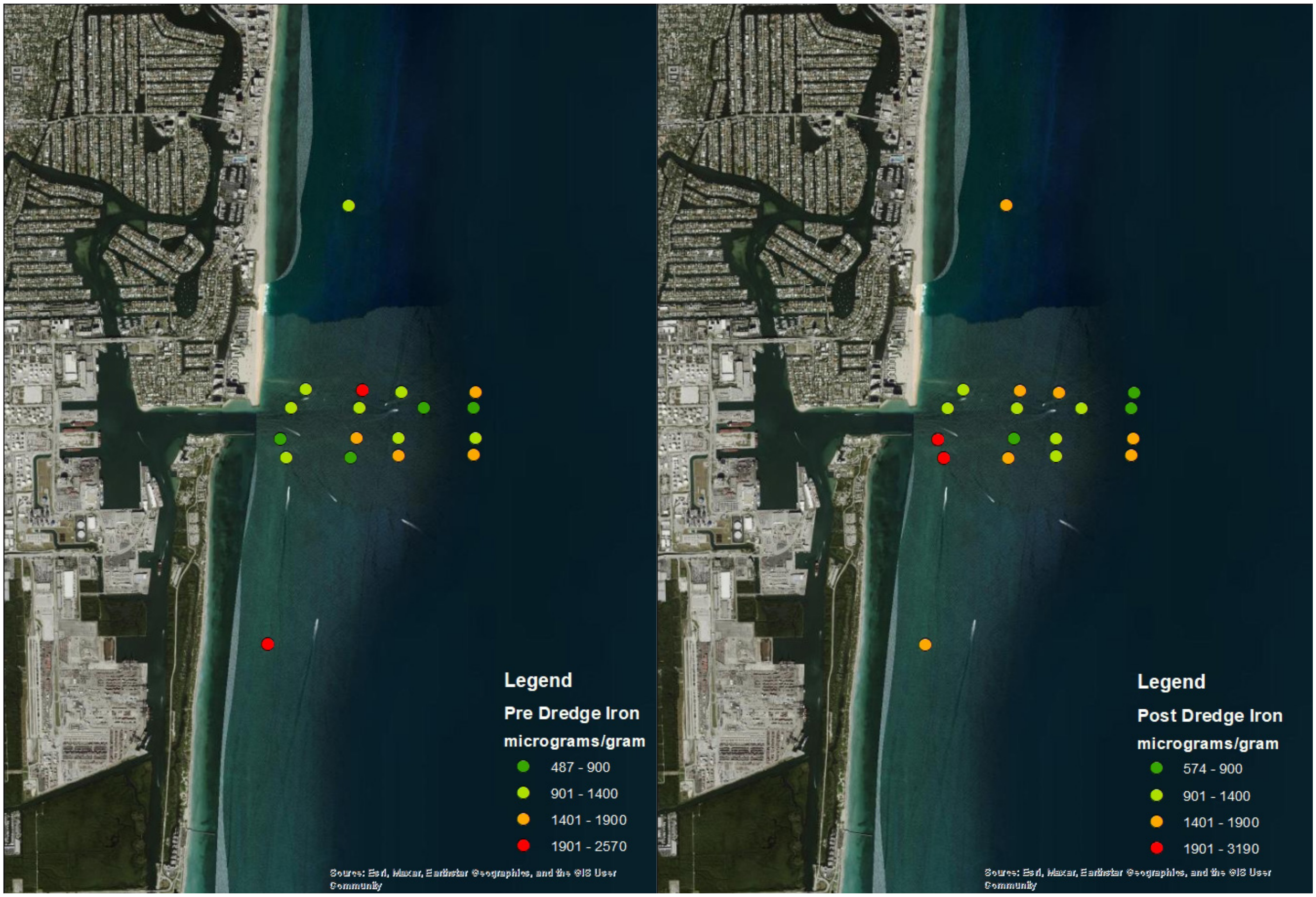

Figure 7: Map of sediment concentrations of total iron, pre- and post dredging.

Zinc has a variety of sources (ceramics, textiles, automobile tires, pigments, batteries, alloys and pharmaceuticals) but is also found in anti-fouling paints (Miller et al. 2020)) which is particularly relevant to the port. Although zinc is a micronutrient for both animals and plants, it can be toxic in high concentrations. Zinc has been shown to be toxic to aquatic organisms, including fish and sea urchins (Novellini et al. 2003; Besser and Lieb, 2007; Dermeche et al. 2012; Edullantes and Galapate, 2014). In corals, zinc accumulates primarily in the tissues rather than the skeletons (Metian et al. 2014) and has been shown to lead to a reduction in fertilization success (Reichelt-Brushett and Harrison, 2005).

For the other metals that did not have statistically significant pre- and post-dredge patterns (Ag, As, Al, Cd, Cr, Cu, Mn, Pb, Sb, Se, Si, Sn), graphs and maps can be found in the Appendix. One metal that perhaps deserves more discussion is tin; organotins (e.g., tributyltin) have historically been used in anti-fouling paints on boats. Although these were banned in the US for most applications in the 1980s and for all applications in 2008, they are still found in the environment especially in areas of international traffic, owing to uneven enforcement in some countries. In this study, total tin values were low, with all but two values below the limit of detection (Figure A9). Because this is total tin, this captures the organic component (i.e., organotins would be included) and elemental tin would be the ultimate breakdown product of those organics. So, despite heavy boat traffic for decades, tin concentrations, including organotins, in and around Port Everglades are not likely to be of ecological concern. Another recent study (Giarikos et al. 2023) found similar results related to heavy metals, specifically levels of metals in near reef sediments were below levels associated with toxicity, although they did measure high (possible toxic) levels of arsenic at one sediment control site.

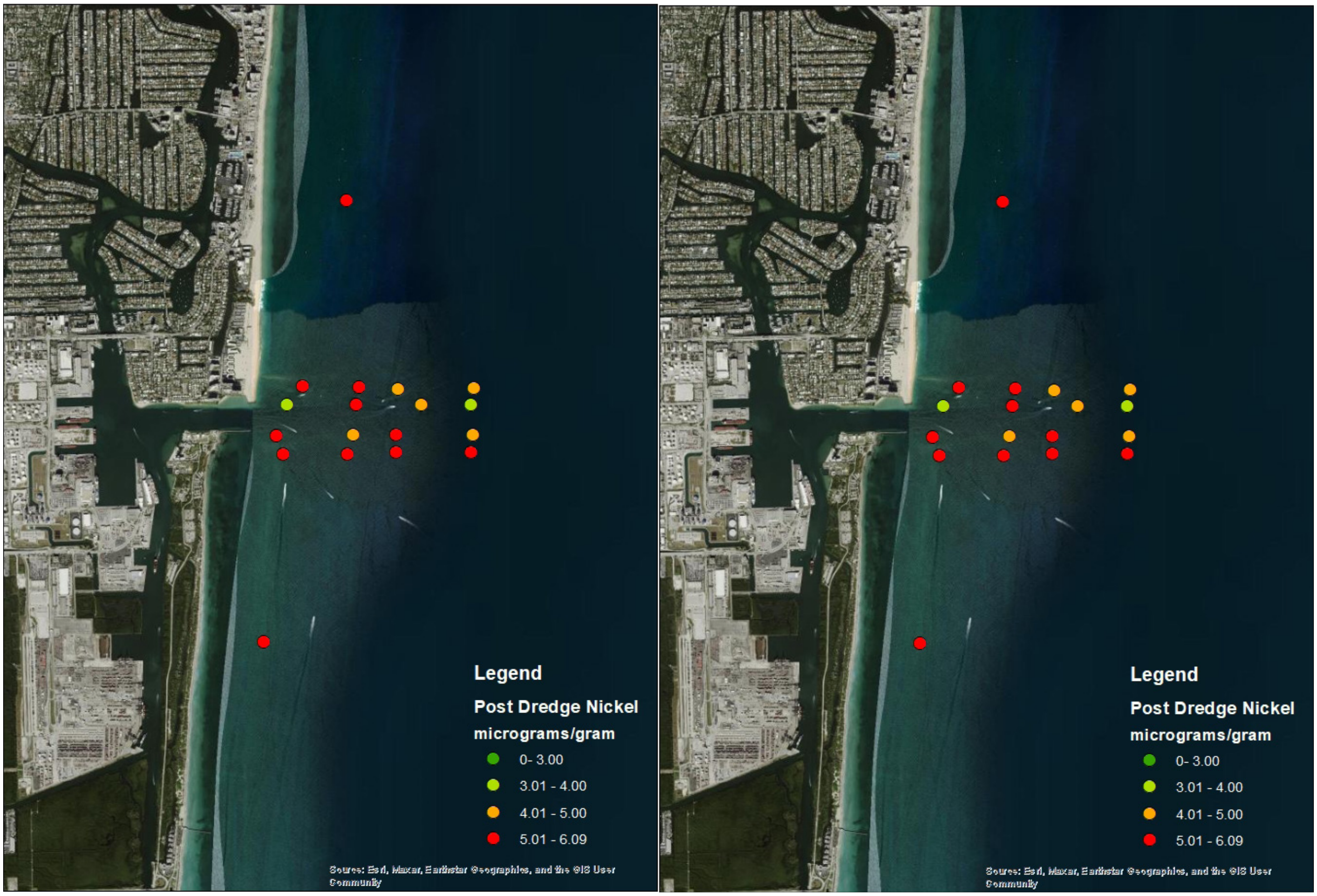

Figure 8: Map of sediment concentrations of total nickel, pre- and post dredging. Note: “0” indicates below method detection limit.

Sediment Grain Size and Total Organic Carbon

Sediment grain size was dominated by coarse size fractions (sand and gravel, Figures 10-13; Appendix Table A5) with the finer fractions (silt and clay; Figures A12-A13) making up <3% of the total sediment by weight. This pattern is not uncommon for coral reef ecosystems as the sediment is often primarily biogenic (i.e., calcium carbonate from coral skeletons) which breaks down into relatively coarse sized particles. There was a noticeable and statistically significant shift towards even coarser sediment (i.e., shift from sand to gravel) post dredging (Figures 12 and 13). This shift could have adverse effects both on corals themselves as well as on other reef organisms, especially those that live in or feed on the sediment, as sediment size is often a primary driver of infaunal biota (McArthur et al. 2010).

Total organic carbon (TOC) and total inorganic carbon (TIC) were also relatively low in terms of percent dry weight (Figures A13-A14). There were no statistically significant differences between pre-dredge and post-dredge TOC or TIC content. The combination of low TOC and coarse grain size may help explain the surprising lack of most organic contaminants (see discussion above). Previous work has also identified shifts in the benthic microbial community of sediments following this same maintenance dredging in Port Everglades (Krausfeldt et al 2023).

Conclusions

This study demonstrated significant differences in both physical (grain size) and chemical (PAHs and metals) characteristics between the pre- and post-dredging samples around Port Everglades. While it cannot be definitely stated that the dredging was the cause of these changes, the timing of the dredging related to these data makes that a reasonable hypothesis. While natural sediment transport (i.e., winds, tides, currents) could theoretically result in both chemical and grain size changes, there were no major storms during this time period and some of the patterns (i.e., decreasing PAH concentrations) would be difficult to explain via natural processes alone.

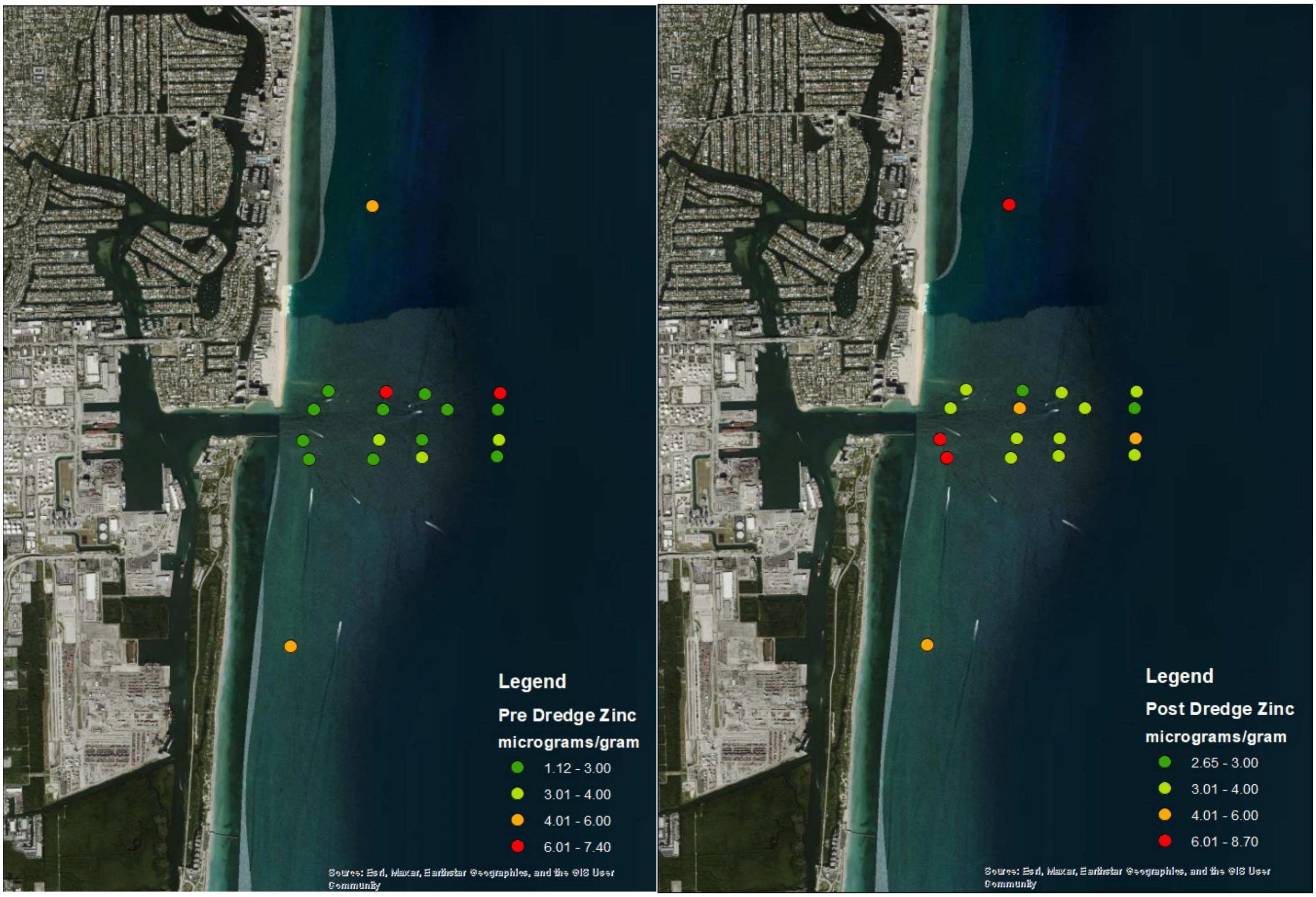

Figure 9: Map of sediment concentrations of total zinc, pre- and post dredging.

