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Piney Point Effluent Release: Impact Assessment for Benthos and Fishes

A Report to the Florida Department of Environmental Protection
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1. Introduction

Due to bankruptcy in 2001, the Mulberry Corporation left the Piney Point phosphate plant, located near Bishops Harbor in Tampa Bay, abandoned (Garrett et al., 2011). The fertilizer manufacturing process produces effluent, typically stored in above ground phosphogypsum stacks. The remaining effluent (1.9 billion liters), which consisted of ammonium nitrogen compounds, heavy metals, and radioactive phosphorus, was left to the State of Florida to dispose of and manage (Garrett et al., 2011). The Florida Department of Environmental Protection (FDEP) released 1.9 million liters per day of treated (reduced phosphorus, metals and radioisotope concentrations) wastewater from July 2002-January 2003. In January 2003, FDEP was forced to increase the release to 7.6 million liters per day due to increased precipitation (Garrett et al., 2011). Wastewater releases from the early 2000's as well as a release in 2011 contributed to local increases in macroalgae and harmful algal blooms (HAB)(Beck et al., 2022).

Due to a tear in the plastic liner of the southern holding pond (1.8 million liters) at the Piney Point Point facility, leakages were reported in March 2021 (Beck et al., 2022). According to a measurement in 2019, the effluent had concentrations of total nitrogen and phosphorus three orders magnitude higher than Tampa Bay waters (Beck et al., 2022). In addition to increased nutrients, other contaminants and radioisotopes were also present at concentrations higher than Tampa Bay waters (Beck et al., 2022). Approximately 814 million liters of effluent were released into Port Manatee (lower Tampa Bay) from March 30-April 9, 2021. Beck et al., (2022) report that this resulted in an estimated 186 metric tons of nitrogen to the bay. This resulted in a phytoplankton bloom (diatoms) in April, filamentous cyanobacteria blooms in June, and then a harmful algal bloom (*K. brevis*), which caused fish kills but no significant seagrass die-offs (Beck et al., 2022). Overall, Beck et al., (2022) demonstrated that water quality was diminished due to nitrogen loading as compared to baseline environmental measurements.

This research effort investigated potential impacts to the benthos and to fishes from the Piney Point effluent release in 2021 with the goals of 1) providing environmental context (sedimentology) of the benthos and identifying any physical change(s) to the benthic environment of Tampa Bay; 2) establishing benthic baselines, and assessing any impacts and responses utilizing benthic foraminifera based monitoring tools and bioindicators of ecological quality status, 3) analyzing sediments for a potential elevation in radioisotopes associated with the effluent, and utilize radioisotopes as tracers of the effluent release to establish the benthic spatial distribution and incorporation into the benthos and 4) analyzing fish tissue samples to assess potential elevation in radioisotopes associated with the effluent and 5) reporting water quality parameters (pH, dissolved oxygen, temperature, salinity etc.). These analyses were performed on 70 existing sediment grab samples, fish tissue samples and water quality data collected by small boat operations and onboard the *Weatherbird II*, operated by the Florida Institute of Oceanography. Sampling efforts took place once a month from April-July 2021, creating a time-series for a total temporal coverage of up to four months following the effluent release. The PIs collaborated with Dr. Steve Murawski (CMS), who provided 57 fish tissue samples for radioisotope analysis. Analyses were performed at Eckerd College, Galbraith Marine Science Laboratory and the University of South Florida College of Marine Science Radiochemistry Laboratory.

2. Methods

2.1 Field Methods

Surface sediment samples (upper ~2 cm) were collected using a Petit Ponar Grab Sampler at 33 sites from January 6, 2021 to June 28, 2021 to provide a pre-effluent release to post-effluent release times series (Figure 1, Table 1). Subsequently, vibracores and push cores were collected at six sites during September 2021. Subsamples of each grab sample were collected and analyzed for sedimentology, radiochemistry and benthic foraminifera analyses. Each push core was subsampled by extrusion (Schwing et al., 2016) at 0.5-1 cm intervals from the surface to the bottom of the core. Vibracores were split longitudinally, sampled at intervals based on lithology, and analyzed for texture and composition. Water quality measurements (Temperature, salinity, dissolved oxygen, and pH) were also recorded using a YSI probe on April 7, 2021 (during release), April 28, 2021 (post-release) and June 18, 2021 (post-release).

2.2 Lab Methods

2.2.1 Sedimentology (Environmental context)

Sediment texture and composition analyses were conducted on 0.5-1.0 cm samples from extruded sediment cores (Schwing et al., 2016), Vibracore subsamples, sediment trap and grab samples, to determine variability in sediment sources, environmental and depositional settings. Analyses included grain size (wet sieve and pipette method; Folk, 1965), which is reported as % sand, % silt and % clay, total organic matter (%TOM) determined by Loss on Ignition (LOI), at 550° C (Dean 1974; Heiri et al. 2001), and calcium carbonate content (acid leaching) reported as %$CaCO_3$ (Milliman 1974).

2.2.2 Benthic Foraminifera (Benthic health indicators)

Benthic faunae play essential roles in carbon degradation and preservation processes of marine sediments (Levin et al., 2009; Ramirez-llodra et al. 2011; Jobstvogt et al., 2014). Benthic foraminifera have commonly been used as indicators of anthropogenic and natural environmental change in marine environments (Morvan et al., 2004; Denoyelle et al., 2010; Lei et al., 2015; Schwing et al., 2018). Benthic foraminifera assemblages (living and dead), density and diversity were characterized from each field collection (Sen Gupta et al. 2009). Subsamples were stained (rose Bengal), weighed and washed with a sodium hexametaphosphate solution through a 63-µm sieve to disaggregate detrital particles from foraminiferal tests (Osterman et al. 2003; Schönfeld et al. 2012). The fraction remaining on the sieve (>63-µm) was dried in an oven at 32^{O} C for 12 hours, weighed again, and stored at room temperature (Osterman et al., 2003). Between 200 and 400 individuals from each subsample were identified to the species-level and counted. The fraction of the sample that was identified and weighed. It was necessary to count between 200-400 individuals per sample to distinguish 2% significant variability in density and relative abundance between sample intervals (Patterson and Fishbein, 1989). Finally, the *Ammonia-Elphidium* index (AEI; Sen gupta et al., 1996; Sen Gupta and Platon, 2006) will be used as a bioindicator of oxygen depletion.

An AZTI Marine Biotic Index (AMBI) was populated using benthic foraminifera assemblage data (f-AMBI) to determine benthic ecosystem quality status following the methods presented in O'Malley et al., (2021). The f-AMBI utilizes species composition to rank each species in one of five groups from sensitive to first order opportunist to measure Ecological Quality Status (EQS) rated on a 1-7 scale (easy to interpret).

2.2.3 Short-lived radioisotopes (age models, fluxes, sediment transport/resuspension, food web)

Sedimentary short-lived radioisotope activities and geochronologies (age models) were produced to provide chronological context (last 100 years) for sedimentary baseline measurements, mass accumulation rates and input fluxes for bulk sediment and contaminants, bioturbation and identify surface sediment dynamics (passive transport). Short-lived radioisotope activities were also measured in various fish tissues (gills, liver, gall bladder) to assess uptake and potential vectors into the food web. The most commonly used chronometers for recent sedimentation are short-lived radioisotopes including excess ^{234}Th and ^{210}Pb, ^{137}Cs, and ^{7}Be (Swarzenski 2014; Holmes 1998; Appleby 2001). Sediment core samples were analyzed for short-lived radioisotopes by gamma spectrometry on Series HPGe (high-purity Germanium) Coaxial Planar Photon Detectors for total ^{210}Pb (46.5 keV), ^{214}Pb (295 keV and 351 keV), ^{214}Bi (609 keV), ^{234}Th (63 keV) ^{137}Cs (661 keV), and ^{7}Be (477). Activities were reported as disintegrations per minute per gram of sediment (dpm/g) using methodology described by Brooks et al. (2015). The primary sediment age-models were based on $^{210}Pb_{xs}$ and comprised of the constant flux, constant sedimentation model (CF:CS) and/or the constant rate of supply (CRS) model depending on sedimentary setting (Appleby and Oldfield 1983; Holmes et al. 1998; Appleby 2001).

Detector efficiencies (limit of detection) were all <3% of the activities measured, determined by similar methods to Kitto et al. (1991). Efficiency calibrations were based on analyzing 12 varying masses (1-50g) of the IAEA-414 (fish) and IAEA-447 (sediment) standard. By relating the counts measured at variable masses to the known activities of the standard, self-absorption is also included in the efficiency calibrations (Hussain et al., 1996). The Cutshall method (Cutshall et al, 1983) was used on select samples, and results show that the self-absorption and variability is negligible and within detection error. The mean activities of the ^{214}Pb (295 Kev), ^{214}Pb (351 Kev), and ^{214}Bi (609 Kev) was used as a proxy for ^{226}Ra activity.

2.2.4 Geochemistry

Selected samples were analyzed by x-ray fluorescence (XRF) to determine elemental sediment composition, specifically phosphorus, which is potentially useful for tracking the Piney Point effluent plume. Previously dried and bagged archive samples of core extrusions were ground to a consistent texture with a mortar and pestle. The grains were loosely packed and leveled in acrylic puck wells 25mm in diameter and 2mm deep. Elemental analysis of the packed samples was then carried out using a Bruker S1 Titan handheld portable x-ray fluorescence (XRF) spectrometer by placing each puck under the detection window at a set distance and running a custom “mudrock” analysis program. Relative concentrations of elements ranging from Mg to U in each sample were directly recorded from the instrument in parts per million (PPM).

