NEW JERSEY SPORTS AND EXPOSITION AUTHORITY

Benthic Biodiversity and Benthic Pollutant Loads in Emergent Marshes of the NJ Meadowlands

Technical Report

MERI, NJSEA

1/31/2020

Abstract

The goal of the study was twofold. On the one hand, we set out to assess changes in benthic fauna diversity at two restored wetland sites of the Hackensack Meadowland Estuary prior to and after the restoration. In this case, we compared benthos id's, species distribution, and abundance in samples taken before and over a decade after restoration. On the other hand, we assessed the risk of contaminant exposure and potential accumulation throughout the food chain in the estuary. We collected sediment samples and benthic invertebrate from three wetland sites in the Hackensack Meadows and analyzed the heavy metal and organic contaminant load in both sediment and tissue samples, along with physical and chemical parameters of both the sediment and the water column at the sampling stations. As a result, we assessed and document any changes in the last 15 years that improvements in water and habitat quality may have had on benthic fauna at the restored wetland sites. As for the benthic contaminant load, we have developed baselines and formal assessments to determine the extent of contaminant transfer from the sediment to the primary consumers in the wetlands' food chain. It is important to understand the risk of whether animals that use the Meadowlands as their feeding and or breeding area are exposed to contaminants by feeding on benthic organisms that carry heavy contaminant loads from the sediments. The result of this study is of great interest and consequence to the future expansion and management of the estuary.

Table of Contents

I. Introduction *(Francisco Artigas)*

The New Jersey Meadowland Commission's (NJMC, now NJSEA) Wetland Program Plan (WPP), among other objectives, calls for monitoring biota, including fish and benthic invertebrate fauna, and documenting any changes that the improvement of water and habitat quality may have on fauna. Although MERI and NJMC's Natural Resources have carried out studies of the benthic invertebrates in the Hackensack River and major tributaries previously (Bragin et al. 2009; Feltes 2003; Learn et al. 2004), there is a clear need for a comprehensive study that assesses the changes in contamination over time in the sediment and its transfer through the Lower Hackensack River Estuary's food web.

Since the last study (Feltes, 2003), landfills have been closed or properly contained, industrial sites have been cleaned up, and wetland marshes in the Meadowlands have been ecologically enhanced. Long term continuous water monitoring records show that water quality in the District has been steadily improving as oxygen levels are at their highest in 20 years, and hypoxia events during summer months have decreased significantly (Shin et al. 2013). Following the WPP, it is now time to assess how habitat and water quality improvements during the last decade have affected benthic communities at District wetland sites. There is a concern among some wildlife managers that because of the long legacy of sediment contamination in the District, new wetland enhancements may attract healthy wildlife to contaminated sites with adverse effects on the fauna. Healthy animals would ingest contaminants by feeding on benthic organisms carrying contaminant loads that mirror concentrations found in the sediments. This reasoning is leading to recommendations to potentially abandon wetland restoration and wetland enhancement initiatives for mitigation in the District. The fact is that there is no hard evidence showing that this is the case since contaminant loads of benthic invertebrate organisms in the Meadowlands District have never been published and seldom measured and, most importantly, no conclusive evidence of significant damage to fauna in the Meadowlands has been documented.

II. Technical Scope of the Project *(Francisco Artigas)*

The tasks of this project involve, on the one hand, replicating a benthic study from 15 years ago where benthic diversity and abundances were measured and on the other hand, collecting benthic and sediment samples and analyzing these for benthic diversity, trace elements and POP's. Figure 1 (Appendix I.) shows the proposed sampling sites. Furthermore, sediment physical-chemical parameters such as texture or particle size, salinity, temperature, and total organic carbon were measured to determine factors that may be influencing the bioavailability of contaminants.

Task 1: Benthic taxonomy, diversity, and abundances: Benthic samples were collected from mudflats, tidal creeks, impoundments, and high marsh pools at Harrier Meadow (HM) and Mill Creek Marsh (MC). During the months of August-September, seven locations were sampled at the Mill Creek Marsh and six locations at Harrier Meadow. Samples were processed, sorted, and sent out to Montclair State University for specimen identification. Every effort was made to identify the organisms collected to the lowest practical taxonomic level. The number of taxa, relative abundances of taxa and taxa densities were then be compared to the results from the 1999-2002 studies. Figure 2 and 3 (Appendix I.) shows the sampling stations at HM and MC respectively.

Task 2: Benthic contaminant loads: Along with the previous task contaminant load from the benthos were measured from three wetland sites including Riverbend Marsh (RB, 58.2 acres), Anderson Creek Marsh (AC, 48.8 acres) and Secaucus High School Wetland Enhancement Site (SHS 32 acres) (Figure 1, Appendix I.). Each of the three sites had five sampling stations. At each station, a meter square bulk sample (7cm deep) containing the benthic macro-invertebrates were collected (total of 15 samples, Figure 4, Appendix I.). Each sample was passed through a 1 mm sieve and what remained was brought to the laboratory to be processed and sorted. NJMC benthic investigations conducted in 1987, 2002, and 2013-2014 have all used a 1.0 mm mesh when processing the benthic collections, hence the choice of the mesh size. Where possible, organisms were sorted into major taxa (e.g., Polychaetes, Crustacea, Oligochaetes) and analyzed for contaminants as one composite sample and/or by sub-groups where possible. (Please refer to further Background information on page 9). Inorganic contaminants were analyzed at the MERI Environmental Chemistry lab using ICP-MS. Determinations were made for the following: major elements and 21 trace elements (Figure 5, Appendix I.). Persistent organic pollutants (POPs), including 109 polychlorinated biphenyls (PCB) congeners and 18 organochlorine pesticides (OCPs), were determined from benthos samples and were analyzed by an Agilent 6890 gas chromatograph equipped with electron capture detector (ECD). PAH was analyzed by Agilent 6890/5975 gas chromatograph equipped with MSD. *Mytilus edulis* (CRM-1) for animal tissue standard will be run every tenth sample, and a method blank was run every sixth sample during the gas chromatographic analysis.