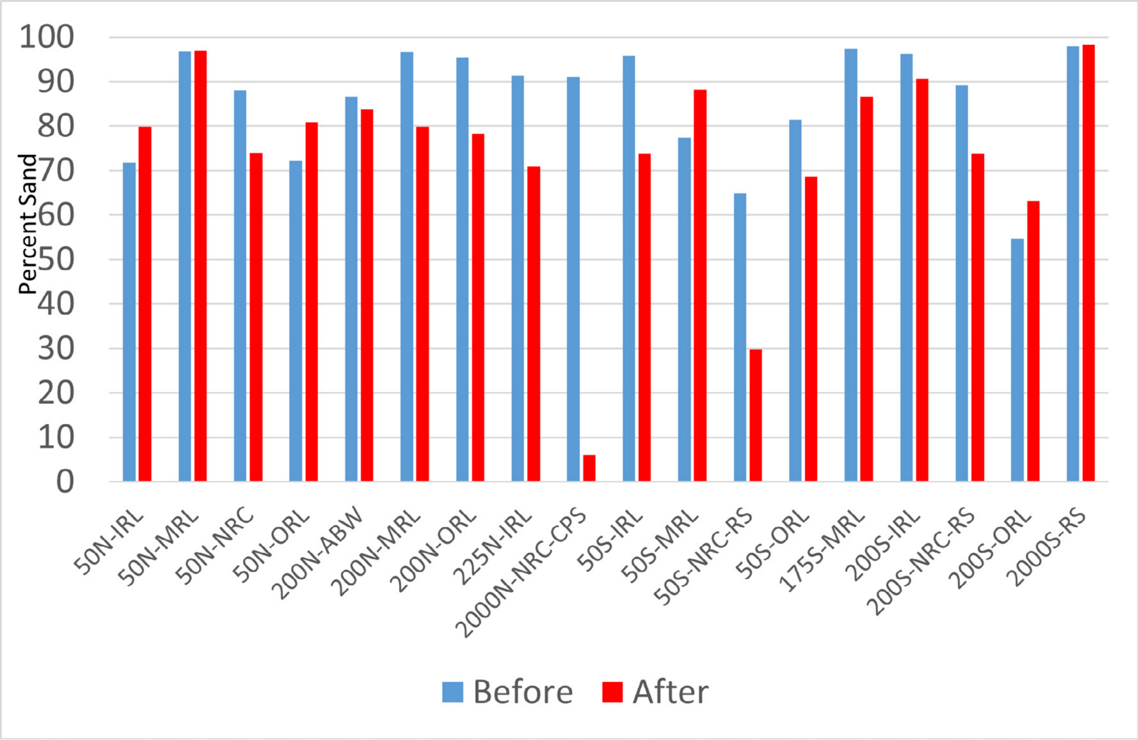

Figure 10: Sediment grain size as percent sand, pre- and post-dredging.

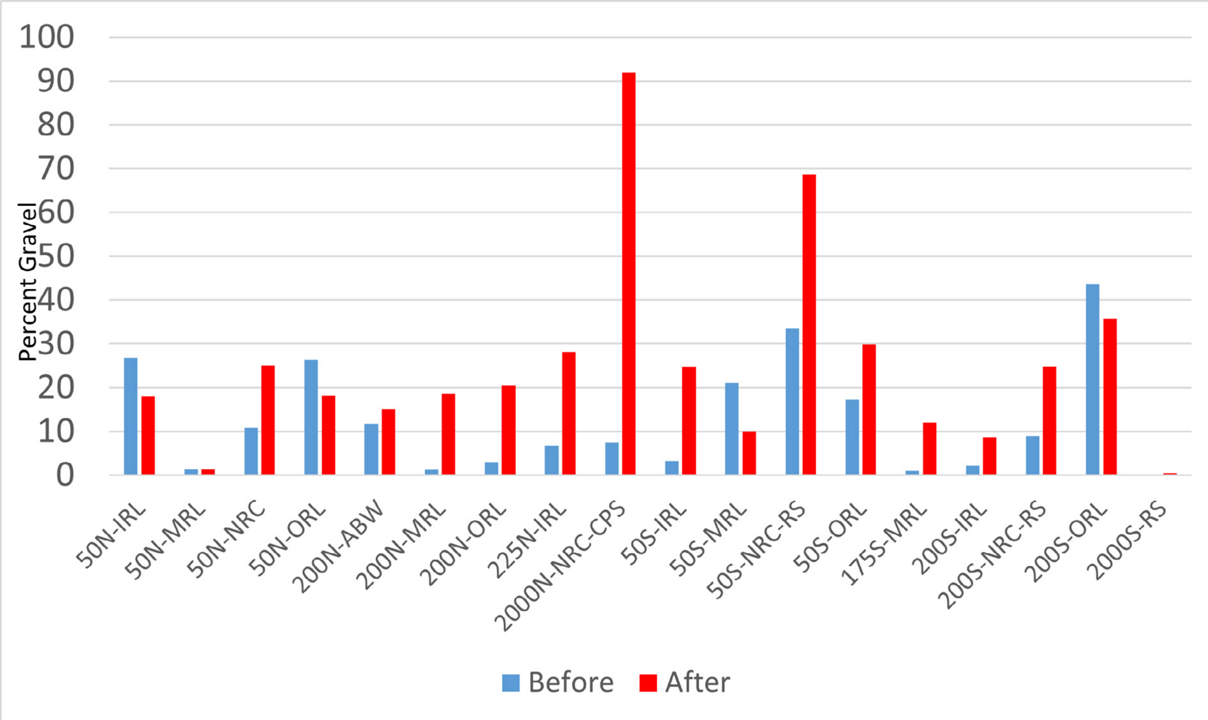

Figure 11: Sediment grain size as percent gravel, pre- and post-dredging.

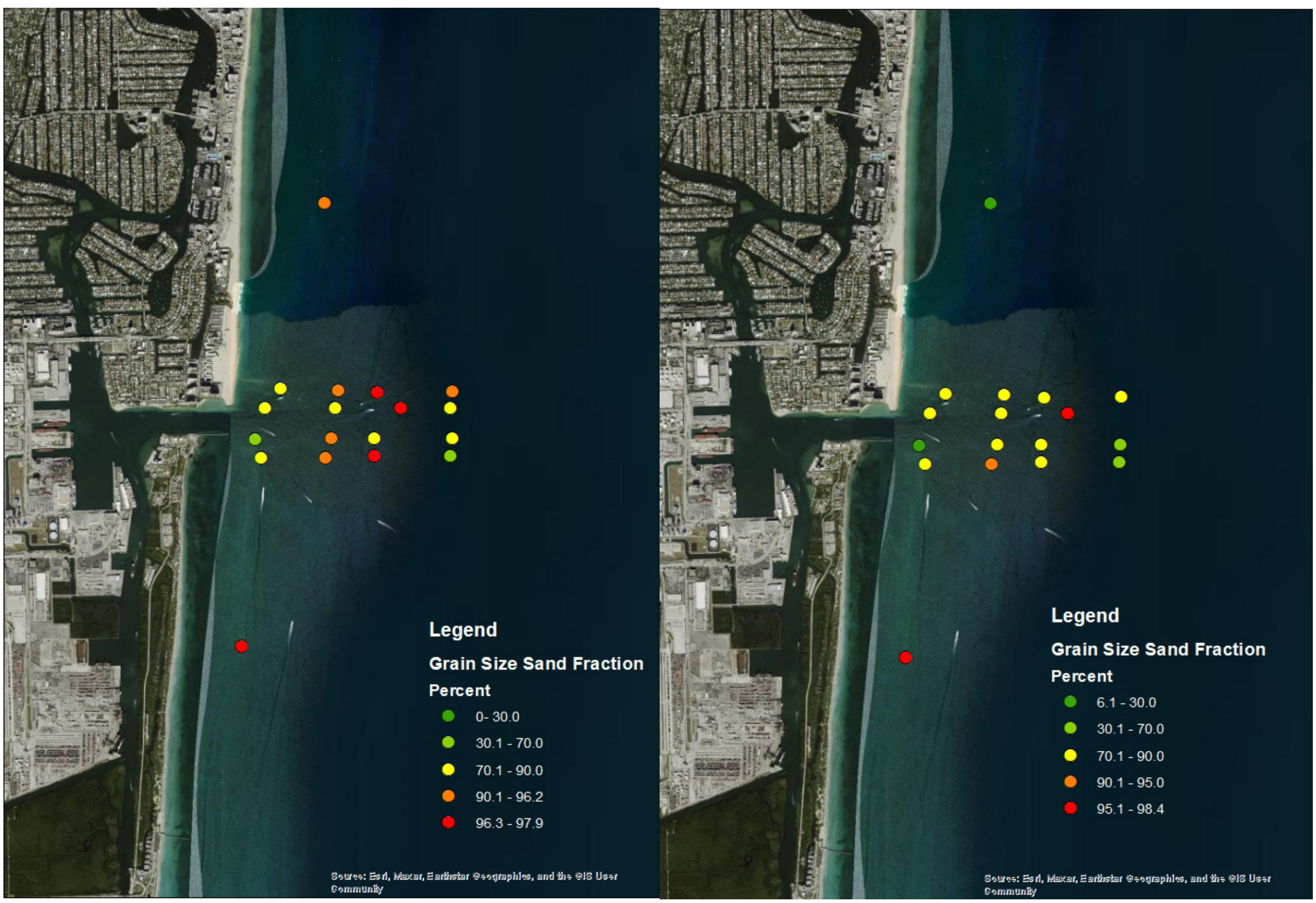

Figure 12: Map of sediment grain size as percent sand, pre- and post-dredging. Note: “0” indicates below method detection limits.

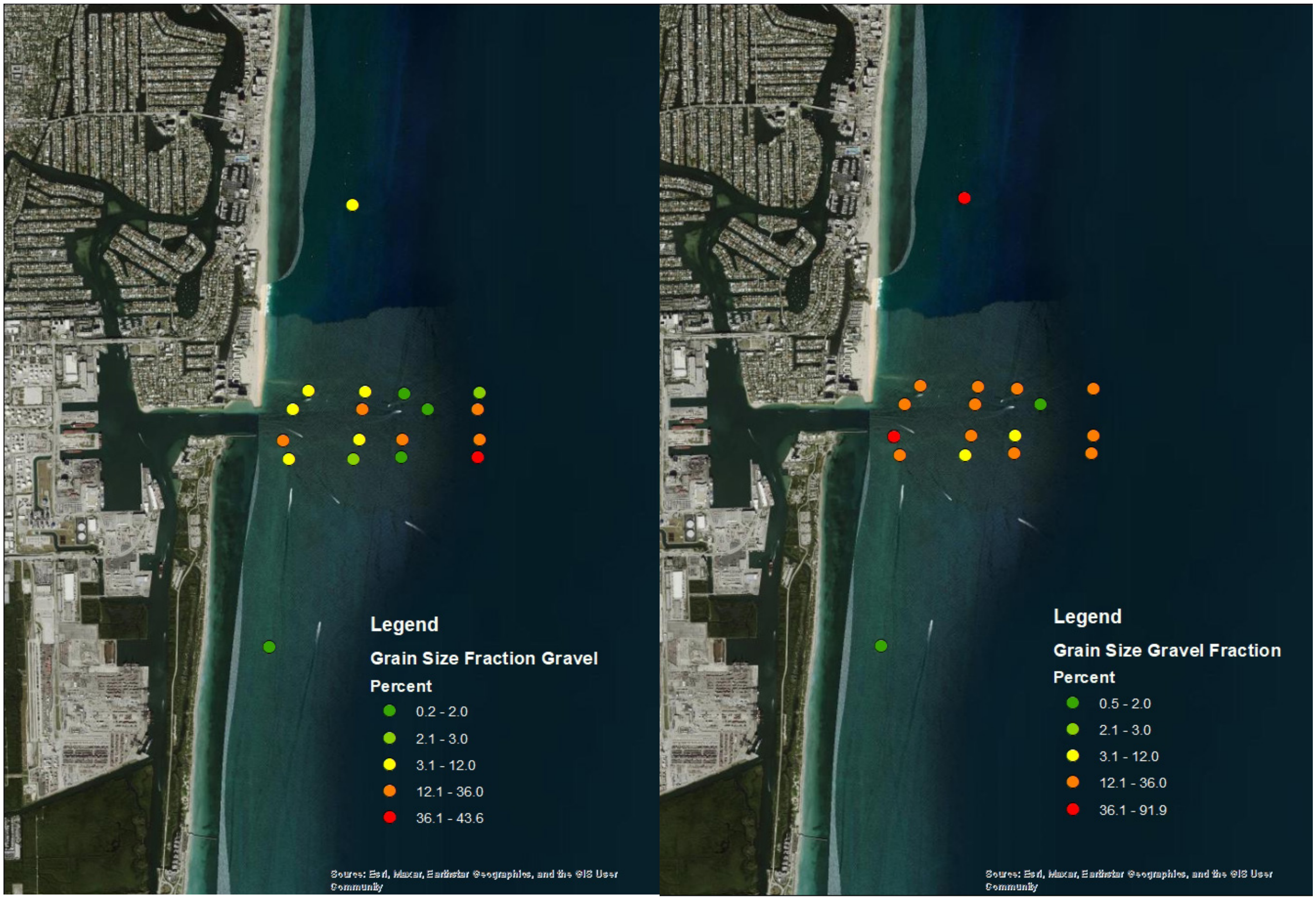

Figure 13: Map of sediment grain size as percent gravel, pre- and post-dredging.

Appendix

Table A1: Organic compounds method detection limits. Units are ng/g.

Target Compounds	MDL
Aldrin	0.044
Dieldrin	0.321
Endrin	0.264
Endrin Aldehyde	0.264
Endrin Ketone	0.264
Heptachlor	0.027
Heptachlor-Epoxide	0.039
Oxychlordane	0.063
Alpha-Chlordane	0.050
Gamma-Chlordane	0.048
Trans-Nonachlor	0.023
Cis-Nonachlor	0.022
1,2,3,4-Tetrachlorobenzene	0.013
1,2,4,5-Tetrachlorobenzene	0.019
Hexachlorobenzene	0.018
Pentachloroanisole	0.017
Pentachlorobenzene	0.016
Endosulfan II	0.193
Endosulfan I	0.193
Endosulfan Sulfate	0.076
Mirex	0.023
Chlorpyrifos	0.286
Total PCBs	0.010
Total DDTs	0.022
Total HCH	0.045
Total PAHs	0.041

Table A2: Trace and major elements method detection limits.