3. Results

3.1 Water Quality

During the April 7, 2021 sampling event, temperature ranged from 21.4-25.0 ^{0}C, salinity ranged from 28.1-29.6, dissolved oxygen ranged from 5.1-10.8 ml/L and pH ranged from 7.89-8.64

across all sites and depths (Figure 2, Table 2). During the April 28, 2021 sampling event, temperature ranged from 25.3-25.8 ^{0}C, salinity ranged from 28.7-30.4, dissolved oxygen ranged from 6.4-7.3 ml/L and pH ranged from 8.59-8.73 across all sites and depths. During the June 18, 2021 sampling event, temperature ranged from 27.7-29.1 ^{0}C, salinity ranged from 31.0-32.2, dissolved oxygen ranged from 3.7-6.3 ml/L and pH ranged from 8.51-8.73 across all sites and depths.

3.2 Benthic Foraminifera (Benthic health indicators)

A total of 9,138 individual benthic foraminifera were identified to species level from 53 time series samples collected at 27 sites from January 6, 2021 to September 28, 2021 to provide a pre-effluent release to post-effluent release times series. Total counts are reported as they are the most statistically robust and consistent with previous literature (Dix, 2001; Hill et al., 2003). Stained counts are provided in supplementary material 1.

Of the 27 sites sampled, 15 produced viable (greater than 200 total counts) benthic foraminifera assemblages (Figure 3, Table 3). Many sites were barren of any foraminifera tests and/or live benthic foraminifera. The number of taxa ranged from 9-38 with a mean of 24 (± 7). Abundance ranged widely from 9-5650 indiv./g with a mean of 662 (± 1507). Shannon ranged from 0.2-2.8 with a mean of 2.1 (± 0.7). Evenness ranged from 0.1-0.6 with a mean of 0.4 (± 0.1). Fisher's Alpha ranged from 1.7-11.5 with a mean of 6.2 (± 2.4). The *Ammonia-Elphidium* index (inverse to oxygen) ranged from 0-100 with a mean of 62.6 (± 31.6).

An initial calibration and validation of the f-AMBI has been developed for lower Tampa Bay and the proximal West Florida Shelf (Figure 4), which will provide an easy-to-use and cost-effective monitoring and decision support tool to measure seafloor health in both geological records (cores) and also in near real-time through examination of time series sediment samples. Additional calibration is needed using existing and future collections to increase effectiveness.

3.3 Sedimentology (Environmental context)

Sediment texture and composition were reported for 66 grab samples and 21 sub-samples from one sediment core at site 09 (Figure 5, Tables 4 and 5). Sediment texture and composition is variable throughout surface sediment sites with % gravel ranging from 0% to 46.9%, % sand ranging from 16.6% to 98.8%, % mud ranging from 0.6% to 83.4%, % carbonate ranging from 7.3% to 96.5%, and % TOM ranging from 0.1% to 10.8%. Downcore sediment texture and composition for core PP-21-PC-09 showed little to no variability in sediment texture and composition over time with % gravel ranging from 0% to 0.9%, % sand ranging from 95.6% to 98.9%, % mud ranging from 1.1% to 4.4%, % carbonate ranging from 7.8% to 9.1%, and % TOM ranging from 0% to 0.8%.

3.4 Short-lived radioisotopes (age models, fluxes, sediment transport/resuspension, food web)

Sediment

Short-lived radioisotope analyses of surface sediments yielded activities for various radioisotopes to identify areas of active deposition, but also radioisotope activities associated with the sediments and potential elevations from the Piney Point discharge. Excess Pb-210

($^{210}Pb_{xs}$) activities were generally low reflecting low sediment accumulation at most sites and the influence of coarser grained sediments (generally lower $^{210}Pb_{xs}$ activities). Supported Pb-210 ($^{210}Pb_{sup}$) and ^{226}Ra activities were variable with elevated activities dominantly in the Port Manatee and Bishops Harbor areas (Figure 6, Figure 7, Table 6).

Low and variable $^{210}Pb_{xs}$ activities in sediment cores inhibited the ability to produce geochronologies for the 3 sediment cores. Increases in $^{210}Pb_{xs}$ near the base of cores is likely a reflection of groundwater input at these sites. Elevations in $^{210}Pb_{sup}$ and ^{226}Ra activities indicate changes in sediment type that may be associated with changes in phosphorous (Figure 8, Table 7, Table 8, Table 9).

Fish tissue

Out of 57 fish tissue samples from 14 species measured, 25 had detectable short-lived radioisotope (^{226}Ra) activities (Table 10). The activities ranged from 0.010 dpm/g to 0.142 dpm/g (± 0.030 dpm/g). The activities in the gills ranged from 0.027-0.142 dpm/g with an overall mean of 0.076 (± 0.027 dpm/g). The activities in the muscle samples ranged from 0.077-0.114 dpm/g with an overall mean of 0.093 (± 0.011 dpm/g). The activities in the liver samples ranged from 0.010-0.111 dpm/g with an overall mean of 0.072 (± 0.037 dpm/g).

3.5 Geochemistry

XRF analyses focused on the determination of phosphorus concentrations (Figure 6, Tables 4 and 5) in sediment samples. Phosphorus concentrations in the surface sediment grab samples ranged from 91ppm (PP-USF-04; Table 4) to 7855 ppm (PP-21-SS-03). Phosphorus concentrations ranged from 1326 ppm to the highest concentration (6987 ppm) at the base of core PP-21-PC-09 (100-105 mm; Table 5).

4 Discussion

4.1 Observations

Water quality

The increase in temperature and salinity along with the decrease in dissolved oxygen from April to June is consistent with seasonal warming and stratification of the bay during warmer, dryer summer months. The pH was noticeably lower at the sites nearest the effluent release location during the effluent release (April 7, 2021) versus the other sampling events (April 28 and June 18, 2021). This pH decrease was likely caused by the release of the effluent.

Benthic Foraminifera

Many sampling sites were barren with respect to live benthic foraminifera or benthic foraminifera tests. Benthic foraminifera assemblage baselines (both live and total) have been established for most of middle and lower Tampa Bay, which did not previously exist at the species level. There was no direct impact from the Piney Point effluent release assessed on benthic foraminifera assemblages from April to June 2021. Benthic foraminifera indices (Figure 3) were quite heterogeneous throughout Tampa Bay. Fisher's Alpha (richness) and abundance (indiv./g) were highest in Southeast Tampa Bay near Port Manatee and Bishops Harbor.

Shannon and evenness were highest in lower Tampa Bay near Boca Ciega Bay. The lowest A/E index values were in south-central Tampa Bay, which is indicative of higher oxygen levels.

Sedimentology

Surface sediment texture and composition were variable, but distribution patterns are consistent with what is expected, and what has previously been reported, for Tampa Bay (Brooks and Doyle, 1998). Finer grained (higher % mud) sediments were located dominantly in deeper water with lower currents/energy. Carbonate content generally increased toward Lower Tampa Bay as expected, reflecting increased marine influence/production. Higher % Carbonate values in Port Manatee is likely a reflection of dredged material from recent maintenance of the shipping channel (Figure 5). The Phosphorous distribution was also variable, but higher concentrations in the Port Manatee and Bishops Harbor areas likely are associated with local geology and/or anthropogenic activities in the surrounding watershed.

Sedimentary Radioisotopes

Short-lived radioisotopes in surface sediment samples exhibited high variability, with elevated activities in $^{210}\mathrm{Pb}_{\mathrm{sup}}$ and $^{226}\mathrm{Ra}$ dominantly in the Port Manatee and Bishops Harbor areas, concurrent with higher concentrations of phosphorous, which could be from natural sources, the discharge, or other anthropogenic inputs (Figure 6). These concurrent elevations in $^{210}\mathrm{Pb}_{\mathrm{sup}}$ and $^{226}\mathrm{Ra}$, and Phosphorous concentrations, are also evident in the sediment cores. $^{210}\mathrm{Pb}_{\mathrm{xs}}$ activities are relatively low in surface sediment samples indicating slow sediment accumulation rates, and/or the influence of coarser grained sediments. Additionally, downcore $^{210}\mathrm{Pb}_{\mathrm{xs}}$ profiles do not show exponential decreases in activities, which are required to produce reliable geochronologies. Sites 08 and 09 increases in $^{210}\mathrm{Pb}_{\mathrm{xs}}$ near the core base likely reflects input from groundwater (Figure 8). Further investigation into the $^{210}\mathrm{Pb}_{\mathrm{sup}}$ and $^{226}\mathrm{Ra}$ elevations and Phosphorous are necessary to deconvolute the role of the natural geology (phosphorous), anthropogenic inputs (last ~50+ years), and the Piney Point discharge with regards to these radioisotope elevations.

Fish Tissue Radioisotopes

The short-lived radioisotope ($^{226}\mathrm{Ra}$) activities measured in fish tissues (liver, muscle, gills) were very low. The activities in muscle (long-term signal) were slightly higher than those in the gills and liver (short-term signal), which suggests that there was no short-term increase in radioisotope uptake during or following the Piney Point effluent release above natural ambient levels.

4.2 Accomplishments

Seventy samples were analyzed for benthic foraminifera assemblage characterization (68 proposed). Sedimentological analyses were performed on eighty-seven samples (66 surface grab samples and 21 down-core subsamples; 68 proposed). Fifty-seven analysis days were allotted to fish tissue and 144 analysis days were allotted to sediments for radioisotope analysis (201 total, 168 proposed).

