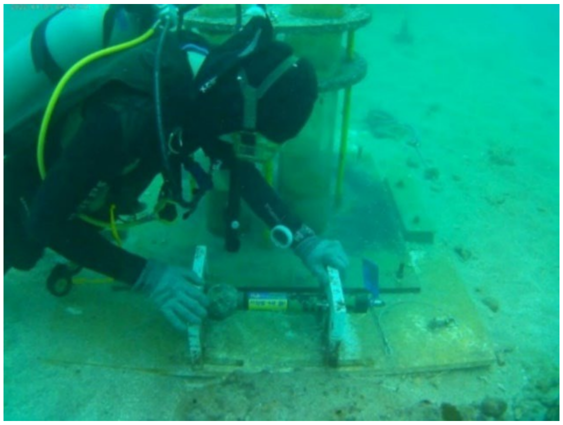
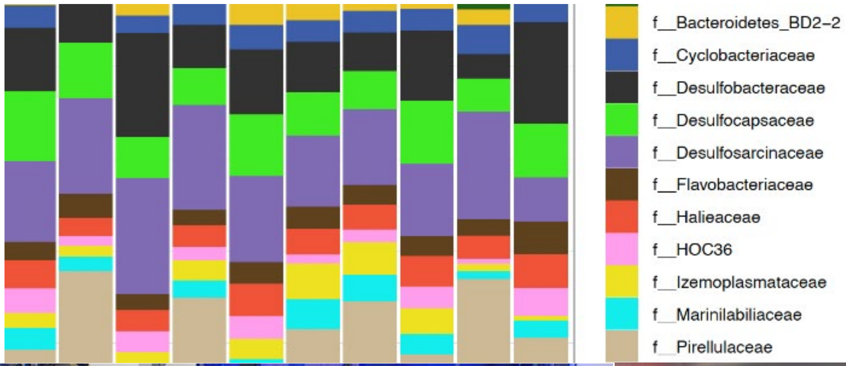
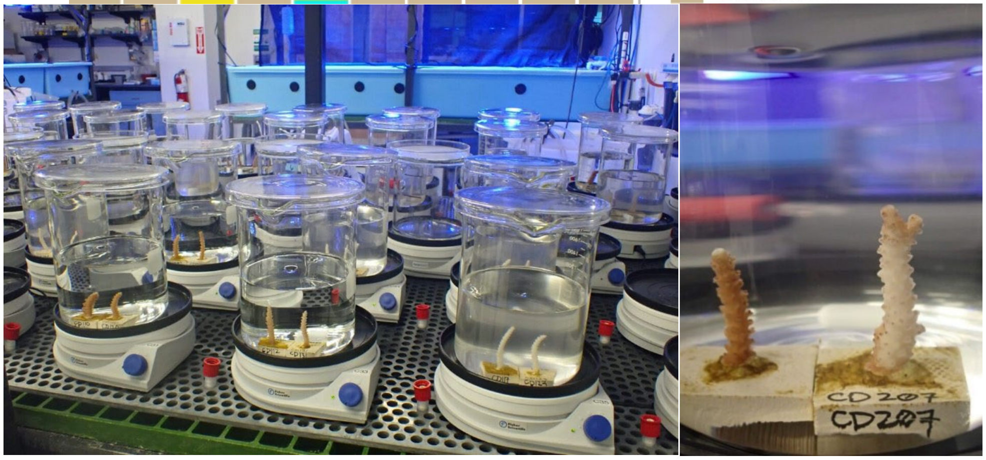
Heavy Metals Implications to Sediment Microbiome and Coral Response to Arsenic Dosing







FLORIDA'S CORAL REEF

Heavy Metals Implications to Sediment Microbiome and Coral Response to Arsenic Dosing

Final Report

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Management Summary

Statistical analyses from Phase 1 (FDEP agreement #C0FEDD) indicated that triplicate sediment cores per location had very few heavy metal concentrations differences. The port sediment had arsenic (As) and molybdenum (Mo) contamination and some overall heavy metal contamination, while the reef sites had minor contamination. Microbial community composition based on metagenomics data differed between sediments at the control, coral, and port sites. Coral sites had lower functional diversity than the port sites, while the port had higher metal concentrations associated with the functional composition.

Sediment collected from traps at the coral sites indicated that the North Reef sites had higher geometric mean concentrations of aluminum (Al), As, copper (Cu), iron (Fe), manganese (Mn), and tin (Sn) compared to the South Reef. Arsenic exhibited overall moderate to strong contamination while Mo exhibited moderate contamination during the September collection period, indicating possible contaminated sediment being suspended.

Coral sediments collected from sediment traps at the reef sites were processed for molecular genetics. 16S rRNA gene amplicons microbial community analyses reinforced community composition profiles obtained in previous years.

Abiotic data and sedimentation rates collected at the coral reef sites indicated that temperature was higher during the June-September months and that turbidity and sedimentation rates increased during storms and high wind action.

Overall, the branching *A. cervicornis* was more sensitive to both As(V) and As(III) compared to *O. faveolata*. For *A cervicornis*, As (V) was more acutely toxic than As (III) for all metrics while for *O. faveolata*, As (III) was more toxic than As (V), but only for mortality.

Regional data was collected and synthesized on the concentration and distribution of potentially toxic chemicals on Florida Coral Reef. The data can be used to identify contaminants of greatest concern and examine the potential interactive/synergistic effects of multiple stressors on the southeast Florida reef system.

Executive Summary

Statistical analyses were performed on ecological indices on all port sediment core depths and reef sediment heavy metal data from Phase 1 of FDEP project (agreement #C0FEDD). Analyses were also performed on the microbial community composition and the heavy metals.

Surface sediment were collected on three separate occasions at six nearby coral reef sites adjacent to the port. The sediments were analyzed for 14 heavy metals using inductively coupled plasma-mass spectrometry (ICP-MS). The sediments were also processed for microbial profiling. Instrument platforms were positioned at the six coral reef sites with ST-30 sediment traps and Aqua TROLL sensors, and abiotic data (temperature, conductivity, pressure, dissolved oxygen, pH, and turbidity) were measured. Four static 96-h exposure assays were performed with two coral species, *A. cervicornis* and *O. faveolata,* which determined the acute and subacute threshold concentrations for 2 inorganic species of arsenic (arsenite and arsenate). Finally, regional data was collected and synthesized on the concentration and distribution of potentially toxic chemicals on Florida Coral Reef.

Statistical Analyses. The triplicate port cores collected in Phase 1 showed very little to no heavy metal concentration differences. Arsenic and Mo had significant geo-accumulation indices at the port and the potential ecological risk values indicated that all sediment cores and sediment at the reef sites had some overall heavy metal contamination. The metal with the most significant toxic levels for all the cores and coral sediment was As. Microbial community composition differed between sediments at the control, coral, and in the port sites. Coral sites had lower functional diversity than the port sites, and the higher metal concentrations were associated with the functional composition of the port.

Coral Reef Sediment Heavy Metal Data. Heavy metal results of sediment collected from six ST-30 sediment traps at six coral reef sites located north and south of Port Everglades (1N, 2N, 3N, 1S, 2S, and 3S) indicate moderate to strong contamination at the reef sites based on the geo-accumulation (I_{geo}). Arsenic concentrations were all above the upper continental crust value of 1.5 µg/g and 19% of the samples were above TEL (7.24 µg/g). Molybdenum also exhibited moderately contaminated geo-accumulation values during the September collection periods for 1N, 2N, 3N, 1S, and 2S locations, indicating possible contaminated sediment being suspended during the June-September months. All coral reef sites (1N, 2N, 3N, 1S, 2S, and 3S) showed moderate overall metal contamination during some period of collection that was primarily due to As.

Sedimentation and Abiotic Data. The four acrylic cylinders, comprising a single sediment trap, at each of the six reef site platforms indicated that sedimentation was low during May - September and much higher during September – April. The abiotic data (temperature, conductivity (salinity), pressure (depth), dissolved oxygen, pH, and

turbidity) collected from the six platforms at the six coral reef sites with Aqua TROLL 600 sondes were of expected values across the sites. Temperature, however, fluctuated during seasons with the summer months going as high as 31.8ºC and the turbidity fluctuated significantly during storm events.

Microbiome/ Metagenomics. Extensive data from 16S rRNA amplicon libraries and metagenome sequencing has been generated. Within the sediment trap samples adjacent to the port indicated little differences in microbial community compositions, most likely due to the proximity of samples and the likely mixing sediments in this turbid area. By contrast the date of collection indicated significant beta diversity differences. When the reef sediment trap samples are included with previously cored samples from Phase I via deep metagenomic sequencing, reef trap microbiome samples group closest to inlet microbiome. Metagenomics revealed 45 bacterial taxa that were differentially abundant in the coral sediments compared to the Port. There were 24 taxa that were differentially abundant in the West Lake compared to the port, while 202 taxa that were differentially abundant in the PEI compared to the port. Full integration of the molecular and chemistry data was performed.

Arsenic Dosing. Arsenate (As(V)) exposure with *Acropora cervicornis* and *Orbicella faveolata* indicated that the 96-hr LC50s were 36.88 µg/L and 458.3 µg/L, the EC50s were 34.91 µg/L and 165.8 µg/L, and the IC50s were 35.80 µg/L and 294.3 µg/L, respectively. Arsenite (As(III)) exposure with *A. cervicornis* and *O. faveolata* indicated that the 96-hr LC50s were 116.0 µg/L and 255.8 µg/L, the EC50s were 100.1 µg/L and 146.1 µg/L, and the IC50s were 138.6 µg/L and 307.2 µg/L, respectively. Overall, the branching *A. cervicornis* was more sensitive to both As (V) and As (III) compared to *O. faveolata*. For *A. cervicornis*, As (V) was more acutely toxic than As (III) for all metrics (mortality, condition, and photosynthetic efficiency). This was not the case for *O. faveolata*, where As (III) was more toxic than As (V), but only for mortality; threshold concentrations were similar for condition and photosynthetic efficiency.

Literature Review. Geospatial databases for 12 contaminant classes, consisting of over 2.9 million data points for water and sediments, and covering over 32,000 sites in the five counties which encompass the FRT (Broward County, Miami-Dade County, Martin County, Monroe County, and Palm Beach County) FCR (Broward, Miami-Dade, Palm Beach, Martin, and Monroe), were compiled from resources including USGS, STEWARDS, NWIS, NWQMC, MusselWatch, NOAA'S National Status and Trends, and peer-reviewed literature. This data has been divided into individual databases for each contaminant type (cyanotoxins, inorganics (metals and nonmetals), organics (herbicides, pesticides, and others), and radiochemicals, Overall, a range of contaminants are present in the marine environment of Florida's Coral Reef which could pose a threat to the health and resilience of coral reefs. Based on existing knowledge, the categories of contaminants that pose the highest risks are metals, pesticides, and other organic compounds, as well as certain inorganic compounds (arsenic). Continued and potentially expanded environmental monitoring is necessary to monitor the temporal and spatial distribution of these contaminants in the environment. For compounds where no toxicology thresholds exist for corals but have potentially harmful concentrations in the environment (for example arsenic or molybdenum), establishment of chronic exposure thresholds is recommended.

Table of Contents

LIST OF FIGURES

Figure 13. Weekly average turbidity (NTU) at the six reef sites (1N, 2N, 3N, 1S, 2S, and 3S).

Figure 14. Top 20 Phyla of the 18 sediment trap samples in Table 108 collected 9/13/23, 12/1/23 and 4/3/24 from reef (1N.2, 2N.2 3N.2, 1S.2, 3S.2, 1N.3, 2N.3, 3N.3, 1S.3, 2S.3). (Please disregard the "X," which was used for annotation and programming).

Figure 15. Top 20 Orders of the 18 sediment trap samples listed in Table 108 collected 9/13/23, 12/1/23, and 4/3/24 and generated high yield of 16S rRNA sequences.

Figure 16. Top 20 families of the 18 coral reef sediment samples listed in Table 108.

Figure 17. Alpha diversity of microbiomes in the North reef (1N, 2N, and 3N) and South reef (1S, 2S, and 3S) sediment represented by A) Species Richness, B) Species Evenness, C) Shannon Diversity and D) Inverse Simpson Indices from the 18 reef sediment samples.

Figure 18. Alpha diversity of microbiomes in the reef closest to the port (1N and 1S, red), mid-distance from the port (2N and 2S, blue), and furthest from the port (3N and 3S, green) represented by A) Species Richness, B) Species Evenness, C) Shannon Diversity and D) Inverse Simpson Indices. None of the mean differences were significant.

Figure 19. Alpha diversity of microbiomes based on the sequencing run (Cosmos, red; Lopez Lab, blue), represented by A) Species Richness, B) Species Evenness, C) Shannon Diversity and D) Inverse Simpson Indices from the 10 sediment samples based on high yield 16S rRNA data. All differences were statistically significant.

Figure 20. NMDS plot of first 10 sediment samples (1N.2, 2N.2 3N.2, 1S.2, 3S.2, 1N.3, 2N.3, 3N.3, 1S.3, 2S.3) grouped by date. These were collected 9/13/23 and 12/01/23 and generated high yield of 16S rRNA sequences.

Figure 21. NMDS plot of first 10 sediment samples (1N.2, 2N.2 3N.2, 1S.2, 3S.2, 1N.3, 2N.3, 3N.3, 1S.3, 2S.) shown in Figure 20 and Table 108 grouped by reef site.

Figure 22. NMDS plot of 8 sediment samples collected in April 2024 from coral reef sites (1N.4, 2N.4, 3N.4, 1S.4, 2S.4, 3S.4, 2S.2) but yielded low sequence reads indicated in Table 108.

Figure 23. Heatmap of Phase I port sediment core samples and Phase II reef sediment samples based on metagenomics data.

Figure 24 – Box plots of alpha diversity metrics based on metagenomics data showing observed taxa from N or S reef sites.

Figure 25. Principles Component Analysis plot of twelve sediment trap samples according to site collected September and December 2023 (see Table 108).
Figure 26. Results of arsenate 96-hr acute exposure for Acropora cervicornis A) dark-adapted maximum quantum yield (mean ± SE) (n=6 replicates) at 0 hr and 9h hr, B) dark-adapted maximum quantum yield dose-response curve, C) coral condition scores (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, D) coral condition dose-response curve, E) % mortality (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, and F) mortality dose-response curve.

Figure 27. Results of arsenite 96-hr acute exposure for Acropora cervicornis A) dark-adapted maximum quantum yield (mean ± SE) (n=6 replicates) at 0 hr and 9h hr, B) dark-adapted maximum quantum yield dose-response curve, C) coral condition scores (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, D) coral condition dose-response curve, E) % mortality (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, and F) mortality dose-response curve.

Figure 28. Results of arsenate 96-hr acute exposure for Orbicella faveolata. A) dark-adapted maximum quantum yield (mean ± SE) (n=6 replicates) at 0 hr and 9h hr, B) dark-adapted maximum quantum yield dose-response curve, C) coral condition scores (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, D) coral condition dose-response curve, E) % mortality (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, and F) mortality dose-response curve.

Figure 29. Results of arsenite 96-hr acute exposure for Orbicella faveolata. A) dark-adapted maximum quantum yield (mean ± SE) (n=6 replicates) at 0 hr and 9h hr, B) dark-adapted maximum quantum yield dose-response curve, C) coral condition scores (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, D) coral condition dose-response curve, E) % mortality (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, and F) mortality dose-response curve.

LIST OF TABLES

Table 1. Locations of sediment traps and Aqua TROLL 600 sondes in latitude and longitude.

Table 2. Threshold Effect Level (TEL), Probable Effect Level (PEL), and continental crust values. NA is not available.

Table 3. The p-values of a Kruskal-Wallis test performed for the 5 sediment core locations (DCC, PEC, PHQ, PLI, STB) and control site (WL) for 16 heavy metals, looking at differences between cores. Bolded values indicate statistically significant differences.

Table 4. Geo-accumulation indices for arsenic (As) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Dania Cutoff Canal (DCC). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 5. Geo-accumulation indices for arsenic (As) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Park Education Center (PEC). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 6. Geo-accumulation indices for arsenic (As) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Park Headquarters (PHQ). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 7. Geo-accumulation indices for arsenic (As) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Port Everglades Inlet (PEI). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 8. Geo-accumulation indices for arsenic (As) of each sediment core (core 1, core 2 and core 3) per depth (cm) from South Turning Basin (STB). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 9. Geo-accumulation indices for arsenic (As) of each sediment core (core 1, core 2 and core 3) per depth (cm) from West Lake (WL). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 10. Geo-accumulation indices for arsenic (As) of each surface sediment collection (sample 1, sample 2 and sample 3) from traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 11. Geo-accumulation indices for molybdenum (Mo) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Dania Cutoff Canal (DCC). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 12. Geo-accumulation indices for molybdenum (Mo) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Park Education Center (PEC). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 13. Geo-accumulation indices for molybdenum (Mo) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Park Headquarters (PHQ). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately

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Table 14. Geo-accumulation indices for molybdenum (Mo) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Port Everglades Inlet (PEI). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 15. Geo-accumulation indices for molybdenum (Mo) of each sediment core (core 1, core 2 and core 3) per depth (cm) from South Turning Basin (STB). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 16. Geo-accumulation indices for molybdenum (Mo) of each sediment core (core 1, core 2 and core 3) per depth (cm) from West Lake (WL). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 17. Geo-accumulation indices for molybdenum (Mo) of each surface sediment collection (sample 1, sample 2 and sample 3) per depth (cm) from traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 18. B-H corrected p-values for the geo-accumulation index of arsenic (As). Bolded values indicate statistically significant differences between cores collected at the same site ($p < 0.05$).

Table 19. B-H corrected p-values for the geo-accumulation index of molybdenum (Mo). Bolded values indicate statistically significant differences between cores collected at the same site ($p < 0.05$).

Table 20. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). PLI >1 (highlighted red) is considered polluted. SE = standard error and CI LB = 95% confidence interval lower bound.

Table 21. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). PLI>1 (highlighted red) is considered polluted) SE = standard error and CI LB = 95% confidence interval lower bound.

Table 22. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). PLI>1 (highlighted red) is considered polluted. SE = standard error and CI LB = 95% confidence interval lower bound.

Table 23. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). PLI>1 (highlighted red) is considered polluted. SE = standard error and CI LB = 95% confidence interval lower bound.

Table 24. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). PLI>1 (highlighted red) is considered polluted. SE = standard error and CI LB = 95% confidence interval lower bound.

Table 25. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from West Lake (WL). PLI>1 (highlighted red) is considered polluted. SE = standard error and CI LB = 95% confidence interval lower bound.

Table 26. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from the traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). PLI>1 (highlighted red) is considered polluted. SE = standard error and CI LB = 95% confidence interval lower bound.

Table 27. B-H corrected p-values for pollution load index (PLI) among all three cores (core 1, core 2, and core 3) per location (DCC, PEC, PHQ, PEI, STB, and WL). Bolded values indicate statistically significant differences between cores collected at the same site ($p < 0.05$).

Table 28. Potential ecological risk (PER) of sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 29. Potential ecological risk (PER) of sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). The color of the value indicates: low contamination

(< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 30. Potential ecological risk (PER) of sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 31. Potential ecological risk (PER) of sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 32. Potential ecological risk (PER) of sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 33. Potential ecological risk (PER) of sediment cores (core 1, core 2, and core 3) from West Lake (WL). The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 34. Potential ecological risk (PER) of surface sediment samples (sample 1, sample 2, and sample 3) from the traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 35. B-H corrected p-values for potential ecological risk (PER) among all three cores (core 1, core 2, and core 3) per location (DCC, PEC, PHQ, PEI, STB, and WL). Bolded values indicate statistically significant differences between cores collected at the same site ($p < 0.05$).

Table 36. Al enrichment factors (EF) for molybdenum (Mo) of sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment ($2 \le EF < 5$, yellow), significant enrichment ($5 \le EF < 20$, orange), very high enrichment ($20 \le EF < 40$, red),

and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 37. Al enrichment factors (EF) for molybdenum (Mo) of sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 38. Al enrichment factors (EF) for molybdenum (Mo) of sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 39. Al enrichment factors (EF) for molybdenum (Mo) sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 40. Al enrichment factors (EF) for molybdenum (Mo) of sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 41. Al enrichment factors (EF) for molybdenum (Mo) of sediment cores (core 1, core 2, and core 3) from West Lake (WL). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 42. Al enrichment factors (EF) for molybdenum (Mo) of sediment samples (sample 1, sample 2, and sample 3) from traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange),

very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 43. Al enrichment factors (EF) for arsenic (As) of sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 44. Al enrichment factors (EF) for arsenic (As) of sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 45. Al enrichment factors (EF) for arsenic (As) of sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 46. Al enrichment factors (EF) for arsenic (As) of sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 47. Al enrichment factors (EF) for arsenic (As) of sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 48. Al enrichment factors (EF) for arsenic (As) of sediment cores (core 1, core 2, and core 3) from West Lake (WL). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and

extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 49. Al enrichment factors (EF) for arsenic (As) of sediment (sample 1, sample 2, and sample 3) from traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 50. Fe enrichment factors (EF) for arsenic of sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 51. Fe enrichment factors (EF) for arsenic of sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 52. Fe enrichment factors (EF) for arsenic of sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 53. Fe enrichment factors (EF) for arsenic of sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 54. Fe enrichment factors (EF) for arsenic of sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and

extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 55. Fe enrichment factors (EF) for arsenic of sediment cores (core 1, core 2, and core 3) from West Lake (WL). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 56. Fe enrichment factors (EF) for arsenic of sediment (sample 1, sample 2, and sample 3) collected from traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 57. B-H corrected p-values for the Fe enrichment factor (EF) of arsenic (As) among all three cores (core 1, core 2, and core 3) per location (DCC, PEC, PHQ, PEI, STB, and WL). Bolded values indicate statistically significant differences between cores collected at the same site ($p < 0.05$).

Table 58. B-H corrected p-values for the Al enrichment factor (EF) of molybdenum (Mo) among all three cores (core 1, core 2, and core 3) per location (DCC, PEC, PHQ, PEI, STB, and WL). Bolded values indicate statistically significant differences between cores collected at the same site ($p < 0.05$).

Table 59. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) collected from Dania Cutoff Canal (DCC). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 60. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 61. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 62. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 63. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 64. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from West Lake (WL). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 65. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from traps at the reef sites (1N, 2N, 3N, 1S, 2S, 3S). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 66. Cadmium (Cd) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 67. Cadmium (Cd) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 68. Cadmium (Cd) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 69. Cadmium (Cd) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). Values highlighted in yellow are above the

continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 70. Cadmium (Cd) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 71. Cadmium (Cd) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from West Lake (WL). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 72. Cadmium (Cd) concentrations (mg/g) from traps at the reef sites (1N, 2N, 3N, 1S, 2S, 3S). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 73. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 74. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 75. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 76. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (>

0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 77. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 78. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from West Lake (WL). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 79. Mercury (Hg) concentrations (mg/g) in sediment from traps at the reef sites (1N, 2N, 3N, 1S, 2S, 3S). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 80. Molybdenum (Mo) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 81. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 82. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 83. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 84. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 85. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from West Lake (WL). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 86. Mercury (Hg) concentrations (mg/g) in sediment from traps at the reef sites (1N, 2N, 3N, 1S, 2S, 3S). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

Table 87. Results from PERMANOVA using Bray Curtis distance. P values in red indicate correlation to microbial community composition.

Table 88. Genera that correlate to Mo. Positive log2fold is positive correlation, and negative log2fold is negative correlation.

Table 89. Genera that correlate to As. Positive log2fold is positive correlation, and negative log2fold is negative correlation

Table 90. Genera that correlate to specific heavy metals.

Table 91: The concentration ranges, geometric and arithmetic means of the 14 heavy metals analyzed at the three North Reef (NR) 1N, 2N, and 3N and three South Reef (SR) 1S, 2S, and 3S sediment trap samples from June 2023, September 2023, November 2023, and March 2024. Nd= non-detected.

Table 92. Triplicate reef geo-accumulation index of sediment from traps for 1N, 2N, 3N, 1S, 2S, and 3S locations. The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound. The June 2023 data were collected during Phase I of FDEP project (#C0FEDD).

Table 93. Threshold effect level (TEL), probable effect level (PEL), and continental crust values. NA is not available.

Table 94. Triplicate coral reef heavy metal concentrations (µg/g) of sediment samples from the traps for 1N, 2N, 3N, 1S, 2S, and 3S locations. Values highlighted in yellow are above upper continental crust (background) values and in orange are above threshold effect levels (TEL). The June 2023 data were collected during Phase I of FDEP project (#C0FEDD).

Table 95. Triplicate reef pollution load index (PLI) of sediment samples from the traps for 1N, 2N, 3N, 1S, 2S, and 3S locations. PLI>1 is considered polluted sediment. PLI<1

is considered non-polluted sediment. The June 2023 data were collected during Phase I of FDEP project (#C0FEDD).

Table 96. Triplicate reef potential ecological risk (PER) of sediment from the traps for 1N, 2N, 3N, 1S, 2S, and 3S locations. The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Table 97. Triplicate reef Fe enrichment factors (EF) of sediment samples in traps for 1N, 2N, 3N, 1S, 2S, and 3S locations. The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound. The June 2023 data were collected during Phase I of FDEP project (#C0FEDD).

Table 98. Triplicate reef Al enrichment factors (EF) of sediment samples in traps for 1N, 2N, 3N, 1S, 2S, and 3S locations. The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound. The June 2023 data were collected during Phase I of FDEP project (#C0FEDD).

Table 99. Sedimentation rates in g/day for each of the six coral reef sites (1N, 2N, 3N, 1S, 2S, and 3S) for each period (dates).

Table 100. Range and mean values for each of the abiotic conditions at the reef sites 1N, 2N, and 3N.

Table 101. Weekly averages for the abiotic conditions at reef site 1N from 2 June 2023 to 28 May 2024. ND indicates no data was collected and D indicates data was deleted due to erroneous sensor readings.

Table 102. Weekly averages for the abiotic conditions at reef site 2N from 2 June 2023 to 28 May 2024.

Table 103. Weekly averages for the abiotic conditions at reef site 3N from 2 June 2023 to 28 May 2024. ND indicates no data was collected and D indicates data was deleted due to erroneous sensor readings.

Table 104. Range and mean values for each of the abiotic conditions at the reef sites 1S, 2S, and 3S.

Table 105. Weekly averages for the abiotic conditions at reef site 1S from 2 June 2023 to 28 May 2024.

Table 106. Weekly averages for the abiotic conditions at reef site 2S from 2 June 2023 to 28 May 2024.

Table 107. Weekly averages for the abiotic conditions at reef site 3S from 2 June 2023 to 28 May 2024.

Table 108 - Yield of sediment samples used in 16S Microbiome sequencing from the six coral reef sites (1N, 2N, 3N, 1S, 2S, and 3S). The last ten shaded samples encompass problems encountered during sequences, as indicated by the lower read amounts.

Table 109. Taxa that are differentially abundant in coral compared to port. Positive log2fold change means they are higher in abundance in coral and vice versa. Based on metagenomics.

Table 110. Summary of compiled contaminant databases.

Table 111. Summary of cyanotoxin database, including cyanotoxin category, media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.

Table 112. Summary of inorganic minor metals database, including, for each metal, the media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.

Table 113. Summary of inorganic minor non-metals database, including, for each non-metal or metalloid, the media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.

Table 114. Summary of pesticides and herbicides database, including, the media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.

Table 115. Summary of polychlorinated biphenyls database, including, for each, the media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.

Table 116. Summary of other organics database, including, for each category, the media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.

Table 117. Summary of radiochemicals database, including the media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.

Table 118. Summary of chemicals in the compiled databases, for datapoints from the marine environment, including the media (water or sediment), decade, measurement units, number of datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.

List of Acronyms
DCC (Dania Cutoff Canal)
PEC (Park Education Center)
PEI (Port Everglades Inlet)
PHQ (Park Headquarters)
STB (South Turning Basin)
WL (West Lake)
1N (Reef North Location 1)
2N (Reef North Location 2)
3N (Reef North Location 3)
1S (Reef South Location 1)
2S (Reef South Location 2)
3S (Reef South Location 3)
As(V) (arsenate)
As(III) (arsenite)
EF (enrichment factor)
I_{geo} (geo-accumulation index)
PER (potential ecological risk
PLI (pollution load index)
TEL (threshold effect level)
PEL (potential effect level)
PCBs (polychlorinated biphenyls)
PCDDs (polychlorinated dibenzodioxins)
PCDFs (polychlorinated dibenzofurans)
Al (aluminum)
As (arsenic)
Cd (cadmium)
Co (cobalt)
Cr (chromium)
Cu (copper)
Fe (iron)
Hg (mercury)
Mn (manganese)
Mo (molybdenum)
Ni (nickel)
Pb (lead)
Se (selenium)
Sn (tin)
V (vanadium)
Zn (zinc)

1. INTRODUCTION

Protecting endangered coral reef communities in the marine environment is of extreme environmental and economic importance. Healthy coral reefs, where half of all federally managed fisheries reside, support jobs and businesses through tourism and recreation (Riegl and Dodge, 2008). A suite of environmental conditions impact coral community survivability (Riegl et al., 2009; Hay and Rasher, 2010).

1.1 Statistics

Statistical analysis of heavy metals and ecological indices such as geo-accumulation, pollution load, enrichment factors, and potential ecological risk facilitates the assessment of ecological risks associated with sediment contamination and can help identify the possible sources of contamination. It also helps in predicting potential impacts on microbial-mediated processes and ecosystem services such as nutrient cycling and water quality regulation.

Statistical analysis of heavy metals and microbiome in sediment is essential for advancing our understanding of sediment ecology, assessing environmental risks, and developing strategies for sustainable management and conservation of aquatic ecosystems (Haofeng et al., 2022). Sediment microbiomes play a vital role in ecosystem functioning, including nutrient cycling, organic matter decomposition, and pollutant degradation. Statistical analysis allows researchers to assess how heavy metal contamination influences the structure and function of sediment microbiomes, providing insights into the overall health of aquatic ecosystems (Zampieri et al., 2020; Krausfeldt et al. 2023). It enables identification of correlations and associations between heavy metal concentrations and microbial community composition, which helps in understanding how heavy metal contamination affects microbial diversity, abundance, and activity in sediment environments. Understanding the complex interactions between heavy metals and sediment microbiomes is essential for designing effective restoration and remediation approaches (Changchao et al., 2020).

This information can be valuable for implementing targeted management and remediation strategies to mitigate sediment pollution and evaluate any future changes that might be occurring due to environmental changes and/or anthropogenic influences.

1.2 Heavy Metals in Sediment

Coastal sediments associated with commercial activities can be laden with inorganic and organic pollutants (Qian, et al., 2015; Armiento et al., 2020). Sediments can become contaminated when metals and persistent organic pollutants (POPs) attach, or sorb, to mineral surfaces or biofilms on mineral surfaces, making them useful indicators for anthropogenic contaminants (Power and Chapman, 2018). Contaminated sediments in aquatic ecosystems throughout the world have been linked with ecological risks (Long et al., 1996; Turgeon et al., 1998; U.S. EPA, 2002). Dredged sediments can be contaminated with chemical pollutants and, if resuspended, the metals can be remobilized and may be distributed, ingested, or absorbed by marine organisms. This could result in toxic effects through bioaccumulation in the food web and pose a potential risk to biological organisms, particularly in benthic communities (U.S. EPA, 2021). Evidence of remobilized contaminants has been found in sentinel crabs (*Macrophthalmus* spp.), common periwinkle (*Littorina littorea*), and Sydney rock oysters (*Saccostrea glomerata)* (Davies et al., 2009; Hedge et al., 2009; Saadati et al., 2020). Prior to the pending dredging event, Giarikos et al. (2023) analyzed replicate sediment samples from Port Everglades, a nearby control site, and the adjacent nearshore coral reef for 16 heavy metals aluminum (Al), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se), tin (Sn), vanadium (V), and zinc (Zn). Geo-accumulation index reveals that the port sediments have moderate to strong contamination of As and Mo and potential ecological risk index indicates moderate to significantly high overall heavy metal contamination. Arsenic concentrations in port sediment exceed both threshold effect level (TEL, 7.24 µg/g) and probable effect level (PEL, 41.6 µg/g). TEL is the minimum level for benthic biologic effects and PEL is when a large percentage of benthic organisms exhibit a toxic response. Heavy metal concentration spikes above TEL were also observed in the port sediment cores for Cd, Cu, Hg, Mo, Pb, Sn, and Zn. Conversely, the coral reef surface sediment had very low contaminant concentrations. The contaminated port sediment dredge material is proposed to be deposited on the ocean floor 1.19 nmi offshore from the outer reef tract and these contaminants are of major concern to biological organisms (White, 2021).

This study will provide key information to develop an ecological risk assessment to understand the impact port dredging has on imperiled nearby coral reef communities and will advance knowledge in the fields of environmental and marine chemistry to help create new management and environmental dredging risk assessments.

1.3 Sedimentation and Abiotic data

Coral reefs are among the most diverse and productive ecosystems on the planet, providing vital habitats for numerous marine species and serving as critical barriers against coastal erosion and storm damage (Odum & Odum, 1955; Moberg & Folke, 1999). However, these ecosystems are increasingly threatened by various environmental stressors, including sedimentation, turbidity, temperature, pH, and dissolved oxygen.

Several studies have shown that resuspended sediments and accompanying increased turbidity of seawater can degrade coral reef health around the world (Dodge and Vaisnys, 1977; Fabricius, 2005; Wolanski et al., 2009; Bessell-Browne et al., 2017; Tuttle et al., 2020).

Turbidity refers to the cloudiness or haziness of water caused by suspended particles such as sediment, organic matter, and plankton. High turbidity levels can reduce light penetration into the water column, which is essential for the growth of coral zooxanthellae that provide corals with energy through photosynthesis. An indirect effect of turbidity and temperature is changes to dissolved oxygen. Turbidity reduces the amount of light available for photosynthesis by aquatic plants, algae, and phytoplankton.

This decrease in photosynthetic activity can lead to lower rates of oxygen production during daylight hours.

Temperature, pH, and dissolved oxygen also play a critical role in shaping the health and survival of coral reefs. One of the most immediate and visible impacts of temperature change on coral reefs is coral bleaching. Rising temperatures also exacerbate the effects of ocean acidification (pH lowers), another consequence of increased carbon dioxide levels in the atmosphere. Acidification makes it harder for corals to build their calcium carbonate skeletons, which are essential for their structure and growth (Anthony et al., 2008). Temperature also has a significant influence on the dissolved oxygen levels in the ocean and, consequently, on coral reefs. Generally, colder water can hold more dissolved oxygen than warmer water. Changes in salinity can stress corals, making them more susceptible to diseases and bleaching events (Coles and Jokiel, 1992; Ding D-S et al., 2022). Changes in salinity, such as those caused by heavy rainfall or drought, can lead to coral mortality.

Understanding these abiotic dynamics is crucial for assessing the impacts of climate change and human activities on coral reefs and implementing conservation strategies to mitigate these effects.

1.4 Sediment Microbiome

Microbial communities (also known as the "microbiome") provide important ecological and biogeochemical processes; therefore, microbial community profiling also reveals valuable information about any ecosystem (Egger et al., 2018). When combined with corresponding environmental metadata, microbiomes can provide source information about water masses and serve as indicators of degradation or alteration of water quality. Microbes also act as integral symbionts to most resident organisms, such as in sensitive ecosystems like coral reefs. For example, Peixoto et al. (2017) have shown certain microbial symbionts positively affect and protect coral species. O'Connell et al. (2018) conducted a weekly sampling of Port Everglades Inlet (PEI) surface waters and found a stable microbial composition, with increased microbial abundance and richness in the early spring and late summer months, most likely related to increased temperatures, ultraviolet radiation, and precipitation. Thus, understanding microbial dynamics positively impacts the health of human and resident marine life.

In 2020 and 2021, the Guy Harvey Oceanographic Center Marine Molecular Genomics (MMG) laboratory run by Dr. Jose Lopez was contracted by Florida Department of Environmental Protection (FDEP) to characterize PEI and proximal Florida Coral Reef surface sediments for Coral Reef Conservation Program (CRCP) project number 13 (CRCP 13). Results from CRCP 13 established baseline bacterial community characterizations and their patterns of diversity prior to and after maintenance dredging (Krausfeldt et al., 2023). Port Everglades sediment samples were collected from the PEI and surface sediments from the adjacent coral reef for two consecutive years, 2020 (Phase I, before maintenance dredging) and 2021 (Phase II, after maintenance dredging). Despite the proximity and tidal connections through the PEI, reef and port sediment microbial communities were distinct. Changes in microbial diversity within the intracoastal waterway, a route for community exchange or transfers, were the greatest after maintenance dredging occurred. Microbial diversity in reef sediments also changed after dredging, indicating potential influence from resuspended sediments due to an associated increase in heavy metals and decrease in cyanobacterial diversity. Determining physical factors that can affect microbiomes requires proper experimental design and attention to metadata (Knight et al, 2012). Sediments were identified as a possible source of human and coral pathogens, although dredging did not affect the relative abundances of these indicator microorganisms. This study highlighted the utility and relative ease of applying current molecular ecology methods to address macroscale questions with environmental management ramifications.

1.5 Coral Arsenic Dosing

In 2019 and 2023, Giarikos et al. (2023a, 2023b) conducted an analysis of sediment from Port Everglades, finding arsenic concentrations surpassing both the Threshold Effect Level (TEL) at 7.24 µg/g and the Probable Effect Level (PEL) at 41.6 µg/g. The geo-accumulation ecological index indicated moderate to strong contamination of arsenic in the port sediments. While these indices serve as overall indicators for arsenic contamination in marine benthic organisms, they lack specificity regarding coral. Arsenic exists in various species (speciation), and the specific species present in marine sediments remain unidentified.

In its inorganic forms, arsenic poses a lethal threat to the environment and organisms (Jaishankar et al., 2014). Its toxicity to marine organisms is intricate due to the presence of two inorganic arsenic species, arsenite (As(III)) and arsenate (As(V)), both commonly found in aquatic ecosystems (Liber et al., 2011). Arsenite, being more lipid-soluble, exhibits higher acute toxicity compared to arsenate (Spehar et al., 1980). In its organoarsenical form, arsenic is considered non-toxic to marine organisms. Two prevalent organic forms, methylarsonic acid (MMA) and dimethylarsinic acid (DMA), are frequently detected in seawater, marine sediments, and marine organism tissues. Marine bacteria, macroalgae, yeasts, and plants facilitate the reduction of accumulated arsenate to arsenite, which is then oxidized to form organoarsenicals MMA and DMA, which are subsequently excreted. This suggests that arsenic methylation might serve as a detoxification mechanism for marine organisms (Neff, 1997).

Current knowledge on the toxicity levels of each arsenic species (arsenite, arsenate, MMA, and DMA) to marine organisms is limited. Some studies have utilized arsenate to assess toxicity risks to anemone, barnacle, oyster, mussel, sea urchin, copepod, and snail larval development but have not evaluated the other three arsenic species (Golding et al., 2022). Several other studies have examined the toxicity of arsenite to juvenile bay scallops, amphipods, shrimp, and larvae of dungeness crab, while one study investigated the toxicity of arsenate to mysid and shrimp (Neff, 1997).

In this study we conducted semi-static 96-hour exposure assays separately testing the two inorganic arsenic species considered toxic to benthic organisms (arsenate and arsenite) with two coral species, *Acropora cervicornis* and *Orbicella faveolata*.

1.6 Synthesis of contaminant spatiotemporal and toxicological data

Gathering and consolidating existing regional data on the levels and spread of potentially harmful chemicals across the Florida Coral Reef (FCR) is extremely important. We can gain a comprehensive understanding of the environmental health status of the Florida Coral Reef ecosystem, information which is essential for assessing the potential risks posed by chemical pollutants to coral reefs and associated marine life. Since chemical contaminants can have detrimental effects on coral health, including coral bleaching, reduced growth rates, and increased susceptibility to diseases, gathering data helps in identifying specific threats to coral reefs within the FCR and prioritizing areas for conservation and management efforts. The information can also help to determine if contaminants originate from human activities such as industrial discharges, agricultural runoff, and urban development. By analyzing regional data on chemical levels, researchers can assess the extent of human impact on the FCR and advocate for sustainable practices to minimize pollution and protect coral reef ecosystems. Consolidating existing data allows researchers to track temporal trends in chemical contamination across the FCR. Long-term monitoring provides insights into changes in pollution levels, sources, and impacts on coral reef health, helping to guide adaptive management approaches and evaluate the effectiveness of conservation measures. The data, analysis, and evidence-based recommendations support informed conservation management decisions and will be widely disseminated via incorporation into Florida's Department of Environmental Protection's (FDEP) coral reef decision support system (CRDSS).

2. METHODOLOGY

Permits for sediment core collection were provided by Broward County (Environmental Resource License # DF22-1259), U.S. Army Corps of Engineers (# SAJ-2022-03494), Florida Department of State Historical Resources (# 2022-7512), Florida Department of Environmental Protection Division of Recreation and Parks (#11302215 and #1218315), and Florida Department of Environmental Protection (#06-427980-001,002-EE).

2.1 Statistics

Statistical analyses were performed on the ecological indices (geo-accumulation, pollution load, potential ecological risk, enrichment factor) on all port sediment core depths and reef sediment from Phase 1 of FDEP project (agreement #C0FEDD) collected heavy metal data. Heavy metal concentrations were compared to TEL, PEL, and background continental crust values to determine the minimal potential ecological contamination (to 95% confidence).

Statistical analyses were conducted in R v. 4.4.0 (2024 Release) and in Microsoft Excel 365 (2019 release). Statistical significance was determined as $p < 0.05$. For all indices at all depths, a one-sided 95% T-confidence interval was used to determine the lower 95% confidence bound for that index. Those values were compared to reference values for a determination of the minimal potential contamination (to 95% confidence). Differences among replicate cores were determined using matched pairs T-tests with Bonferroni-Holms (B-H) correction and significance level 0.05. For statistical purposes, half of the limit of detection was used for non-detected (nd) samples.

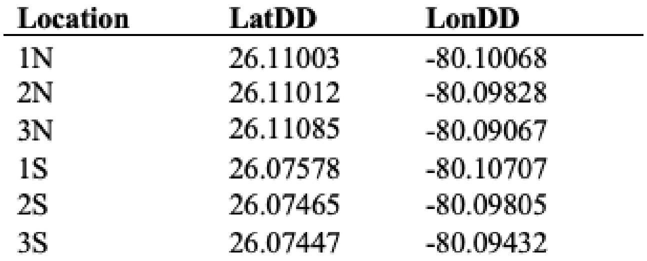
Relative abundance of bacteria and copies per million (CPM) of Gene Ontology (GO) terms representing functional potential from the CosmosID HUB were downloaded and analyzed using R (v. 4.3.2). Differences in alpha diversity of bacteria between sites were examined using Shannon Index, Inverse Simpson, Evenness, and Observed Species within the vegan package using a one-way ANOVA followed by Tukey multiple comparisons of means. Functional diversity was calculated using Observed Species with one-way ANOVA followed by Tukey multiple comparisons of means. Relationships with site and metal concentrations with beta diversity (microbial community composition) and functional composition were determined using PERMANOVA within the vegan package. Differential abundance analysis with the package and function Maaslin2 was performed to determine specific taxa and functions that correlated to site and metal concentrations. Metal correlations were performed with location as a fixed effect to remove co-variate factor of site.

2.2 Sediment Sampling from Coral Reef Traps

A total of 54 surface sediment samples, triplicates at each site, were collected from sediment traps (Fig. 1) on three different occasions by the dive team at six reef sites approximately 1.5 km north (1N, 2N, 3N) and south (1S, 2S, 3S) of the inlet to Port Everglades (Fig. 2 and Table 1). The sediments were placed in 5-gallon buckets and taken to the lab for the total weight per sediment trap. The sediments were homogenized to compare 14 heavy metal (Al, As, Cd, Co, Cu, Fe, Mn, Mo, Ni, Pb, Se, Sn, V, and Zn) concentration variations within each site, as marine sediments are subject to dispersal by water movement (Wang and Andutta, 2012), and processed for molecular genetics.

Figure 1. Constructed platform with ST-30 sediment trap and Aqua TROLL 600 sonde.

Table 1. Locations of sediment traps and AquaTroll 600 sondes in latitude and longitude.



Location	LatDD	LonDD
1N	26.11003	-80.10068
2N	26.11012	-80.09828
3N	26.11085	-80.09067
1S	26.07578	-80.10707
2S	26.07465	-80.09805
3S	26.07447	-80.09432

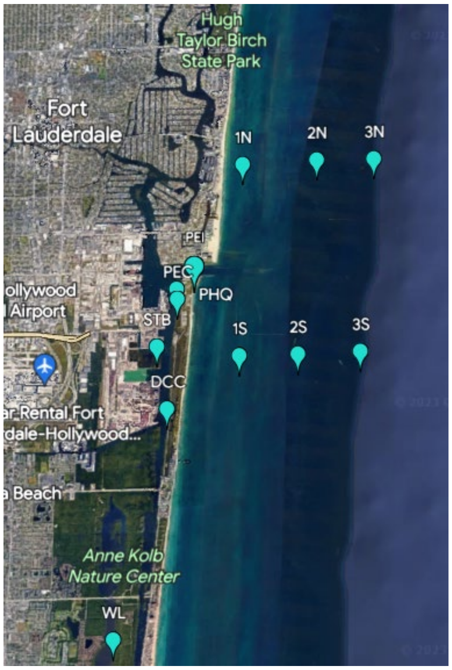


Figure 2. Map of Port Everglades study site showing the Intracoastal Waterway, Port Everglades, sediment core, and surface sample locations. Port Everglades Inlet (PEI), Park Education Center (PEC), Park Headquarters (PHQ), South Turning Basin (STB), Dania Cut-Off Canal (DCC), West Lake (WL), north coral reef sites – 1N, 2N, 3N, and south coral reef sites – 1S, 2S, 3S.

2.3 Collection of Abiotic Data from Aqua TROLL 600 Sondes and Calibrations

In-Situ Aqua TROLL 600 multiparameter sondes outfitted with temperature, conductivity (salinity), pressure, dissolved oxygen, pH, and turbidity sensors were mounted on anchored platforms at the same six reef sites (1N, 2N, 3N, 1S, 2S, 3S) where the surface sediment was sampled (Fig. 1 and Table 1). Water chemistry data, including temperature, conductivity (salinity), pressure, dissolved oxygen, pH, and turbidity, were recorded hourly by each of the six sondes. Sonde sensors were calibrated, and data downloaded to an Android phone every 1-2 months. All calibrations were performed according to the standard quality assurance plan for DEP agreement. The data was then extracted into Excel spreadsheets.

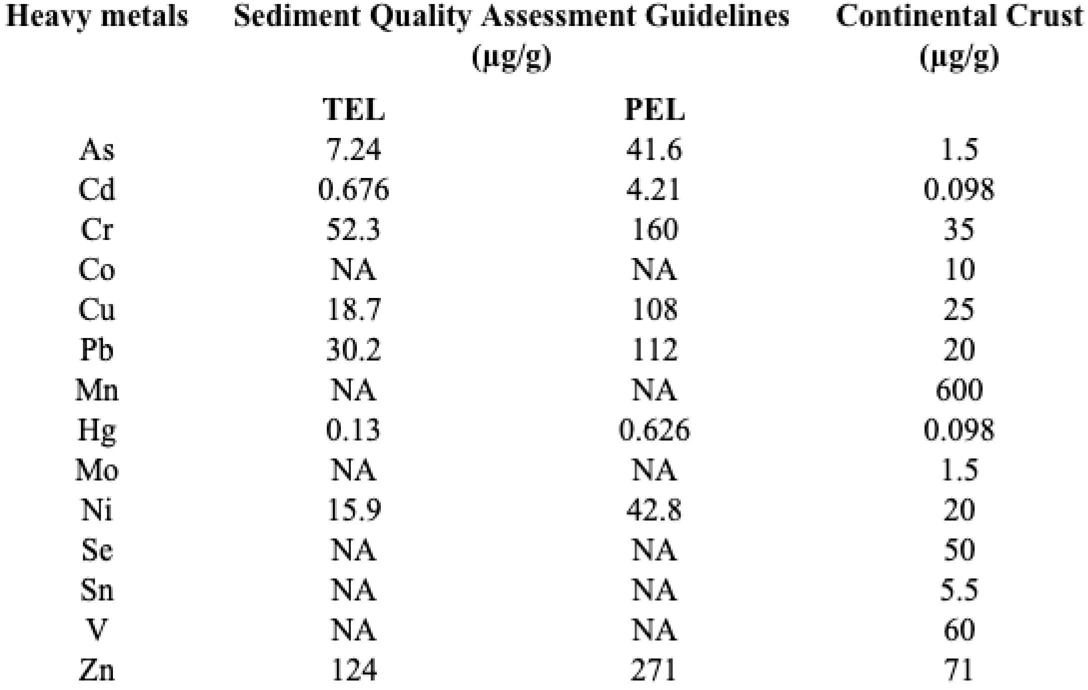
2.4 Digestion and Analysis

Each sediment sample taken from sediment traps was homogenized in the lab and sealed in a 100 mL polypropylene digestion tube. The sediment tubes were shipped to the NELAC-certified (E87982) Brooks Applied Lab in Seattle, WA. The samples were digested using the US Environmental Protection Agency (EPA) digestion method 3050B (EPA 1996). Heavy metal analyses of Al, As, Cd, Co, Cu, Fe, Pb, Mo, Mn, Ni, Se, Sn, V, and Zn were performed using an inductively coupled plasma mass spectrometer (ICP-MS). Deionized water equipment blanks were collected from the polypropylene containers used to digest the sediment and from the polypropylene containers used to store the sediments for microbiome studies. The blanks were analyzed for all 14 heavy metals.

2.5 Continental Crust Composition

The elemental composition of the Earth’s upper crust, also called background elemental composition concentration, is used to assess geochemical anomalies (heavy metal contamination) (Table 2). Since comprehensive background values for marine sediments for all 14 heavy metals have not been determined for this area, the concentrations were compared to continental crust values derived from the post-Archean Australian average shale (PAAS), European shale composite (ES), and North American shale composite (NASC) (Taylor and McLennan, 1995; Al-Mutairi and Yap, 2021).

Table 2. Threshold Effect Level (TEL), Probable Effect Level (PEL), and continental crust values. NA is not available.



Heavy metals	Sediment Quality Assessment Guidelines (μg/g)		Continental Crust (μg/g)
	TEL	PEL	
As	7.24	41.6	1.5
Cd	0.676	4.21	0.098
Cr	52.3	160	35
Co	NA	NA	10
Cu	18.7	108	25
Pb	30.2	112	20
Mn	NA	NA	600
Hg	0.13	0.626	0.098
Mo	NA	NA	1.5
Ni	15.9	42.8	20
Se	NA	NA	50
Sn	NA	NA	5.5
V	NA	NA	60
Zn	124	271	71

2.6 Geo-accumulation Index

The geo-accumulation index (I_{geo}) is a quantitative measure of the degree of contamination in sediments (Förstner, 1980) and was used here to measure the pollution intensity at individual sample locations. The I_{geo} is calculated as follows:

$$I_{geo} = \log_2 ((C_n/(1.5xB_n))$$

C_n = concentrations within the sediment cores and B_n = background continental crust levels. Rudnick and Gao (2014) provide values that quantify the degree of contamination: 4 - 5: strongly to extremely contaminated; 3 - 4: strongly contaminated; 2 - 3: moderately to strongly contaminated; 1 - 2: moderately contaminated; 0 - 1: uncontaminated to moderately contaminated; < 0: uncontaminated.

2.7 Pollution Load Index

The pollution load index (PLI) was developed by Tomlinson et al. (1980) and is calculated using contamination factors (CF), represented by the concentrations of the sample metals and the background continental crust values $C_{metal}/C_{background}$. The calculation for PLI is:

$$PLI = (CF_1 \text{ x } CF_2 \text{ x} CF_3 \text{ x } \ldots CF_n)^{1/n}$$

where n = number of elements. This approach assesses total contamination load within the sediment and provides a PLI value that explains overall metal pollution within each sample. A sample with a $PLI > 1$ is classified as polluted while a sample with a $PLI < 1$ indicates no contamination (Tomlinson et al., 1980; Ray et al., 2006; Badr et al., 2009).

2.8 Threshold Effect Level (TEL) and Probable Effect Level (PEL)

The Florida Department of Environmental Protection created sediment quality assessment guidelines (SQAGs) to address coastal ecosystem contamination concerns. Numerical SQAGs were derived for nine metals (As, Cd, Cr, Cu, Hg, Ni, Pb, tributyltin, Zn) that occur in Florida coastal sediments (MacDonald et al., 1996; Table 3). A threshold effect level (TEL) and probable effect level (PEL) were developed for these metals as powerful tools to assess contaminant levels in sediment (MacDonald and Ingersoll, 1993; MacDonald et al., 1996). The TEL is the concentration below which adverse effects rarely occur to benthic organisms, while the PEL is the concentration above which adverse effects frequently occur (Thompson and Wasserman, 2015; Geoenvironmental Engineering, 2015).

2.9 Potential Ecological Risk Index

The potential ecological risk index (PER) determines the degree of contamination for combined metal concentrations within each sediment sample (Guo et al., 2010). The PER is calculated as:

$$PER = \Sigma E$$

$$E = TC$$

$$C = C_a/C_b$$

where C_a = element content within sample, C_b = reference value of the element, and T = toxic response factor for metals: Mn and Zn = 1, Cr = 2, Cu and Pb = 5, Ni = 6, As = 10, and Cd = 30 (Hakanson, 1980; Fu et al., 2009; Guo et al., 2010; Cao et al., 2015).

2.10 Enrichment Factor (EF)

The enrichment factor (EF) ascertains whether heavy metals in sediments are of anthropogenic origin. EF is a means of quantifying the enrichment of potentially contaminant-derived heavy metals in sediment relative to a defined background composition using Fe and Al as the reference metals (Zoller et al., 1974). The EF is calculated as:

$$EF = [(C_n/C_{ref})] / [(B_n/B_{ref})]$$

C_n is concentration of the examined element in the sediment; C_{ref} is concentration of the examined element in the Earth's crust (upper continental crust); B_n is the concentration of the reference element (Al or Fe) in the sediment; B_{ref} is the concentration of the reference element (Al or Fe) in the Earth's crust (upper continental crust). The degree of enrichment is quantified as follows: < 2 deficiency to minimal enrichment, 2 < EF < 5 moderate enrichment, 5 < EF < 20 significant enrichment, 20 < EF < 40 very high enrichment, and EF > 40 extremely high enrichment.

2.11 16SrRNA Gene Amplicon Microbiome Analyses

Microbial genomic DNA/RNA that can be used for both 16S amplicon and metagenomics (and metatranscriptomics) was extracted from sediment samples following the routine protocol for the QIAGEN DNEasy PowerLyzer PowerSoil Kit (100). For DNA extraction, the manufacturer's protocols were followed. Purified DNAs were quantified using a Qubit 4.0.

16S rRNA gene amplicons were sequenced using standard Earth Microbiome Project protocols for the Illumina MiSeq platform in the MMG Laboratory (Thompson et al., 2017; Eason and Lopez, 2019; Krausfeldt and Lopez et al, 2023). The 515F and 806R primers were used to amplify the ~300bp sequence of the V3 and V4 region of the 16S gene (Caporaso et al., 2011; Eason and Lopez, 2019) The PCR products were then cleaned using AMPure XP beads. This process is used to purify the 16S V3 and V4 amplicon away from free primers and primer dimer species. The final DNA (and RNA) concentrations were checked to high precision using a Qubit® 4.0 Fluorometer. Once concentrations were obtained, each sample was then diluted to a normalization of 4 pM. All the samples were library pooled and rechecked on the Qubit to make sure the concentration was between 4-6 ng/µL. If the pool passes then a final quality check was done using an Agilent 4150TS Tapestation, which checks the quality of DNA and for any possible contamination. The pooled DNA product was loaded into the Illumina MiSeq for 16S metagenomic DNA using the MiSeq Reagent Kit v3 at 600 cycles of sequencing following a modified Illumina workflow protocol. All DNA samples were prepared for library preparation and sequencing on an Illumina NextSeq or HiSeq at CosmosID.

2.12 Sequence Data Analyses

Once 16S rRNA gene amplicon sequencing was completed, detailed alpha and beta diversity were assessed using the statistical software QIIME2 and R Studio following routine methods performed in the Lopez laboratory of Halmos College of Arts and Sciences (HCAS) for analysis of other sample types such as South Florida surface water samples (Campbell et al, 2015; O'Connell et al., 2018; Easson and Lopez, 2019; Krausfeldt and Lopez et al., 2023), deep-sea anglerfish (Freed et al., 2019), sharks (Karns et al., 2017), sponges (Cuvelier et al., 2014) and bacterioplankton in coordination with the DEEPEND consortium (Easson and Lopez, 2019).

The Quantitative Insights into Microbial Ecology v.2 (QIIME2) pipeline was used to demultiplex, quality filter, assign taxonomy, reconstruct phylogeny, and produce diversity analysis and visualizations from the FASTQ DNA sequence files (Caporaso et al., 2011). Quality filtering and data trimming was conducted in DADA2 using the "dada2 denoise" command, which was then used to create a feature-table. The QIIME2-generated sequences were assigned taxonomy through a learned SILVA classifier (silva-132-99- 515-806-nb-classifier.qza).

The R Studio statistical software packages “vegan” and “phyloseq” were utilized to assess diversity between samples (McMurdie Holmes, 2013; Oksanen et al., 2018). Alpha diversity, which describes the species richness and evenness within a sampling location, was looked at for each sample. This was determined using multiple measures such as Observed and Chao1 for species richness estimators and Shannon and Inverse Simpson indices for relative abundance diversity (Lande, 1996; Kim et al. 2017). Statistical differences between samples will be calculated after normality determination using Analysis of Variance (ANOVA) or Kruskal-Wallis one-way analysis of variance test.

2.13 Metagenomic Methods

All sediment samples were stored immediately after subsampling at -80º C until they were needed for DNA extractions. Purified genomic DNA samples were sent to a high throughput sequencing vendor, CosmosID. Partial analyses have been applied with the CosmosID online analysis hub using bacterial databases. Reads from metagenomes generated from sediment samples collected were trimmed and filtered for quality using bbduk within the bbtools package (minlen=25, trimq=20, qtrim=rl ref=adapters.fa) (Bushnell, 2014). Reads were taxonomically annotated on the CosmosID-HUB (https://docs.cosmosid.com/docs/methods). Metagenomes were also co-assembled by location in Kbase using MegaHit v1.2.9 (Li et al., 2016).

Relative abundance of bacteria and copies per million (CPM) of Gene Ontology (GO) terms representing functional potential from the CosmosID HUB were downloaded and analyzed using R (v4.3.2). Differences in alpha diversity of bacteria between sites was examined using Shannon Index, Inverse Simpson, Evenness, and Observed Species within the vegan package using a one-way ANOVA followed by Tukey multiple comparisons of means. Functional diversity was calculated using Observed Species with one-way ANOVA followed by Tukey multiple comparisons of means. Relationships between metals and alpha diversity or functional diversity were analyzed using the corplot package and Spearman correlations. Relationships with site and metal concentrations with beta diversity (microbial community composition) and functional composition were determined using PERMANOVA within the vegan package. Differential abundance analysis with the package and function Maaslin2 was performed to determine specific taxa and functions that correlated to site and metal concentrations.

2.14 Arsenic Dosing

2.14.1. **Experimental organisms.**

For *Acropora cervicornis*, branch tips (4 cm in length) were cut from multiple colonies of *A. cervicornis* maintained in the NSU Onshore Coral Nursery and immediately attached with a minimal amount of cyanoacrylate gel glue to small (2 cm diameter) numbered ceramic bases. For *Orbicella faveolata*, colony fragments (2 x 2 cm) were cut using a wet bandsaw and attached with a minimal amount of cyanoacrylate gel glue to small (2 cm diameter) numbered ceramic bases. All corals were allowed to heal in the 1100 L indoor coral culture system for a minimum of 2 weeks. Corals were fed a commercial coral-specific amino acid solution (Brightwell Aquatics CoralAmino) and particulate food (Brightwell ReefBlizzard-S) 3x per week. Artificial seawater (prepared from RO/DI water and Tropic Marin Classic™ sea salt) was used; the system was maintained at 35 PSU and 25°C, with artificial light provided by Radion XR30 Pro (Ecotech Marine) LED lights (12 h photoperiod, programmed sunrise and sunset, max PAR 220 µmol m-2 sec-1).

2.14.2. Experiment design.

Six treatments were used for each exposure, including a negative (seawater only) control and five concentrations of arsenate (As (V)) (nominally 0.06, 0.18, 0.55, 1.6, and 5 mg/L) or arsenite (As (III)) (nominally 0.03, 0.09, 0.27, 0.83, and 2.5 mg/L), with six replicate test chambers (glass, 2 L, stirred) per treatment and two corals per replicate chamber. Treatments and corals were randomly assigned to test chambers. Exposure media for each test concentration was prepared in large media bottles by adding a calculated amount of arsenate stock solution to 6.1 L of filtered (to 1 µm) seawater sourced from the indoor coral culture system. Test solutions were stirred at 300 rpm on 10” stir plates for 1 hour, then 1 L of test solution was added to each replicate beaker, and two corals were placed in each chamber to begin the 96-h exposure. New test solutions were prepared and exchanged daily (100%) after the corals were assessed. Each chamber was covered during the experiment to limit evaporation. Illumination was provided by Radion® XR30 Pro (Ecotech Marine) LED lights (12 h photoperiod, programmed sunrise and sunset). Dissolved oxygen, pH, temperature, and salinity were measured daily in all test vessels. The concentration of arsenate or arsenite in the exposures was quantified in samples collected at the beginning (T0) (from samples collected from each exposure media bottle), and after 24 hours (T24) (from samples collected from two randomly selected chambers of each concentration) to assess changes in the concentration of As species over time. Samples were collected in accordance with the protocol specified by Brooks Applied Laboratories, and samples were shipped to Brooks via FedEx Priority Overnight after the T24 samples were collected. Brooks Applied Lab (NELAC ID #E87892) tested the As speciation using EPA Method 1632 and hydride generation and quartz furnace atomic absorption detection to determine the As species concentrations.

2.14.3. Coral assessment.

During the exposure, coral condition was assessed at 12, 24, 48, 72, and 96 hours after exposure initiation. The condition of each coral was semi-quantitatively scored [including color, polyp extension/retraction, tissue swelling/distension, and mucus production, on a scale of 0 (normal limits) to 3 (severely affected)]. Percent recent mortality was visually estimated concurrent with coral condition observations. Dark-adapted photosynthetic efficiency measurements (Fv/Fm), taken with a pulse amplitude modulated fluorometer (Diving-PAM, Walz, Germany) at the beginning and end of the 96-h exposure was used as an indicator of the physiological status of the autotrophic endosymbiotic zooxanthellae.

2.14.4. Acute toxicity thresholds.

Log-logistic 4-parameter dose-response models were used to estimate threshold concentrations for mortality (LC50), physical effect ($EC50_{Condition}$, based on coral condition scores), and inhibition of photosynthetic efficiency ($IC50_{Yield}$, based on Fv/Fm). To estimate the arsenate concentration that resulted in a 50% effect on coral condition, the individual scores for each criterion were summed, and the $EC50_{Condition}$ estimated from mean percent effect. To estimate the arsenate concentration that inhibited photosynthetic efficiency by 50% ($IC50_{Yield}$), the dark-adapted maximum quantum yield (Fv/Fm) (measured prior to and after 96 h of exposure) were used, expressed as the percentage of pre-exposure yield for each coral.

2.15 Synthesis of contaminant spatiotemporal and toxicological data

2.15.1. Contaminant spatiotemporal data.

Geospatial databases for 12 contaminant classes, consisting of over 2.9 million data points for water and sediments, and covering over 32,000 sites in the five Florida counties encompassing FCR (Broward, Miami-Dade, Palm Beach, Martin, and Monroe), were compiled from the National Water Quality Monitoring Council's Water Quality Portal, which combines data from the United States Geological Survey (USGS), the National Water Information System (NWIS), EPA's Storage and Retrieval Data Warehouse (STORET), and the Department of Agriculture's Sustaining the Earth's Watersheds Agricultural Research Database System (STEWARDS). Data was also collected from NWQMC, MusselWatch, NOAA's National Status and Trends, and peer-reviewed literature. These databases contain information about projects from the Florida Fish and Wildlife Conservation Commission, the Florida Department of Environmental Protection, the National Park Service, the Environmental Protection Agency, and others. In order to have a full picture of water quality entering the Florida coral Reef system, all sites labeled as "Ocean," "Estuary," "Stream," "Wetland," and "Lake/Reservoir" were included in these databases; the files are separated by contaminant type and contain data points ranging from the early 1900s (depending on the contaminant) to December 2023.

Within each database, datapoints were categorized by date range (pre-1940, 1940-1949, 1950-1959, 1960-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2009, 2010-2019, and 2020-2029) to facilitate evaluation of temporal tends. Individual analytes were further categorized by contaminant class to facilitate hazard assessment. Chemical/contaminant classes are groupings that relate chemicals by similar features, such as structural similarity, uses, or physical properties. Contaminant class was assigned based on OECD and EPA Toxic Substances Control Act (TSCA) recommendations. Measurements were also subdivided by media (water or sediment).

2.15.2. Coral toxicological data.

Concurrently, toxicological data for scleractinian corals was compiled from the EPA Ecotox database and peer reviewed literature for the same range of contaminant classes. These two datasets were then compared to establish existing knowledge gaps in both environmental monitoring data and contaminant effects on corals, and to identify any emerging contaminants of concern along the FCR. Where toxicological data for corals was not available, dat**a for related organisms (i.e., another cnidarian) was used to evaluate potential hazard, and where environmental data was not available, then potential sources and likelihood of occurrence for key contaminants was evaluated to estimate exposure risk.**

3. RESULTS/DISCUSSION

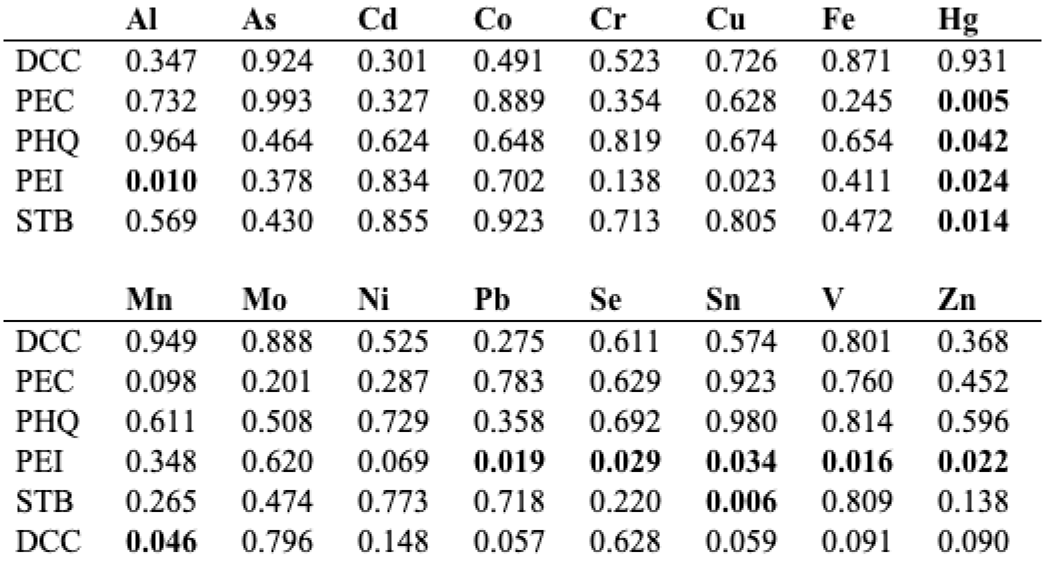
3.1 Statistical Analysis on the Differences of Port Sediment Triplicate Cores from the Same Locations from Phase I

Ninety-six Kruskal-Wallis statistical analyses tests were performed for 5 port locations (DCC, PEC, PHQ, PEI, STB) and one control site (WL) for 16 heavy metals, determining differences between the three (triplicate) sediment cores collected (core 1 vs core 2 vs core 3) at the same sites from the Phase I 2023 DEP agreement C0FEDD. The length of each core was different, so the variability of depth was ignored in the analyses.

The PEI location stood out because the three cores had differences for Al, Hg, Pb, Se, Sn, V, and Zn. Unfortunately, the PEI cores were not representative of any of the port sediment cores because it was determined that the sediment of the PEI was sand that has been used for beach renourishment in that area. Overall, the three cores per all other locations had very few differences.

The cores from PEC and PHQ had significant differences only for Hg, while the STB cores had differences for Hg and Sn. The WL control location had significant differences for Cu and Mn (Table 3).

Table 3. The p-values of a Kruskal-Wallis test performed for the 5 sediment core locations (DCC, PEC, PHQ, PLI, STB) and control site (WL) for 16 heavy metals, looking at differences between cores. Bolded values indicate statistically significant differences.



	Al	As	Cd	Co	Cr	Cu	Fe	Hg
DCC	0.347	0.924	0.301	0.491	0.523	0.726	0.871	0.931
PEC	0.732	0.993	0.327	0.889	0.354	0.628	0.245	**0.005**
PHQ	0.964	0.464	0.624	0.648	0.819	0.674	0.654	**0.042**
PEI	**0.010**	0.378	0.834	0.702	0.138	0.023	0.411	**0.024**
STB	0.569	0.430	0.855	0.923	0.713	0.805	0.472	**0.014**

	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
DCC	0.949	0.888	0.525	0.275	0.611	0.574	0.801	0.368
PEC	0.098	0.201	0.287	0.783	0.629	0.923	0.760	0.452
PHQ	0.611	0.508	0.729	0.358	0.692	0.980	0.814	0.596
PEI	0.348	0.620	0.069	**0.019**	**0.029**	**0.034**	**0.016**	**0.022**
STB	0.265	0.474	0.773	0.718	0.220	**0.006**	0.809	0.138
DCC	**0.046**	0.796	0.148	0.057	0.628	0.059	0.091	0.090

3.2 Statistical Analysis on Geo-accumulation Index and Heavy Metal Data of Port Cores and Reef Sediment from Phase I

Statistical analyses were performed to determine if any of the 16 heavy metals in the port cores and the coral reef sites from the samples collected in 2023 from the Phase I DEP agreement C0FEDD had any significant geo-accumulation values for the specific metals with 95% confidence.

Only two heavy metals (As and Mo) had significant geo-accumulation index values. All statistical analyses performed used a 95% confidence interval lower bound (CI LB) and all the results are discussed based on the CI LB.

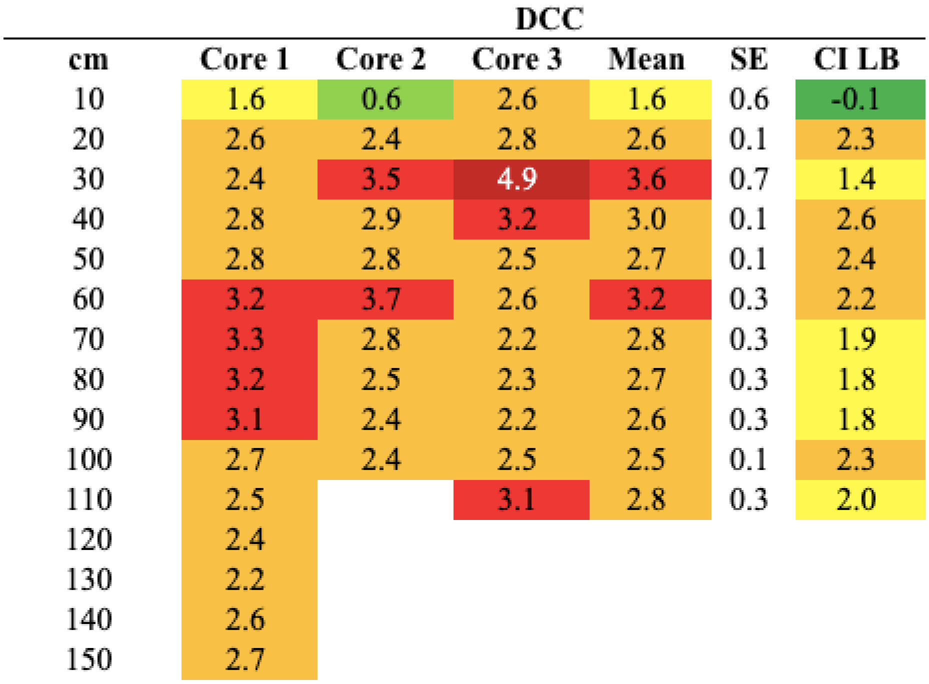
Overall, As geo-accumulation values indicated that all sediment cores except for PEI had some type of contamination, while the reef sites were overall uncontaminated (Tables 4-10). The PEI cores were mainly sand that has been used for beach renourishment in that area, so they showed no significant geo-accumulation results. Molybdenum geo-accumulation values showed that the DCC, STB, and PHQ cores had some form of contamination while the PEC, PEI, and WL cores and reef sites were overall uncontaminated (Tables 11-17).

The PEC cores were overall uncontaminated with As except at the 120 – 150 cm depths. The PHQ cores showed moderate As contamination, while the DCC and STB cores indicated moderate to strong As contamination. Surprisingly, the control site, WL, had strong to extreme As contamination, which indicates that As has been accumulating in that location either through the canals or through atmospheric deposition.

Molybdenum contamination was less prominent than As, but still a matter of concern. The DCC cores were overall uncontaminated with Mo except for the 30-40 cm depths, while the PHQ cores varied per depth with moderate to strong Mo contamination between 30 – 90 cm and overall uncontaminated to moderate contamination for the rest of the depths. The STB cores had the highest Mo geo-accumulation values indicating strong to extremely high contamination.

In addition, all 3 cores were compared for differences in their geo-accumulation index for As and Mo per location. There were no observed statistically significant differences between the As and Mo geo-accumulation indices in the 3 cores per location and the reef sites except between core 1 and core 3 for PEI (Tables 18-19).

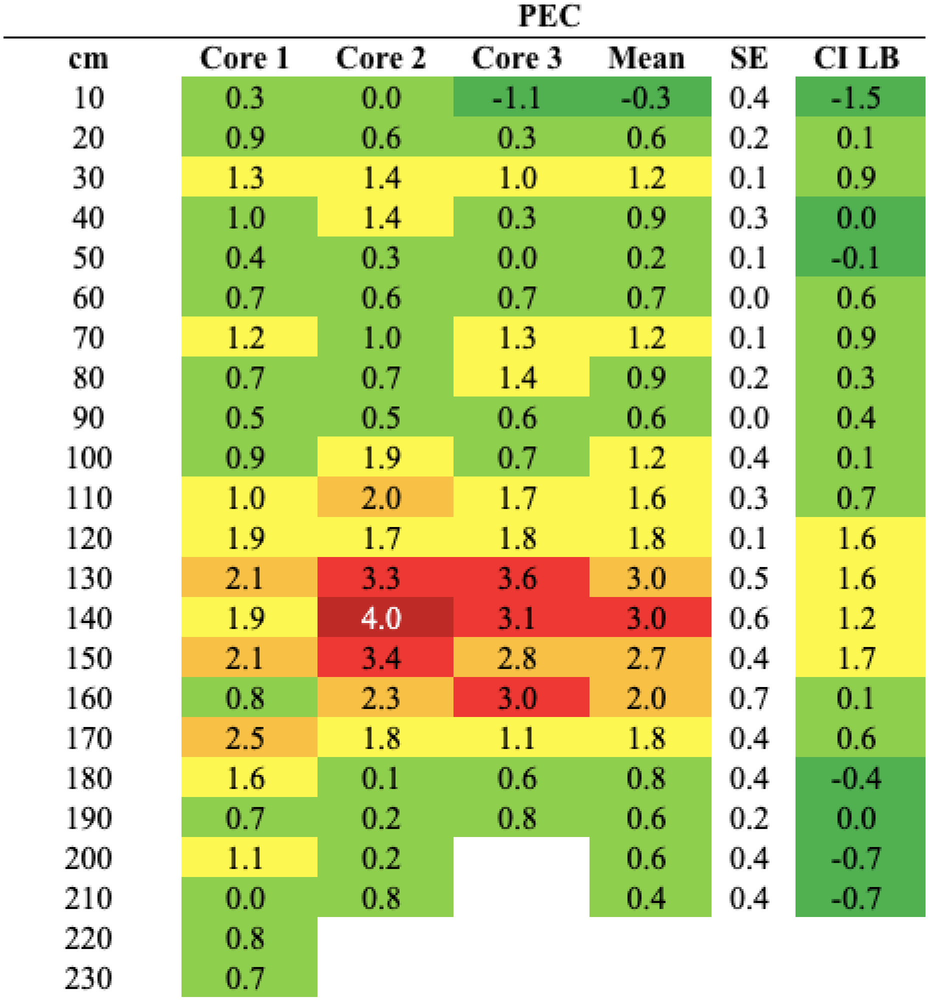
Table 4. Geo-accumulation indices for arsenic (As) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Dania Cutoff Canal (DCC). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.



			DCC			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	1.6	0.6	2.6	1.6	0.6	-0.1
20	2.6	2.4	2.8	2.6	0.1	2.3
30	2.4	3.5	4.9	3.6	0.7	1.4
40	2.8	2.9	3.2	3.0	0.1	2.6
50	2.8	2.8	2.5	2.7	0.1	2.4
60	3.2	3.7	2.6	3.2	0.3	2.2
70	3.3	2.8	2.2	2.8	0.3	1.9
80	3.2	2.5	2.3	2.7	0.3	1.8
90	3.1	2.4	2.2	2.6	0.3	1.8
100	2.7	2.4	2.5	2.5	0.1	2.3
110	2.5		3.1	2.8	0.3	2.0
120	2.4					
130	2.2					
140	2.6					
150	2.7					

Table 5. Geo-accumulation indices for arsenic (As) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Park Education Center (PEC). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely

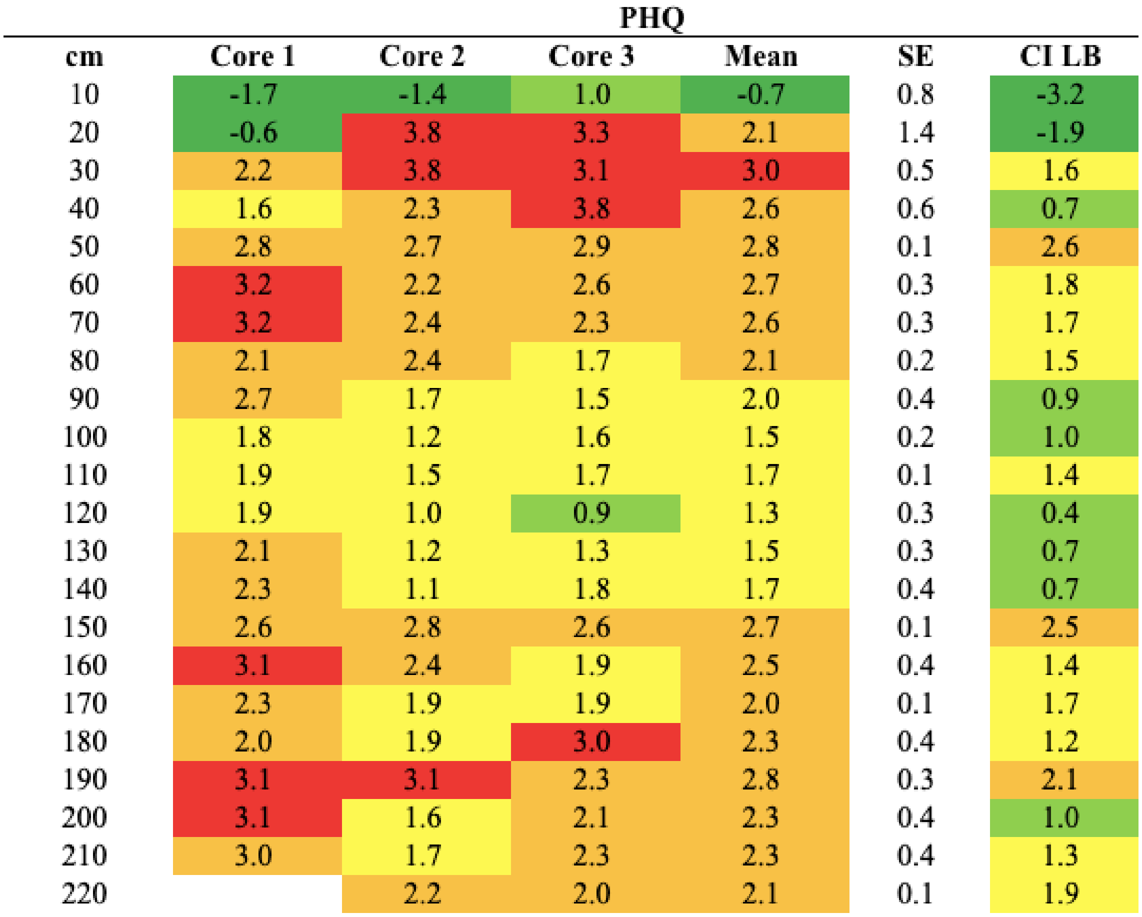
contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.