Element	MDL
Ag	0.00985
As	0.0739
Cd	0.00985
Ni	0.197
Pb	0.0493
Sb	0.00985
Se	0.0493
Sn	0.0197
Al	2.55
Cr	0.0256
Cu	0.0354
Fe	0.162
Mn	0.0187
Si	19.4
Zn	0.062

Table A3: Total PAH concentrations in surface sediments. Units are ng/g.

Sample ID	Pre PAHs	Post PAHs
2000N-NRC-CPS	9.82	14.2
225N-IRL	10.5	8.87
200N-ABW	1.86	8.11
200N-MRL	16.3	9.50
200N-ORL	7.66	8.83
50N-IRL	9.02	2.98
50N-MRL	34.5	4.96
50N-NRC	8.08	2.52
50N-ORL	129	2.83
50S-IRL	4.56	3.76
50S-MRL	9.8	3.83
50S-NRC-RS	41.2	13.7
50S-ORL	5.82	8.93
175S-MRL	8.63	10.5
200S-IRL	4.75	9.91
200S-NRC-RS	10.5	52.2
200S-ORL	6.81	9.23
2000S-RS	3.14	6.12

Table A4: Total metals concentrations in surface sediments.

Site	Ag	Ag	Al	Al	As	As	Cd
	Before	After	Before	After	Before	After	Before
	<MDL	<MDL	332	354	5.59	6.5	<MDL
200N-ABW	<MDL	<MDL	663	575	2.74	2.2	<MDL
200N-MRL	<MDL	0.349	885	234	4.66	4.45	<MDL
200N-ORL	<MDL	0.142	239	185	1.88	2.38	<MDL
225N-IRL	<MDL	<MDL	364	546	5.74	3.66	<MDL
50N-IRL	0.134	<MDL	316	357	5.56	8.04	<MDL
50N-MRL	<MDL	0.213	613	353	3.07	3.83	<MDL
50N-NRC	<MDL	<MDL	336	521	5.36	2.89	<MDL
50N-ORL	<MDL	<MDL	675	340	1.75	2.63	<MDL
50S-IRL	0.828	<MDL	239	475	6.65	3.25	<MDL
50S-MRL	<MDL	<MDL	359	259	3.01	6.79	<MDL
50S-NRC-RS	<MDL	<MDL	529	361	7.14	5.39	<MDL
50S-ORL	<MDL	<MDL	386	268	2.19	5.15	<MDL
175S-MRL	<MDL	<MDL	382	334	4.57	8.95	<MDL
200S-IRL	<MDL	<MDL	342	198	6.55	6.3	<MDL
200S-NRC-RS	<MDL	<MDL	264	418	7.23	9.81	<MDL
200S-ORL	<MDL	<MDL	660	633	4.26	4.91	<MDL
2000S-RS	0.108	<MDL	423	407	8.72	8.72	<MDL

	Cu	Cu	Fe	Fe	Hg	Hg	Mn
Site	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**
2000N-NRC-CPS	<MDL	<MDL	1410	1460	0.00261	0.00193	20.3
200N-ABW	<MDL	0.399	1430	1390	0.00151	0.00175	26.4
200N-MRL	<MDL	<MDL	971	1580	0.0044	0.00484	22.1
200N-ORL	<MDL	<MDL	624	618	0.0025	0.00321	11.7
225N-IRL	<MDL	<MDL	1250	1620	0.00309	0.00247	14.8
50N-IRL	<MDL	<MDL	1220	1250	0.00258	0.00263	13.8
50N-MRL	<MDL	<MDL	889	918	0.00611	0.00639	16.3
50N-NRC	<MDL	<MDL	1320	1190	0.00213	0.00194	25.1
50N-ORL	<MDL	0.452	487	574	0.0051	0.00243	12.6
50S-IRL	<MDL	0.769	1390	590	0.00312	0.00517	16.7
50S-MRL	<MDL	<MDL	1110	1400	0.00646	0.0043	13.9
50S-NRC-RS	1.26	0.616	1740	1970	0.00603	0.00678	21.4
50S-ORL	<MDL	<MDL	867	1720	0.00749	0.00305	9.65
175S-MRL	<MDL	<MDL	1040	1290	0.00478	0.00515	20
200S-IRL	<MDL	<MDL	1600	1490	0.00258	0.00335	15.9
200S-NRC-RS	<MDL	2.7	2570	3190	0.00683	0.00598	22.7
200S-ORL	<MDL	<MDL	1050	1690	0.00377	0.00347	13.3
2000S-RS	<MDL	<MDL	1910	1740	0.00227	0.00268	31.3
	Pb	**Pb**	**Sb**	**Sb**	**Se**	**Se**	**Si**
Site	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**
2000N-NRC-CPS	1.45	1.57	<MDL	<MDL	<MDL	<MDL	41200
200N-ABW	1.03	1.23	<MDL	<MDL	<MDL	<MDL	140000
200N-MRL	1.67	1.64	<MDL	<MDL	<MDL	<MDL	134000
200N-ORL	1.1	1.68	<MDL	<MDL	<MDL	<MDL	165000
225N-IRL	0.997	0.994	0.12	<MDL	<MDL	<MDL	95900
50N-IRL	1.35	2.53	0.101	0.129	<MDL	<MDL	77500
50N-MRL	1.68	1.67	<MDL	<MDL	<MDL	<MDL	141000
50N-NRC	1.19	1.13	<MDL	<MDL	<MDL	<MDL	193000
50N-ORL	1.31	1.99	<MDL	<MDL	<MDL	<MDL	256000
50S-IRL	1.47	1.74	0.153	<MDL	<MDL	<MDL	79200
50S-MRL	1.38	2.3	<MDL	0.127	<MDL	<MDL	57800
50S-NRC-RS	2.62	2.41	0.102	<MDL	<MDL	<MDL	146000
50S-ORL	1.08	1.23	0.354	<MDL	<MDL	<MDL	215000
175S-MRL	1.81	1.74	0.0973	0.231	<MDL	<MDL	84300
200S-IRL	1.18	1.15	0.141	0.154	<MDL	<MDL	36400
200S-NRC-RS	2.04	3.22	0.107	0.146	<MDL	<MDL	57400
200S-ORL	2.28	1.44	<MDL	<MDL	<MDL	<MDL	154000
2000S-RS	1.65	1.06	0.198	0.147	<MDL	<MDL	71400

Site	Cd After	Cr Before	Cr After	Mn After	Ni Before	Ni After	Si After	Sn Before	Sn After	Zn Before	Zn After
2000N-NRC-CPS	<MDL	8.08	7.87	21.8	4.91	6.09	101000	<MDL	<MDL	3.67	6.09
200N-ABW	<MDL	6.35	7.81	23.6	5.03	5.78	156000	<MDL	<MDL	3.39	3.95
200N-MRL	<MDL	7.31	5.54	18.8	4.77	4.85	9080	<MDL	<MDL	1.77	3.79
200N-ORL	<MDL	4.23	5.29	11.7	3.59	4.9	117000	<MDL	<MDL	2.29	3.57
225N-IRL	<MDL	7.84	9.05	21.9	5.31	5.55	119000	<MDL	<MDL	3.84	2.83
50N-IRL	<MDL	6.76	7.07	18.8	4.37	5.7	28100	<MDL	<MDL	1.77	4.02
50N-MRL	<MDL	6.79	5.89	13.2	4.12	5	87100	<MDL	<MDL	2.09	3.73
50N-NRC	<MDL	5.99	6.06	17.3	3.82	3.23	181000	<MDL	<MDL	2.15	3.73
50N-ORL	<MDL	4.03	4.06	10.6	3.46	3.58	263000	<MDL	<MDL	1.19	2.65
50S-IRL	<MDL	7.86	4.96	10.7	5.76	4.46	276000	<MDL	<MDL	1.73	3.09
50S-MRL	<MDL	5.12	5.98	18.3	4.94	5.26	95700	<MDL	<MDL	2	3.59
50S-NRC-RS	<MDL	6.65	6.51	19.2	4.95	5.49	90100	0.567	<MDL	6.93	8.7
50S-ORL	<MDL	6.76	7.31	17.5	2.56	4.36	51500	<MDL	<MDL	1.12	5.03
175S-MRL	<MDL	6.66	6.08	15	5.16	5.82	65800	<MDL	<MDL	1.5	3.58
200S-IRL	<MDL	8.72	5.92	14.2	5.24	5.06	56600	<MDL	<MDL	2.51	3.46
200S-NRC-RS	<MDL	6.71	7.76	27.8	5.57	5.47	44400	0.204	<MDL	7.4	8.38
200S-ORL	<MDL	5.9	6.24	18.2	5.93	5.38	136000	<MDL	<MDL	4.3	3.25
2000S-RS	<MDL	8.31	8.99	17.8	5.66	5.55	143000	<MDL	<MDL	5.08	4.14

Table A5: Sediment grain size as percent size fractions.

	Gravel		Sand		Silt		Clay	
Site	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
2000N-NRC-CPS	7.54	91.88	90.92	6.12	0.00	0.20	1.54	1.80
200N-ABW	11.81	15.11	86.58	83.85	0.08	0.00	1.53	1.04
200N-MRL	1.20	18.57	96.64	79.92	0.64	0.00	1.52	1.51
200N-ORL	2.91	20.53	95.42	78.23	0.06	0.00	1.61	1.24
225N-IRL	6.73	28.08	91.42	70.99	0.28	0.00	1.57	0.93
50N-IRL	26.84	18.00	71.73	79.80	0.20	0.66	1.23	1.54
50N-MRL	1.31	1.37	96.80	97.05	0.09	0.00	1.80	1.58
50N-NRC	10.75	25.02	87.95	73.95	0.07	0.07	1.23	0.96
50N-ORL	26.42	18.17	72.17	80.72	0.07	0.22	1.34	0.89
50S-IRL	3.19	24.69	95.77	73.79	0.07	0.00	0.97	1.52
50S-MRL	21.10	9.93	77.34	88.18	0.17	0.28	1.39	1.61
50S-NRC-RS	33.46	68.58	64.78	29.79	0.28	0.12	1.48	1.51
50S-ORL	17.19	29.83	81.44	68.64	0.00	0.10	1.37	1.43
175S-MRL	0.95	12.07	97.38	86.57	0.07	0.29	1.60	1.07
200S-IRL	2.11	8.59	96.24	90.57	0.07	0.21	1.58	0.63
200S-NRC-RS	8.97	24.74	89.10	73.85	0.28	0.00	1.65	1.41
200S-ORL	43.57	35.73	54.58	63.07	0.08	0.17	1.77	1.03
2000S-RS	0.20	0.46	97.91	98.36	0.16	0.00	1.73	1.18

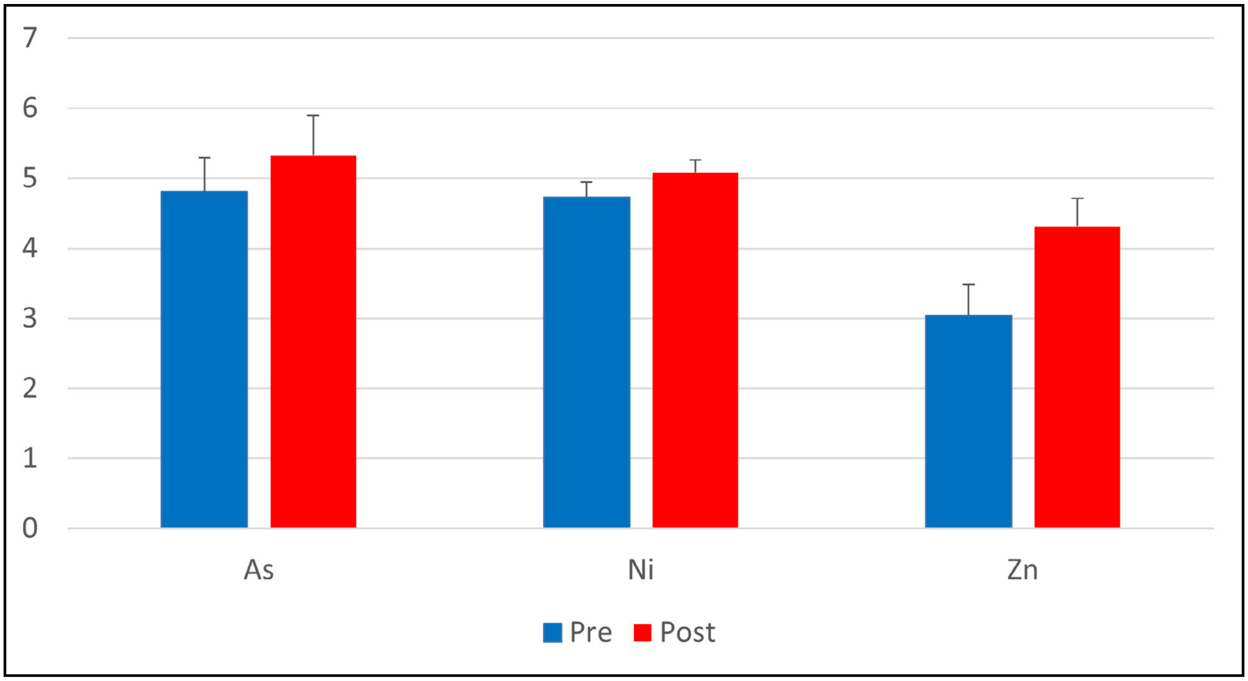

Figure A1: Mean concentrations of metals (As, Ni, Zn) in surface sediments, pre and post dredging.