The primary findings of this study are reported below each deliverable (italicized) stated in the proposal:

1. *Determination of any changes in sediment sources, environmental and depositional settings in Tampa Bay (e.g. algal blooms) for four months following the Piney Point effluent release.*

   Sediment texture and composition show multiple sediment sources dominated by coarse-grained, marine carbonates that increase toward the bay mouth, and fine-grained siliciclastics increasing toward the bay head, reflecting continental input. This sediment distribution pattern is consistent with what has been reported in the past. XRF data show locally elevated phosphorus concentrations (relative to other parts of the bay), which is consistent with the Piney Point effluent release, but could also reflect local geology.

2. *Determination of elevated radioisotope activities in fish tissue and sediments throughout Tampa Bay associated with the effluent release.*

   There was no short-term increase in radioisotope uptake in fish liver, gills or muscle assessed during or following the Piney Point effluent release above natural ambient levels.

   Radioisotope activities in fish were low but previous data of this type are not available for comparison to identify any potential elevations. Additional sampling and analyses for radioisotopes in fish will determine spatial patterns in Tampa Bay and help further resolve any elevations in radioisotopes in fish. This data can then be compared with other radioisotope data for potential sources such as the Piney Point discharge, anthropogenic inputs, and natural sources.

3. *Constraint of the benthic spatial distribution of the effluent throughout Tampa Bay (using radioisotope tracers).*

   Radioisotope activities in surface sediments and downcore sub-sample showed little $^{210}Pb_{xs}$ for geochronological purposes but did have variability in $^{210}Pb_{sup}$ and ^{226}Ra with highest elevations in the Port Manatee and Bishops Harbor areas of the Bay. These elevations may be associated with the regional geology, anthropogenic input of phosphorus, and/or the Piney Point discharge. These elevations in radioisotopes appear to be linked with higher phosphorus content in sediments. Further analyses and sampling will help define this relationship and resolve the source(s) of the phosphorous, primarily high phosphorous in the sediments/geologic in this region, potential input of phosphorous from anthropogenic activities in the area in the past, and/or the Piney Point discharge.

4. *Establishment of benthic ecological quality status and variability for four months following the effluent release.*

Benthic foraminifera assemblage (total and live) baselines were established (which were not present before this project). These baselines can now be used to assess impact and response from future perturbations.

An initial f-AMBI calibration and validation has been set for lower Tampa Bay (through this funding) and the proximal West Florida Shelf (through other funding). Additional calibration and validation (longer time series) is ongoing.

5. *Assessment of benthic impact from, and response to, the effluent release (toxicity) and extenuating circumstances (algal bloom, hypoxia) for up to four months following the effluent release.*

There was no direct impact from the Piney Point effluent release assessed on benthic foraminifera assemblages from April to June 2021 time series grab samples. Downcore analysis is suggested to provide context with longer term (decadal-scale) trends.

4.3 Recommendations for next steps

1. Considering the affinity for Ra to replace Ca in bone structure, we recommend that ^{226}Ra be measured in the bones of fish potentially exposed to increased radioactivity.
2. Continuation of time series sampling and analysis of benthic foraminifera, sedimentology and radiochemistry (water, fish, sediments) to provide a temporal baseline on the interannual scale, from which quantitative impact/response characterization can be assessed during and post any future perturbation. With longer time series records, development of more robust statistical methods will be possible (PCA, General additive models) to determine controlling environmental parameters.
3. Continued enhancement of stained (living) benthic foraminifera analyses to better reflect the impact/response and temporal variability of the living assemblages.
4. Refinement of the f-AMBI (marine biotic index) utilizing broader temporal sampling to streamline benthic health assessment and increase effectiveness as an impact/response indicator.
5. Analysis of downcore (historical) benthic foraminifera assemblages for comparison of pre-human development baselines to post-human development conditions.
6. X-ray diffraction (XRD) of sediments will identify specific minerals present, which will help determine if the observed elevated phosphorus levels are a result of the Piney Point effluent release, or reflect the natural geologic conditions. Specifically, if XRD shows elevated levels of the mineral Francolite (carbonate fluorapatite), which is the phosphate mineral mined locally, and these elevated levels correspond with increases in phosphorus values observed in XRF data, then it can logically be assumed that elevated phosphorus is natural. However, if the elevated phosphorus levels do not correspond with elevated Francolite concentrations, then elevated phosphorus is more likely to represent recent

anthropogenic input, such as the Piney Point effluent release. The Eckerd College Marine Science program recently (June 2022) acquired a new state-of- the-art XRD, which will be used for this investigation.

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7 Appendix:

7.1 Figures

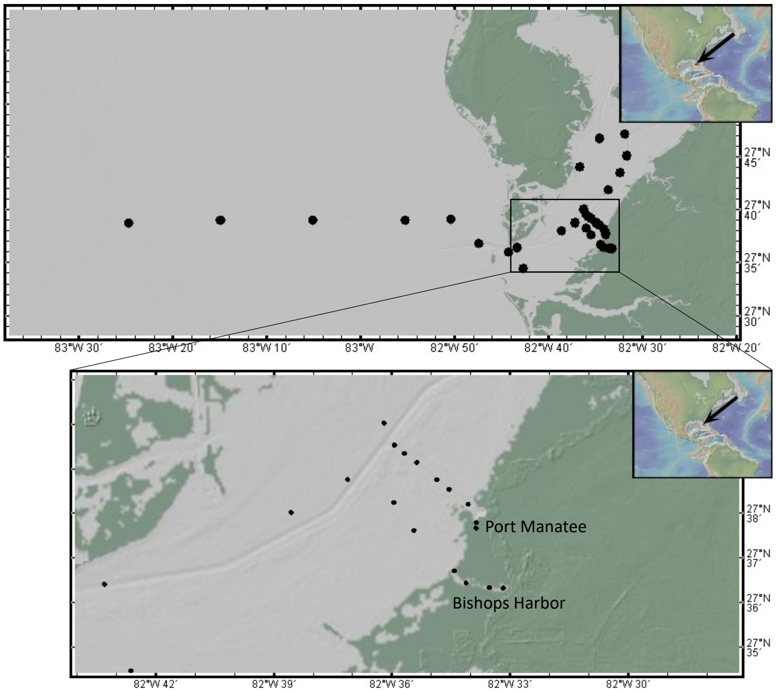


Figure 1: Map of sampling sites including an inset map with reference to Port Manatee and Bishops Harbor.

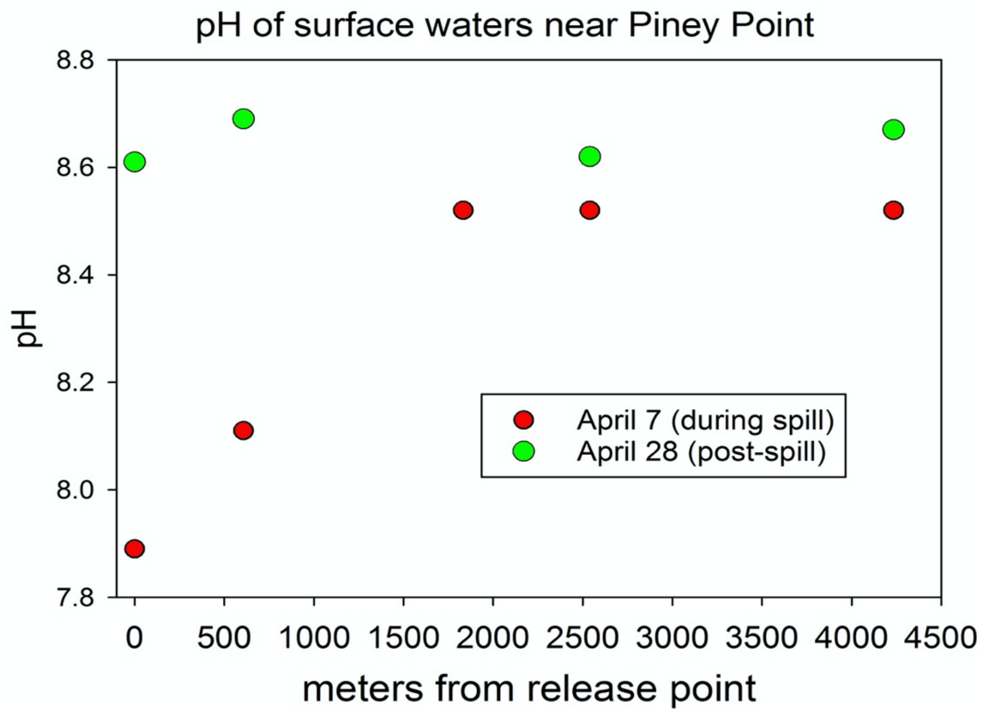
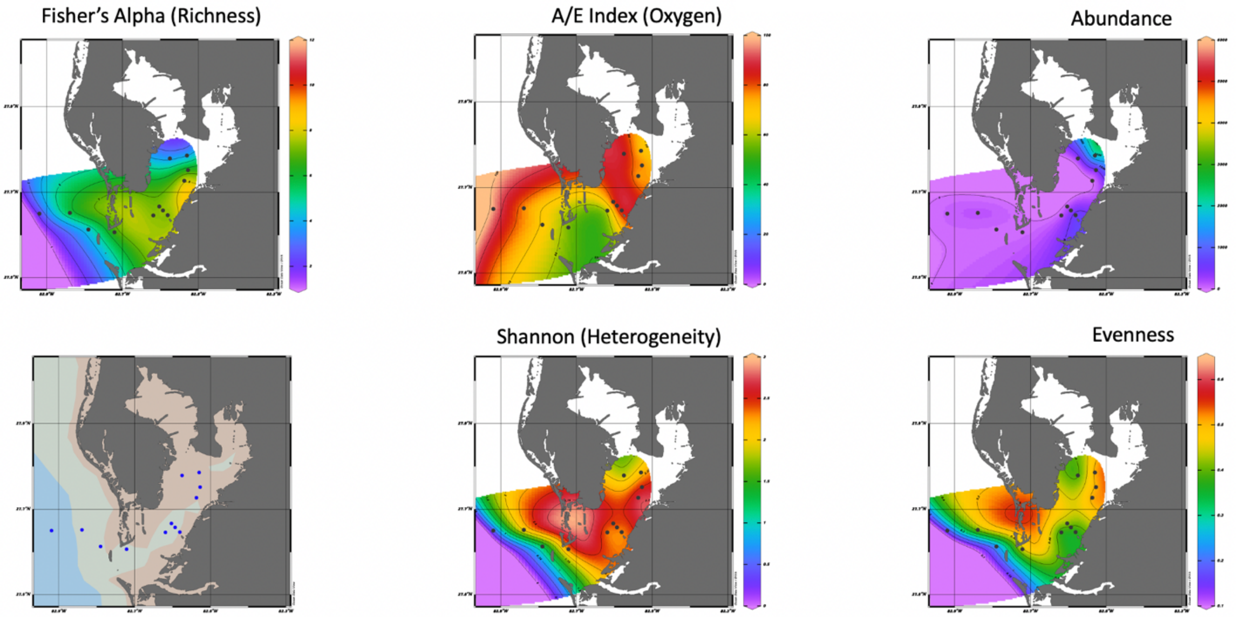