Task 3: Sediment sampling and contaminant determinations: Three replicate sediment samples to be analyzed for contaminants were collected from each sampling station at each of the three sites (total of 45 samples). The same inorganic and organic elements determined for the benthos were analyzed using the same method as in sediment samples. Certified reference marine sediment (MESS-1) for soils was run every tenth sample, and a method blank was run every sixth sample during the gas chromatographic analysis.

Task 4 Sediment physical-chemical measurements: Salinity, conductivity, temperature, dissolved oxygen, and pH were all measured in the field from each of the 15 sampling stations in all three sites where benthos and sediment samples are collected. These parameters were determined with a YSI 6920 V2-2 multi-parameter sonde with a YSI 650 MDS Multiparameter Display System for instantaneous readings. Total organic carbon (TOC) was determined using weight loss on ignition (LOI) method following Wang (2012). Particle size distribution was assessed from ten-gram samples from each of the 15 sampling stations. Samples were were classified using the Wentworth Scale particle size classification.

Task 5: Data analysis: The sampling design for the first component of the project followed the sampling design of the 1999-2002 benthic studies (Figure 2, Appendix I.). Tables of invertebrate taxa from the new study were compared to the corresponding table from the 1999-2002 studies in terms of invertebrate taxa found, the number of taxa collected, and the density of benthic organisms and relative abundance of invertebrate organisms both as a total and by habitat type. ANOVA was applied to define significant differences within and among the sampling sites. Multiple regression analysis determined the effects of independent variables (i.e., salinity, pH, dissolved oxygen, temperature, soil particle size, and total organic carbon) on the concentrations of pollutants in benthos and sediments (27 inorganic elements and 150 organic contaminants).

III. Component 1 *(Ross Feltes, Drew McQuade)*

Stations were re-established where collections had been previously made during past monitoring to determine the change in diversity and density over time. Six stations were re-established for the purpose of taking benthic core samples at Harrier Meadow as shown in Feltes (2003). These stations matched the locations where benthic invertebrate specimens had been taken in core samples from 1999 through 2001. Seven stations were re-established at Mill Creek Marsh where benthic core samples had been taken from 2000 through 2002 as shown in Learn et al. (2004).

III.1. Methods - Field Sampling

III.1.1 Core Sampling and Sample Processing

At Harrier Meadow, sampling stations that NJMC (now NJSEA) established in 1999 for the purpose of collecting benthic invertebrates represent different aquatic habitats including mudflats (Mudflat) (station 5); channels (Channel) (stations 7 and 9); impoundments (Impoundment) (11 and 12); and high marsh pools (14) (Figure 2, Appendix I.). Three replicate core samples were collected at each station in 1999. Four replicate samples were collected at each station in 2000, 2001, 2002, and 2015. The high marsh station at Harrier (14) was dry in 2015 and thus it was dropped from further consideration as no comparisons could be made.

Similarly, stations were established in 2000 at Mill Creek Marsh for the purpose of collecting benthic invertebrates in core samples. These represent various aquatic habitats including mudflats (Mudflat) (station 1); channels (Channel) (stations 4 and 5); and impoundments (Impoundment) (stations 2, 3, 6, and 7) (Figure 3, Appendix I.). High marsh pools were not present at this site. Three replicate samples were collected at each station in 2000 and 2001. Four replicate samples were collected at each station in 2002 and 2015.

2015 core samples were taken at Harrier on September 10 and 16. 2015 collections were made at Mill Creek Marsh on October 7.

Samples were taken when the marsh surface was exposed at low tide. Benthic invertebrates were collected using 3.8 cm diameter acrylic core samplers. The top 5 cm of sediment from the marsh was removed from each core and then fixed in 20% formalin in the field. After fixation for approximately one week, the samples were washed through a 300 µm sieve. The specimens were then preserved and stained with rose bengal in 70% ethanol.

III.1.2. Identification and nomenclature

Samples were sorted and identified with the aid of illuminated magnifiers and dissecting microscopes. Identification of the specimens for collections made from 1999 through 2002 was performed in the lab of Dr. Jean Marie Hartman at Rutgers University. Dr. Robert S. Prezant's Lab at Montclair State University identified the specimens collected in 2015. Identification was made to the lowest practical level of taxonomic resolution which varied with the taxa. Resources used in identification and taxonomic determination for 2015 are included in References.

Taxa identified at all levels of resolution (phylum to species) were included in the counts and then used in the determination of population densities. Unidentified specimens were used in density calculations but were not included in diversity calculations. The World Register of Marine Species (WoRMS) (WoRMS Editorial Board 2018) was used as the final authority on nomenclature. It is linked to the Interagency Taxonomic Information System (ITIS). Nomenclature applied to 1999-2002 and 2015 specimens were made consistent.

In some cases, lower taxa were incorporated into higher taxa, listed as such, and the more inclusive dataset was used in calculations. This reflects the level of confidence in identification or the ability to resolve the taxonomy. For this study, *Spionidae* included specimens identified as *Streblospio benedicti*. *Gastropoda* included Family *Hydrobiidae*. Most, if not all, specimens identified as *Gastropoda* may be *Littoridinops tenuipes*. Most specimens identified as *Copepoda* are probably *Harpacticoida*. Specimens identified as *Diptera*, but with no further resolution, were larval forms that could not be identified to family. Most, if not all, were probably *Chironomidae*, but simply designated as *Diptera*. *Coleoptera* included specimens identified as *Curculionidae*.