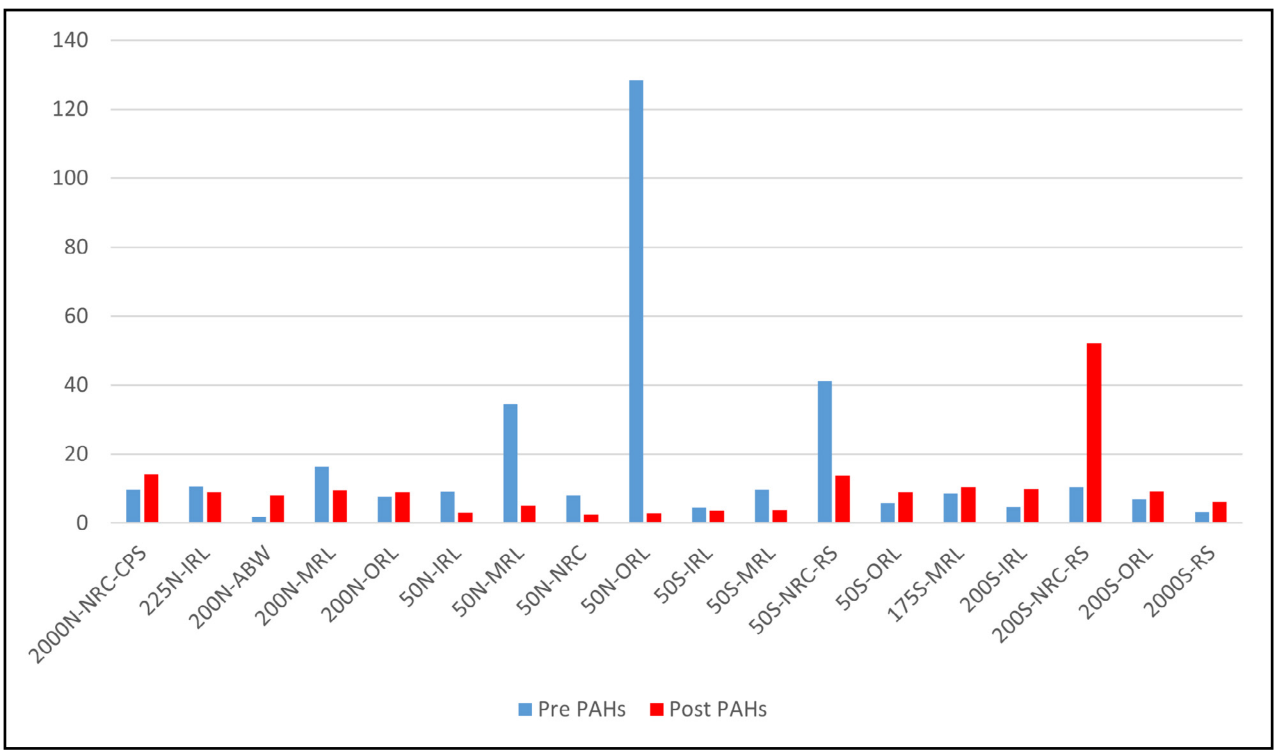

Figure A2: Mean concentrations of iron in surface sediments, pre and post dredging.

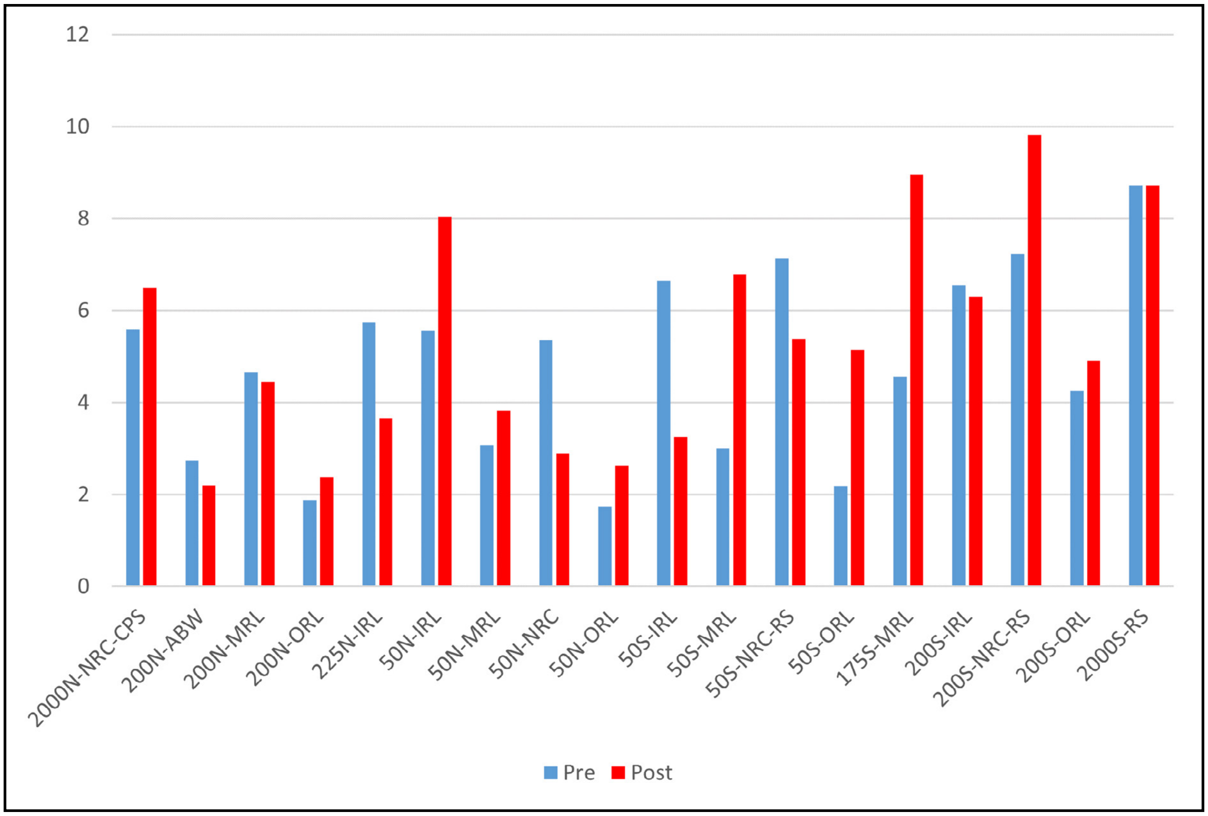

Figure A3: Arsenic concentrations in surface sediments pre- and post-dredging.

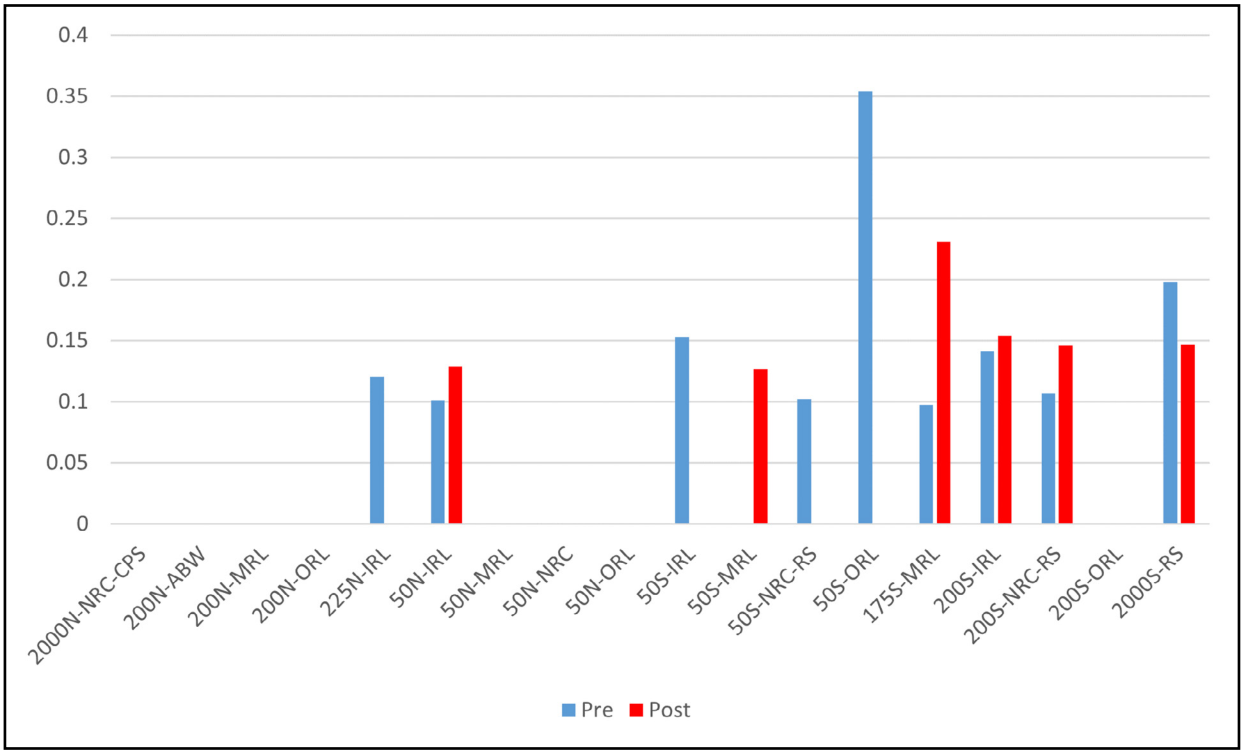

Figure A4: Aluminum concentrations in surface sediments pre- and post-dredging.

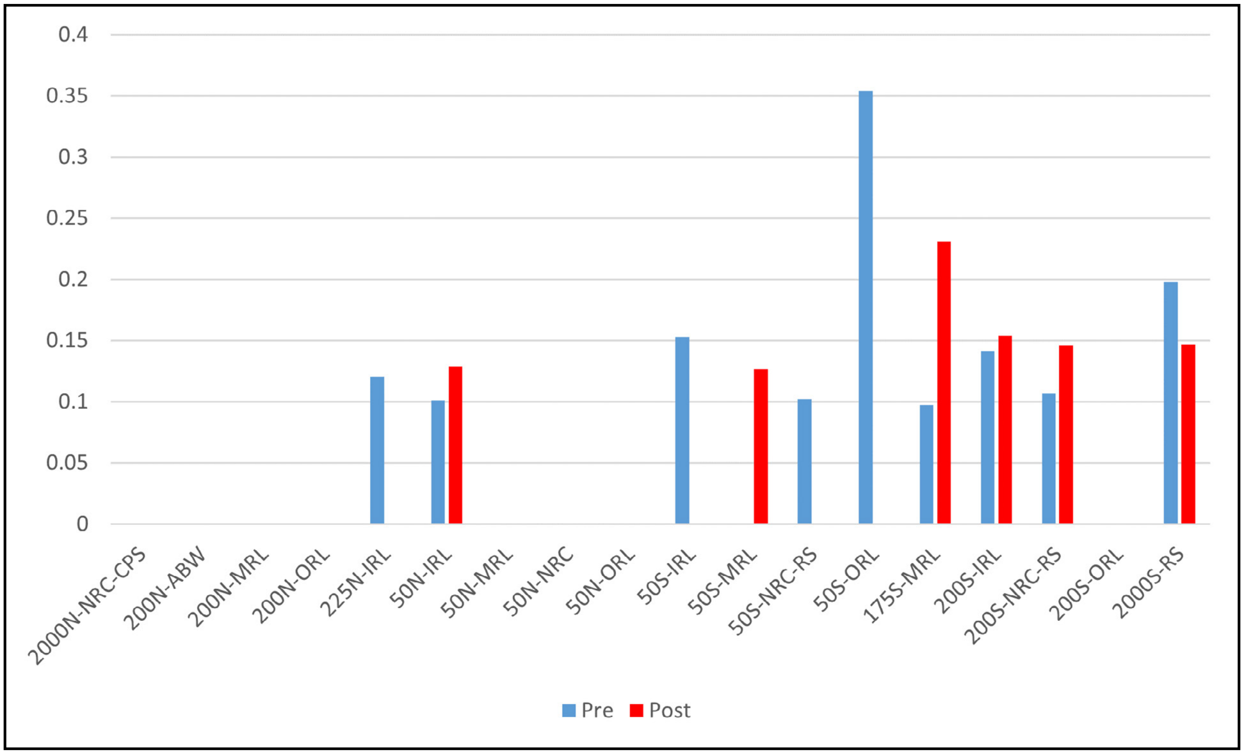

Figure A5: Antimony concentrations in surface sediments pre- and post-dredging.

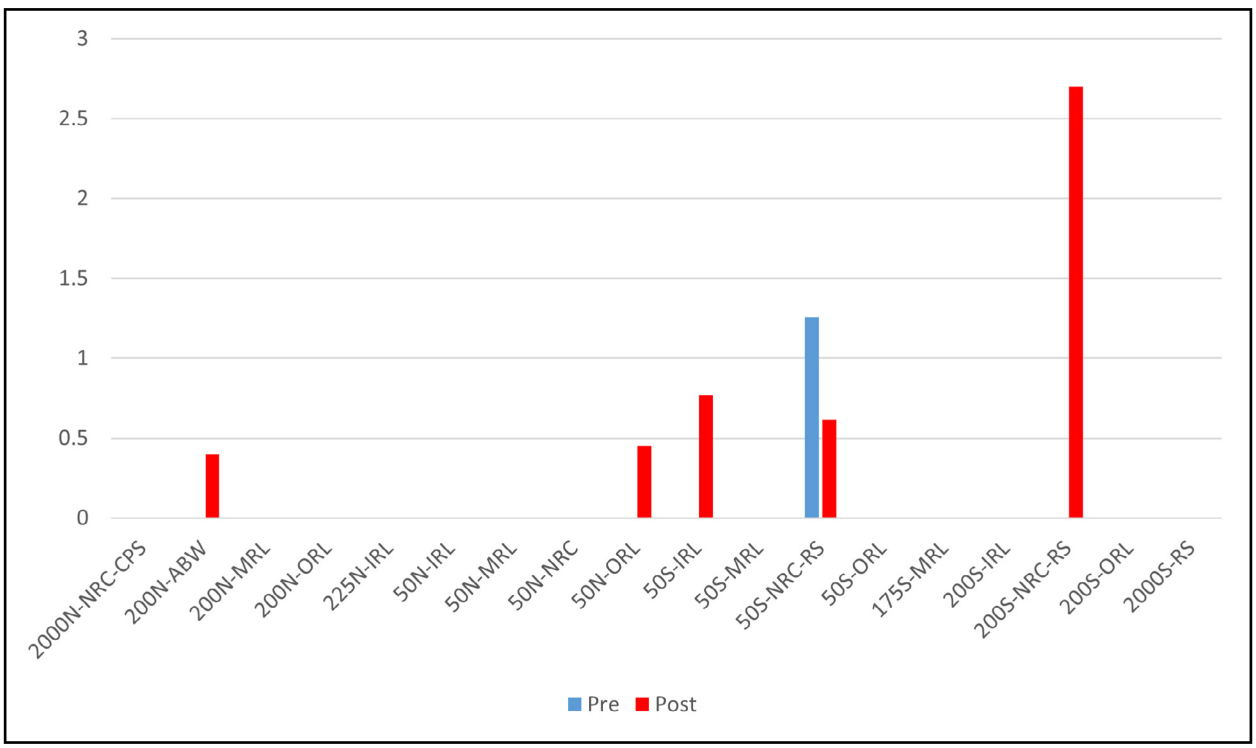

Figure A6: Chromium concentrations in surface sediments pre- and post-dredging.