Figure 2: pH of surface waters along a transect seaward (WNW) from Bishops Harbor into middle Tampa Bay on April 7, 2021 (during effluent release) and April 28 (post-release).


Fisher's Alpha (Richness)

A/E Index (Oxygen)

Abundance

Shannon (Heterogeneity)

Evenness

Figure 3: DIVA gridded (interpolation) maps of benthic foraminifera baseline species richness (Fisher's Alpha), *Ammonia-Elphidium* index (inverse to oxygen concentration), abundance (individuals per gram), Shannon and Evenness for middle, lower Tampa Bay and nearshore West Florida Shelf.

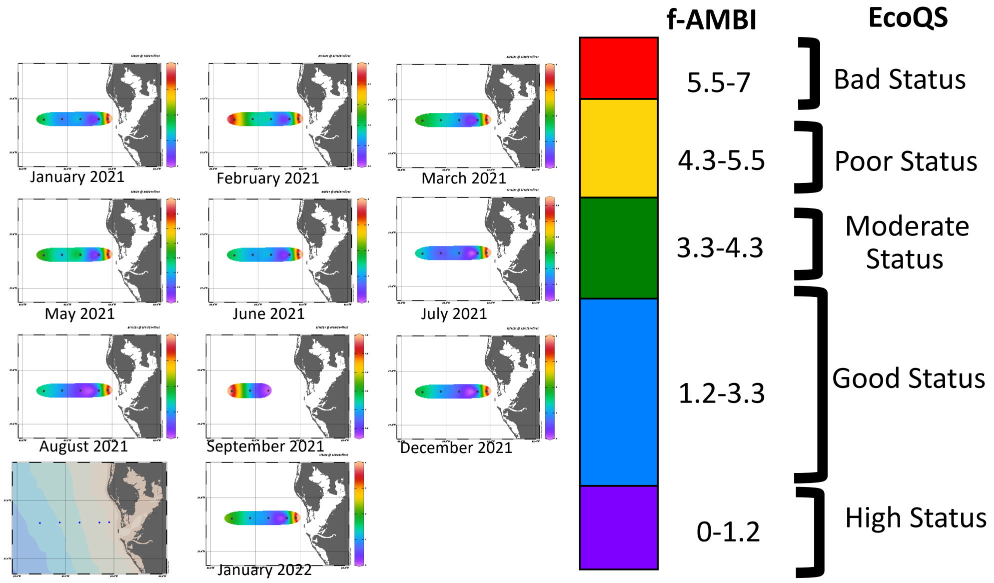
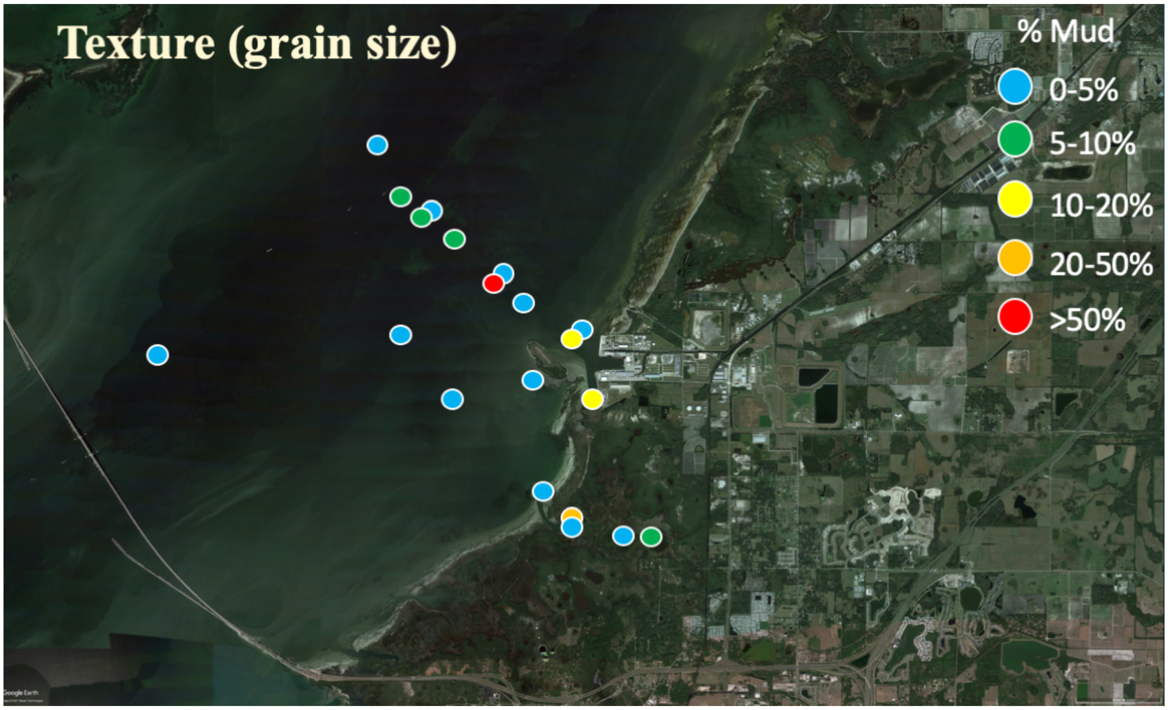


Figure 4: Spatiotemporal DIVA gridded plots of West Florida Shelf time series sediment grab sample benthic foraminifera f-AMBI scores from January 2021-January 2022. The f-AMBI scores are color coded (purple=high, blue=good, green=moderate, yellow=poor, red=bad) according to the ecological quality status (EcoQS).

A)



B)