Ecological group classification values for taxa are from Gillett Supplemental Material 1 (Gillett, 2015 using the groupings of Grall and Glémarec (1997) as described in Borja et al. (2000) below.

Group I. Species very sensitive to organic enrichment and present under unpolluted conditions (initial state). They include the specialist carnivores and some deposit-feeding tubicolous polychaetes.

Group II. Species indifferent to enrichment, always present in low densities with non-significant variations with time (from the initial state to slight unbalance). These include suspension feeders, less selective carnivores and scavengers.

Group III. Species tolerant of excess organic matter enrichment. These species may occur under normal conditions, but their populations are stimulated by organic enrichment (slight unbalance situations). They are surface deposit-feeding species, as tubicolous spionids.

Group IV. Second-order opportunistic species (slight to pronounced unbalanced situations). Mainly small-sized polychaetes: subsurface deposit-feeders, such as cirratulids.

Group V. First-order opportunistic species (pronounced unbalanced situations). These are deposit-feeders, which flourish in reduced sediments.

III.1.3. Analysis

Diversity at the stations was described using three common diversity indices: the Shannon-Weiner Index (H'), Simpson's Dominance (D), and Pielou's Evenness (J'). These indices were calculated using the following formulas:

$$\mathrm{H}' = -\Sigma \mathrm{p}_i \ln(\mathrm{p}_i)$$

$$\mathrm{D} = \Sigma(p_i^2)$$

$$J' = \frac{H'}{H'_{max}} \text{ where } H'_{max} = \ln(s)$$

To compare differences in diversity at each site between the different years, we pooled all of the records from every station in that year and calculated H' with the pooled data. A Hutchenson's t-test was used to test for significance between H' from different years. Hutchenson's t-test is given as (Citation):

$$t = \frac{|H'_1 - H'_2|}{\sqrt{Var(H'_1) + Var(H'_2)}}$$

where

$$Var(H) = \frac{\Sigma p_i(\ln(p_i))^2 - (\Sigma p_i \ln(p_i))^2}{N} + \frac{S-1}{2N^2}$$

The results of the Hutchenson's t-test were used to test the significance of any differences in H' between the 2015 collection data and every previous year. This was done by comparing the calculated t-value to the critical t value for a two-tailed test found at both α=.05 and α=.01, with degrees of freedom (v) calculated with the following equation:

$$v = \frac{(Var(H'_1) + Var(H'_2))^2}{(Var(H'_1))^2/N_1 + (Var(H'_2))^2/N_2}$$

To analyze the diversity of the different habitats between the different years, all data from each habitat were pooled, and a Hutchenson's t-test was used to test for significant differences in H' between the 2015 collection data and every previous year.

Density (n/m^2) was calculated for each replicate for Harrier from 1999, 2001, 2002, and 2015. Calculations for Mill Creek were performed on samples from 2000, 2001, 2002, and 2015. Density was determined by multiplying the area of the sample collected with one core tube [$\pi r^2 = \pi \times (1.9cm)^2$] by a constant (881.7448) to scale the area up to a m^2. Average densities were calculated for each site by year and for each habitat by years. Normality of each data set was assessed with a Shapiro-Wilk test as well as graphically using histograms. When testing the normality of the habitat specific data, all years were pooled to increase the sample sizes. The results of the Shapiro-Wilk tests served to determine which statistical tests to use on the data. Non-parametric Kruskal-Wallis tests were run for each entire site over all years and for each habitat at a site over all years. Non-parametric Dunn's tests were run on pairs of years using the Holm correction to determine the source of significant differences shown by Kruskal-Wallis tests. The Holm correction was used to control the family-wise error rate of the multiple comparisons, and represents a more conservative statistical approach. Both the adjusted and unadjusted p-values were reported. After consideration of our expected frequency of type 1 error, and the often large differences in diversities between 2015 and the other years, the less conservative unadjusted p-values were used when discussing the results. An α level of 0.05 was used in all statistical tests. All tests were run using R 3.4.3.

III.2 Results

III.2.1. Diversity

III.2.1.1.Harrier

Thirty-two taxa of benthic invertebrates were collected at Harrier from 1999 through 2002 and 2015 and Mill Creek from 2000 through 2002 and 2015 (Table 1, Appendix I.). Table 2 lists the taxa collected by site and year. Of those, 14 taxa were documented at both sites. Six of the 32 taxa collected were categorized by Gillett (2015) in the ecological groups of Grall and Glémarec (1997) as described in Borja et al. (2000) as Group I, four in Group II, seven in Group III, two in Group IV, two in Group V, and eleven were not listed (Table 1, Appendix I.). Thus, the largest number of taxa from both sites were grouped as tolerant, the second largest as sensitive, and the third as indifferent. Over all years of collections 26 taxa were reported at Harrier (Table 2, Appendix I.). Nematoda, Ostracoda, Copepoda, and Chironomidae were taken in all years. Anthozoa and Oligochaeta were taken from 1999 through 2002, but not in 2015. The greatest number of taxa observed in a given year was 16, during 2000 and 2001 (Tables 2 and 3, Appendix I.). The majority of the categorized taxa fell into ecological Groups I and III.

With collections from all Harrier stations combined, 2000 showed the greatest diversity in terms of Shannon-Weiner Index (H′) and of Simpson's Dominance (D) (Table 3, Appendix I.). The

2015 community was the second most diverse community in terms of Shannon-Weiner Index (H′), and the third most diverse in terms of Simpson's Dominance (D). That year also had the second highest Pielou's Evenness score (J′). The 2015 H′ was significantly higher than 1999 and 2002, significantly lower than 2000, and not significantly different than 2001. Both the number of species or richness (S) and sample size or abundance (N) were the lowest in the 2015 collections; however, because the 1999 and 2002 communities were dominated each by a single taxon the 2015 collections were more diverse.