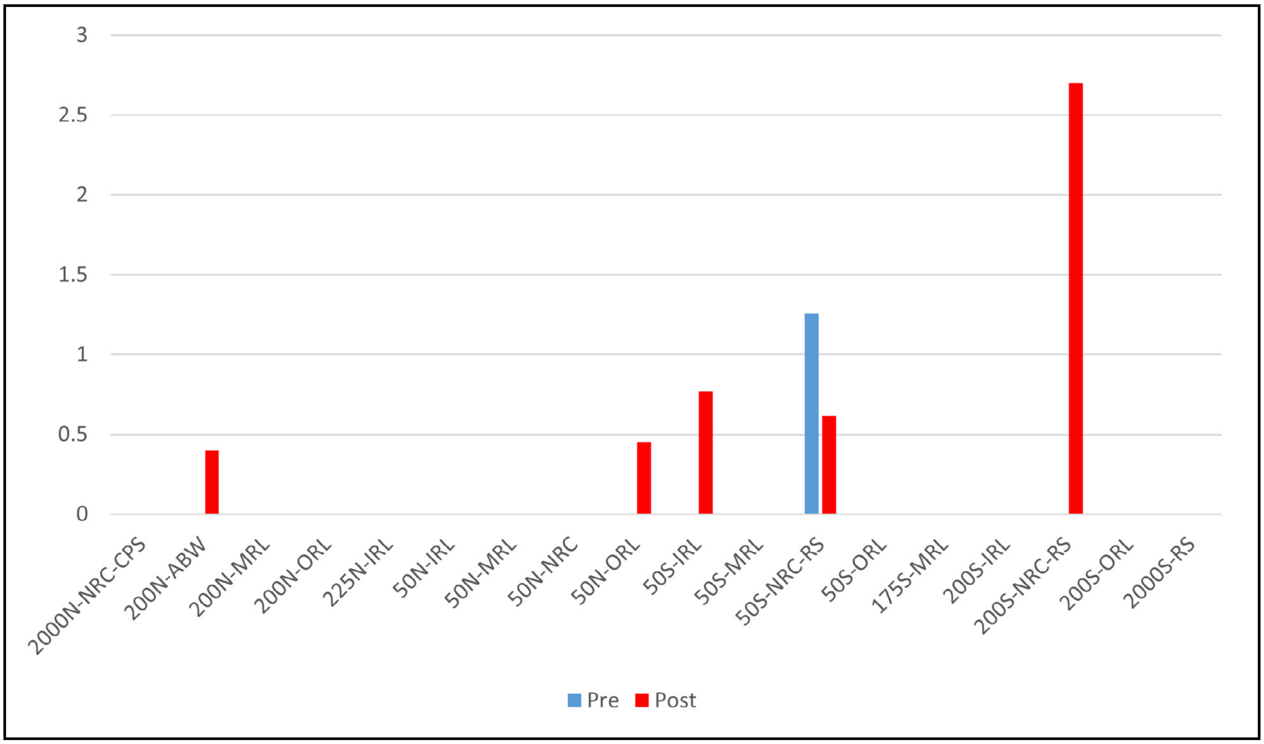

Figure A7: Copper concentrations in surface sediments pre- and post-dredging.

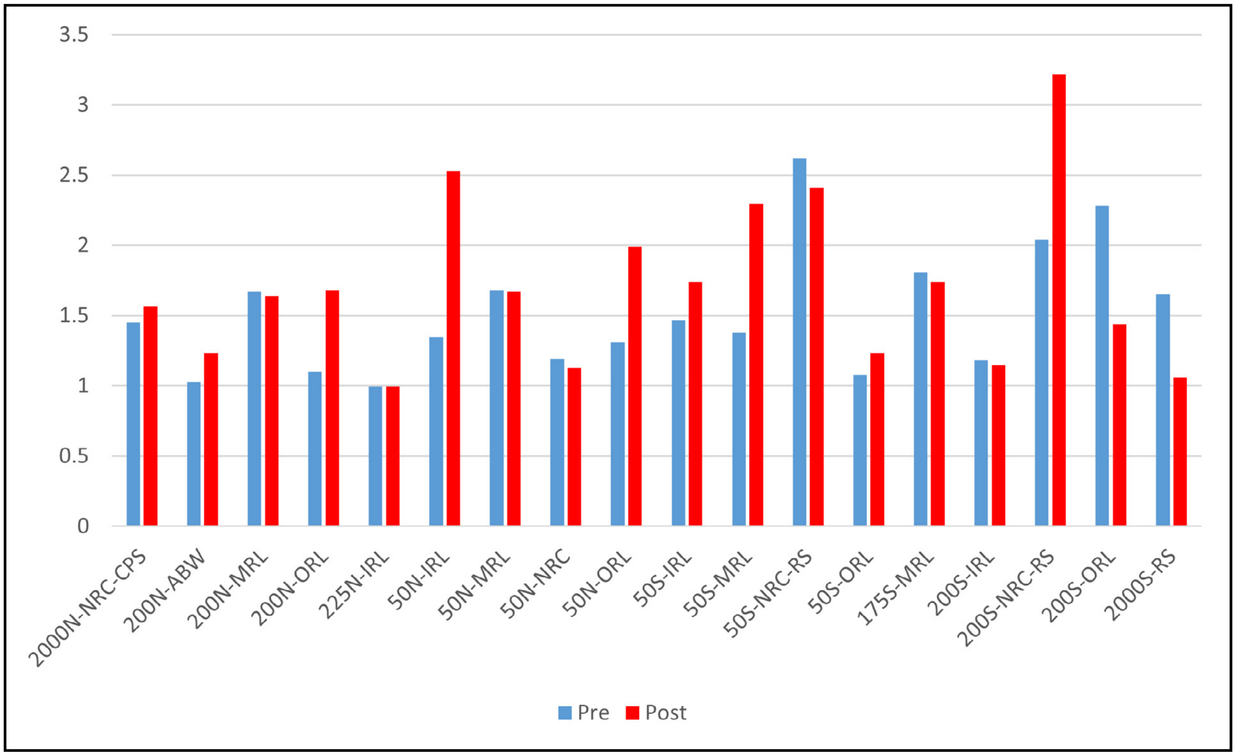

Figure A8: Lead concentrations in surface sediments pre- and post-dredging.

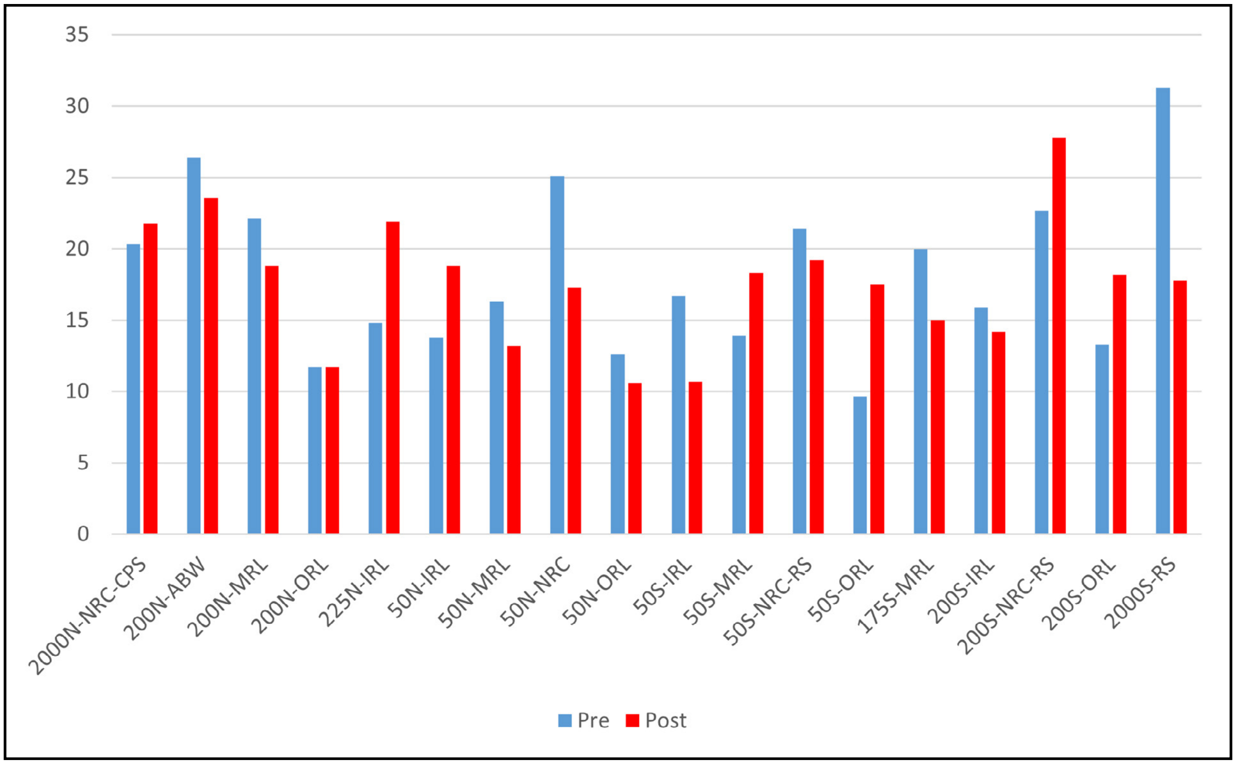

Figure A9: Manganese concentrations in surface sediments pre- and post-dredging.

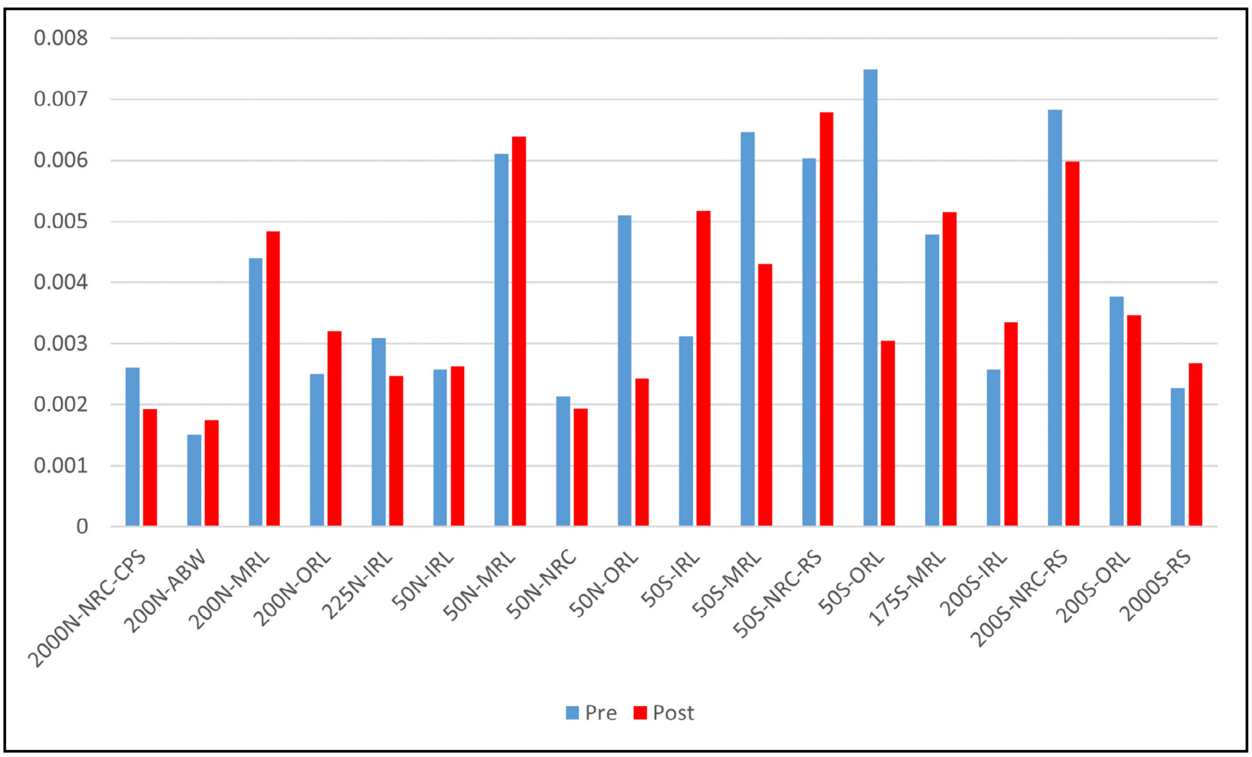

Figure A10: Mercury concentrations in surface sediments pre- and post-dredging.

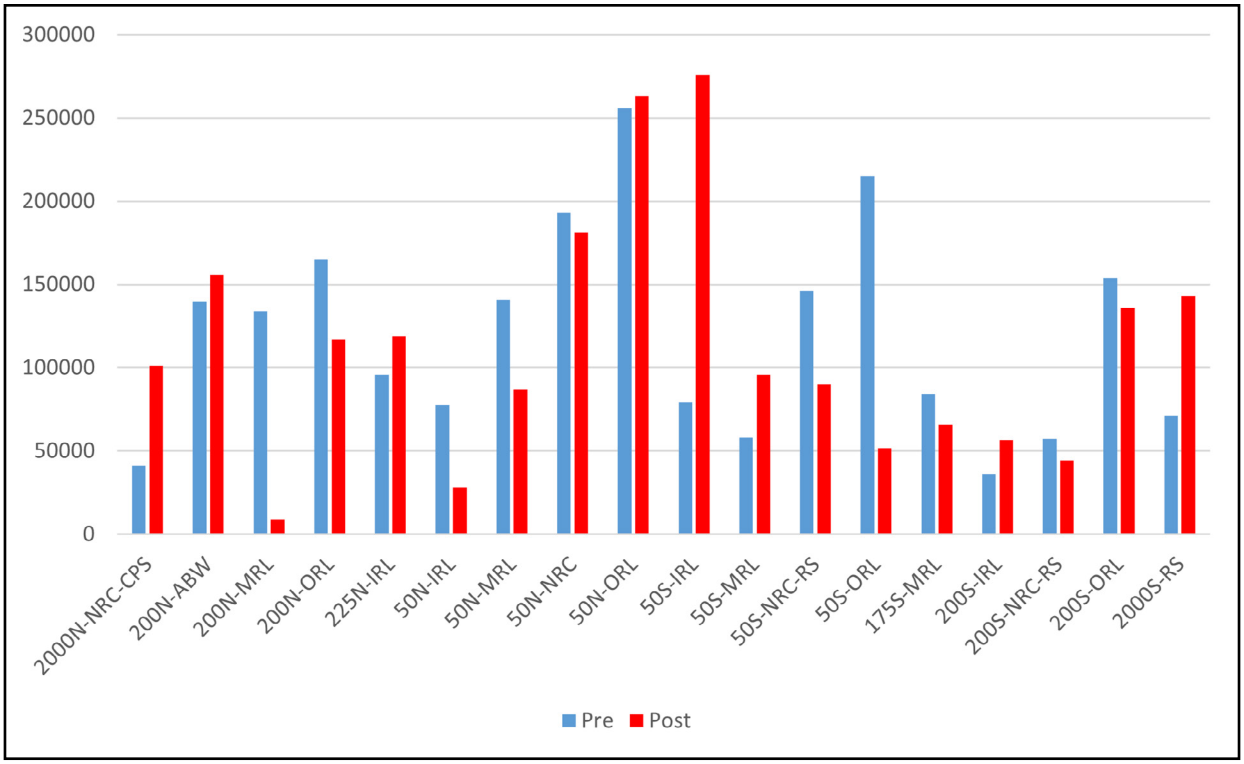

Figure A11: Silica concentrations in surface sediments pre- and post-dredging.