			PEC			
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	0.3	0.0	-1.1	-0.3	0.4	-1.5
20	0.9	0.6	0.3	0.6	0.2	0.1
30	1.3	1.4	1.0	1.2	0.1	0.9
40	1.0	1.4	0.3	0.9	0.3	0.0
50	0.4	0.3	0.0	0.2	0.1	-0.1
60	0.7	0.6	0.7	0.7	0.0	0.6
70	1.2	1.0	1.3	1.2	0.1	0.9
80	0.7	0.7	1.4	0.9	0.2	0.3
90	0.5	0.5	0.6	0.6	0.0	0.4
100	0.9	1.9	0.7	1.2	0.4	0.1
110	1.0	2.0	1.7	1.6	0.3	0.7
120	1.9	1.7	1.8	1.8	0.1	1.6
130	2.1	3.3	3.6	3.0	0.5	1.6
140	1.9	4.0	3.1	3.0	0.6	1.2
150	2.1	3.4	2.8	2.7	0.4	1.7
160	0.8	2.3	3.0	2.0	0.7	0.1
170	2.5	1.8	1.1	1.8	0.4	0.6
180	1.6	0.1	0.6	0.8	0.4	-0.4
190	0.7	0.2	0.8	0.6	0.2	0.0
200	1.1	0.2		0.6	0.4	-0.7
210	0.0	0.8		0.4	0.4	-0.7
220	0.8					
230	0.7					

Table 6. Geo-accumulation indices for arsenic (As) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Park Headquarters (PHQ). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated

(0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

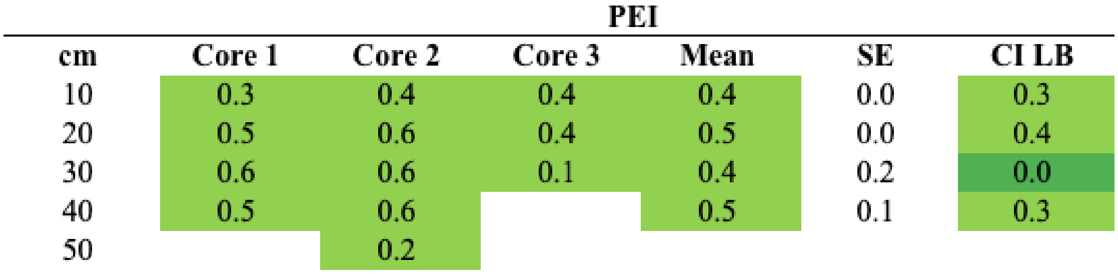


PHQ

cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	-1.7	-1.4	1.0	-0.7	0.8	-3.2
20	-0.6	3.8	3.3	2.1	1.4	-1.9
30	2.2	3.8	3.1	3.0	0.5	1.6
40	1.6	2.3	3.8	2.6	0.6	0.7
50	2.8	2.7	2.9	2.8	0.1	2.6
60	3.2	2.2	2.6	2.7	0.3	1.8
70	3.2	2.4	2.3	2.6	0.3	1.7
80	2.1	2.4	1.7	2.1	0.2	1.5
90	2.7	1.7	1.5	2.0	0.4	0.9
100	1.8	1.2	1.6	1.5	0.2	1.0
110	1.9	1.5	1.7	1.7	0.1	1.4
120	1.9	1.0	0.9	1.3	0.3	0.4
130	2.1	1.2	1.3	1.5	0.3	0.7
140	2.3	1.1	1.8	1.7	0.4	0.7
150	2.6	2.8	2.6	2.7	0.1	2.5
160	3.1	2.4	1.9	2.5	0.4	1.4
170	2.3	1.9	1.9	2.0	0.1	1.7
180	2.0	1.9	3.0	2.3	0.4	1.2
190	3.1	3.1	2.3	2.8	0.3	2.1
200	3.1	1.6	2.1	2.3	0.4	1.0
210	3.0	1.7	2.3	2.3	0.4	1.3
220		2.2	2.0	2.1	0.1	1.9

Table 7. Geo-accumulation indices for arsenic (As) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Port Everglades Inlet (PEI). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly

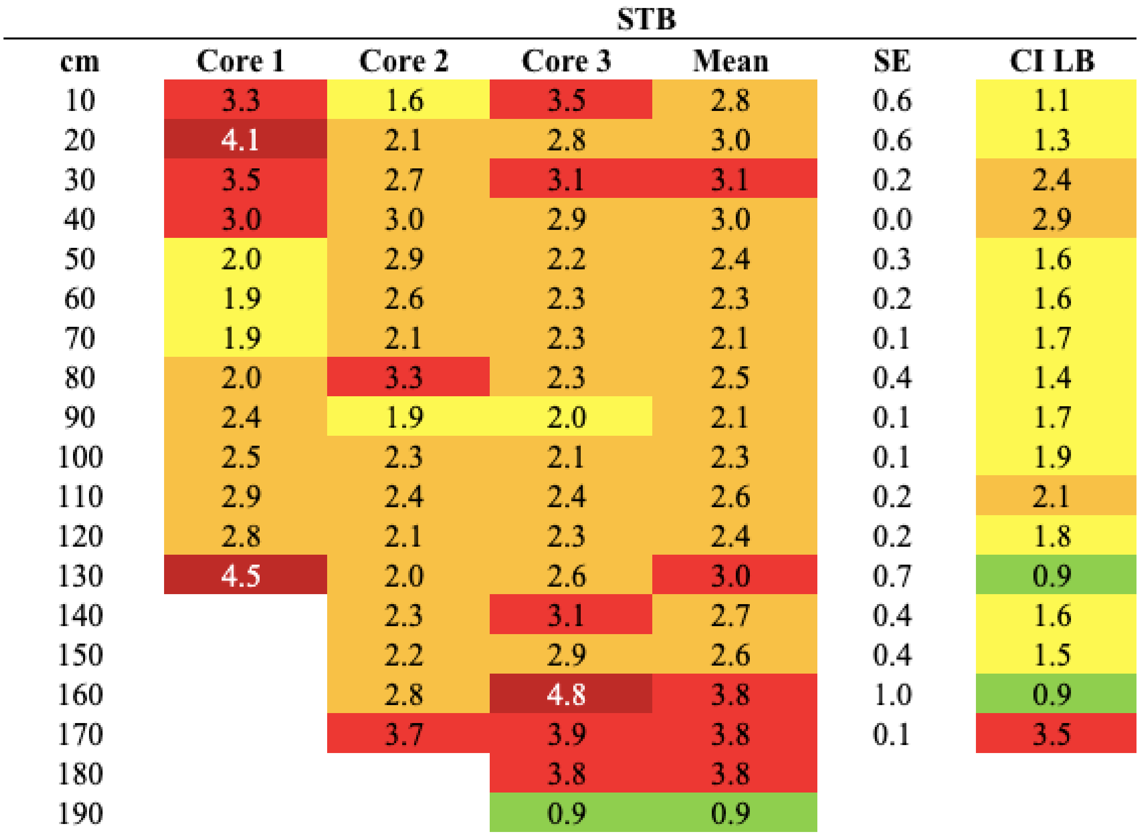
contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.



PEI

cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	0.3	0.4	0.4	0.4	0.0	0.3
20	0.5	0.6	0.4	0.5	0.0	0.4
30	0.6	0.6	0.1	0.4	0.2	0.0
40	0.5	0.6		0.5	0.1	0.3
50		0.2				

Table 8. Geo-accumulation indices for arsenic (As) of each sediment core (core 1, core 2 and core 3) per depth (cm) from South Turning Basin (STB). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.



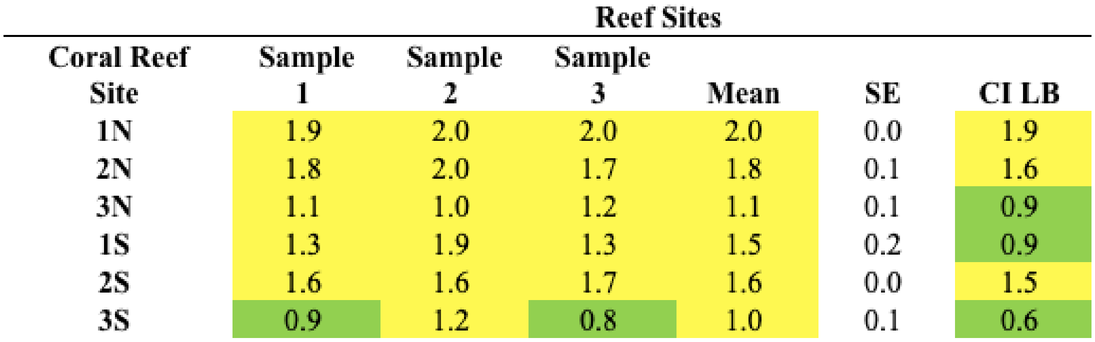
			STB			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	3.3	1.6	3.5	2.8	0.6	1.1
20	4.1	2.1	2.8	3.0	0.6	1.3
30	3.5	2.7	3.1	3.1	0.2	2.4
40	3.0	3.0	2.9	3.0	0.0	2.9
50	2.0	2.9	2.2	2.4	0.3	1.6
60	1.9	2.6	2.3	2.3	0.2	1.6
70	1.9	2.1	2.3	2.1	0.1	1.7
80	2.0	3.3	2.3	2.5	0.4	1.4
90	2.4	1.9	2.0	2.1	0.1	1.7
100	2.5	2.3	2.1	2.3	0.1	1.9
110	2.9	2.4	2.4	2.6	0.2	2.1
120	2.8	2.1	2.3	2.4	0.2	1.8
130	4.5	2.0	2.6	3.0	0.7	0.9
140		2.3	3.1	2.7	0.4	1.6
150		2.2	2.9	2.6	0.4	1.5
160		2.8	4.8	3.8	1.0	0.9
170		3.7	3.9	3.8	0.1	3.5
180			3.8	3.8		
190			0.9	0.9		

Table 9. Geo-accumulation indices for arsenic (As) of each sediment core (core 1, core 2 and core 3) per depth (cm) from West Lake (WL). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5,

dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

			WL			
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	3.5	3.4	3.7	3.5	0.1	3.2
20	3.0	2.8	3.0	2.9	0.1	2.7
30	3.0	3.1	4.1	3.4	0.4	2.3
40	5.0	3.2	4.1	4.1	0.5	2.5
50	3.8	3.2	3.5	3.5	0.2	2.9
60	3.6	3.0	2.7	3.1	0.3	2.3
70	2.9	3.8		3.3	0.5	2.0
80	3.7	3.8		3.7	0.1	3.5

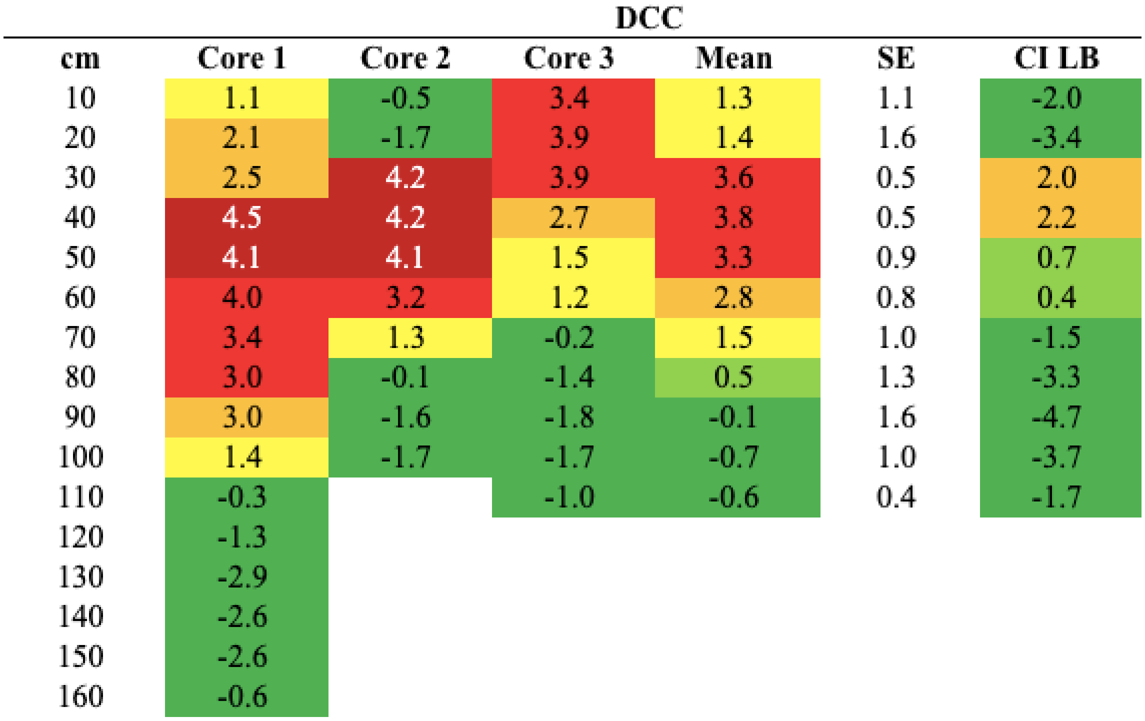
Table 10. Geo-accumulation indices for arsenic (As) of each surface sediment collection (sample 1, sample 2 and sample 3) from traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.



			Reef Sites			
Coral Reef Site	Sample 1	Sample 2	Sample 3	Mean	SE	CI LB
1N	1.9	2.0	2.0	2.0	0.0	1.9
2N	1.8	2.0	1.7	1.8	0.1	1.6
3N	1.1	1.0	1.2	1.1	0.1	0.9
1S	1.3	1.9	1.3	1.5	0.2	0.9
2S	1.6	1.6	1.7	1.6	0.0	1.5
3S	0.9	1.2	0.8	1.0	0.1	0.6

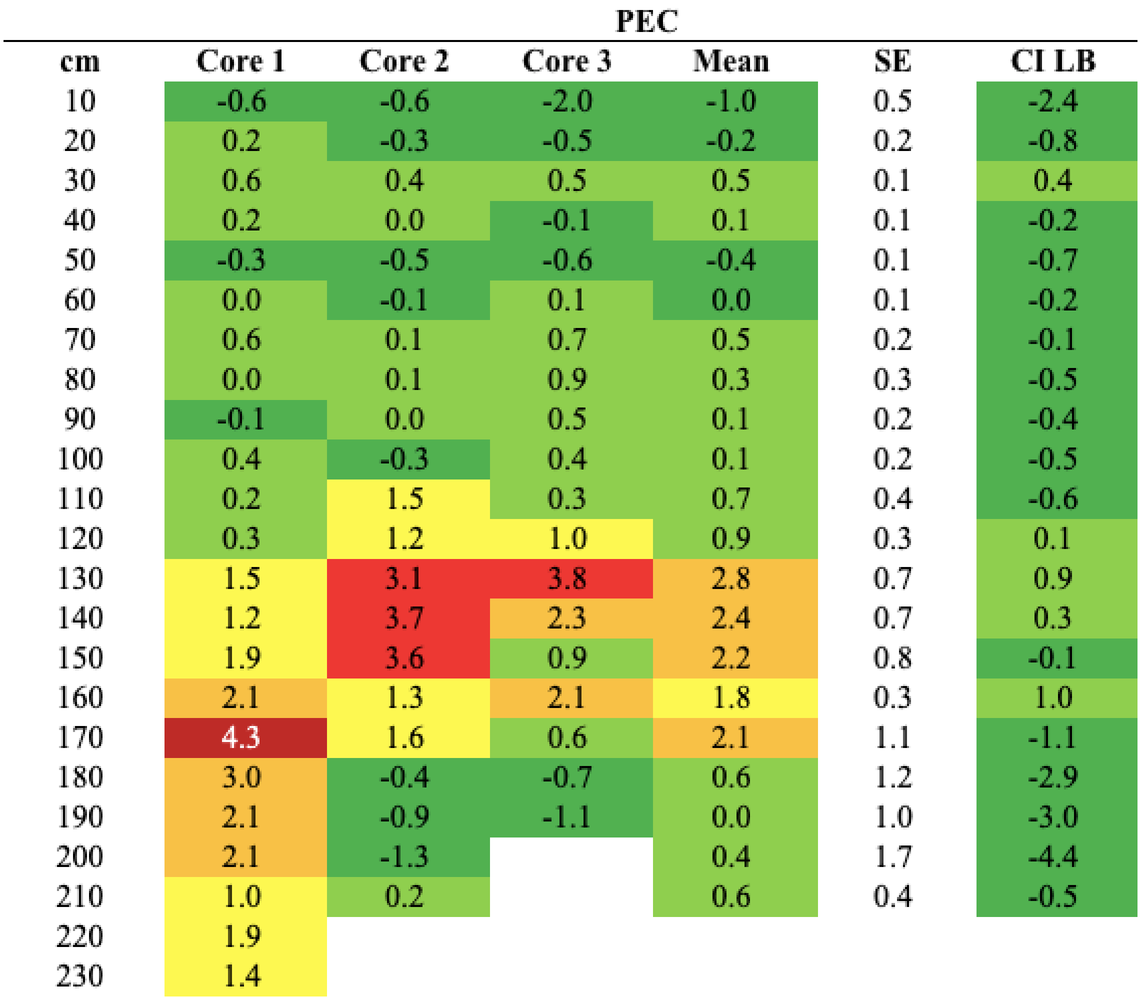
Table 11. Geo-accumulation indices for molybdenum (Mo) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Dania Cutoff Canal (DCC). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to

strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.



			DCC			
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	1.1	-0.5	3.4	1.3	1.1	-2.0
20	2.1	-1.7	3.9	1.4	1.6	-3.4
30	2.5	4.2	3.9	3.6	0.5	2.0
40	4.5	4.2	2.7	3.8	0.5	2.2
50	4.1	4.1	1.5	3.3	0.9	0.7
60	4.0	3.2	1.2	2.8	0.8	0.4
70	3.4	1.3	-0.2	1.5	1.0	-1.5
80	3.0	-0.1	-1.4	0.5	1.3	-3.3
90	3.0	-1.6	-1.8	-0.1	1.6	-4.7
100	1.4	-1.7	-1.7	-0.7	1.0	-3.7
110	-0.3		-1.0	-0.6	0.4	-1.7
120	-1.3					
130	-2.9					
140	-2.6					
150	-2.6					
160	-0.6					

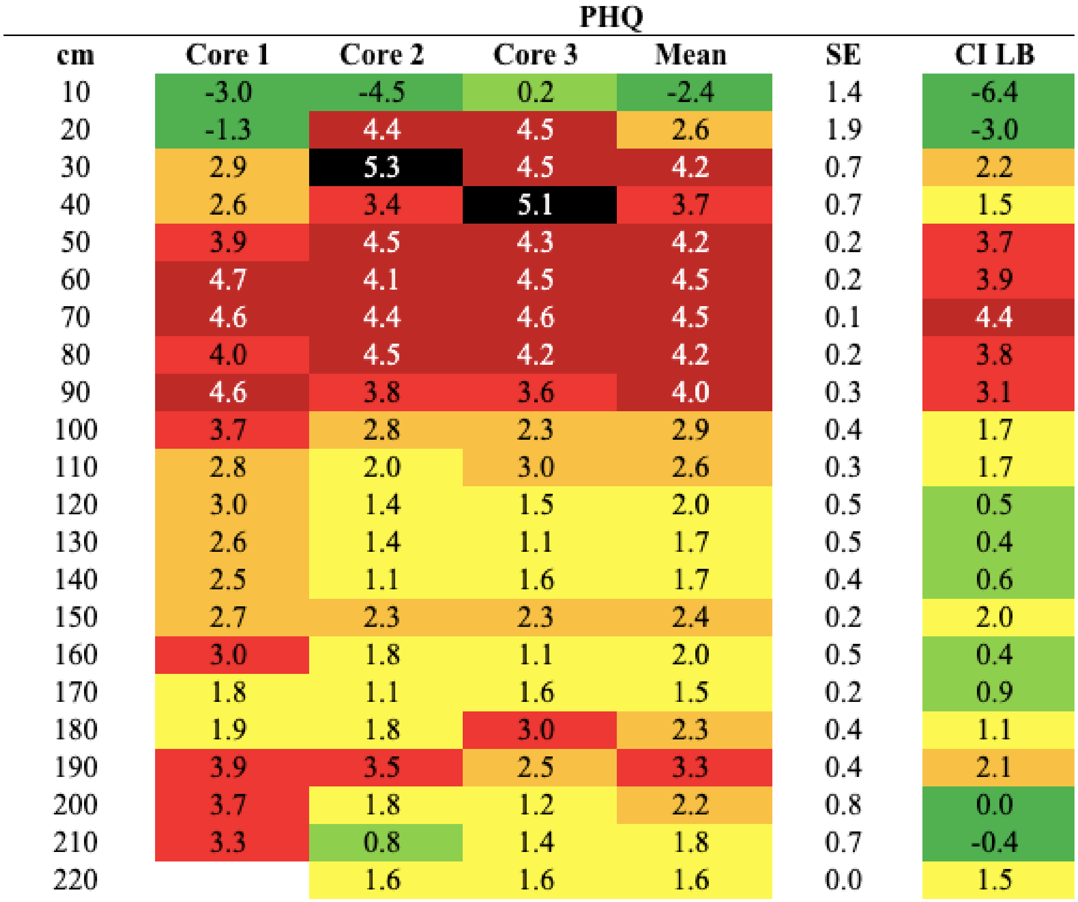
Table 12. Geo-accumulation indices for molybdenum (Mo) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Park Education Center (PEC). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.



			PEC			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	-0.6	-0.6	-2.0	-1.0	0.5	-2.4
20	0.2	-0.3	-0.5	-0.2	0.2	-0.8
30	0.6	0.4	0.5	0.5	0.1	0.4
40	0.2	0.0	-0.1	0.1	0.1	-0.2
50	-0.3	-0.5	-0.6	-0.4	0.1	-0.7
60	0.0	-0.1	0.1	0.0	0.1	-0.2
70	0.6	0.1	0.7	0.5	0.2	-0.1
80	0.0	0.1	0.9	0.3	0.3	-0.5
90	-0.1	0.0	0.5	0.1	0.2	-0.4
100	0.4	-0.3	0.4	0.1	0.2	-0.5
110	0.2	1.5	0.3	0.7	0.4	-0.6
120	0.3	1.2	1.0	0.9	0.3	0.1
130	1.5	3.1	3.8	2.8	0.7	0.9
140	1.2	3.7	2.3	2.4	0.7	0.3
150	1.9	3.6	0.9	2.2	0.8	-0.1
160	2.1	1.3	2.1	1.8	0.3	1.0
170	4.3	1.6	0.6	2.1	1.1	-1.1
180	3.0	-0.4	-0.7	0.6	1.2	-2.9
190	2.1	-0.9	-1.1	0.0	1.0	-3.0
200	2.1	-1.3		0.4	1.7	-4.4
210	1.0	0.2		0.6	0.4	-0.5
220	1.9					
230	1.4					

Table 13. Geo-accumulation indices for molybdenum (Mo) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Park Headquarters (PHQ). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to

extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.



			PHQ			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	-3.0	-4.5	0.2	-2.4	1.4	-6.4
20	-1.3	4.4	4.5	2.6	1.9	-3.0
30	2.9	5.3	4.5	4.2	0.7	2.2
40	2.6	3.4	5.1	3.7	0.7	1.5
50	3.9	4.5	4.3	4.2	0.2	3.7
60	4.7	4.1	4.5	4.5	0.2	3.9
70	4.6	4.4	4.6	4.5	0.1	4.4
80	4.0	4.5	4.2	4.2	0.2	3.8
90	4.6	3.8	3.6	4.0	0.3	3.1
100	3.7	2.8	2.3	2.9	0.4	1.7
110	2.8	2.0	3.0	2.6	0.3	1.7
120	3.0	1.4	1.5	2.0	0.5	0.5
130	2.6	1.4	1.1	1.7	0.5	0.4
140	2.5	1.1	1.6	1.7	0.4	0.6
150	2.7	2.3	2.3	2.4	0.2	2.0
160	3.0	1.8	1.1	2.0	0.5	0.4
170	1.8	1.1	1.6	1.5	0.2	0.9
180	1.9	1.8	3.0	2.3	0.4	1.1
190	3.9	3.5	2.5	3.3	0.4	2.1
200	3.7	1.8	1.2	2.2	0.8	0.0
210	3.3	0.8	1.4	1.8	0.7	-0.4
220		1.6	1.6	1.6	0.0	1.5

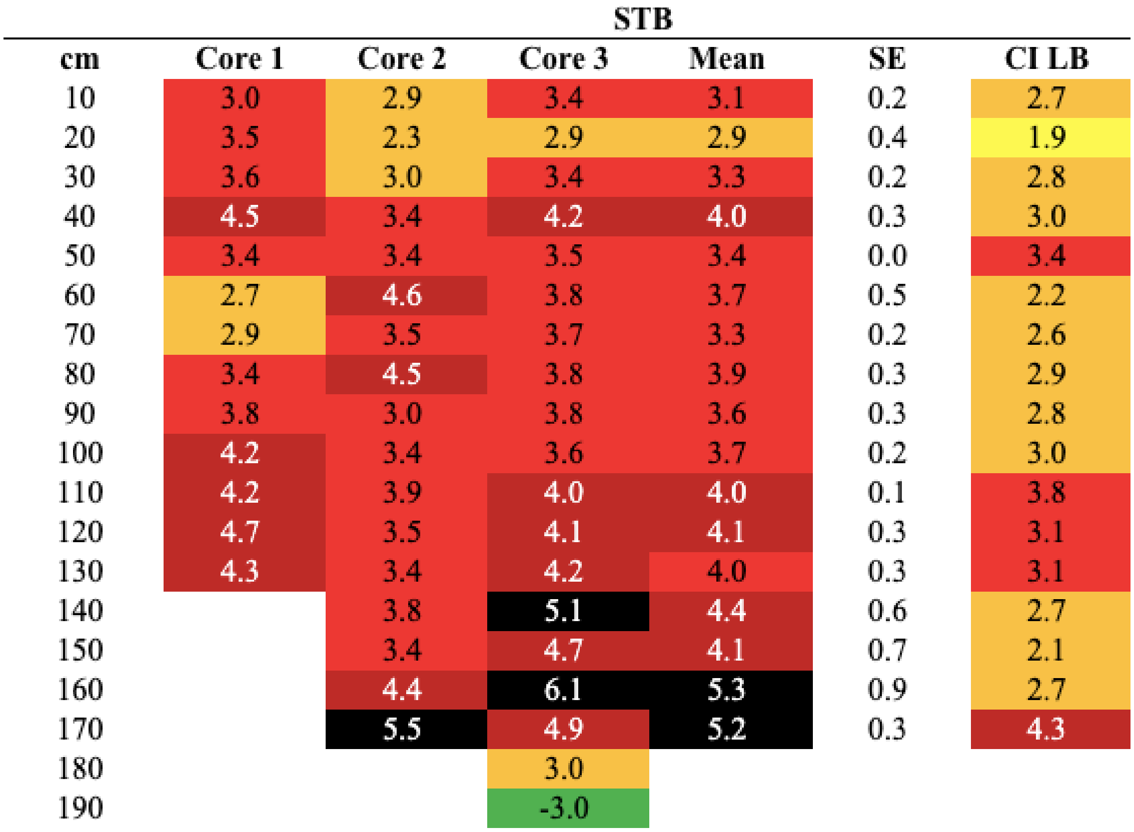
Table 14. Geo-accumulation indices for molybdenum (Mo) of each sediment core (core 1, core 2 and core 3) per depth (cm) from Port Everglades Inlet (PEI). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to

extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

	PEI					
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	-4.6	-5.3	-4.8	-4.9	0.2	-5.5
20	-4.8	-5.2	-5.0	-5.0	0.1	-5.3
30	-4.9	-4.7	-5.0	-4.9	0.1	-5.1
40	-5.0	-4.7		-4.9	0.2	-5.4
50		-5.5				

Table 15. Geo-accumulation indices for molybdenum (Mo) of each sediment core (core 1, core 2 and core 3) per depth (cm) from South Turning Basin (STB). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to

extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.



			STB			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	3.0	2.9	3.4	3.1	0.2	2.7
20	3.5	2.3	2.9	2.9	0.4	1.9
30	3.6	3.0	3.4	3.3	0.2	2.8
40	4.5	3.4	4.2	4.0	0.3	3.0
50	3.4	3.4	3.5	3.4	0.0	3.4
60	2.7	4.6	3.8	3.7	0.5	2.2
70	2.9	3.5	3.7	3.3	0.2	2.6
80	3.4	4.5	3.8	3.9	0.3	2.9
90	3.8	3.0	3.8	3.6	0.3	2.8
100	4.2	3.4	3.6	3.7	0.2	3.0
110	4.2	3.9	4.0	4.0	0.1	3.8
120	4.7	3.5	4.1	4.1	0.3	3.1
130	4.3	3.4	4.2	4.0	0.3	3.1
140		3.8	5.1	4.4	0.6	2.7
150		3.4	4.7	4.1	0.7	2.1
160		4.4	6.1	5.3	0.9	2.7
170		5.5	4.9	5.2	0.3	4.3
180			3.0			
190			-3.0			

Table 16. Geo-accumulation indices for molybdenum (Mo) of each sediment core (core 1, core 2 and core 3) per depth (cm) from West Lake (WL). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely

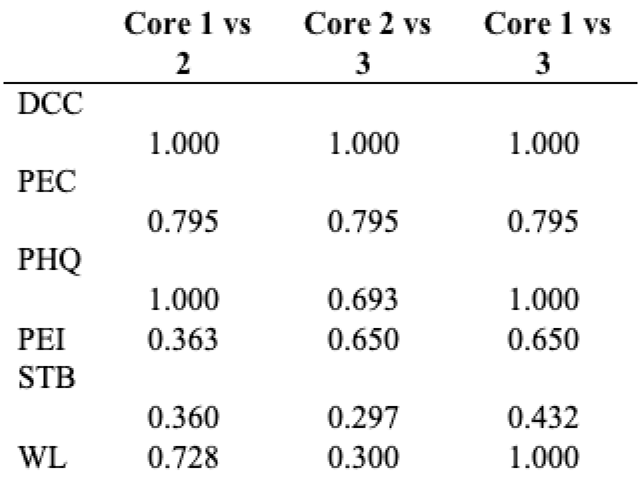
contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

WL						
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	-0.9	-1.1	0.1	-0.6	0.4	-1.7
20	-0.2	-1.0	-0.8	-0.7	0.2	-1.3
30	-1.0	-1.5	-1.0	-1.2	0.2	-1.7
40	-0.9	-1.4	-1.6	-1.3	0.2	-1.9
50	-2.1	-1.0	-2.4	-1.8	0.4	-3.0
60	-2.5	-1.2	-3.5	-2.4	0.7	-4.3
70	-3.6	-1.2		-2.4	1.2	-5.9
80	-3.3	0.5		-1.4	1.9	-7.0

Table 17. Geo-accumulation indices for molybdenum (Mo) of each surface sediment collection (sample 1, sample 2 and sample 3) per depth (cm) from traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound.

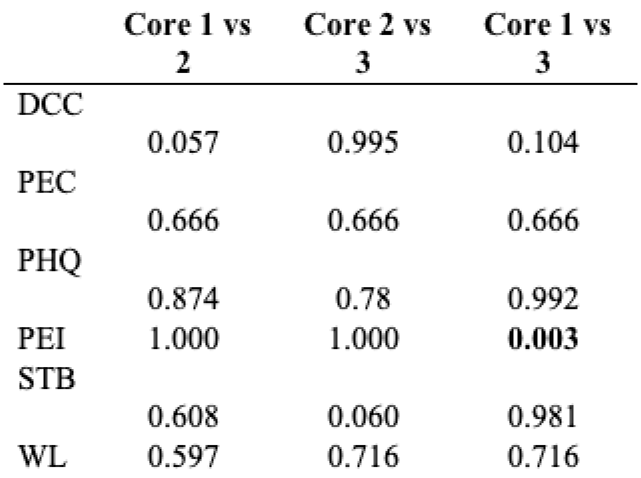
Reef Sites						
Coral Reef Site	**Sample 1**	**Sample 2**	**Sample 3**	**Mean**	**SE**	**CI LB**
1N	-3.3	-3.3	-3.2	-3.3	0.0	-3.4
2N	-3.5	-3.3	-3.5	-3.4	0.1	-3.6
3N	-3.2	-3.6	-3.4	-3.4	0.1	-3.7
1S	-3.6	-3.5	-3.9	-3.7	0.1	-4.0
2S	-3.7	-3.5	-3.5	-3.6	0.1	-3.8
3S	-3.3	-3.4	-3.7	-3.5	0.1	-3.8

Table 18. B-H corrected p-values for the geo-accumulation index of arsenic (As). Bolded values indicate statistically significant differences between cores collected at the same site ($p < 0.05$).



	Core 1 vs 2	Core 2 vs 3	Core 1 vs 3
DCC	1.000	1.000	1.000
PEC	0.795	0.795	0.795
PHQ	1.000	0.693	1.000
PEI	0.363	0.650	0.650
STB	0.360	0.297	0.432
WL	0.728	0.300	1.000

Table 19. B-H corrected p-values for the geo-accumulation index of molybdenum (Mo). Bolded values indicate statistically significant differences between cores collected at the same site ($p < 0.05$).



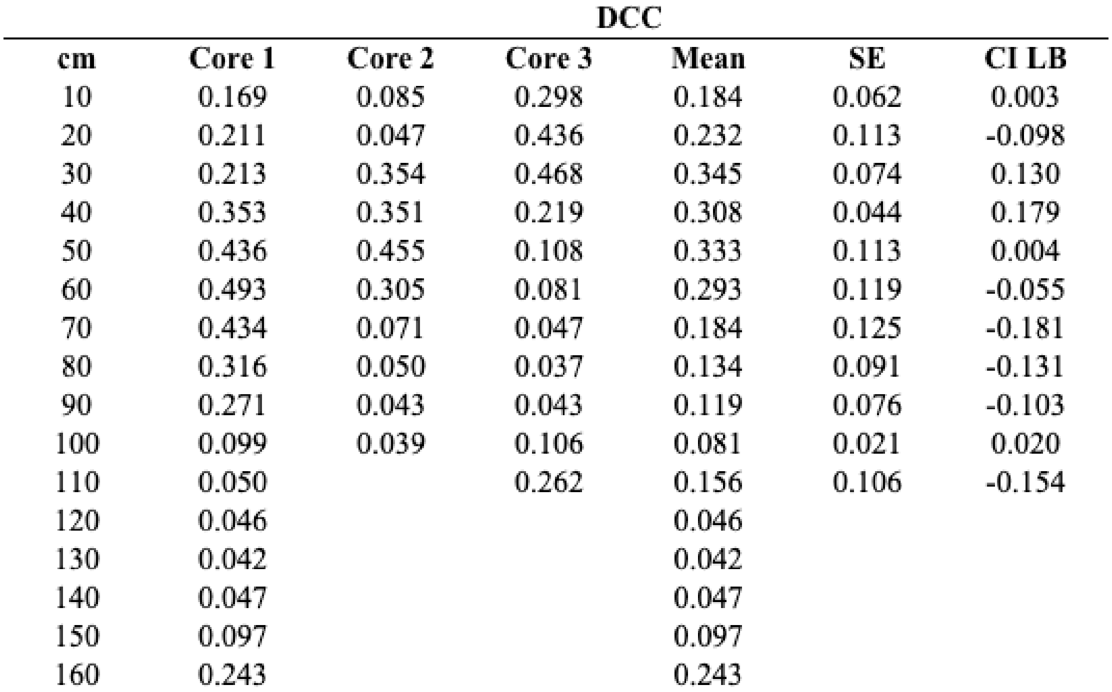
	Core 1 vs 2	Core 2 vs 3	Core 1 vs 3
DCC	0.057	0.995	0.104
PEC	0.666	0.666	0.666
PHQ	0.874	0.78	0.992
PEI	1.000	1.000	**0.003**
STB	0.608	0.060	0.981
WL	0.597	0.716	0.716

3.3 Statistical Analysis on Pollution Load Index and Heavy Metal Data of Port Cores and Reef Sediment from Phase I

Statistical analyses were performed to determine if any of the three sediment cores collected per site (port cores and the control site, as well as the three sediment grabs per location at the coral reef sites) collected in 2023 from the Phase I DEP agreement C0FEDD had any significant pollution load index values. All statistical analyses performed used a 95% confidence interval lower bound (CI LB) and all of the results are discussed based on the CI LB.

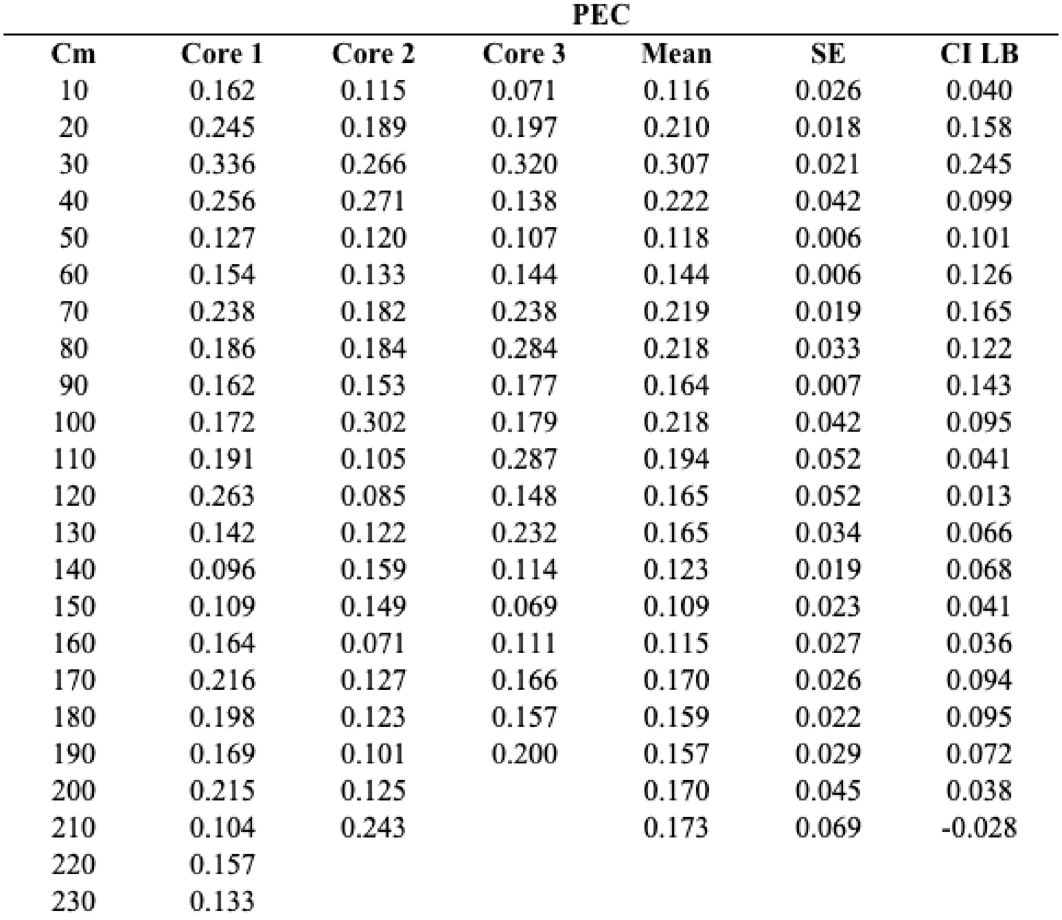
The results, shown in tables 20-26, indicated that the pollution load index of the cores showed no heavy metal pollution. In addition, there was no indication that there were any significant differences between the PLI and the three sediment cores per location (Table 27).

Table 20. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). PLI >1 (highlighted red) is considered polluted. SE = standard error and CI LB = 95% confidence interval lower bound.



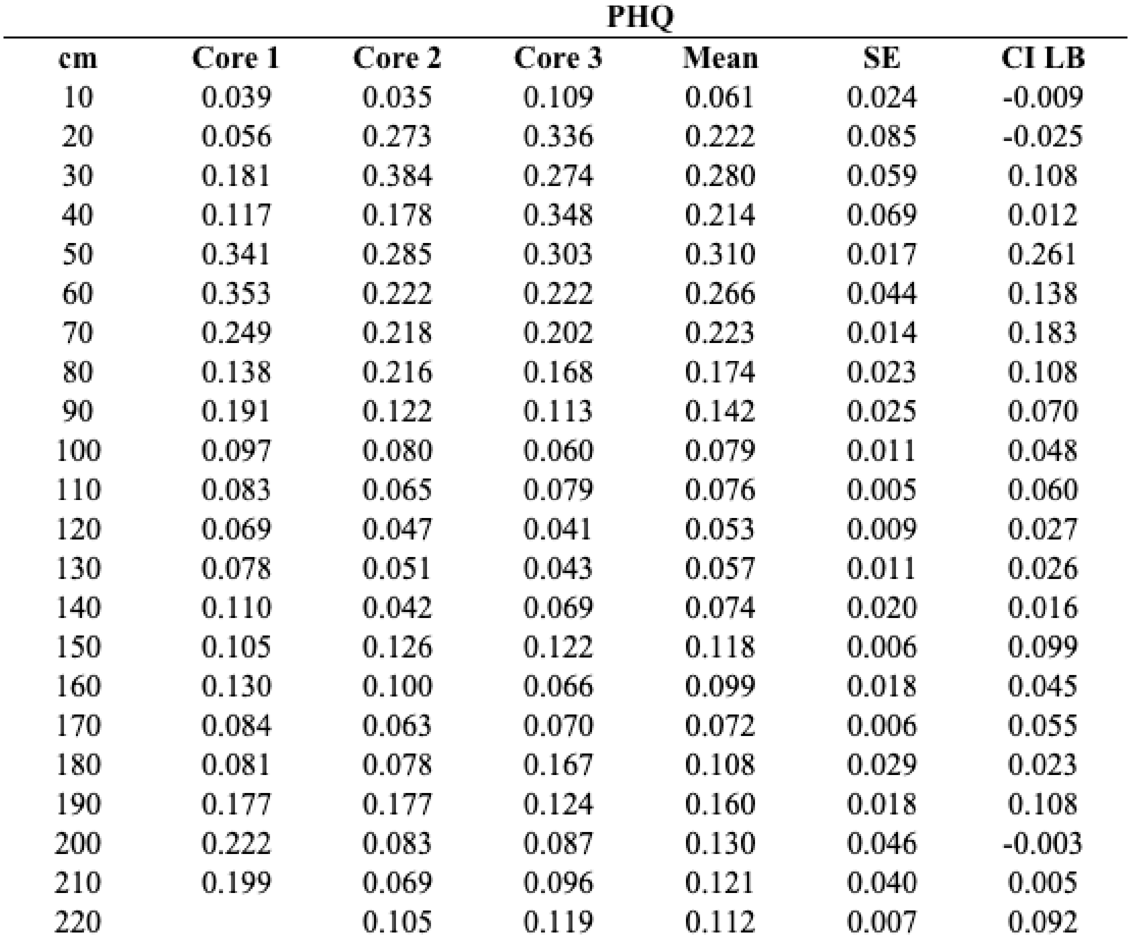
			DCC			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.169	0.085	0.298	0.184	0.062	0.003
20	0.211	0.047	0.436	0.232	0.113	-0.098
30	0.213	0.354	0.468	0.345	0.074	0.130
40	0.353	0.351	0.219	0.308	0.044	0.179
50	0.436	0.455	0.108	0.333	0.113	0.004
60	0.493	0.305	0.081	0.293	0.119	-0.055
70	0.434	0.071	0.047	0.184	0.125	-0.181
80	0.316	0.050	0.037	0.134	0.091	-0.131
90	0.271	0.043	0.043	0.119	0.076	-0.103
100	0.099	0.039	0.106	0.081	0.021	0.020
110	0.050		0.262	0.156	0.106	-0.154
120	0.046			0.046		
130	0.042			0.042		
140	0.047			0.047		
150	0.097			0.097		
160	0.243			0.243		

Table 21. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). PLI>1 (highlighted red) is considered polluted) SE = standard error and CI LB = 95% confidence interval lower bound.



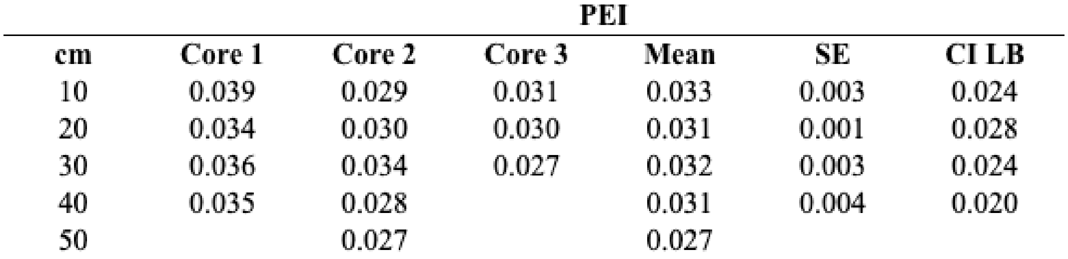
			PEC			
Cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.162	0.115	0.071	0.116	0.026	0.040
20	0.245	0.189	0.197	0.210	0.018	0.158
30	0.336	0.266	0.320	0.307	0.021	0.245
40	0.256	0.271	0.138	0.222	0.042	0.099
50	0.127	0.120	0.107	0.118	0.006	0.101
60	0.154	0.133	0.144	0.144	0.006	0.126
70	0.238	0.182	0.238	0.219	0.019	0.165
80	0.186	0.184	0.284	0.218	0.033	0.122
90	0.162	0.153	0.177	0.164	0.007	0.143
100	0.172	0.302	0.179	0.218	0.042	0.095
110	0.191	0.105	0.287	0.194	0.052	0.041
120	0.263	0.085	0.148	0.165	0.052	0.013
130	0.142	0.122	0.232	0.165	0.034	0.066
140	0.096	0.159	0.114	0.123	0.019	0.068
150	0.109	0.149	0.069	0.109	0.023	0.041
160	0.164	0.071	0.111	0.115	0.027	0.036
170	0.216	0.127	0.166	0.170	0.026	0.094
180	0.198	0.123	0.157	0.159	0.022	0.095
190	0.169	0.101	0.200	0.157	0.029	0.072
200	0.215	0.125		0.170	0.045	0.038
210	0.104	0.243		0.173	0.069	-0.028
220	0.157					
230	0.133					

Table 22. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). PLI>1 (highlighted red) is considered polluted. SE = standard error and CI LB = 95% confidence interval lower bound.



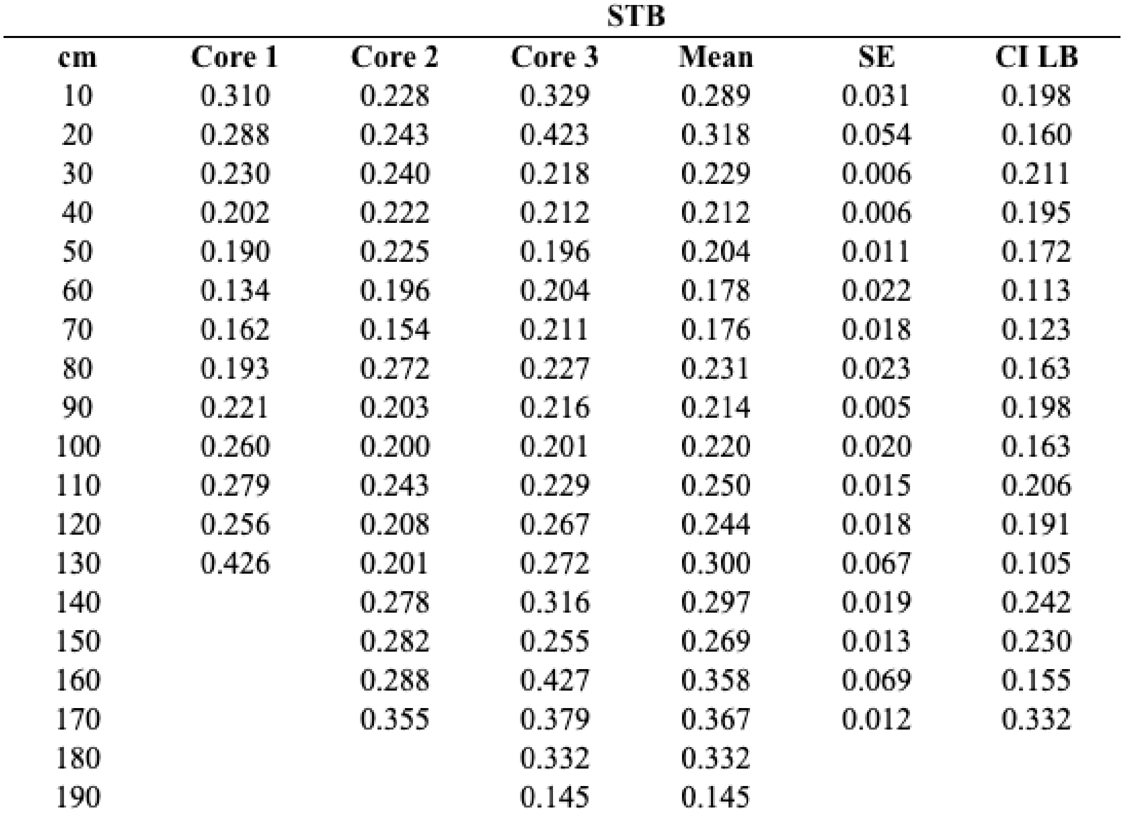
			PHQ			
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	0.039	0.035	0.109	0.061	0.024	-0.009
20	0.056	0.273	0.336	0.222	0.085	-0.025
30	0.181	0.384	0.274	0.280	0.059	0.108
40	0.117	0.178	0.348	0.214	0.069	0.012
50	0.341	0.285	0.303	0.310	0.017	0.261
60	0.353	0.222	0.222	0.266	0.044	0.138
70	0.249	0.218	0.202	0.223	0.014	0.183
80	0.138	0.216	0.168	0.174	0.023	0.108
90	0.191	0.122	0.113	0.142	0.025	0.070
100	0.097	0.080	0.060	0.079	0.011	0.048
110	0.083	0.065	0.079	0.076	0.005	0.060
120	0.069	0.047	0.041	0.053	0.009	0.027
130	0.078	0.051	0.043	0.057	0.011	0.026
140	0.110	0.042	0.069	0.074	0.020	0.016
150	0.105	0.126	0.122	0.118	0.006	0.099
160	0.130	0.100	0.066	0.099	0.018	0.045
170	0.084	0.063	0.070	0.072	0.006	0.055
180	0.081	0.078	0.167	0.108	0.029	0.023
190	0.177	0.177	0.124	0.160	0.018	0.108
200	0.222	0.083	0.087	0.130	0.046	-0.003
210	0.199	0.069	0.096	0.121	0.040	0.005
220		0.105	0.119	0.112	0.007	0.092

Table 23. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). PLI>1 (highlighted red) is considered polluted. SE = standard error and CI LB = 95% confidence interval lower bound.



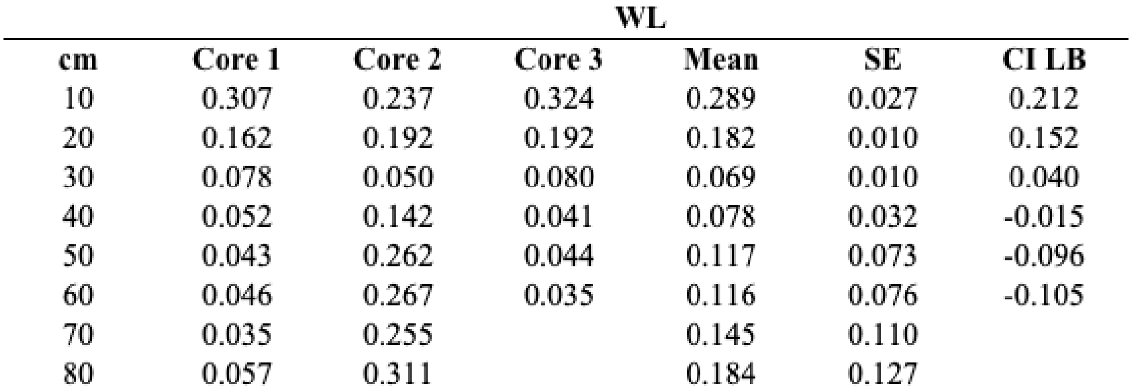
			PEI			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.039	0.029	0.031	0.033	0.003	0.024
20	0.034	0.030	0.030	0.031	0.001	0.028
30	0.036	0.034	0.027	0.032	0.003	0.024
40	0.035	0.028		0.031	0.004	0.020
50		0.027		0.027		

Table 24. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). PLI>1 (highlighted red) is considered polluted. SE = standard error and CI LB = 95% confidence interval lower bound.



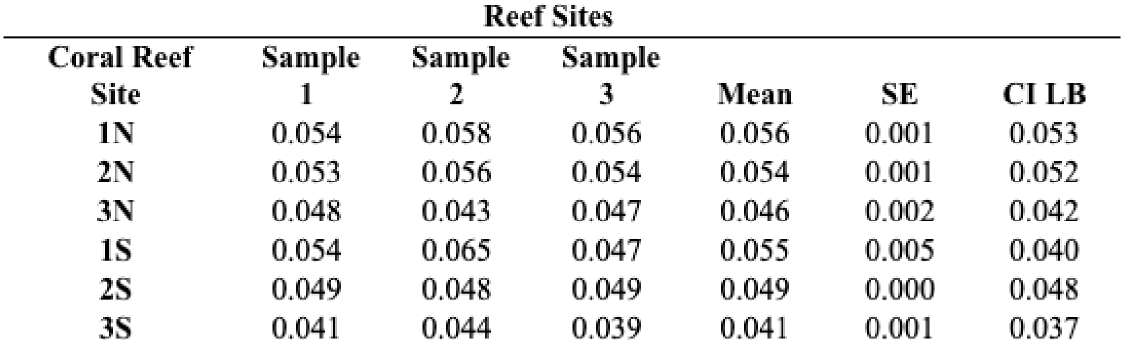
			STB			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.310	0.228	0.329	0.289	0.031	0.198
20	0.288	0.243	0.423	0.318	0.054	0.160
30	0.230	0.240	0.218	0.229	0.006	0.211
40	0.202	0.222	0.212	0.212	0.006	0.195
50	0.190	0.225	0.196	0.204	0.011	0.172
60	0.134	0.196	0.204	0.178	0.022	0.113
70	0.162	0.154	0.211	0.176	0.018	0.123
80	0.193	0.272	0.227	0.231	0.023	0.163
90	0.221	0.203	0.216	0.214	0.005	0.198
100	0.260	0.200	0.201	0.220	0.020	0.163
110	0.279	0.243	0.229	0.250	0.015	0.206
120	0.256	0.208	0.267	0.244	0.018	0.191
130	0.426	0.201	0.272	0.300	0.067	0.105
140		0.278	0.316	0.297	0.019	0.242
150		0.282	0.255	0.269	0.013	0.230
160		0.288	0.427	0.358	0.069	0.155
170		0.355	0.379	0.367	0.012	0.332
180			0.332	0.332		
190			0.145	0.145		

Table 25. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from West Lake (WL). PLI>1 (highlighted red) is considered polluted. SE = standard error and CI LB = 95% confidence interval lower bound.



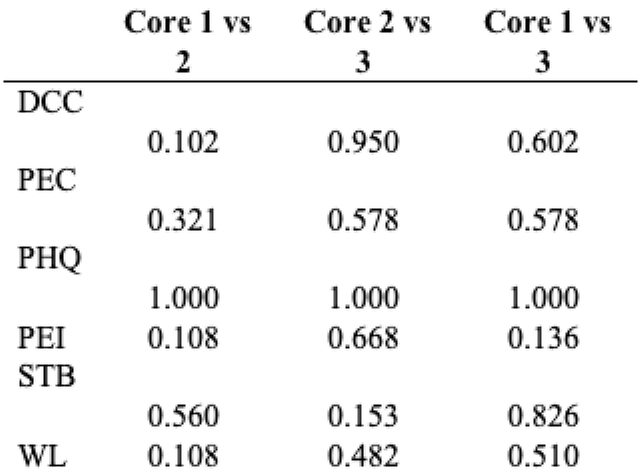
			WL			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.307	0.237	0.324	0.289	0.027	0.212
20	0.162	0.192	0.192	0.182	0.010	0.152
30	0.078	0.050	0.080	0.069	0.010	0.040
40	0.052	0.142	0.041	0.078	0.032	-0.015
50	0.043	0.262	0.044	0.117	0.073	-0.096
60	0.046	0.267	0.035	0.116	0.076	-0.105
70	0.035	0.255		0.145	0.110	
80	0.057	0.311		0.184	0.127	

Table 26. Pollution load index (PLI) of sediment cores (core 1, core 2, and core 3) from the traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). PLI>1 (highlighted red) is considered polluted. SE = standard error and CI LB = 95% confidence interval lower bound.



			Reef Sites			
Coral Reef Site	**Sample 1**	**Sample 2**	**Sample 3**	**Mean**	**SE**	**CI LB**
1N	0.054	0.058	0.056	0.056	0.001	0.053
2N	0.053	0.056	0.054	0.054	0.001	0.052
3N	0.048	0.043	0.047	0.046	0.002	0.042
1S	0.054	0.065	0.047	0.055	0.005	0.040
2S	0.049	0.048	0.049	0.049	0.000	0.048
3S	0.041	0.044	0.039	0.041	0.001	0.037

Table 27. B-H corrected p-values for pollution load index (PLI) among all three cores (core 1, core 2, and core 3) per location (DCC, PEC, PHQ, PEI, STB, and WL). Bolded values indicate statistically significant differences between cores collected at the same site ($p < 0.05$).



	Core 1 vs 2	Core 2 vs 3	Core 1 vs 3
DCC	0.102	0.950	0.602
PEC	0.321	0.578	0.578
PHQ	1.000	1.000	1.000
PEI	0.108	0.668	0.136
STB	0.560	0.153	0.826
WL	0.108	0.482	0.510

3.4 Statistical Analysis on Potential Ecological Risk and Heavy Metal Data of Port Cores and Reef Sediment from Phase I

Statistical analyses were performed to determine if any of the 16 heavy metals in the port cores and the coral reef sites from the samples collected in 2023 from the Phase I DEP agreement C0FEDD had any significant potential ecological risk values for the specific metals. All statistical analyses performed used a 95% confidence interval lower bound (CI LB) and all of the results are discussed based on the CI LB.

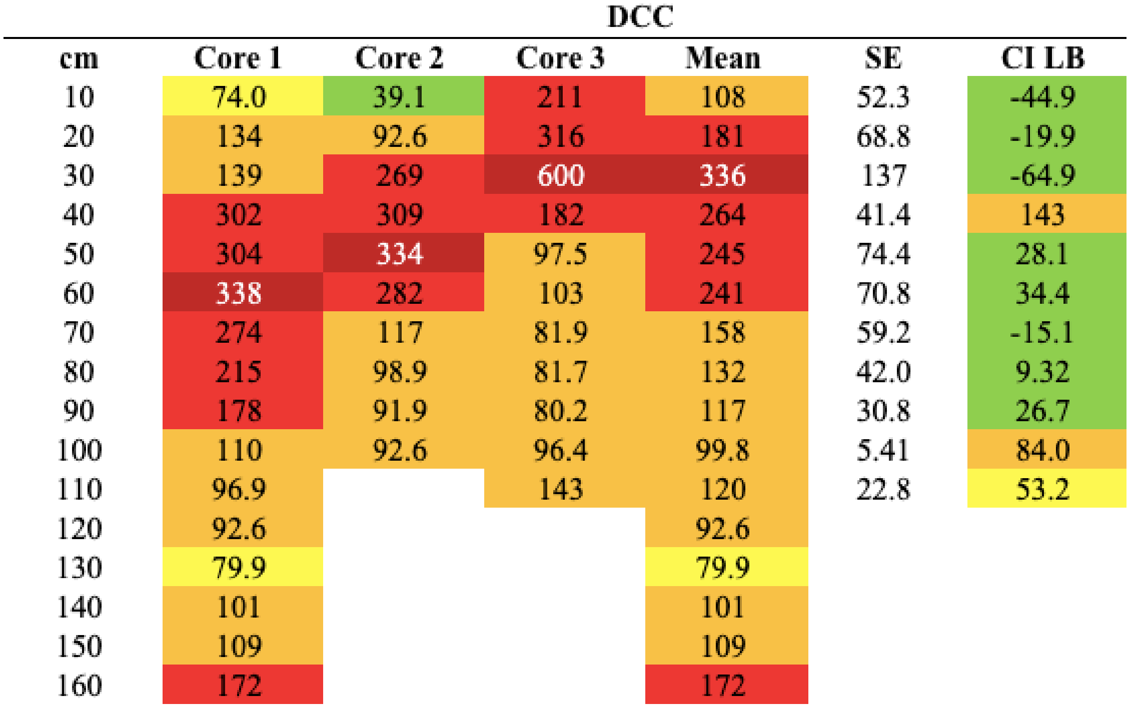
The PEI cores were mainly sand that has been used for beach renourishment in that area, so they showed no significant potential ecological risks.

Overall, potential ecological risk values indicated that all sediment cores and sediment at the reef sites had some type of overall heavy metal contamination except for the PEI cores (Tables 28-34).

The STB cores showed overall considerable heavy metal contamination and the PEC and PHQ cores overall moderate to considerable, while the DCC cores showed some overall contamination based on depth. The WL cores also showed moderate to considerable contamination mostly based off of their As concentrations. All three north reef sites (1N, 2N, and 3N) and the 2S site showed moderate overall contamination, while the south reef sites 1S and 3S showed low contamination.

In addition, all 3 cores showed no observed statistically significant differences between the index and the 3 cores per location (Table 35).

Table 28. Potential ecological risk (PER) of sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.



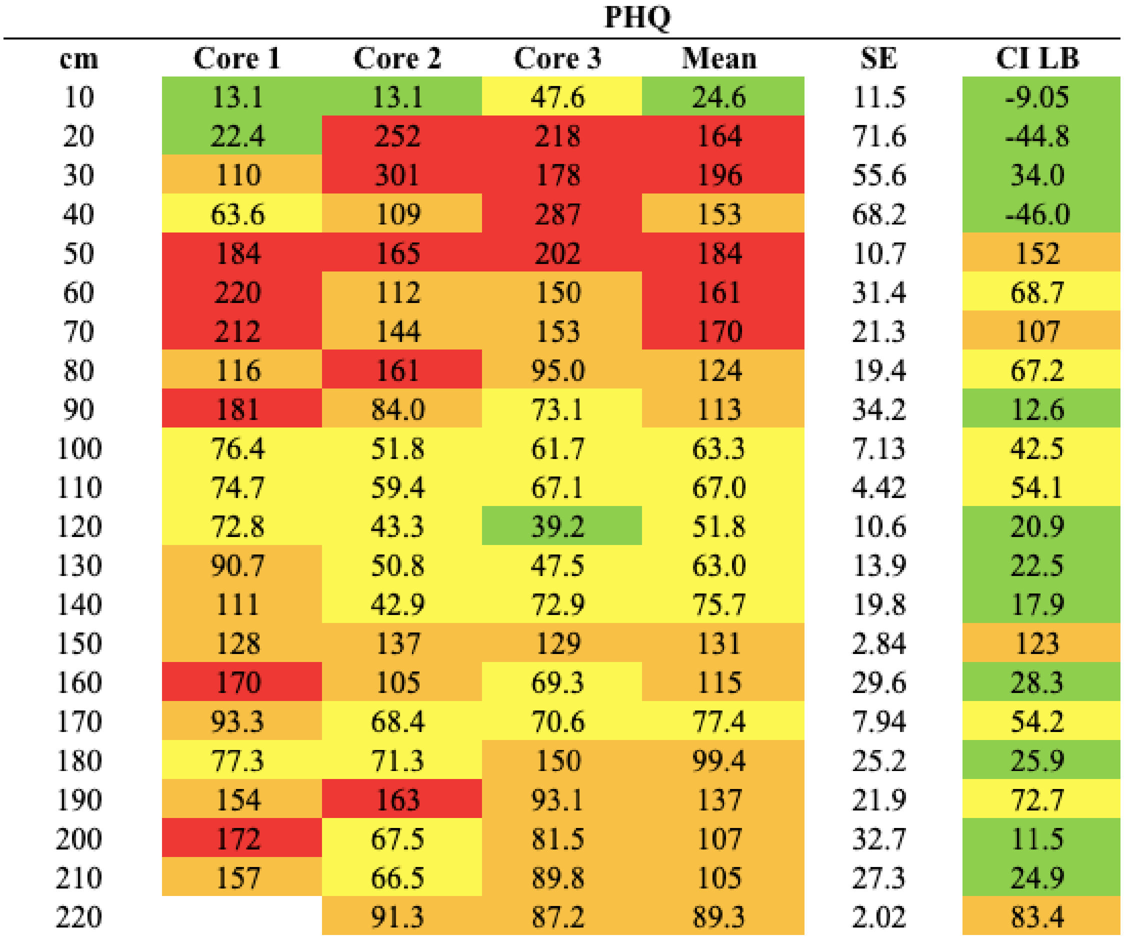
DCC

cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	74.0	39.1	211	108	52.3	-44.9
20	134	92.6	316	181	68.8	-19.9
30	139	269	600	336	137	-64.9
40	302	309	182	264	41.4	143
50	304	334	97.5	245	74.4	28.1
60	338	282	103	241	70.8	34.4
70	274	117	81.9	158	59.2	-15.1
80	215	98.9	81.7	132	42.0	9.32
90	178	91.9	80.2	117	30.8	26.7
100	110	92.6	96.4	99.8	5.41	84.0
110	96.9		143	120	22.8	53.2
120	92.6			92.6		
130	79.9			79.9		
140	101			101		
150	109			109		
160	172			172		

Table 29. Potential ecological risk (PER) of sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

	PEC					
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	47.3	37.6	24.6	36.5	6.56	17.4
20	76.0	61.9	56.5	64.8	5.80	47.9
30	115	99.3	114	109	5.09	94.6
40	81.6	88.9	46.1	72.2	13.2	33.6
50	39.7	36.6	35.9	37.4	1.18	33.9
60	47.3	41.7	46.3	45.1	1.74	40.0
70	66.5	55.1	70.0	63.9	4.52	50.7
80	50.5	54.4	77.0	60.6	8.28	36.4
90	44.7	44.3	54.0	47.7	3.18	38.4
100	51.6	116	54.7	74.2	21.1	12.6
110	56.7	86.8	98.9	80.8	12.5	44.2
120	124	71.8	80.4	92.2	16.3	44.6
130	102	161	207	156	30.4	67.6
140	82.6	265	142	163	53.6	6.51
150	87.9	175	113	125	26.0	49.3
160	45.3	90.5	144	93.3	28.5	10.0
170	120	69.2	52.5	80.5	20.3	21.3
180	72.9	33.0	39.1	48.4	12.4	12.1
190	50.8	29.5	42.4	40.9	6.20	22.8
200	55.1	31.2		43.1	11.9	8.32
210	30.3	48.3		39.3	9.04	12.9
220	44.7			44.7		
230	40.4			40.4		

Table 30. Potential ecological risk (PER) of sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.



			PHQ			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	13.1	13.1	47.6	24.6	11.5	-9.05
20	22.4	252	218	164	71.6	-44.8
30	110	301	178	196	55.6	34.0
40	63.6	109	287	153	68.2	-46.0
50	184	165	202	184	10.7	152
60	220	112	150	161	31.4	68.7
70	212	144	153	170	21.3	107
80	116	161	95.0	124	19.4	67.2
90	181	84.0	73.1	113	34.2	12.6
100	76.4	51.8	61.7	63.3	7.13	42.5
110	74.7	59.4	67.1	67.0	4.42	54.1
120	72.8	43.3	39.2	51.8	10.6	20.9
130	90.7	50.8	47.5	63.0	13.9	22.5
140	111	42.9	72.9	75.7	19.8	17.9
150	128	137	129	131	2.84	123
160	170	105	69.3	115	29.6	28.3
170	93.3	68.4	70.6	77.4	7.94	54.2
180	77.3	71.3	150	99.4	25.2	25.9
190	154	163	93.1	137	21.9	72.7
200	172	67.5	81.5	107	32.7	11.5
210	157	66.5	89.8	105	27.3	24.9
220		91.3	87.2	89.3	2.02	83.4

Table 31. Potential ecological risk (PER) of sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). The color of the value indicates: low contamination (<

40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

PEI

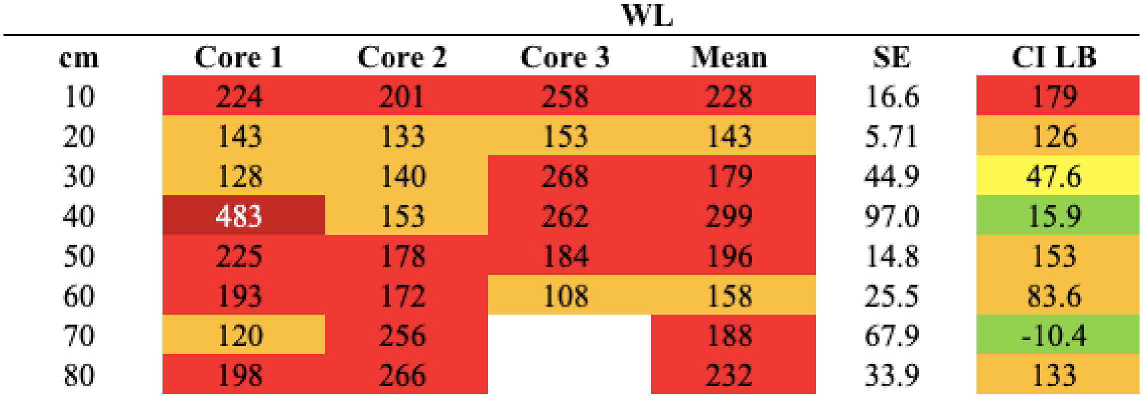
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	26.0	26.2	27.3	26.5	0.410	25.3
20	28.5	27.0	27.3	27.6	0.471	26.2
30	30.1	30.6	23.7	28.1	2.23	21.6
40	28.3	23.5		25.9	2.42	18.8
50		23.5		23.5		

Table 32. Potential ecological risk (PER) of sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

STB

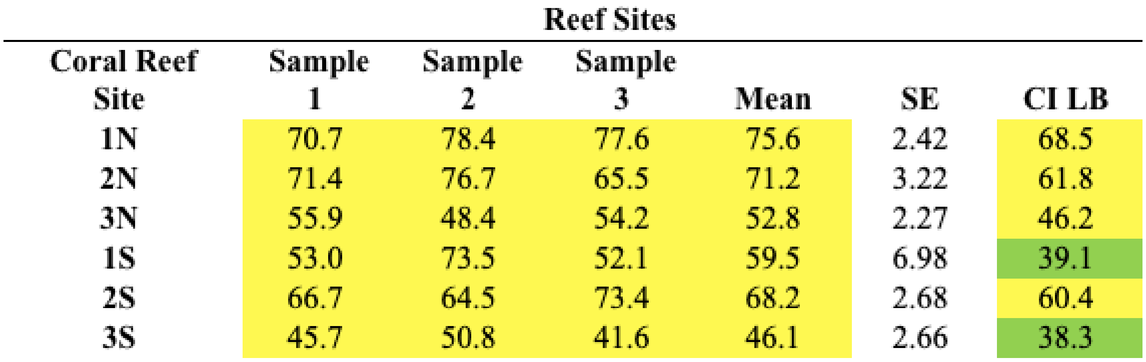
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	216	88.4	232	179	45.5	46.1
20	318	111	165	198	62.1	16.8
30	214	137	181	177	22.5	112
40	162	158	155	158	2.15	152
50	97.1	157	103	119	19.0	63.7
60	87.2	134	110	111	13.7	70.7
70	90.7	102	120	104	8.69	79.0
80	93.6	186	110	130	28.4	46.7
90	117	98.9	102	106	5.70	89.2
100	131	114	104	116	8.01	92.8
110	152	118	119	129	11.2	96.8
120	154	105	117	125	14.8	82.0
130	380	103	135	206	87.3	-48.9
140		120	202	161	41.1	41.4
150		113	160	137	23.4	68.4
160		152	509	331	179	-192
170		272	262	267	5.12	252
180			250	250		
190			40.7	40.7		

Table 33. Potential ecological risk (PER) of sediment cores (core 1, core 2, and core 3) from West Lake (WL). The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.



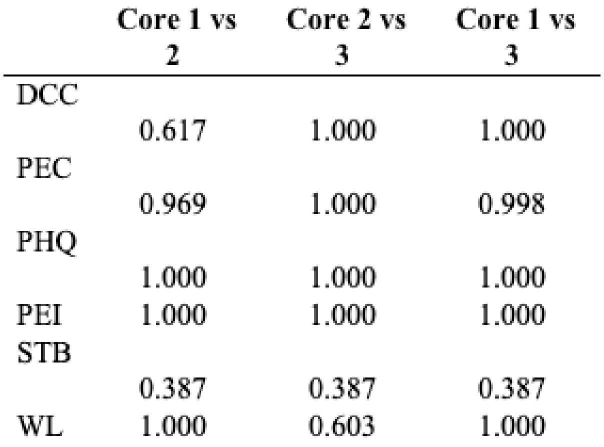
			WL			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	224	201	258	228	16.6	179
20	143	133	153	143	5.71	126
30	128	140	268	179	44.9	47.6
40	483	153	262	299	97.0	15.9
50	225	178	184	196	14.8	153
60	193	172	108	158	25.5	83.6
70	120	256		188	67.9	-10.4
80	198	266		232	33.9	133

Table 34. Potential ecological risk (PER) of surface sediment samples (sample 1, sample 2, and sample 3) from the traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.



			Reef Sites			
Coral Reef Site	**Sample 1**	**Sample 2**	**Sample 3**	**Mean**	**SE**	**CI LB**
1N	70.7	78.4	77.6	75.6	2.42	68.5
2N	71.4	76.7	65.5	71.2	3.22	61.8
3N	55.9	48.4	54.2	52.8	2.27	46.2
1S	53.0	73.5	52.1	59.5	6.98	39.1
2S	66.7	64.5	73.4	68.2	2.68	60.4
3S	45.7	50.8	41.6	46.1	2.66	38.3

Table 35. B-H corrected p-values for potential ecological risk (PER) among all three cores (core 1, core 2, and core 3) per location (DCC, PEC, PHQ, PEI, STB, and WL). Bolded values indicate statistically significant differences between cores collected at the same site ($p < 0.05$).



	Core 1 vs 2	Core 2 vs 3	Core 1 vs 3
DCC	0.617	1.000	1.000
PEC	0.969	1.000	0.998
PHQ	1.000	1.000	1.000
PEI	1.000	1.000	1.000
STB	0.387	0.387	0.387
WL	1.000	0.603	1.000

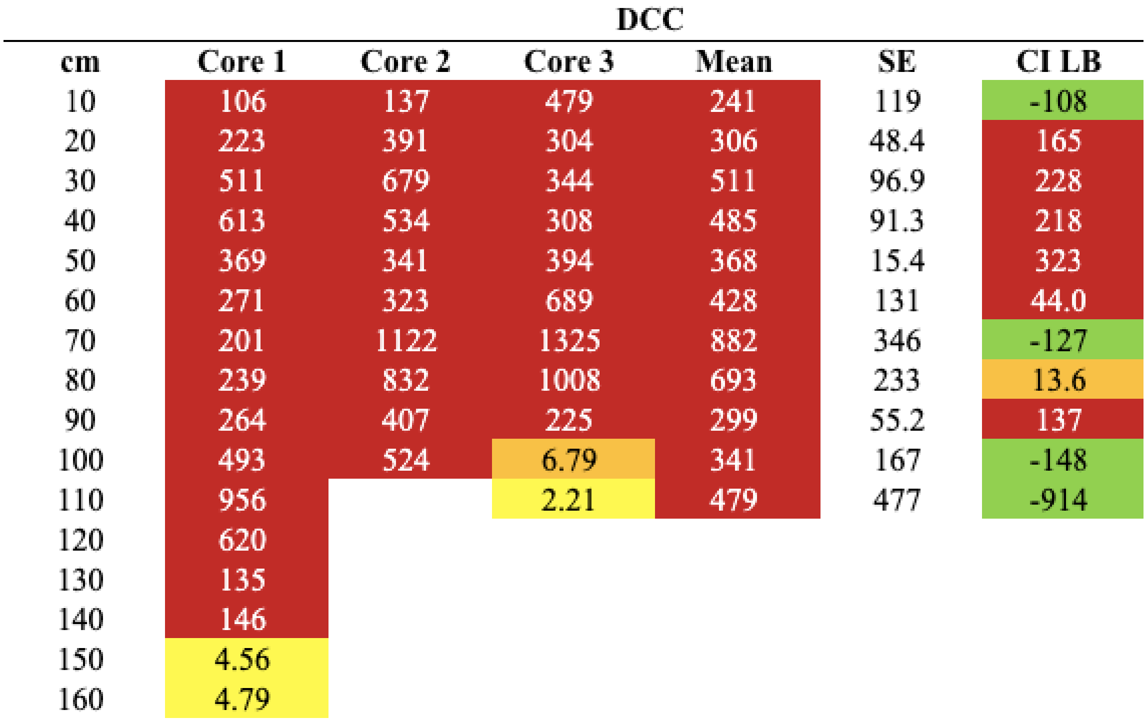
3.5 Statistical Analysis on Enrichment Factor and Heavy Metal Data of Port Cores and Reef Sediment from Phase I

The enrichment factor (EF) was used to determine how much the presence of an element (heavy metal) in sediment has increased, due to human activity, relative to the average natural abundance based off the Al or the Fe in the upper continental crust. All statistical analyses performed used a 95% confidence interval lower bound (CI LB) and all of the results are discussed based on the CI LB.

Tables 36-56 show the EFs in the port and control sediment cores and in the surface sediment of the six coral reef locations, respectively. The overall degree of enrichment for all the results seems relatively high; **therefore, using only EF to determine contamination is not recommended.** This could be since the upper continental crust value for Fe (50,000 µg/g) is much higher than the mean Fe (8021 µg/g) found in the South FL marine environment and the Al is much higher (81,300 µg/g) than the Al (6342 µg/g) found in the South FL marine environment, which can skew the degree of enrichment (Castro et al. 2013).

In addition, all 3 cores showed no observed statistically significant differences between the index and the 3 cores per location (Tables 57-58).