For Mudflat, only the 2002 data was significantly more diverse (H′) than the 2015 data (Table 4, Appendix I.). Because J′ and D were only marginally better in 2002 than in 2015, the difference in diversity is likely due to the higher richness. The H′, D, and J′ values for 2015 were higher than for 1999 and 2001, with the difference in H' being significant. The 1999 data had a much higher abundance (N), but was dominated by Nematoda (81%), which drove diversity (H′) down. There was a much higher abundance (N) and richness (S) in 2001 than in 2015. The 2001 community was not dominated by a single taxon, but rather had a large number of species with low abundance.

For Channel, diversity (H′) was lower in 2015 than in three of the other four years (Table 5). Evenness (J′) in 2000 was similar to 2015, but the species richness (S) was the lowest in 2015, leading to a lower diversity (H′). The 2015 collections were significantly more diverse than those from 2001. The 2001 community had a much lower evenness (J′) than in 2015, and thus a lower diversity (H′), despite a greater richness (S). The lower evenness (J′) was due to the community being dominated by Nematoda (86%).

The 2015 Impoundment collections were significantly more diverse (H′) than the other years, except 1999 (Table 6). 2015 had the lowest richness (S) and the much lower abundance (N) than in any year in this habitat. The 2015 Harrier Impoundment had the highest evenness (J′) for any site, habitat, and year in this study. Three of the other four years were dominated by Ostracoda, leading to lower diversities (H′).

Contributions to abundance at Harrier, across all habitats, by the different taxa was highly variable from year to year (Figures 6 and 7, Appendix I.). Nematoda was a significant component in 1999, 2000, and 2001, but much less in 2002. Ostracoda dominated 2002.

In the Mudflat habitat (Figure 5, Appendix I.) the total number of specimens increased from

1999 through 2001. Abundance was much less in 2002 and 2015. Nematoda was dominant in collections from 1999, 2001, and 2002 (Figures 8 and 9, Appendix I.). *Manayunkia aestuarina* was taken in relatively large numbers in 2000 and 2001. Though overall numbers were modest, a large percentage of the catch in 2015 was Capitellidae. More Anthozoa were taken in 2002 than other years.

The number of specimens collected in the Channel habitat were relatively high in 1999 and 2000 when *Copepoda* and Nematoda were prominent (Figure 10, Appendix I.). The catch was much smaller in 2001, which was dominated by Nematoda (Figures 10 and 11, Appendix I.). Relatively few specimens were taken in 2002 and 2015. In 2002 the dominant taxa was Copepoda, and in 2015 Capitellidae.

The peak year for number of organisms taken in the Harrier Impoundment habitat was 2002 and the lowest catch was in 2015 (Figure 12, Appendix I.). Ostracoda was by far the most abundant taxa taken in this habitat (Figures 12 and 13, Appendix I.). Ostracoda was present in the largest numbers in 2002, which was the reason the total abundance for that year was much greater than all others for that habitat.

III.2.1.2. Mill Creek

Over all years of collections 20 taxa were reported at Mill Creek (Table 1, Appendix I.). Nematoda, Capitellidae, *Hobsonia florida*, Gastropoda, and Ostracoda were taken in all years. *Manayunkia aestuarina*, Oligochaeta, Acari, and Chironomidae were taken from 2000 through 2002, but not in 2015. The greatest number of taxa observed in a given year was 17, during 2001 (Tables 2 and 7, Appendix I.). As with Harrier, the majority of the categorized taxa fell into ecological Groups I and III.

With collections from all Mill Creek stations combined 2001 had the highest diversity in terms of both H′ and D (Table 7, Appendix I.). The 2015 community had a significantly lower diversity in terms of both H′ and D than all other years. While evenness (J′) was similar throughout the years, the species richness (S) was the lowest in the 2015 collections. This is probably the cause of the significantly lower diversity.

For Mudflat (Table 8), the 2015 collections were the least diverse of all years by both of the calculated diversity indices (H′ and D). The 2015 collections had a higher evenness (J′) than the

2000 collections, but not 2001 or 2002. 2015 was also tied with 2002 for the lowest richness (N). 2105 had the lowest abundance (S). 2002’s evenness (J′) was affected by having a large number of taxa of species with low abundance, rather than by having a single dominant taxon.

For Channel (Table 9), the 2015 collections indicate that the community had significantly higher H′ diversity scores than in 2002, but was less diverse than 2000. The 2015 data was the second most diverse in terms of D scores. This discrepancy between H′ and D shows that evenness had a large influence on the diversity. Species richness (S) was lowest in 2015, and the higher diversity compared to 2002 was a result of the higher evenness (J′). The community in 2002 was dominated by Nematoda and Capitellidae, which together made up over 96% of the abundance. The top two species in 2015 made up roughly 90%, so it is likely that the large number of unabundant taxa in 2002 were responsible for the lower evenness (J′).

For Impoundment (Table 10, Appendix I.), the 2015 data did not show significantly different diversity (H′) compared to 2000 or 2002, and was less diverse than 2001. Richness (S) was highest in 2001. Evenness was low in 2000 with those collections being dominated by Spionidae (~75%). The 2002 collections had both a lower richness (S) and abundance (N) than 2015, but had a slightly higher evenness.

Nematoda and Capitellidae were the most abundant taxa across all habitats at Mill Creek in 2001, 2002, and 2015 (Figures 14 and 15, Appendix I.). Ostracoda was significant in 2001 and 2002. The makeup of collections in 2000 was quite different with Oligochaeta and Spionidae dominating the cumulative catch.