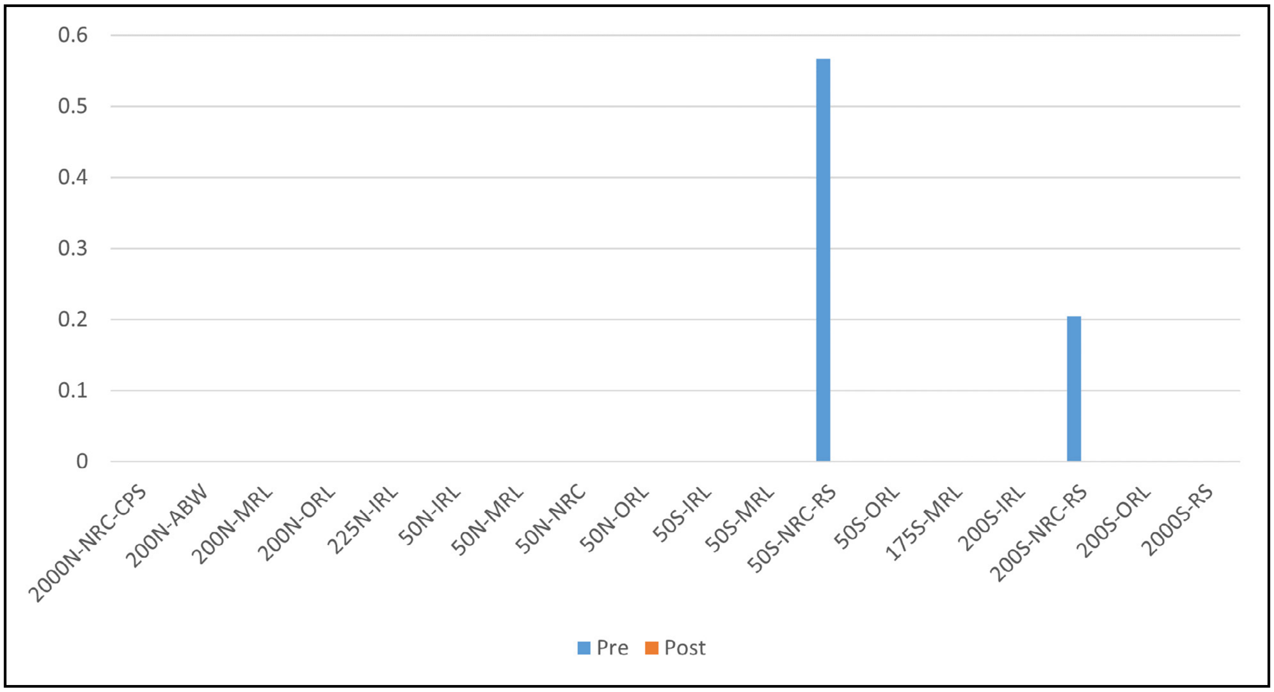

Figure A12: Tin concentrations in surface sediments pre- and post-dredging. Note: “0” indicates

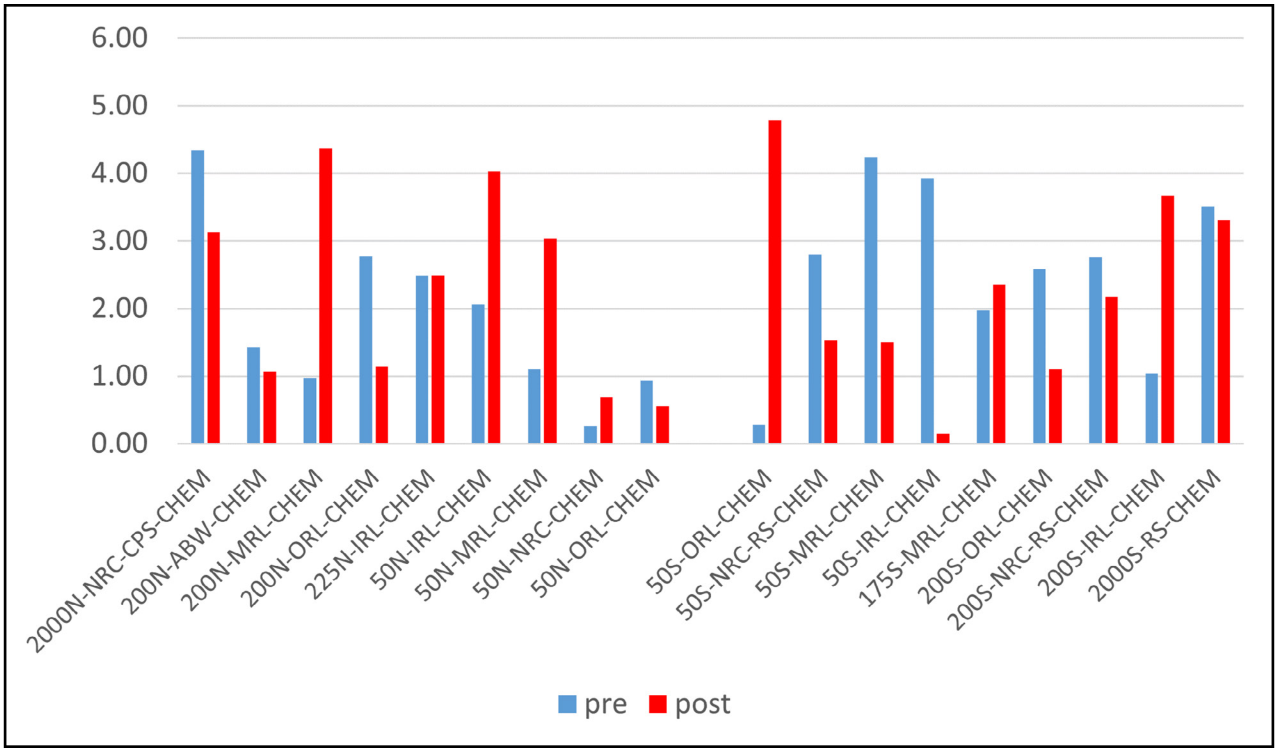

Figure A13: Sediment total organic carbon (TOC) as a percent of dry weight pre- and post-dredging.

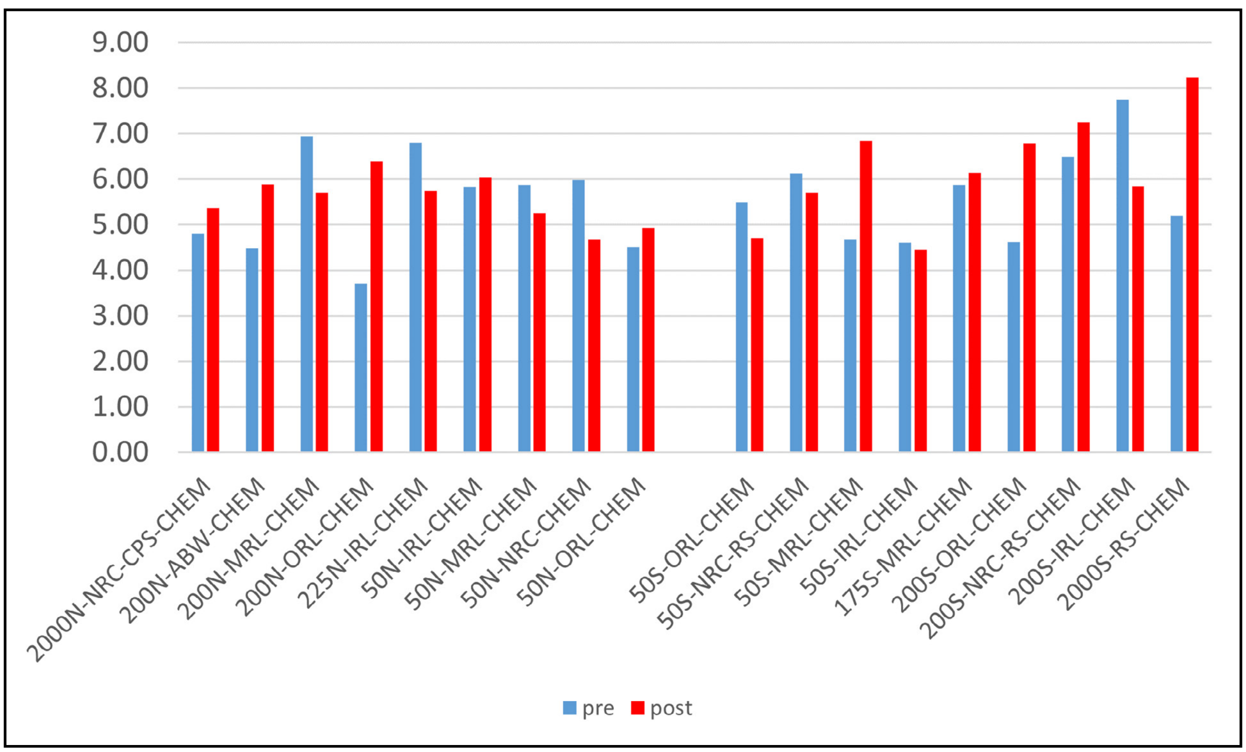

Figure A14: Sediment total inorganic carbon (TIC) as a percent of dry weight pre- and post-dredging.

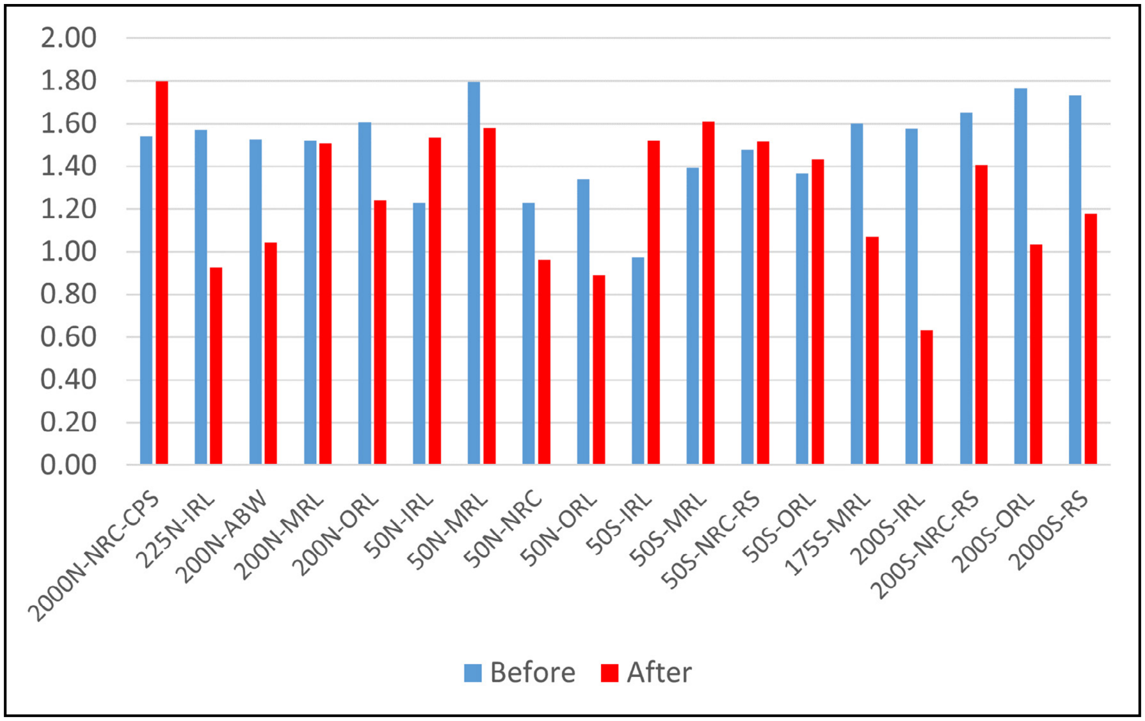

Figure A15: Sediment grain size as percent clay pre- and post-dredging.

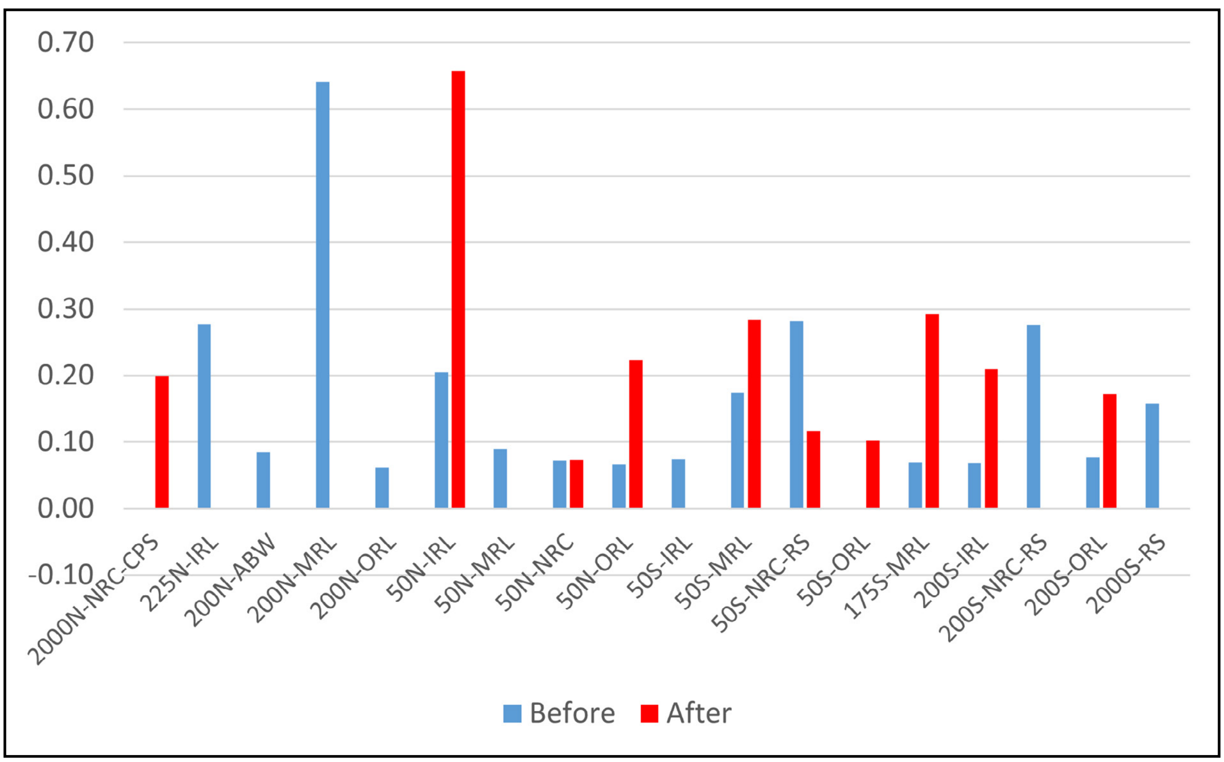

Figure A16: Sediment grain size as percent silt pre- and post-dredging.