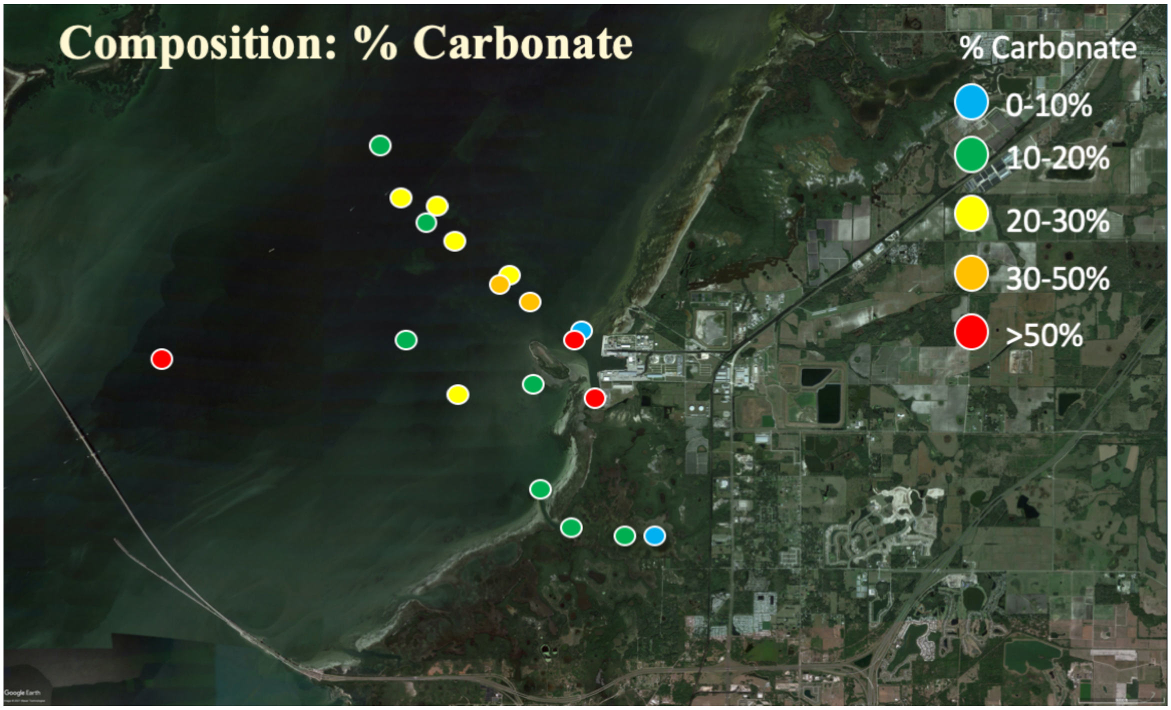
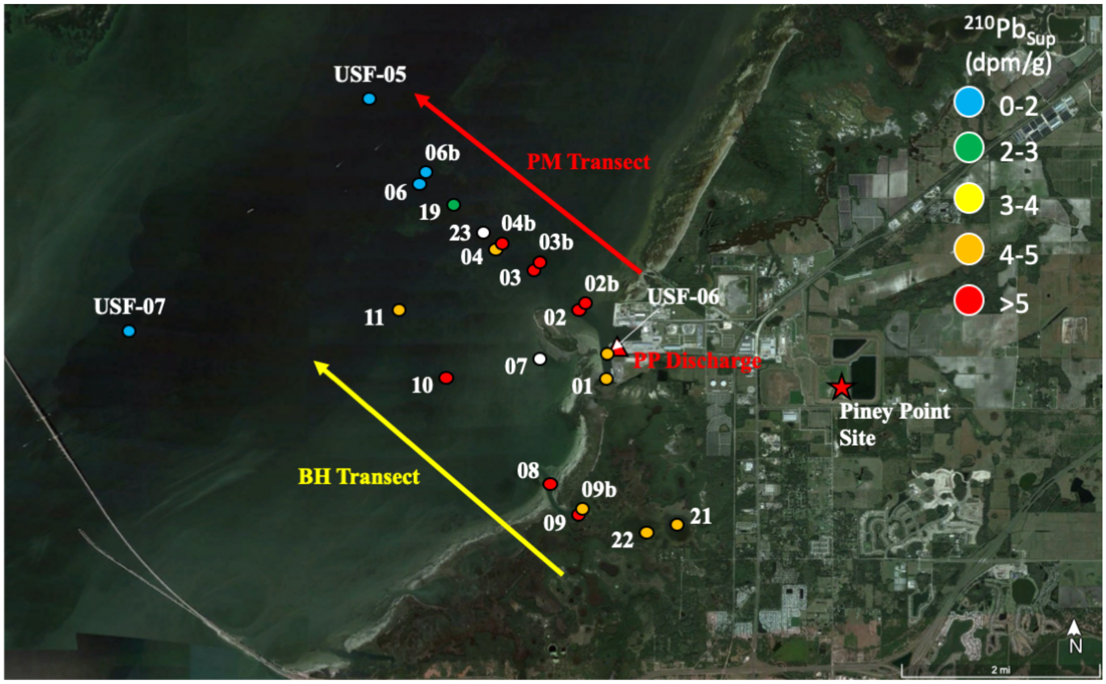


Figure 5: Map of Port Manatee and Bishops Harbor sites with A) grain size represented as % Mud and B) composition represented as % Carbonate for surface sediment samples.

A)



B)

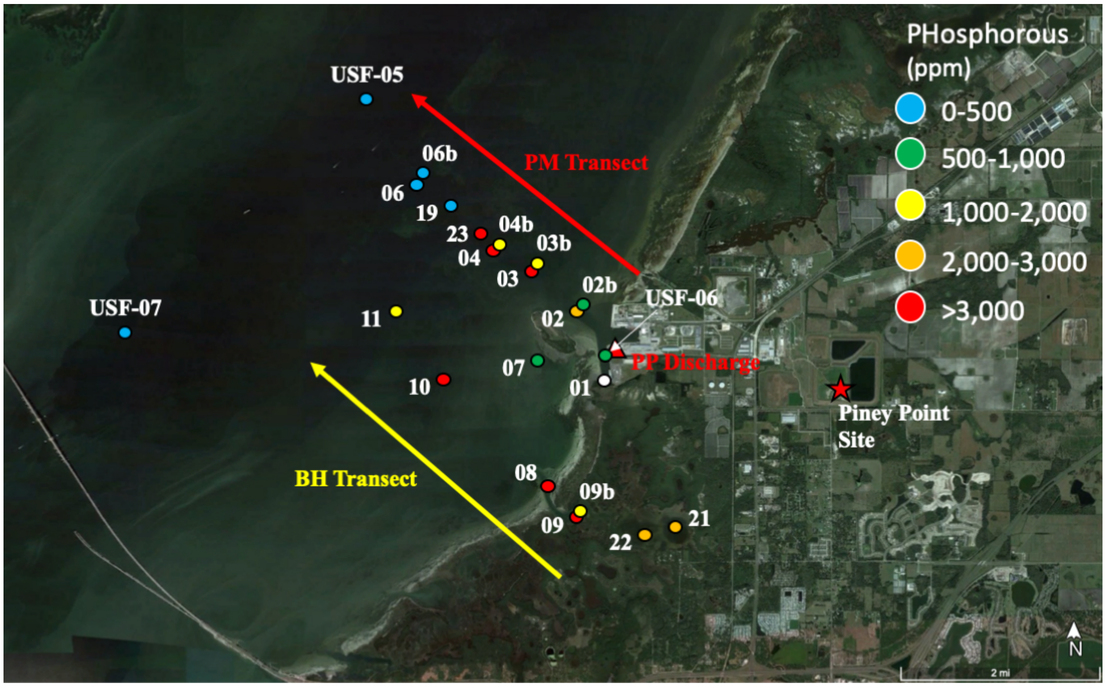


Figure 6: Map of Port Manatee and Bishops Harbor sites with A) $^{210}Pb_{sup}$ activities (dpm/g) and B) Phosphorous concentrations (ppm) for surface sediment samples.

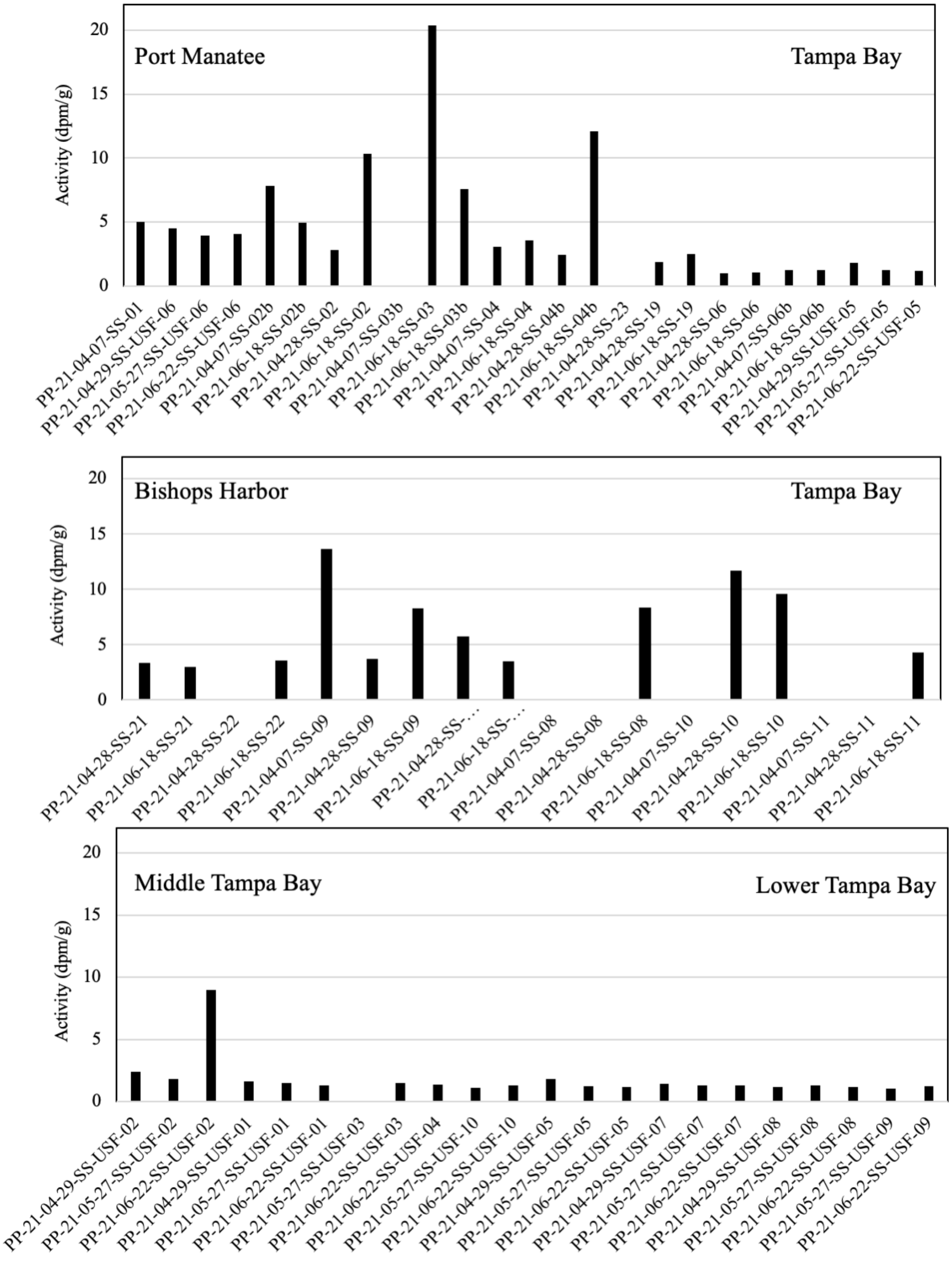


Figure 7: $^{210}Pb_{sup}$ activities of surface sediment samples from all collections along 3 transects, upper Port Manatee into Tampa Bay, middle Bishops Harbor into Tampa Bay, and Lower Middle Tampa Bay to Lower Tampa Bay.