The importance of Capitellidae and Nematoda in collections for the entire site is reflected in the collections of Mudflat, as well as for the Channel habitat (Figures 16, 17, 18, and 19, Appendix I.). The abundance of specimens in Mudflat was greatest in 2000, where Oligochaeta dominated (Figures 16, 17, Appendix I.). Copepoda was important in 2002.

In the Channel habitat Nematoda and Capitellidae were taken in relatively large numbers in 2001, 2002, and 2015 (Figures 18 and 19, Appendix I.). Oligochaeta, Spionidae, and Ostracoda made up most of the catch in 2000.

Like Mudflat and Channel, the composition of the collections in the Impoundment habitat was most different in 2000 from other years (Figures 20 and 21, Appendix I.). In 2000, in this habitat, Spionidae dominated, with a significant number of Oligochaeta. In 2001 and 2015 Nematoda and Capitellidae were important, though in 2001 Ostracoda was the second most abundance taxa. In 2002 Ostracoda dominated the collections.

III.2.2 Density

III.2.2.1. Harrier

Site wide Comparison

The Shapiro-Wilk tests of population density by years, each with data pooled across all habitats, reject that the data had a normal distribution (Table 11, Appendix I.). Examination of the histograms showed that the data generally had a heavy right skew. For these reasons, non-parametric tests were used.

The highest average density across the three habitats was recorded in 2001, and the lowest was found in 2015 (Figure 19 and Table 12, Appendix I.). The Kruskal-Wallis rank sum test found a significant difference in density between years for pooled stations (chi-squared =26.302, df = 4, p-value =2.751E-05). The Dunn multiple comparison tests found the 2015 average to be significantly lower than all other years (Table 13, Appendix I.). Both 1999 and 2002 were significantly different than 2000.

Habitat Specific Comparisons

Shapiro-Wilk tests run for each habitat with all years pooled together to increase the sample size found data from each habitat to differ significantly from a normal distribution (Table 14, Appendix I.). Examination of the histograms showed a heavy right skew for all data sets. For these reasons, non-parametric tests were used.

Of the three habitat types, Channel had the lowest average density (Figure 20). The highest average density for Mudflat was found during 2001, and the lowest was found in 2002 (Figure 20 and Table 15, Appendix I.). Density for Channel was also less than in Impoundment collections in 2000, 2001, and 2002, but not 1999 and 2015. The Kruskal-Wallis test showed there was a significant difference between the years for Mudflat as a whole (Table 16, Appendix I.). The Dunn's test found 2015 to be significantly lower than both 2000 and 2001 (Table 17, Appendix I.). 2002 was also found to be significantly lower than 2000 and 2001. Due to the small sample sizes for Mudflat, and the non-parametric tests using ranks and not the absolute data values, the results of these tests should be considered conservatively. An examination of the averages and standard errors (Figure 21, Appendix I.) may be a more reliable way to assess significance.

The highest average density for Channel was found during 2000, and the lowest was found during 2015 (Figure 20 and Table 15, Appendix I.). The Kruskal-Wallis test indicated that a significant difference existed between the years for Channel (Table 16, Appendix I.). The Dunn's tests found that 2015 was significantly lower than both 1999 and 2000 (Table 17, Appendix I.). 2002 was found to be significantly lower than 2000.

The highest average density for Impoundment was found in 2002, and the lowest was found in 2015 (Figure 20 and Table 15, Appendix I.). The Kruskal-Wallis test indicated that a significant difference existed (Table 16, Appendix I.). The Dunn's test found that 2015 was significantly lower than 2000, 2001, and 2002 (Table 17, Appendix I.). 1999 was also found to be significantly lower than 2000, 2001, and 2002.

The greatest average density of organisms for all habitats and years at Harrier was found in the Mudflat samples in 2001 (Figures 20 and 21; and Table 15, Appendix I.). Densities for Mudflat were high and increased from 1999 through 2000 and 2001. These were greatly higher than for other habitats or years. There was an abrupt drop in density for that habitat for 2002, with similarly lower densities again in 2015. Other than increases from 1999 to 2000, the changes in densities for the three habitats over the years were not similar to each other. The lowest density, by far, for all years and habitats, was in Impoundment in 2015 (Figures 20 and 21; and Table 15, Appendix I.).

The changes in the densities of the different habitat types from year to year were not correlated (Figure 21). The three habitats had peak densities in different years. The lowest density for Channel and Impoundment, as well as the second lowest for Mudflat was in 2015.

III.2.2.2. Mill Creek Marsh

Site-wide Comparison

Shapiro-Wilk tests on the Mill Creek (MC) yearly data sets and the pooled data from all years rejected that the data had a normal distribution (Table 18, Appendix I.). Examination of the histograms from each dataset showed a heavy right skew for all datasets. For these reasons non-parametric tests were used.

The highest average density over all stations was recorded in 2001, and the lowest was found during the 2002 surveys (Figure 22 and Table 19, Appendix I.). The Kruskal-Wallis rank sum test found a significant difference in density between years for pooled stations chi-squared =7.9875, df = 3, p-value =4.627E-02). Dunn test for Kruskal-Wallis multiple comparisons found that the only significant difference was between 2001 and 2002 (Table 20, Appendix I.).

Habitat Specific Comparisons

The results of Shapiro-Wilk tests for invertebrate data by habitat with all years pooled (Table 21, Appendix I.) indicate that the data sets were significantly different than a normal distribution. Examination of the histograms for each habitat showed that the data were skewed right. For these reasons non-parametric tests were used.

The highest average density for Mudflat was found in 2000 (Figure 23 and Table 22, Appendix I.). That density was much greater than for other years and habitats. The results of the Kruskal-Wallis test showed that a significant difference existed between at least one set of years (Table 23, Appendix I.). The Dunn test revealed that the 2000 average was significantly different than the 2015 and 2001 averages (Table 24, Appendix I.). Since the non-parametric tests use ranks and not the absolute data values, the results of the tests should be considered cautiously. A visual examination of the averages and standard errors (Figure 24, Appendix I.) may be a more reliable way to assess significance, especially between 2000 and the other years.