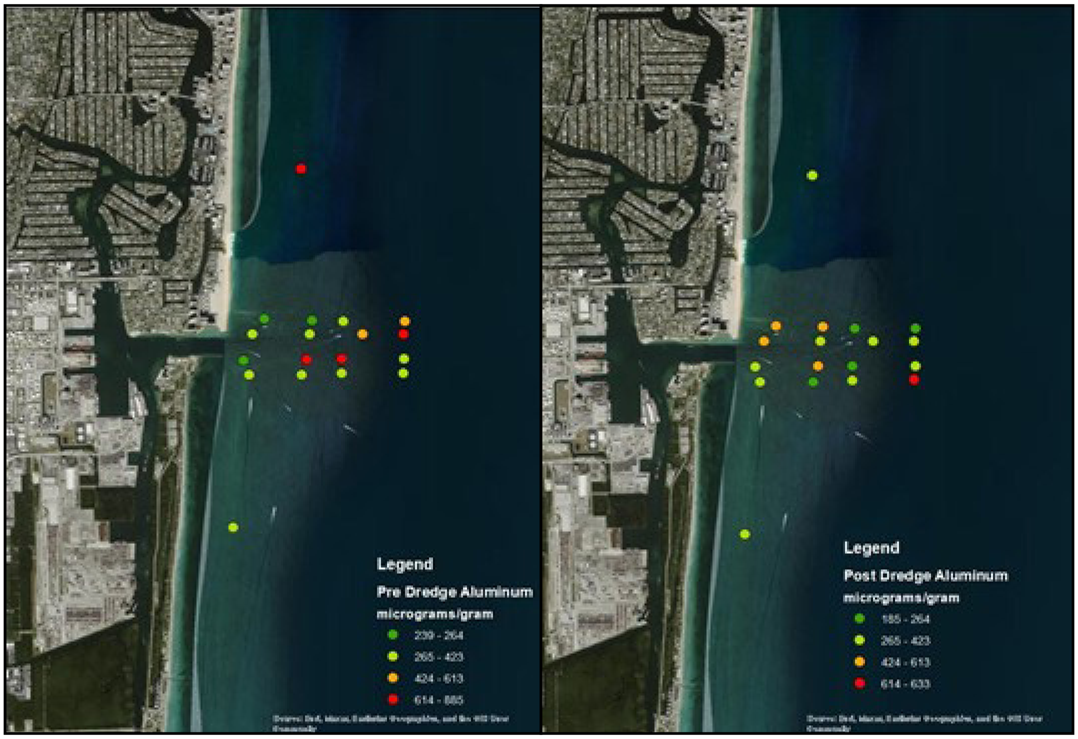

Figure A17: Map of sediment concentrations of total aluminum, pre and post dredging.

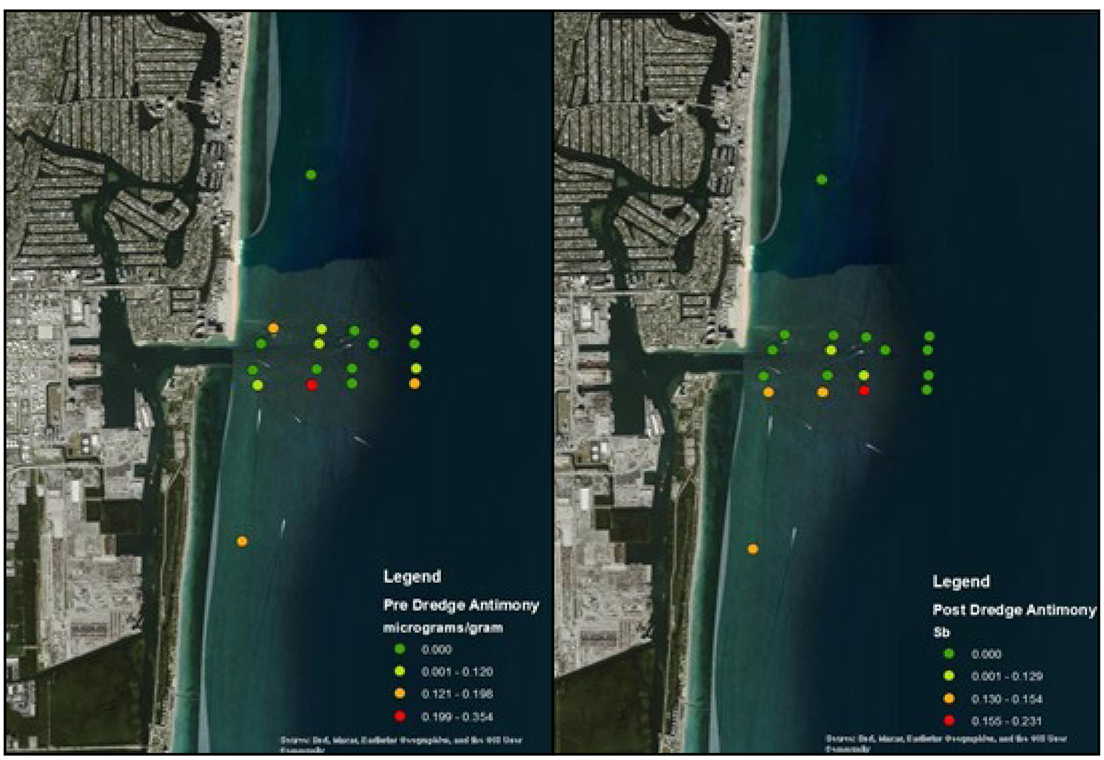

Figure A18: Map of sediment concentrations of total antimony, pre- and post-dredging. Note: "0" indicates below method detection limit.

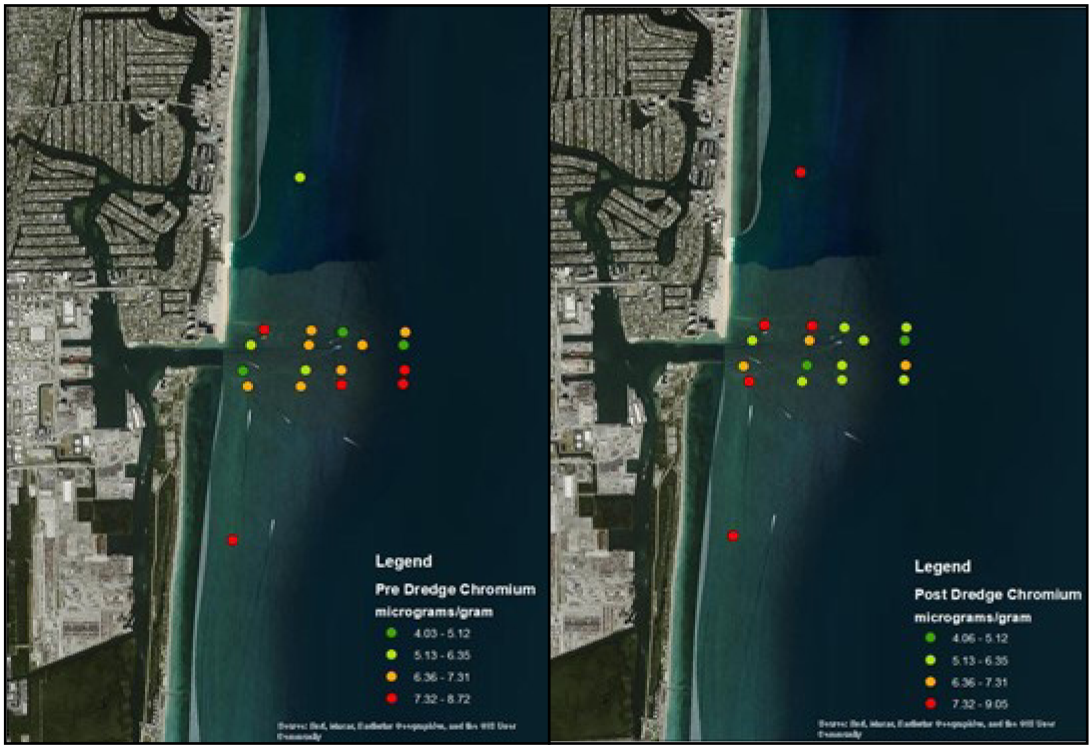

Figure A19: Map of sediment concentrations of total arsenic, pre- and post-dredging. Note: “0” indicates below method detection limit.

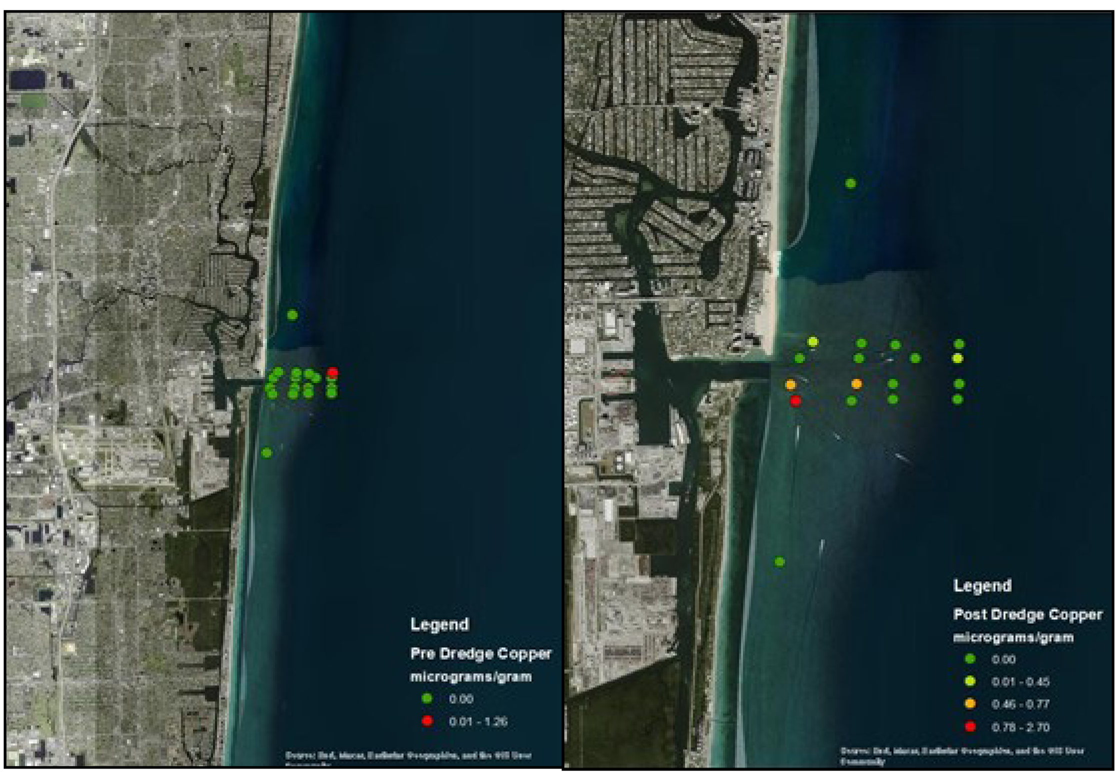

Figure A20: Map of sediment concentrations of total chromium, pre- and post dredging.

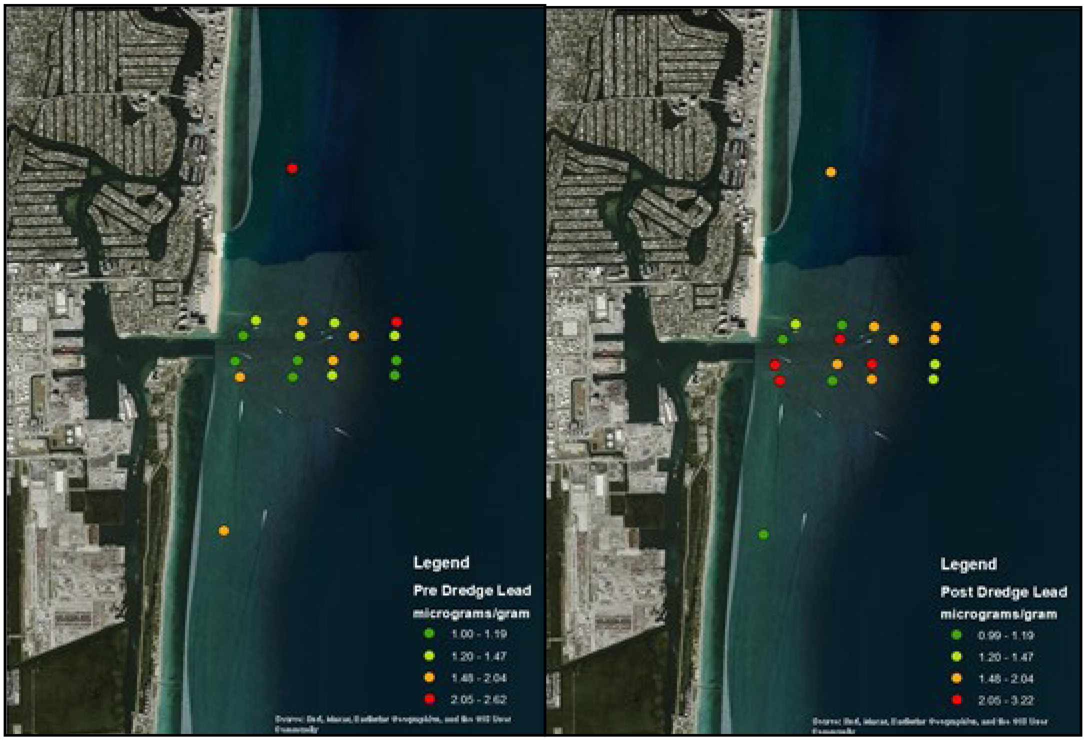

Figure A21: Map of sediment concentrations of total copper, pre- and post dredging.
Note: “0” indicates below method detection limit.