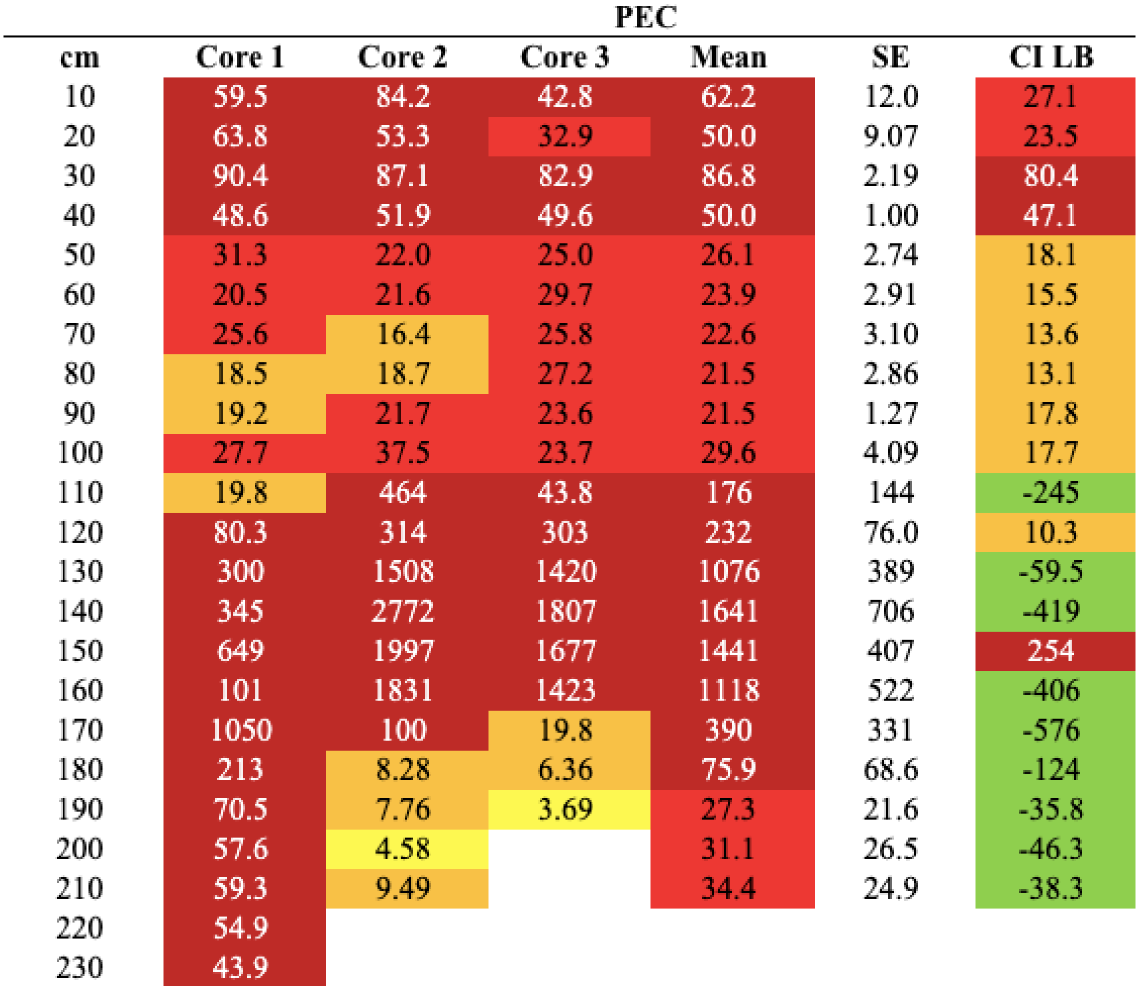
Table 36. Al enrichment factors (EF) for molybdenum (Mo) of sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.



			DCC			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	106	137	479	241	119	-108
20	223	391	304	306	48.4	165
30	511	679	344	511	96.9	228
40	613	534	308	485	91.3	218
50	369	341	394	368	15.4	323
60	271	323	689	428	131	44.0
70	201	1122	1325	882	346	-127
80	239	832	1008	693	233	13.6
90	264	407	225	299	55.2	137
100	493	524	6.79	341	167	-148
110	956		2.21	479	477	-914
120	620					
130	135					
140	146					
150	4.56					
160	4.79					

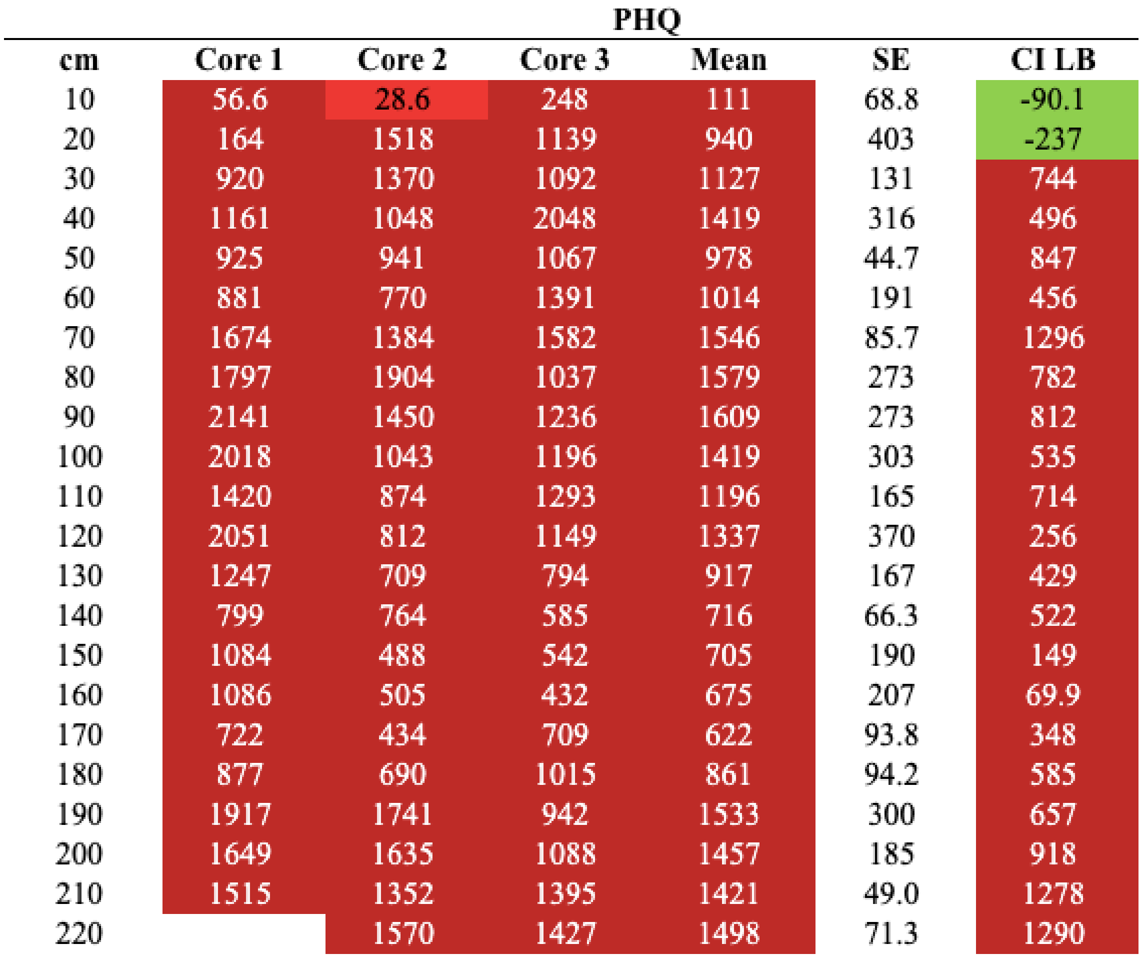
Table 37. Al enrichment factors (EF) for molybdenum (Mo) of sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). The color of the value indicates:

depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.



			PEC			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	59.5	84.2	42.8	62.2	12.0	27.1
20	63.8	53.3	32.9	50.0	9.07	23.5
30	90.4	87.1	82.9	86.8	2.19	80.4
40	48.6	51.9	49.6	50.0	1.00	47.1
50	31.3	22.0	25.0	26.1	2.74	18.1
60	20.5	21.6	29.7	23.9	2.91	15.5
70	25.6	16.4	25.8	22.6	3.10	13.6
80	18.5	18.7	27.2	21.5	2.86	13.1
90	19.2	21.7	23.6	21.5	1.27	17.8
100	27.7	37.5	23.7	29.6	4.09	17.7
110	19.8	464	43.8	176	144	-245
120	80.3	314	303	232	76.0	10.3
130	300	1508	1420	1076	389	-59.5
140	345	2772	1807	1641	706	-419
150	649	1997	1677	1441	407	254
160	101	1831	1423	1118	522	-406
170	1050	100	19.8	390	331	-576
180	213	8.28	6.36	75.9	68.6	-124
190	70.5	7.76	3.69	27.3	21.6	-35.8
200	57.6	4.58		31.1	26.5	-46.3
210	59.3	9.49		34.4	24.9	-38.3
220	54.9					
230	43.9					

Table 38. Al enrichment factors (EF) for molybdenum (Mo) of sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.



	PHQ					
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	56.6	28.6	248	111	68.8	-90.1
20	164	1518	1139	940	403	-237
30	920	1370	1092	1127	131	744
40	1161	1048	2048	1419	316	496
50	925	941	1067	978	44.7	847
60	881	770	1391	1014	191	456
70	1674	1384	1582	1546	85.7	1296
80	1797	1904	1037	1579	273	782
90	2141	1450	1236	1609	273	812
100	2018	1043	1196	1419	303	535
110	1420	874	1293	1196	165	714
120	2051	812	1149	1337	370	256
130	1247	709	794	917	167	429
140	799	764	585	716	66.3	522
150	1084	488	542	705	190	149
160	1086	505	432	675	207	69.9
170	722	434	709	622	93.8	348
180	877	690	1015	861	94.2	585
190	1917	1741	942	1533	300	657
200	1649	1635	1088	1457	185	918
210	1515	1352	1395	1421	49.0	1278
220		1570	1427	1498	71.3	1290

Table 39. Al enrichment factors (EF) for molybdenum (Mo) sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

PEI						
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	22.9	19.2	31.4	24.5	3.60	14.0
20	23.6	23.0	29.1	25.2	1.95	19.5
30	21.6	26.3	38.7	28.9	5.10	14.0
40	19.7	26.9		23.3	3.62	12.8
50		20.5				

Table 40. Al enrichment factors (EF) for molybdenum (Mo) of sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

STB						
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	322	339	520	394	63.4	208
20	500	192	275	322	91.9	53.9
30	886	344	713	647	160	181
40	3636	562	2012	2070	888	-523
50	503	871	708	694	106	383
60	602	2650	884	1378	641	-493
70	508	1235	932	892	211	277
80	432	1034	687	718	174	209
90	970	395	879	748	178	228
100	763	808	684	752	36.2	646
110	500	787	835	707	104	402
120	1626	640	500	922	354	-113
130	658	619	684	654	18.8	599
140		590	1509	1049	459	-292
150		201	1133			
160		1015	2459			
170		2401	940			
180			322			
190			1.18			

Table 41. Al enrichment factors (EF) for molybdenum (Mo) of sediment cores (core 1, core 2, and core 3) from West Lake (WL). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

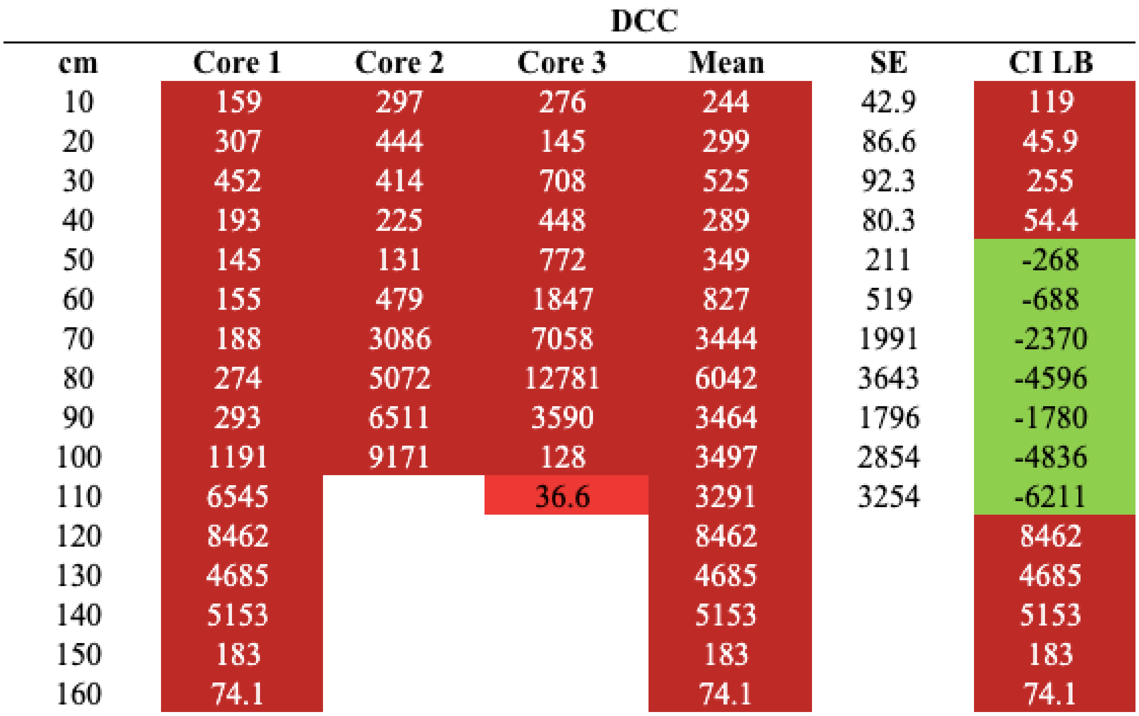
			WL			
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	42.5	56.4	88.1	62.3	13.5	23.0
20	134	64.0	91.5	96.4	20.3	37.2
30	222	314	308	281	29.7	194
40	602	75.9	601	427	175	-85.4
50	320	47.8	204	191	78.9	-39.7
60	234	19.9	177	144	64.0	-43.2
70	124	42.1		83.2	41.1	-36.8
80	17.4	81.8		49.6	32.2	-44.4

Table 42. Al enrichment factors (EF) for molybdenum (Mo) of sediment samples (sample 1, sample 2, and sample 3) from traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

			Reef Sites			
Coral Reef Site	Sample 1	Sample 2	Sample 3	Mean	SE	CI LB
1N	68.6	74.3	70.6	71.2	1.67	66.3
2N	58.3	61.2	65.2	61.6	2.01	55.7
3N	95.6	76.2	73.7	81.8	6.91	61.6
1S	57.0	39.1	40.9	45.6	5.70	29.0
2S	59.1	78.7	77.0	71.6	6.26	53.3
3S	125	95.4	83.0	101	12.6	64.5

Table 43. Al enrichment factors (EF) for arsenic (As) of sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and

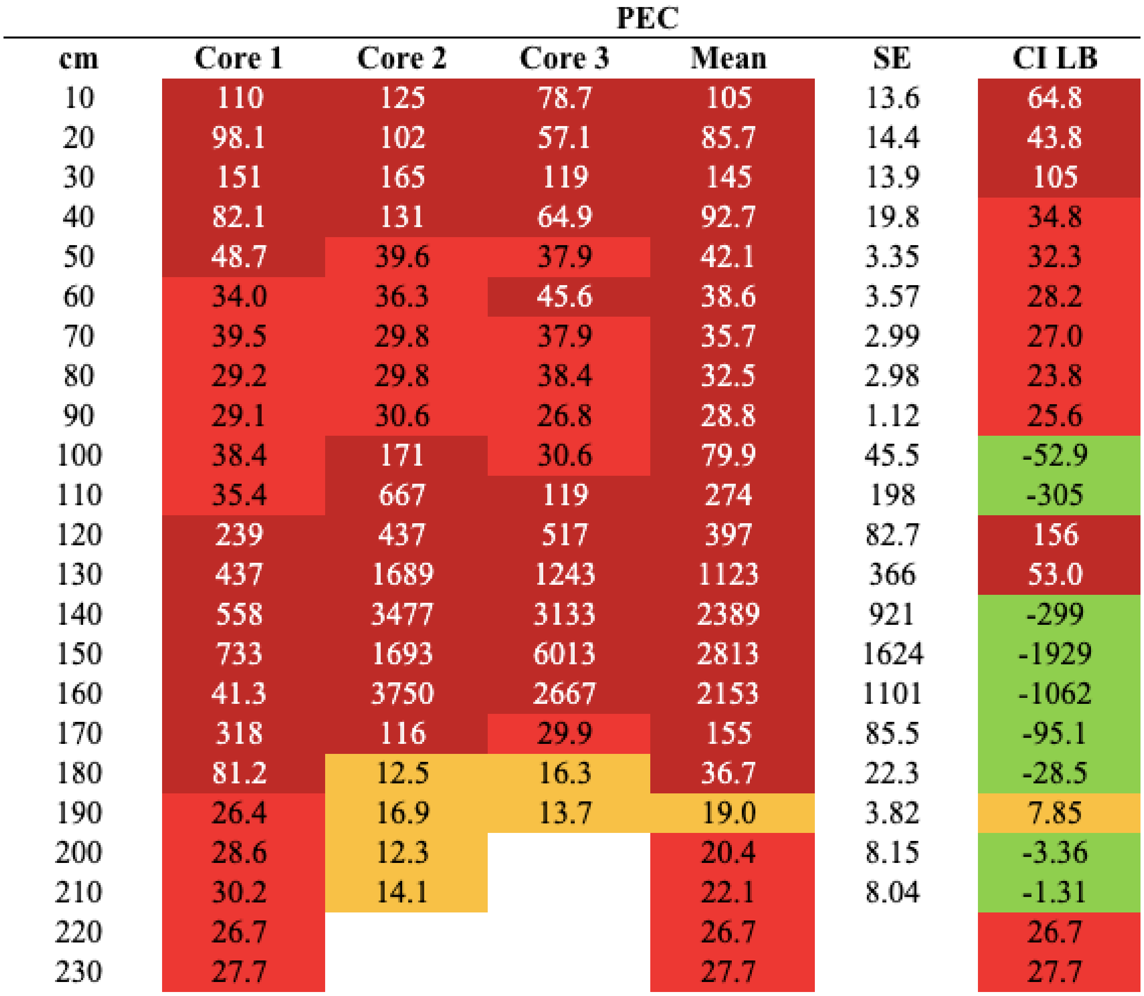
extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.



			DCC			
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	159	297	276	244	42.9	119
20	307	444	145	299	86.6	45.9
30	452	414	708	525	92.3	255
40	193	225	448	289	80.3	54.4
50	145	131	772	349	211	-268
60	155	479	1847	827	519	-688
70	188	3086	7058	3444	1991	-2370
80	274	5072	12781	6042	3643	-4596
90	293	6511	3590	3464	1796	-1780
100	1191	9171	128	3497	2854	-4836
110	6545		36.6	3291	3254	-6211
120	8462			8462		8462
130	4685			4685		4685
140	5153			5153		5153
150	183			183		183
160	74.1			74.1		74.1

Table 44. Al enrichment factors (EF) for arsenic (As) of sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow),

significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.



PEC

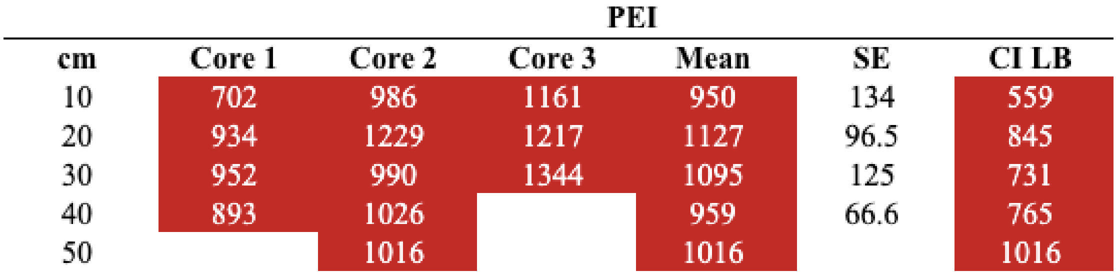
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	110	125	78.7	105	13.6	64.8
20	98.1	102	57.1	85.7	14.4	43.8
30	151	165	119	145	13.9	105
40	82.1	131	64.9	92.7	19.8	34.8
50	48.7	39.6	37.9	42.1	3.35	32.3
60	34.0	36.3	45.6	38.6	3.57	28.2
70	39.5	29.8	37.9	35.7	2.99	27.0
80	29.2	29.8	38.4	32.5	2.98	23.8
90	29.1	30.6	26.8	28.8	1.12	25.6
100	38.4	171	30.6	79.9	45.5	-52.9
110	35.4	667	119	274	198	-305
120	239	437	517	397	82.7	156
130	437	1689	1243	1123	366	53.0
140	558	3477	3133	2389	921	-299
150	733	1693	6013	2813	1624	-1929
160	41.3	3750	2667	2153	1101	-1062
170	318	116	29.9	155	85.5	-95.1
180	81.2	12.5	16.3	36.7	22.3	-28.5
190	26.4	16.9	13.7	19.0	3.82	7.85
200	28.6	12.3		20.4	8.15	-3.36
210	30.2	14.1		22.1	8.04	-1.31
220	26.7			26.7		26.7
230	27.7			27.7		27.7

Table 45. Al enrichment factors (EF) for arsenic (As) of sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and

extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

PHQ						
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	137	232	408	259	79.4	27.0
20	254	948	505	569	203	-22.6
30	544	505	416	488	37.9	378
40	588	489	800	626	91.8	358
50	416	276	423	372	48.0	231
60	300	201	373	291	50.0	145
70	635	334	321	430	103	130
80	480	447	185	371	93.1	98.9
90	593	340	290	408	93.8	134
100	553	330	754	546	122	188
110	763	619	529	637	68.2	438
120	956	637	775	789	92.2	520
130	877	619	881	792	86.5	540
140	722	740	686	716	16.1	669
150	948	696	695	779	84.1	534
160	1164	750	727	880	142	466
170	972	729	899	867	71.8	657
180	924	735	1010	889	81.3	652
190	1132	1366	830	1109	155	656
200	1115	1498	2030	1547	265	773
210	1226	2554	2567	2116	445	817
220		2344	1882	2113	231	1438

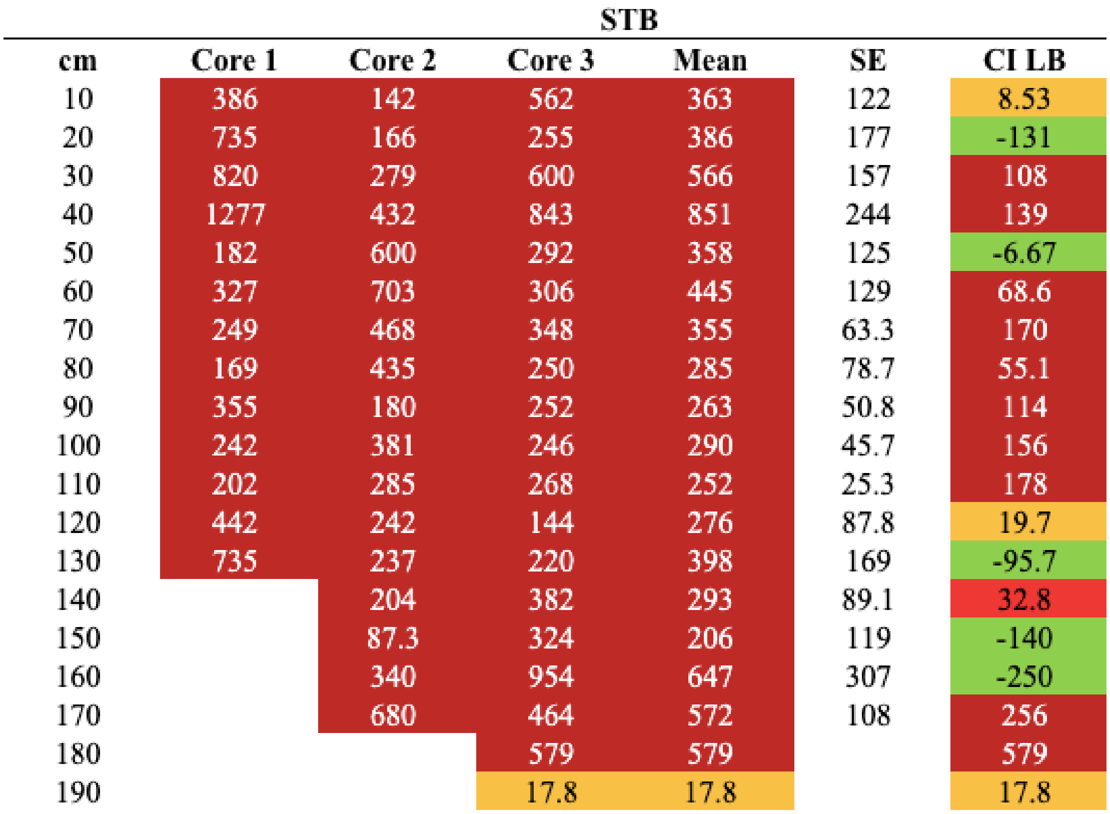
Table 46. Al enrichment factors (EF) for arsenic (As) of sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.



PEI

cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	702	986	1161	950	134	559
20	934	1229	1217	1127	96.5	845
30	952	990	1344	1095	125	731
40	893	1026		959	66.6	765
50		1016		1016		1016

Table 47. Al enrichment factors (EF) for arsenic (As) of sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.



STB

cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	386	142	562	363	122	8.53
20	735	166	255	386	177	-131
30	820	279	600	566	157	108
40	1277	432	843	851	244	139
50	182	600	292	358	125	-6.67
60	327	703	306	445	129	68.6
70	249	468	348	355	63.3	170
80	169	435	250	285	78.7	55.1
90	355	180	252	263	50.8	114
100	242	381	246	290	45.7	156
110	202	285	268	252	25.3	178
120	442	242	144	276	87.8	19.7
130	735	237	220	398	169	-95.7
140		204	382	293	89.1	32.8
150		87.3	324	206	119	-140
160		340	954	647	307	-250
170		680	464	572	108	256
180			579	579		579
190			17.8	17.8		17.8

Table 48. Al enrichment factors (EF) for arsenic (As) of sediment cores (core 1, core 2, and core 3) from West Lake (WL). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and

extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

WL

cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	875	1276	1103	1084	116	745
20	1296	867	1234	1132	134	741
30	3437	7675	10459	7190	2042	1229
40	35481	1754	30727	22654	10540	-8122
50	19098	862	12361	10774	5324	-4772
60	15808	376	12681	9622	4710	-4132
70	10919	1313		6116	4803	-7908
80	2151	808		1480	672	-482

Table 49. Al enrichment factors (EF) for arsenic (As) of sediment (sample 1, sample 2, and sample 3) from traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

Reef Sites

Coral Reef Site	Sample 1	Sample 2	Sample 3	Mean	SE	CI LB
1N	2424	2934	2655	2671	147	2240
2N	2253	2304	2389	2315	39.7	2200
3N	1883	1866	1824	1858	17.5	1806
1S	1703	1607	1493	1601	60.7	1424
2S	2411	2619	2910	2647	145	2224
3S	2304	2330	1895	2176	141	1765

Table 50. Fe enrichment factors (EF) for arsenic of sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

			DCC			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	159	297	276	244	42.9	119
20	307	444	145	299	86.6	45.9
30	452	414	708	525	92.3	255
40	193	225	448	289	80.3	54.4
50	145	131	772	349	211	-268
60	155	479	1847	827	519	-688
70	188	3086	7058	3444	1991	-2370
80	274	5072	12781	6042	3643	-4596
90	293	6511	3590	3464	1796	-1780
100	1191	9171	128	3497	2854	-4836
110	6545		36.6	3291	3254	-6211
120	8462			8462		8462
130	4685			4685		4685
140	5153			5153		5153
150	183			183		183
160	74.1			74.1		74.1

Table 51. Fe enrichment factors (EF) for arsenic of sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

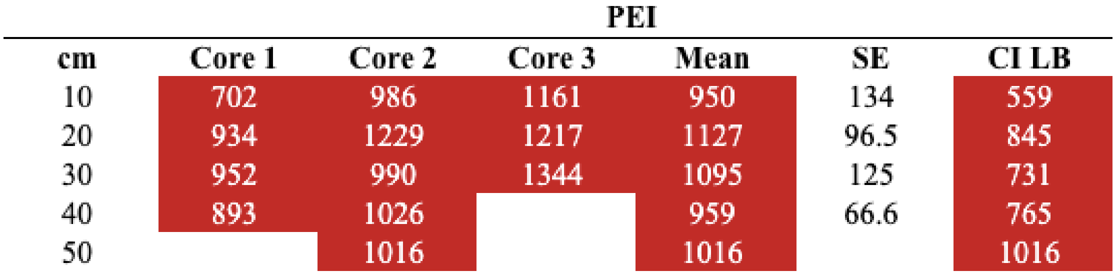
	PEC					
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	110	125	78.69	105	13.6	64.8
20	98.1	102	57.10	85.7	14.4	43.8
30	151	165	119	145	13.9	105
40	82.1	131	64.85	92.7	19.8	34.8
50	48.7	39.6	37.9	42.1	3.35	32.3
60	34.0	36.3	45.6	38.6	3.57	28.2
70	39.5	29.8	37.9	35.7	2.99	27.0
80	29.2	29.8	38.4	32.5	2.98	23.8
90	29.1	30.6	26.8	28.8	1.12	25.6
100	38.4	171	30.6	79.9	45.5	-52.9
110	35.4	667	119	274	198	-305
120	239	437	517	397	82.7	156
130	437	1689	1243	1123	366	53.0
140	558	3477	3133	2389	921	-299
150	733	1693	6013	2813	1624	-1929
160	41.3	3750	2667	2153	1101	-1062
170	318	116	29.9	155	85.5	-95.1
180	81.2	12.5	16.3	36.7	22.3	-28.5
190	26.4	16.9	13.7	19.0	3.82	7.85
200	28.6	12.3		20.4	8.15	-3.36
210	30.2	14.1		22.1	8.04	-1.31
220	26.7			26.7		26.7
230	27.7			27.7		27.7

Table 52. Fe enrichment factors (EF) for arsenic of sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

				PHQ		
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	137	232	408	259	79.4	27.0
20	254	948	505	569	203	-22.6
30	544	505	416	488	37.9	378
40	588	489	800	626	91.8	358
50	416	276	423	372	48.0	231
60	300	201	373	291	50.0	145
70	635	334	321	430	103	130
80	480	447	185	371	93.1	98.9
90	593	340	290	408	93.8	134
100	553	330	754	546	122	188
110	763	619	529	637	68.2	438
120	956	637	775	789	92.2	520
130	877	619	881	792	86.5	540
140	722	740	686	716	16.1	669
150	948	696	695	779	84.1	534
160	1164	750	727	880	142	466
170	972	729	899	867	71.8	657
180	924	735	1010	889	81.3	652
190	1132	1366	830	1109	155	656
200	1115	1498	2030	1547	265	773
210	1226	2554	2567	2116	445	817
220		2344	1882	2113	231	1438

Table 53. Fe enrichment factors (EF) for arsenic of sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95%

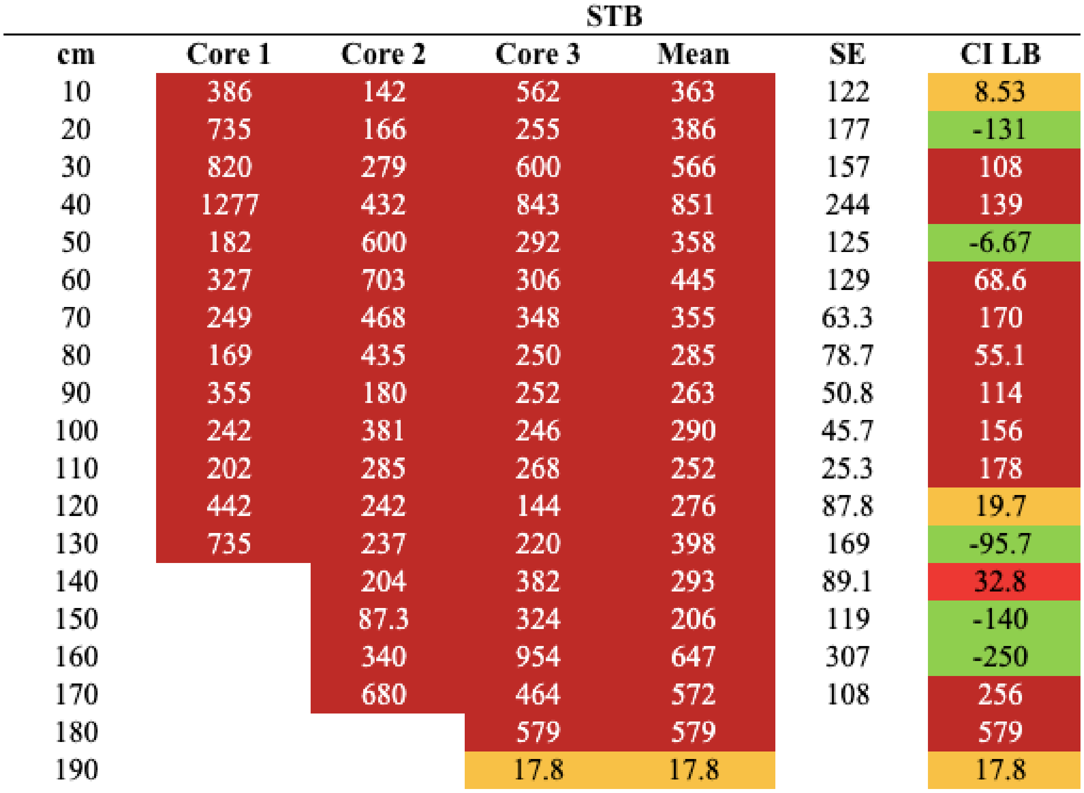
confidence interval lower bound.



PEI

cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	702	986	1161	950	134	559
20	934	1229	1217	1127	96.5	845
30	952	990	1344	1095	125	731
40	893	1026		959	66.6	765
50		1016		1016		1016

Table 54. Fe enrichment factors (EF) for arsenic of sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.



STB

cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	386	142	562	363	122	8.53
20	735	166	255	386	177	-131
30	820	279	600	566	157	108
40	1277	432	843	851	244	139
50	182	600	292	358	125	-6.67
60	327	703	306	445	129	68.6
70	249	468	348	355	63.3	170
80	169	435	250	285	78.7	55.1
90	355	180	252	263	50.8	114
100	242	381	246	290	45.7	156
110	202	285	268	252	25.3	178
120	442	242	144	276	87.8	19.7
130	735	237	220	398	169	-95.7
140		204	382	293	89.1	32.8
150		87.3	324	206	119	-140
160		340	954	647	307	-250
170		680	464	572	108	256
180			579	579		579
190			17.8	17.8		17.8

Table 55. Fe enrichment factors (EF) for arsenic of sediment cores (core 1, core 2, and core 3) from West Lake (WL). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant

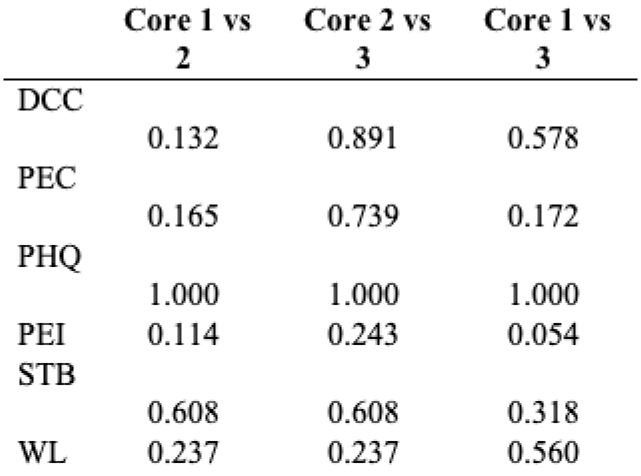
enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

	WL					
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	875	1276	1103	1084	116	745
20	1296	866.5	1234	1132	134	741
30	3437	7675	10459	7190	2042	1229
40	35481	1754	30727	22654	10540	-8122
50	19098	862	12361	10774	5324	-4772
60	15808	376	12681	9622	4710	-4132
70	10919	1313		6116	4803	-7908
80	2151	808		1480	672	-482

Table 56. Fe enrichment factors (EF) for arsenic of sediment (sample 1, sample 2, and sample 3) collected from traps at the six reef sites (1N, 2N, 3N, 1S, 2S, 3S). The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound.

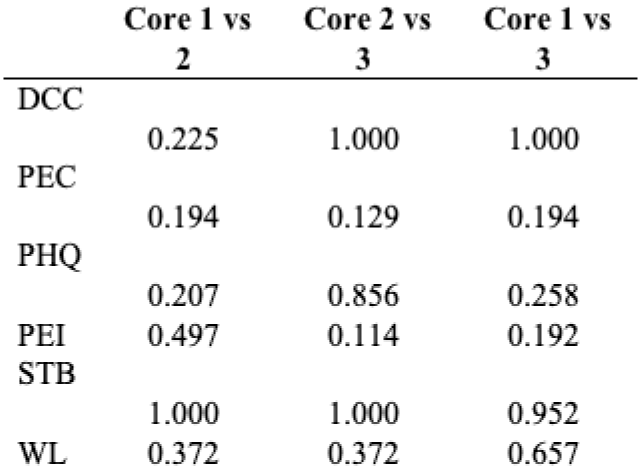
	Reef Sites					
Coral Reef Site	**Sample 1**	**Sample 2**	**Sample 3**	**Mean**	**SE**	**CI LB**
1N	2424	2934	2655	2671	147	2240
2N	2253	2304	2389	2315	39.7	2200
3N	1883	1866	1824	1858	17.5	1806
1S	1703	1607	1493	1601	60.7	1424
2S	2411	2619	2910	2647	145	2224
3S	2304	2330	1895	2176	141	1765

Table 57. B-H corrected p-values for the Fe enrichment factor (EF) of arsenic (As) among all three cores (core 1, core 2, and core 3) per location (DCC, PEC, PHQ, PEI, STB, and WL). Bolded values indicate statistically significant differences between cores collected at the same site ($p < 0.05$).



	Core 1 vs 2	Core 2 vs 3	Core 1 vs 3
DCC	0.132	0.891	0.578
PEC	0.165	0.739	0.172
PHQ	1.000	1.000	1.000
PEI	0.114	0.243	0.054
STB	0.608	0.608	0.318
WL	0.237	0.237	0.560

Table 58. B-H corrected p-values for the Al enrichment factor (EF) of molybdenum (Mo) among all three cores (core 1, core 2, and core 3) per location (DCC, PEC, PHQ, PEI, STB, and WL). Bolded values indicate statistically significant differences between cores collected at the same site ($p < 0.05$).



	Core 1 vs 2	Core 2 vs 3	Core 1 vs 3
DCC	0.225	1.000	1.000
PEC	0.194	0.129	0.194
PHQ	0.207	0.856	0.258
PEI	0.497	0.114	0.192
STB	1.000	1.000	0.952
WL	0.372	0.372	0.657

3.5 Statistical Analysis on Threshold Effect Levels, Potential Effect Levels, Continental Crust Values and Heavy Metal Data of Port Cores and Reef Sediment from Phase I

Statistical analyses were performed to determine if any of the 16 heavy metals in the port cores and the coral reef sites from the samples collected in 2023 from the Phase I

DEP agreement C0FEDD had any significant values with 95% confidence above the continental crust background values, the TEL and PEL, which are values that could be causing ecological toxic effects. All statistical analyses were performed used a 95% confidence interval lower bound (CI LB) and all of the results are discussed based on the CI LB.

The results show that Co, Cr, Ni, Mn, Pb, Se, Sn, V, and Zn had no significant concentrations for any port or coral reef locations or depths of port sediment cores above the continental crust background values, the TEL, or PEL values.

The most significant results were found for As, Cd, Mo, and Hg. Arsenic was the only heavy metal that affected both the port cores and coral reef sediments.

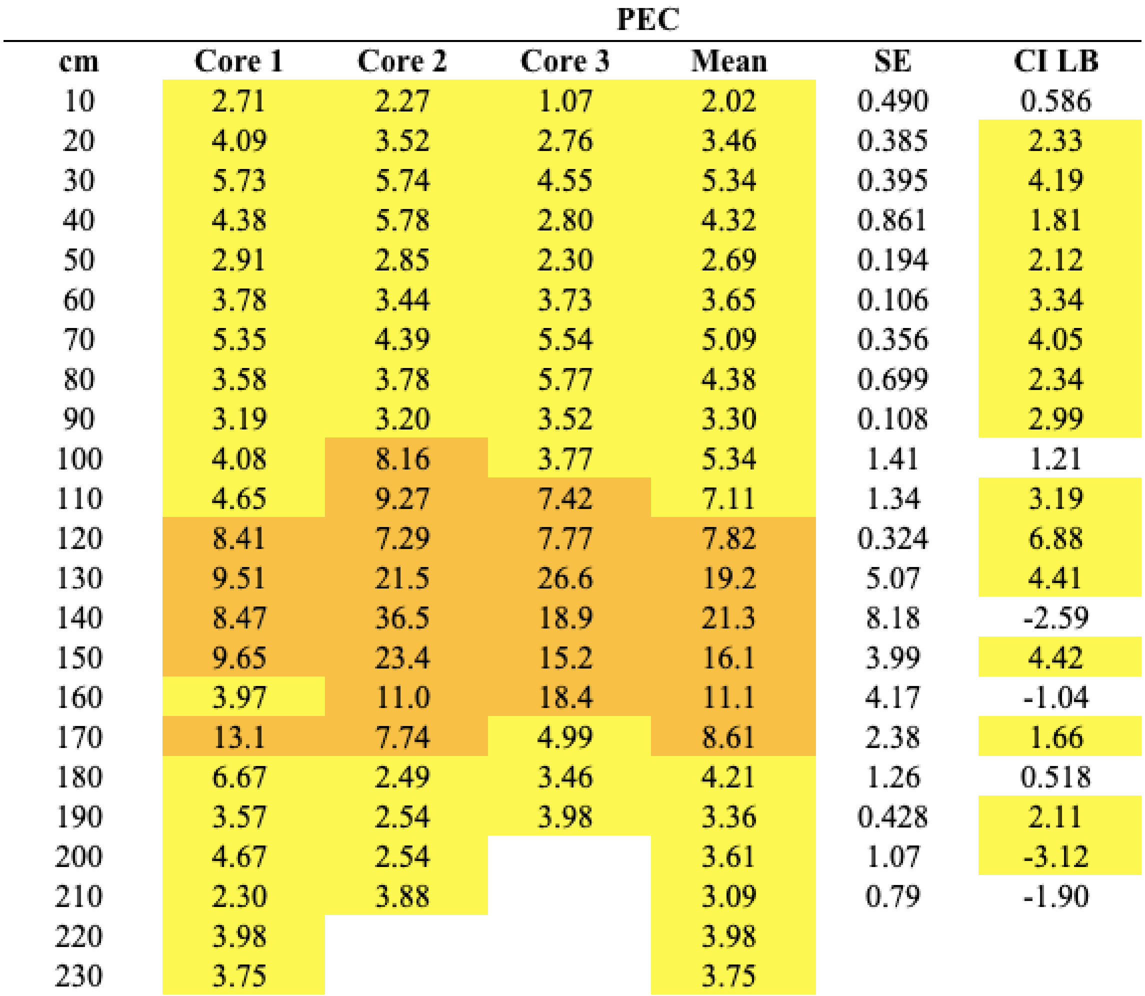
All of the DCC, PHQ, STB, and WL cores and the 1N reef location had significant concentrations above the TEL value for As, while the PEC and PEI cores and the rest of the coral reef sites had values above the continental crust value. Molybdenum values in DCC, PEC, PHQ, and STB cores in almost all depths had significant values above continental crust, while Cd had values in PHQ and STB cores above continental crust. PEC and WL cores had significant Hg concentrations above continental crust values at certain depths (Tables 59-86).

Overall, the most significant toxic levels for all the cores at all depths and coral sediment was determined to be for As, while Mo, Cd, and Hg also had some concerning levels to consider.

Table 59. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) collected from Dania Cutoff Canal (DCC). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

DCC						
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	7.03	3.38	13.6	8.00	2.99	-0.728
20	13.7	13.2	15.9	14.3	0.829	11.8
30	11.6	25.9	68.6	35.4	17.1	-14.6
40	15.6	17.0	21.1	17.9	1.65	13.1
50	15.3	15.3	12.5	14.4	0.933	11.6
60	20.1	30.2	13.8	21.4	4.78	7.42
70	22.7	15.6	10.6	16.3	3.51	6.05
80	21.3	13.1	10.8	15.1	3.19	5.76
90	19.7	12.0	10.4	14.0	2.87	5.65
100	14.5	12.2	12.7	13.1	0.698	11.1
110	12.8		18.9	15.9	3.05	-3.41
120	12.1			12.1		
130	10.2			10.2		
140	13.5			13.5		
150	14.6			14.6		
160	23.5			23.5		

Table 60. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

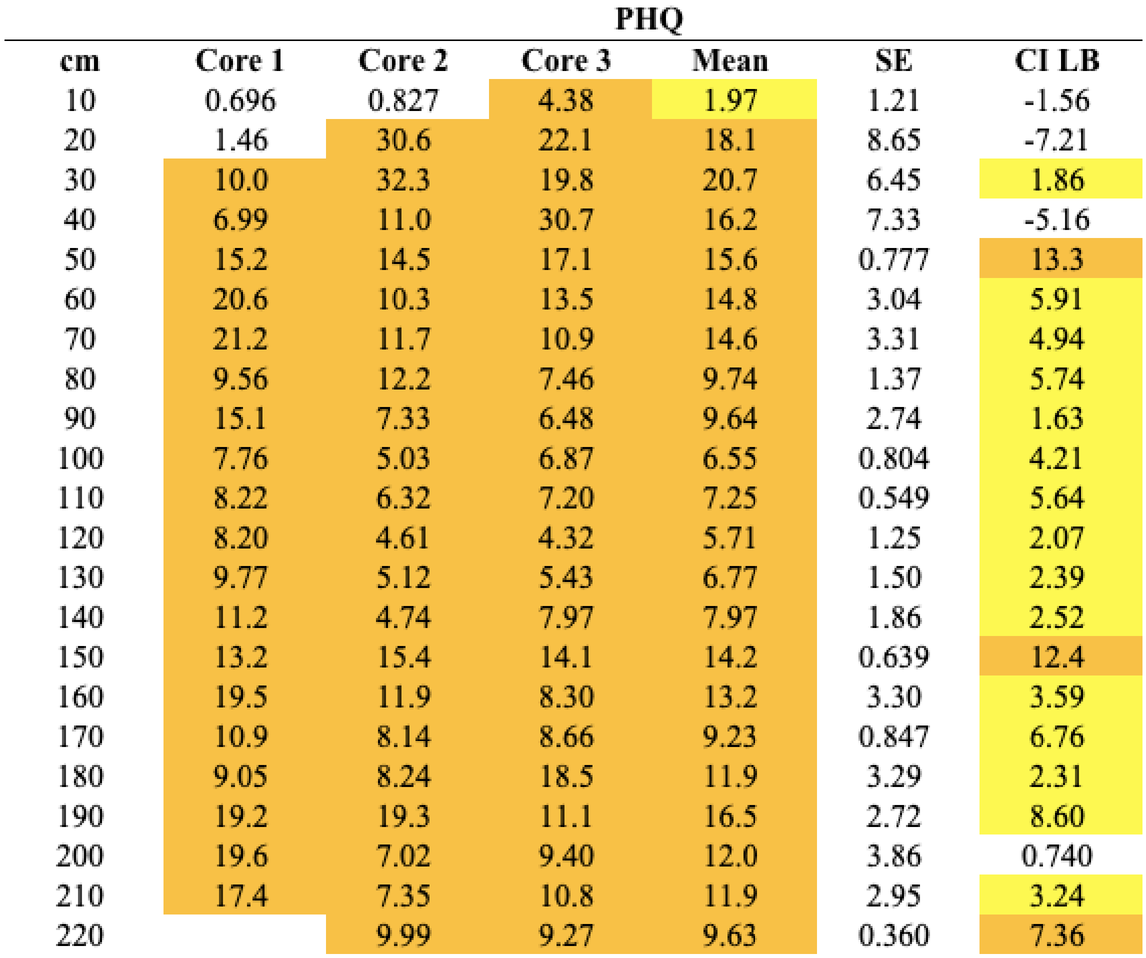


PEC

cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	2.71	2.27	1.07	2.02	0.490	0.586
20	4.09	3.52	2.76	3.46	0.385	2.33
30	5.73	5.74	4.55	5.34	0.395	4.19
40	4.38	5.78	2.80	4.32	0.861	1.81
50	2.91	2.85	2.30	2.69	0.194	2.12
60	3.78	3.44	3.73	3.65	0.106	3.34
70	5.35	4.39	5.54	5.09	0.356	4.05
80	3.58	3.78	5.77	4.38	0.699	2.34
90	3.19	3.20	3.52	3.30	0.108	2.99
100	4.08	8.16	3.77	5.34	1.41	1.21
110	4.65	9.27	7.42	7.11	1.34	3.19
120	8.41	7.29	7.77	7.82	0.324	6.88
130	9.51	21.5	26.6	19.2	5.07	4.41
140	8.47	36.5	18.9	21.3	8.18	-2.59
150	9.65	23.4	15.2	16.1	3.99	4.42
160	3.97	11.0	18.4	11.1	4.17	-1.04
170	13.1	7.74	4.99	8.61	2.38	1.66
180	6.67	2.49	3.46	4.21	1.26	0.518
190	3.57	2.54	3.98	3.36	0.428	2.11
200	4.67	2.54		3.61	1.07	-3.12
210	2.30	3.88		3.09	0.79	-1.90
220	3.98			3.98		
230	3.75			3.75		

Table 61. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and

values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.



			PHQ			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.696	0.827	4.38	1.97	1.21	-1.56
20	1.46	30.6	22.1	18.1	8.65	-7.21
30	10.0	32.3	19.8	20.7	6.45	1.86
40	6.99	11.0	30.7	16.2	7.33	-5.16
50	15.2	14.5	17.1	15.6	0.777	13.3
60	20.6	10.3	13.5	14.8	3.04	5.91
70	21.2	11.7	10.9	14.6	3.31	4.94
80	9.56	12.2	7.46	9.74	1.37	5.74
90	15.1	7.33	6.48	9.64	2.74	1.63
100	7.76	5.03	6.87	6.55	0.804	4.21
110	8.22	6.32	7.20	7.25	0.549	5.64
120	8.20	4.61	4.32	5.71	1.25	2.07
130	9.77	5.12	5.43	6.77	1.50	2.39
140	11.2	4.74	7.97	7.97	1.86	2.52
150	13.2	15.4	14.1	14.2	0.639	12.4
160	19.5	11.9	8.30	13.2	3.30	3.59
170	10.9	8.14	8.66	9.23	0.847	6.76
180	9.05	8.24	18.5	11.9	3.29	2.31
190	19.2	19.3	11.1	16.5	2.72	8.60
200	19.6	7.02	9.40	12.0	3.86	0.740
210	17.4	7.35	10.8	11.9	2.95	3.24
220		9.99	9.27	9.63	0.360	7.36

Table 62. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

			PEI			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	2.76	2.93	3.00	2.90	0.071	2.69
20	3.17	3.31	3.01	3.16	0.087	2.91
30	3.39	3.05	2.43	2.96	0.281	2.14
40	3.08	3.35		3.22	0.135	2.36
50		2.53		2.53		

Table 63. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

			STB			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	22.3	6.94	25.7	18.3	5.77	1.46
20	38.4	9.66	15.6	21.2	8.76	-4.36
30	24.8	14.2	19.7	19.6	3.06	10.6
40	18.4	17.7	16.8	17.6	0.463	16.3
50	8.82	16.6	10.4	11.9	2.37	5.01
60	8.20	14.0	11.0	11.1	1.67	6.18
70	8.14	9.33	10.8	9.42	0.769	7.18
80	9.10	21.6	11.2	14.0	3.86	2.68
90	11.8	8.48	8.98	9.75	1.03	6.74
100	12.8	10.9	9.55	11.1	0.943	8.33
110	16.4	12.1	11.8	13.4	1.49	9.09
120	15.5	9.42	11.2	12.0	1.80	6.77
130	50.2	9.20	13.6	24.3	13.0	-13.6
140		11.1	18.9	15.0	3.90	-9.62
150		10.4	17.3	13.9	3.45	-7.93
160		15.8	60.9	38.4	22.6	-104
170		28.6	32.5	30.6	1.95	18.2
180			31.5	31.5		
190			4.31	4.31		

Table 64. Arsenic (As) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from West Lake (WL). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

			WL			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	25.5	23.3	29.3	26.0	1.75	20.9
20	18.6	15.7	17.4	17.2	0.841	14.8
30	17.5	19.4	38.4	25.1	6.67	5.62
40	70.7	20.0	37.7	42.8	14.9	-0.580
50	32.1	20.2	26.0	26.1	3.44	16.1
60	27.3	18.3	14.6	20.1	3.77	9.06
70	16.6	31.5		24.1	7.45	-23.0
80	28.3	31.9		30.1	1.80	18.7

Table 65. Arsenic (As) concentrations (mg/g) in sediment from traps at the reef sites (1N, 2N, 3N, 1S, 2S, 3S). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g), values highlighted in orange are above TEL (> 7.24 mg/g), and values highlighted in red are above PEL (> 41.6 mg/g). SE = standard error and CI LB = confidence interval lower bound.

			Reef Sites			
Coral Reef Site	**Sample 1**	**Sample 2**	**Sample 3**	**Mean**	**SE**	**Lower CI**
1N	8.23	9.04	9.21	8.83	0.302	7.94
2N	7.69	8.84	7.36	7.96	0.449	6.65
3N	4.69	4.58	5.25	4.84	0.207	4.23
1S	5.50	8.27	5.59	6.45	0.909	3.80
2S	6.85	6.62	7.41	6.96	0.235	6.27
3S	4.06	5.03	3.95	4.35	0.343	3.34

Table 66. Cadmium (Cd) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

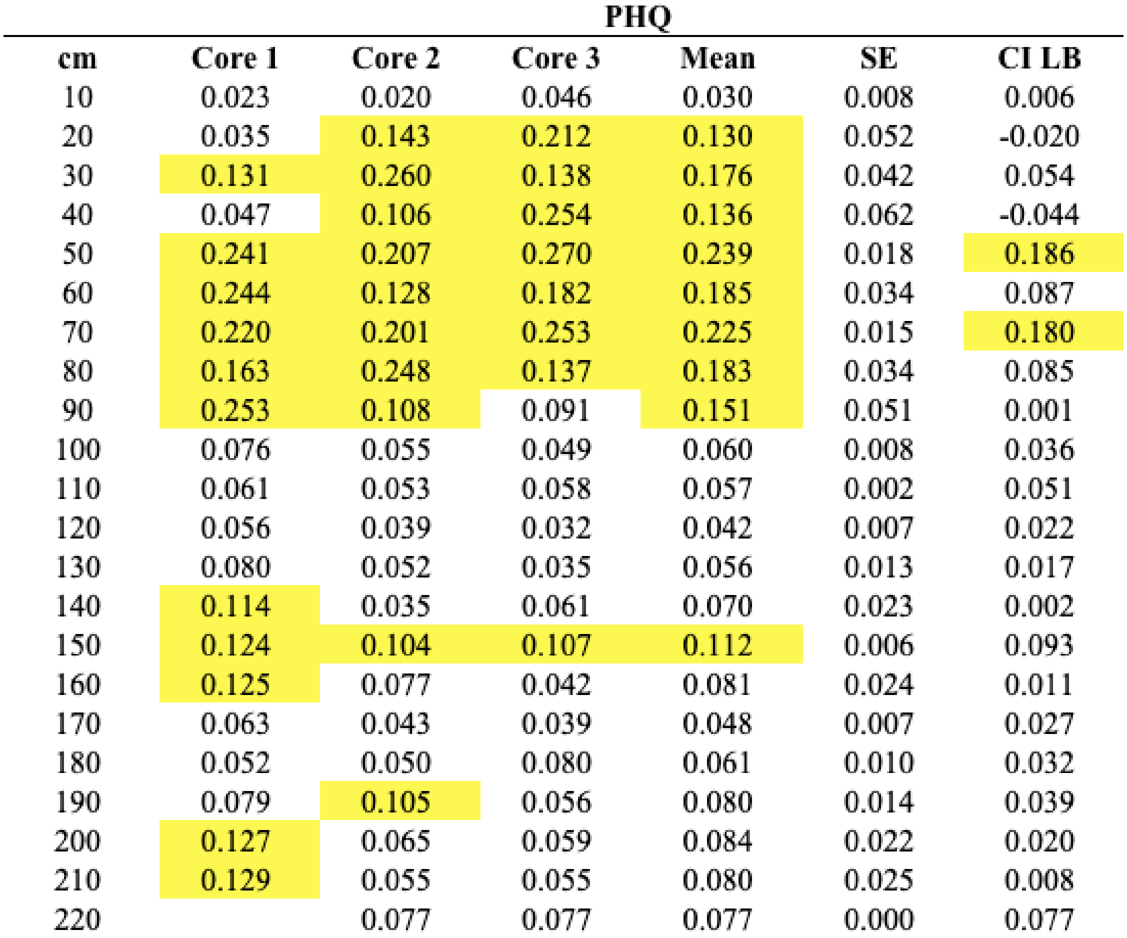
	DCC					
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.076	0.046	0.372	0.165	0.104	-0.139
20	0.122	0.136	0.659	0.306	0.177	-0.210
30	0.182	0.293	0.440	0.305	0.075	0.087
40	0.628	0.620	0.121	0.456	0.168	-0.033
50	0.632	0.729	0.042	0.468	0.215	-0.159
60	0.633	0.246	0.034	0.304	0.175	-0.208
70	0.370	0.040	0.035	0.148	0.111	-0.175
80	0.219	0.036	0.030	0.095	0.062	-0.086
90	0.135	0.037	0.034	0.069	0.033	-0.028
100	0.041	0.035	0.033	0.036	0.002	0.029
110	0.036		0.033	0.035	0.002	0.030
120	0.037					
130	0.037					
140	0.035					
150	0.034					
160	0.035					

Table 67. Cadmium (Cd) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

PEC

cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	0.067	0.055	0.047	0.056	0.006	0.039
20	0.129	0.101	0.098	0.109	0.010	0.081
30	0.206	0.167	0.230	0.201	0.018	0.147
40	0.143	0.132	0.075	0.117	0.021	0.055
50	0.056	0.047	0.058	0.054	0.003	0.044
60	0.060	0.050	0.058	0.056	0.003	0.047
70	0.081	0.069	0.088	0.079	0.006	0.063
80	0.071	0.079	0.103	0.084	0.010	0.056
90	0.063	0.062	0.084	0.070	0.007	0.049
100	0.066	0.168	0.080	0.105	0.032	0.011
110	0.069	0.076	0.133	0.093	0.020	0.033
120	0.198	0.071	0.084	0.118	0.040	0.000
130	0.117	0.053	0.087	0.086	0.018	0.032
140	0.080	0.066	0.049	0.065	0.009	0.039
150	0.072	0.058	0.035	0.055	0.011	0.024
160	0.053	0.054	0.067	0.058	0.005	0.045
170	0.099	0.053	0.053	0.068	0.015	0.024
180	0.084	0.045	0.041	0.057	0.014	0.017
190	0.079	0.034	0.036	0.050	0.015	0.007
200	0.066	0.037		0.052	0.015	0.009
210	0.043	0.056		0.050	0.006	0.031
220	0.049					
230	0.042					

Table 68. Cadmium (Cd) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.



			PHQ			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.023	0.020	0.046	0.030	0.008	0.006
20	0.035	0.143	0.212	0.130	0.052	-0.020
30	0.131	0.260	0.138	0.176	0.042	0.054
40	0.047	0.106	0.254	0.136	0.062	-0.044
50	0.241	0.207	0.270	0.239	0.018	0.186
60	0.244	0.128	0.182	0.185	0.034	0.087
70	0.220	0.201	0.253	0.225	0.015	0.180
80	0.163	0.248	0.137	0.183	0.034	0.085
90	0.253	0.108	0.091	0.151	0.051	0.001
100	0.076	0.055	0.049	0.060	0.008	0.036
110	0.061	0.053	0.058	0.057	0.002	0.051
120	0.056	0.039	0.032	0.042	0.007	0.022
130	0.080	0.052	0.035	0.056	0.013	0.017
140	0.114	0.035	0.061	0.070	0.023	0.002
150	0.124	0.104	0.107	0.112	0.006	0.093
160	0.125	0.077	0.042	0.081	0.024	0.011
170	0.063	0.043	0.039	0.048	0.007	0.027
180	0.052	0.050	0.080	0.061	0.010	0.032
190	0.079	0.105	0.056	0.080	0.014	0.039
200	0.127	0.065	0.059	0.084	0.022	0.020
210	0.129	0.055	0.055	0.080	0.025	0.008
220		0.077	0.077	0.077	0.000	0.077

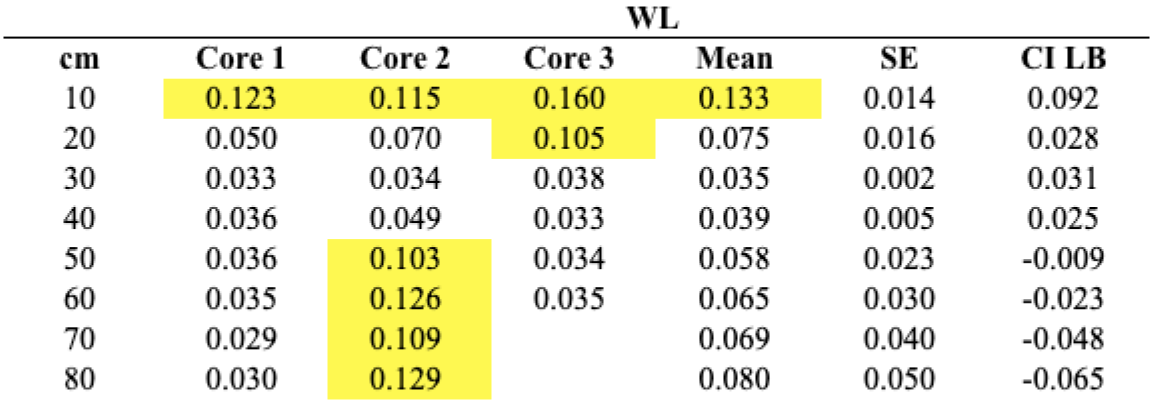
Table 69. Cadmium (Cd) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

			PEI			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.022	0.020	0.022	0.021	0.001	0.019
20	0.022	0.019	0.022	0.021	0.001	0.018
30	0.022	0.020	0.023	0.022	0.001	0.019
40	0.023	0.025		0.024	0.001	0.022
50		0.020		0.020		

Table 70. Cadmium (Cd) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

			STB			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.204	0.125	0.175	0.168	0.023	0.101
20	0.191	0.139	0.150	0.160	0.016	0.114
30	0.152	0.124	0.155	0.144	0.010	0.115
40	0.122	0.120	0.135	0.126	0.005	0.112
50	0.117	0.144	0.104	0.122	0.012	0.087
60	0.101	0.130	0.113	0.115	0.008	0.090
70	0.113	0.125	0.151	0.130	0.011	0.097
80	0.099	0.128	0.107	0.111	0.009	0.086
90	0.117	0.130	0.128	0.125	0.004	0.113
100	0.139	0.127	0.124	0.130	0.005	0.117
110	0.125	0.113	0.122	0.120	0.004	0.109
120	0.156	0.129	0.124	0.136	0.010	0.107
130	0.129	0.129	0.132	0.130	0.001	0.127
140		0.139	0.235	0.187	0.048	0.047
150		0.127	0.135	0.131	0.004	0.119
160		0.140	0.319	0.230	0.090	-0.032
170		0.253	0.128	0.191	0.062	0.008
180			0.110			
190			0.027			

Table 71. Cadmium (Cd) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from West Lake (WL). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

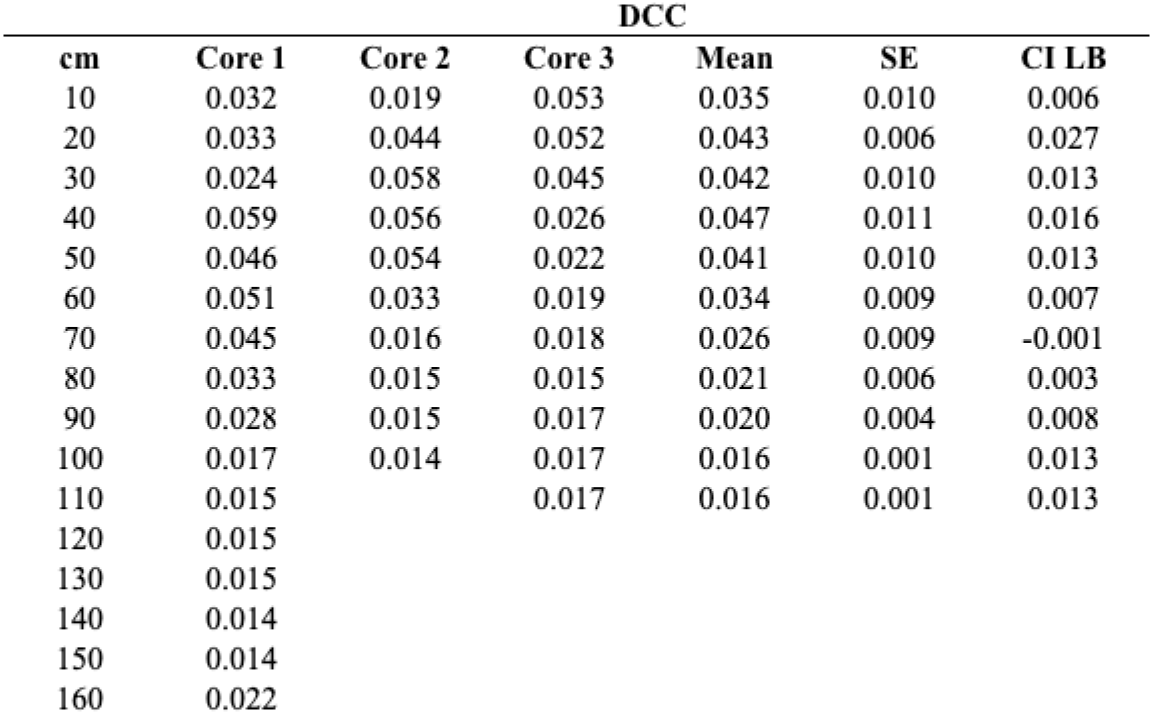


			WL			
cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	0.123	0.115	0.160	0.133	0.014	0.092
20	0.050	0.070	0.105	0.075	0.016	0.028
30	0.033	0.034	0.038	0.035	0.002	0.031
40	0.036	0.049	0.033	0.039	0.005	0.025
50	0.036	0.103	0.034	0.058	0.023	-0.009
60	0.035	0.126	0.035	0.065	0.030	-0.023
70	0.029	0.109		0.069	0.040	-0.048
80	0.030	0.129		0.080	0.050	-0.065

Table 72. Cadmium (Cd) concentrations (mg/g) from traps at the reef sites (1N, 2N, 3N, 1S, 2S, 3S). Values highlighted in yellow are above the continental crust value (> 0.098 mg/g), values highlighted in orange are above TEL (> 0.68 mg/g), and values highlighted in red are above PEL (> 4.21 mg/g). SE = standard error and CI LB = confidence interval lower bound.

			Reef Sites			
Coral Reef Site	Sample 1	Sample 2	Sample 3	Mean	SE	Lower CI
1N	0.048	0.055	0.049	0.051	0.002	0.044
2N	0.062	0.054	0.050	0.055	0.004	0.045
3N	0.077	0.055	0.059	0.064	0.007	0.044
1S	0.049	0.055	0.045	0.050	0.003	0.041
2S	0.065	0.063	0.075	0.068	0.004	0.057
3S	0.058	0.053	0.047	0.053	0.003	0.043

Table 73. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.

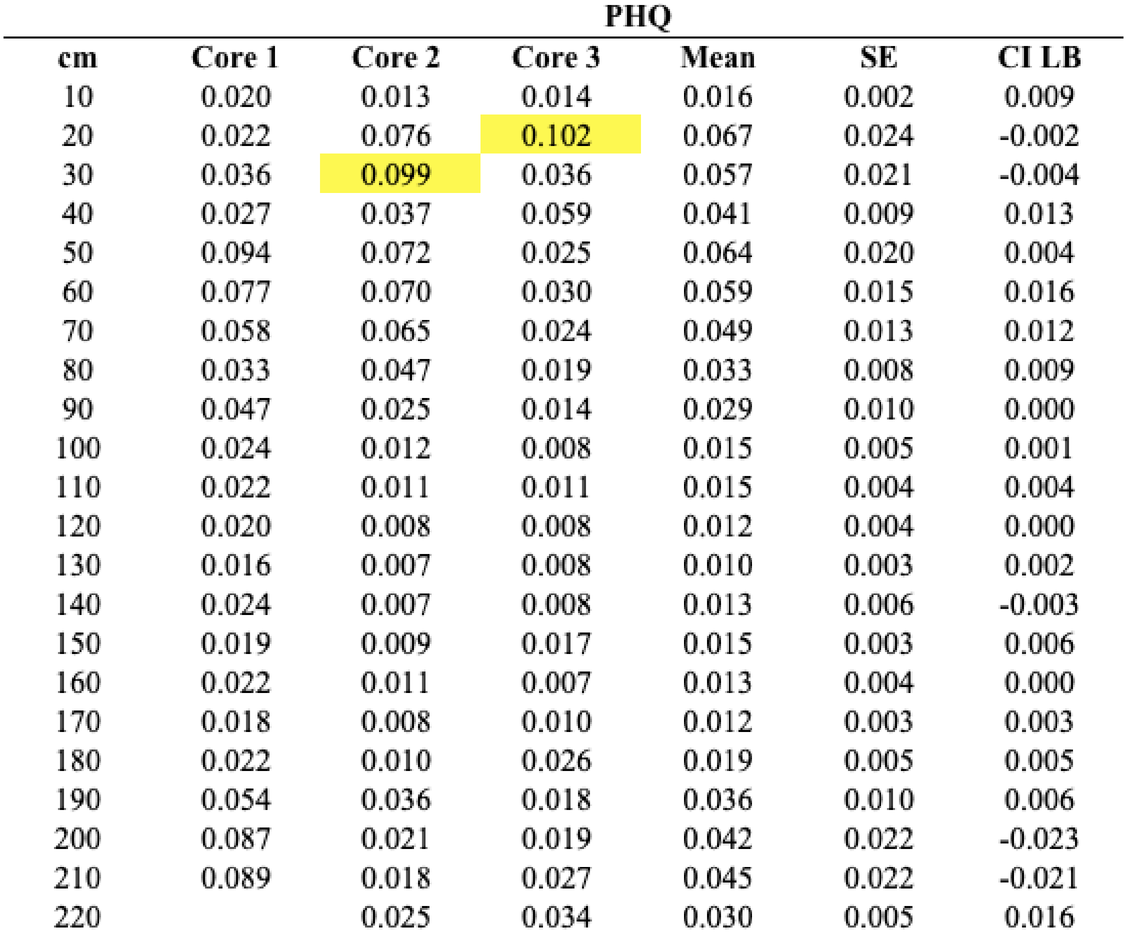


			DCC			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.032	0.019	0.053	0.035	0.010	0.006
20	0.033	0.044	0.052	0.043	0.006	0.027
30	0.024	0.058	0.045	0.042	0.010	0.013
40	0.059	0.056	0.026	0.047	0.011	0.016
50	0.046	0.054	0.022	0.041	0.010	0.013
60	0.051	0.033	0.019	0.034	0.009	0.007
70	0.045	0.016	0.018	0.026	0.009	-0.001
80	0.033	0.015	0.015	0.021	0.006	0.003
90	0.028	0.015	0.017	0.020	0.004	0.008
100	0.017	0.014	0.017	0.016	0.001	0.013
110	0.015		0.017	0.016	0.001	0.013
120	0.015					
130	0.015					
140	0.014					
150	0.014					
160	0.022					

Table 74. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.

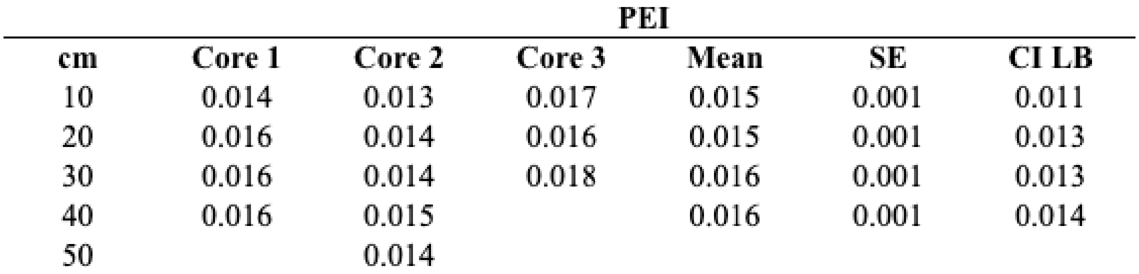
			PEC			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.061	0.026	0.023	0.037	0.012	0.001
20	0.092	0.068	0.059	0.073	0.010	0.044
30	0.207	0.135	0.160	0.167	0.021	0.106
40	0.112	0.152	0.017	0.094	0.040	-0.023
50	0.027	0.021	0.038	0.029	0.005	0.014
60	0.027	0.018	0.036	0.027	0.005	0.012
70	0.048	0.024	0.048	0.040	0.008	0.017
80	0.045	0.031	0.110	0.062	0.024	-0.009
90	0.039	0.025	0.031	0.032	0.004	0.020
100	0.036	0.320	0.025	0.127	0.097	-0.155
110	0.043	0.036	0.218	0.099	0.060	-0.075
120	0.224	0.010	0.105	0.113	0.062	-0.068
130	0.056	0.021	0.117	0.065	0.028	-0.017
140	0.024	0.033	0.053	0.037	0.009	0.012
150	0.036	0.019	0.061	0.039	0.012	0.003
160	0.039	0.018	0.036	0.031	0.007	0.012
170	0.088	0.030	0.050	0.056	0.017	0.006
180	0.075	0.020	0.027	0.041	0.017	-0.010
190	0.052	0.012	0.060	0.041	0.015	-0.002
200	0.100	0.015		0.058	0.043	-0.067
210	0.038	0.046		0.042	0.004	0.030
220	0.032					
230	0.048					

Table 75. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.



			PHQ			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.020	0.013	0.014	0.016	0.002	0.009
20	0.022	0.076	0.102	0.067	0.024	-0.002
30	0.036	0.099	0.036	0.057	0.021	-0.004
40	0.027	0.037	0.059	0.041	0.009	0.013
50	0.094	0.072	0.025	0.064	0.020	0.004
60	0.077	0.070	0.030	0.059	0.015	0.016
70	0.058	0.065	0.024	0.049	0.013	0.012
80	0.033	0.047	0.019	0.033	0.008	0.009
90	0.047	0.025	0.014	0.029	0.010	0.000
100	0.024	0.012	0.008	0.015	0.005	0.001
110	0.022	0.011	0.011	0.015	0.004	0.004
120	0.020	0.008	0.008	0.012	0.004	0.000
130	0.016	0.007	0.008	0.010	0.003	0.002
140	0.024	0.007	0.008	0.013	0.006	-0.003
150	0.019	0.009	0.017	0.015	0.003	0.006
160	0.022	0.011	0.007	0.013	0.004	0.000
170	0.018	0.008	0.010	0.012	0.003	0.003
180	0.022	0.010	0.026	0.019	0.005	0.005
190	0.054	0.036	0.018	0.036	0.010	0.006
200	0.087	0.021	0.019	0.042	0.022	-0.023
210	0.089	0.018	0.027	0.045	0.022	-0.021
220		0.025	0.034	0.030	0.005	0.016

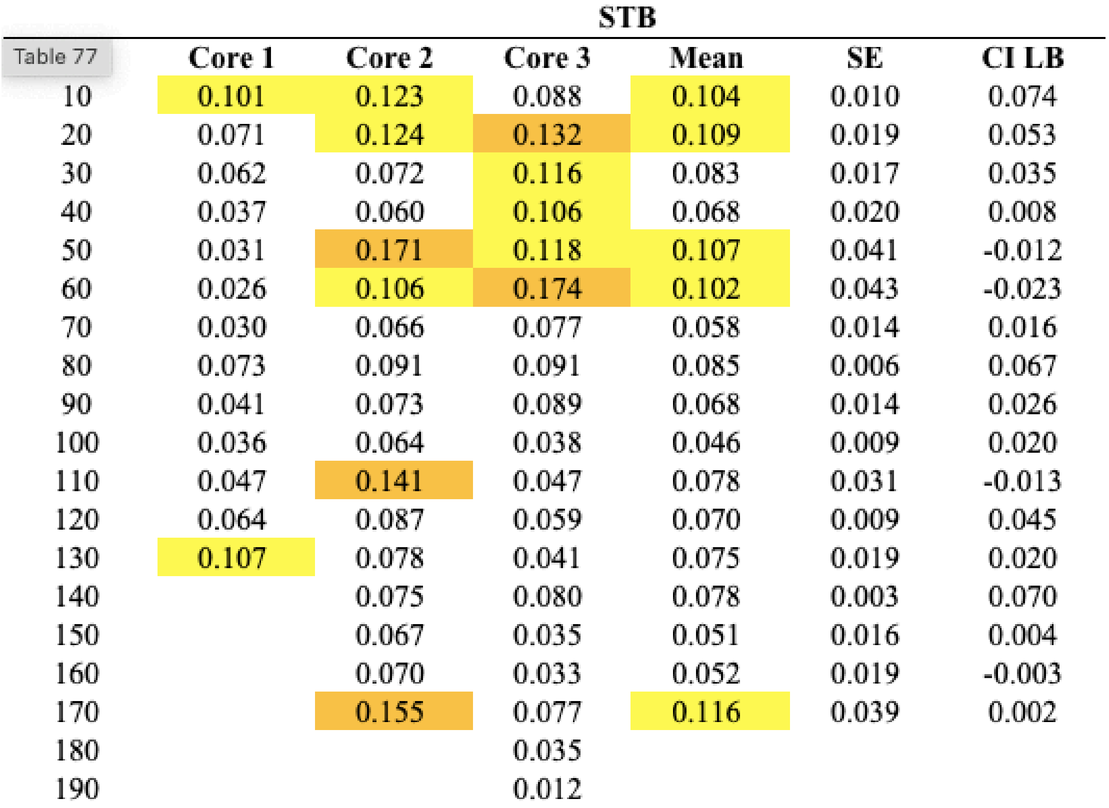
Table 76. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.



PEI

cm	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	0.014	0.013	0.017	0.015	0.001	0.011
20	0.016	0.014	0.016	0.015	0.001	0.013
30	0.016	0.014	0.018	0.016	0.001	0.013
40	0.016	0.015		0.016	0.001	0.014
50		0.014				

Table 77. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.



STB

Table 77	Core 1	Core 2	Core 3	Mean	SE	CI LB
10	0.101	0.123	0.088	0.104	0.010	0.074
20	0.071	0.124	0.132	0.109	0.019	0.053
30	0.062	0.072	0.116	0.083	0.017	0.035
40	0.037	0.060	0.106	0.068	0.020	0.008
50	0.031	0.171	0.118	0.107	0.041	-0.012
60	0.026	0.106	0.174	0.102	0.043	-0.023
70	0.030	0.066	0.077	0.058	0.014	0.016
80	0.073	0.091	0.091	0.085	0.006	0.067
90	0.041	0.073	0.089	0.068	0.014	0.026
100	0.036	0.064	0.038	0.046	0.009	0.020
110	0.047	0.141	0.047	0.078	0.031	-0.013
120	0.064	0.087	0.059	0.070	0.009	0.045
130	0.107	0.078	0.041	0.075	0.019	0.020
140		0.075	0.080	0.078	0.003	0.070
150		0.067	0.035	0.051	0.016	0.004
160		0.070	0.033	0.052	0.019	-0.003
170		0.155	0.077	0.116	0.039	0.002
180			0.035			
190			0.012			

Table 78. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from West Lake (WL). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.

			WL			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.128	0.119	0.111	0.119	0.005	0.105
20	0.055	0.077	0.078	0.070	0.008	0.048
30	0.017	0.017	0.027	0.020	0.003	0.011
40	0.018	0.037	0.024	0.026	0.006	0.010
50	0.019	0.109	0.024	0.051	0.029	-0.035
60	0.018	0.090	0.025	0.044	0.023	-0.023
70	0.015	0.096		0.056	0.033	-0.041
80	0.016	0.112		0.064	0.039	-0.050

Table 79. Mercury (Hg) concentrations (mg/g) in sediment from traps at the reef sites (1N, 2N, 3N, 1S, 2S, 3S). Values highlighted in yellow are above the continental crust value (> 0.096 mg/g), values highlighted in orange are above TEL (> 0.13 mg/g), and values highlighted in red are above PEL (> 0.63 mg/g). SE = standard error and CI LB = confidence interval lower bound.