The highest average density for Channel was found in 2002 (Figure 23 and Table 22, Appendix I.). The Kruskal-Wallis test showed that no significant differences existed in the yearly samples taken from Channel (Table 23, Appendix I.). However, the Dunn's tests suggested that 2015 was significantly different than 2002. (Table 24, Appendix I.).

The highest and lowest averages for Impoundment occurred during 2001 and 2002 respectively (Figure 23 and Table 22, Appendix I.). Kruskal-Wallis tests showed that significant differences existed in the yearly samples taken from Impoundment (Table 23, Appendix I.). The Dunn's tests found that 2002 was significantly lower than all other years (Table 24, Appendix I.). -No other significant differences occurred between any other pair of years in this habitat.

The greatest average density of organisms for all habitats and years at Mill Creek Marsh was found in the Mudflat samples in 2000 (Figures 23 and 24, Appendix I.). This was much greater than for that habitat in any other years or other habitats in any of the years. The lowest density for that site, for all years and habitats, was in Impoundment in 2002 (Figures 23 and 24~~)~~ and Table 22, Appendix I.).

III.2.2.3. Harrier and Mill Creek

There are no consistent trends in the relative abundance of organisms between habitats at each site over the years sampled, between years, or between the two sites. The average density at Harrier for all stations by year showed a high peak in 2001 and then a decline to the lowest average density for the site in 2015 (Figure 19, Appendix I.). Mill Creek also peaked in 2001, with the lowest density by year the following year, and an increase in 2015 (Figure 22, Appendix I.). There was less variation overall by year at Mill Creek than Harrier.

The density of organisms in Mudflat at Harrier in collections from the highest in 2001, then 2000, and 1999, as well as Mill Creek in 2000 were the greatest recorded in this study (Figures 20 and 23, Appendix I.). The density of organisms in Impoundment at Harrier in 2015 was exceptionally low, with 1999 also low. -The density of Harrier Channel collections from 2015, 2002, and 2001 were low in density. Harrier showed greater variation in density over all collections at the site relative to Mill Creek. The density of specimens from Impoundment at Mill Creek in 2002 was low for this study.

IV. Component 2 *(Cheryl Yao, Ildiko Pechmann)*

Benthic speciemns and sediment sampoles from their inmediate environment were collected from three different marshes in the Meadowlands (Figure 1, Appendix I.) to assess metal and organic contaminant load and its transfer into the estuary's foodweb.

IV.1 Methods - Field Sampling

3.1 Sediment and Benthic Invertebrate Sampling

Contaminant loads from the benthos were measured from three wetland sites including Riverbend Marsh (RB, 58.2 acres), Anderson Creek Marsh (AC, 48.8 acres), and Secaucus High School (SHS) Wetland Enhancement Site (32 acres). Each of the three sites had five sampling stations to account for special variability within the wetland. At each station a one meter square, approximatly 7 cm deep bulk sample containing the benthic macro-invertebrates was collected (total 15 samples). The top 5 cm of sediment was removed and each sample was passed through a 1 mm sieve. The sieved subsamples were fixed in 10% formalin with rose Bengal stain. After one week of fixation, each sample was washed, preserved in 70% isopropyl solution, and the taxa identified. The remains were brought to the laboratory to be processed and sorted. Benthic samples were not homogenized. In each case sediment samples were collected for total organic carbon (TOC), grain size, and chemical analysis.

IV.1.2 Water Quality Measurements

Salinity, conductivity, temperature, dissolved oxygen, and pH were determined in the field from each of the three sites and 15 sampling stations where benthos and sediment samples were collected. These parameters were determined with a YSI 6920 V2-2 multi-parameter sonde with a YSI 650 MDS Multi-parameter Display System for instantaneous readings.

IV. 1.3 Sediment Chemical Analysis

Sediment and tissue sample preparation for analysis

Freeze-dry: Sediment and tissue samples were frozen first and then freeze-dried 48 hr by Labcono 2.5L Freezone Freeze Dryer. After freeze-drying, all the sediment and tissue samples were weighed and homogenized by pulverizing. Samples were stored in the dark at -20 °C prior to analysis. Samples were kept in amber glass flasks for 1 week maximum before extraction and sample analysis.

Sample extraction for organic contaminants-PAHs, PCBs and OCPs

Sample extraction procedure for organic contaminants is based on Method 3545 Pressurized Fluid Extractions (PFE). Freeze-dried sediment and benthic samples were extracted by Accelerated Solvent Extractor (ASE) (DIONEX ASE 100). About 0.1 g to 0.5 g benthic/sediment sample and ~16 g baked Prep Diatomaceous Earth (Prep DE) (baked in furnace for 4 hrs. at 450°C) were added into a baker to make sure samples are dry.

After extraction, gel permeation chromatography (GPC, Autoprep 2000, OI Analytical, USA) was used to clean the samples before GC-ECD and GC-MS. The extracts were concentrated to 1mL by rotary evaporation at a temperature 30°C.

The extracted samples were fractioned by florisil column (10mm I.D. x 300 mm length) for PCBs and OCPs. Ten grams of florisil (60-100 mesh; J.T Baker) which was activated at 550 °C for 4 hours and then partially deactivated by the addition of deionized H_2O (2.5% by wt.) was loaded into the head of the column and covered with a layer of sodium sulfate to a depth of 10 mm. The concentrated extracts were transferred to the florisil column and subsequently eluted with 35 mL of hexane for PCB analysis. A second fraction for OCPs analysis was eluted with 50 mL of dichloromethane and hexane in a 1:1 ratio and collected in a separate vial. Each fraction was solvent exchanged into hexane while concentrated to 5 mL via rotary evaporation. Each sample was finally reduced to 1 mL using a gentle stream of dry nitrogen evaporator (N-EVAP 111, OA-SYS).