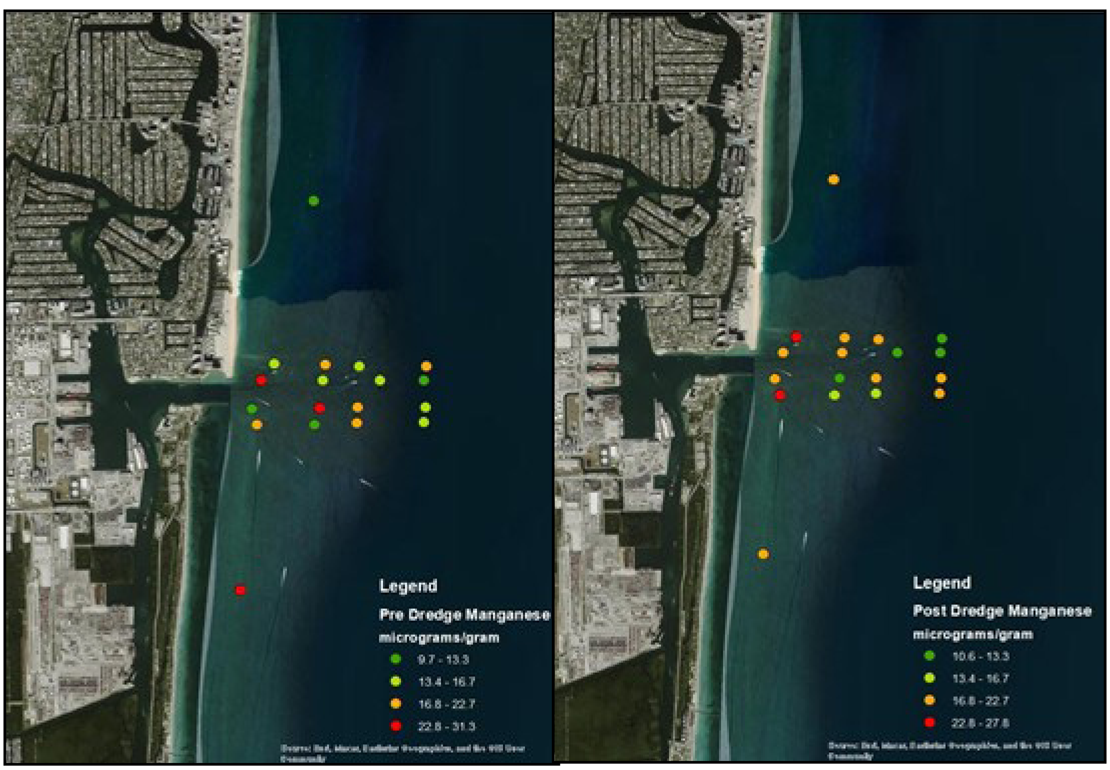

Figure A22: Map of sediment concentrations of total lead, pre- and post dredging.

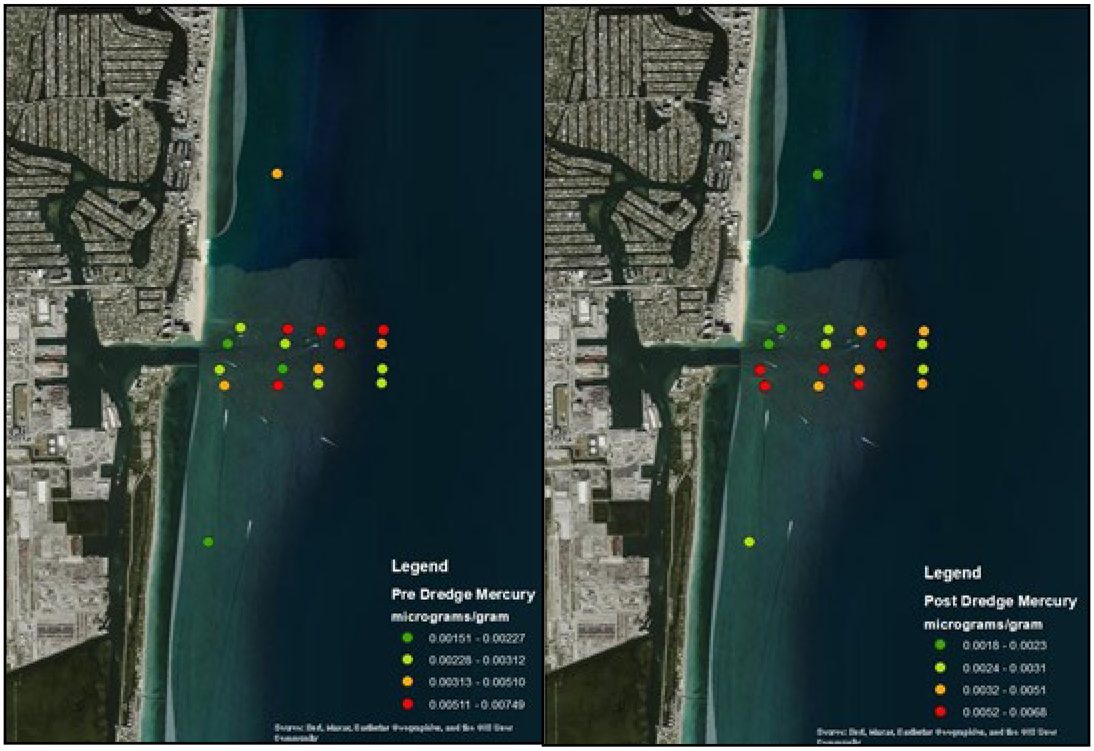

Figure A23: Map of sediment concentrations of total manganese, pre- and post dredging.

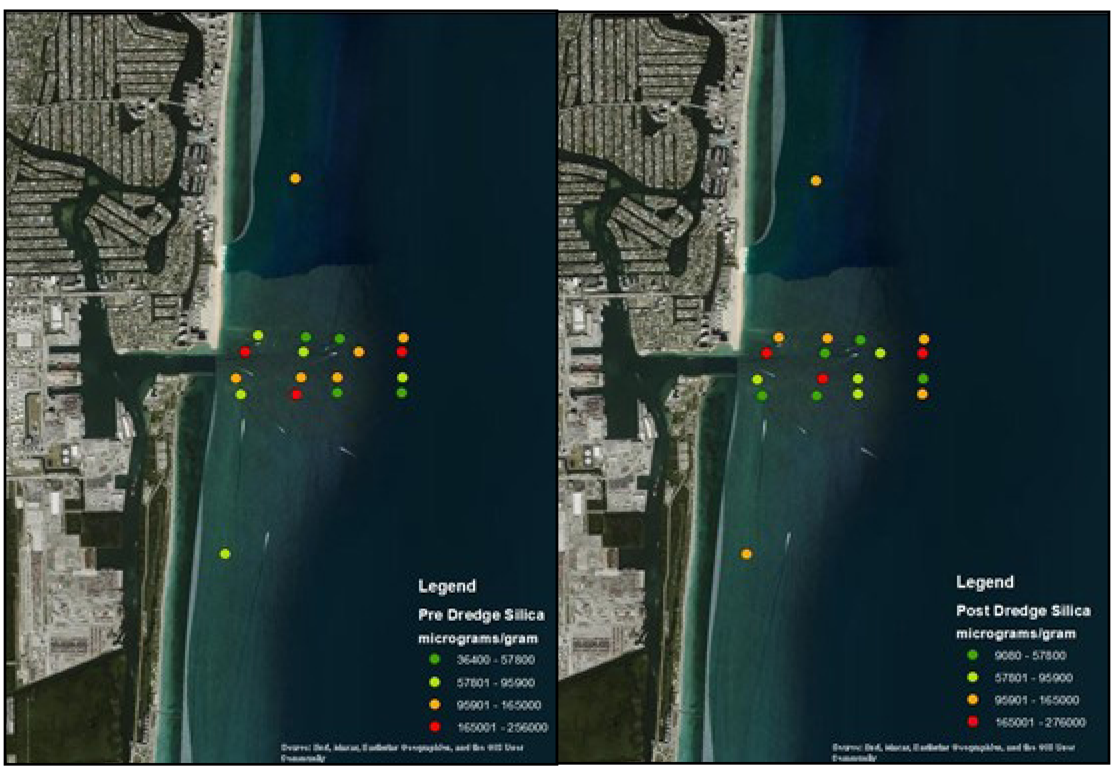

Figure A24: Map of sediment concentrations of total mercury, pre- and post dredging.

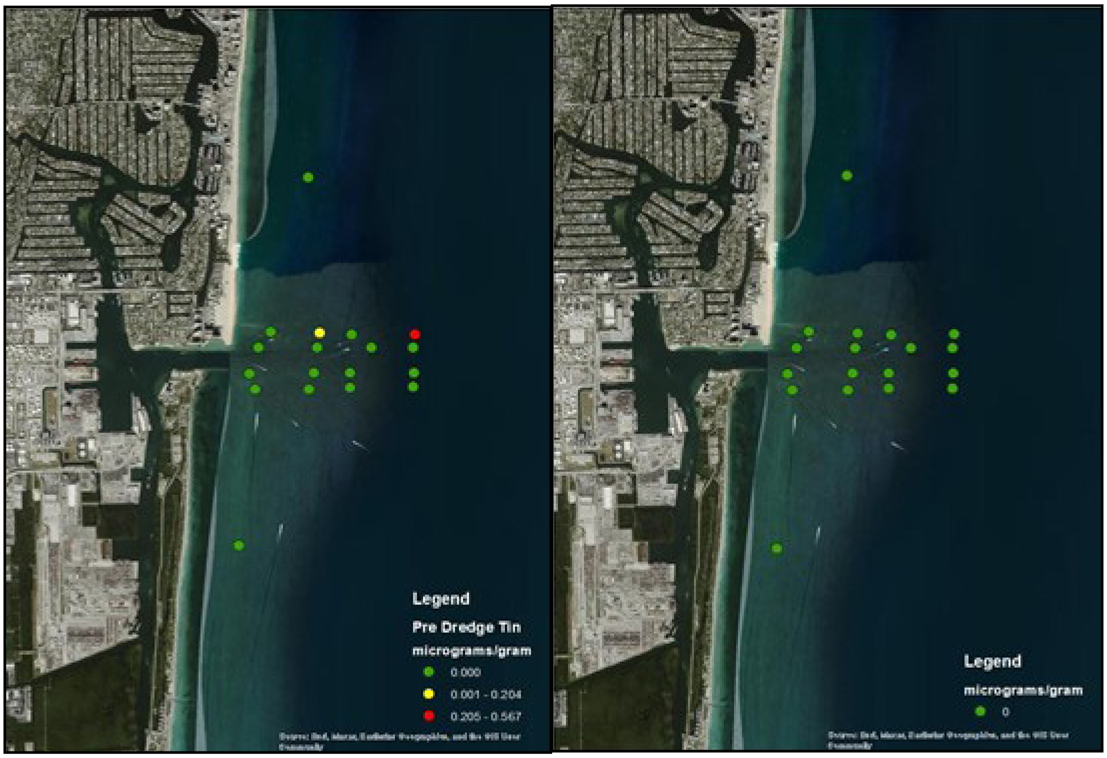

Figure A25: Map of sediment concentrations of total silica, pre- and post dredging.

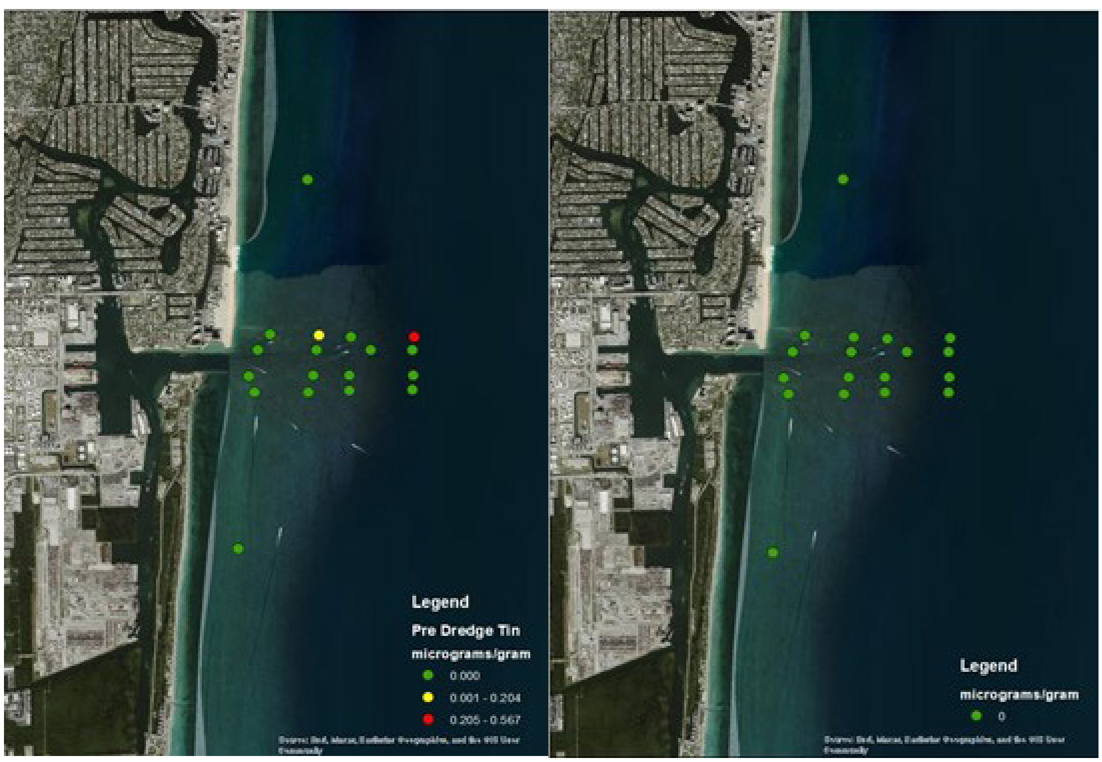

Figure A26: Map of sediment concentrations of total tin, pre- and post dredging. Note: "0" indicates below method detection limit.

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