			Reef Sites			
Coral Reef Site	**Sample 1**	**Sample 2**	**Sample 3**	**Mean**	**SE**	**CI LB**
1N	0.008	0.007	0.008	0.008	0.000	0.007
2N	0.006	0.007	0.013	0.009	0.002	0.002
3N	0.012	0.007	0.009	0.009	0.001	0.005
1S	0.007	0.008	0.007	0.007	0.000	0.006
2S	0.007	0.007	0.007	0.007	0.000	0.007
3S	0.008	0.007	0.007	0.007	0.000	0.006

Table 80. Molybdenum (Mo) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Dania Cutoff Canal (DCC). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

	DCC					
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	4.68	1.56	23.6	9.95	6.89	-10.2
20	9.95	11.6	33.4	18.3	7.56	-3.75
30	13.1	42.5	33.3	29.6	8.68	4.28
40	49.4	40.4	14.5	34.8	10.5	4.22
50	38.9	39.9	6.39	28.4	11.0	-3.74
60	35.3	20.4	5.15	20.3	8.70	-5.13
70	24.2	5.67	1.99	10.6	6.87	-9.45
80	18.6	2.15	0.852	7.20	5.71	-9.48
90	17.8	0.750	0.652	6.40	5.70	-10.2
100	6.00	0.697	0.674	2.46	1.77	-2.72
110	1.87		1.14	1.51	0.365	0.439
120	0.886					
130	0.293					
140	0.382					
150	0.364					
160	1.52					

Table 81. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Education Center (PEC). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

	PEC					
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	1.46	1.53	0.582	1.19	0.305	0.300
20	2.66	1.84	1.59	2.03	0.323	1.09
30	3.42	3.02	3.18	3.21	0.116	2.87
40	2.59	2.29	2.14	2.34	0.132	1.95
50	1.87	1.58	1.52	1.66	0.108	1.34
60	2.28	2.05	2.43	2.25	0.111	1.93
70	3.47	2.42	3.78	3.22	0.412	2.02
80	2.27	2.37	4.08	2.91	0.587	1.19
90	2.11	2.27	3.10	2.49	0.307	1.60
100	2.94	1.79	2.92	2.55	0.380	1.44
110	2.60	6.45	2.73	3.93	1.26	0.241
120	2.83	5.23	4.55	4.20	0.714	2.12
130	6.53	19.2	30.4	18.7	6.90	-1.42
140	5.23	29.1	10.9	15.1	7.20	-5.95
150	8.55	27.6	4.24	13.5	7.18	-7.49
160	9.74	5.37	9.82	8.31	1.47	4.02
170	43.2	6.73	3.31	17.7	12.8	-19.5
180	17.5	1.65	1.35	6.83	5.33	-8.74
190	9.52	1.17	1.07	3.92	2.80	-4.26
200	9.40	0.946		5.17	4.23	-7.17
210	4.52	2.61		3.57	0.955	0.776
220	8.17					
230	5.94					

Table 82. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Park Headquarters (PHQ). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

PHQ						
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.288	0.102	2.66	1.02	0.823	-1.39
20	0.940	49.0	49.8	33.2	16.2	-13.9
30	16.9	87.7	52.0	52.2	20.4	-7.48
40	13.8	23.6	78.6	38.7	20.2	-20.2
50	33.8	49.5	43.1	42.1	4.56	28.8
60	60.5	39.5	50.3	50.1	6.06	32.4
70	55.9	48.5	53.7	52.7	2.19	46.3
80	35.8	52.0	41.7	43.2	4.73	29.3
90	54.5	31.3	27.6	37.8	8.42	13.2
100	28.3	15.9	10.9	18.4	5.17	3.26
110	15.3	8.92	17.6	13.9	2.60	6.36
120	17.6	5.87	6.40	9.96	3.82	-1.21
130	13.9	5.86	4.89	8.22	2.86	-0.121
140	12.4	4.89	6.80	8.03	2.25	1.45
150	15.1	10.8	11.0	12.3	1.40	8.21
160	18.2	8.02	4.93	10.4	4.01	-1.32
170	8.10	4.85	6.83	6.59	0.946	3.83
180	8.59	7.74	18.6	11.6	3.49	1.46
190	32.5	24.6	12.6	23.2	5.79	6.34
200	29.0	7.66	5.04	13.9	7.59	-8.26
210	21.5	3.89	5.87	10.4	5.57	-5.84
220		6.69	7.03	6.86	0.170	6.36

Table 83. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from Port Everglades Inlet (PEI). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

PEI						
Cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	0.090	0.057	0.081	0.076	0.010	0.047
20	0.080	0.062	0.072	0.071	0.005	0.056
30	0.077	0.081	0.070	0.076	0.003	0.067
40	0.068	0.088		0.078	0.010	0.049
50		0.051				

Table 84. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from South Turning Basin (STB). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

STB						
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	18.6	16.5	23.8	19.6	2.17	13.3
20	26.1	11.2	16.8	18.0	4.35	5.35
30	26.8	17.5	23.4	22.6	2.72	14.6
40	52.4	23.0	40.1	38.5	8.52	13.6
50	24.3	24.1	25.2	24.5	0.338	23.5
60	15.1	52.8	31.8	33.2	10.9	1.39
70	16.6	24.6	28.9	23.4	3.60	12.8
80	23.2	51.3	30.8	35.1	8.39	10.6
90	32.2	18.6	31.3	27.4	4.39	14.5
100	40.4	23.1	26.5	30.0	5.29	14.5
110	40.6	33.4	36.8	36.9	2.08	30.9
120	57.0	24.9	38.9	40.3	9.29	13.1
130	44.9	24.0	42.3	37.1	6.58	17.9
140		32.1	74.6	53.4	21.3	-8.70
150		24.0	60.4	42.2	18.2	-10.9
160		47.2	157	102	54.9	-58.2
170		101	65.9	83.5	17.6	32.2
180			17.5			
190			0.285			

Table 85. Mercury (Hg) concentrations (mg/g) in sediment cores (core 1, core 2, and core 3) from West Lake (WL). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

			WL			
cm	**Core 1**	**Core 2**	**Core 3**	**Mean**	**SE**	**CI LB**
10	1.24	1.03	2.34	1.54	0.406	0.351
20	1.92	1.16	1.29	1.46	0.235	0.771
30	1.13	0.794	1.13	1.02	0.112	0.691
40	1.20	0.865	0.738	0.934	0.138	0.532
50	0.538	1.12	0.429	0.696	0.214	0.069
60	0.404	0.971	0.204	0.526	0.230	-0.144
70	0.189	1.01		0.600	0.411	-0.599
80	0.229	3.23		1.73	1.50	-2.65

Table 86. Mercury (Hg) concentrations (mg/g) in sediment from traps at the reef sites (1N, 2N, 3N, 1S, 2S, 3S). Values highlighted in yellow are above the continental crust value (> 1.5 mg/g). SE = standard error and CI LB = confidence interval lower bound.

			Reef Sites			
Coral Reef Site	**Sample 1**	**Sample 2**	**Sample 3**	**Mean**	**SE**	**CI LB**
1N	0.233	0.229	0.245	0.236	0.005	0.222
2N	0.199	0.235	0.201	0.212	0.012	0.178
3N	0.238	0.187	0.212	0.212	0.015	0.169
1S	0.184	0.201	0.153	0.179	0.014	0.138
2S	0.168	0.199	0.196	0.188	0.010	0.159
3S	0.221	0.206	0.173	0.200	0.014	0.159

3.6 Statistical Analysis on Microbiome Diversity and Heavy Metals of Port Cores and Reef Sediment from Phase I

Due to the abundance of information, not all of the statistical analyses are shown in this report. All of the information is provided at: *https://nsuworks.nova.edu/secler_data/*

Overall, the port PEI site was higher in alpha diversity, specifically when evaluating observed number of species, in the PEI sediments compared to sediments at sites from the coral reef tracts (1N, 2N, 3N, 1S, 2S, and 3S), the control West Lake site (Lake), and the port sites (DCC, STB, PHQ, and PEC). Microbial community composition differed between sediments at sites in West Lake, coral, PEI, and in the port. Coral sites had lower functional diversity than the port and PEI. There was a difference in functional composition between PEI, the port, coral, and West Lake sediments (Figures 3-5).

Functional composition correlated to Al, As, Co, Cr, Fe, Hg, Mo, Ni, Se, Sn, and V. Higher metal concentrations were associated with the functional composition of the port and West Lake sites.

Alpha diversity negatively correlated Cr, Ni, Hg, Sn, Cd, and Se and evenness correlated to Al, Ni, Co, and Se. **There were 45 taxa that were differentially abundant in the coral compared to the Port sites.** There were 24 taxa that were differentially abundant in West Lake compared to the port. There were 202 taxa that were differentially abundant in the PEI compared to the port. This is due to the PEI site having sand that was used for beach renourishment in that area. Microbial community composition correlated to the following heavy metals: Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Sn, and V. The port sites and the WL site were associated with higher concentrations of metals (Tables 87-89 and Figures 6-7).

A closer look at two important heavy metal contaminants in this report, As and Mo, indicated that both Mo and As correlated with the *Methylocystis* microbial genus, while As also correlated with *Staphylococcus* (Tables 88-90). The *Methylocystis* genome has been seen to contain various genes for nitrogen fixation, polyhydroxybutyrate synthesis, antibiotic resistance, and detoxification of arsenic, cyanide and mercury (Tikhonova et al. 2021), while many classes of Bacilli (such as the *Staphylococcus*) are known to have As resistance (see table in Kabirai et al. 2022).

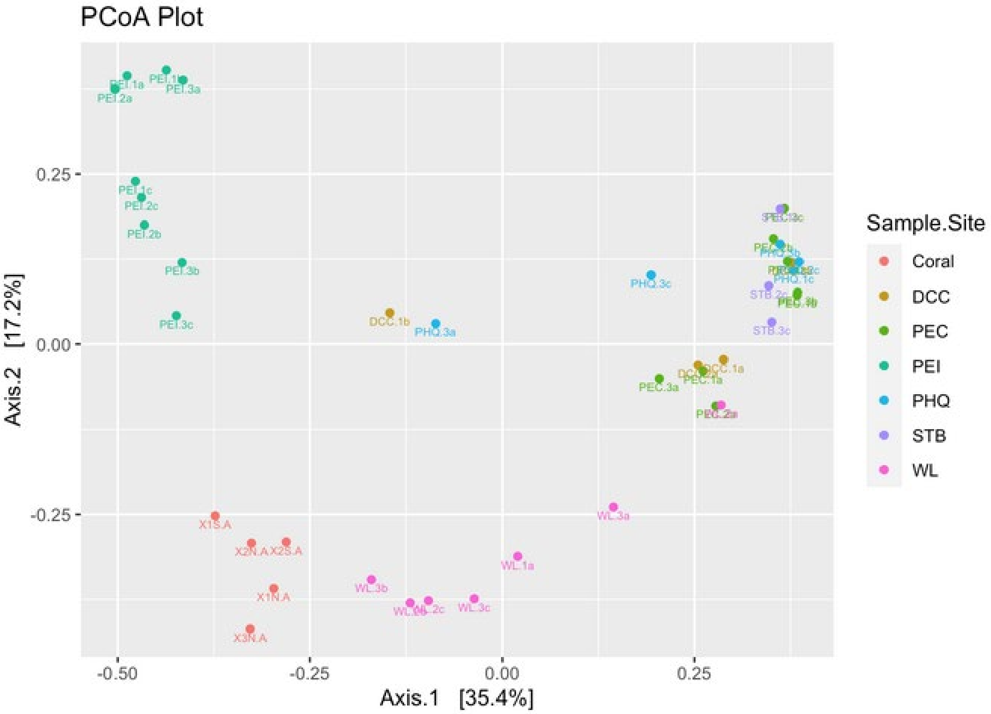


Figure 3. PERMANOVA differences in microbial community composition between sites. Coral (1N, 2N, 3N, 1S, 2S, and 3S sites), port sites (DCC, PEC, PHQ, PEI, STB) and control lake site (WL).

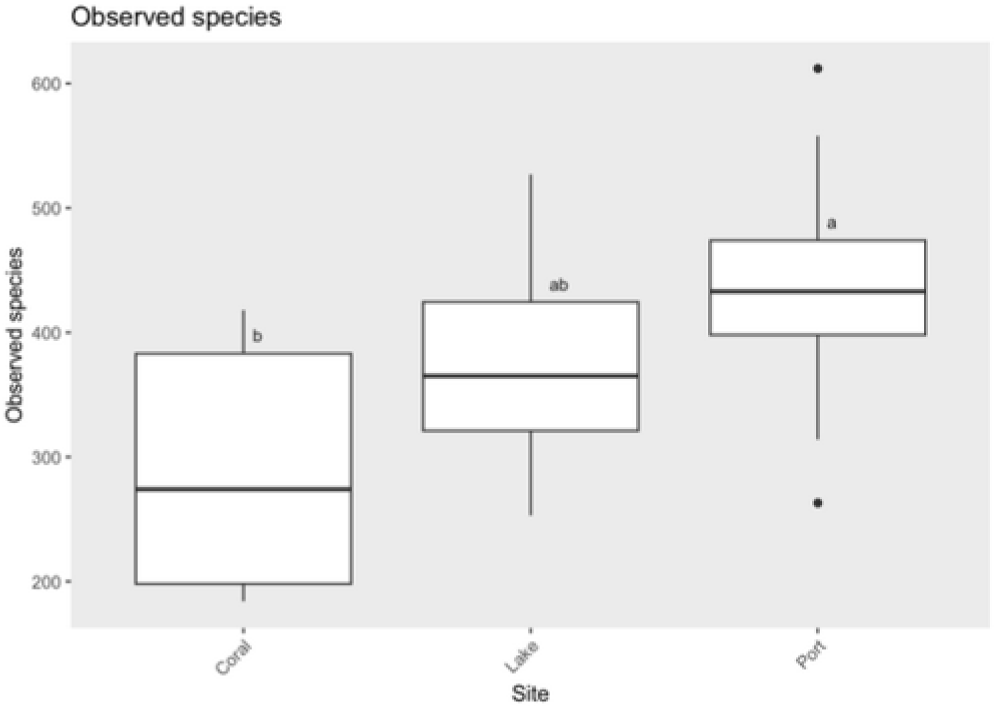


Figure 4. Microbial alpha diversity by location. Coral (1N, 2N, 3N, 1S, 2S, and 3S sites), port sites (DCC, PEC, PHQ, PEI, STB) and control lake site (Lake = WL).

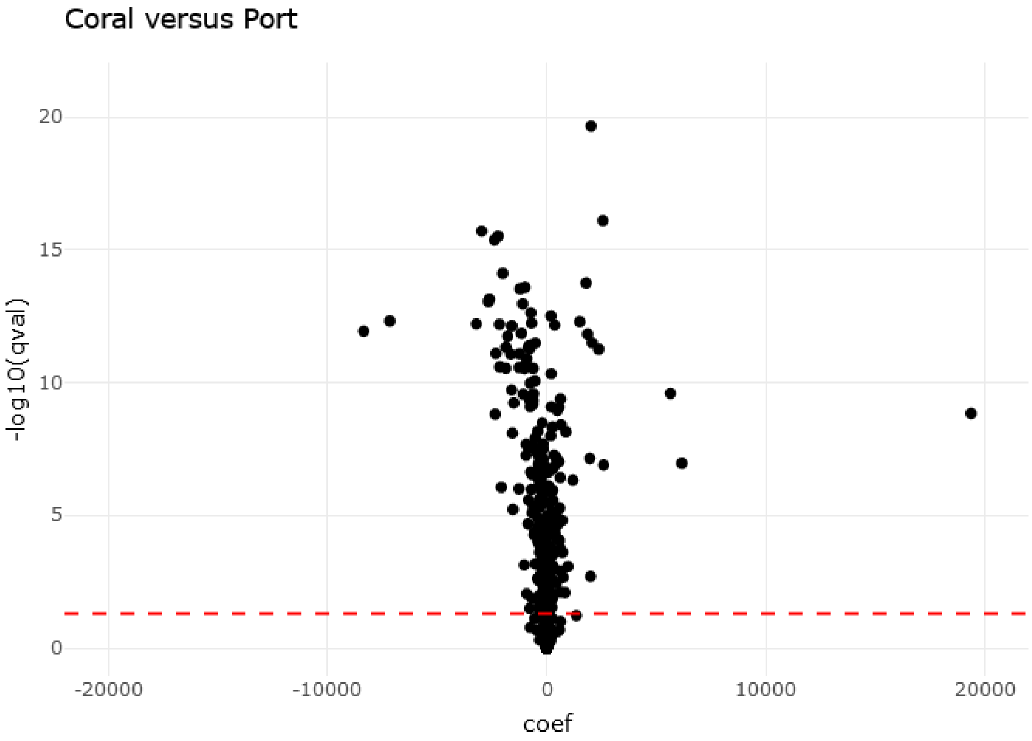


Figure 5. Volcano plot indicating microbial differences in coral sediments compared to port sediments. Points higher on the y axis are more significant. The X axis is the effect size (coef).

Table 87. Results from PERMANOVA using Bray Curtis distance. P values in red indicate correlation to microbial community composition.

	R^2	P
Location_Specific	0.528	0.001
Al	0.126	0.001
As	0.055	0.038
Cd	0.094	0.002
Co	0.112	0.001
Cr	0.102	0.001
Cu	0.071	0.012
Fe	0.065	0.015
Hg	0.086	0.005
Mn	0.065	0.018
Mo	0.043	0.076
Ni	0.135	0.001
Pb	0.076	0.008
Se	0.101	0.002
Sn	0.114	0.001
V	0.1	0.001

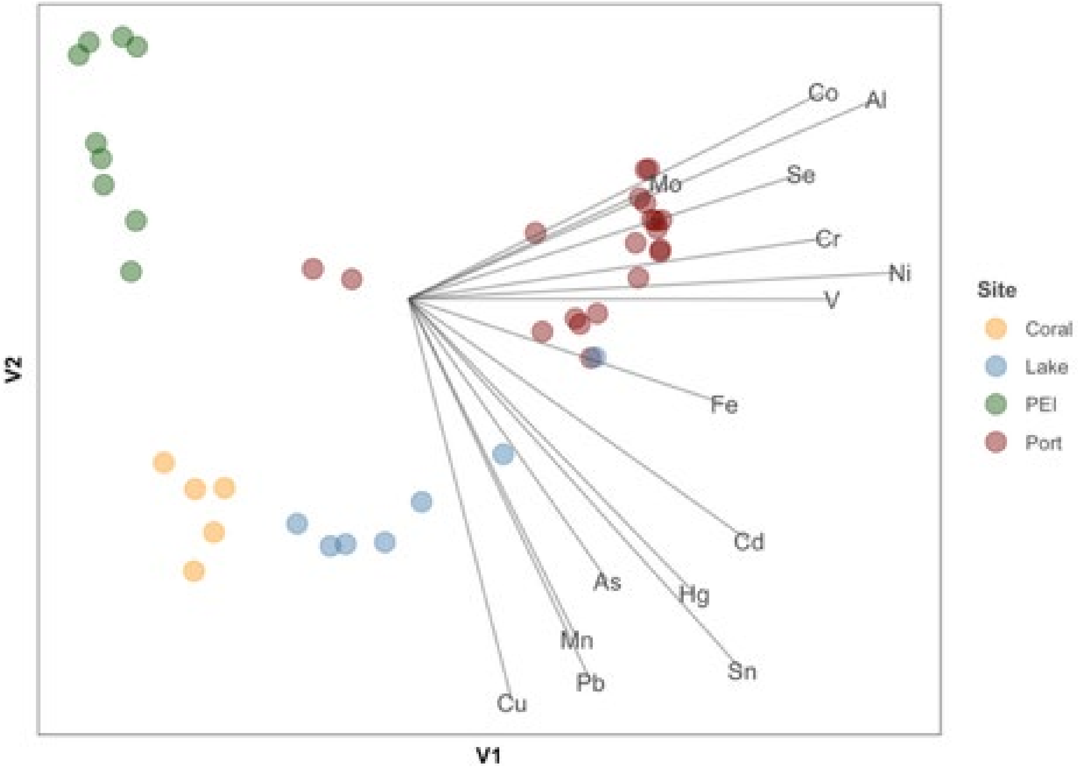


Figure 6. Ordination showing relationships between samples based on microbial community composition. Vectors are overlaid showing metals correlating to specific sites. Coral (1N, 2N, 3N, 1S, 2S, and 3S sites), port sites (DCC, PEC, PHQ, STB), port inlet (PEI) and control lake site (Lake = WL).

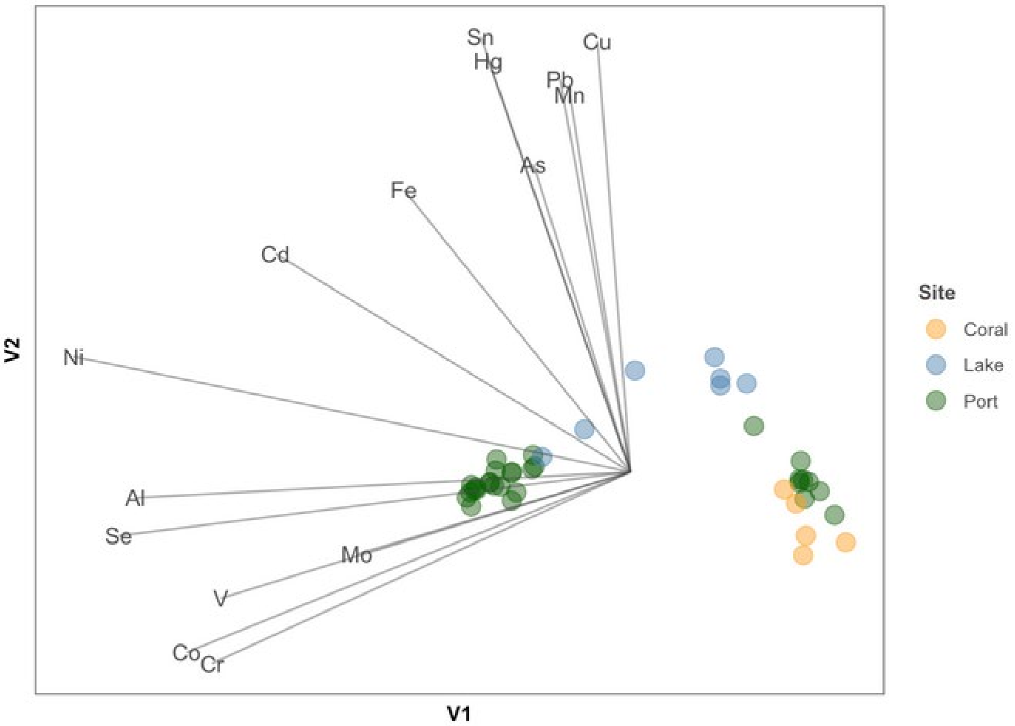


Figure 7. Ordination showing relationships between samples based on functional composition. Vectors are overlaid showing metals correlating to specific sites. Coral (1N, 2N, 3N, 1S, 2S, and 3S sites), port sites (DCC, PEC, PHQ, STB, PEI) and control lake site (Lake = WL).

Table 88. Genera that correlate to Mo. Positive log2fold is positive correlation, and negative log2fold is negative correlation.

Phylum	Proteobacteria
Class	Alphaproteobacteria
Order	Rhizobiales
Family	Methylocystaceae
Genus	*Methylocystis*
log2fold	1.40
qval	0.000252

Table 89. Genera that correlate to As. Positive log2fold is positive correlation, and negative log2fold is negative correlation.

Phylum	Proteobacteria	Firmicutes
Class	Alphaproteobacteria	Bacilli
Order	Rhizobiales	Bacillales
Family	Methylocystaceae	Staphylococcaceae
Genus	*Methylocystis*	*Staphylococcus*
log2fold	1.35	2.68
qval	0.000258	0.0461

Table 90. Genera that correlate to specific heavy metals.

Phylum	Proteobacteria	Firmicutes
Class	Alphaproteobacteria	Bacilli
Order	Rhizobiales	Bacillales
Family	Methylocystaceae	Staphylococcaceae
Genus	*Methylocystis*	*Staphylococcus*
log2fold	1.35	2.68
qval	0.000258	0.0461
Heavy Metals positive correlations	As, Cu, Fe, Mo	As and Se

3.7 Sediment Trap Heavy Metal Concentrations at the Six Reef Sites

The concentration ranges, geometric and arithmetic means of the 14 heavy metals were determined in sediment from the traps at the six coral reef sites (Table 91).

When comparing all three NR sites vs the three SR sites, the NR had higher geometric mean concentrations of Al, As, Cu Fe, Mn, and Sn while the concentrations of Cd, Co, Mo, Ni, Pb, Se, and Zn were within a 5% difference between the sites. Overall, the 2N and 3N north sites had higher heavy metal concentrations than the 2S and 3S south sites, while the 1S had higher than the 1N sites.

Comparing all six sites, the north (1N) and south (1S) sites closer to the coast had similar geometric mean concentrations for Cd, Co, and Mn. The 1N site had higher geometric mean concentrations of As, Fe, and V, while the 1S site had higher Al, Cu, Mo, Ni, Pb, Se, Sn, and Zn concentrations. The 2N and 2S sites had similar Cd, Co, and Se geometric mean concentrations, while the 3S and 3S sites had similar Cd and Co concentrations as well. Both 2N and 3N locations had higher geometric mean concentrations of Al, As, Cu, Fe, Mn, Mo, Ni, Pb, Sn, V, and Zn compared to 2S and 3S.

Table 91: The concentration ranges, geometric and arithmetic means of the 14 heavy metals analyzed at the three North Reef (NR) 1N, 2N, and 3N and three South Reef (SR) 1S, 2S, and 3S sediment trap samples from June 2023, September 2023, November 2023, and March 2024. Nd= non-detected.

	NR			SR		
Heavy Metals	**Range (µg/g)**	**Geometric Mean (µg/g)**	**Arithmetic Mean (µg/g)**	**Range (µg/g)**	**Geometric Mean (µg/g)**	**Arithmetic Mean (µg/g)**
Al	133-2464	367	626	95.5-1316	305	405
As	2.77-9.67	5.32	5.73	2.56-8.27	3.97	4.16
Cd	0.028-0.110	0.050	0.053	0.030-0.076	0.049	0.051
Co	0.148-0.589	0.276	0.301	0.177-0.421	0.274	0.282
Cu	0.420-21.1	2.09	5.37	0.350-8.87	1.84	3.22
Fe	612-3840	1475	1686	563-2059	1115	1199
Mn	12.3-30.7	18.2	18.8	11.8-23.7	16.7	17.1
Mo	0.176-4.85	0.495	1.03	0.144-3.62	0.481	0.828
Ni	0.503-9.53	1.17	1.90	0.425-4.35	1.16	1.49
Pb	0.901-16.1	2.87	4.61	0.906-10.7	2.57	3.52
Se	0.130-0.754	0.231	0.276	0.131-0.522	0.220	0.234
Sn	0.080-0.749	0.161	0.217	0.071-0.424	0.131	0.148
V	3.23-21.8	8.04	9.19	2.85-13.8	6.48	7.08
Zn	1.47-55.2	7.20	14.4	1.38-27.2	7.08	10.5

		1N			1S	
Heavy Metals	**Range (µg/g)**	**Geometric Mean (µg/g)**	**Arithmetic Mean (µg/g)**	**Range (µg/g)**	**Geometric Mean (µg/g)**	**Arithmetic Mean (µg/g)**
Al	137-1720	340	560	175-992	473	532
As	4.86-9.21	6.71	6.88	3.20-8.27	4.13	4.31
Cd	0.032-0.110	0.049	0.052	0.035-0.074	0.048	0.049
Co	0.148-0.477	0.258	0.280	0.185-0.389	0.293	0.299
Cu	0.590-18.0	1.90	5.10	0.630-8.51	3.76	5.08
Fe	1220-3056	1831	1923	1160-1940	1491	1512
Mn	14.4-28.3	18.8	19.4	12.6-23.7	19.4	19.7
Mo	0.181-2.43	0.418	0.762	0.153-2.70	0.644	0.962
Ni	0.503-4.39	1.01	1.55	0.425-3.29	1.47	1.76
Pb	1.40-12.3	2.94	4.42	1.30-8.66	4.03	4.73
Se	0.130-0.527	0.199	0.237	0.131-0.364	0.216	0.228
Sn	0.097-0.479	0.163	0.203	0.090-0.248	0.171	0.181
V	7.12-14.0	9.94	10.2	5.83-12.0	8.19	8.44
Zn	3.31-42.2	7.57	13.8	3.80-27.2	14.0	16.4

	2N			2S		
Heavy Metals	**Range (µg/g)**	**Geometric Mean (µg/g)**	**Arithmetic Mean (µg/g)**	**Range (µg/g)**	**Geometric Mean (µg/g)**	**Arithmetic Mean (µg/g)**
Al	167-2464	495	830	137-1316	354	500
As	3.24-8.84	5.42	5.78	3.09-7.41	4.41	4.65
Cd	0.028-0.084	0.049	0.052	0.034-0.075	0.052	0.054
Co	0.192-0.589	0.298	0.328	0.218-0.421	0.286	0.296
Cu	0.520-21.1	3.28	7.01	0.380-8.87	2.13	3.49
Fe	1020-3840	1748	1982	832-2059	1279	1345
Mn	16.0-30.7	20.5	21.1	15.1-20.9	18.1	18.2
Mo	0.199-4.85	0.703	1.49	0.168-3.62	0.609	1.15
Ni	0.504-5.99	1.38	2.12	0.514-4.35	1.29	1.77
Pb	1.28-16.1	3.94	6.01	1.09-10.7	3.14	4.36
Se	0.137-0.754	0.248	0.313	0.145-0.522	0.237	0.263
Sn	0.087-0.749	0.185	0.264	0.071-0.424	0.142	0.169
V	5.15-21.8	9.46	11.0	5.43-13.8	7.73	8.28
Zn	2.82-44.8	10.8	17.0	1.91-23.7	6.67	9.50

	3N			3S		
Heavy Metals	**Range (µg/g)**	**Geometric Mean (µg/g)**	**Arithmetic Mean (µg/g)**	**Range (µg/g)**	**Geometric Mean (µg/g)**	**Arithmetic Mean (µg/g)**
Al	133-1437	295	489	95.5-305	169	182
As	2.77-9.67	4.14	4.53	2.56-5.03	3.43	3.53
Cd	0.031-0.089	0.052	0.055	0.030-0.076	0.047	0.050
Co	0.176-0.540	0.273	0.294	0.177-0.315	0.245	0.251
Cu	0.420-14.8	1.46	4.01	0.350-3.14	0.783	1.10
Fe	612-2410	1002	1153	563-1060	727	740
Mn	12.3-24.3	15.5	16.0	11.8-17.2	13.3	13.4
Mo	0.176-3.48	0.412	0.844	0.144-0.928	0.284	0.375
Ni	0.564-9.53	1.14	2.03	0.481-1.88	0.821	0.936
Pb	0.901-10.0	2.04	3.39	0.906-2.59	1.35	1.46
Se	0.170-0.563	0.249	0.280	0.159-0.268	0.209	0.212
Sn	0.080-0.498	0.139	0.186	0.074-0.129	0.093	0.094
V	3.23-14.4	5.53	6.43	2.85-8.15	4.30	4.54
Zn	1.47-55.2	4.57	12.4	1.38-15.8	3.81	5.77

3.8 Geo-accumulation Index (I_{geo})

Geo-accumulation index measures the pollution intensity of individual sample locations and is a quantitative measure of the contamination degree in sediments relative to background continental crust values (Förstner, 1980).

The geo-accumulation index of the sediment from the traps per coral reef sites (1N, 2N, 3N, 1S, 2S, and 3S) and collection periods (June 2023, September 2023, November 2023, and March 2024) are shown in table 92.

Arsenic is the only heavy metal that exhibited strong to extremely contaminated geo-accumulation values in the port and control sites but moderate to strong contamination at the reef sites.

Molybdenum also exhibited moderately contaminated geo-accumulation values during the September collection period for 1N, 2N, 3N, 1S, and 2S locations, indicating possible contaminated sediment being suspended during the June-September summer months. Copper also exhibited moderately contaminated geo-accumulation values during the same months for 1N, 2N, and 3N sites.

The North sites showed higher As contamination throughout the year compared to the South sites.

Table 92. Triplicate reef geo-accumulation index of sediment from traps for 1N, 2N, 3N, 1S, 2S, and 3S locations. The color of the value indicates: uncontaminated (< 0, dark green), uncontaminated to moderately contaminated (0-1, light green), moderately contaminated (1-2, yellow), moderately to strongly contaminated (2-3, orange), strongly contaminated (3-4, red), strongly to extremely contaminated (4-5, dark red), and extremely contaminated (>5 black). SE = standard error and CI LB = 95% confidence interval lower bound. The June 2023 data were collected during Phase I of FDEP project (#C0FEDD).

		Al	As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	1N-1	-9.4	1.9	-1.6	-6.3	-1.3	-5.5	-5.9	-3.3	-5.9	-4.4	-9.1	-6.2	-3.2	-5.0
	1N-2	-9.5	2.0	-1.4	-6.0	-1.2	-5.2	-5.6	-3.3	-5.7	-4.3	-9.0	-6.2	-3.0	-5.0
	1N-3	-9.3	2.0	-1.6	-6.4	-1.3	-5.4	-5.7	-3.2	-5.8	-4.4	-9.0	-6.3	-3.0	-5.0
	Mean	-9.4	2.0	-1.5	-6.2	-1.3	-5.4	-5.7	-3.3	-5.8	-4.4	-9.0	-6.2	-3.1	-5.0
Sept 23	1N-1	-6.3	1.2	-1.2	-5.0	0.2	-4.7	-5.1	0.1	-2.8	-1.3	-7.2	-4.2	-2.7	-1.4
	1N-2	-6.3	1.1	-1.1	-5.1	0.2	-4.6	-5.0	0.0	-2.8	-1.3	-7.2	-4.2	-2.8	-1.3
	1N-3	-6.1	1.2	-0.4	-5.0	0.2	-4.7	-5.0	0.1	-2.8	-1.3	-7.3	-4.1	-2.7	-1.4
	Mean	-6.2	1.2	-0.9	-5.0	0.2	-4.7	-5.0	0.0	-2.8	-1.3	-7.2	-4.2	-2.7	-1.4
Nov 23	1N-1	-8.6	1.6	-1.8	-5.7	-0.9	-5.7	-5.6	-2.8	-5.1	-3.8	-8.8	-5.9	-3.4	-3.8
	1N-2	-8.8	1.8	-2.0	-5.7	-1.0	-5.6	-5.8	-3.3	-5.1	-3.7	-8.9	-6.0	-3.3	-4.3
	1N-3	-8.8	1.3	-2.1	-5.9	-0.9	-5.6	-5.7	-3.0	-5.3	-3.6	-9.1	-6.0	-3.7	-4.3
	Mean	-8.7	1.6	-1.9	-5.7	-0.9	-5.6	-5.7	-3.0	-5.2	-3.7	-8.9	-6.0	-3.4	-4.1
Mar 24	1N-1	-9.8	1.3	-2.2	-6.7	-1.2	-5.9	-6.0	-3.6	-5.9	-4.1	-9.2	-6.4	-3.6	-5.0
	1N-2	-9.4	1.7	-2.0	-6.3	-1.1	-5.7	-5.7	-3.4	-5.6	-3.8	-9.0	-6.1	-3.3	-4.5
	1N-3	-9.5	1.8	-1.7	-6.4	-1.1	-5.7	-5.9	-3.3	-5.8	-4.0	-9.0	-6.4	-3.5	-4.9
	Mean	-9.6	1.6	-2.0	-6.5	-1.1	-5.8	-5.8	-3.5	-5.8	-4.0	-9.0	-6.3	-3.5	-4.8

		Al	As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	2N-1	-9.4	1.8	-1.2	-6.2	-1.3	-5.6	-5.7	-3.5	-5.8	-4.5	-8.9	-6.6	-3.3	-5.2
	2N-2	-9.2	2.0	-1.4	-6.2	-1.3	-5.4	-5.6	-3.3	-5.7	-4.6	-9.0	-6.5	-3.1	-5.0
	2N-3	-9.5	1.7	-1.6	-6.3	-1.3	-5.5	-5.8	-3.5	-5.9	-4.3	-9.1	-6.4	-3.2	-5.2
	Mean	-9.4	1.8	-1.4	-6.2	-1.3	-5.5	-5.7	-3.4	-5.8	-4.5	-9.0	-6.5	-3.2	-5.2
Sept 23	2N-1	-5.7	1.8	-0.8	-4.7	0.3	-4.3	-4.9	1.1	-2.4	-0.9	-6.6	-3.5	-2.0	-1.3
	2N-2	-5.6	1.7	-0.8	-4.7	0.3	-4.3	-4.9	1.1	-2.4	-0.9	-6.7	-3.5	-2.1	-1.3
	2N-3	-5.7	1.7	-1.0	-4.7	0.3	-4.3	-4.9	1.1	-2.3	-0.9	-6.8	-3.8	-2.1	-1.3
	Mean	-5.7	1.7	-0.9	-4.7	0.3	-4.3	-4.9	1.1	-2.4	-0.9	-6.7	-3.6	-2.1	-1.3
Nov 23	2N-1	-8.5	1.0	-1.9	-5.5	-0.7	-5.8	-5.5	-2.1	-4.7	-3.3	-8.2	-5.9	-3.6	-2.7
	2N-2	-8.4	0.9	-1.8	-5.7	-0.6	-5.7	-5.6	-2.2	-4.8	-3.1	-8.7	-6.0	-3.7	-3.6
	2N-3	-8.4	0.9	-2.2	-5.6	-0.6	-5.7	-5.5	-2.3	-4.7	-3.3	-8.8	-5.7	-3.7	-3.5
	Mean	-8.4	0.9	-2.0	-5.6	-0.7	-5.7	-5.5	-2.2	-4.7	-3.2	-8.6	-5.9	-3.7	-3.3
Mar 24	2N-1	-8.4	0.5	-2.4	-6.2	-0.5	-6.2	-5.7	-1.9	-4.9	-3.1	-8.8	-6.0	-4.1	-3.6
	2N-2	-8.4	0.6	-2.1	-6.1	-0.3	-6.2	-5.6	-2.4	-4.9	-3.1	-8.7	-5.9	-4.1	-3.5
	2N-3	-8.3	0.6	-1.9	-6.1	-0.5	-6.1	-5.7	-2.3	-4.9	-3.1	-8.7	-6.0	-4.0	-3.5
	Mean	-8.3	0.6	-2.1	-6.1	-0.5	-6.2	-5.7	-2.2	-4.9	-3.1	-8.7	-6.0	-4.1	-3.5

		Al	As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**3N-1**	-9.8	1.1	-0.9	-6.1	-1.4	-6.3	-6.0	-3.2	-5.6	-4.9	-8.5	-6.7	-4.1	-6.0
	3N-2	-9.8	1.0	-1.4	-6.2	-1.4	-6.4	-6.0	-3.6	-5.7	-5.1	-8.5	-6.7	-4.1	-6.2
	3N-3	-9.6	1.2	-1.3	-6.2	-1.4	-6.2	-5.9	-3.4	-5.5	-5.0	-8.6	-6.6	-3.9	-6.0
	Mean	-9.8	1.1	-1.2	-6.1	-1.4	-6.3	-6.0	-3.4	-5.6	-5.0	-8.5	-6.7	-4.0	-6.1
Sept 23	**3N-1**	-6.4	1.6	-0.7	-5.0	0.1	-5.0	-5.2	0.0	-2.7	-1.6	-7.1	-4.2	-2.9	-1.5
	3N-2	-6.4	2.1	-0.9	-4.8	0.1	-5.0	-5.3	0.6	-1.7	-1.6	-7.1	-4.1	-2.6	-0.9
	3N-3	-6.4	1.5	-1.1	-5.1	0.1	-5.1	-5.3	0.0	-2.8	-1.6	-7.2	-4.3	-2.9	-1.6
	Mean	-6.4	1.7	-0.9	-5.0	0.1	-5.0	-5.3	0.2	-2.4	-1.6	-7.1	-4.2	-2.8	-1.3
Nov 23	**3N-1**	-9.1	0.3	-2.2	-5.6	-0.9	-6.7	-6.1	-2.9	-5.2	-4.3	-8.7	-6.0	-4.5	-4.9
	3N-2	-9.1	0.4	-2.1	-5.6	-1.0	-6.7	-6.1	-3.1	-5.3	-4.4	-8.5	-6.6	-4.5	-4.9
	3N-3	-9.0	0.3	-1.6	-5.7	-1.0	-6.6	-6.0	-3.1	-5.1	-4.3	-8.5	-6.5	-4.5	-4.7
	Mean	-9.1	0.3	-2.0	-5.6	-1.0	-6.7	-6.1	-3.0	-5.2	-4.3	-8.6	-6.4	-4.5	-4.9
Mar 24	**3N-1**	-9.4	0.4	-1.8	-6.3	-1.2	-6.8	-6.0	-3.6	-5.6	-4.5	-8.6	-6.3	-4.7	-5.9
	3N-2	-9.6	0.3	-2.0	-6.4	-1.2	-6.9	-6.2	-3.7	-5.6	-4.7	-8.8	-6.5	-4.8	-5.9
	3N-3	-9.6	0.4	-2.0	-6.4	-1.2	-6.9	-6.2	-3.6	-5.7	-4.6	-8.8	-6.3	-4.8	-6.0
	Mean	-9.5	0.4	-1.9	-6.4	-1.2	-6.9	-6.1	-3.6	-5.6	-4.6	-8.7	-6.4	-4.7	-5.9

		Al	As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**1S-1**	-9.4	1.3	-1.6	-6.0	-1.2	-5.8	-5.9	-3.6	-5.9	-4.2	-9.1	-6.4	-3.4	-4.1
	1S-2	-8.8	1.9	-1.4	-5.8	-1.1	-5.3	-5.6	-3.5	-5.6	-4.1	-8.8	-6.3	-3.1	-4.4
	1S-3	-9.2	1.3	-1.7	-6.3	-1.3	-5.9	-6.2	-3.9	-6.1	-4.5	-9.2	-6.5	-3.6	-4.8
	Mean	-9.1	1.5	-1.6	-6.1	-1.2	-5.6	-5.9	-3.7	-5.9	-4.3	-9.0	-6.4	-3.4	-4.4
Sept 23	**1S-1**	-7.2	0.8	-1.0	-5.4	-0.1	-5.3	-5.5	0.1	-3.2	-1.9	-7.7	-5.1	-3.0	-2.0
	1S-2	-7.4	0.5	-1.2	-5.4	-0.2	-5.4	-5.4	-0.1	-3.6	-1.9	-7.8	-5.3	-3.1	-2.2
	1S-3	-6.9	0.9	-1.7	-5.4	-0.1	-5.4	-5.5	0.3	-3.4	-1.8	-7.7	-5.1	-2.9	-2.0
	Mean	-7.2	0.7	-1.3	-5.4	-0.1	-5.4	-5.5	0.1	-3.4	-1.9	-7.7	-5.1	-3.0	-2.1
Nov 23	**1S-1**	-8.0	0.7	-1.7	-5.4	-0.3	-5.5	-5.2	-1.8	-4.3	-2.6	-8.5	-5.1	-3.6	-2.7
	1S-2	-8.0	0.6	-1.9	-5.5	-0.3	-5.7	-5.3	-2.1	-4.3	-2.8	-8.6	-5.4	-3.7	-2.4
	1S-3	-7.9	0.8	-2.1	-5.3	-0.3	-5.7	-5.3	-2.0	-3.7	-2.8	-8.4	-5.4	-3.5	-2.7
	Mean	-8.0	0.7	-1.9	-5.4	-0.3	-5.7	-5.3	-1.9	-4.1	-2.8	-8.5	-5.3	-3.6	-2.6
Mar 24	**1S-1**	-7.8	0.5	-1.7	-5.9	-0.3	-6.0	-5.5	-1.7	-4.1	-2.7	-8.6	-5.6	-3.9	-2.7
	1S-2	-7.7	0.6	-1.5	-5.8	-0.3	-5.9	-5.4	-1.7	-4.0	-2.7	-8.3	-5.5	-3.8	-2.6
	1S-3	-7.7	0.6	-1.7	-5.9	-0.3	-5.9	-5.5	-1.8	-4.0	-2.7	-8.6	-5.6	-3.9	-2.7
	Mean	-7.7	0.6	-1.6	-5.9	-0.3	-5.9	-5.5	-1.7	-4.0	-2.7	-8.5	-5.5	-3.9	-2.7

		Al	As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**2S-1**	-9.6	1.6	-1.2	-6.1	-1.4	-5.8	-5.7	-3.7	-5.7	-4.8	-8.8	-6.8	-3.4	-5.7
	2S-2	-9.8	1.6	-1.2	-6.1	-1.4	-5.8	-5.8	-3.5	-5.8	-4.8	-8.8	-6.9	-3.4	-5.8
	2S-3	-9.8	1.7	-1.0	-6.1	-1.5	-5.6	-5.6	-3.5	-5.9	-4.8	-9.0	-6.8	-3.3	-5.7
	Mean	-9.7	1.6	-1.1	-6.1	-1.4	-5.7	-5.7	-3.6	-5.8	-4.8	-8.9	-6.8	-3.4	-5.8
Sept 23	**2S-1**	-6.6	1.2	-1.3	-5.2	-0.1	-5.2	-5.4	0.7	-2.8	-1.6	-7.4	-4.3	-2.7	-2.3
	2S-2	-6.7	1.1	-1.2	-5.2	-0.1	-5.3	-5.5	0.6	-2.8	-1.5	-7.3	-4.9	-2.8	-2.2
	2S-3	-6.5	1.2	-1.0	-5.2	-0.1	-5.2	-5.4	0.6	-2.8	-1.5	-7.2	-4.7	-2.7	-2.3
	Mean	-6.6	1.2	-1.2	-5.2	-0.1	-5.2	-5.4	0.6	-2.8	-1.5	-7.3	-4.6	-2.8	-2.3
Nov 23	**2S-1**	-8.5	0.5	-2.1	-5.6	-0.6	-6.1	-5.6	-2.0	-4.5	-3.2	-8.4	-6.1	-4.0	-3.7
	2S-2	-8.6	0.5	-2.0	-5.5	-0.6	-6.1	-5.6	-2.0	-4.6	-3.2	-8.4	-5.9	-4.0	-3.7
	2S-3	-8.6	0.5	-1.8	-5.6	-0.6	-6.2	-5.6	-2.3	-4.5	-3.3	-8.3	-5.9	-4.0	-3.7
	Mean	-8.6	0.5	-2.0	-5.5	-0.6	-6.2	-5.6	-2.1	-4.5	-3.2	-8.4	-6.0	-4.0	-3.7
Mar 24	**2S-1**	-8.7	0.7	-1.6	-6.0	-0.7	-6.4	-5.8	-2.5	-5.0	-3.4	-8.8	-5.8	-4.0	-4.2
	2S-2	-8.9	0.6	-1.6	-6.0	-0.7	-6.5	-5.9	-2.5	-5.0	-3.6	-8.6	-6.0	-4.1	-4.2
	2S-3	-8.9	0.6	-1.8	-6.1	-0.8	-6.4	-5.8	-2.4	-5.1	-3.5	-8.6	-6.3	-4.0	-4.4
	Mean	-8.8	0.6	-1.7	-6.0	-0.7	-6.4	-5.8	-2.5	-5.0	-3.5	-8.7	-6.0	-4.0	-4.3

		Al	As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**3S-1**	-10.3	0.9	-1.3	-6.2	-1.5	-6.6	-6.1	-3.3	-6.0	-5.0	-8.4	-6.6	-4.3	-6.0
	3S-2	-10.0	1.2	-1.5	-6.1	-1.5	-6.1	-6.1	-3.4	-5.7	-4.9	-8.6	-6.7	-4.0	-5.7
	3S-3	-10.1	0.8	-1.6	-6.2	-1.5	-6.6	-6.2	-3.7	-5.9	-5.0	-8.7	-6.8	-4.3	-6.0
	Mean	-10.1	0.9	-1.5	-6.2	-1.5	-6.4	-6.1	-3.5	-5.8	-5.0	-8.6	-6.7	-4.2	-5.9
Sept 23	**3S-1**	-8.6	0.9	-1.0	-5.7	-0.6	-6.5	-6.1	-1.3	-4.2	-3.5	-8.1	-6.0	-4.1	-3.3
	3S-2	-8.7	1.0	-1.0	-5.6	-0.6	-6.4	-6.0	-1.3	-4.1	-3.6	-8.1	-6.3	-4.0	-3.3
	3S-3	-8.7	0.9	-1.0	-5.6	-0.6	-6.5	-5.7	-1.3	-4.0	-3.6	-8.2	-6.3	-4.1	-3.4
	Mean	-8.7	0.9	-1.0	-5.6	-0.6	-6.5	-5.9	-1.3	-4.1	-3.6	-8.2	-6.2	-4.1	-3.3
Nov 23	**3S-1**	-9.4	0.2	-2.2	-5.6	-1.2	-6.7	-6.1	-3.1	-4.7	-4.5	-8.4	-6.4	-3.5	-5.4
	3S-2	-9.3	0.3	-1.9	-5.7	-1.2	-6.9	-6.1	-3.3	-5.2	-4.6	-8.4	-6.5	-4.8	-3.7
	3S-3	-9.4	0.2	-2.0	-5.6	-1.2	-6.9	-6.1	-3.6	-5.2	-4.6	-8.5	-6.6	-4.8	-2.7
	Mean	-9.4	0.2	-2.0	-5.6	-1.2	-6.8	-6.1	-3.3	-5.0	-4.6	-8.4	-6.5	-4.3	-3.9
Mar 24	**3S-1**	-9.9	0.4	-2.3	-6.4	-1.3	-7.1	-6.3	-4.0	-5.8	-4.8	-8.9	-6.3	-5.0	-6.0
	3S-2	-9.8	0.4	-2.1	-6.3	-1.3	-7.0	-6.1	-3.7	-5.7	-4.7	-8.8	-6.8	-4.9	-6.3
	3S-3	-9.8	0.3	-1.8	-6.3	-1.3	-7.0	-6.2	-3.8	-5.8	-4.7	-8.7	-6.4	-5.0	-6.0
	Mean	-9.8	0.4	-2.1	-6.3	-1.3	-7.0	-6.2	-3.8	-5.8	-4.8	-8.8	-6.5	-4.9	-6.1

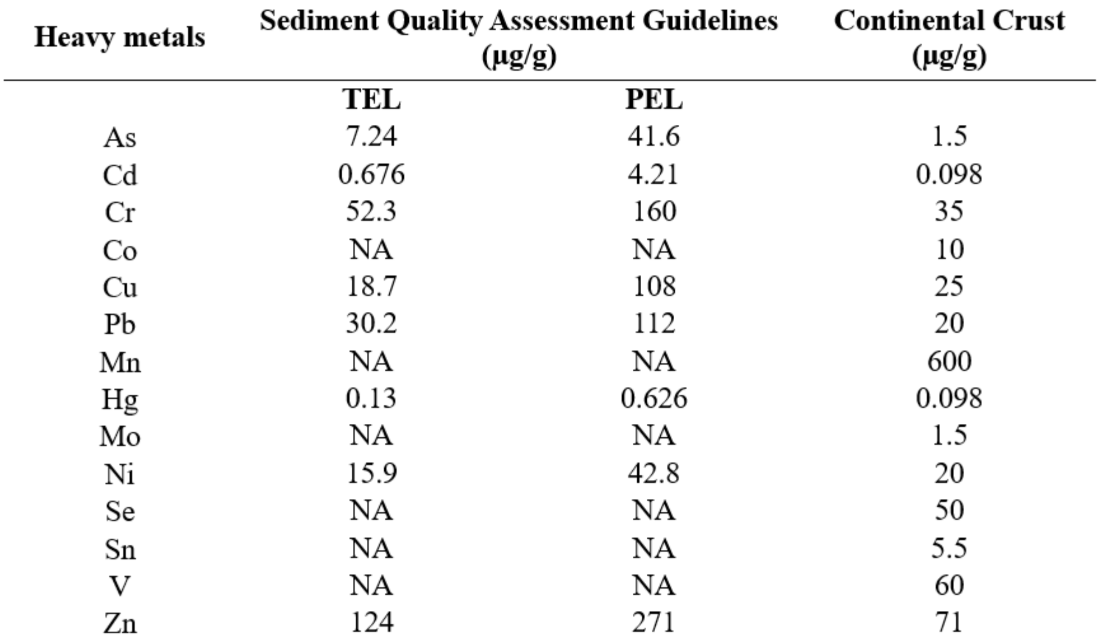
3.9 Threshold and Probable Effect Levels (TEL and PEL) and Continental Cust Comparisons

Threshold effect level (TEL) and a probable effect level (PEL) have been derived for nine metals (As, Cd, Cr, Cu, Hg, Ni, Pb, tributyltin, Zn) that occur in Florida coastal sediments (MacDonald, 1996). The threshold effect level (TEL), probable effect level (PEL), and continental crust values are shown in Table 89.

The heavy metal data at all the reef sites (1N, 2N, 3N, 1S, 2S, and 3S) indicate that all the sediment during all periods had As concentrations above the upper continental crust value of 1.5 µg/g. Of the 72 total samples analyzed, 100 % had values above the continental crust values and 19 % (14/72) had values above the TEL (7.24 µg/g), but none had values above the PEL (41.6 µg/g). The only other heavy metal that had any high concentrations was Cu, with values above the continental crust (25 µg/g) and TEL (18.7 µg/g) values during the September collection period for the 2N location (Tables 93-94). All these values could indicate anthropogenic contamination in the sediment.

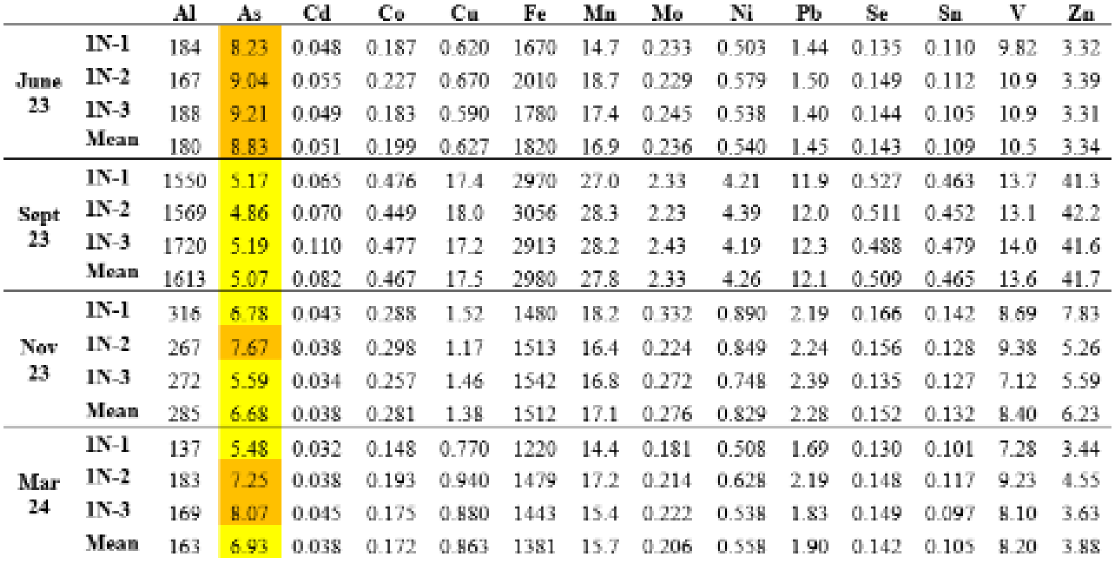
Preliminary observations indicated that the overall As heavy metal mean concentrations were highest during the June collection period for 1N (8.83 µg/g), 2N (7.96 µg/g), 1S (6.45 µg/g), 2S (6.96 µg/g), and 3S (4.35 µg/g). 2N had its highest mean As value (7.52 µg/g) during the September collection. The data also indicated that the mean As concentrations generally decreased from the nearest shore locations (1N and 1S) to the furthest shore locations (3N and 3S), indicating possible higher contamination at the nearshore compared to offshore locations (Tables 93-94).

Table 93. Threshold effect level (TEL), probable effect level (PEL), and continental crust values. NA is not available.

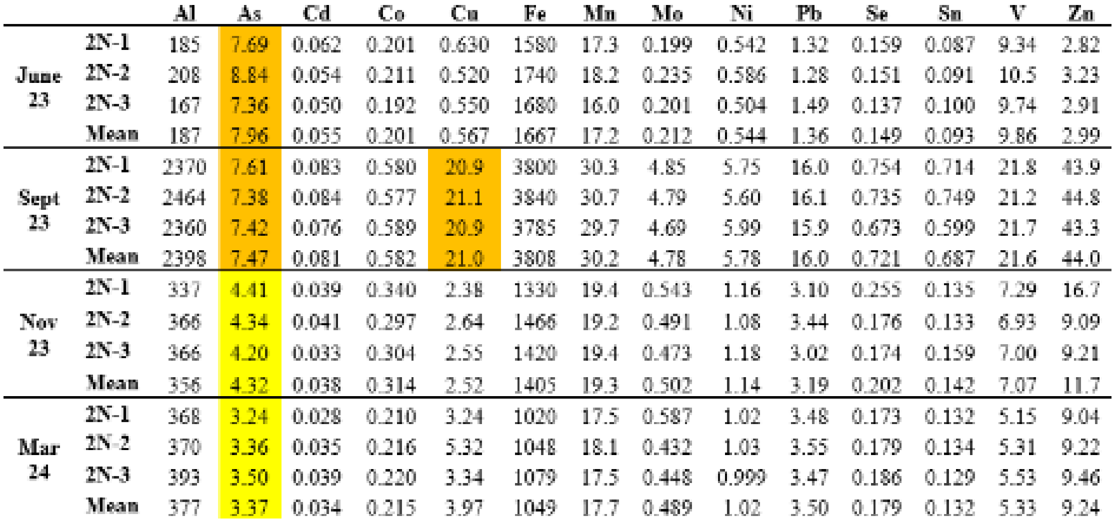


Heavy metals	Sediment Quality Assessment Guidelines (µg/g)		Continental Crust (µg/g)
	TEL	PEL	
As	7.24	41.6	1.5
Cd	0.676	4.21	0.098
Cr	52.3	160	35
Co	NA	NA	10
Cu	18.7	108	25
Pb	30.2	112	20
Mn	NA	NA	600
Hg	0.13	0.626	0.098
Mo	NA	NA	1.5
Ni	15.9	42.8	20
Se	NA	NA	50
Sn	NA	NA	5.5
V	NA	NA	60
Zn	124	271	71

Table 94. Triplicate coral reef heavy metal concentrations (µg/g) of sediment samples from the traps for 1N, 2N, 3N, 1S, 2S, and 3S locations. Values highlighted in yellow are above upper continental crust (background) values and in orange are above threshold effect levels (TEL). The June 2023 data were collected during Phase I of FDEP project (#C0FEDD).



		Al	As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**1N-1**	184	8.23	0.048	0.187	0.620	1670	14.7	0.233	0.503	1.44	0.135	0.110	9.82	3.32
	1N-2	167	9.04	0.055	0.227	0.670	2010	18.7	0.229	0.579	1.50	0.149	0.112	10.9	3.39
	1N-3	188	9.21	0.049	0.183	0.590	1780	17.4	0.245	0.538	1.40	0.144	0.105	10.9	3.31
	Mean	180	8.83	0.051	0.199	0.627	1820	16.9	0.236	0.540	1.45	0.143	0.109	10.5	3.34
Sept 23	**1N-1**	1550	5.17	0.065	0.476	17.4	2970	27.0	2.33	4.21	11.9	0.527	0.463	13.7	41.3
	1N-2	1569	4.86	0.070	0.449	18.0	3056	28.3	2.23	4.39	12.0	0.511	0.452	13.1	42.2
	1N-3	1720	5.19	0.110	0.477	17.2	2913	28.2	2.43	4.19	12.3	0.488	0.479	14.0	41.6
	Mean	1613	5.07	0.082	0.467	17.5	2980	27.8	2.33	4.26	12.1	0.509	0.465	13.6	41.7
Nov 23	**1N-1**	316	6.78	0.043	0.288	1.52	1480	18.2	0.332	0.890	2.19	0.166	0.142	8.69	7.83
	1N-2	267	7.67	0.038	0.298	1.17	1513	16.4	0.224	0.849	2.24	0.156	0.128	9.38	5.26
	1N-3	272	5.59	0.034	0.257	1.46	1542	16.8	0.272	0.748	2.39	0.135	0.127	7.12	5.59
	Mean	285	6.68	0.038	0.281	1.38	1512	17.1	0.276	0.829	2.28	0.152	0.132	8.40	6.23
Mar 24	**1N-1**	137	5.48	0.032	0.148	0.770	1220	14.4	0.181	0.508	1.69	0.130	0.101	7.28	3.44
	1N-2	183	7.25	0.038	0.193	0.940	1479	17.2	0.214	0.628	2.19	0.148	0.117	9.23	4.55
	1N-3	169	8.07	0.045	0.175	0.880	1443	15.4	0.222	0.538	1.83	0.149	0.097	8.10	3.63
	Mean	163	6.93	0.038	0.172	0.863	1381	15.7	0.206	0.558	1.90	0.142	0.105	8.20	3.88



		Al	As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**2N-1**	185	7.69	0.062	0.201	0.630	1580	17.3	0.199	0.542	1.32	0.159	0.087	9.34	2.82
	2N-2	208	8.84	0.054	0.211	0.520	1740	18.2	0.235	0.586	1.28	0.151	0.091	10.5	3.23
	2N-3	167	7.36	0.050	0.192	0.550	1680	16.0	0.201	0.504	1.49	0.137	0.100	9.74	2.91
	Mean	187	7.96	0.055	0.201	0.567	1667	17.2	0.212	0.544	1.36	0.149	0.093	9.86	2.99
Sept 23	**2N-1**	2370	7.61	0.083	0.580	20.9	3800	30.3	4.85	5.75	16.0	0.754	0.714	21.8	43.9
	2N-2	2464	7.38	0.084	0.577	21.1	3840	30.7	4.79	5.60	16.1	0.735	0.749	21.2	44.8
	2N-3	2360	7.42	0.076	0.589	20.9	3785	29.7	4.69	5.99	15.9	0.673	0.599	21.7	43.3
	Mean	2398	7.47	0.081	0.582	21.0	3808	30.2	4.78	5.78	16.0	0.721	0.687	21.6	44.0
Nov 23	**2N-1**	337	4.41	0.039	0.340	2.38	1330	19.4	0.543	1.16	3.10	0.255	0.135	7.29	16.7
	2N-2	366	4.34	0.041	0.297	2.64	1466	19.2	0.491	1.08	3.44	0.176	0.133	6.93	9.09
	2N-3	366	4.20	0.033	0.304	2.55	1420	19.4	0.473	1.18	3.02	0.174	0.159	7.00	9.21
	Mean	356	4.32	0.038	0.314	2.52	1405	19.3	0.502	1.14	3.19	0.202	0.142	7.07	11.7
Mar 24	**2N-1**	368	3.24	0.028	0.210	3.24	1020	17.5	0.587	1.02	3.48	0.173	0.132	5.15	9.04
	2N-2	370	3.36	0.035	0.216	5.32	1048	18.1	0.432	1.03	3.55	0.179	0.134	5.31	9.22
	2N-3	393	3.50	0.039	0.220	3.34	1079	17.5	0.448	0.999	3.47	0.186	0.129	5.53	9.46
	Mean	377	3.37	0.034	0.215	3.97	1049	17.7	0.489	1.02	3.50	0.179	0.132	5.33	9.24

		Al	**As**	**Cd**	**Co**	**Cu**	**Fe**	**Mn**	**Mo**	**Ni**	**Pb**	**Se**	**Sn**	**V**	**Zn**
June 23	**3N-1**	135	4.69	0.077	0.226	0.460	933	14.4	0.238	0.600	1.01	0.204	0.081	5.42	1.70
	3N-2	133	4.58	0.055	0.208	0.450	871	13.6	0.187	0.581	0.901	0.206	0.080	5.18	1.47
	3N-3	156	5.25	0.059	0.209	0.420	1010	14.7	0.212	0.660	0.959	0.196	0.083	5.83	1.65
	Mean	141	4.84	0.064	0.214	0.443	938	14.2	0.212	0.614	0.957	0.202	0.081	5.48	1.61
Sept 23	**3N-1**	1430	6.65	0.089	0.459	14.8	2410	24.3	2.30	4.54	9.82	0.563	0.455	12.3	37.8
	3N-2	1398	9.67	0.078	0.540	13.8	2302	23.3	3.48	9.53	9.82	0.534	0.498	14.4	55.2
	3N-3	1437	6.24	0.068	0.440	12.8	2191	22.7	2.32	4.20	10.0	0.527	0.427	12.1	35.0
	Mean	1422	7.52	0.078	0.480	13.8	2301	23.4	2.70	6.09	9.89	0.541	0.460	13.0	42.7
Nov 23	**3N-1**	224	2.85	0.031	0.299	1.27	735	13.2	0.311	0.791	1.50	0.186	0.126	3.89	3.59
	3N-2	222	2.89	0.034	0.311	1.02	716	12.9	0.255	0.784	1.47	0.205	0.088	4.00	3.52
	3N-3	243	2.77	0.050	0.287	1.08	759	14.5	0.271	0.854	1.49	0.205	0.093	3.93	3.97
	Mean	230	2.84	0.038	0.299	1.12	737	13.5	0.279	0.810	1.48	0.199	0.102	3.94	3.69
Mar 24	**3N-1**	175	2.98	0.042	0.187	0.680	662	13.8	0.192	0.635	1.32	0.196	0.102	3.52	1.84
	3N-2	158	2.80	0.037	0.176	0.680	612	12.6	0.176	0.605	1.18	0.171	0.089	3.23	1.77
	3N-3	162	2.95	0.037	0.182	0.660	636	12.3	0.187	0.564	1.22	0.170	0.104	3.33	1.69
	Mean	165	2.91	0.039	0.182	0.673	637	12.9	0.185	0.601	1.24	0.179	0.098	3.36	1.76

		Al	**As**	**Cd**	**Co**	**Cu**	**Fe**	**Mn**	**Mo**	**Ni**	**Pb**	**Se**	**Sn**	**V**	**Zn**
June 23	**1S-1**	175	5.50	0.049	0.239	0.780	1360	14.7	0.184	0.499	1.59	0.136	0.095	8.32	6.13
	1S-2	279	8.27	0.055	0.261	0.890	1930	18.7	0.201	0.631	1.81	0.168	0.108	10.7	5.22
	1S-3	203	5.59	0.045	0.185	0.630	1290	12.6	0.153	0.425	1.30	0.131	0.090	7.55	3.80
	Mean	219	6.45	0.050	0.228	0.767	1527	15.3	0.179	0.518	1.57	0.145	0.098	8.86	5.05
Sept 23	**1S-1**	851	3.98	0.074	0.356	8.51	1940	19.8	2.40	3.29	8.32	0.356	0.244	11.6	26.2
	1S-2	703	3.28	0.063	0.353	7.94	1733	21.3	2.06	2.48	7.97	0.345	0.214	10.4	23.6
	1S-3	992	4.10	0.046	0.346	8.07	1743	19.3	2.70	2.92	8.66	0.364	0.248	12.0	27.2
	Mean	849	3.79	0.061	0.352	8.17	1805	20.1	2.39	2.90	8.32	0.355	0.235	11.3	25.7
Nov 23	**1S-1**	465	3.72	0.045	0.349	5.77	1620	23.7	0.657	1.48	4.80	0.204	0.247	7.61	16.8
	1S-2	477	3.51	0.040	0.341	5.50	1397	22.8	0.537	1.51	4.26	0.195	0.197	7.08	20.6
	1S-3	500	3.82	0.035	0.389	5.45	1441	23.1	0.581	2.32	4.29	0.219	0.191	7.91	16.9
	Mean	481	3.68	0.040	0.360	5.57	1486	23.2	0.592	1.77	4.45	0.206	0.212	7.53	18.1
Mar 24	**1S-1**	565	3.20	0.045	0.246	5.44	1160	19.6	0.692	1.75	4.55	0.191	0.171	5.83	16.0
	1S-2	588	3.38	0.052	0.270	6.28	1294	21.1	0.714	1.91	4.69	0.233	0.186	6.32	17.6
	1S-3	583	3.33	0.044	0.257	5.69	1239	20.0	0.668	1.86	4.51	0.194	0.176	6.04	16.3
	Mean	579	3.30	0.047	0.258	5.80	1231	20.2	0.691	1.84	4.58	0.206	0.178	6.06	16.6

		Al	As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**2S-1**	154	6.85	0.065	0.221	0.430	1370	17.5	0.168	0.575	1.09	0.164	0.074	8.35	1.98
	2S-2	137	6.62	0.063	0.218	0.410	1370	16.1	0.199	0.529	1.09	0.170	0.071	8.28	1.91
	2S-3	138	7.41	0.075	0.223	0.380	1600	19.1	0.196	0.514	1.10	0.145	0.074	9.13	1.98
	Mean	143	6.96	0.068	0.221	0.407	1447	17.6	0.188	0.539	1.09	0.160	0.073	8.59	1.96
Sept 23	**2S-1**	1280	5.14	0.059	0.413	8.43	1980	20.9	3.62	4.33	10.2	0.450	0.424	13.5	21.2
	2S-2	1197	4.88	0.063	0.421	8.72	1954	20.5	3.33	4.34	10.7	0.478	0.285	12.9	23.7
	2S-3	1316	5.19	0.074	0.411	8.87	2059	20.8	3.44	4.35	10.6	0.522	0.320	13.8	22.0
	Mean	1264	5.07	0.065	0.415	8.67	1998	20.8	3.46	4.34	10.5	0.483	0.343	13.4	22.3
Nov 23	**2S-1**	326	3.09	0.034	0.320	2.89	1060	18.8	0.568	1.35	3.19	0.216	0.119	5.59	8.17
	2S-2	320	3.12	0.036	0.323	2.85	1061	18.5	0.557	1.27	3.27	0.225	0.143	5.53	8.15
	2S-3	324	3.12	0.043	0.320	2.69	1043	18.3	0.467	1.28	3.11	0.232	0.135	5.51	8.05
	Mean	323	3.11	0.038	0.321	2.81	1055	18.5	0.531	1.30	3.19	0.224	0.132	5.54	8.12
Mar 24	**2S-1**	285	3.54	0.049	0.230	2.06	913	16.6	0.406	0.921	2.76	0.166	0.146	5.66	5.90
	2S-2	263	3.31	0.047	0.231	2.18	832	15.1	0.386	0.942	2.55	0.192	0.127	5.43	5.75
	2S-3	263	3.52	0.042	0.221	1.96	897	16.3	0.414	0.889	2.68	0.192	0.107	5.71	5.17
	Mean	270	3.45	0.046	0.227	2.07	880	16.0	0.402	0.917	2.66	0.183	0.127	5.60	5.61

		Al	As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**3S-1**	95.5	4.06	0.058	0.209	0.370	772	13.3	0.221	0.481	0.917	0.226	0.084	4.47	1.70
	3S-2	117	5.03	0.053	0.218	0.390	1060	13.5	0.206	0.584	1.02	0.189	0.077	5.70	2.00
	3S-3	113	3.95	0.047	0.206	0.350	782	12.2	0.173	0.515	0.906	0.182	0.076	4.53	1.70
	Mean	109	4.35	0.053	0.211	0.370	871	13.0	0.200	0.527	0.948	0.199	0.079	4.90	1.80
Sept 23	**3S-1**	305	4.25	0.075	0.288	2.67	833	13.3	0.899	1.62	2.59	0.265	0.129	5.34	11.0
	3S-2	292	4.46	0.073	0.308	2.67	881	14.6	0.916	1.72	2.43	0.268	0.107	5.63	11.0
	3S-3	294	4.18	0.076	0.304	3.14	855	17.2	0.928	1.88	2.51	0.253	0.104	5.25	10.4
	Mean	297	4.29	0.075	0.300	2.83	856	15.0	0.914	1.74	2.51	0.262	0.113	5.41	10.8
Nov 23	**3S-1**	184	2.56	0.031	0.306	0.670	699	12.7	0.263	1.18	1.32	0.219	0.098	8.15	2.54
	3S-2	193	2.68	0.039	0.298	0.640	649	13.6	0.232	0.812	1.22	0.221	0.093	3.29	8.44
	3S-3	184	2.59	0.038	0.315	0.680	635	13.2	0.182	0.813	1.23	0.205	0.088	3.27	15.8
	Mean	187	2.61	0.036	0.306	0.663	661	13.1	0.226	0.935	1.25	0.215	0.093	4.91	8.94
Mar 24	**3S-1**	131	2.88	0.030	0.177	0.540	563	11.8	0.144	0.539	1.07	0.159	0.102	2.88	1.61
	3S-2	138	2.99	0.035	0.190	0.540	584	13.2	0.173	0.567	1.13	0.170	0.074	3.05	1.38
	3S-3	140	2.76	0.042	0.192	0.550	569	12.2	0.165	0.521	1.14	0.183	0.101	2.85	1.68
	Mean	136	2.88	0.036	0.186	0.543	572	12.4	0.161	0.542	1.11	0.171	0.092	2.93	1.56

3.10 Pollution Load Index (PLI)

The ratio of metal concentration and background upper continental crust value yields the pollution load index. No significant PLI>1.00 were found for any of sediments at any of the sites, indicating no pollution (Table 95).

Table 95. Triplicate reef pollution load index (PLI) of sediment samples from the traps for 1N, 2N, 3N, 1S, 2S, and 3S locations. PLI>1 is considered polluted sediment. PLI<1 is considered non-polluted sediment. The June 2023 data were collected during Phase I of FDEP project (#C0FEDD).

June 23	**1N-1**	0.047	**June 23**	**2N-1**	0.047	**June 23**	**3N-1**	0.040
	1N-2	0.052		**2N-2**	0.049		**3N-2**	0.036
	1N-3	0.049		**2N-3**	0.045		**3N-3**	0.039
	Mean	0.049		**Mean**	0.047		**Mean**	0.038
Sept 23	**1N-1**	0.191	**Sept 23**	**2N-1**	0.263	**Sept 23**	**3N-1**	0.187
	1N-2	0.191		**2N-2**	0.264		**3N-2**	0.215
	1N-3	0.201		**2N-3**	0.255		**3N-3**	0.175
	Mean	0.195		**Mean**	0.261		**Mean**	0.193
Nov 23	**1N-1**	0.064	**Nov 23**	**2N-1**	0.074	**Nov 23**	**3N-1**	0.045
	1N-2	0.058		**2N-2**	0.069		**3N-2**	0.043
	1N-3	0.056		**2N-3**	0.069		**3N-3**	0.046
	Mean	0.059		**Mean**	0.071		**Mean**	0.045
Mar 24	**1N-1**	0.041	**Mar 24**	**2N-1**	0.063	**Mar 24**	**3N-1**	0.037
	1N-2	0.051		**2N-2**	0.066		**3N-2**	0.034
	1N-3	0.048		**2N-3**	0.065		**3N-3**	0.034
	Mean	0.047		**Mean**	0.064		**Mean**	0.035
June 23	**1S-1**	0.047	**June 23**	**2S-1**	0.042	**June 23**	**3S-1**	0.053
	1S-2	0.057		**2S-2**	0.041		**3S-2**	0.057
	1S-3	0.041		**2S-3**	0.043		**3S-3**	0.051
	Mean	0.049		**Mean**	0.042		**Mean**	0.054
Sept 23	**1S-1**	0.137	**Sept 23**	**2S-1**	0.161	**Sept 23**	**3S-1**	0.072
	1S-2	0.123		**2S-2**	0.157		**3S-2**	0.072
	1S-3	0.133		**2S-3**	0.164		**3S-3**	0.073
	Mean	0.131		**Mean**	0.161		**Mean**	0.073
Nov 23	**1S-1**	0.091	**Nov 23**	**2S-1**	0.066	**Nov 23**	**3S-1**	0.043
	1S-2	0.086		**2S-2**	0.067		**3S-2**	0.043
	1S-3	0.090		**2S-3**	0.066		**3S-3**	0.044
	Mean	0.089		**Mean**	0.066		**Mean**	0.043
Mar 24	**1S-1**	0.082	**Mar 24**	**2S-1**	0.058	**Mar 24**	**3S-1**	0.031
	1S-2	0.090		**2S-2**	0.056		**3S-2**	0.032
	1S-3	0.084		**2S-3**	0.055		**3S-3**	0.033
	Mean	0.086		**Mean**	0.056		**Mean**	0.032

3.11 Potential Ecological Risk (PER)

The combined metal concentrations within each sediment sample determined the potential ecological risk (Guo et al., 2010). Sediment samples are ranked within five levels, (low, moderate, considerable, high, and significantly high).

All coral reef sites (1N, 2N, 3N, 1S, 2S, and 3S) showed moderate contamination during some period of collection. The contamination was primarily due to As.

Preliminary observations indicated a higher mean PER for the North sites 1N (64.7), 2N (58.3), and 3N (49.4) during every period compared to the South sites 1S (46.8), 2S (50.1), and 3S (39.7). The data also indicated that the mean PER values generally decreased from the nearest shore locations (1N and 1S) to the furthest shore locations (3N and 3S) indicating possible higher contamination at the nearshore compared to offshore locations (Table 96).

Table 96. Triplicate reef potential ecological risk (PER) of sediment from the traps for 1N, 2N, 3N, 1S, 2S, and 3S locations. The color of the value indicates: low contamination (< 40, green), moderate contamination (40-80, yellow), considerable contamination (80-160, orange), high contamination (160-320, red), and significantly high contamination (>320, dark red). SE = standard error and CI LB = 95% confidence interval lower bound. The June 2023 data were collected during Phase I of FDEP project (#C0FEDD).