Sample digestion for Metals

All freeze-dried sediment and benthic samples were digested using the modified US EPA method 3051 for microwave-assisted acid digestion. In order to completely digest the sediment and benthic samples (about 0.01-0.5 g dry weight), 5-10 ml HNO3 and 1-2 ml H_2O_2 were added. After pre-digestion for two hour in room temperature, vessels were sealed and placed in MiniWAVE microwave digestion system (SCP Science, Canada). After digestion, samples were diluted with ultrapure DI water into 10 or 25 ml depending on initial sample weight. Then samples were stored in polypropylene sample tubes at 4 °C until further analysis.

Sample Analysis

All methods selected correspond to standard methods used for the analysis of these analytes in benthos and sediment. All PAH, PCB congener, pesticide and metal results are reported in micrograms or milligrams per kilogram (µg/kg or mg/kg) on a dry weight basis.

PAHs, PCBs and OCPs

PAHs: Sample extracts were analyzed for the 16 PAHs (Table 23, Appendix I.). PAHs were quantified by Agilent 6890N gas chromatography and 5975 inert mass spectrometer (GC-MS) operating in the selected-ion-monitoring (SIM) mode. Chromatographic resolution was achieved with 30m x 250µm x 0.25 µm HP-5MS capillary column (Agilent, Palo Alto, CA) with helium carrier gas. The concentrations of PAH compounds were determined by the internal standard method.

The PAHs analyzed in this study are listed along with the primary and secondary ions from their mass spectra. The analytical quality of data was assessed using field blank and recoveries of surrogate standards and a series of performance standards including internal standards.

16 PAH stock solution were purchased from commercial sources (Ultra Scientific, RI or AccuStandards, CT). Calibration standards were diluted in dichloromethane from a stock mixture of 16PAHs, 0.01, 0.02, 0.05, 0.1, 0.2, 0.5 and 1 mg/L. Deuterated internal standards were purchased from Cambridge Isotope, MA. The internal standards were used in this study were d8-Naphthalene, d10-Phenanthrane, d10-Acenaphthene, and d12-Perylene. These internal standards were spiked to the extract before GC-MS analysis, to yield a final concentration of 0.5µg.

Deuterated surrogates standards were purchased from Cambridge Isotope, MA. The surrogate standards used in this study were d10-Anthracene and d12-Benzo(e)Pyrene. These surrogates were spiked to the sample prior to PFE extraction, to yield a final concentration of 1µg.

Internal standard compounds were used to calculate RRF (Relative Response Factor) and mass and its recovery.

$$\text{RRF}= (\text{Mass comp} \times \text{Area, ISTD})/(\text{Mass ISTD} \times \text{Area, Comp})$$

Where: **Mass, comp** = amount of the compounds to be measured, ng; **Area, ISTD** = area of the primary ion for the internal standard, counts; **Mass, ISTD** = amount of the internal standard to be measured, ng; **Area, Comp** = area of the primary ion for the compounds to be measured, counts

Each PAH in sample is identified by comparing the retention times of the peaks in the sample chromatogram with those of the peaks in standard chromatograms. ChemStation does identification and all calculations automatically after data is analyzed.

$$\text{Concentration, (ng/m3)} = (\text{Ax} \times \text{Is} \times \text{Vt} \times \text{Df})/(\text{Ais} \times \text{Vi} \times \text{RRFav})$$

Where: **Ax** = area response for the compound to be measured, counts; **Is** = amount of internal standard, ng/uL; **Vt** = Volume of final extract, uL; **Df** = dilution factor; **Ais** = area response for internal standard, count; **Vi** = volume of air sampled, m3; **RRFav** = the mean RRF from calibration

Above concentration should be finally adjusted by percentage of surrogate recovery as follows.

$$\text{Surrogate Recovery (\%)} = (\text{Qd} / \text{Qa}) \times 100$$

Where: **Qd** = Quantity determined by analysis, **Qs** = Quantity added to the sample /blank before extraction

MDL is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the value is above zero. Concentrations of samples should be 2-5 times of MDL in the method’s table for MD. Minimum of seven aliquots of samples will be used to calculate MDL table – for each compound.

PCBs and Pesticides: Specific PCB congener and organochloride pesticides analysis were performed using a modified EPA Method 608. Using this protocol, 109 PCB congeners or congener groups and 18 pesticides could be identified and quantified. With this analytical method, there are some coeluting PCB and pesticides peaks in the analysis. Where this occurs, coeluting peaks are calibrated as sum of congeners.

Initial calibration consists of the analysis of a minimum of three or four calibration solutions. Pesticides and PCBs stock solution were purchased from commercial sources (Ultra Scientific, RI or AccuStandards, CT) for the standard preparation. Organic chlorine pesticides were calibrated with its standards (M8080-CAL-SET, Accustandard or ERA QC sample). PCB congeners were calibrated with Mullin mixture, containing 250 µg/L of Aroclor 1232, 180 µg/L of Aroclor 1248 and 180 µg/L of Aroclor 1262 yielding a total PCB concentration of 610 µg/L. The concentration ranges were 2-20ng/mL for the organochlorine pesticides and 0.1-4µg/mL for the PCBs. The known PCB calibration mixture were obtained from the EPA's National Health and Environmental Effects Research Laboratory in Grosse Ile, Michigan. Concentrations of individual PCB congeners in this mixture have been obtained from Mullin (1994). Calibration standards were diluted in acetone from a stock mixture of 18 organochlorine pesticides and PCB congeners.