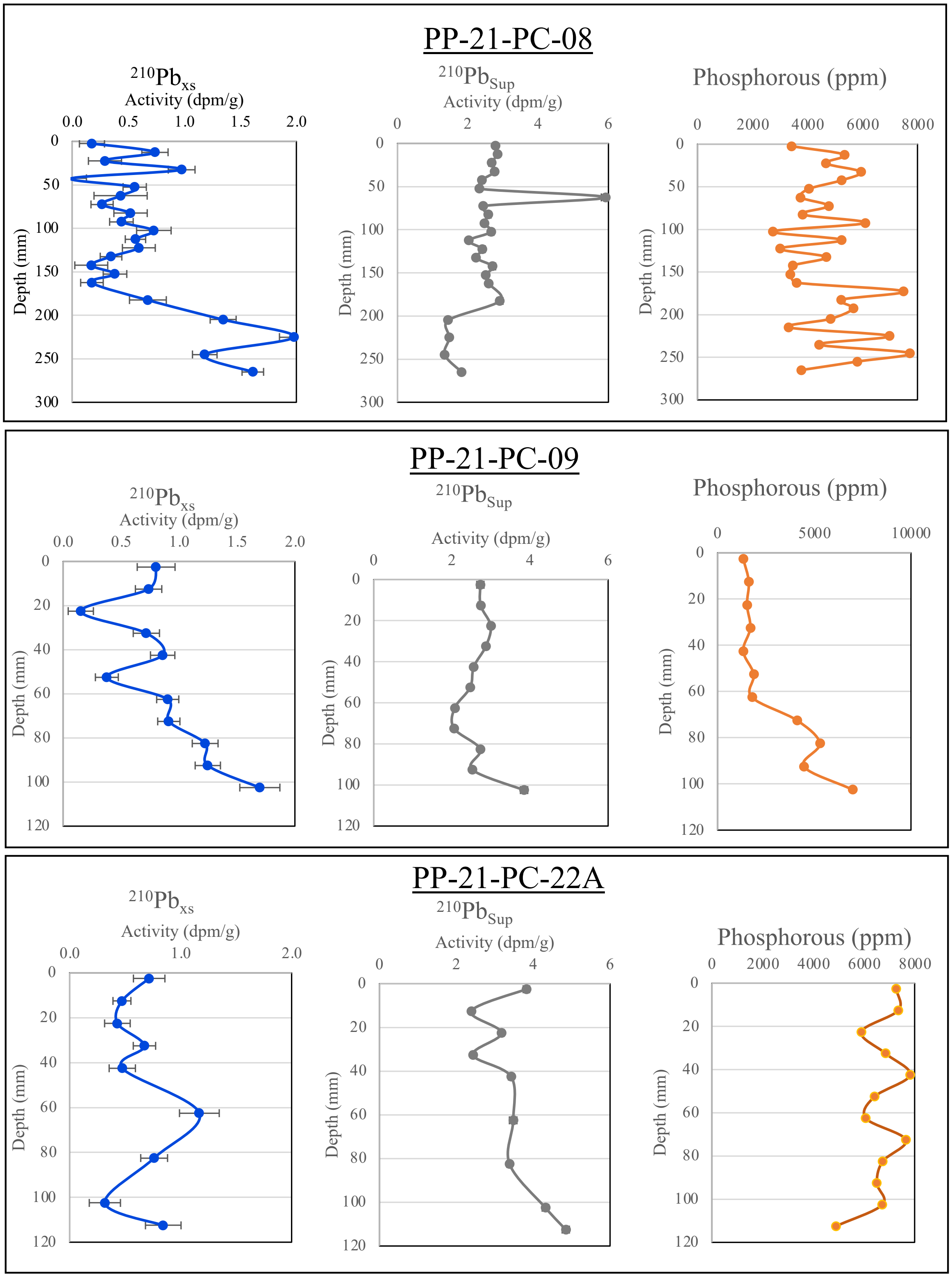


Figure 8: Downcore profiles of $^{210}Pb_{xs}$, $^{210}Pbs_{up}$, and Phosphorous concentrations for 3 push cores collected in/near Bishops Harbor.

8.2 Tables

Table 1: Sampling site names and locations. Note: Sites where vibracores were collected are denoted as "VC".

Site	Latitude	Longitude
PP-21-01	27.6272	-82.4357
PP-21-02	27.6356	-82.4332
PP-21-03	27.6428	-82.4244
PP-21-04	27.6457	-82.4178
PP-21-05	27.6475	-82.4035
PP-21-06	27.6552	-82.4048
PP-21-07	27.6301	-82.4246
PP-21-08	27.6119	-82.4264
PP-21-09	27.6072	-82.4316
PP-21-10	27.6270	-82.4092
PP-21-11	27.6372	-82.4010
PP-21-19	27.6523	-82.4106
PP-21-20	27.6588	-82.4015
PP-21-21	27.6056	-82.5529
PP-21-22	27.6057	-82.5588
PP-21-23	27.6471	-82.4164
PP-21-VC-08	27.6118	-82.4267
PP-21-VC-09	27.6072	-82.4319
PP-21-VC-21	27.6057	-82.4460
PP-21-VC-22	27.6050	-82.4424
PP-21-VC-24	27.6103	-82.4248
PP-21-VC-25	27.6165	-82.4302
USF-1	27.7789	-82.5751
USF-2	27.7861	-82.5300
USF-3	27.7253	-82.5387
USF-4	27.6977	-82.5601

USF-5	27.6674	-82.6034
USF-6	27.6301	-82.5643
USF-7	27.6339	-82.6427
USF-8	27.5745	-82.7105
CPO5	27.7517	-82.5271
CPO7	27.6462	-82.6188
CPO9	27.6070	-82.7217
CPO10	27.6133	-82.7900
ROME01	27.6460	-83.4110
ROME02	27.6500	-83.2480
ROME03	27.6500	-83.0840
ROME04	27.6500	-82.9200
ROME05	27.6520	-82.8390

Table 2: Water quality measurements including pH, dissolved oxygen (ml/L), temperature (C), and salinity for all sites, depths and time stamps.

		4/7/21				4/28/21				6/18/21			
Site ID	depth (m)	pH	DO	T	S	pH	DO	T	S	pH	DO	T	S
1	1	7.89	8.1	22.2	29	8.61	6.9	25.8	29.1	8.6	5.8	28.4	31
	5	7.95	8.05	22.2	29	8.64	6.9	25.8	29.1	8.63	6	28.9	31.4
	10	7.94	5.9	22.1	29.2	8.67	6.7	25.8	29.1	8.66	4.6	28.9	31.9
2	1	8.11	8.7	21.8	28.1	8.69	6.7	25.7	29.1	8.73	6.3	28.6	31.1
	5	8.26	8.8	22.1	29.1	8.68	6.5	25.6	29.1	8.69	5.1	28.5	31.7
	10	8.33	7.8	21.7	29.6	8.69	6.4	25.6	29.1	8.7	5.2	28.3	31.7
3	1	8.52	9.2	22	29.1					8.7	5.8	28.4	31.3
	5	8.53	9.3	22	29.1					8.69	5.8	28.4	31.3
	10	8.56	9.4	22	29.1					8.68	5.7	28.4	31.3
4	1	8.52	9	21.9	29.2	8.62	7.2	25.4	29	8.69	5.4	28.5	31.4
	5	8.53	8.9	21.9	29.2	8.62	6.9	25.3	29.1	8.65	5.4	28.5	31.5
	10					8.64	6.8	25.4	29.4	8.64	5.3	28.5	31.5

6	1	8.52	7.4	22.1	28.6	8.67	7.3	25.4	29.2	8.66	5.7	28.8	31.4
	5	8.52	7.6	22	29	8.66	7.1	25.4	29.4	8.65	5.7	28.9	31.5
	10	8.53	7.5	22	29.1	8.68	6.4	25.4	29.7	8.64	5.7	28.9	31.9
8	1	8.6	10.8	22.7	29.2	8.69	7.3	25.7	29.4	8.69	5.6	28	31.9
	2	8.63	10.8	22.6	29.2	8.69	7.3	25.5	29.4	8.7	5.3	27.9	31.9
9	1	8.34	6.2	24.2	28.4	8.68	7	25.6	29.4	8.65	5.5	28	32.2
	2	8.62	7.9	24	28.5	8.69	7	25.6	29.4	8.67	5.1	27.9	32.2
10	1	8.64	5.7	21.4	28.4	8.64	7	25.6	29.8	8.67	6	28.4	31.6
	2	8.64	6.1	23.7	28.5	8.64	7	25.5	29.8	8.66	5.4	28.4	31.6
	4					8.65	6.9	25.4	29.8	8.66	5.8	28.4	31.6
11	1	8.59	5.1	25	28.5	8.59	6.7	25.6	30.4	8.66	5.8	28.8	32.2
	3	8.59	5.4	24.5	28.5	8.62	6.8	25.5	30.4	8.65	5.8	28.8	32.2
	6					8.63	6.7	25.4	30.4	8.63	5.5	28.8	32.2
19	1					8.63	6.9	25.4	29.3	8.65	5.6	28.9	31.8
	5					8.64	6.9	25.3	29.3	8.65	5.7	28.9	31.8
	10					8.66	6.7	25.4	29.6	8.65	5.6	28.9	31.9
20	1					8.66	6.9	25.5	29.3	8.65	5.7	29	31.4
	5					8.66	7.1	25.4	29.4	8.64	5.6	29.1	31.9
	10					8.71	6.9	25.5	29.5	8.64	5.6	29.1	32
21	0					8.73	6.8	25.5	28.8	8.52	4.1	27.7	31.8
	1.5					8.69	6.8	25.4	28.7	8.51	3.7	27.7	31.9
22	0					8.63	6.7	25.3	29.3	8.56	4.4	27.7	32
	1.5					8.65	6.7	25.3	29.3	8.58	4.4	27.7	32
23	1					8.69	6.9	25.3	29.1				
	5					8.65	6.7	25.3	29.2				
	10					8.66	6.6	25.4	29.5				

Table 3: Benthic foraminifera data for grab samples including the number of taxa, abundance (individuals per gram), Shannon, Evenness, Fisher’s Alpha, and the *Ammonia-Elphidium* index.