June 23	**1N-1**	70.3
	1N-2	77.9
	1N-3	77.1
	Mean	75.1
Sept 23	**1N-1**	62.7
	1N-2	62.3
	1N-3	76.7
	Mean	67.2
Nov 23	**1N-1**	59.6
	1N-2	63.9
	1N-3	48.9
	Mean	57.5
Mar 24	**1N-1**	47.1
	1N-2	61.0
	1N-3	68.4
	Mean	58.8
Overall Mean		64.7

June 23	**2N-1**	70.9
	2N-2	76.1
	2N-3	65.1
	Mean	70.7
Sept 23	**2N-1**	86.7
	2N-2	85.5
	2N-3	83.3
	Mean	85.2
Nov 23	**2N-1**	43.2
	2N-2	43.4
	2N-3	39.9
	Mean	42.2
Mar 24	**2N-1**	32.2
	2N-2	35.5
	2N-3	37.2
	Mean	35.0
Overall Mean		58.3

June 23	**3N-1**	55.4
	3N-2	47.9
	3N-3	53.6
	Mean	52.3
Sept 23	**3N-1**	78.9
	3N-2	97.3
	3N-3	69.3
	Mean	81.82
Nov 23	**3N-1**	29.4
	3N-2	30.6
	3N-3	34.7
	Mean	31.6
Mar 24	**3N-1**	33.4
	3N-2	30.7
	3N-3	31.6
	Mean	31.9
Overall Mean		49.4

June 23	**1S-1**	52.5
	1S-2	72.9
	1S-3	51.7
	Mean	59.0
Sept 23	**1S-1**	54.4
	1S-2	45.8
	1S-3	46.5
	Mean	48.9
Nov 23	**1S-1**	41.6
	1S-2	38.6
	1S-3	39.3
	Mean	39.9
Mar 24	**1S-1**	38.1
	1S-2	41.8
	1S-3	38.7
	Mean	39.5
Overall Mean		46.8

June 23	**2S-1**	66.2
	2S-2	64.0
	2S-3	72.9
	Mean	67.7
Sept 23	**2S-1**	58.2
	2S-2	57.9
	2S-3	63.3
	Mean	59.8
Nov 23	**2S-1**	32.9
	2S-2	33.7
	2S-3	35.8
	Mean	34.2
Mar 24	**2S-1**	40.1
	2S-2	37.9
	2S-3	37.7
	Mean	38.6
Overall Mean		50.1

June 23	**3S-1**	45.3
	3S-2	50.3
	3S-3	41.2
	Mean	45.6
Sept 23	**3S-1**	53.1
	3S-2	53.9
	3S-3	53.1
	Mean	53.4
Nov 23	**3S-1**	27.4
	3S-2	30.6
	3S-3	29.8
	Mean	29.3
Mar 24	**3S-1**	29.0
	3S-2	31.2
	3S-3	31.9
	Mean	30.7
Overall Mean		39.7

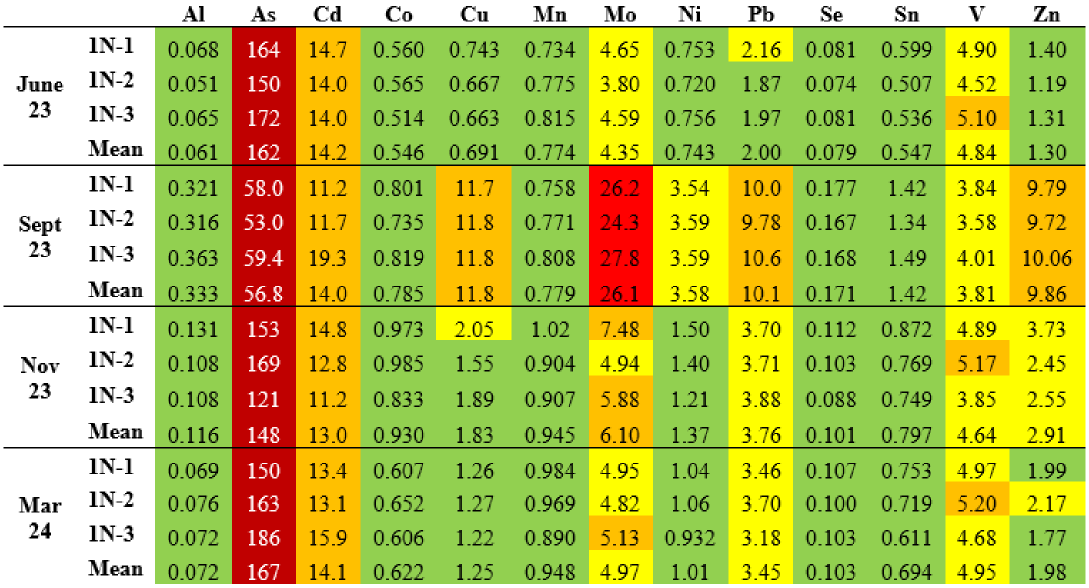
3.12 Enrichment Factor Based on Fe

The enrichment factor (EF) is used to determine how much the presence of an element (heavy metal) in sediment has increased, due to human activity, relative to the average natural abundance based off the Fe in the upper continental crust.

Table 97 shows the EFs in the sediment of the six coral reef locations (1N, 2N, 3N, 1S, 2S, and 3S) for each collection date (June, September, November, and March). The overall degree of enrichment for all the results seems relatively high; **therefore, using only EF to determine contamination is not recommended.** This could be since the upper continental crust value for Fe (50,000 µg/g) is much higher than the Fe found in the South FL marine environment, which can skew the degree of enrichment.

Preliminary results show overall high enrichment in all heavy metals except for Al, Co, Mn, Se, and Sn. There was overall extremely high enrichment in As, high to very high for Cd, as well as high enrichment for Mo and moderate for Ni, Pb, V, and Zn.

Table 97. Triplicate reef Fe enrichment factors (EF) of sediment samples in traps for 1N, 2N, 3N, 1S, 2S, and 3S locations. The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound. The June 2023 data were collected during Phase I of FDEP project (#C0FEDD).

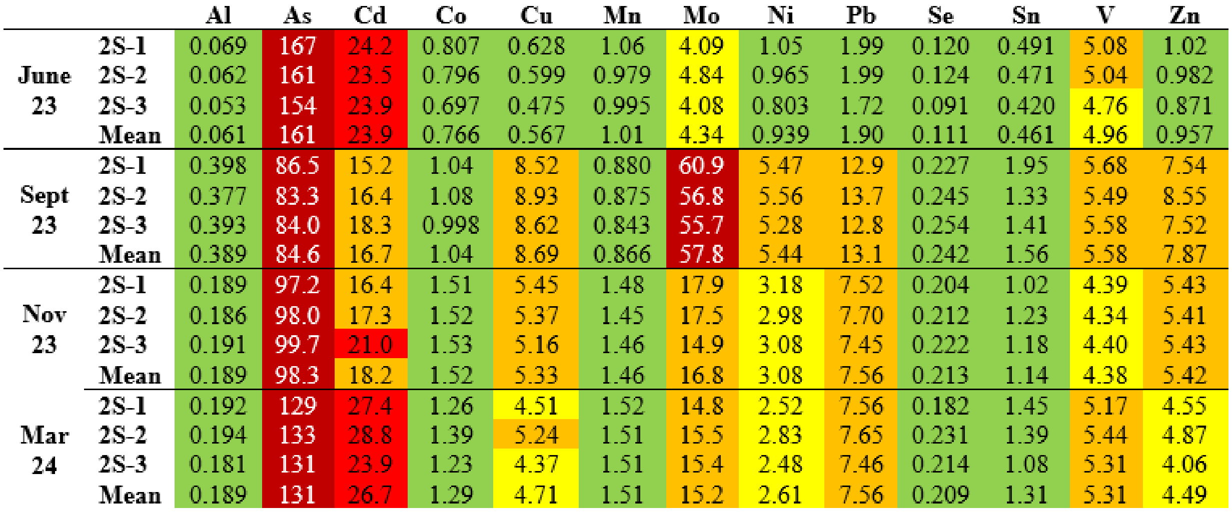


		Al	As	Cd	Co	Cu	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**1N-1**	0.068	164	14.7	0.560	0.743	0.734	4.65	0.753	2.16	0.081	0.599	4.90	1.40
	1N-2	0.051	150	14.0	0.565	0.667	0.775	3.80	0.720	1.87	0.074	0.507	4.52	1.19
	1N-3	0.065	172	14.0	0.514	0.663	0.815	4.59	0.756	1.97	0.081	0.536	5.10	1.31
	Mean	0.061	162	14.2	0.546	0.691	0.774	4.35	0.743	2.00	0.079	0.547	4.84	1.30
Sept 23	**1N-1**	0.321	58.0	11.2	0.801	11.7	0.758	26.2	3.54	10.0	0.177	1.42	3.84	9.79
	1N-2	0.316	53.0	11.7	0.735	11.8	0.771	24.3	3.59	9.78	0.167	1.34	3.58	9.72
	1N-3	0.363	59.4	19.3	0.819	11.8	0.808	27.8	3.59	10.6	0.168	1.49	4.01	10.06
	Mean	0.333	56.8	14.0	0.785	11.8	0.779	26.1	3.58	10.1	0.171	1.42	3.81	9.86
Nov 23	**1N-1**	0.131	153	14.8	0.973	2.05	1.02	7.48	1.50	3.70	0.112	0.872	4.89	3.73
	1N-2	0.108	169	12.8	0.985	1.55	0.904	4.94	1.40	3.71	0.103	0.769	5.17	2.45
	1N-3	0.108	121	11.2	0.833	1.89	0.907	5.88	1.21	3.88	0.088	0.749	3.85	2.55
	Mean	0.116	148	13.0	0.930	1.83	0.945	6.10	1.37	3.76	0.101	0.797	4.64	2.91
Mar 24	**1N-1**	0.069	150	13.4	0.607	1.26	0.984	4.95	1.04	3.46	0.107	0.753	4.97	1.99
	1N-2	0.076	163	13.1	0.652	1.27	0.969	4.82	1.06	3.70	0.100	0.719	5.20	2.17
	1N-3	0.072	186	15.9	0.606	1.22	0.890	5.13	0.932	3.18	0.103	0.611	4.68	1.77
	Mean	0.072	167	14.1	0.622	1.25	0.948	4.97	1.01	3.45	0.103	0.694	4.95	1.98

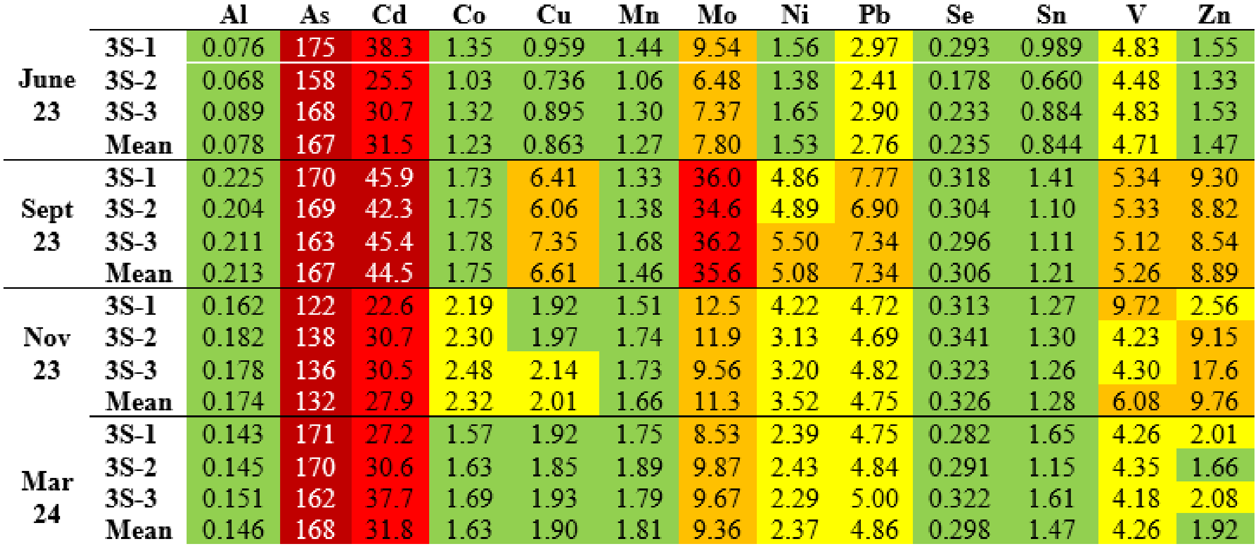
		Al	As	Cd	Co	Cu	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**2N-1**	0.072	162	20.0	0.636	0.797	0.912	4.20	0.858	2.09	0.101	0.501	4.93	1.26
	2N-2	0.074	169	15.8	0.606	0.598	0.872	4.50	0.842	1.84	0.087	0.475	5.03	1.31
	2N-3	0.061	146	15.2	0.571	0.655	0.794	3.99	0.750	2.22	0.082	0.541	4.83	1.22
	Mean	0.069	159	17.0	0.605	0.683	0.859	4.23	0.817	2.05	0.090	0.506	4.93	1.26
Sept 23	**2N-1**	0.384	66.8	11.1	0.763	11.0	0.664	42.5	3.78	10.5	0.198	1.71	4.78	8.14
	2N-2	0.395	64.1	11.2	0.751	11.0	0.665	41.6	3.64	10.4	0.191	1.77	4.59	8.21
	2N-3	0.383	65.3	10.2	0.778	11.0	0.654	41.3	3.96	10.5	0.178	1.44	4.78	8.05
	Mean	0.387	65.4	10.9	0.764	11.0	0.661	41.8	3.79	10.5	0.189	1.64	4.72	8.13
Nov 23	**2N-1**	0.156	111	15.0	1.28	3.58	1.22	13.6	2.18	5.827	0.192	0.923	4.57	8.84
	2N-2	0.153	98.7	14.3	1.01	3.60	1.09	11.2	1.84	5.865	0.120	0.825	3.94	4.37
	2N-3	0.159	98.6	11.9	1.07	3.59	1.14	11.1	2.07	5.310	0.123	1.02	4.11	4.57
	Mean	0.156	103	13.7	1.12	3.59	1.15	12.0	2.03	5.67	0.145	0.922	4.20	5.93
Mar 24	**2N-1**	0.222	106	14.0	1.03	6.35	1.43	19.2	2.50	8.529	0.170	1.18	4.21	6.24
	2N-2	0.217	107	17.0	1.03	10.2	1.44	13.7	2.46	8.473	0.171	1.16	4.22	6.19
	2N-3	0.224	108	18.4	1.02	6.19	1.35	13.8	2.31	8.049	0.172	1.09	4.27	6.17
	Mean	0.221	107	16.5	1.03	7.57	1.41	15.6	2.43	8.35	0.171	1.14	4.23	6.20

		Al	As	Cd	Co	Cu	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**3N-1**	0.089	168	42.1	1.21	0.986	1.29	8.50	1.61	2.71	0.219	0.789	4.84	1.28
	3N-2	0.094	175	32.2	1.19	1.03	1.30	7.16	1.67	2.59	0.237	0.835	4.96	1.19
	3N-3	0.095	173	29.8	1.03	0.832	1.21	7.00	1.63	2.37	0.194	0.747	4.81	1.15
	Mean	0.093	172	34.7	1.15	0.950	1.27	7.55	1.64	2.56	0.216	0.790	4.87	1.21
Sept 23	**3N-1**	0.365	92.0	18.8	0.952	12.3	0.840	31.8	4.71	10.2	0.234	1.72	4.25	11.0
	3N-2	0.373	140	17.3	1.17	12.0	0.842	50.4	10.4	10.7	0.232	1.97	5.23	16.9
	3N-3	0.403	94.9	15.8	1.00	11.7	0.864	35.2	4.80	11.4	0.241	1.77	4.62	11.3
	Mean	0.381	109	17.3	1.04	12.0	0.849	39.2	6.62	10.8	0.235	1.82	4.70	13.1
Nov 23	**3N-1**	0.187	129	21.5	2.03	3.46	1.50	14.1	2.69	5.10	0.253	1.56	4.41	3.44
	3N-2	0.191	135	24.2	2.17	2.85	1.50	11.9	2.74	5.13	0.286	1.12	4.66	3.47
	3N-3	0.197	122	33.6	1.89	2.85	1.59	11.9	2.81	4.89	0.270	1.11	4.32	3.68
	Mean	0.192	129	26.5	2.03	3.05	1.53	12.6	2.75	5.04	0.270	1.26	4.46	3.53
Mar 24	**3N-1**	0.163	150	32.4	1.41	2.05	1.74	9.67	2.40	4.98	0.296	1.40	4.43	1.96
	3N-2	0.159	153	30.8	1.44	2.22	1.71	9.58	2.47	4.81	0.279	1.32	4.40	2.03
	3N-3	0.157	155	29.7	1.43	2.08	1.61	9.81	2.22	4.78	0.268	1.49	4.37	1.87
	Mean	0.159	152	31.0	1.43	2.12	1.69	9.69	2.36	4.86	0.281	1.40	4.40	1.95

		Al	As	Cd	Co	Cu	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**1S-1**	0.079	135	18.4	0.879	1.15	0.901	4.51	0.917	2.92	0.100	0.635	5.10	3.17
	1S-2	0.089	143	14.5	0.676	0.922	0.807	3.47	0.817	2.34	0.087	0.509	4.62	1.90
	1S-3	0.097	144	17.8	0.717	0.977	0.814	3.95	0.824	2.52	0.102	0.634	4.88	2.07
	Mean	0.088	141	16.9	0.757	1.02	0.841	3.98	0.853	2.60	0.096	0.593	4.87	2.38
Sept 23	**1S-1**	0.270	68.4	19.5	0.918	8.77	0.851	41.2	4.24	10.7	0.184	1.14	4.98	9.51
	1S-2	0.250	63.1	18.5	1.02	9.16	1.02	39.6	3.57	11.5	0.199	1.12	4.98	9.60
	1S-3	0.350	78.4	13.5	0.993	9.26	0.921	51.6	4.19	12.4	0.209	1.29	5.72	11.0
	Mean	0.290	69.9	17.2	0.976	9.07	0.932	44.1	4.00	11.6	0.197	1.19	5.23	10.0
Nov 23	**1S-1**	0.177	76.5	14.2	1.08	7.12	1.22	13.5	2.28	7.41	0.126	1.39	3.91	7.30
	1S-2	0.210	83.7	14.6	1.22	7.87	1.36	12.8	2.70	7.63	0.140	1.28	4.22	10.4
	1S-3	0.213	88.4	12.4	1.35	7.56	1.33	13.4	4.03	7.45	0.152	1.20	4.57	8.25
	Mean	0.200	82.9	13.7	1.22	7.52	1.30	13.3	3.01	7.50	0.139	1.29	4.24	8.65
Mar 24	**1S-1**	0.300	92.0	19.8	1.06	9.38	1.41	19.9	3.77	9.81	0.165	1.34	4.19	9.71
	1S-2	0.279	87.1	20.5	1.04	9.71	1.36	18.4	3.69	9.05	0.180	1.31	4.07	9.55
	1S-3	0.289	89.5	18.1	1.04	9.18	1.34	18.0	3.76	9.11	0.157	1.29	4.06	9.26
	Mean	0.289	89.5	19.5	1.05	9.42	1.37	18.8	3.74	9.32	0.167	1.31	4.11	9.51



		Al	As	Cd	Co	Cu	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**2S-1**	0.069	167	24.2	0.807	0.628	1.06	4.09	1.05	1.99	0.120	0.491	5.08	1.02
	2S-2	0.062	161	23.5	0.796	0.599	0.979	4.84	0.965	1.99	0.124	0.471	5.04	0.982
	2S-3	0.053	154	23.9	0.697	0.475	0.995	4.08	0.803	1.72	0.091	0.420	4.76	0.871
	Mean	0.061	161	23.9	0.766	0.567	1.01	4.34	0.939	1.90	0.111	0.461	4.96	0.957
Sept 23	**2S-1**	0.398	86.5	15.2	1.04	8.52	0.880	60.9	5.47	12.9	0.227	1.95	5.68	7.54
	2S-2	0.377	83.3	16.4	1.08	8.93	0.875	56.8	5.56	13.7	0.245	1.33	5.49	8.55
	2S-3	0.393	84.0	18.3	0.998	8.62	0.843	55.7	5.28	12.8	0.254	1.41	5.58	7.52
	Mean	0.389	84.6	16.7	1.04	8.69	0.866	57.8	5.44	13.1	0.242	1.56	5.58	7.87
Nov 23	**2S-1**	0.189	97.2	16.4	1.51	5.45	1.48	17.9	3.18	7.52	0.204	1.02	4.39	5.43
	2S-2	0.186	98.0	17.3	1.52	5.37	1.45	17.5	2.98	7.70	0.212	1.23	4.34	5.41
	2S-3	0.191	99.7	21.0	1.53	5.16	1.46	14.9	3.08	7.45	0.222	1.18	4.40	5.43
	Mean	0.189	98.3	18.2	1.52	5.33	1.46	16.8	3.08	7.56	0.213	1.14	4.38	5.42
Mar 24	**2S-1**	0.192	129	27.4	1.26	4.51	1.52	14.8	2.52	7.56	0.182	1.45	5.17	4.55
	2S-2	0.194	133	28.8	1.39	5.24	1.51	15.5	2.83	7.65	0.231	1.39	5.44	4.87
	2S-3	0.181	131	23.9	1.23	4.37	1.51	15.4	2.48	7.46	0.214	1.08	5.31	4.06
	Mean	0.189	131	26.7	1.29	4.71	1.51	15.2	2.61	7.56	0.209	1.31	5.31	4.49



		Al	As	Cd	Co	Cu	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**3S-1**	0.076	175	38.3	1.35	0.959	1.44	9.54	1.56	2.97	0.293	0.989	4.83	1.55
	3S-2	0.068	158	25.5	1.03	0.736	1.06	6.48	1.38	2.41	0.178	0.660	4.48	1.33
	3S-3	0.089	168	30.7	1.32	0.895	1.30	7.37	1.65	2.90	0.233	0.884	4.83	1.53
	Mean	0.078	167	31.5	1.23	0.863	1.27	7.80	1.53	2.76	0.235	0.844	4.71	1.47
Sept 23	**3S-1**	0.225	170	45.9	1.73	6.41	1.33	36.0	4.86	7.77	0.318	1.41	5.34	9.30
	3S-2	0.204	169	42.3	1.75	6.06	1.38	34.6	4.89	6.90	0.304	1.10	5.33	8.82
	3S-3	0.211	163	45.4	1.78	7.35	1.68	36.2	5.50	7.34	0.296	1.11	5.12	8.54
	Mean	0.213	167	44.5	1.75	6.61	1.46	35.6	5.08	7.34	0.306	1.21	5.26	8.89
Nov 23	**3S-1**	0.162	122	22.6	2.19	1.92	1.51	12.5	4.22	4.72	0.313	1.27	9.72	2.56
	3S-2	0.182	138	30.7	2.30	1.97	1.74	11.9	3.13	4.69	0.341	1.30	4.23	9.15
	3S-3	0.178	136	30.5	2.48	2.14	1.73	9.56	3.20	4.82	0.323	1.26	4.30	17.6
	Mean	0.174	132	27.9	2.32	2.01	1.66	11.3	3.52	4.75	0.326	1.28	6.08	9.76
Mar 24	**3S-1**	0.143	171	27.2	1.57	1.92	1.75	8.53	2.39	4.75	0.282	1.65	4.26	2.01
	3S-2	0.145	170	30.6	1.63	1.85	1.89	9.87	2.43	4.84	0.291	1.15	4.35	1.66
	3S-3	0.151	162	37.7	1.69	1.93	1.79	9.67	2.29	5.00	0.322	1.61	4.18	2.08
	Mean	0.146	168	31.8	1.63	1.90	1.81	9.36	2.37	4.86	0.298	1.47	4.26	1.92

3.13 Enrichment Factor Based on Al

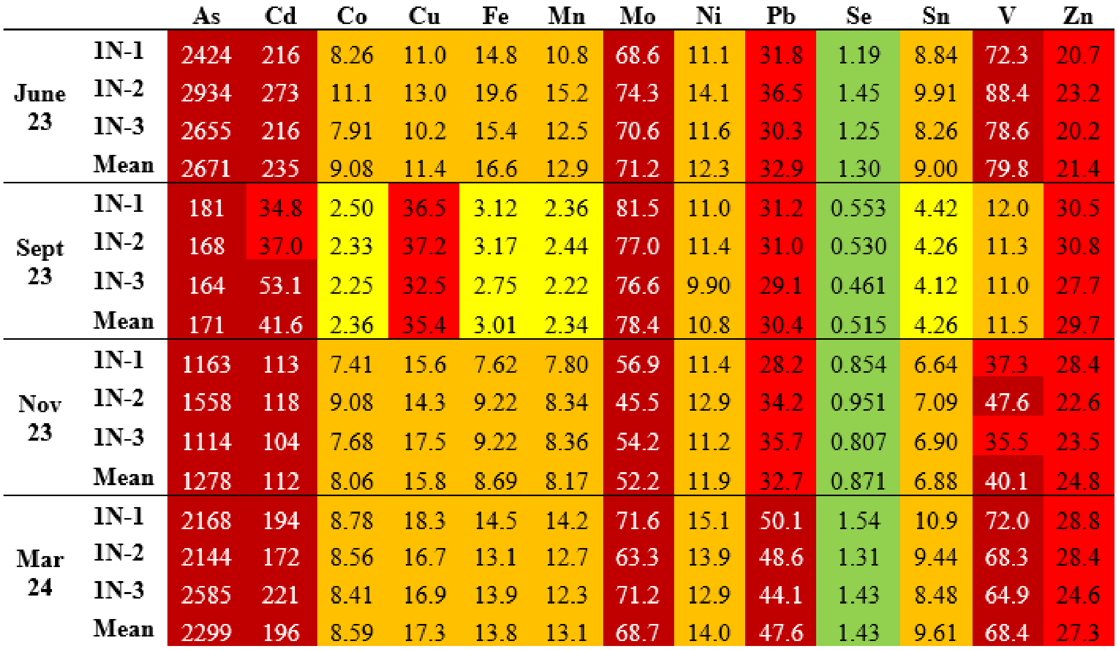
The enrichment factor (EF) is used to determine how much the presence of an element (heavy metal) in sediment has increased, due to human activity, relative to the average natural abundance based off the Al in the upper continental crust.

Table 98 below shows the EFs in the sediment traps of the six coral reef locations (1N, 2N, 3N, 1S, 2S, and 3S) for each collection date (June, September, November, and March).

Preliminary results show overall high enrichment in all heavy metals except for Se. The overall degree of enrichment for all the metals and all the results is extremely high, so using EF based on Al to determine contamination is not recommended as the sole source of contaminant information. This is due to the much lower Al concentrations found in the sediment cores compared to the upper continental crust value for Al (81,300 µg/g).

Results show overall high enrichment in all heavy metals except for Se. There was overall extremely high enrichment in As, Cd, Mo, Pb, and Zn, as well as high enrichment for Co Cu, Fe, Mn, Ni, and Sn.

Table 98. Triplicate reef Al enrichment factors (EF) of sediment samples in traps for 1N, 2N, 3N, 1S, 2S, and 3S locations. The color of the value indicates: depletion to mineral enrichment (< 2, green), moderate enrichment (2 ≤ EF < 5, yellow), significant enrichment (5 ≤ EF < 20, orange), very high enrichment (20 ≤ EF < 40, red), and extremely high enrichment (EF > 40, dark red). SE = standard error and CI LB = 95% confidence interval lower bound. The June 2023 data were collected during Phase I of FDEP project (#C0FEDD).

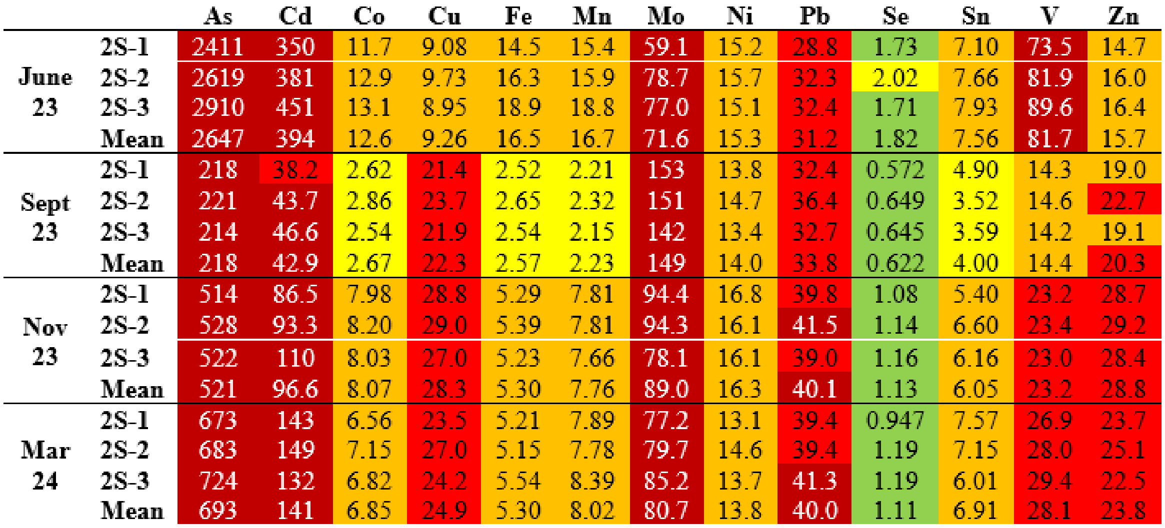


		As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**1N-1**	2424	216	8.26	11.0	14.8	10.8	68.6	11.1	31.8	1.19	8.84	72.3	20.7
	1N-2	2934	273	11.1	13.0	19.6	15.2	74.3	14.1	36.5	1.45	9.91	88.4	23.2
	1N-3	2655	216	7.91	10.2	15.4	12.5	70.6	11.6	30.3	1.25	8.26	78.6	20.2
	Mean	2671	235	9.08	11.4	16.6	12.9	71.2	12.3	32.9	1.30	9.00	79.8	21.4
Sept 23	**1N-1**	181	34.8	2.50	36.5	3.12	2.36	81.5	11.0	31.2	0.553	4.42	12.0	30.5
	1N-2	168	37.0	2.33	37.2	3.17	2.44	77.0	11.4	31.0	0.530	4.26	11.3	30.8
	1N-3	164	53.1	2.25	32.5	2.75	2.22	76.6	9.90	29.1	0.461	4.12	11.0	27.7
	Mean	171	41.6	2.36	35.4	3.01	2.34	78.4	10.8	30.4	0.515	4.26	11.5	29.7
Nov 23	**1N-1**	1163	113	7.41	15.6	7.62	7.80	56.9	11.4	28.2	0.854	6.64	37.3	28.4
	1N-2	1558	118	9.08	14.3	9.22	8.34	45.5	12.9	34.2	0.951	7.09	47.6	22.6
	1N-3	1114	104	7.68	17.5	9.22	8.36	54.2	11.2	35.7	0.807	6.90	35.5	23.5
	Mean	1278	112	8.06	15.8	8.69	8.17	52.2	11.9	32.7	0.871	6.88	40.1	24.8
Mar 24	**1N-1**	2168	194	8.78	18.3	14.5	14.2	71.6	15.1	50.1	1.54	10.9	72.0	28.8
	1N-2	2144	172	8.56	16.7	13.1	12.7	63.3	13.9	48.6	1.31	9.44	68.3	28.4
	1N-3	2585	221	8.41	16.9	13.9	12.3	71.2	12.9	44.1	1.43	8.48	64.9	24.6
	Mean	2299	196	8.59	17.3	13.8	13.1	68.7	14.0	47.6	1.43	9.61	68.4	27.3

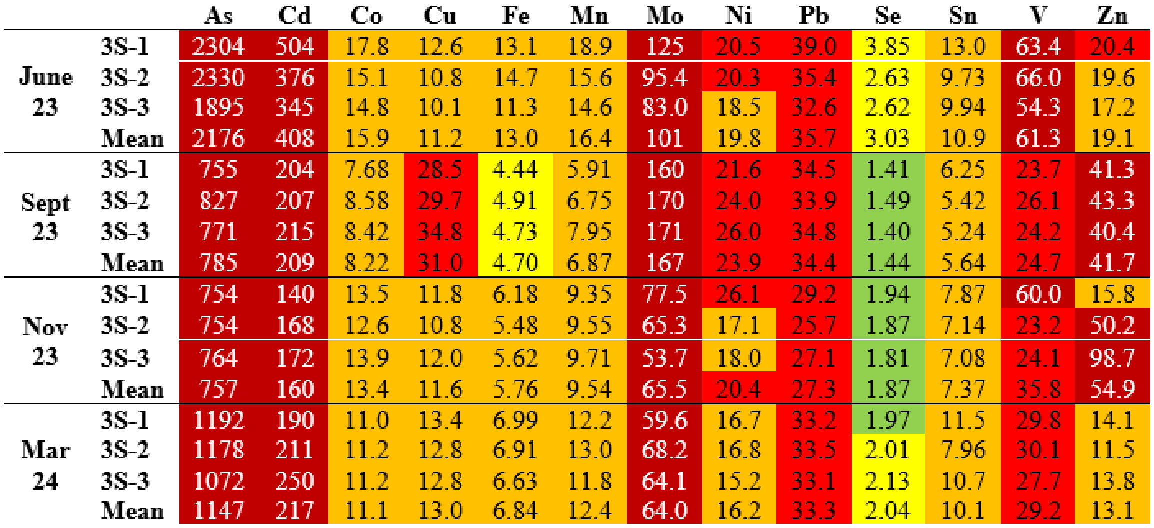
		As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**2N-1**	2253	278	8.83	11.1	13.9	12.7	58.3	11.9	29.0	1.40	6.95	68.4	17.5
	2N-2	2304	215	8.25	8.13	13.6	11.9	61.2	11.5	25.0	1.18	6.47	68.4	17.8
	2N-3	2389	248	9.35	10.7	16.4	13.0	65.2	12.3	36.3	1.33	8.85	79.0	20.0
	Mean	2315	247	8.81	9.97	14.6	12.5	61.6	11.9	30.1	1.30	7.42	72.0	18.4
Sept 23	**2N-1**	174	29.1	1.99	28.7	2.61	1.73	111	9.86	27.4	0.517	4.45	12.5	21.2
	2N-2	162	28.3	1.90	27.9	2.53	1.69	105	9.23	26.5	0.485	4.49	11.6	20.8
	2N-3	170	26.7	2.03	28.8	2.61	1.70	108	10.3	27.3	0.464	3.75	12.5	21.0
	Mean	169	28.0	1.97	28.4	2.58	1.71	108	9.80	27.1	0.489	4.23	12.2	21.0
Nov 23	**2N-1**	709	96.0	8.20	23.0	6.42	7.80	87.3	14.0	37.4	1.23	5.92	29.3	56.7
	2N-2	643	93.0	6.60	23.5	6.51	7.11	72.7	12.0	38.2	0.782	5.37	25.6	28.5
	2N-3	622	74.7	6.75	22.6	6.30	7.17	70.0	13.0	33.5	0.772	6.41	25.9	28.8
	Mean	658	87.9	7.18	23.0	6.41	7.36	76.7	13.0	36.4	0.928	5.90	27.0	38.0
Mar 24	**2N-1**	477	63.1	4.64	28.6	4.51	6.44	86.5	11.3	38.4	0.764	5.30	19.0	28.1
	2N-2	492	78.5	4.75	46.8	4.61	6.64	63.3	11.3	39.0	0.787	5.36	19.5	28.5
	2N-3	483	82.3	4.55	27.6	4.46	6.03	61.8	10.3	35.9	0.769	4.85	19.0	27.5
	Mean	484	74.6	4.65	34.4	4.53	6.37	70.5	11.0	37.8	0.774	5.17	19.2	28.1

		As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**3N-1**	1883	473	13.6	11.1	11.2	14.5	95.6	18.1	30.4	2.46	8.87	54.4	14.4
	3N-2	1866	343	12.7	11.0	10.6	13.9	76.2	17.8	27.5	2.52	8.89	52.8	12.7
	3N-3	1824	314	10.9	8.76	10.5	12.8	73.7	17.2	25.0	2.04	7.86	50.6	12.1
	Mean	1858	377	12.4	10.3	10.8	13.7	81.8	17.7	27.7	2.34	8.54	52.6	13.1
Sept 23	**3N-1**	252	51.6	2.61	33.7	2.74	2.30	87.2	12.9	27.9	0.640	4.70	11.7	30.3
	3N-2	375	46.3	3.14	32.1	2.68	2.26	135	27.7	28.6	0.621	5.27	14.0	45.2
	3N-3	235	39.3	2.49	29.0	2.48	2.14	87.4	11.9	28.3	0.596	4.39	11.4	27.9
	Mean	288	45.7	2.75	31.6	2.63	2.23	103	17.5	28.3	0.619	4.79	12.4	34.5
Nov 23	**3N-1**	690	115	10.9	18.4	5.34	7.98	75.3	14.4	27.2	1.35	8.31	23.5	18.4
	3N-2	706	127	11.4	14.9	5.24	7.85	62.2	14.3	26.8	1.50	5.85	24.4	18.1
	3N-3	619	171	9.60	14.5	5.08	8.10	60.4	14.3	24.9	1.37	5.66	21.9	18.7
	Mean	671	138	10.6	15.9	5.22	7.98	66.0	14.3	26.3	1.41	6.61	23.3	18.4
Mar 24	**3N-1**	923	199	8.69	12.6	6.15	10.7	59.5	14.8	30.7	1.82	8.62	27.3	12.0
	3N-2	962	195	9.07	14.0	6.31	10.8	60.5	15.6	30.3	1.76	8.34	27.7	12.8
	3N-3	983	189	9.11	13.2	6.36	10.3	62.4	14.1	30.4	1.70	9.47	27.8	11.9
	Mean	956	194	8.96	13.3	6.27	10.6	60.8	14.8	30.5	1.76	8.81	27.6	12.3

		As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**1S-1**	1703	232	11.1	14.5	12.6	11.4	57.0	11.6	36.9	1.26	8.02	64.4	40.1
	1S-2	1607	164	7.61	10.4	11.2	9.08	39.0	9.19	26.4	0.979	5.72	52.0	21.4
	1S-3	1493	184	7.41	10.1	10.3	8.41	40.9	8.51	26.0	1.05	6.55	50.4	21.4
	Mean	1601	193	8.71	11.7	11.4	9.63	45.6	9.77	29.8	1.10	6.77	55.6	27.7
Sept 23	**1S-1**	253	72.1	3.40	32.5	3.71	3.15	153	15.7	39.7	0.680	4.24	18.5	35.3
	1S-2	253	74.3	4.08	36.7	4.01	4.10	159	14.3	46.1	0.798	4.50	19.9	38.5
	1S-3	224	38.5	2.84	26.5	2.86	2.63	147	12.0	35.5	0.597	3.70	16.3	31.4
	Mean	243	61.6	3.44	31.9	3.52	3.30	153	14.0	40.4	0.692	4.14	18.3	35.0
Nov 23	**1S-1**	434	80.3	6.10	40.4	5.66	6.91	76.6	12.9	42.0	0.713	7.85	22.2	41.4
	1S-2	399	69.6	5.81	37.5	4.76	6.46	61.0	12.9	36.3	0.665	6.11	20.1	49.5
	1S-3	415	58.1	6.33	35.5	4.69	6.25	63.0	18.9	34.9	0.713	5.65	21.5	38.7
	Mean	416	69.3	6.08	37.8	5.04	6.54	66.9	14.9	37.7	0.697	6.54	21.3	43.2
Mar 24	**1S-1**	307	66.1	3.54	31.3	3.34	4.70	66.4	12.6	32.7	0.550	4.47	14.0	32.4
	1S-2	312	73.4	3.73	34.7	3.58	4.86	65.8	13.2	32.4	0.644	4.68	14.6	34.2
	1S-3	309	62.7	3.59	31.8	3.46	4.65	62.1	13.0	31.5	0.541	4.47	14.1	32.0
	Mean	309	67.4	3.62	32.6	3.46	4.74	64.8	12.9	32.2	0.578	4.54	14.2	32.9



		As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**2S-1**	2411	350	11.7	9.08	14.5	15.4	59.1	15.2	28.8	1.73	7.10	73.5	14.7
	2S-2	2619	381	12.9	9.73	16.3	15.9	78.7	15.7	32.3	2.02	7.66	81.9	16.0
	2S-3	2910	451	13.1	8.95	18.9	18.8	77.0	15.1	32.4	1.71	7.93	89.6	16.4
	Mean	2647	394	12.6	9.26	16.5	16.7	71.6	15.3	31.2	1.82	7.56	81.7	15.7
Sept 23	**2S-1**	218	38.2	2.62	21.4	2.52	2.21	153	13.8	32.4	0.572	4.90	14.3	19.0
	2S-2	221	43.7	2.86	23.7	2.65	2.32	151	14.7	36.4	0.649	3.52	14.6	22.7
	2S-3	214	46.6	2.54	21.9	2.54	2.15	142	13.4	32.7	0.645	3.59	14.2	19.1
	Mean	218	42.9	2.67	22.3	2.57	2.23	149	14.0	33.8	0.622	4.00	14.4	20.3
Nov 23	**2S-1**	514	86.5	7.98	28.8	5.29	7.81	94.4	16.8	39.8	1.08	5.40	23.2	28.7
	2S-2	528	93.3	8.20	29.0	5.39	7.81	94.3	16.1	41.5	1.14	6.60	23.4	29.2
	2S-3	522	110	8.03	27.0	5.23	7.66	78.1	16.1	39.0	1.16	6.16	23.0	28.4
	Mean	521	96.6	8.07	28.3	5.30	7.76	89.0	16.3	40.1	1.13	6.05	23.2	28.8
Mar 24	**2S-1**	673	143	6.56	23.5	5.21	7.89	77.2	13.1	39.4	0.947	7.57	26.9	23.7
	2S-2	683	149	7.15	27.0	5.15	7.78	79.7	14.6	39.4	1.19	7.15	28.0	25.1
	2S-3	724	132	6.82	24.2	5.54	8.39	85.2	13.7	41.3	1.19	6.01	29.4	22.5
	Mean	693	141	6.85	24.9	5.30	8.02	80.7	13.8	40.0	1.11	6.91	28.1	23.8



		As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	Se	Sn	V	Zn
June 23	**3S-1**	2304	504	17.8	12.6	13.1	18.9	125	20.5	39.0	3.85	13.0	63.4	20.4
	3S-2	2330	376	15.1	10.8	14.7	15.6	95.4	20.3	35.4	2.63	9.73	66.0	19.6
	3S-3	1895	345	14.8	10.1	11.3	14.6	83.0	18.5	32.6	2.62	9.94	54.3	17.2
	Mean	2176	408	15.9	11.2	13.0	16.4	101	19.8	35.7	3.03	10.9	61.3	19.1
Sept 23	**3S-1**	755	204	7.68	28.5	4.44	5.91	160	21.6	34.5	1.41	6.25	23.7	41.3
	3S-2	827	207	8.58	29.7	4.91	6.75	170	24.0	33.9	1.49	5.42	26.1	43.3
	3S-3	771	215	8.42	34.8	4.73	7.95	171	26.0	34.8	1.40	5.24	24.2	40.4
	Mean	785	209	8.22	31.0	4.70	6.87	167	23.9	34.4	1.44	5.64	24.7	41.7
Nov 23	**3S-1**	754	140	13.5	11.8	6.18	9.35	77.5	26.1	29.2	1.94	7.87	60.0	15.8
	3S-2	754	168	12.6	10.8	5.48	9.55	65.3	17.1	25.7	1.87	7.14	23.2	50.2
	3S-3	764	172	13.9	12.0	5.62	9.71	53.7	18.0	27.1	1.81	7.08	24.1	98.7
	Mean	757	160	13.4	11.6	5.76	9.54	65.5	20.4	27.3	1.87	7.37	35.8	54.9
Mar 24	**3S-1**	1192	190	11.0	13.4	6.99	12.2	59.6	16.7	33.2	1.97	11.5	29.8	14.1
	3S-2	1178	211	11.2	12.8	6.91	13.0	68.2	16.8	33.5	2.01	7.96	30.1	11.5
	3S-3	1072	250	11.2	12.8	6.63	11.8	64.1	15.2	33.1	2.13	10.7	27.7	13.8
	Mean	1147	217	11.1	13.0	6.84	12.4	64.0	16.2	33.3	2.04	10.1	29.2	13.1

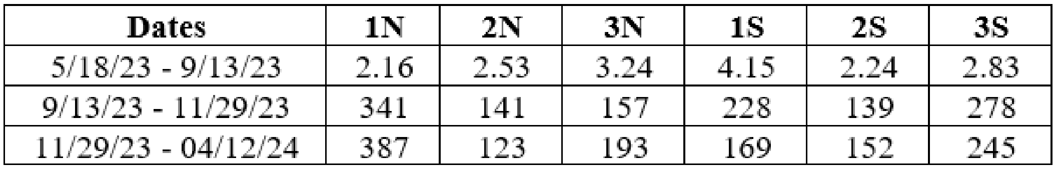
3.14. Sedimentation Rates and Abiotic Data

Sedimentation rates were determined every 78-137 days using the sediment traps located at the six reef sites. The total weight of the sediment was determined and divided by the number of collection days to calculate the rate as g/day.

The sedimentation data exhibited in Table 99 indicate that sedimentation was low during the summer months between May-September, ranging between 2.16 g/day at 1N to 4.15 g/day at 1S. The months between September to April had much higher rates, between 123 g/day – 387 g/day. The 1N location had the overall highest rates during the winter months.

Specific low pressure storm events were recorded beginning in November 2023 and occurred sporadically into March 2024. During the months of November 2023 – January 2024 increase wave action was evidenced by accumulation of benthic sediment covering the instrument platforms at these times and observing the historic wind, precipitation and temperature data available at: https://www.wunderground.com/history/monthly/us/fl/fort-lauderdale/KFLL/date/2024-1.

Table 99. Sedimentation rates in g/day for each of the six coral reef sites (1N, 2N, 3N, 1S, 2S, and 3S) for each period (dates).



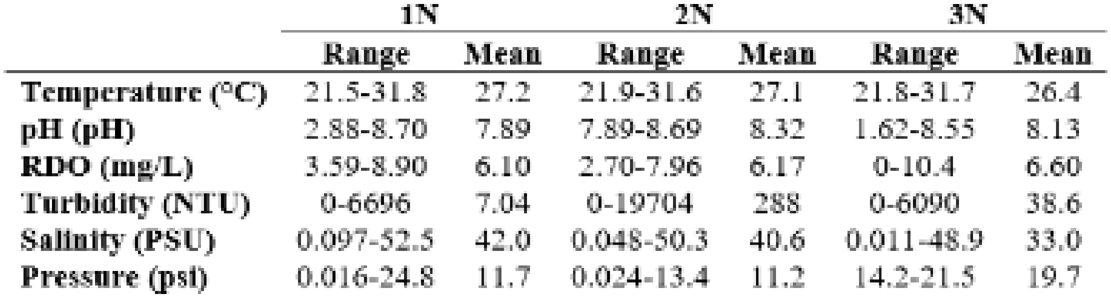
Dates	1N	2N	3N	1S	2S	3S
5/18/23 - 9/13/23	2.16	2.53	3.24	4.15	2.24	2.83
9/13/23 - 11/29/23	341	141	157	228	139	278
11/29/23 - 04/12/24	387	123	193	169	152	245

Water chemistry data were collected hourly at the six reef sites. Tables 100-107 display the weekly abiotic data. The depth of each site ranged from 18-46.5 ft with generally less than 1 ft variation due to tidal range. While multiple chemistry measures are captured, the primary variables for this study were temperature, salinity, pressure, dissolved oxygen, pH, and turbidity. These variables provided not only a measure of physical similarity and differences at the coral reef, but also provided additional explanations for the measure of biological production at the sites (e.g., coral species). The abiotic data generally had relatively close correlations in the six variables among the six sites.

The temperature on the benthos ranged from 21.5-31.8° C for the north sites and 22.6-31.2° C for the south sites. The temperatures during June – September were 3-5ºC warmer than the rest of the months (Fig. 8). The salinity values ranged from 0.011–52.5 psu at the north sites and 12.4–120 psu at the south sites. The near shore sites had greater fluctuations of salinity values, as expected, due to the influence of precipitation runoff from the coast (Fig. 9). The unusually high salinity values (greater than 40 psu) were likely the result of mineralization on the sensor lens that has been verified by the vendor In-Situ inc. Pressure values were constant among the specific sites, fluctuating depending on the depth and the daily tides, (Fig. 10). The ocean temperature influenced the oxygen saturation as expected, with warmer temperatures having lower dissolved oxygen. Figures 8 and 11 demonstrate the inverse relationship of ocean temperature and dissolved oxygen. Dissolved oxygen ranged from 0-10.4 mg/L at the north sites and 0.853–6.36 mg/L at the south sites, which were moderately high oxygen saturation. The pH values, or ocean alkalinity, remained relatively constant at all sites with the north ranging 2.88 - 8.70, and the south 6.28-8.63. The unusual low pH values exhibited at the 1N and 3N sites were the result of bad pH sensors which were replaced by the manufacturer In-Situ Inc (Fig. 12). The turbidity values appear to reflect environmental conditions exhibited by periodic low pressure storm events, resulting in higher wave action and thus higher turbidity values. Some variation in the turbidity data not reflected of environmental conditions were confirmed via manufacturer In-Situ Inc that a permanent film developed on the sensor lens resulting in the sensors replacement. The turbidity ranged from 0-19704 NTU at the north sites and 0-19679 NTU at the south sites. The nephelometric turbidity unit (NTU) is a measure of suspended particles; this is determined through the comparison of light transmission versus light scattering in the water column. Turbidity is expected to have natural fluctuations due to variations in the extent of surface and bottom currents as well as the extent of the nearshore counter current and the offshore Florida Current. Tidal change and coastal water runoff, largely influenced by precipitation, can also affect the volume and rate of various sediment grain sizes throughout the water column, as well as larger storm (wind) activity. These additional data can be acquired from local tide charts and rain gauges overseen by the South Florida Water Management District to test for their influence on turbidity. The combined use of the sediment traps with the turbidity values will allow us to measure the grain sizes being distributed prior to and during dredging events.

No data collection periods, or unexpected values, were likely due to the following: US Naval activities which required the removal of all sondes, anthropogenic interference and damage to the instruments, and technical sensor issues. Details of sensor issues were provided below by In Situ, Inc with the respective sonde serial numbers (S/N): Turbidity sensors (S/N: 992364, 991802, 992357). Sensors had a dark reddish tint on the inside of the lens. We were unable to remove it with alcohol, vinegar, and rubbing with magic erasers, brushes, and wipes. When connected to the sonde they returned error messages in VuSitu software when we put it in calibration solution. The pH sensors are particularly sensitive to marine water due to the their KCl solution and are subject to over-calibration which has affected the longevity sensors. Calibrations schedules have been modified appropriately. AquaTroll 600 (S/N 993649) sonde was deployed 3/13-4/12. Upon retrieval it would not turn on, even though batteries were brand new when deployed. SIM Card only had one reading taken when the log was first started on 3/13, and zero data after that. Sonde appears to have died after that first reading. Batteries were replaced, sonde turned on. It would not stay connected to VuSitu through Bluetooth consistently. It was replaced with a demo sonde. AquaTroll 600 (S/N 993608) sonde was deployed 3/13-4/12. When it came back the cable connector was not solid and would twist using only hand strength. It twists back and forth in the bulkhead. It was sent out for repairs. Salinity and turbidity sensors work in coordination for data collection; therefore, when one sensor is affected, eg. turbidity (above), then salinity values were higher than expected. The variability may be correctable algorithmically and we are working with In Situ, Inc. to do so.

Table 100. Range and mean values for each of the abiotic conditions from 2 June 2023 to 28 May 2024 at the reef sites 1N, 2N, and 3N. RDO is relative dissolved oxygen.



	1N		2N		3N	
	Range	**Mean**	**Range**	**Mean**	**Range**	**Mean**
Temperature (°C)	21.5-31.8	27.2	21.9-31.6	27.1	21.8-31.7	26.4
pH (pH)	2.88-8.70	7.89	7.89-8.69	8.32	1.62-8.55	8.13
RDO (mg/L)	3.59-8.90	6.10	2.70-7.96	6.17	0-10.4	6.60
Turbidity (NTU)	0-6696	7.04	0-19704	288	0-6090	38.6
Salinity (PSU)	0.097-52.5	42.0	0.048-50.3	40.6	0.011-48.9	33.0
Pressure (psi)	0.016-24.8	11.7	0.024-13.4	11.2	14.2-21.5	19.7

Table 101. Weekly averages for the abiotic conditions at reef site 1N from 2 June 2023 to 28 May 2024. ND indicates no data was collected. RDO is relative dissolved oxygen.

Week	**Temperature (°C)**	**pH (pH)**	**RDO (mg/L)**	**Turbidity (NTU)**	**Salinity (PSU)**	**Pressure (psi)**
6/2-6/8	28.2	8.27	6.22	0.095	42.8	9.06
6/9-6/15	28.5	8.24	6.32	0.043	44.1	8.93
6/16-6/22	28.2	8.24	6.25	0.051	44.3	8.84
6/23/6/30	29.2	8.24	6.08	1.05	44.3	8.91
7/11-7/17	30.9	ND	5.41	0.098	50.4	8.92
7/18-7/24	29.8	ND	5.30	0.040	50.9	8.78
7/25-7/31	30.2	ND	5.12	0.052	50.7	8.76
8/1-8/7	30.5	ND	5.14	1.42	51.0	8.93
8/8-8/14	29.4	ND	5.41	0.017	50.8	8.69
8/15-8/21	30.6	ND	4.86	0.779	49.9	8.85
8/22-8/28	30.8	ND	4.93	0.256	47.6	8.99
8/29-9/4	29.2	ND	5.12	0.414	47.8	8.86
9/5-9/11	30.2	ND	5.08	0.557	47.3	8.96
9/12-9/18	30.7	3.12	5.02	1.12	49.3	8.94
9/19-9/25	30.5	3.13	4.83	3.57	46.9	9.12
9/26-10/2	30.1	3.12	4.59	14.0	44.7	9.22
10/3-10/9	29.7	3.31	4.63	20.9	45.3	9.28
10/10-10/16	29.7	8.24	4.77	3.45	49.7	9.15
10/17-10/23	27.9	8.27	5.27	8.40	49.3	9.19
10/24-10/30	26.6	8.24	5.24	12.2	49.1	9.29
10/31-11/6	26.7	8.28	5.30	3.62	49.9	9.36
11/7-11/13	27.4	8.29	5.35	4.94	50.6	9.22
11/14-11/20	26.4	8.28	5.33	24.1	49.6	9.18
11/21-11/27	27.0	8.30	5.07	9.54	50.0	9.11
11-28-12/4	26.1	8.56	5.30	1.81	49.7	9.09
12/5-12/8	25.5	8.67	5.50	1.94	50.0	9.08
1/19-1/25	23.3	8.30	6.89	0.983	34.5	23.4

Week	Temperature (°C)	pH (pH)	RDO (mg/L)	Turbidity (NTU)	Salinity (PSU)	Pressure (psi)
1/26-2/1	23.8	8.32	7.08	ND	34.5	23.5
2/2-2/8	23.0	8.32	7.05	ND	32.3	23.7
2/9-2/15	22.9	8.32	7.21	ND	32.0	23.6
2/16-2/22	22.7	8.32	7.12	ND	32.7	23.5
2/23-2/29	23.6	8.35	7.07	ND	34.6	23.6
3/1-3/7	23.9	8.34	7.02	ND	34.1	23.5
3/8-3/14	24.0	8.36	7.05	ND	35.3	23.5
3/15-3/21	24.6	8.38	6.90	ND	35.0	23.5
3/22-3/28	24.7	8.38	6.69	ND	33.4	23.6
3/29-4/4	24.6	8.41	6.98	ND	33.4	23.6
4/5-4/12	24.4	8.41	6.79	ND	34.1	23.6
4/19-4/25	25.5	8.24	6.67	0.145	39.1	8.34
4/26-5/2	25.4	8.22	6.61	3.05	38.9	8.33
5/3-5/9	26.8	8.23	6.68	41.8	39.0	8.31
5/10-5/16	27.7	8.25	6.43	8.14	39.2	8.27
5/17-5/23	28.2	8.27	6.51	0.788	39.3	8.42
5/24-5/28	29.2	8.26	6.34	2.58	39.3	8.44

Table 102. Weekly averages for the abiotic conditions at reef site 2N from 2 June 2023 to 28 May 2024. RDO is relative dissolved oxygen.

Week	Temperature (°C)	pH (pH)	RDO (mg/L)	Turbidity (NTU)	Salinity (PSU)	Pressure (psi)
6/2-6/8	28.2	8.30	5.96	0.697	39.8	11.5
6/9-6/15	28.4	8.29	6.04	0.114	40.5	11.4
6/16-6/22	28.2	8.28	5.93	0.370	40.4	11.3
6/23/6/30	29.2	8.28	5.84	4.51	40.4	11.4
7/11-7/17	30.7	8.31	6.12	0.033	47.5	11.4
7/18-7/24	29.6	8.30	5.91	4.69	48.2	11.3
7/25-7/31	30.1	8.30	5.73	40.2	48.2	11.3
8/1-8/7	30.4	8.32	5.69	49.8	48.6	11.4
8/8-8/14	28.9	8.34	5.91	38.2	48.8	11.2
8/15-8/21	30.6	8.34	5.45	44.6	48.0	11.4
8/22-8/28	30.9	8.37	5.40	93.3	46.4	11.5
8/29-9/4	29.1	8.38	5.59	171	47.6	11.4
9/5-9/11	30.1	8.42	5.60	122	47.2	11.5
9/12-9/18	30.6	8.31	5.54	5.28	47.8	11.5
9/19-9/25	30.6	8.31	5.37	1.19	47.2	11.6
9/26-10/2	30.1	8.31	5.13	4.48	46.9	11.7
10/3-10/9	29.8	8.34	5.16	21.6	46.8	11.8
10/10-10/16	29.7	8.36	5.29	45.5	47.3	11.7
10/17-10/23	28.1	8.39	5.74	30.6	47.9	11.7
10/24-10/30	27.0	8.38	5.87	171	47.3	11.9
10/31-11/6	27.1	8.40	5.89	169	47.0	11.9
11/7-11/13	27.5	8.28	5.85	6.84	48.3	11.7
11/14-11/20	26.7	8.28	5.88	34.4	47.6	11.6
11/21-11/27	27.1	8.30	5.62	56.2	47.7	11.5
11-28-12/4	26.3	8.44	6.19	1416	37.7	11.4
12/5-12/11	25.5	8.50	6.43	1722	34.5	11.4
12/12-12/18	24.2	8.51	6.87	3096	33.8	11.4
12/19-12/25	24.2	8.54	6.68	1724	34.1	11.5
12/26-1/1	24.3	8.55	6.66	2501	33.4	11.3
1/2-1/8	24.0	8.56	6.51	2023	37.9	11.3
1/9-1/15	23.7	8.54	6.71	1429	31.3	11.2
1/16-1/22	24.1	8.51	6.59	239	36.5	11.2
1/23-1/29	24.0	8.47	6.77	154	34.4	11.1
1/30-2/5	23.8	8.50	6.75	529	35.6	11.3
2/6-2/12	22.9	8.50	6.80	788	35.5	11.3
2/13-2/19	22.9	8.51	6.86	274	34.9	11.1
2/20-2/26	23.2	8.54	6.66	114	40.5	11.2
2/27-2/29	23.5	8.57	6.66	59.7	41.5	11.2
4/19-4/25	25.3	8.20	6.54	0.858	37.8	10.8

Week	Temperature (°C)	pH (pH)	RDO (mg/L)	Turbidity (NTU)	Salinity (PSU)	Pressure (psi)
4/26-5/2	25.4	8.17	6.48	2.37	37.8	10.8
5/3-5/9	26.7	8.17	6.44	0.993	37.9	10.8
5/10-5/16	27.5	8.18	6.28	1.05	37.7	10.7
5/17-5/23	27.9	8.19	6.37	1.29	35.9	10.9
5/24-5/28	28.9	8.18	6.27	1.31	37.6	10.9

Table 103. Weekly averages for the abiotic conditions at reef site 3N from 2 June 2023 to 28 May 2024. ND indicates no data was collected. RDO is relative dissolved oxygen.

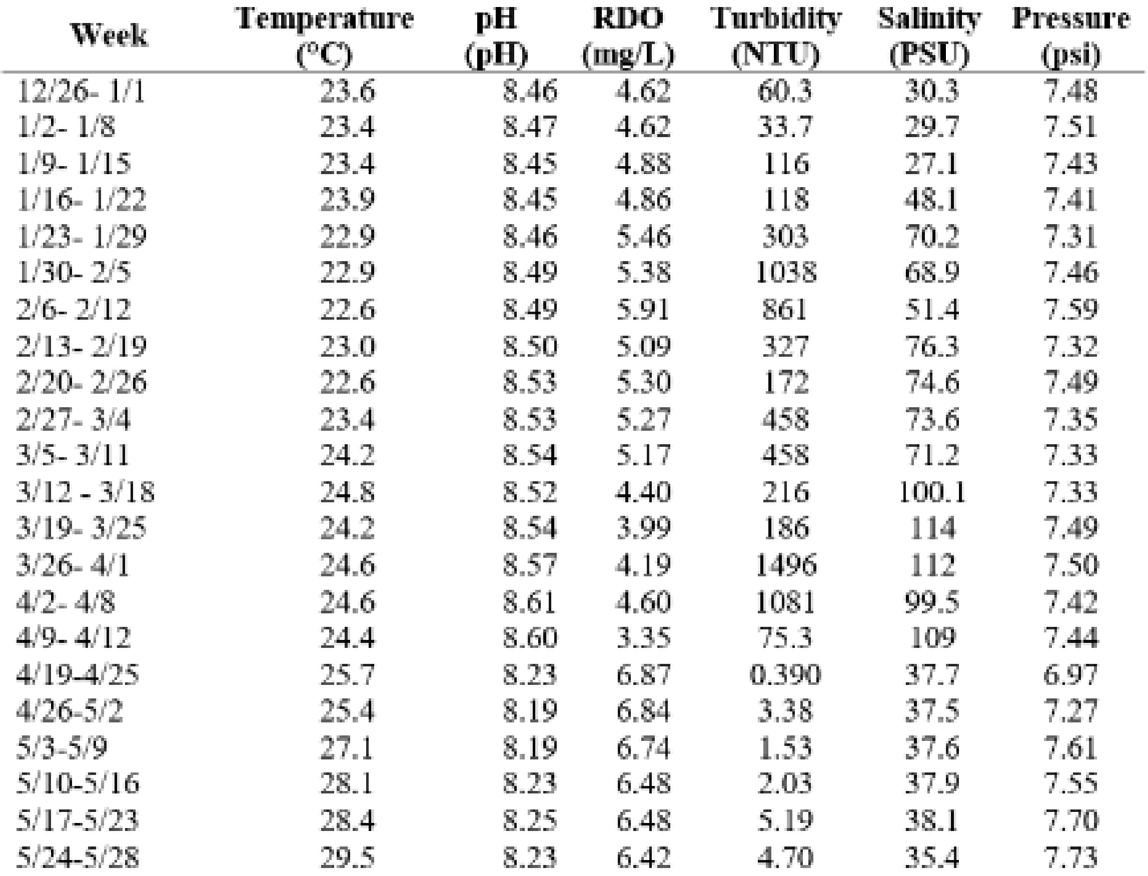
Week	Temperature (°C)	pH (pH)	RDO (mg/L)	Turbidity (NTU)	Salinity (PSU)	Pressure (psi)
6/2-6/8	28.0	8.35	6.00	0.060	47.0	19.7
6/9-6/16	28.1	8.19	6.09	3.46	48.5	19.6
7/11-7/17	29.8	8.31	7.40	0	0.011	19.6
7/18-7/24	28.4	ND	7.38	0.003	0.012	19.5
7/25-8/1	29.2	ND	7.17	0.950	0.012	19.5
9/19-9/25	30.5	8.45	5.96	14.1	38.0	19.9
9/26-10/2	30.1	8.46	5.78	43.5	38.2	20.0
10/3-10/9	29.9	8.47	5.66	57.4	38.3	20.1
10/10-10/16	29.6	8.47	5.56	76.7	38.8	20.0
10/17-10/23	28.5	8.50	6.03	59.6	38.7	20.0
10/24-10/30	27.6	8.51	6.23	253	37.1	20.1
10/31-11/6	27.6	8.50	6.50	168	30.0	20.2
11/7-11/13	27.8	8.24	6.34	2.16	39.4	20.0
11/14-11/20	27.1	8.24	5.21	70.2	22.0	19.9
11/21-11/27	27.1	8.26	6.22	18.5	38.1	19.8
11-28-12/4	26.6	8.18	6.35	13.4	38.9	19.8
12/5-12/11	25.9	8.17	6.43	10.1	39.0	19.7
12/12-12/18	25.1	8.13	5.18	101	28.7	19.8
12/19-12/25	25.2	8.12	4.25	119	29.7	19.8
12/26-1/1	24.7	8.21	6.61	2.14	39.3	19.6
1/2-1/8	24.3	8.22	6.61	2.14	39.7	19.6
1/9-1/15	24.1	8.21	6.59	61.1	38.5	19.6
1/16-1/22	24.5	8.29	6.65	11.5	37.5	19.6
1/23-1/29	24.3	8.37	6.78	3.87	38.1	19.4
1/30-2/5	24.1	8.39	6.75	4.80	38.2	19.6
2/6-2/12	23.3	8.36	6.75	198	33.4	19.7
2/13-2/19	22.8	8.39	7.00	3.66	32.3	19.4
2/20-2/26	23.5	8.39	7.20	7.87	26.7	19.6
2/27-3/4	23.3	8.38	7.20	20.6	24.0	19.5
3/5-3/11	23.5	8.38	6.79	35.5	22.9	19.5
3/12-3/18	24.0	7.17	8.07	13.8	33.3	19.4
3/19-3/25	24.7	6.68	8.47	7.01	35.2	19.6
3/26-4/1	24.6	6.80	8.49	3.79	36.5	19.6
4/2-4/8	24.3	6.82	8.51	7.28	36.6	19.5
4/9-4/12	24.6	6.83	8.53	69.7	36.6	19.5
5/23-5/28	28.5	8.24	6.36	0.050	40.0	19.2

Table 104. Range and mean values for each of the abiotic conditions from 2 June 2023 to 28 May 2024 at the reef sites 1S, 2S, and 3S. RDO is relative dissolved oxygen.

	1S		2S		3S	
	Range	**Mean**	**Range**	**Mean**	**Range**	**Mean**
Temperature (°C)	21.5-32.2	27.0	22.1-31.5	27.0	22.2-30.1	25.9
pH (pH)	6.28-8.71	8.28	8.14-8.55	8.33	8.22-8.57	8.33
RDO (mg/L)	0.853-8.91	5.14	3.37-7.52	6.05	2.75-7.34	6.28
Turbidity (NTU)	0.027-19679	251	0-9819	330	0-5752	73.9
Salinity (PSU)	12.4-120	44.9	28.7-53.1	44.7	29.4-50.7	39.6
Pressure (psi)	5.99-9.33	7.50	13.0-16.2	14.5	8.63-33.6	21.9

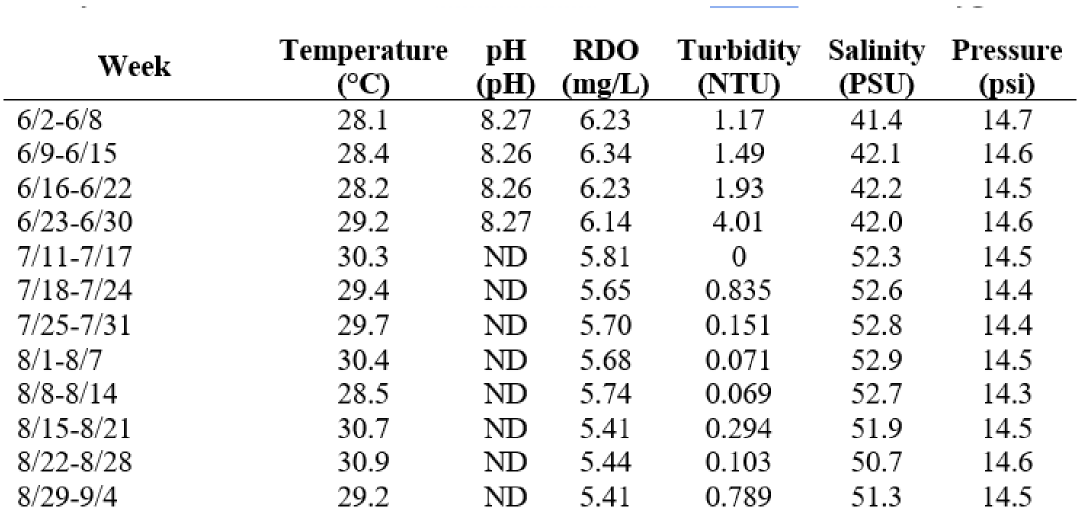
Table 105. Weekly averages for the abiotic conditions at reef site 1S from 2 June 2023 to 28 May 2024. RDO is relative dissolved oxygen.

Week	Temperature (°C)	pH (pH)	RDO (mg/L)	Turbidity (NTU)	Salinity (PSU)	Pressure (psi)
6/2 -6/8	28.2	8.23	6.15	0.985	38.6	7.57
6/9- 6/15	28.8	8.24	6.09	1.01	39.2	7.44
6/16- 6/22	28.6	8.26	6.14	1.62	39.5	7.35
6/23- 6/30	29.5	8.25	5.93	1.75	39.4	7.43
7/11- 7/17	31.4	8.25	3.61	1.88	39.2	7.44
7/18- 7/24	30.4	8.23	3.51	6.38	39.8	7.32
7/25- 7/31	30.7	8.24	3.42	38.1	39.6	7.31
8/1- 8/7	30.7	8.28	3.61	102	39.9	7.45
8/8- 8/14	30.5	8.30	3.78	103	40.1	7.21
8/15- 8/21	30.8	8.29	3.31	77.5	39.3	7.40
8/22- 8/28	31.0	8.32	3.49	86.4	38.0	7.54
8/29- 9/4	29.5	8.34	3.59	87.1	38.3	7.40
9/5- 9/11	30.3	8.36	3.57	204	38.8	7.49
9/12- 9/18	30.9	8.30	3.59	117	38.2	7.48
9/19- 9/25	30.6	8.31	3.37	151	36.9	7.63
9/26- 10/2	30.1	8.31	3.37	286	34.2	7.76
10/3- 10/9	29.8	8.34	3.34	650	30.8	7.83
10/10- 10/16	29.7	8.38	3.52	534	34.0	7.70
10/17- 10/23	28.1	8.45	3.96	264	33.3	7.75
10/24 - 10/30	27.1	8.42	3.84	396	33.3	7.88
10/31-11/6	27.0	8.45	3.90	323	34.5	7.90
11/7- 11/13	27.2	8.28	3.85	2691	38.1	7.80
11/14- 11/20	26.6	6.70	3.62	1742	38.0	7.71
11/21- 11/27	26.8	6.34	3.59	769	38.2	7.70
11/28- 12/4	25.8	8.15	3.97	289	35.1	7.60
12/5- 12/11	25.0	8.41	4.68	251	26.9	7.54
12/12- 12/18	23.8	8.40	5.11	250	24.8	7.63
12/19- 12/25	24.0	8.44	4.36	46.0	32.0	7.70

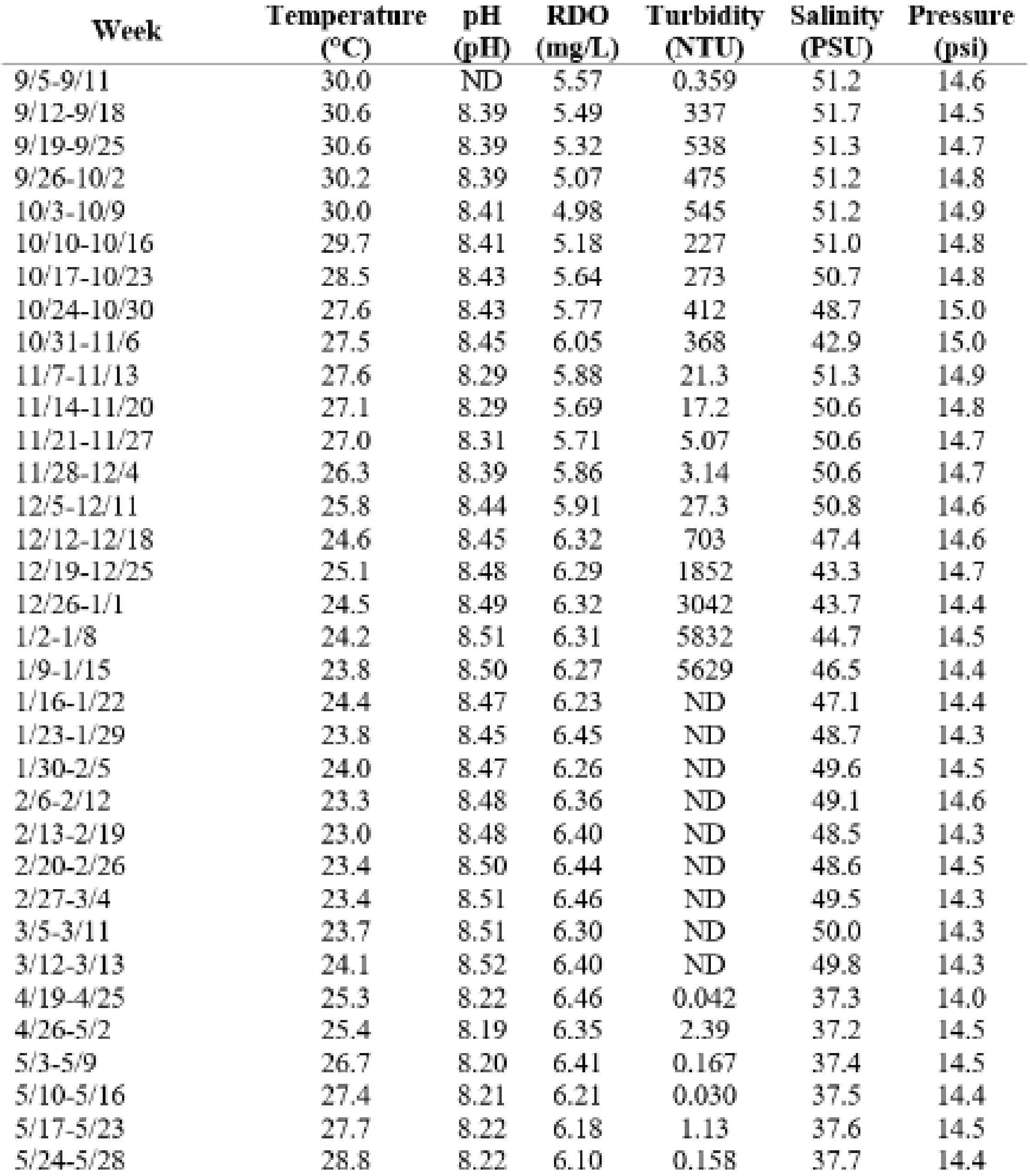


Week	Temperature (°C)	pH (pH)	RDO (mg/L)	Turbidity (NTU)	Salinity (PSU)	Pressure (psi)
12/26- 1/1	23.6	8.46	4.62	60.3	30.3	7.48
1/2- 1/8	23.4	8.47	4.62	33.7	29.7	7.51
1/9- 1/15	23.4	8.45	4.88	116	27.1	7.43
1/16- 1/22	23.9	8.45	4.86	118	48.1	7.41
1/23- 1/29	22.9	8.46	5.46	303	70.2	7.31
1/30- 2/5	22.9	8.49	5.38	1038	68.9	7.46
2/6- 2/12	22.6	8.49	5.91	861	51.4	7.59
2/13- 2/19	23.0	8.50	5.09	327	76.3	7.32
2/20- 2/26	22.6	8.53	5.30	172	74.6	7.49
2/27- 3/4	23.4	8.53	5.27	458	73.6	7.35
3/5- 3/11	24.2	8.54	5.17	458	71.2	7.33
3/12 - 3/18	24.8	8.52	4.40	216	100.1	7.33
3/19- 3/25	24.2	8.54	3.99	186	114	7.49
3/26- 4/1	24.6	8.57	4.19	1496	112	7.50
4/2- 4/8	24.6	8.61	4.60	1081	99.5	7.42
4/9- 4/12	24.4	8.60	3.35	75.3	109	7.44
4/19-4/25	25.7	8.23	6.87	0.390	37.7	6.97
4/26-5/2	25.4	8.19	6.84	3.38	37.5	7.27
5/3-5/9	27.1	8.19	6.74	1.53	37.6	7.61
5/10-5/16	28.1	8.23	6.48	2.03	37.9	7.55
5/17-5/23	28.4	8.25	6.48	5.19	38.1	7.70
5/24-5/28	29.5	8.23	6.42	4.70	35.4	7.73

Table 106. Weekly averages for the abiotic conditions at reef site 2S from 2 June 2023 to 28 May 2024. ND indicates no data was collected. RDO is relative dissolved oxygen.

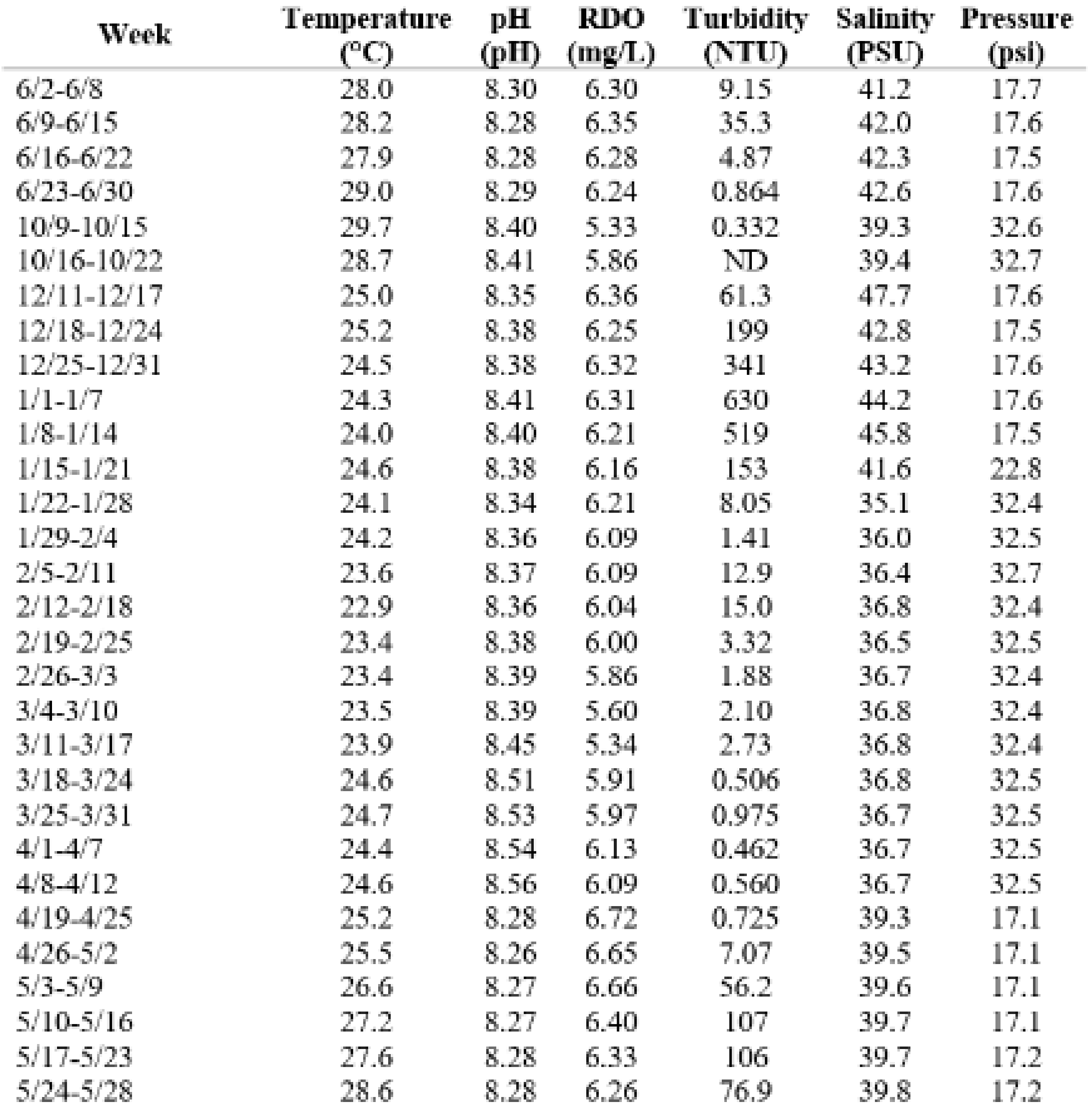


Week	Temperature (°C)	pH (pH)	RDO (mg/L)	Turbidity (NTU)	Salinity (PSU)	Pressure (psi)
6/2-6/8	28.1	8.27	6.23	1.17	41.4	14.7
6/9-6/15	28.4	8.26	6.34	1.49	42.1	14.6
6/16-6/22	28.2	8.26	6.23	1.93	42.2	14.5
6/23-6/30	29.2	8.27	6.14	4.01	42.0	14.6
7/11-7/17	30.3	ND	5.81	0	52.3	14.5
7/18-7/24	29.4	ND	5.65	0.835	52.6	14.4
7/25-7/31	29.7	ND	5.70	0.151	52.8	14.4
8/1-8/7	30.4	ND	5.68	0.071	52.9	14.5
8/8-8/14	28.5	ND	5.74	0.069	52.7	14.3
8/15-8/21	30.7	ND	5.41	0.294	51.9	14.5
8/22-8/28	30.9	ND	5.44	0.103	50.7	14.6
8/29-9/4	29.2	ND	5.41	0.789	51.3	14.5



Week	Temperature (°C)	pH (pH)	RDO (mg/L)	Turbidity (NTU)	Salinity (PSU)	Pressure (psi)
9/5-9/11	30.0	ND	5.57	0.359	51.2	14.6
9/12-9/18	30.6	8.39	5.49	337	51.7	14.5
9/19-9/25	30.6	8.39	5.32	538	51.3	14.7
9/26-10/2	30.2	8.39	5.07	475	51.2	14.8
10/3-10/9	30.0	8.41	4.98	545	51.2	14.9
10/10-10/16	29.7	8.41	5.18	227	51.0	14.8
10/17-10/23	28.5	8.43	5.64	273	50.7	14.8
10/24-10/30	27.6	8.43	5.77	412	48.7	15.0
10/31-11/6	27.5	8.45	6.05	368	42.9	15.0
11/7-11/13	27.6	8.29	5.88	21.3	51.3	14.9
11/14-11/20	27.1	8.29	5.69	17.2	50.6	14.8
11/21-11/27	27.0	8.31	5.71	5.07	50.6	14.7
11/28-12/4	26.3	8.39	5.86	3.14	50.6	14.7
12/5-12/11	25.8	8.44	5.91	27.3	50.8	14.6
12/12-12/18	24.6	8.45	6.32	703	47.4	14.6
12/19-12/25	25.1	8.48	6.29	1852	43.3	14.7
12/26-1/1	24.5	8.49	6.32	3042	43.7	14.4
1/2-1/8	24.2	8.51	6.31	5832	44.7	14.5
1/9-1/15	23.8	8.50	6.27	5629	46.5	14.4
1/16-1/22	24.4	8.47	6.23	ND	47.1	14.4
1/23-1/29	23.8	8.45	6.45	ND	48.7	14.3
1/30-2/5	24.0	8.47	6.26	ND	49.6	14.5
2/6-2/12	23.3	8.48	6.36	ND	49.1	14.6
2/13-2/19	23.0	8.48	6.40	ND	48.5	14.3
2/20-2/26	23.4	8.50	6.44	ND	48.6	14.5
2/27-3/4	23.4	8.51	6.46	ND	49.5	14.3
3/5-3/11	23.7	8.51	6.30	ND	50.0	14.3
3/12-3/13	24.1	8.52	6.40	ND	49.8	14.3
4/19-4/25	25.3	8.22	6.46	0.042	37.3	14.0
4/26-5/2	25.4	8.19	6.35	2.39	37.2	14.5
5/3-5/9	26.7	8.20	6.41	0.167	37.4	14.5
5/10-5/16	27.4	8.21	6.21	0.030	37.5	14.4
5/17-5/23	27.7	8.22	6.18	1.13	37.6	14.5
5/24-5/28	28.8	8.22	6.10	0.158	37.7	14.4

Table 107. Weekly averages for the abiotic conditions at reef site 3S from 2 June 2023 to 28 May 2024. ND indicates no data was collected. RDO is relative dissolved oxygen.