Site	taxa	Abundance	Shannon	Evenness	Fisher alpha	AE Index
ROME01	23	169	2.7	0.6	5.8	0.0
ROME02	18	51	1.9	0.4	4.2	0.0
ROME03	38	5650	2.7	0.4	11.5	20.5
ROME04	9	36	0.2	0.1	1.7	100.0
ROME05	26	219	2.6	0.5	6.8	72.5
CPO5	25	54	2.5	0.5	6.5	80.9
CPO7	27	27	2.2	0.3	7.2	53.3
CPO9	27	15	2.7	0.5	7.2	55.8
CPO10	17	22	0.9	0.1	3.9	70.0
PP-USF-1	16	157	1.8	0.4	3.6	87.9
PP-USF-2	16	2373	2.1	0.5	3.6	69.9
PP-USF-3	30	9	2.8	0.5	8.3	71.6
PP-USF-5	26	16	2.5	0.5	6.8	85.7
PP-21-SS-04B	26	728	2.2	0.4	6.8	88.3
PP-21-SS-06B	30	397	2.4	0.4	8.3	82.9

Table 4: Texture and Composition represented as % dry weight and Phosphorous concentration (XRF) for surface sediments. Note site are averages of all collection dates.

Site	% Gravel	% Sand	% Mud	% Carbonate	% TOM (LOI)	% Other*	Phosphorous (ppm)
PP-21-SS-01	45.0	40.5	14.4	85.6	0.6	13.8	
PP-USF-06	0.0	27.7	72.4	45.3	8.6	46.1	854
PP-21-SS-02	7.8	83.4	8.8	34.5	0.9	64.7	2089
PP-21-SS-02B	17.2	74.3	8.5	47.2	0.4	52.4	984

PP-21-SS-03	8.7	85.5	5.8	43.4	1.0	55.5	7855
PP-21-SS-03B	1.0	95.6	3.4	36.7	0.9	62.4	1370
PP-21-SS-04	11.7	78.6	9.7	42.0	0.4	57.6	3242
PP-21-SS-04B	7.0	66.8	26.1	38.4	2.4	59.2	1309
PP-21-SS-23	1.5	92.0	6.5	27.8	0.3	71.8	7903
PP-21-SS-19	1.2	90.4	8.4	20.5	0.7	78.8	489
PP-21-SS-06	0.1	94.7	5.2	10.4	0.4	89.2	207
PP-21-SS-06B	5.7	89.5	4.8	18.2	0.4	81.4	140
PP-USF-05	4.8	93.0	2.2	28.2	0.2	71.6	113
PP-21-SS-07	0.1	95.4	4.5	10.6	0.1	89.3	532
PP-21-SS-21	0.0	93.7	6.3	8.2	0.5	91.3	2190
PP-21-SS-22	0.0	98.7	1.3	10.5	0.4	89.1	2169
PP-21-SS-09	6.2	89.7	4.0	19.2	0.5	80.2	3127
PP-21-SS-09B	1.6	73.3	25.1	15.4	0.6	84.1	1292
PP-21-SS-08	2.0	97.2	0.9	23.0	0.3	76.8	3916
PP-21-SS-10	1.3	96.7	2.1	25.7	0.3	74.0	4196
PP-21-SS-11	1.9	97.2	0.9	24.4	0.2	75.4	2120
PP-USF-02	3.0	79.6	17.4	25.5	1.8	72.7	525
PP-USF-01	0.2	87.8	12.0	7.7	1.3	91.0	271
PP-USF-03	3.6	94.1	2.3	53.8	0.3	45.9	161
PP-USF-04	5.5	93.0	1.5	26.9	0.1	73.0	91
PP-USF-10	2.7	94.9	2.5	31.8	0.3	68.0	201
PP-USF-07	6.8	91.2	2.0	55.9	0.2	43.9	428
PP-USF-08	28.9	68.2	2.9	35.6	0.3	64.1	413
PP-USF-09	22.8	74.3	3.0	74.9	0.3	24.9	265
Maximum	46.9	98.8	83.4	96.5	10.8	91.9	7903
Minimum	0.0	16.6	0.6	7.3	0.1	3.3	91
Average	6.7	83.7	9.6	31.0	0.9	68.1	1730

Table 5: Texture and Composition represented as % dry weight and Phosphorous concentration (XRF) for core PP-21-PC-09. Note *%Other is all non-carbonate, non-organic.

Top Depth of interval (mm)	Bottom Depth of interval (mm)	Average Depth of interval (mm)	% Gravel	% Sand	% Mud	% Carbonate	% TOM (LOI)	% Other *	Phosphorous (ppm)
0	5	2.5	0.0	98.1	1.9	8.2	0.8	91.0	1326
5	10	7.5	0.0	98.9	1.1	8.3	0.6	91.2	
10	15	12.5	0.0	97.8	2.2	8.4	0.6	91.1	1615
15	20	17.5	0.2	97.4	2.4	8.3	0.7	91.1	
20	25	22.5	0.1	97.2	2.7	8.2	0.7	91.2	1521
25	30	27.5	0.0	98.0	2.0	8.2	0.5	91.3	
30	35	32.5	0.1	98.8	1.1	8.9	0.3	90.8	1694
35	40	37.5	0.1	98.5	1.4	9.1	0.5	90.4	
40	45	42.5	0.1	98.5	1.4	8.8	0.4	90.8	1326
45	50	47.5	0.1	98.4	1.5	8.2	0.4	91.4	
50	55	52.5	0.0	98.5	1.5	8.3	0.3	91.4	1872
55	60	57.5	0.0	97.7	2.3	7.8	0.6	91.6	
60	65	62.5	0.1	97.0	2.8	8.1	0.7	91.3	1775
65	70	67.5	0.0	97.2	2.8	8.1	0.6	91.3	
70	75	72.5	0.3	97.5	2.2	8.1	0.7	91.2	4108
75	80	77.5	0.6	97.2	2.3	8.4	0.0	91.6	
80	85	82.5	0.4	97.1	2.5	8.6	0.6	90.8	5285
85	90	87.5	0.1	97.4	2.4	8.6	0.4	91.0	
90	95	92.5	0.4	96.6	3.1	8.6	0.5	90.9	4466
95	100	97.5	0.9	95.8	3.3	9.0	0.5	90.5	
100	105	102.5	0.0	95.6	4.4	8.6	0.7	90.7	6987

Table 6: Short-lived radioisotope activities for surface sediments. Note site activities are average of all collection dates.

Site	$^{210}Pb_{Tot}$ Activity (dpm/g)	$^{210}Pb_{Tot}$ error (dpm/g)	$^{210}Pb_{Sup}$ Activity (dpm/g)	$^{210}Pb_{Sup}$ error (dpm/g)	$^{210}Pb_{xs}$ Activity (dpm/g)	$^{210}Pb_{xs}$ error (dpm/g)	^{226}Ra Activity (dpm/g)	^{226}Ra error (dpm/g)
PP-21-SS-01	7.0	0.2	5.0	0.1	2.0	0.2	3.8	0.1
PP-USF-06	11.7	0.4	4.2	0.5	7.5	0.4	3.7	0.2
PP-21-SS-02	9.0	0.2	6.6	0.1	2.4	0.2	4.9	0.1
PP-21-SS-02B	8.7	0.2	6.4	0.1	2.4	0.2	4.4	0.1
PP-21-SS-03	18.8	0.3	20.4	0.6	-1.5	0.3	18.0	0.3
PP-21-SS-03B	8.1	0.2	7.6	0.4	0.6	0.2	7.1	0.2
PP-21-SS-04	4.9	0.1	3.3	0.1	1.5	0.2	2.7	0.1
PP-21-SS-04B	10.8	0.2	7.3	0.1	3.5	0.3	5.3	0.1
PP-21-SS-19	3.9	0.1	2.2	0.1	1.7	0.2	1.8	0.1
PP-21-SS-06	1.6	0.1	1.0	0.0	0.6	0.1	1.1	0.0
PP-21-SS-06B	1.8	0.1	1.2	0.1	0.6	0.1	1.1	0.0
PP-USF-05	2.1	0.1	1.4	0.1	0.7	0.1	1.0	0.1
PP-21-SS-21	4.2	0.1	3.2	0.1	1.0	0.2	2.5	0.1
PP-21-SS-22	5.2	0.2	3.6	0.1	1.6	0.3	2.9	0.1
PP-21-SS-09	9.9	0.2	8.6	0.1	1.3	0.3	6.0	0.1
PP-21-SS-09B	5.8	0.2	4.6	0.1	1.1	0.2	3.0	0.1
PP-21-SS-08	9.0	0.2	8.3	0.4	0.7	0.2	7.3	0.2
PP-21-SS-10	10.7	0.2	10.6	0.4	0.1	0.2	11.0	0.2
PP-21-SS-11	4.3	0.1	4.3	0.3	0.0	0.1	4.3	0.1
PP-USF-02	6.2	0.2	4.4	0.3	1.8	0.2	4.0	0.1
PP-USF-01	3.4	0.1	1.5	0.2	1.9	0.1	1.3	0.1
PP-USF-03	3.0	0.1	1.5	0.0	1.5	0.1	1.1	0.0
PP-USF-04	1.6	0.1	1.4	0.2	0.2	0.1	1.0	0.1
PP-USF-10	1.7	0.1	1.2	0.0	0.5	0.1	1.0	0.0
PP-USF-07	2.8	0.1	1.3	0.2	1.5	0.1	0.9	0.1
PP-USF-08	2.0	0.1	1.2	0.2	0.8	0.1	0.8	0.1
PP-USF-09	2.1	0.1	1.2	0.1	0.9	0.1	1.0	0.1

Table 7: Short-lived radioisotope activities for core PP-21-PC-08.

Top Depth of interval (mm)	Bottom Depth of interval (mm)	Average Depth of interval (mm)	$^{210}Pb_{Tot}$ Activity (dpm/g)	$^{210}Pb_{Tot}$ error (dpm/g)	$^{210}Pb_{Sup}$ Activity (dpm/g)	$^{210}Pb_{Sup}$ error (dpm/g)	$^{210}Pb_{xs}$ Activity (dpm/g)	$^{210}Pb_{xs}$ error (dpm/g)	^{226}Ra Activity (dpm/g)	^{226}Ra error (dpm/g)
0	5	2.5	3.0	0.1	2.8	0.1	0.2	0.1	1.9	0.1
10	15	12.5	3.6	0.1	2.8	0.1	0.7	0.1	1.9	0.1
20	25	22.5	3.0	0.1	2.7	0.1	0.3	0.1	2.0	0.1
30	35	32.5	3.7	0.1	2.8	0.1	1.0	0.1	2.3	0.1
40	45	42.5	2.4	0.1	2.4	0.1	0.0	0.1	1.5	0.1
50	55	52.5	2.9	0.1	2.3	0.1	0.6	0.1	1.9	0.1
60	65	62.5	6.4	0.2	5.9	0.1	0.4	0.2	3.8	0.1
70	75	72.5	2.7	0.1	2.4	0.1	0.3	0.1	1.8	0.0
80	85	82.5	3.1	0.1	2.6	0.1	0.5	0.1	1.6	0.1
90	95	92.5	2.9	0.1	2.5	0.1	0.4	0.1	1.9	0.1
100	105	102.5	3.4	0.1	2.7	0.1	0.7	0.2	1.9	0.1
110	115	112.5	2.6	0.1	2.0	0.0	0.6	0.1	1.3	0.0
120	125	122.5	3.0	0.1	2.4	0.1	0.6	0.1	1.7	0.1
130	135	132.5	2.6	0.1	2.2	0.1	0.3	0.1	1.7	0.0
140	145	142.5	2.9	0.1	2.7	0.1	0.2	0.1	1.8	0.1
150	155	152.5	2.9	0.1	2.5	0.1	0.4	0.1	1.9	0.1
160	165	162.5	2.8	0.1	2.6	0.1	0.2	0.1	1.8	0.0
180	185	182.5	3.6	0.1	2.9	0.1	0.7	0.2	2.0	0.1
200	210	205	2.8	0.1	1.4	0.0	1.3	0.1	0.6	0.0
220	230	225	3.5	0.1	1.5	0.0	2.0	0.1	0.7	0.0
240	250	245	2.5	0.1	1.3	0.0	1.2	0.1	0.6	0.0
260	270	265	3.4	0.1	1.8	0.0	1.6	0.1	0.9	0.0

Table 8: Short-lived radioisotope activities for core PP-21-PC-09.

Top Depth of interval (mm)	Bottom Depth of interval (mm)	Average Depth of interval (mm)	$^{210}Pb_{Tot}$ Activity (dpm/g)	$^{210}Pb_{Tot}$ error (dpm/g)	$^{210}Pb_{Sup}$ Activity (dpm/g)	$^{210}Pb_{Sup}$ error (dpm/g)	$^{210}Pb_{xs}$ Activity (dpm/g)	$^{210}Pb_{xs}$ error (dpm/g)	^{226}Ra Activity (dpm/g)	^{226}Ra error (dpm/g)
0	5	2.5	3.5	0.1	2.7	0.1	0.8	0.2	2.4	0.1
10	15	12.5	3.5	0.1	2.7	0.1	0.7	0.1	2.5	0.1
20	25	22.5	3.1	0.1	3.0	0.1	0.2	0.1	2.6	0.1
30	35	32.5	3.6	0.1	2.9	0.1	0.7	0.1	2.7	0.1
40	45	42.5	3.4	0.1	2.6	0.1	0.9	0.1	2.8	0.1
50	55	52.5	2.8	0.1	2.5	0.1	0.4	0.1	2.4	0.1
60	65	62.5	3.0	0.1	2.1	0.0	0.9	0.1	2.4	0.1
70	75	72.5	3.0	0.1	2.1	0.0	0.9	0.1	2.2	0.1
80	85	82.5	4.0	0.1	2.7	0.1	1.2	0.1	2.6	0.1
90	95	92.5	3.8	0.1	2.5	0.1	1.2	0.1	2.4	0.1
100	105	102.5	5.5	0.1	3.8	0.1	1.7	0.2	3.2	0.1

Table 9: Short-lived radioisotope activities for core PP-21-PC-22A.

Top Depth of interval (mm)	Bottom Depth of interval (mm)	Average Depth of interval (mm)	$^{210}Pb_{Tot}$ Activity (dpm/g)	$^{210}Pb_{Tot}$ error (dpm/g)	$^{210}Pb_{Sup}$ Activity (dpm/g)	$^{210}Pb_{Sup}$ error (dpm/g)	$^{210}Pb_{xs}$ Activity (dpm/g)	$^{210}Pb_{xs}$ error (dpm/g)	^{226}Ra Activity (dpm/g)	^{226}Ra error (dpm/g)
0	5	2.5	4.5	0.1	3.8	0.1	0.7	0.1	3.4	0.1
10	15	12.5	2.9	0.1	2.4	0.0	0.5	0.1	2.2	0.1
20	25	22.5	3.6	0.1	3.2	0.1	0.4	0.1	3.0	0.1
30	35	32.5	3.1	0.1	2.4	0.1	0.7	0.1	2.3	0.1
40	45	42.5	3.9	0.1	3.4	0.1	0.5	0.1	3.1	0.1
50	55	52.5	3.5	0.1	2.5	0.1	1.1	0.1	2.6	0.1
60	65	62.5	4.6	0.1	3.5	0.1	1.2	0.2	3.5	0.1
70	75	72.5	4.3	0.1	3.0	0.1	1.3	0.1	2.9	0.1
80	85	82.5	4.1	0.1	3.4	0.1	0.8	0.1	3.2	0.1
90	95	92.5	4.0	0.1	2.8	0.1	1.2	0.1	2.9	0.1

100	105	102.5	4.6	0.1	4.3	0.1	0.3	0.1	3.5	0.1
110	115	112.5	5.7	0.1	4.8	0.1	0.8	0.2	3.9	0.1

Table 10: Short-lived radioisotope (^{226}Ra) data for fish tissue including three tissue types (gills, liver and muscle) for 14 species.

Species	**Number**	**Tissue**	**Ra-226 Activity dpm/g**	**Err+/-**
Spanish Mackerel	2	Gills	0.096	0.009
Spanish Mackerel	2	Muscle	0.086	0.008
Spanish Mackerel	3	Gills	0.142	0.011
Threadfin Herring	7	Muscle	0.101	0.009
Spanish Mackerel	3	Muscle	0.077	0.103
Ladyfish	1	Gills	0.122	0.010
Ladyfish	2	Gills	0.078	0.008
Ladyfish	2	Muscle	0.084	0.008
Gray Snapper	1	Muscle	0.088	0.008
Gray Snapper	2	Gills	0.068	0.006
Gray Snapper	2	Muscle	0.083	0.008
Gray Snapper	3	Gills	0.066	0.006
Gray Snapper	3	Liver	0.072	0.007
Gray Snapper	3	Muscle	0.114	0.010
Gray Snapper	11	Liver	0.010	0.093
Black Seabass	1	Gills	0.027	0.003
Black Seabass	1	Muscle	0.095	0.009
Gulf Toadfish	1	Liver	0.111	0.009
Crevalle Jack	1	Gills	0.100	0.009
Least Puffer	1	Liver	0.087	0.008
Least Puffer	1	Muscle	0.089	0.009
Pinfish	1	Gills	0.037	0.083

Pinfish	1	Muscle	0.097	0.091
Atlantic Bumper	10	Gills	0.027	0.097
Southern Flounder	1	Muscle	0.103	0.088
Blue Runner	1	Liver	0.079	0.101