Week	Temperature (°C)	pH (pH)	RDO (mg/L)	Turbidity (NTU)	Salinity (PSU)	Pressure (psi)
6/2-6/8	28.0	8.30	6.30	9.15	41.2	17.7
6/9-6/15	28.2	8.28	6.35	35.3	42.0	17.6
6/16-6/22	27.9	8.28	6.28	4.87	42.3	17.5
6/23-6/30	29.0	8.29	6.24	0.864	42.6	17.6
10/9-10/15	29.7	8.40	5.33	0.332	39.3	32.6
10/16-10/22	28.7	8.41	5.86	ND	39.4	32.7
12/11-12/17	25.0	8.35	6.36	61.3	47.7	17.6
12/18-12/24	25.2	8.38	6.25	199	42.8	17.5
12/25-12/31	24.5	8.38	6.32	341	43.2	17.6
1/1-1/7	24.3	8.41	6.31	630	44.2	17.6
1/8-1/14	24.0	8.40	6.21	519	45.8	17.5
1/15-1/21	24.6	8.38	6.16	153	41.6	22.8
1/22-1/28	24.1	8.34	6.21	8.05	35.1	32.4
1/29-2/4	24.2	8.36	6.09	1.41	36.0	32.5
2/5-2/11	23.6	8.37	6.09	12.9	36.4	32.7
2/12-2/18	22.9	8.36	6.04	15.0	36.8	32.4
2/19-2/25	23.4	8.38	6.00	3.32	36.5	32.5
2/26-3/3	23.4	8.39	5.86	1.88	36.7	32.4
3/4-3/10	23.5	8.39	5.60	2.10	36.8	32.4
3/11-3/17	23.9	8.45	5.34	2.73	36.8	32.4
3/18-3/24	24.6	8.51	5.91	0.506	36.8	32.5
3/25-3/31	24.7	8.53	5.97	0.975	36.7	32.5
4/1-4/7	24.4	8.54	6.13	0.462	36.7	32.5
4/8-4/12	24.6	8.56	6.09	0.560	36.7	32.5
4/19-4/25	25.2	8.28	6.72	0.725	39.3	17.1
4/26-5/2	25.5	8.26	6.65	7.07	39.5	17.1
5/3-5/9	26.6	8.27	6.66	56.2	39.6	17.1
5/10-5/16	27.2	8.27	6.40	107	39.7	17.1
5/17-5/23	27.6	8.28	6.33	106	39.7	17.2
5/24-5/28	28.6	8.28	6.26	76.9	39.8	17.2

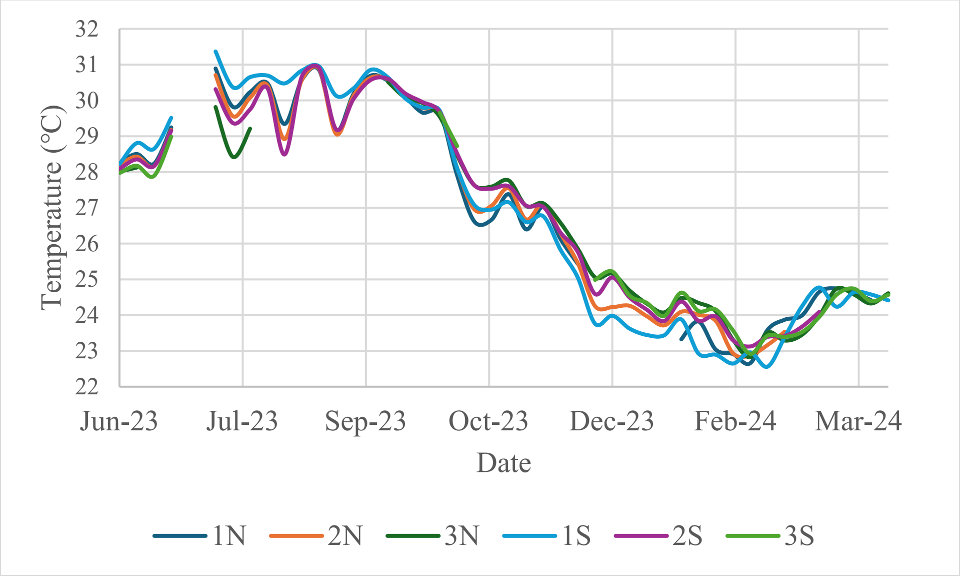


Figure 8. Weekly average temperature (°C) at the six reef sites (1N, 2N, 3N, 1S, 2S, and 3S).

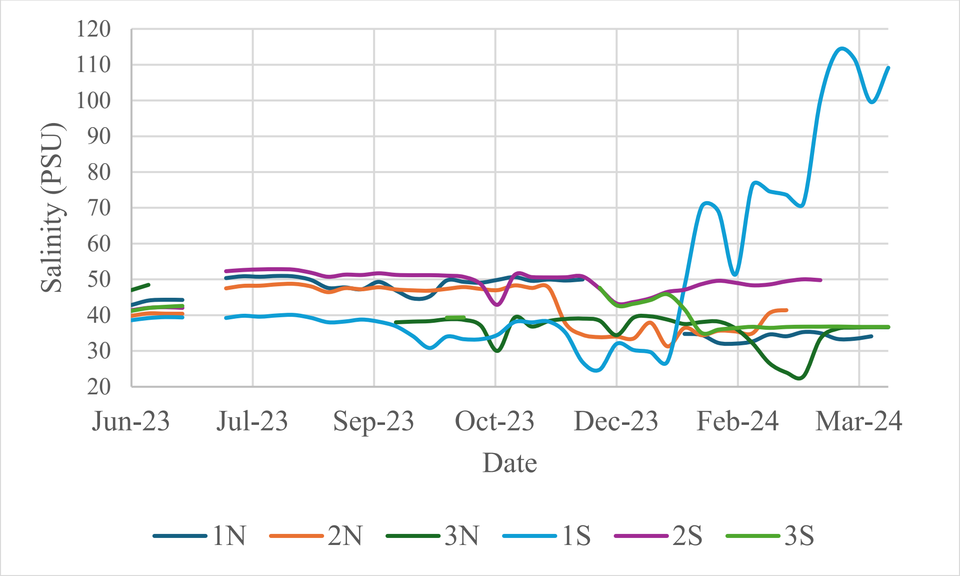


Figure 9. Weekly average salinity (psu) for the six reef sites (1N, 2N, 3N, 1S, 2S, and 3S).

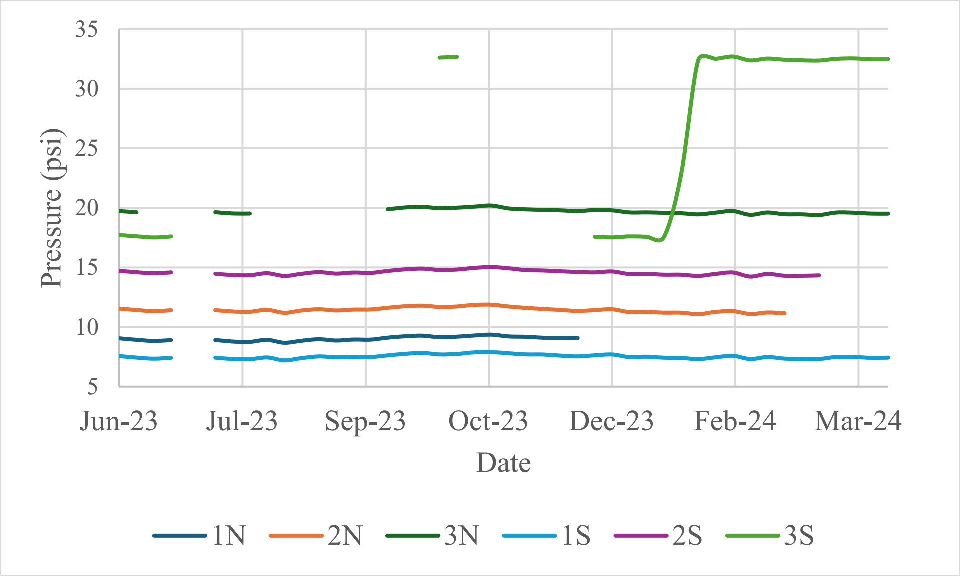


Figure 10. Weekly average pressures (psi) for the six reef sites (1N, 2N, 3N, 1S, 2S, and 3S).

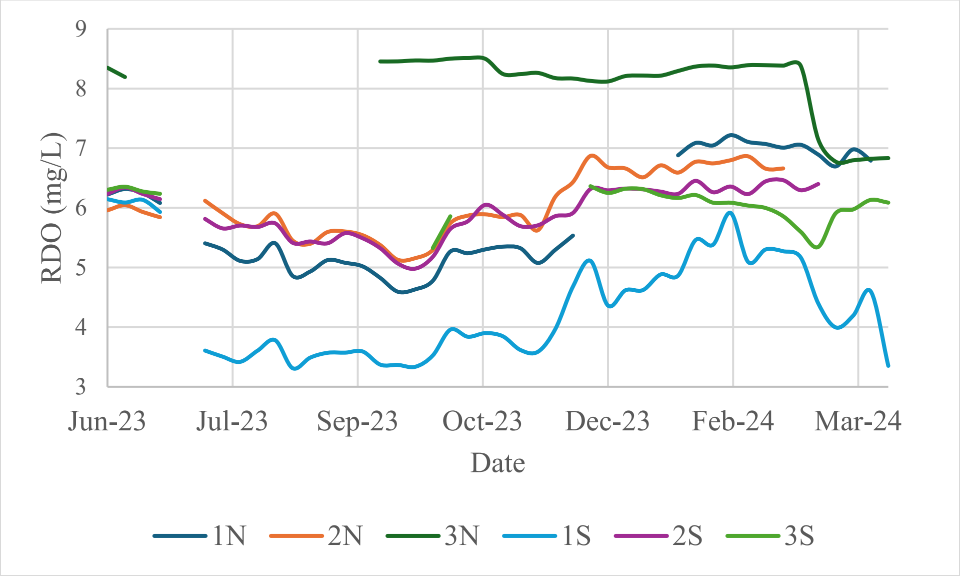


Figure 11. Weekly average relative dissolved oxygen (RDO) (mg/L) at the six reef sites (1N, 2N, 3N, 1S, 2S, and 3S).

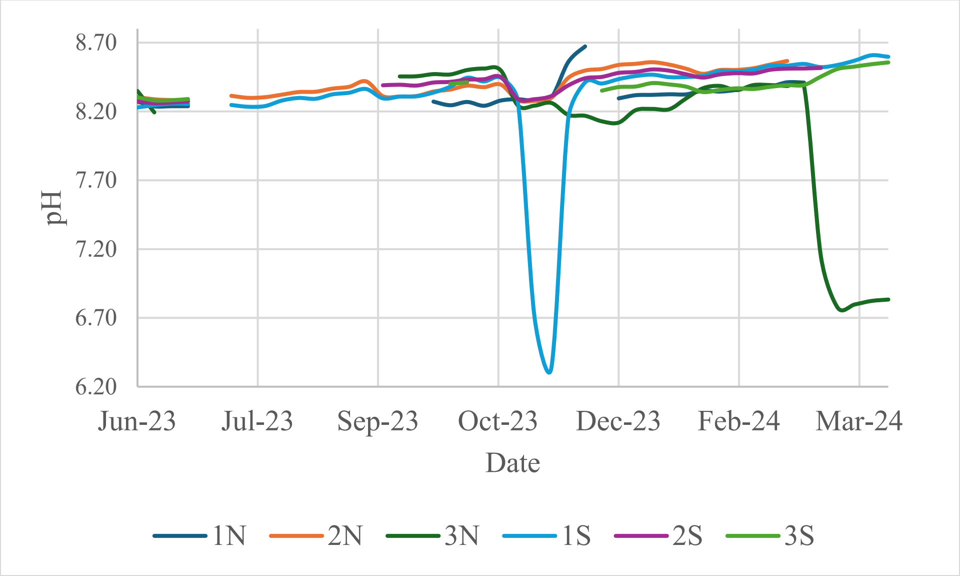


Figure 12. Weekly average pH at the six reef sites (1N, 2N, 3N, 1S, 2S, and 3S).

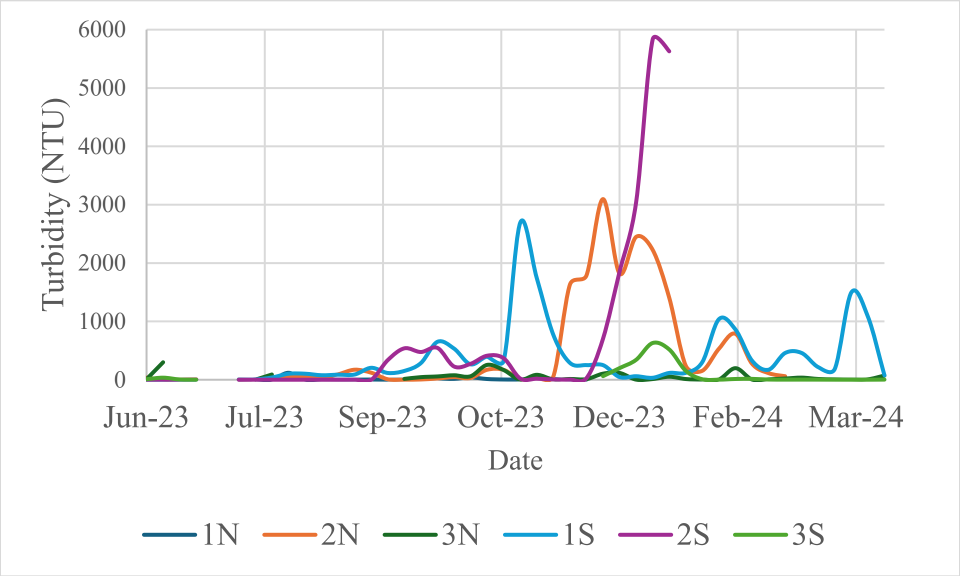


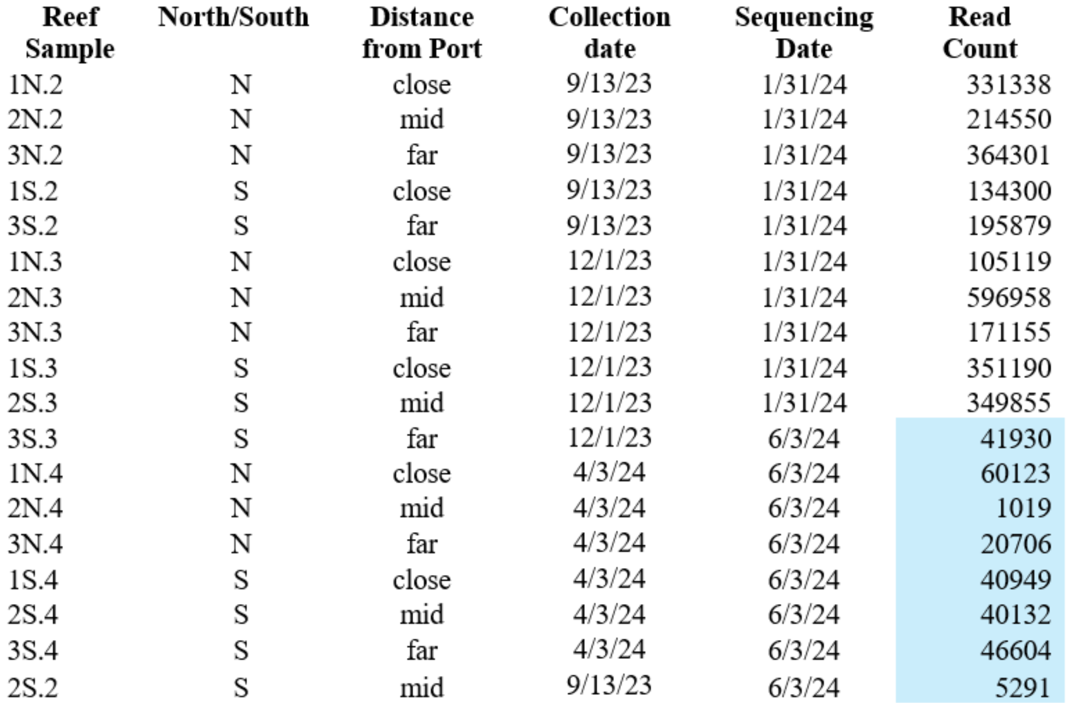
Figure 13. Weekly average turbidity (NTU) at the six reef sites (1N, 2N, 3N, 1S, 2S, and 3S).

3.15 Microbiome Analyses with the standard 16S rRNA gene marker

Our Microbiology and Molecular Genomics Laboratory (MMG) has essentially completed all the sequencing and analyses of the 16S rRNA gene amplicon libraries as indicated in the FDEP scope of work. As a reminder, 16S rRNA microbiomes focus only a single gene for taxonomic identifications, whereas "metagenomics" approaches conduct a deeper sequencing approach to capture larger swaths of bacterial genomes. This section encompasses and describes 16S analyses of the 18 sediment samples collected in this project. All of the raw 16S rRNA sequence data generated in the form of FASTQ files is shared with FL DEP via secure repositories (eg.Dropbox, Box or Google drives).

All samples prepared for microbiome sequencing with their respective ID numbers, and sequence reads are listed in Table 108. As can be seen the first listed ten samples in the table (1N.2, 2N.2 3N.2, 1S.2, 3S.2, 1N.3, 2N.3, 3N.3, 1S.3, 2S.3) yielded sufficient numbers of sequence reads. Typically, over 10,000 reads for sediment samples can be sufficient. Eight problematic samples are highlighted in blue, provided low reads and are labeled as 1N.4, 2N.4, 3N.4, 1S.4, 2S.4, 3S.4, 2S.2. We have made three separate attempts to sequence these last eight samples in the MMG laboratory and this data was the best run.

Table 108. Yield of sediment samples used in 16S Microbiome sequencing from the six coral reef sites (1N, 2N, 3N, 1S, 2S, and 3S). The last ten shaded samples encompass problems encountered during sequences, as indicated by the lower read amounts.



Reef Sample	North/South	Distance from Port	Collection date	Sequencing Date	Read Count
1N.2	N	close	9/13/23	1/31/24	331338
2N.2	N	mid	9/13/23	1/31/24	214550
3N.2	N	far	9/13/23	1/31/24	364301
1S.2	S	close	9/13/23	1/31/24	134300
3S.2	S	far	9/13/23	1/31/24	195879
1N.3	N	close	12/1/23	1/31/24	105119
2N.3	N	mid	12/1/23	1/31/24	596958
3N.3	N	far	12/1/23	1/31/24	171155
1S.3	S	close	12/1/23	1/31/24	351190
2S.3	S	mid	12/1/23	1/31/24	349855
3S.3	S	far	12/1/23	6/3/24	41930
1N.4	N	close	4/3/24	6/3/24	60123
2N.4	N	mid	4/3/24	6/3/24	1019
3N.4	N	far	4/3/24	6/3/24	20706
1S.4	S	close	4/3/24	6/3/24	40949
2S.4	S	mid	4/3/24	6/3/24	40132
3S.4	S	far	4/3/24	6/3/24	46604
2S.2	S	mid	9/13/23	6/3/24	5291

The first ten sediment samples were processed earlier in 2024 and reported in the April deliverables report. These are labeled with the ".2 or .3" sample suffix. The quality of the sequence data was high for these and thus provided more reliable results. Since that time, the last eight sediment samples have been more problematic. After multiple attempts to sequence these samples, including straggling samples "2S.2 and 3S.3", sequence reads remained low (Table 108). We have no clear explanation for this other than possible inhibitors found in these samples. Nonetheless full comprehensive analyses could not be completed at this time. All samples did provide taxonomic assignments, and the last eight samples likely included the same taxa as the larger datasets, but some taxa could also be missing. These ten samples were problematic for unknown reasons, but after sending to CosmosID, we were finally able to obtain sufficient reads, except for 2N.4 (Table 108). The CosmosID effort was taken up after 3 attempts by our lab to sequence these samples. It should be noted that read quality was less than ideal, and most of the reads were filtered out during denoising; one sample, 2N.4, still had reads of 1019. Nonetheless merging of all datasets for final analyses supported our consensus conclusions (see below). Relative abundances may not also match the larger read datasets. Taxonomic assignments are shown for all 18 samples provided in the Excel tables named "taxonomy_013124.csv and taxonomy_060324.csv". Note that the latter samples contain the last eight samples and are highlighted in blue.
Full integration and analysis of the metagenomics data with chemistry has been completed as per the statistical analyses shown in section 3.6. Methods and approaches for 16S microbiomes analyses are conducted similar to previous studies (FL DEP CRCP 13; Krausfeldt and Lopez et al, 2023).

Stacked bar charts of 16S data provide one aspect of alpha diversity via relative abundances of the most common taxa in a sample. The comparisons by stacked bar charts are shown in Figures 14 – 16.

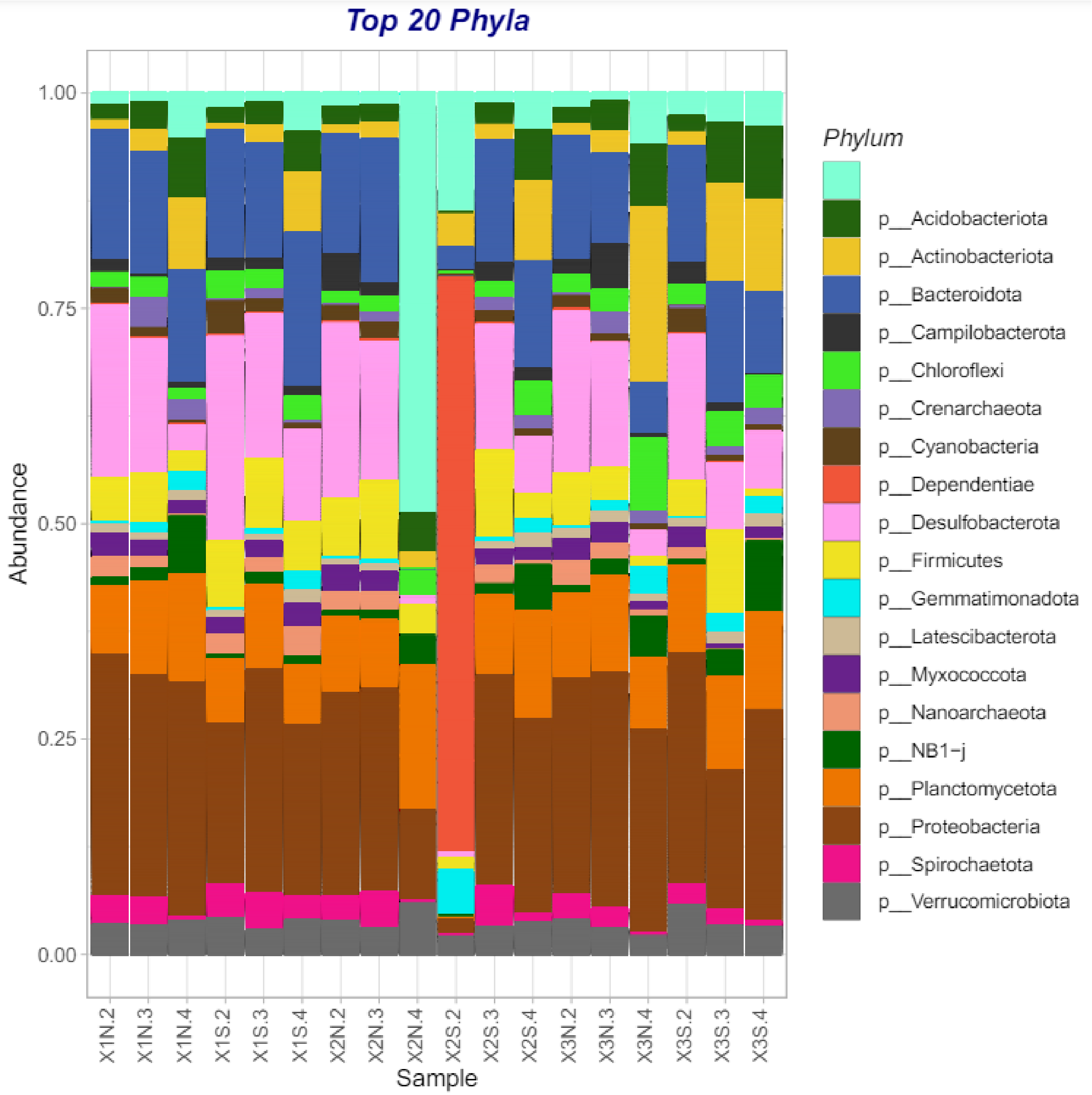


Figure 14. Top 20 Phyla of the 18 sediment trap samples in Table 108 collected 9/13/23, 12/1/23 and 4/3/24 from reef (1N.2, 2N.2 3N.2, 1S.2, 3S.2, 1N.3, 2N.3, 3N.3, 1S.3, 2S.3). (Please disregard the ”X,” which was used for annotation and programming).

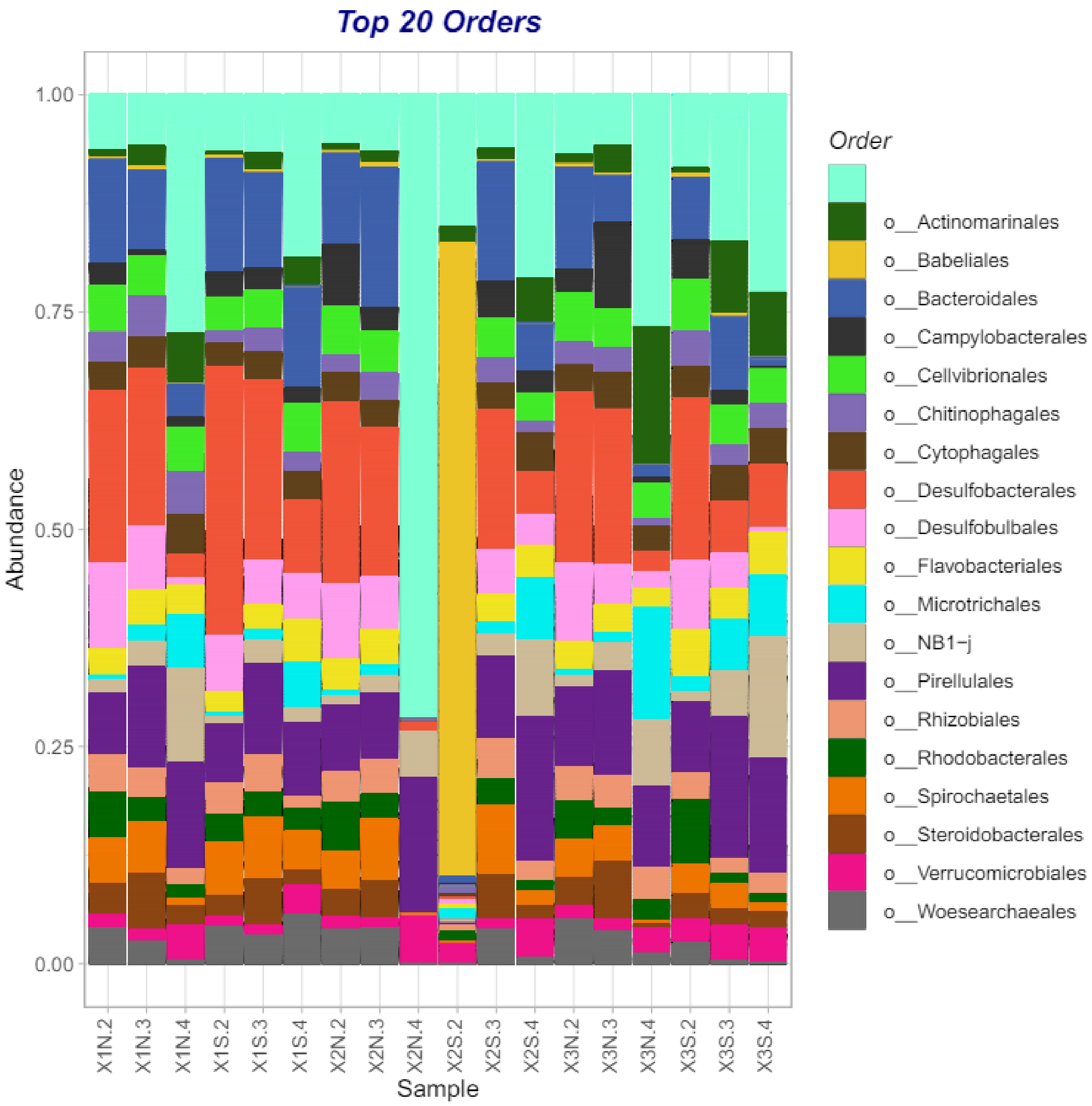


Figure 15. Top 20 Orders of the 18 sediment trap samples listed in Table 108 collected 9/13/23, 12/1/23, and 4/3/24 and generated high yield of 16S rRNA sequences.

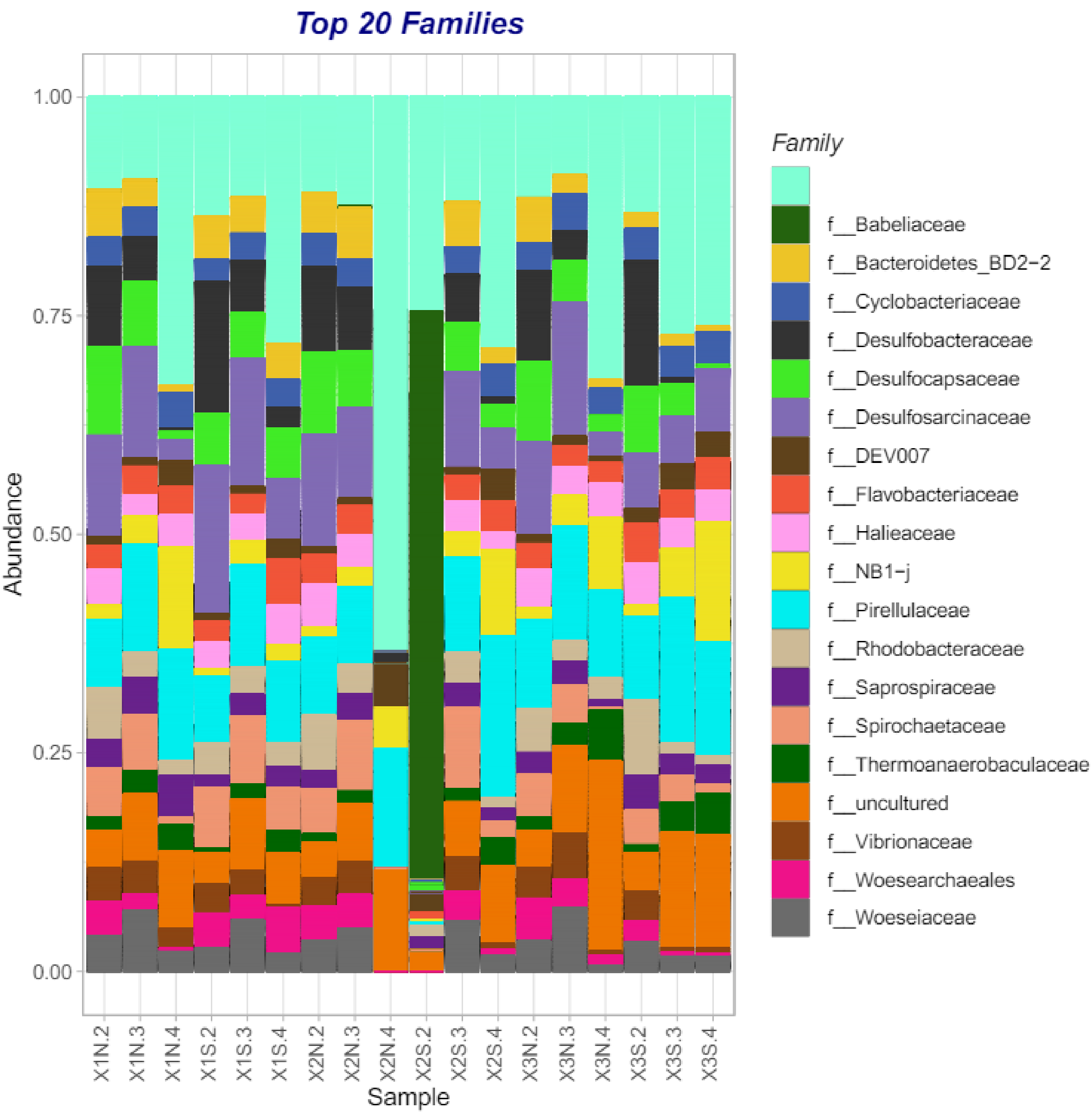


Figure 16. Top 20 families of the 18 coral reef sediment samples listed in Table 108.

In most of the reef samples, we see a predominance of Proteobacteria and Desulfobacteria. Major Proteobacterial orders include Pirellulales, Rhizobiales, Rhodobacteriales and Vibrionales. These occur at slightly different relative abundances, which probably reflects the smaller sequence read numbers for the last set of samples. In addition, samples 2S.2 and 2N.4 had a different composition from the other samples. For 2N.4, this was likely the result of the low read count obtained by CosmosID. For 2S.2, which had a high abundance of Dependentiae not found in any other sample, this may be the result of contamination.

Alpha diversity was also compared between the north reef (N) and south reef (S) samples, the relative distance from the Port, and the sequencing run the samples were on. Figures 17 through 19 provide boxplots of alpha diversity from the 18 sediment trap samples. The significant differences in diversity between N (1N, 2N, and 3N) and S (1S, 2S, and 3S) reef sites found in the latest samples most probably reflect the lower coverage of reads.

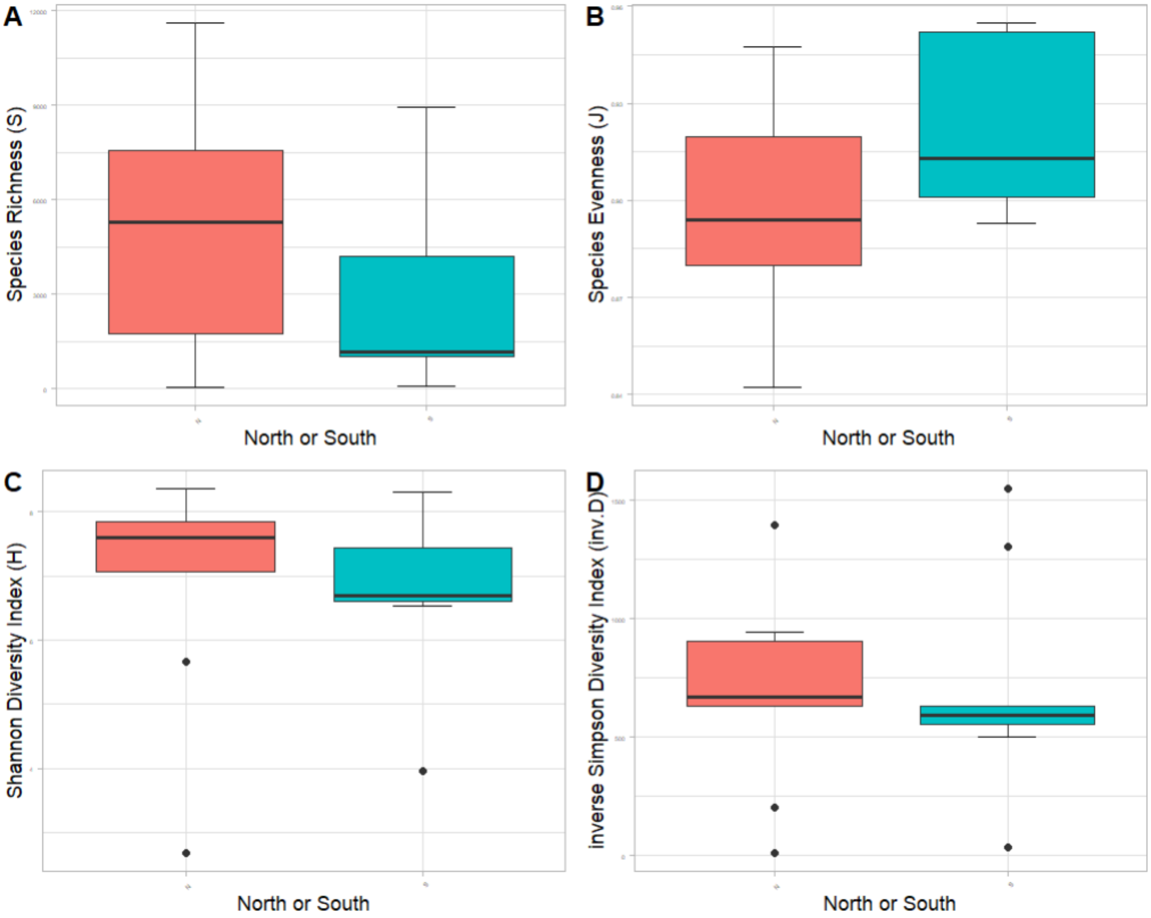


Figure 17. Alpha diversity of microbiomes in the North reef (1N, 2N, and 3N) and South reef (1S, 2S, and 3S) sediment represented by A) Species Richness, B) Species Evenness, C) Shannon Diversity and D) Inverse Simpson Indices from the 18 reef sediment samples.

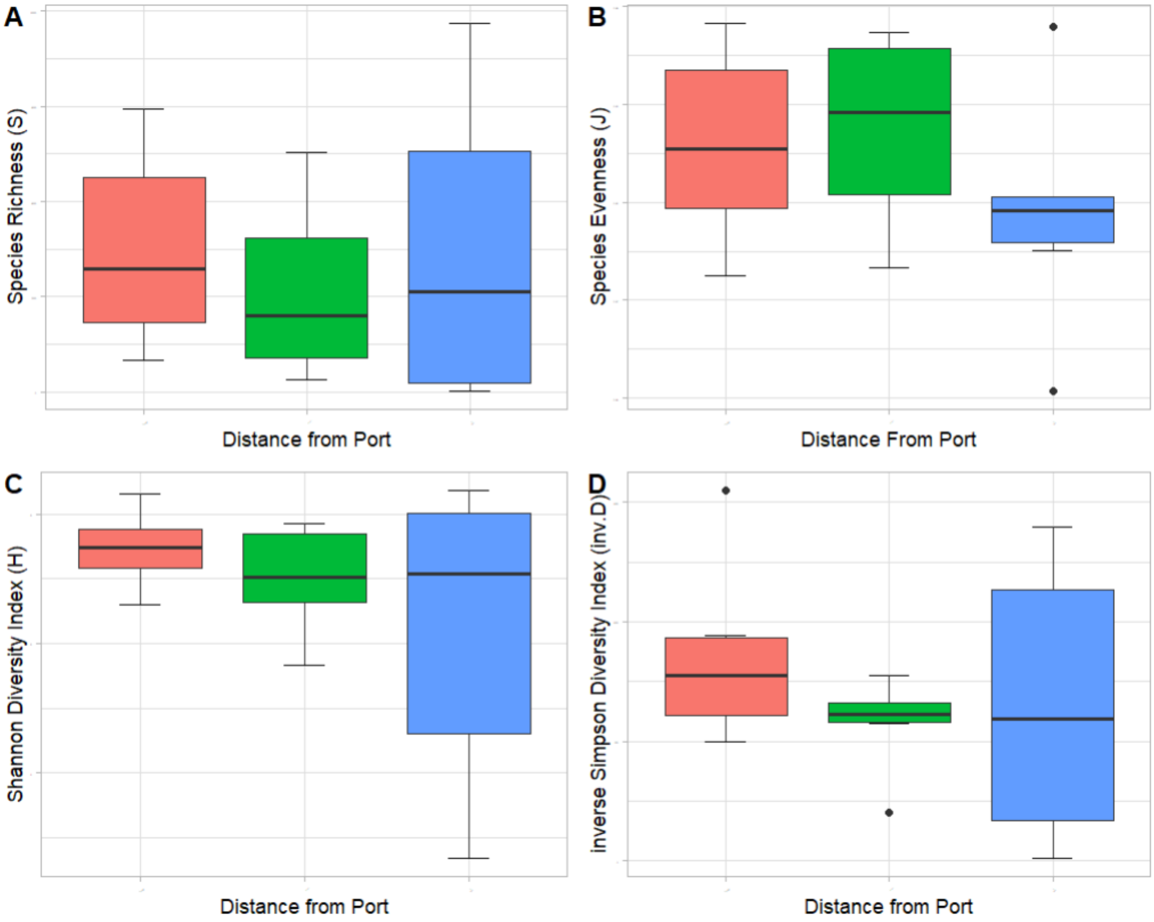


Figure 18. Alpha diversity of microbiomes in the reef closest to the port (1N and 1S, red), mid-distance from the port (2N and 2S, blue), and furthest from the port (3N and 3S, green) represented by A) Species Richness, B) Species Evenness, C) Shannon Diversity and D) Inverse Simpson Indices. None of the mean differences were significant.

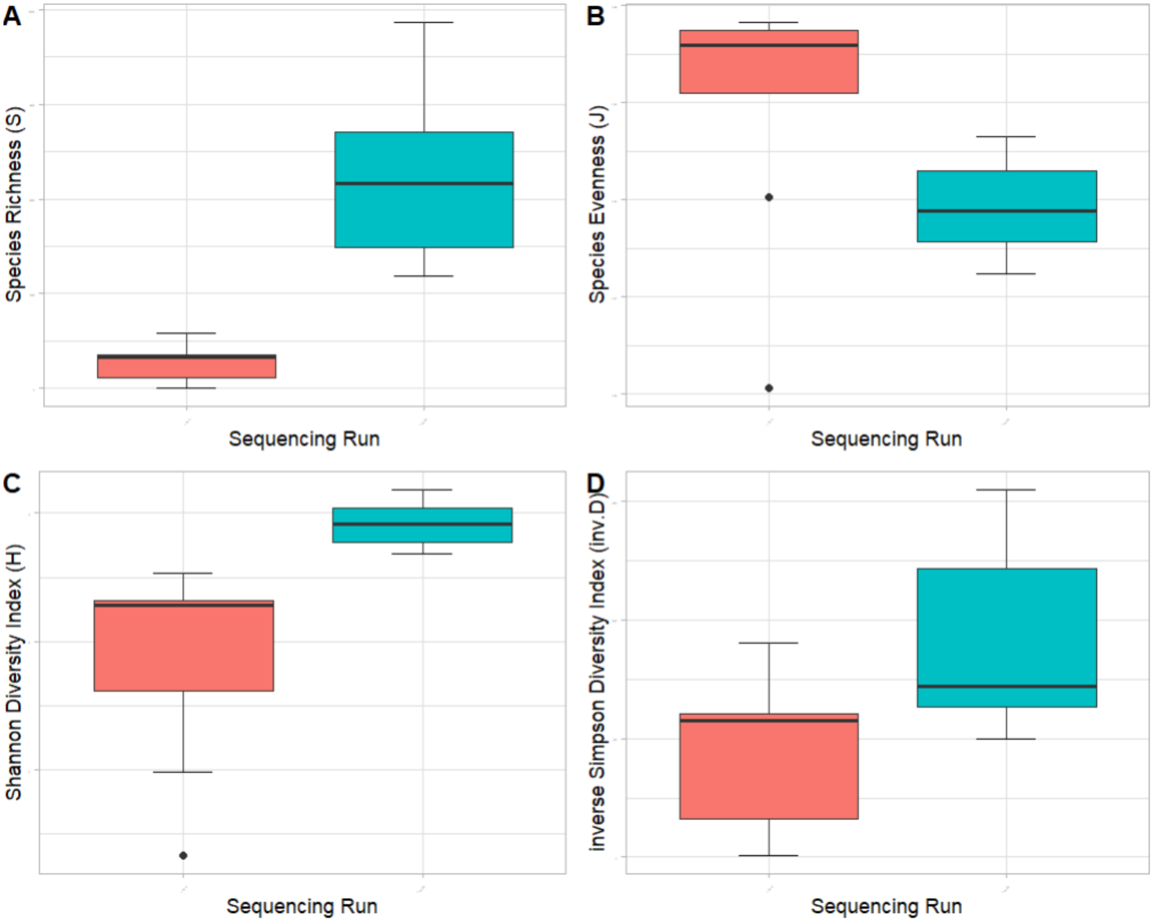


Figure 19. Alpha diversity of microbiomes based on the sequencing run (Cosmos red; Lopez Lab, blue), represented by A) Species Richness, B) Species Evenness, C) Shannon Diversity and D) Inverse Simpson Indices from the 10 sediment samples based on high yield 16S rRNA data. All differences were statistically significant.

Cluster analyses through non-metric dimensional scaling (nMDS) provided visualizations of beta diversity of sediment microbial taxa and was applied on the 16S rRNA gene data (Fig. 20-21). Each point on the plot represents the taxonomic composition of the bacteria based on 16S rRNA in the sample relative to all other samples in the dataset. Clustering of 10 reef sediments by collection date (September vs December) appears evident in the nMDS of Figure 20, but not by north-south position (Fig. 21). We have not yet integrated the March 2024 sediment data, but its N vs. S plot in Figure 21 also does not have any significant clustering. This probably stems from the close proximity of sites to each other as well as the shallow surface grabs.

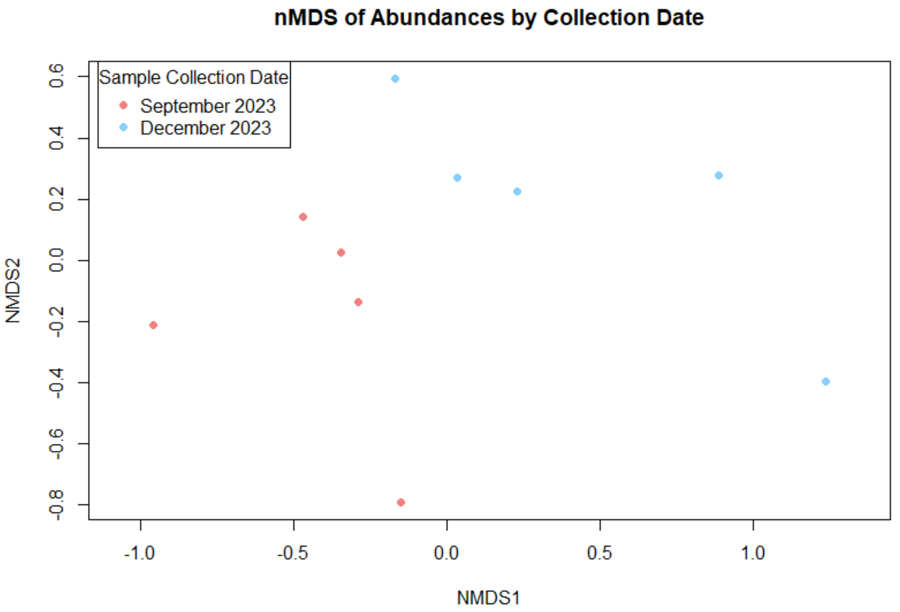


Figure 20. NMDS plot of first 10 sediment samples (1N.2, 2N.2 3N.2, 1S.2, 3S.2, 1N.3, 2N.3, 3N.3, 1S.3, 2S.3) grouped by date. These were collected 9/13/23 and 12/01/23 and generated high yield of 16S rRNA sequences.

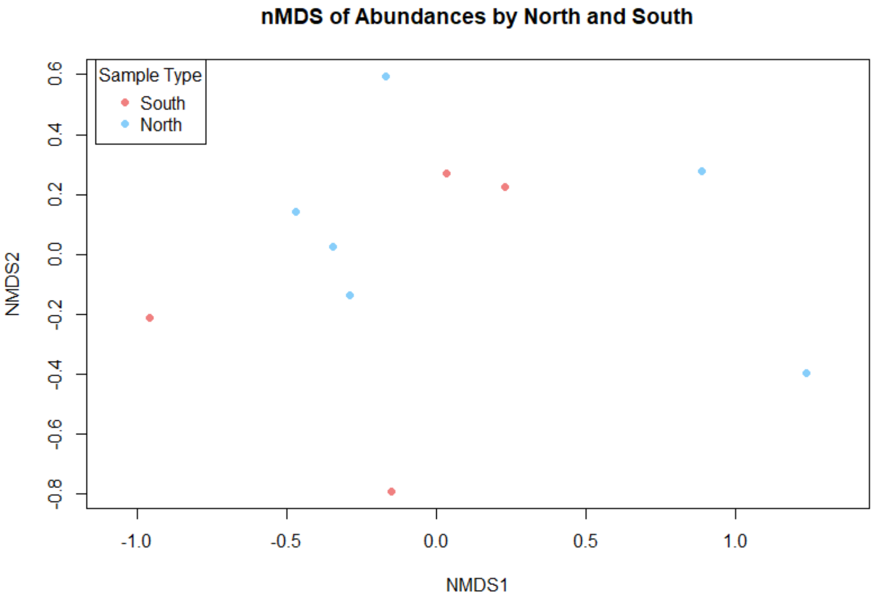


Figure 21. NMDS plot of first 10 sediment samples (1N.2, 2N.2 3N.2, 1S.2, 3S.2, 1N.3, 2N.3, 3N.3, 1S.3, 2S.) shown in Figure 20 and Table 108 grouped by reef site.

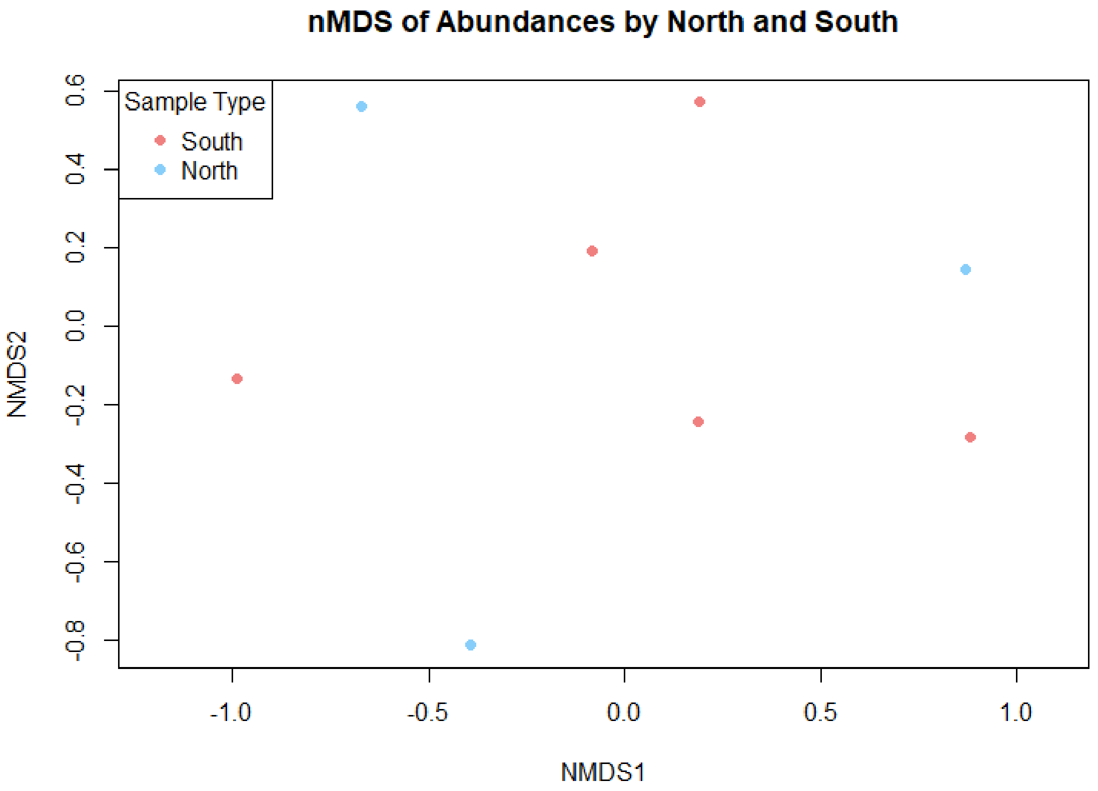


Figure 22. NMDS plot of 8 sediment samples collected in April 2024 from coral reef sites (1N.4, 2N.4, 3N.4, 1S.4, 2S.4, 3S.4, 2S.2) but yielded low sequence reads indicated in Table 108.

3.16 Metagenomics Analyses with deep sequencing

As part of this project, metagenomics analysis was carried out on both a) core sediments collected in Phase I and b) the 18 reef sediment obtained from the traps in this project (Sept 2023/Dec 2023 and March 2024), since broader sequencing goes beyond a single gene analyses of community diversity such as 16S rRNA gene markers. There is consensus that inclusion of broader sequences will provide more information on function and taxonomic identities. The metagenomics dataset sequenced by CosmosID has the dataset ID of “CP04992”.

As mentioned above, some of the taxonomic data derived from metagenomics has already been presented in the statistical analysis of microbial communities with heavy metals in Section 3.6.

Examples of raw metagenomics data are available in the spreadsheets and folders uploaded to the final report folder. These include metagenomics analyses for bacteria, viruses, protists, fungi and combined analyses. At this point, raw sequence data transfer for n = 47 samples has not been finalized since this is over 350 GB. This data has been delivered to FL DEP via electronic transfers. Raw sequence is typically not deposited into a public database such as NCBI until the principal investigators have had a chance to fully analyze the data.

Metagenomics can provide taxonomic data and relative composition of microbial communities but with different genes compared to 16S rRNA. This can be exemplified via a heatmap (Fig. 23), which includes all the core samples from phase I and five reef sediment traps at the far right.

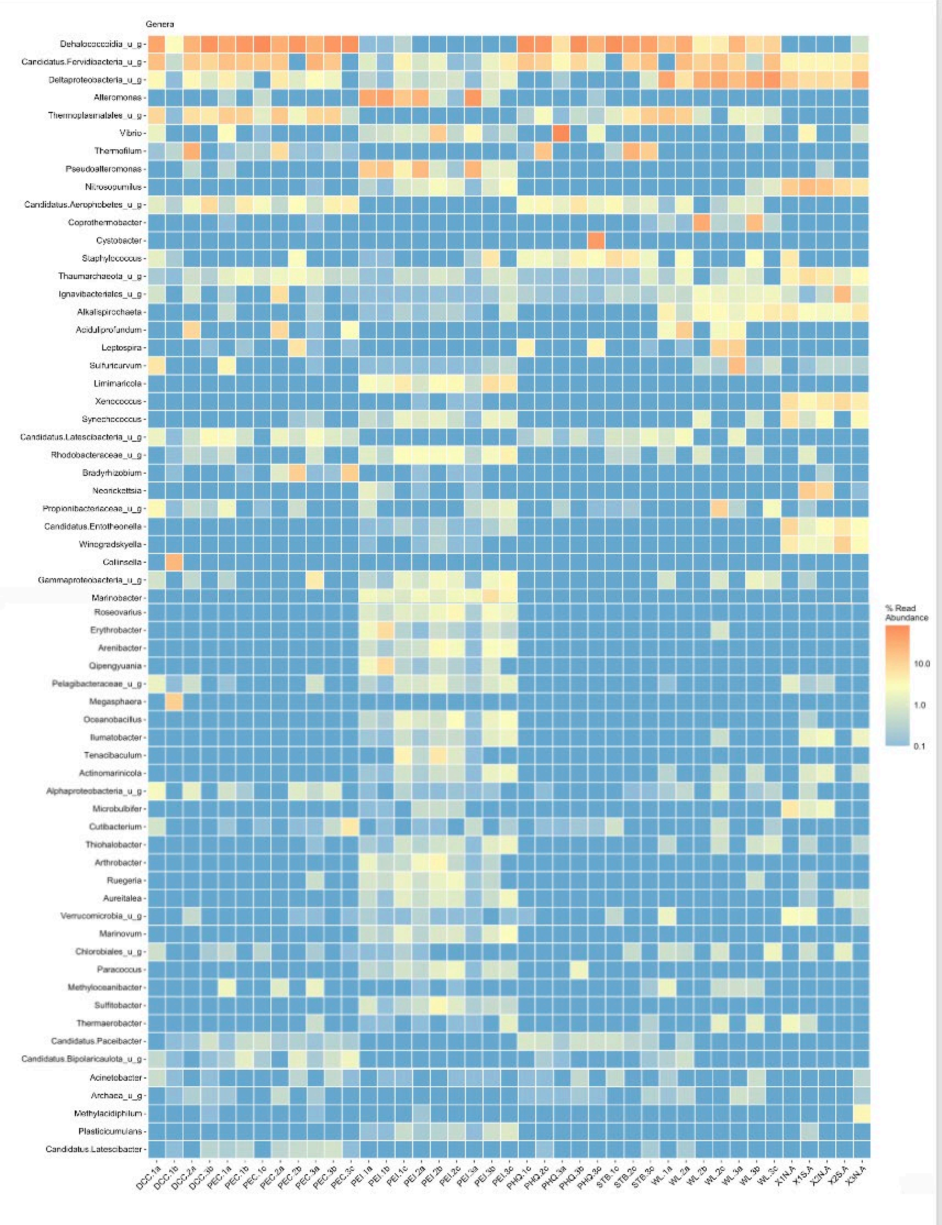


Figure 23. Heatmap of Phase I port sediment core samples and Phase II reef sediment samples based on metagenomics data.

Alpha diversity metrics were applied to the metagenomic data similar to 16S rRNA data (Fig. 18 -19). It should be noted that the alpha diversity analyses of metagenomics data should be more robust than the 16S rRNA data due to more sequences and the inclusion of all samples (Phase I core and Phase II reef sediment from traps) in the box plots (Figure 24). The means of both evenness and the Shannon Index highlight the similarity of PEI and reef sediment microbial communities.

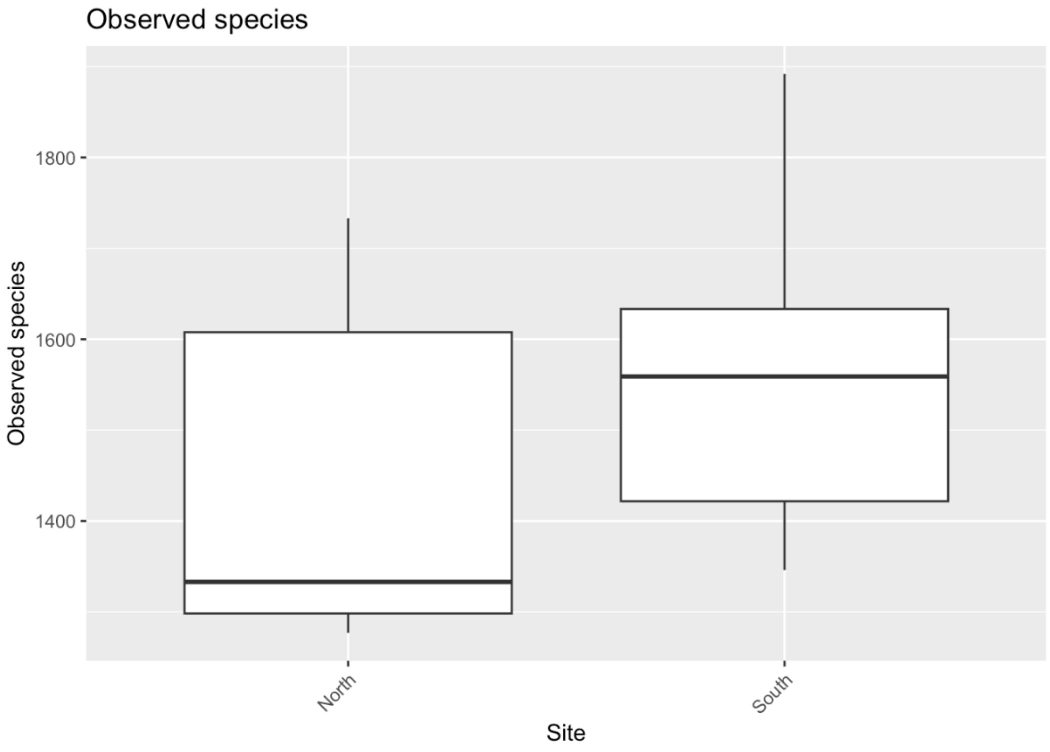


Figure. Functional diversity by site.

Figure 24. Box plots of alpha diversity metrics based on metagenomics data showing observed taxa from N or S reef sites.

In spite of these similarities, several individual taxa can be identified to differ between PEI and reef sediments (Table 109).

Table 109. Taxa that are differentially abundant in coral compared to port. Positive log2fold change means they are higher in abundance in coral and vice versa. Based on metagenomics.

Phylum	Order	Genus	log2fold
Actinobacteria	Acidimicrobiales	Actinomarinicola	4.741
Spirochaetes	Spirochaetales	Alkalispirochaeta	11.628
Proteobacteria	Myxococcales	Anaeromyxobacter	8.895
Bacteroidetes	Flavobacteriales	Aureitalea	3.885
Proteobacteria	Betaproteobacteria_u_o	Candidatus.Accumulibacter	4.253
Candidatus Aerophobetes	Candidatus Aerophobetes_u_o	Candidatus.Aerophobetes_u_g	-7.071
Candidatus Aminicenantes	Candidatus Aminicenantes_u_o	Candidatus.Aminicenantes_u_g	-7.295
Candidatus Atribacteria	Candidatus Atribacteria_u_o	Candidatus.Atribacteria_u_g	-3.461
Candidatus Bipolaricaulota	Candidatus Bipolaricaulota_u_o	Candidatus.Bipolaricaulota_u_g	-5.732
Candidatus Tectomicrobia	Candidatus Tectomicrobia_u_o	Candidatus.Entotheonella	12.596
Candidatus Latescibacteria	Candidatus Latescibacteria_u_o	Candidatus.Latescibacter	-4.162
Candidatus Latescibacteria	Candidatus Latescibacteria_u_o	Candidatus.Latescibacteria_u_g	-5.206
Thaumarchaeota	Thaumarchaeota_u_o	Candidatus.Nitrosopelagicus	4.791
Candidatus Parcubacteria	Candidatus Parcubacteria_u_o	Candidatus.Paceibacter	-6.652
Chloroflexi	Dehalococcoidales	Dehalococcoides	-4.977
Chloroflexi	Dehalococcoidia_u_o	Dehalococcoidia_u_g	-14.733
Proteobacteria	Deltaproteobacteria_u_o	Deltaproteobacteria_u_g	9.281
Proteobacteria	Desulfovibrionales	Desulfomicrobium	4.447
Euryarchaeota	Euryarchaeota_u_o	Euryarchaeota_u_g	-4.792
Gemmatimonadetes	Gemmatimonadetes_u_o	Gemmatimonadetes_u_g	7.822
Proteobacteria	Hyphomonadales	Hyphomonas	2.198
Ignavibacteriae	Ignavibacteriales	Ignavibacteriales_u_g	5.057
Actinobacteria	Acidimicrobiales	Ilumatobacter	5.672
Proteobacteria	Rhodobacterales	Leisingera	3.365
Proteobacteria	Rhodospirillales	Magnetospirillum	2.730

Phylum	Order	Genus	log2fold
Candidatus Thermoplasmatota	Methanomassiliicoccales	Methanomassiliicoccus	-6.062
Proteobacteria	Cellvibrionales	Microbulbifer	6.808
Proteobacteria	Myxococcales	Myxococcaceae_u_g	3.618
Proteobacteria	Rickettsiales	Neorickettsia	8.262
Thaumarchaeota	Nitrosopumilales	Nitrosarchaeum	9.849
Thaumarchaeota	Nitrosopumilales	Nitrosopumilus	11.735
Proteobacteria	Thiotrichales	Piscirickettsia	10.104
Planctomycetes	Planctomycetes_u_o	Planctomycetes_u_g	2.807
Cyanobacteria	Pleurocapsales	Pleurocapsa	13.985
Proteobacteria	Rhodospirillales	Rhodospirillales_u_g	4.400
Proteobacteria	Rickettsiales	Rickettsiales_u_g	4.079
Cyanobacteria	Synechococcales	Synechococcus	6.351
Thaumarchaeota	Thaumarchaeota_u_o	Thaumarchaeota_u_g	5.130
Crenarchaeota	Thermoproteales	Thermofilum	-4.928
Candidatus Thermoplasmatota	Thermoplasmatales	Thermoplasmatales_u_g	-9.410
Proteobacteria	Chromatiales	Thioalkalivibrio	4.042
Proteobacteria	Rhodospirillales	Tistlia	5.511
Bacteroidetes	Flavobacteriales	Winogradskyella	12.081
Proteobacteria	Chromatiales	Woeseia	2.259
Cyanobacteria	Pleurocapsales	Xenococcus	16.069

PCoA plots show no clustering between N or S sites (Fig. 25).

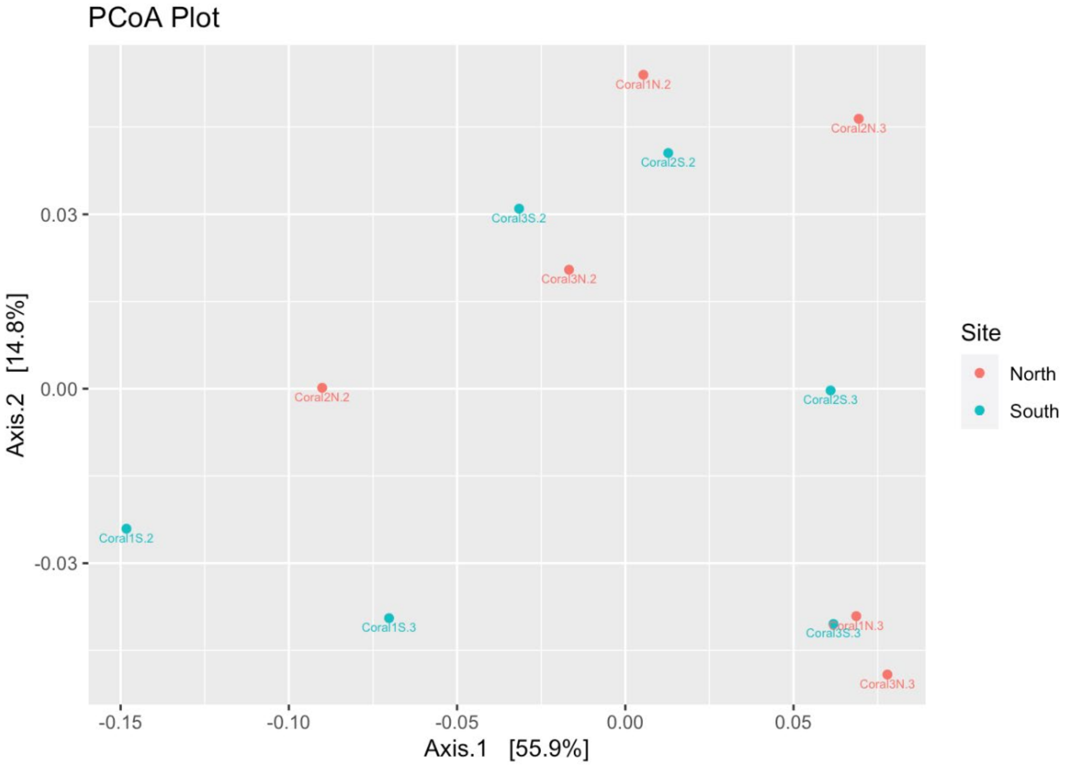


Figure. PCoA showing functional composition between coral sites.

Figure 25. Principles Component Analysis plot of twelve sediment trap samples according to site collected September and December 2023 (see Table 108).

3.17 Coral Arsenic Dosing and Acute Effects

3.17.1. Arsenate (As (V)) exposure with *Acropora cervicornis*:

Arsenate chemistry: The measured concentrations of each tested arsenic species at T0 and T24 for each nominal treatment concentration are provided as processed data.

Acute toxicity thresholds: Log-logistic 4-parameter dose-response models are used to estimate threshold concentrations for mortality (LC50), physical effect (EC50, based on coral condition scores), and inhibition of photosynthetic efficiency (IC50, based on Fv/Fm). For this exposure, the 96-hour LC50 was 36.88 (95% CI 36.52-37.3) µg/L As (V). To estimate the arsenate concentration that resulted in a 50% effect on coral condition, the individual scores for each criterion were summed, and the EC50 estimated from mean percent effect. For this exposure, the 96-hour $EC50_{Condition}$ was 34.91 (95% CI 34.81-35.03) µg/L As (V). To estimate the arsenate concentration that inhibited photosynthetic efficiency by 50% (IC50), the dark-adapted maximum quantum yield (Fv/Fm) (measured prior to and after 96 h of exposure) were used, expressed as the percentage of pre-exposure yield for each coral. For this exposure, the 96-hour $IC50_{Yield}$ was 35.80 µg/L (95% CI 35.74-35.86) As (V) due to 100% mortality in the four highest arsenate concentrations (Fig. 26).

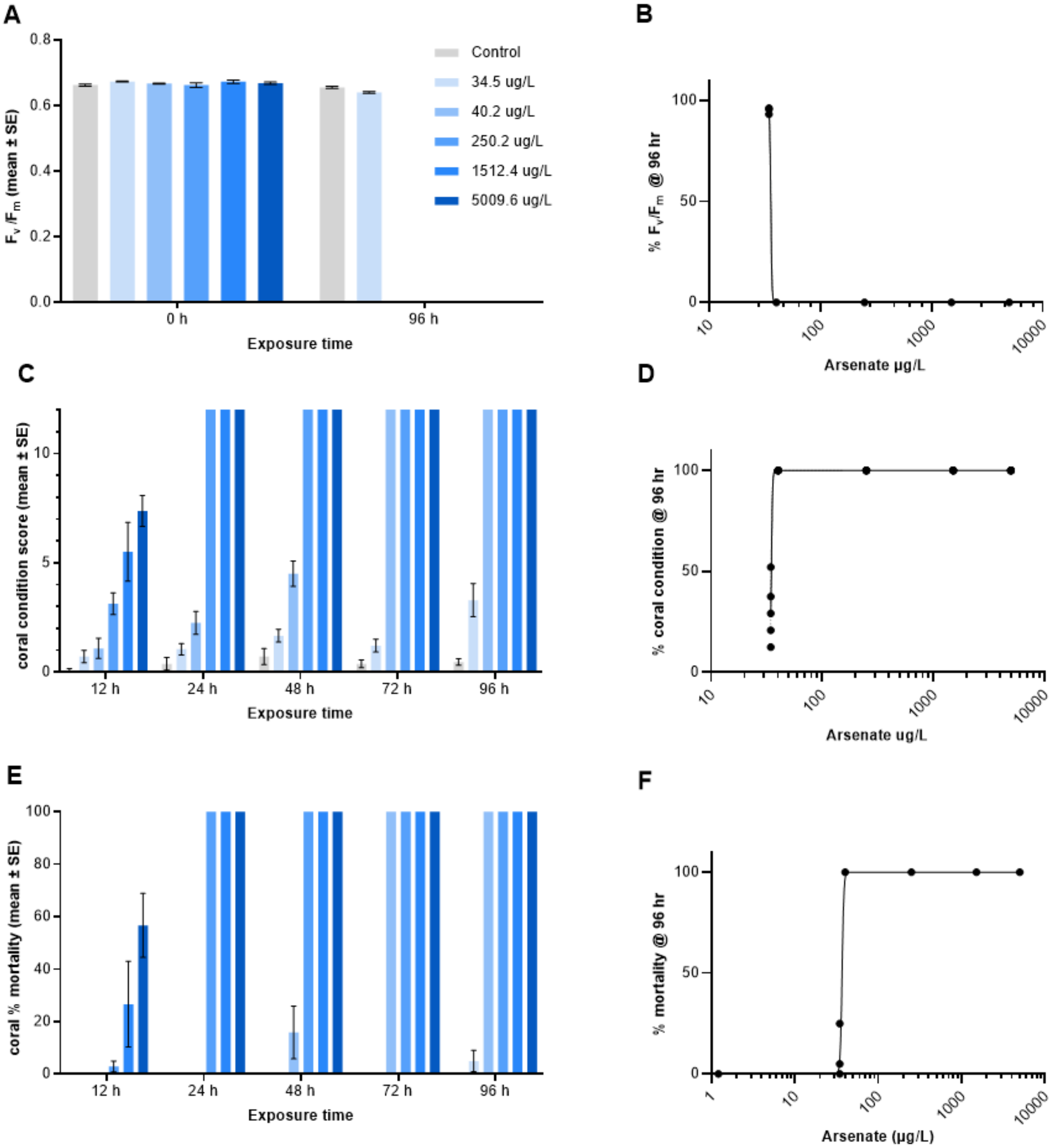


Figure 26. Results of arsenate 96-hr acute exposure for *Acropora cervicornis* A) dark-adapted maximum quantum yield (mean ± SE) (n=6 replicates) at 0 hr and 9h hr, B) dark-adapted maximum quantum yield dose-response curve, C) coral condition scores (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, D) coral condition dose-response curve, E) % mortality (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, and F) mortality dose-response curve.

3.17.2. Arsenite (As (III)) exposure with *Acropora cervicornis*:

Arsenite chemistry: The measured concentrations of each tested arsenic species at T0 and T24 for each nominal treatment concentration are provided as processed data.

Acute toxicity thresholds: Log-logistic 4-parameter dose-response models are used to estimate threshold concentrations for mortality (LC50), physical effect (EC50, based on coral condition scores), and inhibition of photosynthetic efficiency (IC50, based on Fv/Fm). For this exposure, the 96-hour LC50 was 116.0 (95% CI 105.4-130.5) µg/L As (III). To estimate the arsenite concentration that resulted in a 50% effect on coral condition, the individual scores for each criterion were summed, and the EC50 estimated from mean percent effect. For this exposure, the 96-hour $EC50_{Condition}$ was 100.1 (95% CI 88.57-115.4) µg/L As (III). To estimate the arsenite concentration that inhibited photosynthetic efficiency by 50% (IC50), the dark-adapted maximum quantum yield (Fv/Fm) (measured prior to and after 96 h of exposure) were used, expressed as the percentage of pre-exposure yield for each coral. For this exposure, the 96-hour $IC50_{Yield}$ was 138.6 µg/L (95% CI 115.0-158.5) As (III) due to 100% mortality in the four highest arsenate concentrations (Fig. 27).

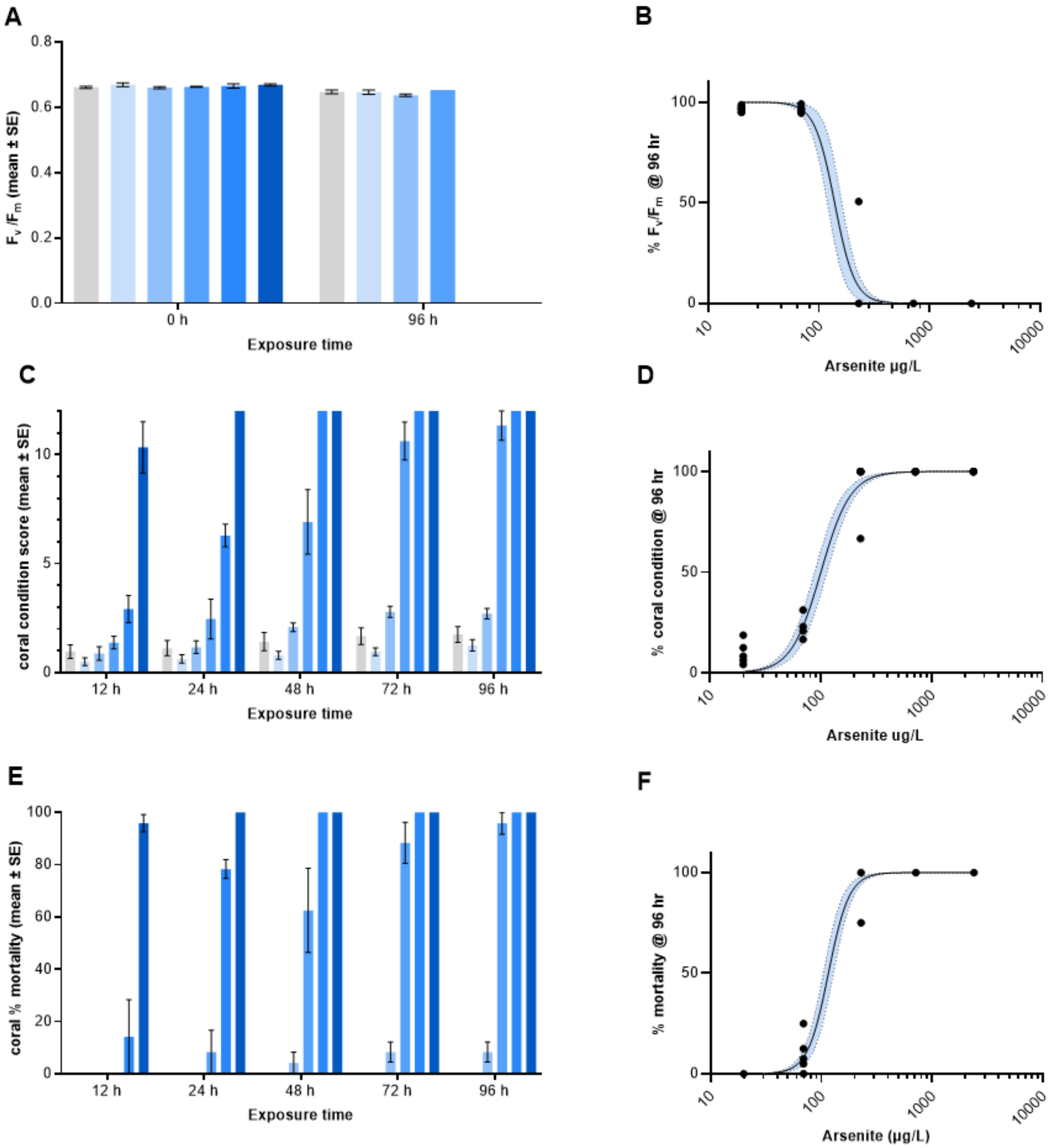


Figure 27. Results of arsenite 96-hr acute exposure for *Acropora cervicornis* A) dark-adapted maximum quantum yield (mean ± SE) (n=6 replicates) at 0 hr and 9h hr, B) dark-adapted maximum quantum yield dose-response curve, C) coral condition scores (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, D) coral condition dose-response curve, E) % mortality (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, and F) mortality dose-response curve.

3.17.3. Arsenate (As V) exposure with *Orbicella faveolata*:

Arsenate chemistry: The measured concentrations of each tested arsenic species at T0 and T24 for each nominal treatment concentration are provided as processed data.

Acute toxicity thresholds: Log-logistic 4-parameter dose-response models are used to estimate threshold concentrations for mortality (LC50), physical effect ($EC50_{Condition}$, based on coral condition scores), and inhibition of photosynthetic efficiency ($IC50_{Yield}$, based on Fv/Fm). For this exposure, the 96-hour LC50 was 458.3 (95% CI 457.7-CNC) µg/L As (V). To estimate the arsenate concentration that resulted in a 50% effect on coral condition, the individual scores for each criterion were summed, and the $EC50_{Condition}$ estimated from mean percent effect. For this exposure, the 96-hour $EC50_{Condition}$ was 165.8 (95% CI 146.2-190.2) µg/L As (V). To estimate the arsenate concentration that inhibited photosynthetic efficiency by 50% ($IC50_{Yield}$), the dark-adapted maximum quantum yield (Fv/Fm) (measured prior to and after 96 h of exposure) were used, expressed as the percentage of pre-exposure yield for each coral. For this exposure, the 96-hour $IC50_{Yield}$ was 294.3 (95% CI 259.4-395.1) µg/L As (V) due to 100% mortality in the three highest arsenate concentrations (Fig. 28).

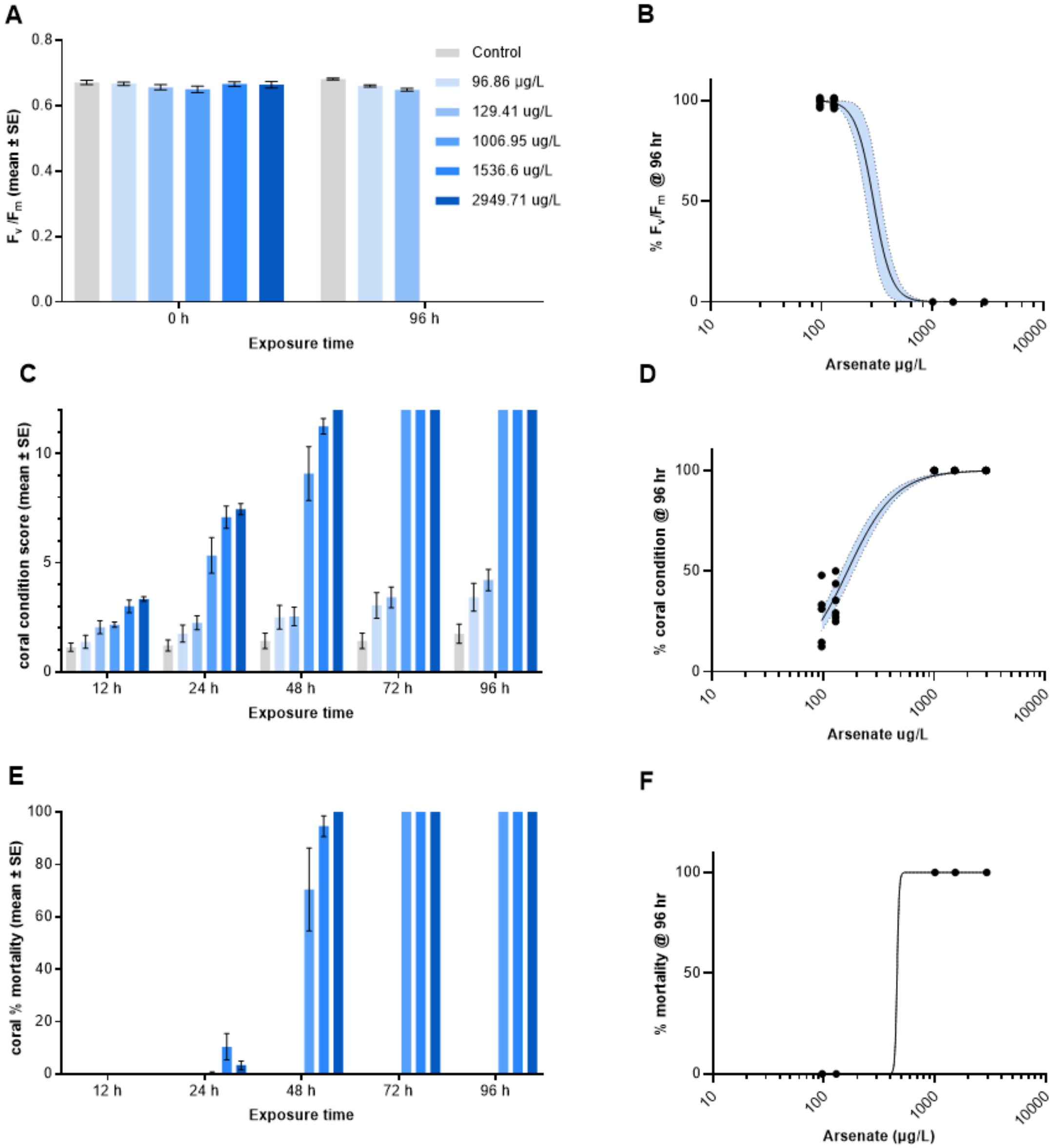


Figure 28. Results of arsenate 96-hr acute exposure for *Orbicella faveolata*. A) dark-adapted maximum quantum yield (mean ± SE) (n=6 replicates) at 0 hr and 9h hr, B) dark-adapted maximum quantum yield dose-response curve, C) coral condition scores (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, D) coral condition dose-response curve, E) % mortality (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, and F) mortality dose-response curve.

3.17.4. Arsenite (As III) exposure with *Orbicella faveolata*:

Arsenite chemistry: The measured concentrations of each tested arsenic species at T0 and T24 for each nominal treatment concentration are provided as processed data.

Acute toxicity thresholds: Log-logistic 4-parameter dose-response models are used to estimate threshold concentrations for mortality (LC50), physical effect (EC50, based on coral condition scores), and inhibition of photosynthetic efficiency (IC50, based on Fv/Fm). For this exposure, the 96-hour LC50 was 255.8 (95% CI 250.7-261.7) µg/L As (III). To estimate the arsenite concentration that resulted in a 50% effect on coral condition, the individual scores for each criterion were summed, and the EC50 estimated from mean percent effect. For this exposure, the 96-hour $EC50_{Condition}$ was 146.1 (95% CI 110.7-191.9) µg/L As (III). To estimate the arsenite concentration that inhibited photosynthetic efficiency by 50% (IC50), the dark-adapted maximum quantum yield (Fv/Fm) (measured prior to and after 96 h of exposure) were used, expressed as the percentage of pre-exposure yield for each coral. For this exposure, the 96-hour $IC50_{Yield}$ was 307.2 µg/L (95% CI 276.6-598.9) As (III) due to 100% mortality in the two highest arsenate concentrations (Fig. 29).

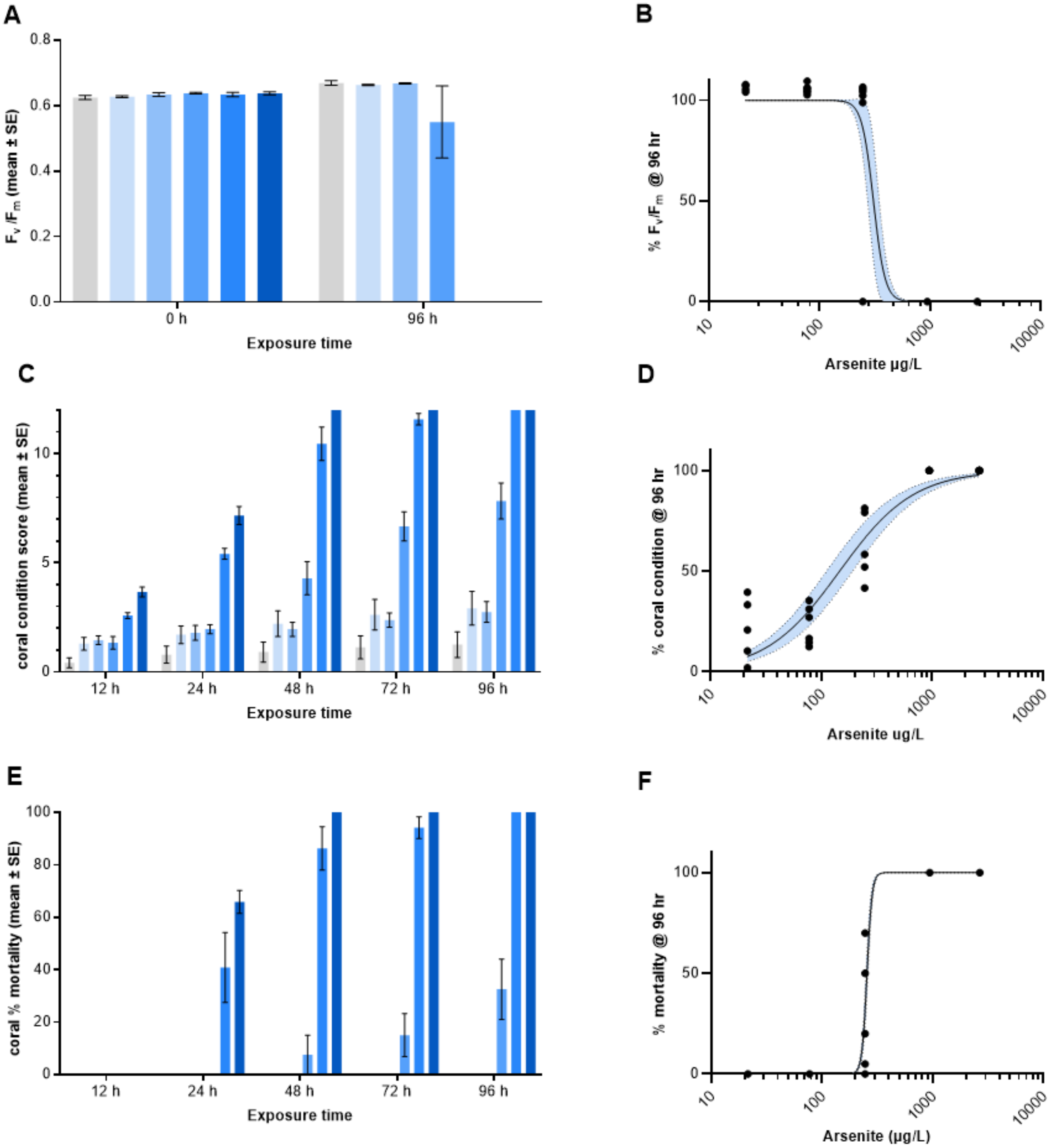


Figure 29. Results of arsenite 96-hr acute exposure for *Orbicella faveolata*. A) dark-adapted maximum quantum yield (mean ± SE) (n=6 replicates) at 0 hr and 9h hr, B) dark-adapted maximum quantum yield dose-response curve, C) coral condition scores (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, D) coral condition dose-response curve, E) % mortality (mean ± SE) (n=6 replicates) at 12 hr, 24 hr, 48 hr, 76 hr, and 96 hr, and F) mortality dose-response curve.

The primary aim of this study was to determine acute exposure thresholds for arsenate (AsV) and arsenite (AsIII) in two coral species, *Acropora cervicornis* and *Orbicella faveolata*. Arsenic levels in marine environments can vary significantly, influenced by natural processes and anthropogenic activities. Coastal areas, especially those near industrial discharges or areas with significant agricultural runoff, often exhibit elevated arsenic levels above the typical continental crust value (Giarikos et al. 2023). Typical seawater concentrations of arsenic range from 0.3 to 2.0 µg/L (ppb), though higher levels have been reported in contaminated areas (Cullen & Reimer 1989). A previous study done in Port Everglades found concentrations of arsenic above the Florida Department of Environmental Protection (FDEP) derived Threshold Effect Level (TEL) of 7.24 µg/g and Probable Effect Level (PEL) of 41.6 µg/g in Port sediments (Macdonald et al. 1996). The concentration of arsenic found in the port sediment cores ranged from 0.607 to 223 µg/g, with a mean of 16.1 µg/g (Giarikos et al. 2023).

Threshold concentrations for marine species are variable; for *Artemia salina,* Byeon et al. (2021) determined an LC50 of 28,080 µg/L As(V) and an LC50 of 10,380 µg/L As(III), and for the marine fish *Oryzias melastigma*, LC50s of 41.565 mg/L As(V) and 21.140 mg/L As(III). The subacute exposure threshold (EC50) for the red sea urchin *Heliocidaris tuberculata* was found 0.170 µg/mL As(V) EC50, based on impacts to growth and other functions (Golding et al., 2022). Both coral species tested here are more sensitive to As (V) and As(III) compared to the standard test species *A. salina* and the marine fish *O. melastigma.*

Overall, the branching *A. cervicornis* was more sensitive to both As(V) and As(III) compared to *O. faveolata*. For *A cervicornis*, As (V) was more acutely toxic than As (III) for all metrics (mortality, condition, and photosynthetic efficiency). This was not the case for *O. faveolata*, where As (III) was more toxic than As (V), but only for mortality; threshold concentrations were similar for condition and photosynthetic efficiency.

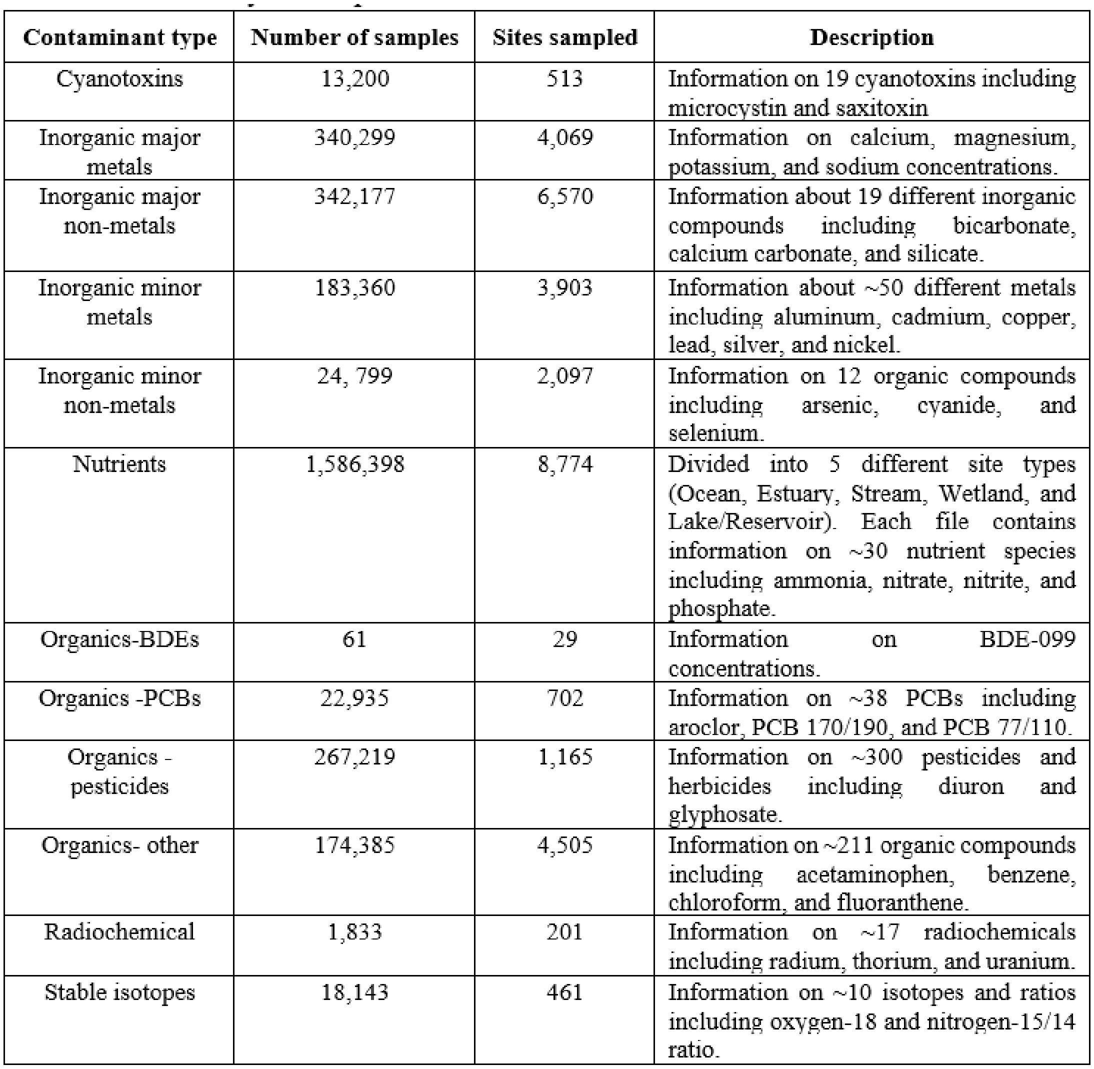
3.18 Synthesis of contaminant spatiotemporal and toxicological data

Geospatial databases for 12 contaminant classes, consisting of over 2.9 million data points for water and sediments, and covering over 32,000 sites in the five counties which encompass the FRT (Broward County, Miami-Dade County, Martin County, Monroe County, and Palm Beach County) FCR (Broward, Miami-Dade, Palm Beach, Martin, and Monroe), were compiled from resources including USGS, STEWARDS, NWIS, NWQMC, MusselWatch, NOAA'S National Status and Trends, and peer-reviewed literature. This data has been divided into individual databases for each contaminant type. In order to have a full picture of water quality entering the Florida Coral Reef system, all sites labeled as “Ocean”, “Estuary”, “Stream”, “Wetland”, and “Lake/Reservoir” were included in these databases. A summary of the compiled data is presented in Table 110.

Within each database, datapoints were categorized by date range (pre-1940, 1940-1949, 1950-1959, 1960-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2009, 2010-2019, and 2020-2029) to facilitate evaluation of temporal tends. Individual analytes were further categorized by contaminant class in order to facilitate hazard assessment.

Chemical/contaminant classes are groupings that relate chemicals by similar features, such as structural similarity, uses, or physical properties. Contaminant class was assigned based on OECD and EPA Toxic Substances Control Act (TSCA) recommendations. Measurements were also subdivided by media (water or sediment).

Table 110. Summary of compiled contaminant databases.

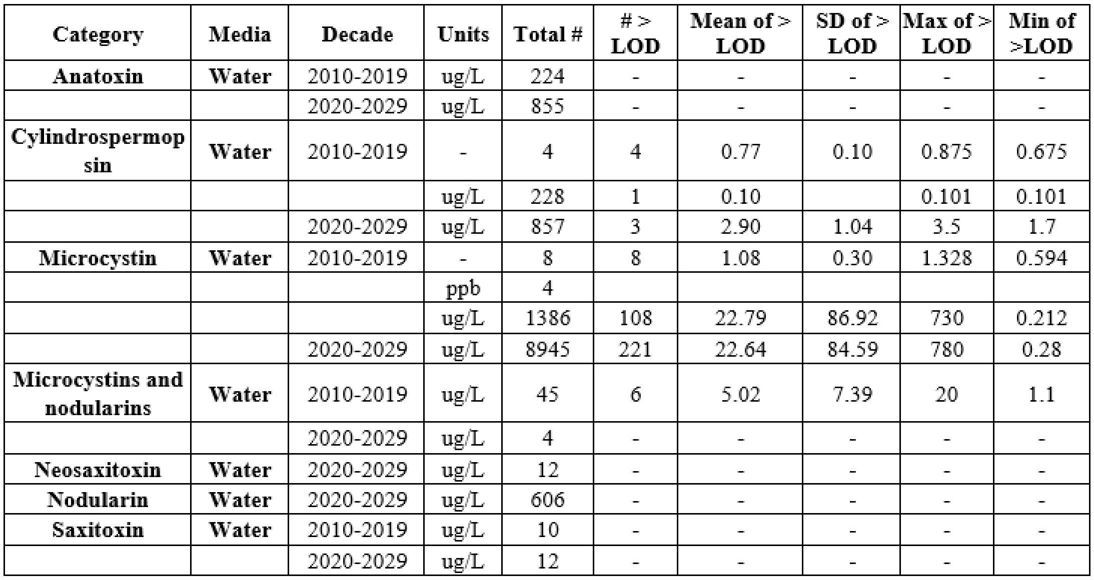


Contaminant type	Number of samples	Sites sampled	Description
Cyanotoxins	13,200	513	Information on 19 cyanotoxins including microcystin and saxitoxin
Inorganic major metals	340,299	4,069	Information on calcium, magnesium, potassium, and sodium concentrations.
Inorganic major non-metals	342,177	6,570	Information about 19 different inorganic compounds including bicarbonate, calcium carbonate, and silicate.
Inorganic minor metals	183,360	3,903	Information about ~50 different metals including aluminum, cadmium, copper, lead, silver, and nickel.
Inorganic minor non-metals	24, 799	2,097	Information on 12 organic compounds including arsenic, cyanide, and selenium.
Nutrients	1,586,398	8,774	Divided into 5 different site types (Ocean, Estuary, Stream, Wetland, and Lake/Reservoir). Each file contains information on ~30 nutrient species including ammonia, nitrate, nitrite, and phosphate.
Organics-BDEs	61	29	Information on BDE-099 concentrations.
Organics -PCBs	22,935	702	Information on ~38 PCBs including aroclor, PCB 170/190, and PCB 77/110.
Organics - pesticides	267,219	1,165	Information on ~300 pesticides and herbicides including diuron and glyphosate.
Organics- other	174,385	4,505	Information on ~211 organic compounds including acetaminophen, benzene, chloroform, and fluoranthene.
Radiochemical	1,833	201	Information on ~17 radiochemicals including radium, thorium, and uranium.
Stable isotopes	18,143	461	Information on ~10 isotopes and ratios including oxygen-18 and nitrogen-15/14 ratio.

To explore contaminant/toxicological relationships, we have focused on the contaminant classes cyanotoxins, inorganic minor metals and non-metals, organics (including pesticides and hydrocarbons) and radiochemicals, as these are the contaminants most likely to be pollutants or indicators of pollution in the environment.

Cyanotoxins. Cyanotoxins are secondary metabolites produced by cyanobacteria that can be toxic to living organisms. This class includes a wide range of compounds, including cyclic peptides (microcystins, nodularins) and alkaloids (cylindrospermopsins, anatoxins, saxitoxins) that can be hepatotoxic, cytotoxic, genotoxic or neurotoxic. Cyanobacterial toxins are among the most hazardous aquatic pollutants and are of particular concern due to the increasing frequency of cyanobacterial blooms. Cyanotoxins have only been measured in water, and overall, 2.66% of samples had tested concentrations that were greater than the method detection limit for that contaminant. Of the cyanotoxins typically tested, cylindrospermopsin and microcystins are most frequently detected, with concentrations ranging from < 1 ug/L to >80 ug/L for microcystins. Over the past two decades, mean concentrations of microcystin have remained relatively constant (Table 111).

Table 111. Summary of cyanotoxin database, including cyanotoxin category, media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.



Category	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
Anatoxin	**Water**	2010-2019	ug/L	224	-	-	-	-	-
		2020-2029	ug/L	855	-	-	-	-	-
Cylindrospermopsin	**Water**	2010-2019	-	4	4	0.77	0.10	0.875	0.675
			ug/L	228	1	0.10		0.101	0.101
		2020-2029	ug/L	857	3	2.90	1.04	3.5	1.7
Microcystin	**Water**	2010-2019	-	8	8	1.08	0.30	1.328	0.594
			ppb	4					
			ug/L	1386	108	22.79	86.92	730	0.212
		2020-2029	ug/L	8945	221	22.64	84.59	780	0.28
Microcystins and nodularins	**Water**	2010-2019	ug/L	45	6	5.02	7.39	20	1.1
		2020-2029	ug/L	4	-	-	-	-	-
Neosaxitoxin	**Water**	2020-2029	ug/L	12	-	-	-	-	-
Nodularin	**Water**	2020-2029	ug/L	606	-	-	-	-	-
Saxitoxin	**Water**	2010-2019	ug/L	10	-	-	-	-	-
		2020-2029	ug/L	12	-	-	-	-	-

Inorganic minor metals. This contaminant category includes known invertebrate toxicants, including copper, lead, mercury, and zinc. Inorganic minor metals, while present in small quantities, can still pose significant threats to aquatic ecosystems due to their toxicity. These metals, including aluminum, cadmium, chromium, copper, lead, mercury, nickel, and zinc, among others, are often released into water bodies, and their occurrence and concentration in the database is summarized below. Metals such as these are typically particle reactive and would therefore be expected to accumulate in sediments. Aluminum is generally considered to be relatively low in toxicity compared to some other metals. Cadmium is highly toxic to aquatic life, and can accumulate in the tissues of aquatic organisms, disrupting physiological processes and impairing reproduction. Chromium exists in various oxidation states, with hexavalent chromium (Cr(VI)) being the most toxic. It can cause severe damage to aquatic organisms, including fish, invertebrates, and plants. Chromium compounds are known to be carcinogenic and can also disrupt cellular processes and DNA integrity in aquatic organisms. Copper, while an essential trace element, has high aquatic toxicity to invertebrates and can be toxic to aquatic life even at low concentrations. Lead is also toxic to aquatic organisms, particularly affecting the nervous system and causing behavioral and developmental abnormalities in fish and other organisms. Mercury is a potent neurotoxin that bioaccumulates in aquatic food chains, posing significant risks to both aquatic organisms and humans consuming contaminated fish. Methylmercury, formed through microbial processes in sediments, is the most toxic form and can cause severe neurological damage, particularly in developing organisms. Nickel is less toxic compared to some other metals but can still pose risks to aquatic organisms, especially in high concentrations. It can interfere with enzyme systems and cellular processes, affecting growth, reproduction, and overall health in aquatic species. Zinc is an essential micronutrient for aquatic organisms, but elevated concentrations can be toxic. Zinc interferes with ion regulation and enzyme activity in aquatic organisms, leading to physiological stress and reduced growth and reproduction. The toxicity of inorganic minor metals varies depending on factors such as chemical speciation, water chemistry, and the sensitivity of aquatic organisms. Approximately 44% of water and sediment samples had tested concentrations greater than the method detection limit for that contaminant (Table 112).

Table 112. Summary of inorganic minor metals database, including, for each metal, the media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.

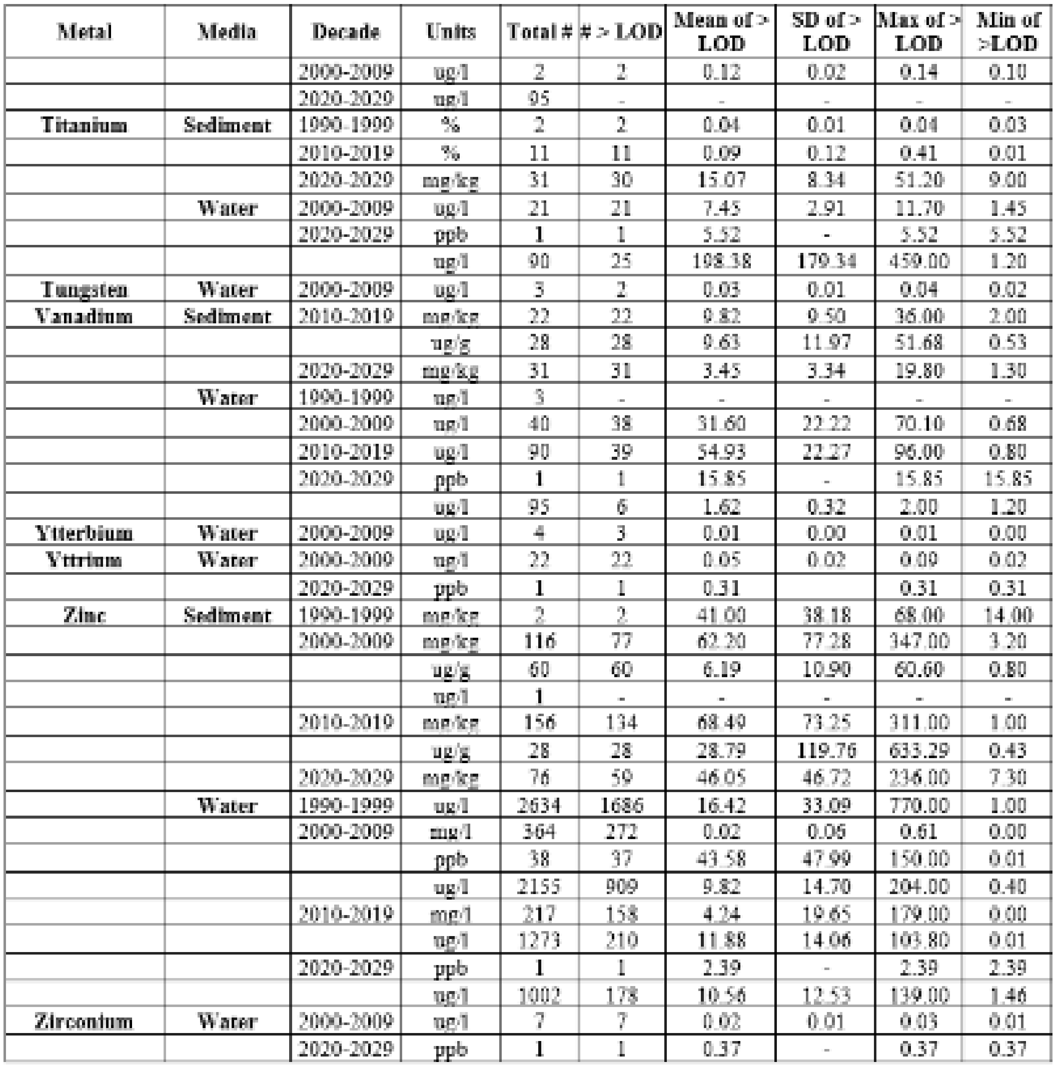
Metal	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
Aluminum	**Sediment**	1990-1999	%	2	2	0.74	0.18	0.87	0.61
		2000-2009	mg/kg	128	128	16776.32	23194.41	108000.00	208.00
			ug/g	140	139	2359.58	3059.35	14750.00	32.10
		2010-2019	%	17	17	0.59	0.95	3.10	0.10
			mg/kg	136	136	20710.29	18945.77	87400.00	330.00
			ug/g	28	28	2747.79	7247.89	36709.30	14.80
		2020-2029	mg/kg	77	77	12791.51	19898.34	82700.00	310.00
	Water	1990-1999	ug/l	3223	3221	45.81	182.82	4546.32	2.00
		2000-2009	mg/kg	9	9	2350.00	1555.06	5500.00	1050.00
			mg/l	2	2	0.70	0.00	0.70	0.70
			ug/l	451	445	62.42	179.74	1730.00	2.10
		2010-2019	mg/l	2	-	-	-	-	-
			ug/l	335	237	220.87	299.97	1880.00	8.70
		2020-2029	ppb	1	1	52.53	-	52.53	52.53
			ug/l	323	210	138.57	171.78	1360.00	21.00
Barium	**Sediment**	1990-1999	mg/kg	2	2	54.00	42.43	84.00	24.00
		2010-2019	mg/kg	22	22	32.27	43.84	170.00	7.00

Metal	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
		2020-2029	mg/kg	31	30	3.02	3.21	18.30	0.96
	Water	1990-1999	ug/l	379	227	25.86	12.84	87.15	10.00
		2000-2009	ug/l	305	303	19.60	10.02	68.00	4.70
		2010-2019	ug/l	313	273	20.12	10.40	88.50	1.19
		2020-2029	ug/l	381	376	17.06	8.06	70.80	2.16
Beryllium	**Sediment**	2010-2019	mg/kg	35	35	0.46	0.44	1.74	0.10
		2020-2029	mg/kg	77	39	0.57	0.39	1.42	0.10
	Water	1990-1999	ug/l	293	28	0.25	0.18	1.00	0.12
		2000-2009	mg/kg	9	8	0.13	0.08	0.31	0.06
			ug/l	131	6	0.54	0.63	1.70	0.11
		2010-2019	ug/l	225	20	0.23	0.35	1.08	0.03
		2020-2029	ug/l	302	8	0.07	0.04	0.15	0.04
Bismuth	**Water**	2000-2009	ug/l	8	8	0.18	0.16	0.50	0.01
Cadmium	**Sediment**	1990-1999	mg/kg	2	2	0.20	0.14	0.30	0.10
		2000-2009	mg/kg	69	7	1.24	0.56	2.29	0.57
			ug/g	100	97	0.63	0.91	3.60	0.03
		2010-2019	mg/kg	105	25	0.66	0.39	1.59	0.10
			ug/g	28	28	0.14	0.45	2.41	0.01
		2020-2029	mg/kg	77	6	1.26	1.50	4.30	0.43
	Water	1990-1999	ug/l	1942	982	0.36	0.44	5.60	0.01
		2000-2009	mg/l	85	34	0.00	0.00	0.01	0.00
			ppb	5	3	1.06	0.16	1.21	0.89
			ug/l	907	154	0.68	1.64	20.35	0.01
		2010-2019	mg/l	62	44	0.01	0.01	0.05	0.00
			ug/l	951	13	0.63	0.32	1.50	0.16
		2020-2029	ug/l	950	2	1.15	0.07	1.20	1.10
Cerium	**Sediment**	1990-1999	mg/kg	2	2	7.00	2.83	9.00	5.00
	Water	2000-2009	ug/l	13	13	0.04	0.04	0.10	0.00
Cesium	**Water**	2000-2009	ug/l	28	28	0.29	0.08	0.41	0.06
Chromium	**Sediment**	1990-1999	mg/kg	2	2	18.00	4.24	21.00	15.00
		2000-2009	mg/kg	127	108	33.33	32.70	153.00	1.20
			ug/g	89	89	7.51	6.82	35.00	0.52
			ug/l	1	-	-	-	-	-
		2010-2019	mg/kg	156	141	35.94	28.44	146.00	3.00
			ug/g	28	28	12.01	16.97	65.41	1.15
		2020-2029	mg/kg	77	65	25.57	25.32	90.00	1.70
	Water	1990-1999	ug/l	321	56	2.24	1.89	10.00	0.52
		2000-2009	mg/kg	10	10	14.52	7.48	30.60	8.20
			mg/l	3	-	-	-	-	-
			ug/l	1289	908	6.57	25.17	225.00	0.22
		2010-2019	ug/l	1267	224	3.44	4.58	40.30	0.21
		2020-2029	ug/l	323	13	2.68	3.65	14.70	1.10
Chromium(VI)	**Water**	1990-1999	ug/l	4	4	8.48	3.67	13.90	5.90
		2000-2009	ug/l	4	4	7.75	1.54	10.00	6.70
Cobalt	**Sediment**	1990-1999	mg/kg	2	2	3.50	0.71	4.00	3.00
		2010-2019	mg/kg	3	3	2.00	1.00	3.00	1.00
		2020-2029	mg/kg	31	5	8.48	6.11	18.70	3.50
	Water	1990-1999	ug/l	2	-	-	-	-	-
		2000-2009	ug/l	52	29	1.31	0.60	3.60	0.31
		2010-2019	ug/l	1	1	0.05	-	0.05	0.05
		2020-2029	ppb	1	1	0.23	-	0.23	0.23
			ug/l	95	11	0.17	0.18	0.69	0.08
Copper	**Sediment**	1990-1999	mg/kg	2	2	26.00	11.31	34.00	18.00

Metal	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
		2000-2009	mg/kg	128	99	93.31	283.10	2350.00	2.27
			ug/g	70	70	6.41	14.55	81.20	0.30
			ug/l	1	-	-	-	-	-
		2010-2019	mg/kg	149	132	61.20	97.88	750.00	0.67
			ug/g	28	28	21.30	94.35	500.68	0.23
		2020-2029	mg/kg	77	72	27.54	43.88	259.00	1.90
	Water	1990-1999	mg/l	1	1	0.02	-	0.02	0.02
			ug/l	3724	2614	4.35	45.09	1774.00	0.38
		2000-2009	mg/l	272	244	0.01	0.02	0.25	0.00
			ppb	75	73	5.00	7.07	41.00	0.01
			ug/l	5348	3887	13.94	285.02	13000.00	0.00
		2010-2019	cfu/100mL	4	4	13.70	6.58	19.40	8.00
			mg/l	574	366	1.52	6.48	72.00	0.00
			ug/l	3013	1558	19.68	37.48	328.00	0.01
		2020-2029	ppb	1	1	1.39	-	1.39	1.39
			ug/l	1073	316	4.22	6.71	86.30	0.81
Dysprosium	**Water**	2000-2009	ug/l	13	13	0.07	0.13	0.43	0.00
Erbium	**Water**	2000-2009	ug/l	6	6	0.01	0.00	0.01	0.00
Europium	**Water**	2000-2009	ug/l	9	8	0.01	0.01	0.02	0.00
Gadolinium	**Water**	2000-2009	ug/l	5	4	0.02	0.01	0.04	0.01
Gallium	**Water**	2000-2009	ug/l	10	10	0.08	0.04	0.13	0.02
		2020-2029	ppb	1	1	0.33	-	0.33	0.33
Gold	**Water**	2000-2009	ug/l	9	9	0.04	0.02	0.08	0.02
Hafnium	**Water**	2000-2009	ug/l	2	2	0.00	0.00	0.00	0.00
Holmium	**Water**	2000-2009	ug/l	14	14	0.02	0.01	0.06	0.00
Indium	**Water**	2000-2009	ug/l	15	15	0.05	0.06	0.16	0.00
Iron	**Sediment**	1990-1999	%	2	2	1.06	0.49	1.40	0.71
		2000-2009	mg/kg	128	128	7799.56	7431.70	27800.00	232.00
			ug/g	136	136	1288.40	1574.90	8000.00	1.80
			ug/l	1	-	-	-	-	-
		2010-2019	%	17	17	0.34	0.40	1.40	0.10
			mg/kg	136	136	9703.26	8137.62	29900.00	375.00
			ug/g	28	28	3218.74	7164.29	29522.20	5.80
		2020-2029	mg/kg	77	77	5819.52	6945.26	28100.00	291.00
	Water	1990-1999	mg/kg	1	1	1900.00	-	1900.00	1900.00
			mg/l	156	143	0.37	0.61	3.30	0.01
			ug/l	9624	9624	214.18	396.45	20100.00	0.20
		2000-2009	mg/kg	20	20	9056.00	4820.75	19800.00	1810.00
			mg/l	23	23	0.20	0.13	0.52	0.03
			ug/l	6897	6560	315.21	772.62	18000.00	0.02
		2010-2019	cfu/100mL	6	6	44.92	34.45	110.00	21.80
			mg/l	318	318	0.11	0.12	1.05	0.00
			ug/l	3025	2229	279.39	609.77	13540.00	3.17
		2020-2029	ug/l	818	513	320.20	573.96	4097.00	3.47
Lanthanum	**Water**	2000-2009	ug/l	21	20	0.03	0.02	0.07	0.00
Lead	**Sediment**	1990-1999	mg/kg	2	2	19.00	12.73	28.00	10.00
		2000-2009	mg/kg	119	81	34.40	30.94	165.00	1.04
			ug/g	50	50	3.11	4.11	21.40	0.30
			ug/l	1	-	-	-	-	-
		2010-2019	mg/kg	141	103	66.47	255.82	2600.00	0.89
			ug/g	28	28	11.22	45.15	240.32	0.18

Metal	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
		2020-2029	mg/kg	77	68	21.23	46.09	359.00	1.10
	Water	1990-1999	mg/l	1	1	0.01	-	0.01	0.01
			ug/l	2303	1132	1.81	4.63	105.00	0.02
		2000-2009	mg/l	159	89	0.01	0.02	0.11	0.00
			ppb	13	11	1.84	1.92	5.78	0.01
			ug/l	1361	218	2.17	5.12	52.50	0.12
		2010-2019	mg/l	79	56	0.51	0.95	4.45	0.00
			ug/l	1214	176	1.87	6.97	49.00	0.05
		2020-2029	ug/l	949	24	0.75	0.37	1.70	0.41
Lithium	**Sediment**	2010-2019	mg/kg	18	18	11.28	11.33	39.00	1.00
	Water	1990-1999	ug/l	7	7	4.57	0.79	6.00	4.00
		2000-2009	ug/l	28	28	175.82	43.54	213.00	31.10
		2010-2019	ug/l	14	14	278.73	134.80	555.00	1.48
Lutetium	**Water**	2000-2009	ug/l	8	7	0.04	0.03	0.07	0.00
Manganese	**Sediment**	1990-1999	mg/kg	2	2	69.00	5.66	73.00	65.00
		2000-2009	mg/kg	24	24	42.35	39.22	171.00	4.90
			ug/g	140	140	24.67	20.61	129.00	3.95
		2010-2019	mg/kg	43	43	65.66	88.35	550.00	7.00
			ug/g	28	28	40.01	56.29	296.51	2.15
		2020-2029	mg/kg	77	77	65.62	119.93	579.00	0.90
	Water	1990-1999	ug/l	1618	1497	27.47	77.06	1390.00	0.41
		2000-2009	ug/l	597	551	17.17	18.59	163.05	0.60
		2010-2019	ug/l	254	188	17.86	13.57	87.70	0.42
		2020-2029	ppb	1	1	23.40	-	23.40	23.40
			ug/l	319	265	16.10	10.98	67.00	0.33
Mercury	**Sediment**	1990-1999	mg/kg	2	2	0.04	0.01	0.04	0.03
		2000-2009	mg/kg	117	76	0.15	0.10	0.47	0.02
			ug/g	83	70	0.08	0.35	2.10	0.00
		2010-2019	mg/kg	143	131	0.14	0.11	0.76	0.00
			ng/g	125	125	148.20	66.23	290.00	19.00
			ug/g	28	28	0.08	0.28	1.51	0.00
		2020-2029	mg/kg	46	46	0.12	0.14	0.67	0.00
	Water	1990-1999	ug/l	1249	981	1.27	1.39	23.00	0.08
		2000-2009	mg/kg	6	5	1.11	0.42	1.70	0.64
			ng/L	278	264	1.67	1.71	16.00	0.12
			ug/l	1791	1672	1.88	2.61	39.00	0.00
		2010-2019	mg/l	1	-	-	-	-	-
			ng/L	463	399	1.24	1.02	8.40	0.01
			ug/l	1		-	-	-	-
		2020-2029	ng/L	87	47	0.81	0.81	4.78	0.06
Molybdenum	**Sediment**	2010-2019	mg/kg	27	18	2.65	1.91	7.00	0.84
		2020-2029	mg/kg	77	35	1.74	1.13	7.20	0.67
	Water	1990-1999	ug/l	2	2	15.00	7.07	20.00	10.00
		2000-2009	ug/l	151	134	3.55	5.38	35.00	0.50
		2010-2019	ug/l	190	153	2.58	3.50	15.60	0.29
		2020-2029	ug/l	264	213	3.01	2.87	12.00	0.62
Neodymium	**Water**	2000-2009	ug/l	11	11	0.10	0.13	0.44	0.01
Nickel	**Sediment**	1990-1999	mg/kg	2	2	5.00	0.00	5.00	5.00
		2000-2009	mg/kg	113	76	12.11	8.64	34.50	1.04
			ug/g	130	130	2.78	1.83	9.80	0.45
		2010-2019	mg/kg	148	117	12.49	7.14	33.30	1.20
			ug/g	28	28	3.00	4.30	14.79	0.12
		2020-2029	mg/kg	77	30	3.62	6.94	34.90	0.38

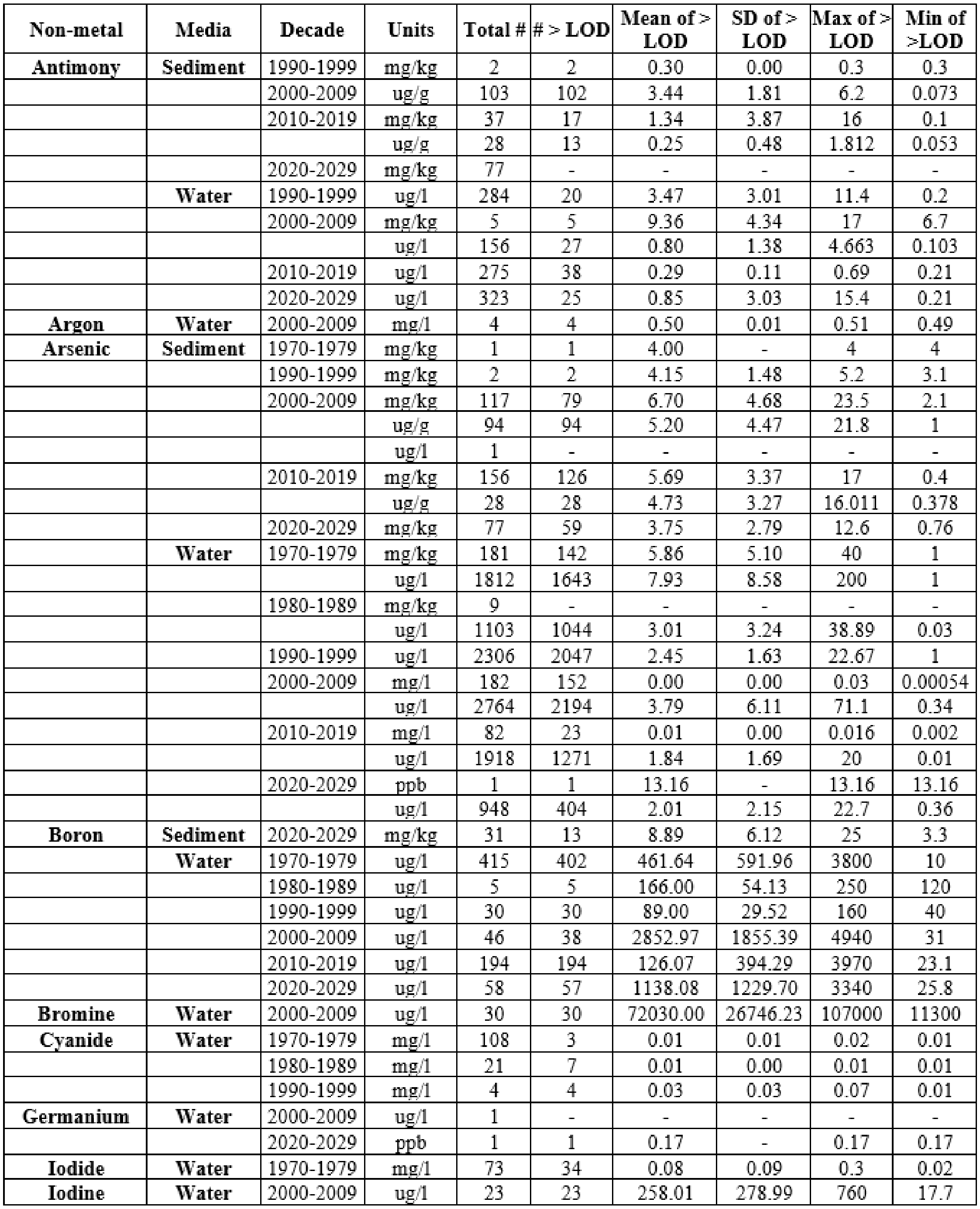
Metal	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
	Water	1990-1999	ug/l	339	75	1.37	1.12	10.00	0.53
		2000-2009	mg/kg	5	5	4.58	1.23	6.30	3.40
			mg/l	1	-	-	-	-	-
			ug/l	473	210	71.85	252.91	1550.00	0.19
		2010-2019	mg/l	2	-	-	-	-	-
			ug/l	1007	207	0.72	0.61	4.10	0.21
		2020-2029	ppb	1	1	2.62	-	2.62	2.62
			ug/l	477	1	5.00	-	5.00	5.00
Niobium	**Water**	2000-2009	ug/l	6	6	0.02	0.01	0.03	0.01
		2020-2029	ppb	1	1	0.55	-	0.55	0.55
Osmium	**Water**	2000-2009	ug/l	1	-	-	-	-	-
Palladium	**Water**	2000-2009	ug/l	26	26	1.11	0.63	2.19	0.02
Platinum	**Water**	2000-2009	ug/l	1	1	0.13	-	0.13	0.13
Praseodymium	**Water**	2000-2009	ug/l	17	16	0.02	0.00	0.03	0.01
Rhenium	**Water**	2000-2009	ug/l	6	6	0.01	0.01	0.02	0.00
Rubidium	**Water**	2000-2009	ug/l	30	30	108.90	37.16	141.00	19.90
		2020-2029	ppb	1	1	9.66		9.66	9.66
Ruthenium	**Water**	2000-2009	ug/l	22	22	0.80	0.73	3.16	0.04
Samarium	**Water**	2000-2009	ug/l	4	4	0.02	0.01	0.03	0.01
Scandium	**Water**	2000-2009	ug/l	1	-	-	-	-	-
		2020-2029	ppb	1	1	2.86	-	2.86	2.86
Silver	**Sediment**	1990-1999	mg/kg	1	1	0.30	-	0.30	0.30
		2000-2009	mg/kg	95	42	0.23	0.46	2.90	0.02
			ug/g	82	82	1.35	1.71	5.80	0.04
		2010-2019	mg/kg	117	50	0.22	0.20	1.20	0.09
			ug/g	28	20	0.52	0.44	1.35	0.03
		2020-2029	mg/kg	77	3	0.11	0.02	0.14	0.10
	Water	1990-1999	ug/l	274	35	1.76	7.54	45.00	0.10
		2000-2009	mg/kg	6	6	0.05	0.04	0.12	0.02
			ug/l	215	54	1.04	0.76	5.10	0.07
		2010-2019	ug/l	682	8	0.05	0.03	0.10	0.02
		2020-2029	ug/l	323	1	0.05	-	0.05	0.05
Strontium	**Sediment**	2010-2019	mg/kg	22	22	2550.59	1810.47	6400.00	70.00
		2020-2029	mg/kg	31	31	45.84	58.53	300.00	5.40
	Water	1990-1999	ug/l	331	331	502.47	269.19	1900.00	110.00
		2000-2009	ug/l	60	60	4290.05	3869.44	11500.00	300.00
		2010-2019	ug/l	21	21	4877.52	3831.65	13900.00	584.00
		2020-2029	ppb	1	1	1062.94	-	1062.94	1062.94
			ug/l	97	97	4233.60	2828.50	15100.00	356.00
Tantalum	**Water**	2000-2000	ug/l	3	1	0.02	-	0.02	0.02
Terbium	**Water**	2000-2009	ug/l	14	13	0.01	0.01	0.02	0.00
Thallium	**Sediment**	2020-2029	mg/kg	31	-	-	-	-	-
	Water	1990-1999	ug/l	272	9	2.96	4.22	13.20	0.56
		2000-2009	mg/kg	4	4	0.11	0.06	0.20	0.07
			ug/l	131	3	0.09	0.15	0.26	0.01
		2010-2019	ug/l	234	-	-	-	-	-
		2020-2029	ug/l	318	-	-	-	-	-
Thulium	**Water**	2000-2009	ug/l	2	-	-	-	-	-
Tin	**Sediment**	2000-2009	ug/g	54	51	12.82	24.04	72.40	0.09
		2010-2019	mg/kg	4	4	12.25	12.53	25.00	1.00
			ug/g	28	26	1.09	3.92	20.16	0.06
		2020-2029	mg/kg	31	-	-	-	-	-
	Water	1990-1999	ug/l	2	-	-	-	-	-



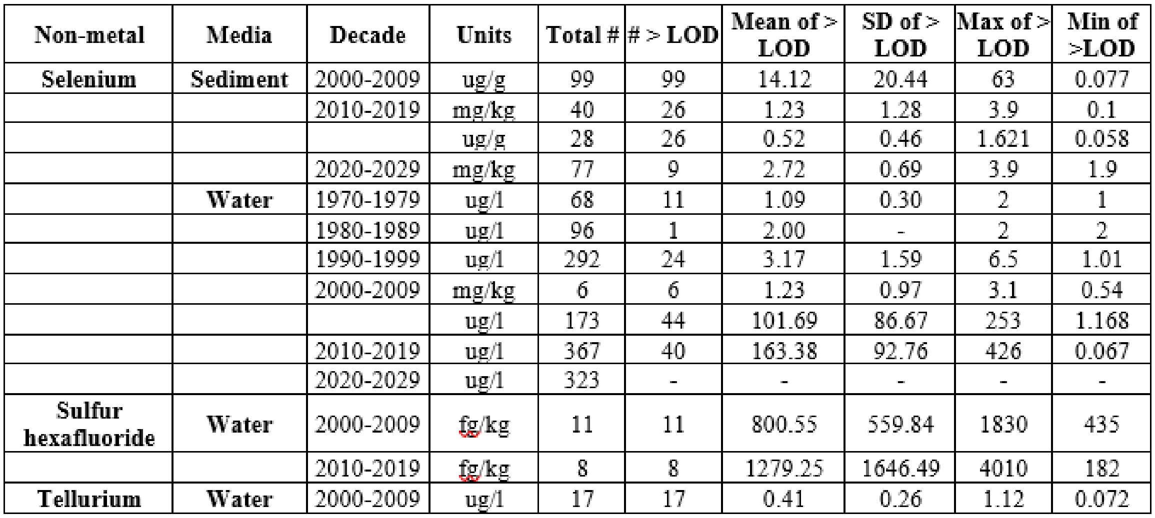
Metal	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
		2000-2009	ug/l	2	2	0.12	0.02	0.14	0.10
		2020-2029	ug/l	95	-	-	-	-	-
Titanium	**Sediment**	1990-1999	%	2	2	0.04	0.01	0.04	0.03
		2010-2019	%	11	11	0.09	0.12	0.41	0.01
		2020-2029	mg/kg	31	30	15.07	8.34	51.20	9.00
	Water	2000-2009	ug/l	21	21	7.45	2.91	11.70	1.45
		2020-2029	ppb	1	1	5.52	-	5.52	5.52
			ug/l	90	25	108.38	179.34	450.00	1.20
Tungsten	**Water**	2000-2009	ug/l	3	2	0.03	0.01	0.04	0.02
Vanadium	**Sediment**	2010-2019	mg/kg	22	22	9.82	9.50	36.00	2.00
			ug/g	28	28	9.63	11.97	51.68	0.53
		2020-2029	mg/kg	31	31	3.45	3.34	19.80	1.30
	Water	1990-1999	ug/l	3	-	-	-	-	-
		2000-2009	ug/l	40	38	31.60	22.22	70.10	0.68
		2010-2019	ug/l	90	39	54.93	22.27	96.00	0.80
		2020-2029	ppb	1	1	15.85	-	15.85	15.85
			ug/l	95	6	1.62	0.32	2.00	1.20
Ytterbium	**Water**	2000-2009	ug/l	4	3	0.01	0.00	0.01	0.00
Yttrium	**Water**	2000-2009	ug/l	22	22	0.05	0.02	0.09	0.02
		2020-2029	ppb	1	1	0.31		0.31	0.31
Zinc	**Sediment**	1990-1999	mg/kg	2	2	41.00	38.18	68.00	14.00
		2000-2009	mg/kg	116	77	62.20	77.28	347.00	3.20
			ug/g	60	60	6.19	10.90	60.60	0.80
			ug/l	1	-	-	-	-	-
		2010-2019	mg/kg	156	134	68.49	73.25	311.00	1.00
			ug/g	28	28	28.79	119.76	633.29	0.43
		2020-2029	mg/kg	76	59	46.05	46.72	236.00	7.30
	Water	1990-1999	ug/l	2634	1686	16.42	33.09	770.00	1.00
		2000-2009	mg/l	364	272	0.02	0.06	0.61	0.00
			ppb	38	37	43.58	47.99	150.00	0.01
			ug/l	2155	909	9.82	14.70	204.00	0.40
		2010-2019	mg/l	217	158	4.24	19.65	179.00	0.00
			ug/l	1273	210	11.88	14.06	103.80	0.01
		2020-2029	ppb	1	1	2.39	-	2.39	2.39
			ug/l	1002	178	10.56	12.53	139.00	1.46
Zirconium	**Water**	2000-2009	ug/l	7	7	0.02	0.01	0.03	0.01
		2020-2029	ppb	1	1	0.37	-	0.37	0.37

Inorganic minor non-metals. This contaminant class includes elements such as arsenic, selenium, and fluoride. Inorganic arsenic compounds are particularly toxic and can cause a range of adverse effects in aquatic organisms, including fish, invertebrates, and algae. Chronic exposure to high levels of selenium can cause a range of adverse effects in aquatic organisms, including impaired growth and reproduction, developmental abnormalities, and neurological disorders. Fluoride can exhibit aquatic toxicity at high concentrations, although chronic exposure is of primary concern. Overall, the aquatic toxicity of inorganic minor non-metals like arsenic, selenium, and fluoride highlights the importance of monitoring and regulating their levels in water bodies to protect aquatic ecosystems and the organisms they support (Table 113).

Table 113. Summary of inorganic minor non-metals database, including, for each non-metal or metalloid, the media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.



Non-metal	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
Antimony	**Sediment**	1990-1999	mg/kg	2	2	0.30	0.00	0.3	0.3
		2000-2009	ug/g	103	102	3.44	1.81	6.2	0.073
		2010-2019	mg/kg	37	17	1.34	3.87	16	0.1
			ug/g	28	13	0.25	0.48	1.812	0.053
		2020-2029	mg/kg	77	-	-	-	-	-
	Water	1990-1999	ug/l	284	20	3.47	3.01	11.4	0.2
		2000-2009	mg/kg	5	5	9.36	4.34	17	6.7
			ug/l	156	27	0.80	1.38	4.663	0.103
		2010-2019	ug/l	275	38	0.29	0.11	0.69	0.21
		2020-2029	ug/l	323	25	0.85	3.03	15.4	0.21
Argon	**Water**	2000-2009	mg/l	4	4	0.50	0.01	0.51	0.49
Arsenic	**Sediment**	1970-1979	mg/kg	1	1	4.00	-	4	4
		1990-1999	mg/kg	2	2	4.15	1.48	5.2	3.1
		2000-2009	mg/kg	117	79	6.70	4.68	23.5	2.1
			ug/g	94	94	5.20	4.47	21.8	1
			ug/l	1	-	-	-	-	-
		2010-2019	mg/kg	156	126	5.69	3.37	17	0.4
			ug/g	28	28	4.73	3.27	16.011	0.378
		2020-2029	mg/kg	77	59	3.75	2.79	12.6	0.76
	Water	1970-1979	mg/kg	181	142	5.86	5.10	40	1
			ug/l	1812	1643	7.93	8.58	200	1
		1980-1989	mg/kg	9	-	-	-	-	-
			ug/l	1103	1044	3.01	3.24	38.89	0.03
		1990-1999	ug/l	2306	2047	2.45	1.63	22.67	1
		2000-2009	mg/l	182	152	0.00	0.00	0.03	0.00054
			ug/l	2764	2194	3.79	6.11	71.1	0.34
		2010-2019	mg/l	82	23	0.01	0.00	0.016	0.002
			ug/l	1918	1271	1.84	1.69	20	0.01
		2020-2029	ppb	1	1	13.16	-	13.16	13.16
			ug/l	948	404	2.01	2.15	22.7	0.36
Boron	**Sediment**	2020-2029	mg/kg	31	13	8.89	6.12	25	3.3
	Water	1970-1979	ug/l	415	402	461.64	591.96	3800	10
		1980-1989	ug/l	5	5	166.00	54.13	250	120
		1990-1999	ug/l	30	30	89.00	29.52	160	40
		2000-2009	ug/l	46	38	2852.97	1855.39	4940	31
		2010-2019	ug/l	194	194	126.07	394.29	3970	23.1
		2020-2029	ug/l	58	57	1138.08	1229.70	3340	25.8
Bromine	**Water**	2000-2009	ug/l	30	30	72030.00	26746.23	107000	11300
Cyanide	**Water**	1970-1979	mg/l	108	3	0.01	0.01	0.02	0.01
		1980-1989	mg/l	21	7	0.01	0.00	0.01	0.01
		1990-1999	mg/l	4	4	0.03	0.03	0.07	0.01
Germanium	**Water**	2000-2009	ug/l	1	-	-	-	-	-
		2020-2029	ppb	1	1	0.17	-	0.17	0.17
Iodide	**Water**	1970-1979	mg/l	73	34	0.08	0.09	0.3	0.02
Iodine	**Water**	2000-2009	ug/l	23	23	258.01	278.99	760	17.7



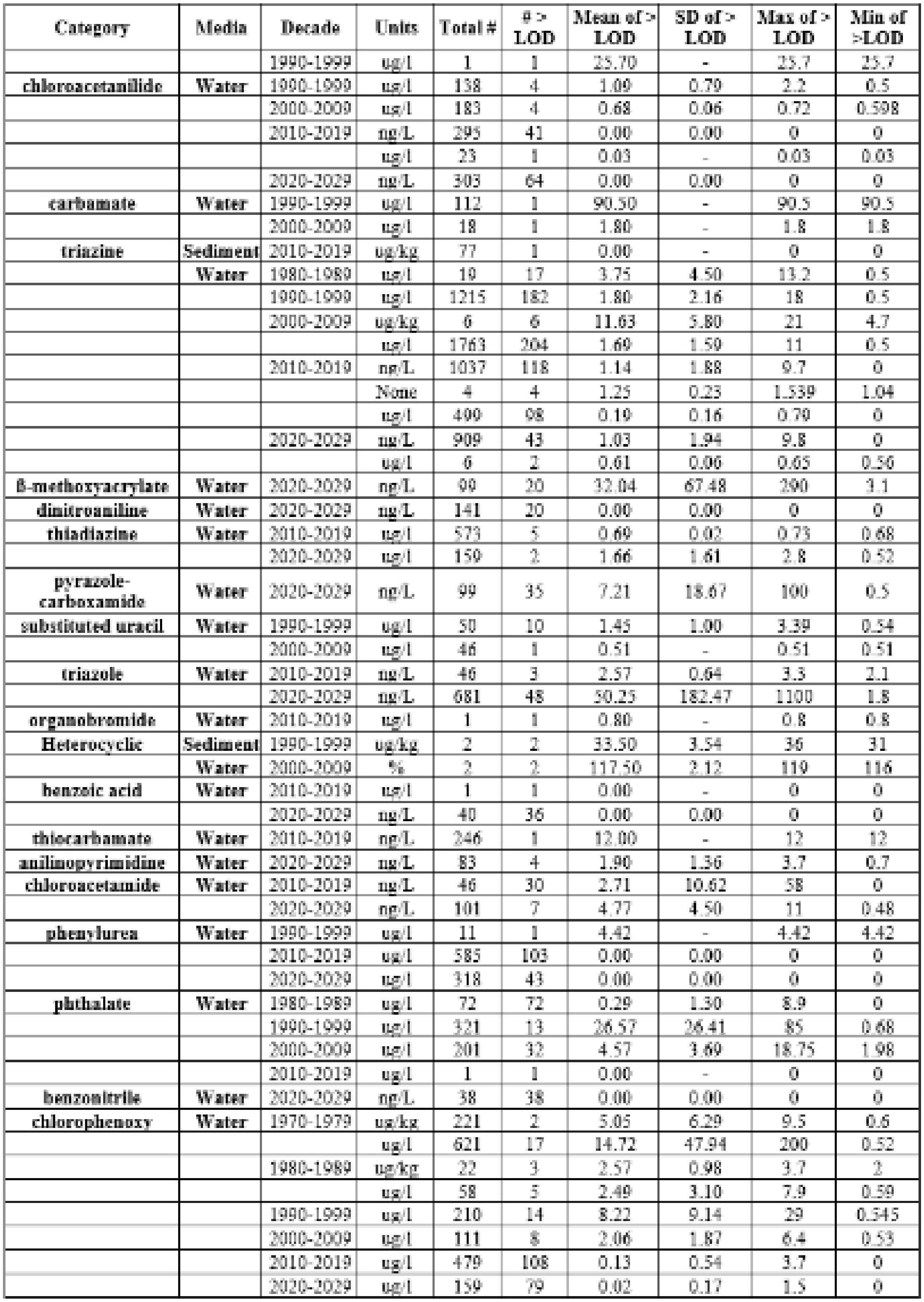
Non-metal	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
Selenium	**Sediment**	2000-2009	ug/g	99	99	14.12	20.44	63	0.077
		2010-2019	mg/kg	40	26	1.23	1.28	3.9	0.1
			ug/g	28	26	0.52	0.46	1.621	0.058
		2020-2029	mg/kg	77	9	2.72	0.69	3.9	1.9
	Water	1970-1979	ug/l	68	11	1.09	0.30	2	1
		1980-1989	ug/l	96	1	2.00	-	2	2
		1990-1999	ug/l	292	24	3.17	1.59	6.5	1.01
		2000-2009	mg/kg	6	6	1.23	0.97	3.1	0.54
			ug/l	173	44	101.69	86.67	253	1.168
		2010-2019	ug/l	367	40	163.38	92.76	426	0.067
		2020-2029	ug/l	323	-	-	-	-	-
Sulfur hexafluoride	**Water**	2000-2009	fg/kg	11	11	800.55	559.84	1830	435
		2010-2019	fg/kg	8	8	1279.25	1646.49	4010	182
Tellurium	**Water**	2000-2009	ug/l	17	17	0.41	0.26	1.12	0.072

Organics. Organic environmental contaminants are a diverse group of chemicals that pose a broad range of potential ecological risks. Organics encompass pesticides, herbicides, hydrocarbons, pharmaceuticals, fire/flame retardants, solvents, plasticizers, dyes, and surfactants. We have grouped organics into pesticides and herbicides, polychlorinated biphenyls (PCBs), and others (which includes hydrocarbons, pharmaceuticals, fire/flame retardants, solvents, plasticizers, dyes, and surfactants).

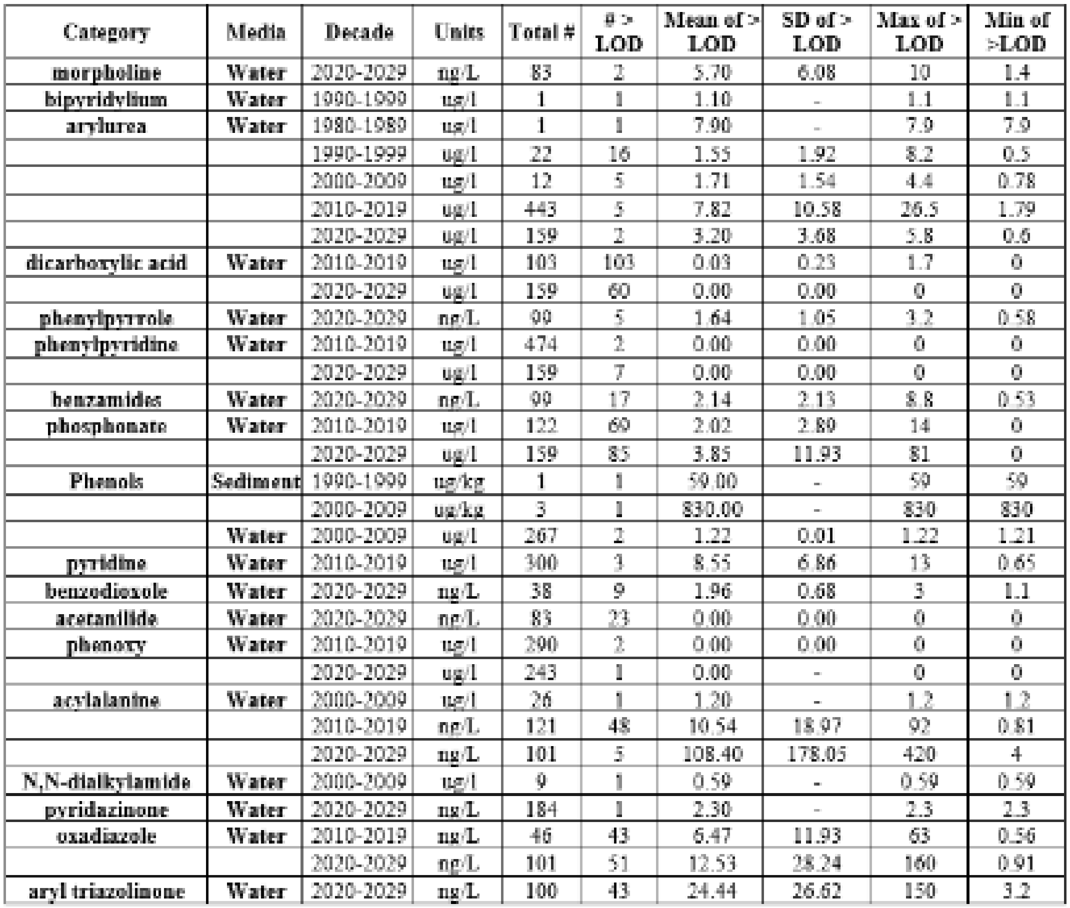
Organics – pesticides and herbicides. Organic pesticides and herbicides are widely used in agriculture, and while these compounds are designed to target specific pests or plants, they can also pose risks to aquatic ecosystems when they enter water bodies through runoff, spray drift, or leaching. They can cause acute or chronic toxicity to a wide range of aquatic organisms, including fish, invertebrates, amphibians, and algae. Some organic pesticides and herbicides have the potential to bioaccumulate in aquatic organisms, particularly those with lipophilic properties. Once absorbed, these compounds can biomagnify through the food chain, leading to higher concentrations in predators compared to their prey. Some herbicides inhibit photosynthesis or interfere with plant growth hormones, leading to reduced biomass, altered community structure, and habitat degradation in aquatic ecosystems. The persistence of organic pesticides and herbicides in aquatic environments varies depending on factors such as chemical structure, environmental conditions, and microbial activity. Some compounds may degrade rapidly, while others can persist for extended periods, increasing the likelihood of long-term exposure and accumulation in aquatic ecosystems (Table 114).

Table 114. Summary of pesticides and herbicides database, including, the media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.

Category	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
Persistent, Bioaccumulative, and Toxic (PBT) Chemicals	**Sediment**	1970-1979	ug/kg	4	1	13.00	-	13	13
		1990-1999	ug/kg	9	9	45.67	101.64	310	1
		2000-2009	ng/g	181	11	47.47	45.54	123.13	0.6
			ppb	1	1	6.20	-	6.2	6.2
			ug/kg	177	2	5.20	2.26	6.8	3.6
		2010-2019	ug/kg	175	13	2.54	1.68	6.2	0.59
	Water	1960-1969	ug/kg	196	54	7.22	9.82	62	0.5
			ug/l	363	1	0.50	-	0.5	0.5
		1970-1979	ug/kg	2783	793	80.05	683.70	13000	0.5
			ug/l	2574	4	0.50	0.00	0.5	0.5
		1980-1989	ug/kg	197	76	10.79	24.24	150	0.5
			ug/l	646	23	2.07	1.76	8.331	0.594
		1990-1999	ug/kg	6	1	0.80	-	0.8	0.8
			ug/l	2155	2	0.98	0.46	1.3	0.65
		2000-2009	ug/kg	14	14	13.47	18.12	64	0.83
		2010-2019	ng/L	1099	2	107.50	130.81	200	15
		2020-2029	ng/L	749	1	0.92	-	0.92	0.92
neonicotinoid	**Water**	2010-2019	ug/l	635	1	1.40	-	1.4	1.4
Neutral organic	**Sediment**	2000-2009	ng/g	1	1	22.00	-	22	22
organochloride	**Sediment**	1970-1979	ug/kg	3	1	0.00	-	0	0
		1990-1999	ug/kg	2	2	16.00	0.00	16	16
		2000-2009	ng/g	109	34	1.08	0.34	2.4	0.9
			ug/kg	106	19	11.63	39.24	170	0
		2010-2019	ug/kg	97	14	2.45	5.04	15	0
	Water	1970-1979	ug/kg	2640	272	69.55	312.76	5000	1
			ug/l	2259		-	-	-	-
		1980-1989	ug/kg	217	51	35.26	53.76	210	1
			ug/l	721	103	0.42	0.96	5.185	0
		1990-1999	ug/kg	4	4	12.75	19.55	42	1
			ug/l	1308	5	2.83	3.52	9.1	0.67
		2000-2009	ug/kg	2	2	34.00	11.31	42	26
			ug/l	946	16	0.00	0.00	0	0
		2010-2019	ng/L	612	66	0.67	5.42	44	0
			ug/l	34	21	0.50	0.00	0.5	0.5
		2020-2029	ng/L	545	40	0.00	0.00	0	0
organophosphate	**Water**	1970-1979	ug/kg	1470	32	13.48	15.45	55	0.7
			ug/l	3032	4	1.99	1.22	3.1	0.87
		1980-1989	ug/kg	125	3	1.53	0.84	2.5	1
		1990-1999	%	136	1	106.00	-	106	106
			ug/l	674	3	2.96	3.83	7.39	0.67
		2000-2009	%	113	1	107.00	-	107	107
			ug/kg	1	1	17.00	-	17	17
			ug/l	288	1	1.40	-	1.4	1.4
		2010-2019	%	9	1	107.00	-	107	107
			ng/L	1060	8	1.99	1.31	4.8	0.68
		2020-2029	ng/L	1504	1	4.20	-	4.2	4.2
			ug/l	160	13	0.00	0.00	0	0
phenylpyrazole	**Water**	2000-2009	ug/l	6	2	0.01	0.00	0.014	0.013
		2010-2019	ng/L	349	79	1.39	1.46	9.3	0.52
		2020-2029	ng/L	404	41	0.98	0.47	2.5	0.5
Soluble complexes of Zinc	**Water**	1980-1989	mg/l	10	10	4.00	1.63	6	2



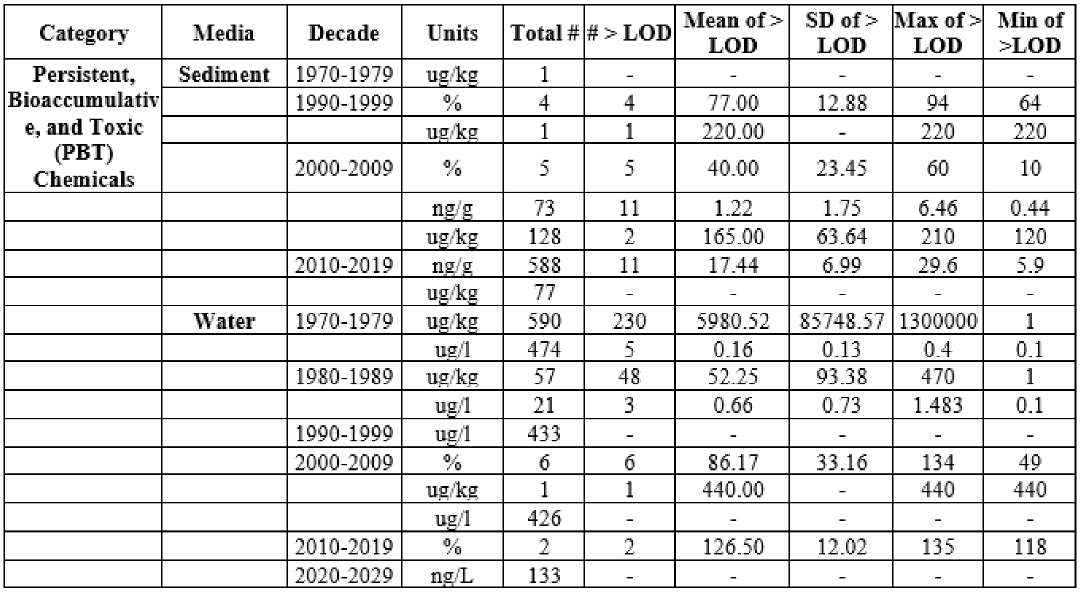
Category	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
		1990-1999	ug/l	1	1	25.70	-	25.7	25.7
chloroacetanilide	**Water**	1990-1999	ug/l	138	4	1.09	0.79	2.2	0.5
		2000-2009	ug/l	183	4	0.68	0.06	0.72	0.598
		2010-2019	ng/L	295	41	0.00	0.00	0	0
			ug/l	23	1	0.03	-	0.03	0.03
		2020-2029	ng/L	303	64	0.00	0.00	0	0
carbamate	**Water**	1990-1999	ug/l	112	1	90.50	-	90.5	90.5
		2000-2009	ug/l	18	1	1.80	-	1.8	1.8
triazine	**Sediment**	2010-2019	ug/kg	77	1	0.00	-	0	0
	Water	1980-1989	ug/l	19	17	3.75	4.50	13.2	0.5
		1990-1999	ug/l	1215	182	1.80	2.16	18	0.5
		2000-2009	ug/kg	6	6	11.63	5.80	21	4.7
			ug/l	1763	204	1.69	1.59	11	0.5
		2010-2019	ng/L	1037	118	1.14	1.88	9.7	0
			None	4	4	1.25	0.23	1.539	1.04
			ug/l	499	98	0.19	0.16	0.79	0
		2020-2029	ng/L	909	43	1.03	1.94	9.8	0
			ug/l	6	2	0.61	0.06	0.65	0.56
ß-methoxyacrylate	**Water**	2020-2029	ng/L	99	20	32.04	67.48	290	3.1
dinitroaniline	**Water**	2020-2029	ng/L	141	20	0.00	0.00	0	0
thiadiazine	**Water**	2010-2019	ug/l	573	5	0.69	0.02	0.73	0.68
		2020-2029	ug/l	159	2	1.66	1.61	2.8	0.52
pyrazole-carboxamide	**Water**	2020-2029	ng/L	99	35	7.21	18.67	100	0.5
substituted uracil	**Water**	1990-1999	ug/l	50	10	1.45	1.00	3.39	0.54
		2000-2009	ug/l	46	1	0.51	-	0.51	0.51
triazole	**Water**	2010-2019	ng/L	46	3	2.57	0.64	3.3	2.1
		2020-2029	ng/L	681	48	50.25	182.47	1100	1.8
organobromide	**Water**	2010-2019	ug/l	1	1	0.80	-	0.8	0.8
Heterocyclic	**Sediment**	1990-1999	ug/kg	2	2	33.50	3.54	36	31
	Water	2000-2009	%	2	2	117.50	2.12	119	116
benzoic acid	**Water**	2010-2019	ug/l	1	1	0.00	-	0	0
		2020-2029	ng/L	40	36	0.00	0.00	0	0
thiocarbamate	**Water**	2010-2019	ng/L	246	1	12.00	-	12	12
anilinopyrimidine	**Water**	2020-2029	ng/L	83	4	1.90	1.36	3.7	0.7
chloroacetamide	**Water**	2010-2019	ng/L	46	30	2.71	10.62	58	0
		2020-2029	ng/L	101	7	4.77	4.50	11	0.48
phenylurea	**Water**	1990-1999	ug/l	11	1	4.42	-	4.42	4.42
		2010-2019	ug/l	585	103	0.00	0.00	0	0
		2020-2029	ug/l	318	43	0.00	0.00	0	0
phthalate	**Water**	1980-1989	ug/l	72	72	0.29	1.30	8.9	0
		1990-1999	ug/l	321	13	26.57	26.41	85	0.68
		2000-2009	ug/l	201	32	4.57	3.69	18.75	1.98
		2010-2019	ug/l	1	1	0.00	-	0	0
benzonitrile	**Water**	2020-2029	ng/L	38	38	0.00	0.00	0	0
chlorophenoxy	**Water**	1970-1979	ug/kg	221	2	5.05	6.29	9.5	0.6
			ug/l	621	17	14.72	47.94	200	0.52
		1980-1989	ug/kg	22	3	2.57	0.98	3.7	2
			ug/l	58	5	2.49	3.10	7.9	0.59
		1990-1999	ug/l	210	14	8.22	9.14	29	0.545
		2000-2009	ug/l	111	8	2.06	1.87	6.4	0.53
		2010-2019	ug/l	479	108	0.13	0.54	3.7	0
		2020-2029	ug/l	159	79	0.02	0.17	1.5	0



Category	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
morpholine	**Water**	2020-2029	ng/L	83	2	5.70	6.08	10	1.4
bipyridylium	**Water**	1990-1999	ug/l	1	1	1.10	-	1.1	1.1
arylurea	**Water**	1980-1989	ug/l	1	1	7.90	-	7.9	7.9
		1990-1999	ug/l	22	16	1.55	1.92	8.2	0.5
		2000-2009	ug/l	12	5	1.71	1.54	4.4	0.78
		2010-2019	ug/l	443	5	7.82	10.58	26.5	1.79
		2020-2029	ug/l	159	2	3.20	3.68	5.8	0.6
dicarboxylic acid	**Water**	2010-2019	ug/l	103	103	0.03	0.23	1.7	0
		2020-2029	ug/l	159	60	0.00	0.00	0	0
phenylpyrrole	**Water**	2020-2029	ng/L	99	5	1.64	1.05	3.2	0.58
phenylpyridine	**Water**	2010-2019	ug/l	474	2	0.00	0.00	0	0
		2020-2029	ug/l	159	7	0.00	0.00	0	0
benzamides	**Water**	2020-2029	ng/L	99	17	2.14	2.13	8.8	0.53
phosphonate	**Water**	2010-2019	ug/l	122	69	2.02	2.89	14	0
		2020-2029	ug/l	159	85	3.85	11.93	81	0
Phenols	**Sediment**	1990-1999	ug/kg	1	1	59.00	-	59	59
		2000-2009	ug/kg	3	1	830.00	-	830	830
	Water	2000-2009	ug/l	267	2	1.22	0.01	1.22	1.21
pyridine	**Water**	2010-2019	ug/l	300	3	8.55	6.86	13	0.65
benzodioxole	**Water**	2020-2029	ng/L	38	9	1.96	0.68	3	1.1
acetanilide	**Water**	2020-2029	ng/L	83	23	0.00	0.00	0	0
phenoxy	**Water**	2010-2019	ug/l	290	2	0.00	0.00	0	0
		2020-2029	ug/l	243	1	0.00	-	0	0
acylalanine	**Water**	2000-2009	ug/l	26	1	1.20	-	1.2	1.2
		2010-2019	ng/L	121	48	10.54	18.97	92	0.81
		2020-2029	ng/L	101	5	108.40	178.05	420	4
N,N-dialkylamide	**Water**	2000-2009	ug/l	9	1	0.59	-	0.59	0.59
pyridazinone	**Water**	2020-2029	ng/L	184	1	2.30	-	2.3	2.3
oxadiazole	**Water**	2010-2019	ng/L	46	43	6.47	11.93	63	0.56
		2020-2029	ng/L	101	51	12.53	28.24	160	0.91
aryl triazolinone	**Water**	2020-2029	ng/L	100	43	24.44	26.62	150	3.2

Organics – polychlorinated biphenyls. Polychlorinated biphenyls (PCBs) are synthetic organic chemicals that were widely used in industrial applications such as electrical equipment, hydraulic fluids, and insulation materials before their production was banned or restricted due to their environmental persistence and toxicity. However, PCBs continue to pose significant risks to aquatic ecosystems due to their persistence, bioaccumulative nature, and ability to biomagnify through food chains. PCBs are highly stable compounds that resist degradation in the environment, resuting in chronic environmental exposures to low concentrations and toxicity to a wide range of aquatic organisms, including fish, invertebrates, amphibians, and algae. These compounds can disrupt various physiological processes, including hormonal regulation, immune function, reproductive function, and neurological development. Chronic exposure to PCBs can lead to adverse health effects such as reduced growth and reproduction, developmental abnormalities, immune suppression, and increased susceptibility to diseases. PCBs are known to act as endocrine disruptors, interfering with the normal functioning of hormones in aquatic organisms which can lead to reproductive disorders, feminization or masculinization of individuals, and impaired development of reproductive organs (Table 115).

Table 115. Summary of polychlorinated biphenyls database, including, for each, the media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.



Category	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
Persistent, Bioaccumulative, and Toxic (PBT) Chemicals	**Sediment**	1970-1979	ug/kg	1	-	-	-	-	-
		1990-1999	%	4	4	77.00	12.88	94	64
			ug/kg	1	1	220.00	-	220	220
		2000-2009	%	5	5	40.00	23.45	60	10
			ng/g	73	11	1.22	1.75	6.46	0.44
			ug/kg	128	2	165.00	63.64	210	120
		2010-2019	ng/g	588	11	17.44	6.99	29.6	5.9
			ug/kg	77	-	-	-	-	-
	Water	1970-1979	ug/kg	590	230	5980.52	85748.57	1300000	1
			ug/l	474	5	0.16	0.13	0.4	0.1
		1980-1989	ug/kg	57	48	52.25	93.38	470	1
			ug/l	21	3	0.66	0.73	1.483	0.1
		1990-1999	ug/l	433	-	-	-	-	-
		2000-2009	%	6	6	86.17	33.16	134	49
			ug/kg	1	1	440.00	-	440	440
			ug/l	426	-	-	-	-	-
		2010-2019	%	2	2	126.50	12.02	135	118
		2020-2029	ng/L	133	-	-	-	-	-

Organics – other. This contaminant category includes hydrocarbons (Neutral organics in the database), pharmaceuticals, fire/flame retardants, solvents, plasticizers, dyes, and surfactants. Hydrocarbons are organic compounds that can enter aquatic environments through natural sources such as oil seeps or anthropogenic activities such as oil spills and runoff from urban areas. Hydrocarbons, particularly petroleum hydrocarbons, can have toxic effects on aquatic organisms, including fish, invertebrates, and plankton. These chemicals can disrupt cellular membranes, impair respiratory function, and cause oxidative stress. Many hydrocarbons are also solvents; solvents such as benzene, toluene, ethylbenzene, and xylene (BTEX) are toxic to aquatic organisms and can cause respiratory distress, neurological effects, and developmental abnormalities. Chronic exposure to solvents can also impair reproductive function and reduce survival rates in fish and other aquatic organisms.

Pharmaceuticals are a diverse group of synthetic and natural compounds; residues in water bodies can have adverse effects on aquatic organisms, including fish, invertebrates, and algae. Chronic exposure to low concentrations of pharmaceuticals can disrupt endocrine function, impair reproductive success, and alter behavior in aquatic organisms. Antibiotics and hormones in particular have been of concern due to their potential to promote antibiotic resistance and disrupt hormone balance in aquatic ecosystems.

Organohalides (compounds containing carbon, hydrogen, and halogen atoms such as chlorine, bromine, or fluorine) are a common environmental contaminant which exhibit varying levels of aquatic toxicity depending on their structure, concentration, and the specific organism exposed. The toxicity of organohalides often correlates with the number and arrangement of halogen atoms; generally, compounds with multiple halogen substituents are more toxic due to increased hydrophobicity and bioaccumulation potential. Organohalides can exert toxicity through various mechanisms, including disruption of cell membranes, interference with enzyme function, and alteration of hormonal regulation (Table 116).

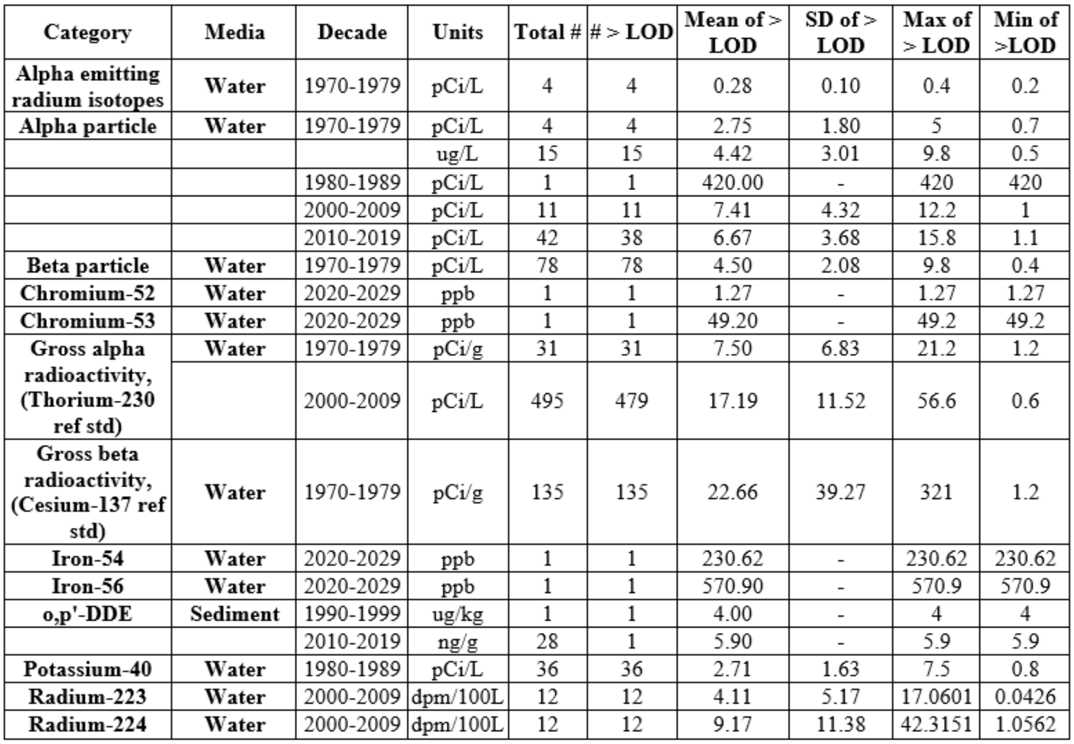
Table 116. Summary of other organics database, including, for each category, the media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant

Category	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
Anilines	**Water**	1990-1999	ug/l	195	78	0.00	0.00	0	0
		2000-2009	ug/l	218	126	0.00	0.00	0	0
		2010-2019	ug/l	12	12	0.75	0.45	1	0
Esters	**Sediment**	1990-1999	ug/kg	8	-	-	-	-	-
	Water	1980-1989	ug/l	335	18	26.20	13.59	54	11
		1990-1999	ug/l	642	216	0.00	0.00	0	0
		2000-2009	ug/l	444	204	0.00	0.06	0.8	0
		2010-2019	ug/l	125	-	-	-	-	-
		2020-2029	ug/l	159	-	-	-	-	-
Heterocyclic	**Water**	1990-1999	ug/l	143	39	0.00	0.00	0	0
		2000-2009	ug/l	105	7	0.00	0.00	0	0
		2010-2019	ug/l	655	16	0.00	0.00	0	0
		2020-2029	ng/L	83	83	0.00	0.00	0	0
			ug/l	318	157	0.00	0.00	0	0
hormone	**Water**	2000-2009	ug/l	14	14	0.00	0.00	0	0
Hydrazines and related	**Water**	2000-2009	ug/l	69	2	0.00	0.00	0	0
Neutral organic	**Sediment**	1990-1999	%	2	2	110.00	0.00	110	110
			ug/kg	26	10	92.60	91.31	260	18
		2000-2009	%	5	5	121.80	52.91	187	71
			ng/g	409	50	3.03	5.18	22	0
			ug/kg	406	107	383.35	643.56	2500	0
		2010-2019	%	13	13	80.45	9.23	98.4	67.4
			ng/g	672	142	-	-	-	-
			ug/kg	275	73	59.39	182.38	1000	0
	Water	1990-1999	%	20	-	-	-	-	-
			mg/l	2	2	0.00	0.00	0	0
			ug/l	5089	1098	0.02	0.51	17	0
		2000-2009	%	12	12	64.65	16.15	84	37.8
			mg/l	8	8	0.28	0.40	1.1	0
			ug/l	3798	1052	0.02	0.24	6.93	0
		2010-2019	%	28	14	67.87	13.12	85.7	50.2
			mg/l	2	2	0.16	0.05	0.19	0.12
			ug/l	112	28	0.11	0.34	1.5	0
		2020-2029	ng/L	61	-	-	-	-	-

Category	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
NSAID	**Water**	2010-2019	ug/l	256	256	0.00	0.01	0.14	0
		2020-2029	ug/l	318	318	0.00	0.00	0	0
Organic dye	**Water**	1970-1979	mg/l	616	616	0.14	0.56	9	0
		1980-1989	mg/l	47	47	0.15	0.19	1	0
		1990-1999	mg/l	8	8	0.13	0.02	0.16	0.1
		2010-2019	mg/l	10	10	0.04	0.06	0.147	0
organochloride	**Sediment**	1990-1999	ug/kg	1	1	33.00	-	33	33
		2000-2009	ng/g	1	1	0.00	-	0	0
		2010-2019	ng/g	28	28	-	-	-	-
		1980-1989	ug/l	18	-	-	-	-	-
	Water	1990-1999	ug/l	5032	1418	0.22	1.90	24.76	0
		2000-2009	ug/l	3310	1022	0.00	0.00	0	0
		2010-2019	ug/l	93	34	0.29	0.44	1	0
		2020-2029	ng/L	38	-	-	-	-	-
organomercury	**Sediment**	2000-2009	mg/kg	13	13	0.00	0.00	0.0017	0
		2010-2019	mg/kg	44	44	0.00	0.00	0.014	0
			ng/g	112	112	1.56	1.51	7.9	0.16
	Water	1990-1999	ng/L	637	637	0.13	0.19	1.8	0
		2000-2009	ng/L	1927	1927	0.29	0.68	12	0
		2010-2019	ng/L	359	359	0.15	0.22	3.1	0
		2020-2029	ng/L	44	44	0.13	0.21	1.25	0
organonitrogen	**Water**	1990-1999	ug/l	619	619	0.00	0.00	0	0
		2000-2009	ug/l	265	265	0.00	0.00	0	0
organophosphate	**Water**	1990-1999	ug/l	39	39	0.00	0.00	0	0
		2000-2009	ug/l	49	-	-	-	-	-
organosulfide	**Water**	1990-1999	ug/l	81	81	21.84	120.72	893	0
other	**Sediment**	2010-2019	mg/kg	8	8	336.25	274.22	1000	150
	Water	1970-1979	mg/kg	12	12	441.67	854.36	2400	0
			mg/l	656	656	9.12	23.82	420	0
		1980-1989	mg/kg	9	9	300.00	595.82	1400	0
			mg/l	180	180	0.74	1.72	11.6	0
		1990-1999	mg/l	166	166	0.18	1.31	10.8	0
			ug/l	39	-	-	-	-	-
		2000-2009	mg/l	128	128	0.88	1.67	7.7	0
			ug/l	56	14	0.00	0.00	0	0
		2010-2019	code	9	9	-	-	-	-
		2020-2029	ng/L	83	-	-	-	-	-
Phenols	**Water**	1990-1999	ug/l	1312	487	0.00	0.00	0	0
		2000-2009	%	12	-	-	-	-	-
			ug/l	959	412	0.00	0.00	0	0
		2010-2019	%	24	-	-	-	-	-
			ug/l	345	6	0.00	0.00	0	0
		2020-2029	ug/l	159	-	-	-	-	-
phytosterol	**Sediment**	2000-2009	ug/kg	5	3	2743.33	388.89	3190	2480
	Water	2000-2009	ug/l	9	3	0.00	0.00	0	0
		2010-2019	ug/l	1	-	-	-	-	-
Polynitroaromatic	**Water**	1990-1999	ug/l	398	199	0.00	0.00	0	0
		2000-2009	ug/l	254	29	0.00	0.00	0	0
		2010-2019	ug/l	51	-	-	-	-	-
sterol	**Water**	1990-1999	ug/l	39	39	0.00	0.00	0	0
		2000-2009	ug/l	43	14	0.00	0.00	0	0
UV filter	**Water**	2020-2029	ng/L	178	89	2.04	14.25	120	0

Radiochemicals. Radiochemicals, which encompass radioactive compounds used in various applications such as research, medicine, industry, and agriculture, can pose significant aquatic toxicity risks if released into aquatic environments. The primary concern with radiochemicals in aquatic environments is the radiation they emit; depending on the type of radiation (alpha, beta, gamma), these emissions can penetrate water and interact with aquatic organisms, causing damage to cells, DNA, and biological molecules. Chronic exposure to radiation can lead to genetic mutations, developmental abnormalities, and increased susceptibility to diseases in aquatic organisms. Some radiochemicals have the potential to bioaccumulate in aquatic organisms, particularly those with long half-lives and high lipid solubility. Once incorporated into the food web, these compounds can biomagnify, meaning their concentrations increase at higher trophic levels. Different radiochemicals exhibit varying degrees of aquatic toxicity. For example, radionuclides like cesium-137 and strontium-90, which are byproducts of nuclear activities, can mimic essential nutrients and be taken up by aquatic organisms, leading to internal radiation exposure and toxicity. Tritium, a radioactive form of hydrogen, can also integrate into water molecules, potentially causing cellular damage (Table 117).

Table 117. Summary of radiochemicals database, including the media (water or sediment), decade, measurement units, total number of datapoints, datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.



Category	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
Alpha emitting radium isotopes	**Water**	1970-1979	pCi/L	4	4	0.28	0.10	0.4	0.2
Alpha particle	**Water**	1970-1979	pCi/L	4	4	2.75	1.80	5	0.7
			ug/L	15	15	4.42	3.01	9.8	0.5
		1980-1989	pCi/L	1	1	420.00	-	420	420
		2000-2009	pCi/L	11	11	7.41	4.32	12.2	1
		2010-2019	pCi/L	42	38	6.67	3.68	15.8	1.1
Beta particle	**Water**	1970-1979	pCi/L	78	78	4.50	2.08	9.8	0.4
Chromium-52	**Water**	2020-2029	ppb	1	1	1.27	-	1.27	1.27
Chromium-53	**Water**	2020-2029	ppb	1	1	49.20	-	49.2	49.2
Gross alpha radioactivity, (Thorium-230 ref std)	**Water**	1970-1979	pCi/g	31	31	7.50	6.83	21.2	1.2
		2000-2009	pCi/L	495	479	17.19	11.52	56.6	0.6
Gross beta radioactivity, (Cesium-137 ref std)	**Water**	1970-1979	pCi/g	135	135	22.66	39.27	321	1.2
Iron-54	**Water**	2020-2029	ppb	1	1	230.62	-	230.62	230.62
Iron-56	**Water**	2020-2029	ppb	1	1	570.90	-	570.9	570.9
o,p'-DDE	**Sediment**	1990-1999	ug/kg	1	1	4.00	-	4	4
		2010-2019	ng/g	28	1	5.90	-	5.9	5.9
Potassium-40	**Water**	1980-1989	pCi/L	36	36	2.71	1.63	7.5	0.8
Radium-223	**Water**	2000-2009	dpm/100L	12	12	4.11	5.17	17.0601	0.0426
Radium-224	**Water**	2000-2009	dpm/100L	12	12	9.17	11.38	42.3151	1.0562

Category	Media	Decade	Units	Total #	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
Radium-226	**Water**	1970-1979	pCi/L	20	20	0.29	0.07	0.4	0.12
		2000-2009	pCi/L	83	79	0.54	0.67	4.4	0.0995
Radium-228	**Water**	2000-2009	pCi/L	26	26	1.58	0.42	2.39	1.08
Radon-222	**Water**	2000-2009	pCi/L	6	2	53.15	24.11	70.2	36.1
Selenium-78	**Water**	2020-2029	ppb	1	1	16.40	-	16.4	16.4
Thorium-232	**Water**	2000-2009	ug/L	13	13	0.03	0.03	0.093	0.002
Tritium	**Water**	2000-2009	pCi/L	14	10	57.70	83.58	211	4.8
		2010-2019	pCi/L	2	2	13.00	0.00	13	13
Uranium	**Water**	1970-1979	pCi/L	1	1	1.00	-	1	1
			ug/L	23	23	0.17	0.16	0.7	0.01
		2000-2009	ug/L	55	55	1.95	1.46	4.2	0.0457
		2010-2019	ug/L	9	9	0.37	0.27	0.852	0.091
Zinc-67	**Water**	2020-2029	ppb	1	1	5.92	-	5.92	5.92
Zinc-68	**Water**	2020-2029	ppb	1	1	3.28	-	3.28	3.28

Coral toxicological data.

The compiled toxicological data for scleractinian corals was evaluated in the context of the environmental monitoring data on the FCR, to establish existing knowledge gaps and identify any emerging contaminants of concern. To facilitate this comparison, marine-only data is summarized in the table below.

Cyanotoxins. While research on the specific impacts of cyanotoxins on corals is still evolving, several studies have highlighted potential mechanisms and consequences of cyanotoxin exposure to corals. Field observations have documented the presence of cyanobacteria and cyanotoxins in coral reef environments, particularly in areas impacted by nutrient pollution and eutrophication (LaPointe et al. 2010). Direct toxicity can result in disruption of cellular processes and tissue damage; cyanotoxins can inhibit protein phosphatases, enzymes crucial for cellular regulation, leading to oxidative stress, apoptosis (programmed cell death), and necrosis in coral tissues (Harland et al. 2013). Some cyanobacteria produce allelopathic compounds that can inhibit the growth and reproduction of other organisms, including corals. These allelochemicals may compete with corals for space and resources on the reef, leading to reduced coral fitness and reef decline (Lirman 2001). Indirect effects can include alteration of composition and dynamics of coral-associated microbial communities. Shifts in microbial symbionts or the proliferation of harmful bacteria in response to cyanotoxin exposure may disrupt coral health and increase susceptibility to diseases. Some studies suggest a potential association between cyanobacterial blooms and coral bleaching events; these blooms can coincide with declines in coral health and reef degradation LaPointe et al. 2010). There is currently no toxicity data available for corals or other cnidarians, but microcystin has been linked to black band disease (Arotsker et al., 2016; Gantar et al., 2009; Glas et al., 2010; Richardson et al., 2009; Richardson et al., 2007).

Inorganics – metals. Trace metals are ubiquitous in the environment, and while low background concentrations are natural and potentially necessary to living organisms, increased and potentially toxic levels are common closer to urbanized areas. Metals are also known to bioaccumulate in coral skeletons and have been used to measure historical water quality. Metals and their toxicity to corals is one of the most studied groups, second only to pesticides (Ouedraogo et al., 2023). However, these studies often only look at toxicity to one metal at a time, whereas in nature several metals are likely contributing to contamination in an area and may have additive effects (Negri, et al., 2011). Also, only a few metals, such as copper, could be considered well-represented in the literature with toxicity data on multiple species at multiple life stages. Trace metal contamination in the aquatic environment is associated with shipping (in anti-fouling coatings), industrial operations, and terrestrial runoff contaminated with organometallic chemicals (Haynes and Johnson, 2000). Metals are highly particle reactive, and thus can occur in higher concentrations in sediments as opposed to the water column. This places sessile benthic organisms, such as corals, at high risk of contact with contaminated sediments. Scleractinian corals may both absorb metals into their tissues and incorporate metals into their calcium carbonate skeleton (Mitterer, 1978; Howard and Brown, 1984; Bastidas and Garcia, 1997; Esslemont, 1999; Al-Rousan et al., 2007, Mitchelmore et al., 2007). As trace metals are essential to many biological processes, elevated metal concentrations have been observed to both enhance zooxanthellae-supported calcification (Harland and Brown, 1989; Marshall, 2002; Reichelt-Brushett and McOrist, 2003) and reduce metabolism, growth and calcification (Howard and Brown, 1987). Bleaching and reductions in photosynthetic efficiency is also commonly observed, although less frequently at low concentrations (Nyström et al., 1997; Harland and Brown, 1989; Jones, 2004; Alutoin et al., 2001; Grant et al., 2003; Markey et al., 2007). Early life history stages are particularly sensitive to even low concentrations of copper, which inhibits fertilization, settlement, and larval metamorphosis (Reichelt-Brushett and Harrison, 1999; Reichelt-Brushett and Harrison, 2000; Negri and Heyward, 2001; Negri et al., 2002; Reichelt-Brushett and Harrison, 2005; Victor and Richmond, 2005). Overall, metals and organometallics are of particular concern as environmental concentrations may exceed established threshold levels for corals, especially in or near port or harbor environments (Reichelt-Brushett and McOrist, 2003). Chronic exposures to even low levels may reduce health and resilience and increase susceptibility to disease on reefs adjacent to such urban locations. Toxicity data summaries for individual metals are provided below.

- Aluminum: Negri et al. (2011) reported that aluminum was less toxic to *Acropora tenuis* than copper, nickel, cadmium and zinc with EC_{50} values for fertilization and settlement inhibition of 2950 µg/L and 1960 µg/L respectively. This is generally higher than the average measured concentrations in the water, however some measurements exceeded these values. Sediment concentrations have routinely exceeded these values.

- Barium: No toxicity data was found, but barium has found in coral skeletons and Ba/Ca ratios are often used as environmental indicators (Chen et al., 2011; Leonard et al., 2019; Weerabaddana et al., 2021).

- Beryllium: No toxicity data was found, but it has been used to date very old corals (Lal et al., 2005).

- Cadmium: Toxicity data examining the effects of cadmium on corals exists but is highly variable. A study assessing fertilization inhibition found that concentrations as high as 200 and 1000 µg/L did not reduce fertilization success in gametes of *Goniastrea aspera* and *Oxypora lacera*, respectively (Reichelt-Brushett & Harrison, 1999). Another study using *Acropora tenuis* gametes had comparatively high lowest observed effect concentrations (LOEC) of 5000 µg/L for reduced fertilization success (Reichelt-Brushett & Harrison, 2005). However, in *Pocillopora damicornis* adults, reduced symbiont density and changes in enzymatic activity and gene expression were detected at concentrations of 20 µg/L; tissue sloughing and partial mortality were observed at 50 µg/L (Mitchelmore et al., 2007; Zhou et al., 2018). This suggests that adult corals may be more sensitive to cadmium exposure than other life stages. Only a small percentage of environmental measurements are above the detection limits for cadmium, but more effects data is needed.

- Chromium: There is limited toxicity data available for chromium, but Xiao et al. (2023) found that concentrations as low as 10 µg/L affected the density, chlorophyll content, and apoptosis in algal symbionts in *Acropora pruinosa,* which could lead to coral bleaching. Additionally, while not a toxicity study, Dal Pizzol et al. (2022) found that increasing concentrations of chromium correlated with inhibition of carbonic anhydrase and increased oxidative damage in the hydrocoral *Millepora alcicornis*. Aquatic chromium concentrations have exceeded this value, and more toxicity data is needed to understand the full extent of effects chromium may have on the coral holobiont.

- Cobalt: Cobalt is an important part of vitamin B12 and is therefore a necessary nutrient for the metabolism of animals and plants (Reichelt-Brushett & Hudspith, 2016). However, there is limited toxicity data to corals. High levels of cobalt (2500 µg/L) did not affect fertilization success of *Platygyra daedalea* gametes, and neither did high levels of cobalt mixed with nickel (Reichelt-Brushett & Hudspith, 2016). However, growth rates of adult *Acropora muricata* and *Stylophora pistillata* decreased significantly at 0.2 µg/L, and photosynthesis was inhibited at 1.06 µg/L (Biscéré et al., 2015). This threshold is close to the average cobalt concentrations in the water, so more research is needed to understand the full scope of effects. According to (Reichelt-Brushett & Hudspith, 2016), the ANZECC and ARMCANZ (2000) trigger value for cobalt to protect 95% of species is 1 µg/L.

- Copper: The effects of copper on a variety of invertebrates, including corals, is well-studied and well understood and it is often used as a reference toxicant in other ecotoxicological studies (Summer et al., 2019). It is extremely toxic to corals with adverse effects being observed at concentrations as low as 1 µg/L (Banc-Prandi & Fine, 2019; Fonseca et al., 2017; Hedouin et al., 2016; Marangoni et al., 2017; Nalley et al., 2021) and mortality observed at concentrations as low as 10 µg/L for larva and 40 µg/L for adult corals (Hedouin et al., 2016; Jones, 1997; Kwok & Ang, 2013; Kwok et al., 2016; Nalley et al., 2021; Reichelt-Brushett & Harrison, 2004). Copper concentrations routinely exceed the lower effect concentration values and should continue to be monitored.

- Iron: Iron is an essential nutrient required for electron transport and is often a limiting factor for primary productivity in the oceans, including potentially limiting photosynthesis in coral symbionts (Dellisanti et al., 2024). However, it can become toxic at high levels. Leigh-Smith et al. (2018) found that the LC_{50} for *Platygyra daedalea* was 47 mg/L after 72 hours and EC_{50} for fertilization success of *Platygyra daedalea* and *Acropora spathulata* were between 44-60 mg/L. However, Harland and Brown (1989) found that concentrations as low as 0.05 mg/L significantly reduced symbiont density in *Porites lutea*. However, it has also been observed that corals may be able to develop a tolerance to higher levels of iron over time (Harland & Brown, 1989). Measured dissolved concentrations have occasionally exceeded the lower limit of these concentrations and measured sediment concentrations have routinely exceeded these thresholds.

- Lead: There is some toxicity data discussing the effects of lead to four species of corals. The EC_{50} values for fertilization inhibition were 1450– 1800 µg/L for *A. tenuis* and *A. longicyathus*, and >2400 µg/L for *Goniastrea aspera* gametes (Reichelt-Brushett & Harrison, 2005). When *G. aspera* larva were exposed to lead an EC_{50} for larval motility of 2900 µg/L and an LC_{50} of 9190 µg/L was established after 72 hours. This is significantly higher than the larval LC_{50} found for *P. damicornis* after 96 hours (681 µg/L) (Hedouin et al., 2016). Adult *P. damicornis* was found to have a 96-hour LC_{50} of 742 µg/L (Hedouin et al., 2016). Additionally, Hedouin et al. (2016) examined if the LC_{50} values would change under elevated temperatures (+3°C) and found that the LC_{50} values were reduced to 477 µg/L and 462 µg/L for adults and larva, respectively. Measured environmental concentrations generally do not exceed these thresholds.

- Manganese: There are a few studies describing manganese toxicity to coral gametes, larva, and adults, but overall results are unclear. Summer et al. (2019) found EC_{50} values of 237 mg/L and 164 mg/L for fertilization success in *Acropora spathulata* and *Platygyra daedalea* respectively, after a 5.5-hour exposure. Additionally, *A. spathulata* larva was calculated to have an LC_{50} of 7 mg/L after 72 hours. However, an acute 48-hour exposure on adult *A. muricata*, resulted in an EC_{50} value of 824 µg/L for tissue sloughing (partial mortality), which is significantly lower than the previous experiment (Binet et al., 2023). Therefore, a chronic exposure would be expected to have an even lower effect concentration, but another 48-hour acute and 14-day chronic exposure did not have any effects on *A. millepora* adults at concentrations of 2560 µg/L and 1090 µg/L respectively (Golding et al., 2023). More research needs to be done to validate these effects and conoder potential differences between species.

- Mercury: Toxicity data of mercury to corals is lacking. Farina et al. (2008) found that concentrations of 10 µg/L did not affect *Porites asteroides* larval survival after 48 hours and Bastidas and García (2004) found that symbiont density and chlorophyll decreased at 180 µg/L in adult *P. asteroides*. Much more research needs to be done to find the toxicity thresholds for mercury, as concentrations above these levels have previously been found in the environment.

- Nickel: Based on currently available data, adult corals appear to be more sensitive to nickel than gametes, and there appears to be significant variation between species. According to Reichelt-Brushett and Hudspith (2016), *Platygyra daedalea* gametes had an EC_{50} value of 1420 µg/L for fertilization success, but Gissi et al. (2017) reported a much higher tolerance of the coral with an EC_{10} of >4610 µg/L. *Acropora aspera* and *A. digitifera* were seemingly more sensitive to nickel exposure with a no effect concentration (NOEC) of <280 µg/L and an EC_{10} of 2000 µg/L respectively (Gissi et al., 2017). In *A. muricata* and *P. damicornis* adults, growth rates were significantly reduced at nickel concentrations of 2.71 µg/L, much lower than the effects seen for gametes (Biscere et al., 2017). In other studies, *A. muricata* has experienced bleaching at dissolved concentrations of 200µg/L – 470 µg/L (Gillmore et al., 2020; Gissi et al., 2019). Measured environmental concentrations occasionally exceed these dissolved thresholds. Additionally, Gillmore et al. (2020) looked at the effect of nickel-spiked suspended sediments on *A. muricata*. This study found that bleaching occurred with only 5 mg/L of total suspended sediment that had a nickel concentration of 6300 mg/kg after seven days and with 30 mg/L of total suspended sediment with a nickel concentration 240 mg/kg after 14 days (Gillmore et al., 2020). This is only one of two studies to examine the effects of contaminated sediment on corals, which is important to evaluate risks from sediment associated contaminants.

- Silver: A single study found that silver nanocolloids (SNCs), which are commonly used in hygiene products for their antibacterial activity, had significant negative impacts on *Acropora japonica* fertilization, larval metamorphosis, and early polyp growth at concentrations of 50 µg/L (Suwa et al., 2014). Measured average environmental concentrations are generally much lower than this value, but more research is needed on different forms of silver and at all coral life stages to fully understand the potential impacts.

- Tin: There is some toxicity data on tin in the form of tributyltin, which is a common additive in antifouling paint. This compound has been shown to be extremely toxic to early life stages of corals. Juvenile growth and symbiont density of *A. tenuis* decreased significantly at concentrations of 0.4 µg/L and 1 µg/L, respectively (Watanabe et al., 2007; Watanabe et al., 2006). Larval metamorphosis of *A. millepora* had an IC50 value of 2.0 µg/L, which was significantly lower than the IC_{50} value of copper in the same experiment (110 µg/L) (Negri & Heyward, 2001). TBT did appear to be less toxic to gametes, however, with an IC_{50} of 200 µg/L (Negri & Heyward, 2001). Additionally, Smith et al. (2003) looked at the toxicity of contaminated sediment which contained a mixture of TBT, copper, and zinc. They found that newly settled *A. microphthalma* exposed to sediments containing a mixture 8.0 mg/kg TBT, 72 mg/kg Cu, and 92 mg/kg Zn significant mortality after 72 hours; recruits exposed to 40 mg/kg TBT, 306 mg/kg Cu, and 403 mg/kg Zn all died within 38 hours; and branchlets from adult *A. formosa* exposed to 160 mg/kg TBT, 1,180 mg/kg Cu, and 1,570 mg/kg Zn suffered significant mortality (Smith et al., 2003). While it is impossible to discern the individual effects of TBT from this experiment, it is one of the only experiments to look at the effects of contaminated sediment and a mixture of contaminants, which is much more similar to how they occur in nature. Recent environmental measurements have not detected tin, but historical sediment concentrations exceeded the thresholds listed here.

- Titanium: Jovanovic and Guzmán (2014) reported that titanium dioxide caused significant bleaching in *Montastrea* cavernosa colonies at concentrations on 100 µg/L, which is below current measured environmental averages. However, when corals were exposed to modified, commercially available forms of titanium dioxide (Eusolex ®T200 and Optisol), no significant effects were observed on *Acropora spp.* (Corinaldesi et al., 2018). More research is needed however, as there have been fairly high measured environmental concentrations recently.

- Vanadium: Negri et al. (2011) reported EC50 values of 2884 µg/L and 675 µg/L for decreased *Acropora millepora* fertilization success and inhibition of metamorphosis, respectively. There is currently no toxicity data available for adult corals. Current environmental measurements do not exceed these thresholds.

- Zinc: Fertilization success in *G. aspera* was not affected by concentrations of zinc up to 500 µg/L (Reichelt-Brushett & Harrison, 1999). However, *A. tenuis* gametes showed decreased fertilization rates at concentrations as low as 10µg/L with no fertilization occurring at all at concentrations of 5000 µg/L (Reichelt-Brushett & Harrison, 2005). In adult *A. aspera*, symbiont density was not significantly different from controls after a 96-hour exposure to 1000µg/L of zinc (Elisabeth et al., 2018). In the form of zinc oxide (commonly in sunscreens), concentrations of 6300 µg/L induced severe and rapid coral bleaching in *Acropora spp*., and membrane lipid metabolism was altered in *Seriatopora caliendrum* at concentrations as low as 50 µg/L (Corinaldesi et al., 2018; Tang et al., 2017). Measured environmental concentrations have exceeded these values.

Inorganics – non-metals.

- Antimony: There is currently no toxicity data for corals available, but antimony has been found within coral skeletons (Edinger et al., 2008).

- Arsenic: There is currently no published toxicology data detailing the effects of arsenic to corals. Dal Pizzol et al. (2022) found that increasing concentrations of arsenic were significantly correlated with carbonic anhydrase inhibition and increased oxidative stress in *M. harttii* and *M. alcicornis*. Recently, the Marine Toxicology lab at Nova Southeastern University completed four acute toxicity experiments for two species of arsenic (arsenate and arsenite) and two species of coral (*A. cervicornis* and *Orbicella faveolata*) (unpublished data). Preliminary results suggest that corals are highly sensitive to arsenic at much lower levels than reported for other organisms. Current recommendations based on arsenic toxicity to other marine invertebrates is a guideline value of 12 µg/L to protect 95% of species (Golding et al., 2022). The measured environmental concentrations have exceeded this value (Giarikos et al., 2023). Additionally, Jafarabadi et al. (2020) found that arsenic is one of three "metals" that pose the highest ecological risks to coral reefs in the Persian Gulf.

- Cyanide: The effects of cyanide have been studied in more than a dozen coral species (Cervino et al., 2003; Jones, 1997; Jones & Hoegh-Guldberg, 1999; Springer et al., 2022). Very brief exposures lasting 1-2 minutes at concentrations ranging from 50 mg/L to 600 mg/L resulted in mortality, loss of zooxanthellae, decreased photosynthetic efficiency, and bleaching that lasted several weeks after exposure occurred (Cervino 2003). These exposures were very similar to what wild corals might experience during cyanide fishing of tropical reef fish for the aquarium trade, however this practice is currently illegal in the US.

- Selenium: There is currently no toxicity data available for corals or other cnidaria, though selenium has been found in coral tissues in comparable concentrations to the surrounding sediments (Miao et al., 2000).

Organics – polychlorinated biphenyls. PCBs have been found to be ubiquitous in the environment and the ocean is likely a potential reservoir for these persistent organic pollutants (Miao, Swenson, Yanagihara, et al., 2000). They have been found in the water, sediments, air, and coral tissues in environments around the world (Hawaii, Puerto Rico, South China sea, Thailand, Japan, Egypt, Persian Gulf) including remote locations such as the Mascarene islands in the Indian Ocean (El Nemr et al., 2004; Hong et al., 2013; Imo et al., 2008; Jafarabadi, Bakhtiari, Aliabadian, et al., 2018; Kumar et al., 2016; Miao, Swenson, Woodward, et al., 2000; van der Schyff et al., 2021; Zhang et al., 2021). PCBs were found to bioaccumulate in corals, with concentrations up to 42.9 ng/g found in coral tissues in the south China sea (Zhang et al., 2021). Additionally, the transport and diffusion of PCBs from the atmosphere to the ocean is very important, as Zhang et al. (2021) found that PCBs in coral tissues were significantly correlated to the concentrations in air samples. There are a few toxicology studies demonstrating the effects of PCBs on corals, but overall, the data is lacking. Vered and Shenkar (2022) found that bisphenol-A did not affect the settlement of *Rhytisma fulvum* and *Stylophora pistillata* larvae at concentrations up to 1000µg/L. The PCB congener 118 was found to increase the amount of heat shock proteins (HSP90) in the octocoral *Dendronephthya klunzingeri (Wiens et al., 2000)*. Chen et al. (2012) found that concentrations of Aroclor 1254 of up to 300 ng/L did not affect the survival, photosynthesis, or growth of *S. pistillata*, but did alter the expression of certain genes. Additionally, while not a toxicology study, (Jafarabadi, Bakhtiari, Maisano, et al., 2018) found a significant negative correlation between concentrations of PCBs and zooxanthellae density and chlorophyll content in the Persian Gulf. In general, we know these compounds are present and persistent in tropical environments, including south Florida, and can bioaccumulate in corals, but it is unclear how environmentally relevant concentrations may affect corals.

Organics – pesticides and herbicides. The majority of pesticides in the marine environment originate from terrestrial runoff (Lewis et al., 2009; Mitchel et al., 2005; Packett et al. 2009). Persistent organochlorine pesticides such as DDT, HCB, dieldrin and chlordane have been phased out in favor of organophosphates, carbamates, organotins, pyrethroids and others. Although modern pesticides are less persistent in the environment, these chemical residues remain ubiquitous in coastal watersheds (Lewis et al., 2009; Mueller et al., 2000), albeit at relatively low concentrations (Glynn et al., 1984; Glynn et al. 1989; Glynn et al., 1995; von Westernhagen and Klumpp, 1995; Haynes et al., 2000; Haynes and Johnson, 2000; Negri et al., 2009). Pesticides as a group includes insecticides, fungicides, and herbicides. This group represents the majority of toxicology studies on corals (Ouedraogo et al., 2023). However, similarly to metals, only a few compounds may be considered well-represented in the literature, such as diuron.

- The toxicological effects of fourteen insecticides (*Bacillus* insecticides, permethrin, diazinon, fipronil, imidacloprid, dibrom, chlordecone, chlorpyrifos, profenofos, endosulfan, carbaryl, 1-naphthol, naled, and dichlorvos) have been examined across nine studies, which overall, has represented six coral species (*Acropora tenuis, A. millepora, Montastraea cavernosa, A, cervicornis, Pocillopora damicornis, and Porites asteroides*) and four life stages (adult, larval, gamete, and juvenile). With the exception of permethrin, chlorpyrifos, naled, and carbaryl, all other insecticides were only found in a single study (Acevedo, 1991; Flores et al., 2020b; MacKnight et al., 2022; Markey et al., 2007; Morgan & Snell, 2002; Negri et al., 2009; Ross et al., 2015; Watanabe et al., 2006; Wecker et al., 2018). *A. millepora* gamete fertilization was not affected by any of the six pesticides tested at concentrations up to 30 µg/L (Markey et al., 2007). Across all larval studies, the most toxic insecticides were naled, chlorpyrifos, and profenofos, which all had effects on larval metamorphosis and survival at concentrations less than 3.0 µg/L (Acevedo, 1991; Markey et al., 2007; Ross et al., 2015). Symbiont density of *A. tenuis* juveniles decreased when exposed to 100 µg/L of dichlorvos (Watanabe et al., 2006). In the adult corals studied, the most toxic insecticides were endosulfan, profenofos, and chlorpyrifos, which both caused significant bleaching and a decreased photosynthetic yield at concentrations of 10 µg/L in *A. millepora* (Markey et al., 2007). Additionally, changes in gene expression and microbial communities were seen at insecticide concentrations of less than 1 µg/L in *A. cervicornis* and *M. cavernosa* (MacKnight et al., 2022; Morgan & Snell, 2002). The only pesticides studied that did not have any effect on larva or juveniles at high concentrations was the *Bacillus* insecticides (Negri et al., 2009). Overall, there are significantly more insecticides in use than have been studied and more research is needed to explore the potential effects.

- The toxicological effects of three fungicides (chlorothalonil, propiconazole, and 2-Methoxy-ethylmercuric chloride (MEMC)) on coral gametes, larva, and adults have been tested (Flores et al., 2020a; Markey et al., 2007). MEMC was the most toxic fungicide with an EC_{50} value of 1.68 µg/L for fertilization inhibition in gametes, 2.5 µg/L for metamorphosis inhibition in larvae, and a LOEC value of 10 µg/L for tissue mortality in adults, all of *A. millepora* (Markey et al., 2007). Chlorothalonil and propiconazole were only tested on larva of *A. tenuis* and chlorothalonil was much more toxic with an EC50 value of 6.0 µg/L compared to the propiconazole EC50 value of 1008 µg/L (Flores et al., 2020b). Fungicides are overall poorly studied and more research is needed to understand their potential impacts to corals.

A wide range of herbicides are identified as aquatic contaminants and are typically introduced into the marine environment via terrestrial runoff, storm discharge, or atmospheric deposition. The herbicides most commonly found on coral reefs include diuron, tebuthiuron ametryn, Irgarol 1051, atrazine, simazine, glyphosate). These chemicals may be ubiquitous in coral reef waters, with the photosystem II (PSII) herbicides being most commonly detected (Lewis et al., 2009; Owen et al., 2002; Packett et al., 2009; Prange et al., 2007; Shaw et al., 2009). These compounds pose a particular risk to corals reefs, as they have a relatively high water solubility and readily penetrate coral tissues, resulting in rapid reduction of the endosymbiont dinoflagellate photosynthetic efficiency. This directly reduces the translocation of energetic products from the symbiont to the host coral, with secondary impacts from a build-up of reactive oxygen species and oxidative stress (Rutherford and Kreiger-Liskay, 2001).

While acute effects on the coral animal may not be immediate, the sublethal disruption of photosynthesis leads to coral bleaching and an overall decrease in fitness of the coral holobiont, including reduced reproductive output (Cantin et al., 2007). While corals have demonstrated the potential for recovery after short term exposures (Jones and Kerswell, 2003; Jones et al. 2003), effects from chronic exposures to relatively low concentrations may be more significant (Cantin et al., 2007).

- The toxicological effects of thirteen herbicides (diuron, Irgarol 1051, 2-4-D, atrazine, hexazinone, glyphosate, prometryn, glufosinate, 2-4-5-T, ametryn, ionynil, simazine, and tebuthiuron) have been examined across fifteen species of corals. The most commonly tested compounds were diuron and Irgarol (a triazine used in antifouling paint), which were included in or were the sole focus of more than half of the collected studies and were the most toxic (Downs & Downs, 2007; Flores et al., 2021; Hirayama et al., 2017; Ishibashi et al., 2018; Ishibashi et al., 2021; Jones & Kerswell, 2003; Jones et al., 2003; Kamei et al., 2020; Katsumata & Takeuchi, 2017; Knutson et al., 2012; Negri et al., 2005; Negri, Flores, et al., 2011; Owen et al., 2003; Owen et al., 2002; Råberg et al., 2003; Takeuchi et al., 2020; Tang et al., 2018). The effects of diuron are well understood, as it is often used as a reference toxicant similarly to copper, and it can affect photosynthetic efficiency at concentrations as low as 1 µg/L, with an EC_{50} value of approximate 2-3 µg/L (Jones, 2004; Jones & Kerswell, 2003; Negri, Flores, et al., 2011; Negri & Heyward, 2001). Igarol is even more toxic with photosynthetic yield decreasing at concentrations as low as 0.2 µg/L with an EC_{50} value of 0.7 µg/L, which are below measured environmental concentrations of triazine (Jones & Kerswell, 2003; Kamei et al., 2020). Corals exposed to Igarol also took longer to recover than when exposed to diuron (Jones & Kerswell, 2003). The majority of these studies focused on adult corals, as these herbicides are often targeting the pathway of photosynthesis and therefore are affecting the coral symbiotic zooxanthellae specifically, which is not yet present in larval or gametic stages (Jones, 2004). However, recruits as young as two weeks were just as sensitive to diuron as adult colonies (Negri et al., 2005). While most studies focused on photosynthetic efficiency as an endpoint, mortality did occur in some cases at high concentrations of diuron (29 µg/L) and a formulation containing 2-4-D (1ppm) (Flores et al., 2021; Glynn et al., 1984). Regarding other herbicides listed, ametryn, hexazinone, and prometryn all had EC50 values < 10 µg/L ((Jones & Kerswell, 2003; Negri, Flores, et al., 2011; Zhou et al., 2024). The least toxic herbicides studied were ionynil, with an EC_{50} value > 1mg/L, and glyphosate which did not have effects significantly different from the controls at 12.0 mg/L, except under elevated temperatures (Amid et al., 2018; Jones & Kerswell, 2003). Additionally, herbicide stress can reduce corals' resilience to other stressors such as rising temperatures (Negri, Flores, et al., 2011; Zhou et al., 2024). Overall, the toxicological effects of many herbicides on corals is well understood, however the full impacts of the many herbicide classes remains understudied in corals.

Organics – other.

- Neutral organics (hydrocarbons): Hydrocarbons have been found to be ubiquitous in the marine environment, with increasing concentrations closer to shore, especially in areas with higher boat traffic, such as large ports, or areas where land-runoff, dumping, or previous oil spills have occurred (Caroselli et al., 2020;

Jafarabadi, Bakhtiari, Aliabadian, et al., 2018; Whitall et al., 2015). Hydrocarbons have also been found in all parts of the coral (the skeleton, mucus, tissue, and zooxanthellae) around the world (Han et al., 2020; Jafarabadi, Bakhtiari, Aliabadian, et al., 2018; Ko et al., 2014; Menezes et al., 2023; Sabourin, 2013). There have been many studies looking at how crude oil and its individual components affect over 50 species of corals at various life stages (adults, larvae, and gametes) since the 1970s. These studies include many different crude oils, the water-accommodated fractions of these oils, dispersed oil, and different polycyclic aromatic hydrocarbons contained in petroleum, as well as how the toxicity changes in the presence of ultraviolet radiation or elevated temperatures (Epstein et al., 2000; Kegler et al., 2015; Liu et al., 2023; Martínez et al., 2007; May et al., 2020; Negri et al., 2016; Nordborg et al., 2022; Nordborg et al., 2021; Nordborg et al., 2018; Nordborg et al., 2023; Overmans et al., 2018; Renegar & Turner, 2021; Turner et al., 2021). Hydrocarbons have been found to cause partial or complete mortality, bleaching, inhibition of metamorphosis, fertilization, and settlement, reduced growth rate, decreased photosynthetic yield, and altered gene expression in corals (Woo et al., 2014). Even though numerous toxicology studies exist, comparison between them can be difficult because they often use only a single concentration, different experimental setups or lengths, only report nominal concentration values, measure different health metrics, and report different effect values (eg. LC50 vs LOEC), as there is not a standardized toxicology procedure. However, in general, hydrocarbons became more toxic in the presence of UVR (Martínez et al., 2007; Negri et al., 2016; Nordborg et al., 2022; Nordborg et al., 2021; Nordborg et al., 2018; Nordborg et al., 2023; Overmans et al., 2018) and dispersed oil was more toxic than non-dispersed oil (Eisler, 1975; Elgershuizen, 1976; Lane, 2000). For individual compounds, benzo(a)pyrene, anthracene, and fluoranthene were the most toxic, and toluene was the least (Farina et al., 2008; Martínez et al., 2007; Nordborg et al., 2021; Nordborg et al., 2023; Overmans et al., 2018; Renegar et al., 2017; Turner et al., 2021). Overall, hydrocarbons and PAHs are ubiquitous pollutants, especially in highly trafficked areas. These compounds have been shown to have detrimental effects on corals, both directly and indirectly by decreasing their ability to respond to other stressors. However, there is a lack of current data for hydrocarbon concentrations on FCR.

- Pharmaceuticals: A few pharmaceutical compounds have been tested for their effects on corals, with the priority focus on endocrine disrupting compounds. *Montipora capitata* colonies treated with 2300 ng/L of estradiol for 3 weeks before spawning released less egg–sperm bundles than controls (Tarrant et al., 2004). *Porites compressa* fragments exposed to estrone for 2 to 8 weeks had lower growth rates than controls (Tarrant et al., 2004). *Pocillopora damicornis* colonies exposed to only 1 μg/L of the xenoestrogen 4-nonylphenol (4NP) for six weeks had changes to levels of enzymatic activity relating to reproductive health

(Rougée et al., 2021). Additionally, several antibiotics were found to accumulate in coral tissue in the south China sea (Zhang et al., 2019).

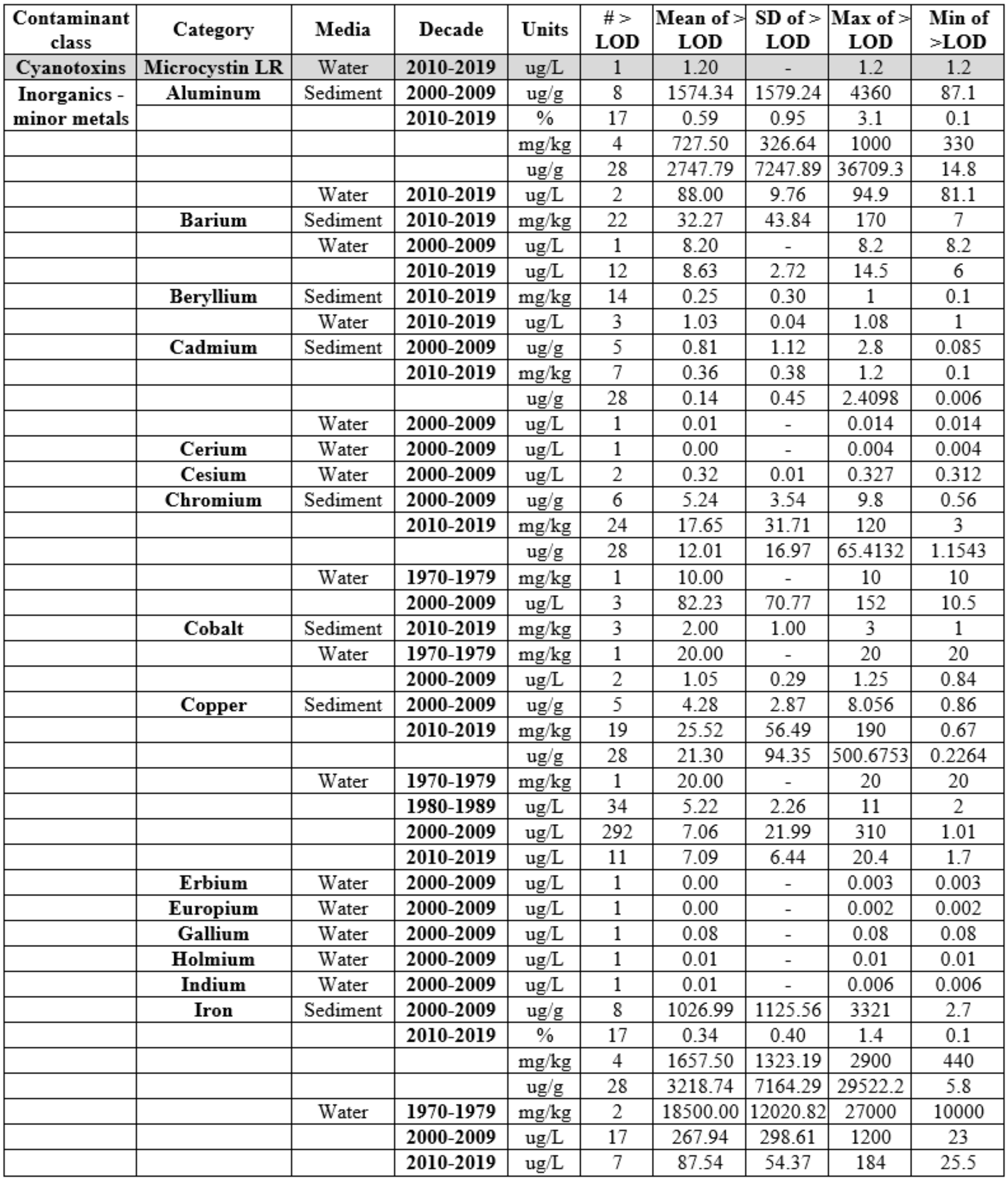
- UV filters: Recently, organic UV filters from sunscreens have emerged as a contaminant of concern in the aquatic environment. In the literature, twelve organic UV filters (octocrylene, avobenzone, uvinal T150, mexoryl XL, mexoryl SX, octinoxate, oxybenzone, ethylhexyl salicylate, and benzophenone -2, -1, -4, and -8) are represented which encompasses fourteen species of mostly adult colonies (Brefeld et al., 2024; Clergeaud et al., 2023; Conway et al., 2021; Danovaro et al., 2008; Downs et al., 2014; Downs et al., 2016; Fel et al., 2019; He, Tsui, Tan, Ma, et al., 2019; He, Tsui, Tan, Ng, et al., 2019; Miller et al., 2022; Stien et al., 2019; Stien et al., 2020; Thorel et al., 2022; Wijgerde et al., 2020; Yang et al., 2023). Additionally, one study examined the toxicological effects of a mixture of twelve different UV filters and one study examined two commercially available sunscreen brands (Danovaro et al., 2008; He et al., 2023). Note that while zinc oxide and titanium dioxide are also considered UV filters or sunscreens, they are not organic UV filters and are therefore discussed in their respective sections (metals). The most studied UV filters are oxybenzone and octocrylene, which were mentioned eight and six times, respectively. The range of EC50 values for oxybenzone was quite large (0.75 µg/L – 5716 µg/L) with *Acropora digitifera* larvae being the most sensitive (Brefeld et al., 2024; Conway et al., 2021; Miller et al., 2022). This suggests that more research needs to be fully understood the effects of oxybenzone, though it has already been banned in several tropical areas such as Hawaii. Oxtocrylene was shown to induce metabolic changes at concentrations as low as 50 – 300 µg/L, but corals showed no signs of bleaching at concentrations up to 1000 µg/L (He, Tsui, Tan, Ma, et al., 2019; Stien et al., 2019; Stien et al., 2020). Regarding the other UV filters, there is a lack of data as most were only mentioned one time and EC_{50} values were often not found. When looking at a mixture of several UV filters, He et al. (2023) found that concentrations as low as 200 ng/L caused bleaching and mortality, suggesting that UV filters may have additive effects. Additionally, it has been reported that some UV filters (oxybenzone and 2-benzophenone) become more toxic in the presence of UV light, which is another aspect that needs further research (Downs et al., 2014; Downs et al., 2016). Overall, limited data is available for UV filters in FCR, with measured environmental concentrations only for two UV filters (oxybenzone and octinoxate).

- Flame retardants: There is an overall lack of data on organophosphate flame retardants' effects on corals. Aminot et al. (2020) found that an approximate concentration of 250 ng/L of a mixture of hexabromocyclododecanes had no considerable effect on coral photosynthetic activity, symbiont concentration and chlorophyll content after 5 days. These compounds have also been found to accumulate in corals (Yan et al., 2024). While we do not fully understand the effects, environmental concentrations of organophosphates are typically very low or zero..

- Surfactants: There have been several studies determining the toxicity of various surfactants to corals, but much of the focus has been on dispersants and dispersants in combination with oil or petroleum products. While the toxicity of several dispersants has been tested, one dispersant (Corexit®) has been tested significantly more frequently. Toxic effects of Corexit® have been tested on three species of coral larvae and about a dozen species of adult corals (Bytingsvik et al., 2020; Cook & Knap, 1983; D. M. DeLeo, 2015; Frometa et al., 2017; Goodbody-Gringley et al., 2013; Lewis, 1971; Negri et al., 2018; Ruiz-Ramos et al., 2017; Studivan et al., 2015; Venn et al., 2009). From these studies, the lowest observed effect concentration for adults ranged from 1 – 100 mg/L, depending on the endpoint measured (bleaching, polyp activity, partial mortality, etc.). The EC_{50} values for larval metamorphosis ranged from 4 – 14 mg/L depending on the length of exposure and LC_{50} values ranged from 33 – 343 mg/L depending on the species (Goodbody-Gringley et al., 2013; Negri et al., 2018). Seven other dispersants have been tested, each only one time, with lowest observed effect concentrations ranging from 0.018 – 0.05 mL/L (Eisler, 1975; Elgershuizen, 1976; Shafir et al., 2007). Two other surfactants linear alkylbenzene sulfonates (LAS) and nonylphenol ethoxylate (NPE) have also been tested in *Stylophora pistillata* and *Pocillopora damicornis* (Shafir et al., 2014). For LAS, the LC50 values were 1.00 mg/L and 2.21 mg/L for *S. pistillata* and *P. damicornis,* respectively, after 24 hours. The LC50 values for NPE were slightly higher at 3.03 mg/L and 2.26 mg/L for *S. pistillata* and *P. damicornis,* respectively, after 24 hours.

Radiochemicals. There is currently a lack of toxicological data on how radiochemicals affect corals. However, these chemicals, especially uranium and lead, have been found in coral skeletons and are often used to date the coral (Ohde 2003, Pingitore 2002, Chen 2021, Robinson 2004, Delany 1989, Choukri 2007).

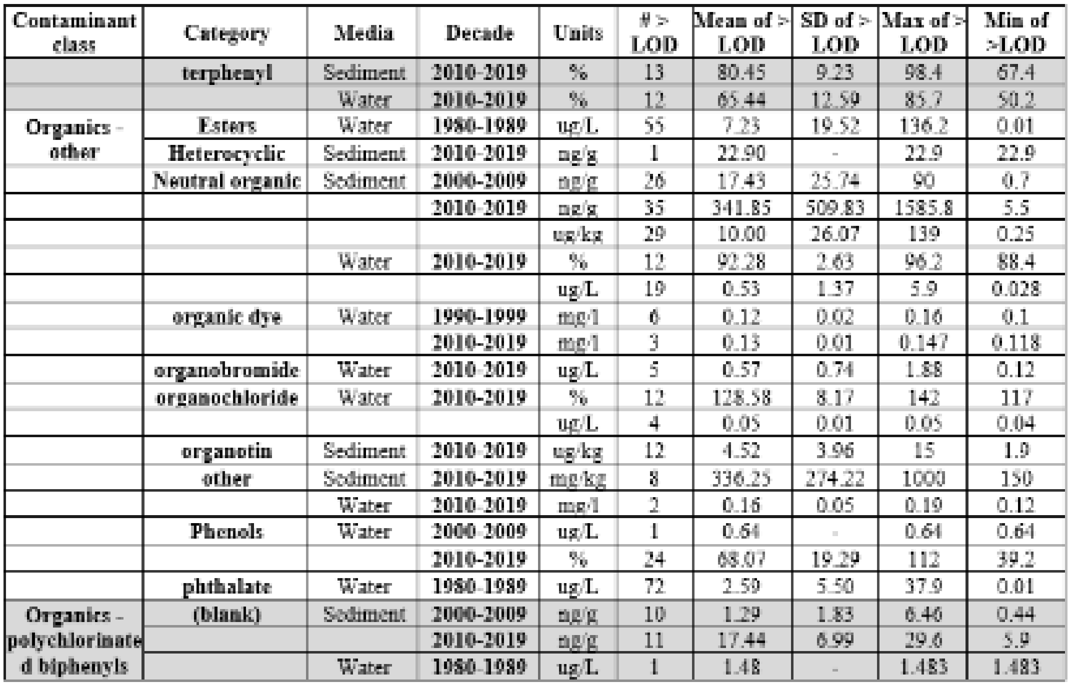
Table 118. Summary of chemicals in the compiled databases, for datapoints from the marine environment, including the media (water or sediment), decade, measurement units, number of datapoints with measured concentrations greater than the method detection limit (LOD) for that contaminant, and the mean, standard deviation (SD), maximum, and minimum concentration of the measured concentrations greater than the LOD for that contaminant.



Contaminant class	Category	Media	Decade	Units	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
Cyanotoxins	**Microcystin LR**	Water	**2010-2019**	ug/L	1	1.20	-	1.2	1.2
Inorganics - minor metals	**Aluminum**	Sediment	**2000-2009**	ug/g	8	1574.34	1579.24	4360	87.1
			2010-2019	%	17	0.59	0.95	3.1	0.1
				mg/kg	4	727.50	326.64	1000	330
				ug/g	28	2747.79	7247.89	36709.3	14.8
		Water	**2010-2019**	ug/L	2	88.00	9.76	94.9	81.1
	Barium	Sediment	**2010-2019**	mg/kg	22	32.27	43.84	170	7
		Water	**2000-2009**	ug/L	1	8.20	-	8.2	8.2
			2010-2019	ug/L	12	8.63	2.72	14.5	6
	Beryllium	Sediment	**2010-2019**	mg/kg	14	0.25	0.30	1	0.1
		Water	**2010-2019**	ug/L	3	1.03	0.04	1.08	1
	Cadmium	Sediment	**2000-2009**	ug/g	5	0.81	1.12	2.8	0.085
			2010-2019	mg/kg	7	0.36	0.38	1.2	0.1
				ug/g	28	0.14	0.45	2.4098	0.006
		Water	**2000-2009**	ug/L	1	0.01	-	0.014	0.014
	Cerium	Water	**2000-2009**	ug/L	1	0.00	-	0.004	0.004
	Cesium	Water	**2000-2009**	ug/L	2	0.32	0.01	0.327	0.312
	Chromium	Sediment	**2000-2009**	ug/g	6	5.24	3.54	9.8	0.56
			2010-2019	mg/kg	24	17.65	31.71	120	3
				ug/g	28	12.01	16.97	65.4132	1.1543
		Water	**1970-1979**	mg/kg	1	10.00	-	10	10
			2000-2009	ug/L	3	82.23	70.77	152	10.5
	Cobalt	Sediment	**2010-2019**	mg/kg	3	2.00	1.00	3	1
		Water	**1970-1979**	mg/kg	1	20.00	-	20	20
			2000-2009	ug/L	2	1.05	0.29	1.25	0.84
	Copper	Sediment	**2000-2009**	ug/g	5	4.28	2.87	8.056	0.86
			2010-2019	mg/kg	19	25.52	56.49	190	0.67
				ug/g	28	21.30	94.35	500.6753	0.2264
		Water	**1970-1979**	mg/kg	1	20.00	-	20	20
			1980-1989	ug/L	34	5.22	2.26	11	2
			2000-2009	ug/L	292	7.06	21.99	310	1.01
			2010-2019	ug/L	11	7.09	6.44	20.4	1.7
	Erbium	Water	**2000-2009**	ug/L	1	0.00	-	0.003	0.003
	Europium	Water	**2000-2009**	ug/L	1	0.00	-	0.002	0.002
	Gallium	Water	**2000-2009**	ug/L	1	0.08	-	0.08	0.08
	Holmium	Water	**2000-2009**	ug/L	1	0.01	-	0.01	0.01
	Indium	Water	**2000-2009**	ug/L	1	0.01	-	0.006	0.006
	Iron	Sediment	**2000-2009**	ug/g	8	1026.99	1125.56	3321	2.7
			2010-2019	%	17	0.34	0.40	1.4	0.1
				mg/kg	4	1657.50	1323.19	2900	440
				ug/g	28	3218.74	7164.29	29522.2	5.8
		Water	**1970-1979**	mg/kg	2	18500.00	12020.82	27000	10000
			2000-2009	ug/L	17	267.94	298.61	1200	23
			2010-2019	ug/L	7	87.54	54.37	184	25.5

Contaminant class	Category	Media	Decade	Units	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
	Lanthanum	Water	**2000-2009**	ug/L	1	0.02	-	0.015	0.015
	Lead	Sediment	**2000-2009**	ug/g	4	2.08	1.83	4.652	0.452
			2010-2019	mg/kg	18	173.16	612.42	2600	0.89
				ug/g	28	11.22	45.15	240.3179	0.1765
		Water	**1970-1979**	mg/kg	1	20.00	-	20	20
			2000-2009	ug/L	3	9.37	5.86	15.4	3.7
			2010-2019	ug/L	2	2.52	2.52	4.3	0.73
	Lithium	Sediment	**2010-2019**	mg/kg	18	11.28	11.33	39	1
		Water	**2000-2009**	ug/L	2	194.50	7.78	200	189
			2010-2019	ug/L	12	324.08	75.90	555	272
	Manganese	Sediment	**2000-2009**	ug/g	8	23.35	28.57	93.35	8.274
			2010-2019	mg/kg	22	46.86	48.13	200	7
				ug/g	28	40.01	56.29	296.514	2.15
		Water	**1970-1979**	mg/kg	2	70.00	14.14	80	60
			2000-2009	ug/L	1	0.75	-	0.75	0.75
			2010-2019	ug/L	9	4.08	2.94	9.53	1.45
	Mercury	Sediment	**2010-2019**	mg/kg	11	0.11	0.23	0.76	0.01
				ug/g	28	0.08	0.28	1.5061	0.0046
		Water	**1970-1979**	mg/kg	1	0.93	-	0.93	0.93
			2000-2009	ug/L	1	0.23	-	0.225	0.225
	Molybdenum	Sediment	**2010-2019**	mg/kg	6	3.67	2.66	7	1
		Water	**2000-2009**	ug/L	1	13.00	-	13	13
			2010-2019	ug/L	12	13.82	1.03	15.6	12.5
	Nickel	Sediment	**2000-2009**	ug/g	8	1.94	1.62	4.8	0.45
			2010-2019	mg/kg	17	4.95	4.87	18	1.2
				ug/g	28	3.00	4.30	14.79	0.12
		Water	**2000-2009**	ug/L	2	1395.00	205.06	1540	1250
			2010-2019	ug/L	2	3.76	0.48	4.1	3.42
	Niobium	Water	**2000-2009**	ug/L	1	0.02	-	0.02	0.02
	Palladium	Water	**2000-2009**	ug/L	2	1.11	1.53	2.19	0.022
	Praseodymium	Water	**2000-2009**	ug/L	1	0.01	-	0.012	0.012
	Rhenium	Water	**2000-2009**	ug/L	1	0.00	-	0.002	0.002
	Rubidium	Water	**2000-2009**	ug/L	2	128.50	7.78	134	123
	Ruthenium	Water	**2000-2009**	ug/L	1	0.97	-	0.965	0.965
	Silver	Sediment	**2000-2009**	ug/g	3	1.25	1.86	3.4	0.153
			2010-2019	mg/kg	1	1.20	#DIV/0!	1.2	1.2
				ug/g	20	0.52	0.44	1.35	0.03
		Water	**2010-2019**	ug/L	1	0.10	-	0.101	0.101
	Strontium	Sediment	**2010-2019**	mg/kg	22	2550.59	1810.47	6400	70
		Water	**1980-1989**	ug/L	11	6500.00	2840.42	11000	2200
			2000-2009	ug/L	2	10005.00	2114.25	11500	8510
			2010-2019	ug/L	12	7849.17	1971.18	13900	6660
	Tellurium	Water	**2000-2009**	ug/L	1	0.65	-	0.653	0.653
	Terbium	Water	**2000-2009**	ug/L	1	0.01	-	0.005	0.005
	Thallium	Water	**2000-2009**	ug/L	1	0.01	-	0.008	0.008
	Tin	Sediment	**2000-2009**	ug/g	3	1.56	1.02	2.2	0.38
			2010-2019	mg/kg	4	12.25	12.53	25	1
				ug/g	26	1.09	3.92	20.164	0.056
	Titanium	Sediment	**2010-2019**	%	11	0.09	0.12	0.41	0.01
		Water	**2000-2009**	ug/L	1	9.98	-	9.98	9.98
	Vanadium	Sediment	**2010-2019**	mg/kg	22	9.82	9.50	36	2
				ug/g	28	9.63	11.97	51.677	0.532
		Water	**2000-2009**	ug/L	2	37.30	10.32	44.6	30

Contaminant class	Category	Media	Decade	Units	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
	Yttrium	Water	**2000-2009**	ug/L	1	0.04	-	0.038	0.038
	Zinc	Sediment	**2000-2009**	ug/g	5	6.39	8.20	20.91	1.6
			2010-2019	mg/kg	25	27.72	60.12	230	1
				ug/g	28	28.79	119.76	633.285	0.434
		Water	**1970-1979**	mg/kg	2	70.00	42.43	100	40
			2000-2009	ug/L	8	37.39	18.30	69	7.09
			2010-2019	ug/L	1	61.00	-	61	61
	Zirconium	Water	**2000-2009**	ug/L	1	0.02	-	0.02	0.02
Inorganics - minor non-metals	**Antimony**	Sediment	**2000-2009**	ug/g	8	2.33	2.40	5.5	0.098
			2010-2019	mg/kg	16	1.41	3.99	16	0.1
				ug/g	13	0.25	0.48	1.812	0.053
		Water	**2000-2009**	ug/L	1	0.22	-	0.222	0.222
	Arsenic	Sediment	**2000-2009**	ug/g	5	4.33	1.88	6.9	1.84
			2010-2019	mg/kg	26	4.94	4.91	17	0.4
				ug/g	28	4.73	3.27	16.011	0.378
		Water	**1970-1979**	mg/kg	1	13.00	-	13	13
			2000-2009	ug/L	18	22.57	14.31	62.9	2.19
			2010-2019	ug/L	107	3.21	3.50	17.9	0.95
			2020-2029	ng/L	5	3.18	1.80	6.3	2.1
	Boron	Water	**2000-2009**	ug/L	2	3710.00	1555.63	4810	2610
	Bromine	Water	**2000-2009**	ug/L	2	90350.00	19304.02	104000	76700
	Dysprosium	Water	**2000-2009**	ug/L	1	0.00	-	0.004	0.004
	Iodine	Water	**2000-2009**	ug/L	1	61.60	-	61.6	61.6
	Selenium	Sediment	**2000-2009**	ug/g	5	24.78	30.32	63	0.111
			2010-2019	mg/kg	19	0.54	0.59	2.1	0.1
				ug/g	26	0.52	0.46	1.621	0.058
		Water	**2000-2009**	ug/L	2	176.00	60.81	219	133
			2010-2019	ug/L	2	2.05	0.81	2.62	1.48
Organics - herbicides	**thiocarbamate**	Water	**2020-2029**	ng/L	-	-	-	-	-
	acetanilide	Water	**2020-2029**	ng/L	-	-	-	-	-
	chloroacetanilide	Water	**2020-2029**	ng/L	-	-	-	-	-
	dinitroaniline	Water	**2020-2029**	ng/L	-	-	-	-	-
	nitrophenyl ether	Water	**2020-2029**	ng/L	-	-	-	-	-
	organochloride	Water	**2020-2029**	ng/L	-	-	-	-	-
	oxadiazole	Water	**2020-2029**	ng/L	-	-	-	-	-
	phenylpyrazole	Water	**2020-2029**	ng/L	-	-	-	-	-
	substituted uracil	Water	**2000-2009**	ug/L	-	-	-	-	-
			2020-2029	ng/L	-	-	-	-	-
	triazine	Water	**2000-2009**	ug/L	-	-	-	-	-
			2020-2029	ng/L	-	-	-	-	-
Organics - pesticides	**organochloride**	Sediment	**2000-2009**	ng/g	3	1.00	0.00	1	1
			2010-2019	ng/g	2	13.35	11.67	21.6	5.1
		Water	**1970-1979**	ug/kg	3	9.73	4.03	14	6
			1980-1989	ug/L	30	0.06	0.11	0.537	0.001
	organosulfide	Water	**2010-2019**	ug/L	4	0.10	0.00	0.1	0.1
	organotin	Sediment	**2010-2019**	ug/kg	12	12.48	15.57	58	2.2
			2020-2029	ug/kg	2	4.85	3.04	7	2.7
	Persistent, Bioaccumulative, and Toxic (PBT) Chemicals	Water	**1980-1989**	ug/L	19	0.06	0.21	0.907	0.001



Contaminant class	Category	Media	Decade	Units	# > LOD	Mean of > LOD	SD of > LOD	Max of > LOD	Min of >LOD
Organics - other	terphenyl	Sediment	2010-2019	%	13	80.45	9.23	98.4	67.4
		Water	2010-2019	%	12	65.44	12.59	85.7	50.2
	Esters	Water	1980-1989	ug/L	55	7.23	19.52	136.2	0.01
	Heterocyclic	Sediment	2010-2019	ng/g	1	22.90	-	22.9	22.9
	Neutral organic	Sediment	2000-2009	ng/g	26	17.43	25.74	90	0.7
			2010-2019	ng/g	35	341.85	509.83	1585.8	5.5
				ug/kg	29	10.00	26.07	139	0.25
		Water	2010-2019	%	12	92.28	2.63	96.2	88.4
				ug/L	19	0.53	1.37	5.9	0.028
	organic dye	Water	1990-1999	mg/l	6	0.12	0.02	0.16	0.1
			2010-2019	mg/l	3	0.13	0.01	0.147	0.118
	organobromide	Water	2010-2019	ug/L	5	0.57	0.74	1.88	0.12
	organochloride	Water	2010-2019	%	12	128.58	8.17	142	117
				ug/L	4	0.05	0.01	0.05	0.04
	organotin	Sediment	2010-2019	ug/kg	12	4.52	3.96	15	1.9
	other	Sediment	2010-2019	mg/kg	8	336.25	274.22	1000	150
		Water	2010-2019	mg/l	2	0.16	0.05	0.19	0.12
	Phenols	Water	2000-2009	ug/L	1	0.64	-	0.64	0.64
			2010-2019	%	24	68.07	19.29	112	39.2
	phthalate	Water	1980-1989	ug/L	72	2.59	5.50	37.9	0.01
Organics - polychlorinated biphenyls	(blank)	Sediment	2000-2009	ng/g	10	1.29	1.83	6.46	0.44
			2010-2019	ng/g	11	17.44	6.99	29.6	5.9
		Water	1980-1989	ug/L	1	1.48	-	1.483	1.483

4. CONCLUSIONS AND RECOMMENDATIONS

Statistical analyses of heavy metal results in port sediment cores and coral surface sediment from Phase 1 of FDEP project (agreement #C0FEDD). indicate a moderate to high overall ecological risk from sediment due to metal contamination and more specifically As and Mo. Microbial community composition differed between sediments at the control, coral, and in the port sites. Coral sites had lower functional diversity than the port sites, and the higher metal concentrations were associated with the functional composition of the port.

Sediment heavy metal results from traps at six coral reef sites indicate moderate to strong contamination mostly due to As. The abiotic data (temperature, conductivity (salinity), pressure (depth), dissolved oxygen, pH, and turbidity) collected at the six coral reef sites were of expected values. Temperature, however, fluctuated during seasons with the summer months going as high as 31.8ºC and the turbidity and sedimentation rates fluctuated significantly during storm events.

Microbiome and metagenomic results were complementary to each other and the environmental data presented. 16S rRNA results reinforced taxonomic identifications that have been carried out for several years in the port and adjacent reefs. Microbial communities appear dynamic but appear adapted to specific environmental factors in their immediate habitats. Metagenomics also provided taxonomic data but added a further dimension of microbial functionalities which correlate to port and reef sites and the presence of specific chemical elements (e.g. HMs). Reef sediments had lower functional diversity than the port and PEI. There was a difference in functional composition between PEI, the port, coral, and lake sediments. composition correlated to Al, As, Co, Cr, Fe, Hg, Mo, Ni, Se, Sn, and V. Higher metal concentrations were associated with the functional composition of the port and lake. Functional diversity (number of functions) correlated positively with Ni.

Dosing *A. cervicornis* and *O. faveolata* with two inorganic species of As, arsenate (As(V)) and arsenite (As(III)), determined that As (V) was more acutely toxic than As (III) for all metrics while for *O. faveolata*, As (III) was more toxic than As (V), but only for mortality. An As(V) concertation as low as 35.80 µg/L can dramatically influence *Acropora cervicornis* survivability. Overall, the branching *A. cervicornis* was more sensitive to both As(V) and As(III) compared to *O. faveolata*. For *A cervicornis*, As (V) was more acutely toxic than As (III) for all metrics (mortality, condition, and photosynthetic efficiency). This was not the case for *O. faveolata*, where As (III) was more toxic than As (V), but only for mortality; threshold concentrations were similar for condition and photosynthetic efficiency.

Evaluation of the compiled contaminant databases identified an overall lack of oceanic samples. Of the approximately 2.9 million data points found for the five counties encompassing the Florida Coral Reef, only ~30,000, or 5%, were from the marine environment. For the toxicological data, the majority were single-stressor studies; the effects of multiple contaminants at once is rarely examined (He et al., 2023; Negri et al., 2011; Reichelt-Brushett & Hudspith, 2016). While this is a necessary approach to establish thresholds of exposure for individual contaminants, multi-stressor studies which assess interactive effects would give a more realistic view of real-world environmental impacts. This also applies to the interaction of contaminants with global stressors such as ocean warming and acidification. Contaminants such as copper, diuron, and hydrocarbons have been shown to have a negative impact on coral resilience to increasing temperatures and ocean acidification (Banc-Prandi & Fine, 2019; Bielmyer-Fraser et al., 2018; Biscéré et al., 2015; Cheng et al., 2024; Fonseca et al., 2017; Hedouin et al., 2016; Liu et al., 2023; Negri & Hoogenboom, 2011; Wijgerde et al., 2020). Finally, most toxicological studies examine dissolved contaminant concentrations; only two of the studies referenced here examined the effects of contaminated sediment to corals (Gillmore et al., 2020; Smith et al., 2003). As corals are vulnerable to exposure to contaminated sediments, and many contaminants partition to sediments, additional studies to evaluate the specific effects of contaminated sediment exposure are recommended.

It is recommended that abiotic data, microbial profiles and sedimentation rates continue to be collected to obtain further information over a longer period. Water chemistry data will allow us to monitor for abiotic fluctuations and potential biotic responses at the reef sites. Additional port sediment cores should be collected to determine other types of possible contaminants such as persistent organic pollutants (POPs). TEL and PEL values of polyaromatic hydrocarbons (PAHs) in S. FL estuarine sediment are known and could be evaluated since port sediment could be influencing the nearby coral. Coral should also be dosed with other heavy metals that were found in the sediment such as Mo and Mn and even with predetermined heavy metal sediment to determine the toxicity concentrations.

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