Two internal standards were used: PCB 30 (2,4,6-trichlorobiphenyl) and PCB 204 (2,2’,3,4,4’,5,6,6’-octachloro biphenyl) (AccuStandards, CT), which are not present in commercial Aroclor mixtures. Following cleanup, extracts were transferred to solvent-rinsed 2 mL vials, internal standards were added at a final concentration of 50 ng/mL, and the final volume adjusted to 1 mL.

Surrogates standards were purchased from AccuStandards, CT. The following surrogate standards were used: for the PCBs, PCB 14 (3,5-diichlorobiphenyl), PCB 65 (2,3,5,6-tetrachloro biphenyl) and PCB 166 (2,3,4,4,5,6-hexachloro biphenyl); for the pesticides, Decachlorobyphenyl and 2,4,5,6 Tetrachloro-m-xylene were used. These surrogates were spiked to the sample prior to PFE extraction, to yield a final concentration of 1µg

External standard (ESTD) calibration method were used for the quantification, and internal standard (ISTD) calibration method were also used for quantification to save calibration time, especially for the multiple PCB congeners quantification, and offset the effects of experimental variations that can negatively impact reproducibility and accuracy.

Trace Metals: Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) (Agilent 7700X, Palo Alto, CA) was used for measurement of metal concentrations in the sample digests.

The 22 selected trace elements to be measured in this study are Be, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Sb, Ba, Hg, Pb, Th, and U. Helium collision mode with kinetic energy discrimination (KED) was used to effectively remove the multiple polyatomic interferences in ICP-MS. Li, Sc, Ge, Y, In, Tb, and Bi were used as internal standards for calibration. The recovery rates of quality control (QC) sample were 90-110%.

Sediment Physical and Chemical Characteristics:

Total organic carbon (TOC) was determined using weight loss on ignition (LOI) method following Wang (2012). Particle size distribution was determined from 10-gram samples from each of the 15 sampling stations. If more than a single collection was necessary, additional samples were taken adjacent to the initial spot at that particular station. Approximately 10 g of sediment was treated in H_2O_2 and shaken overnight in sodium hexametaphosphate for complete dispersion. Samples were classified using the Wentworth Scale particle size classification.

Selected physical and chemical characteristics were determined for each of the sediment samples. Bulk density was determined by weighing the wet samples secured from known volumes, oven-drying the material, and re-weighing the sample.

Statistical analysis

ANOVA and non-parametric Kruskal tests were used to analyze variance and define significant differences in the variables among the sampling sites. The correlations between diversity index and tissue contaminants or sediment contaminants, and between sediment and tissue contaminants were analyzed. Multiple regression analysis determined the effects of independent variables (i.e., salinity, pH, dissolved oxygen, temperature, soil particle size, and total organic carbon) on the concentrations of pollutants in benthos and sediments (27 inorganic elements and organic contaminants). Regression models were created between biodiversity and water/sediment parameters or contaminant concentration.

IV.2. Results

IV.2.1 Water Quality Results

Table 24 (Appendix I.) lists the readings of the YSI 6920 V2-2 multi-parameter sonde at the time of sediment sampling. These data are meant to be complementary to the chemical analysis showing the water quality of the sampling station at the time of sampling. The data listed does not reflect on the overall water quality of the sampling stations.

IV.2.2 Sediment Chemical Analysis Results

The results of particle size analysis are listed in Table 25 (Appendix I.). For most location, the major component is silt, and the second component is clay. But for the sediment samples from RB47 and SHS08, the major component is sand and the second major component is silt.

The percentage of organic matters and percentage of moisture in sediment samples are shown in Table 26 (Appendix I.). The percentage of organic matters varies from 6.21% to 17.6%, and the average is 12.3%. Site SHS08 has the lowest percentage of organic matters which is 6.21% and AC04 has the highest percentage of organic matters (17.6).

The percentage of moisture ranges from 44.7% to 69.6% and it was used to calculate the organic pollutants' concentration in dry weight.

The metal concentrations of sediment samples are shown in Table 27 (Appendix I.), and the metal concentration of benthic and canned tuna samples are listed in Table 28 (Appendix I.). Most metals have the highest concentration in Anderson Creek site, and Riverbend sediment has the highest concentration of Mn. The average metal concentrations in sediment samples of the three locations are shown in Figure 25 (Appendix I.).

Furthermore, comparing the metal concentrations in benthic samples, the benthic samples from Anderson Creek have the highest average concentration of Al, As, Cr, Hg, Mo, Ni, Ti, V, U, and Zn. The Cd, Cu and Pb concentrations of Riverbend benthic samples are the highest among the three locations. The Secaucus High School benthic samples have the highest concentrations of Ag, Ba, Fe, Mn, and Se. The average metal concentrations of benthic and canned tuna samples are shown in Figure 26. The concentrations of Ag, Al, As, Ba, Be, Co, Cr, Cu, Fe, Mn, Mo, Ni, Ti, Th, V, and Zn in benthic samples are significantly higher than that in canned tuna samples. The average concentrations of Cd and Pb are higher in the benthic samples, but there is no significant difference between benthic samples and canned tuna samples. The Hg concentration in benthic samples and tuna samples are in the same range.

Data processing and statistical analysis were carried out under MERI-Rutgers.

The total PCB, OCP, and PAH concentrations in sediment samples are shown in Table 29 (Appendix I.). The Secaucus High School sediment has the highest average concentration of total PCB and OCP, and the Riverbend sediment has the highest average concentration of total PAH.

The comparison of the total PCB, OCP, and PAH concentration in sediment samples is shown in Figure 27 (Appendix I.).

The total PCB, OCP, and PAH concentrations in benthic and tuna samples are shown in Table 30 (Appendix I.). The Secaucus High School benthic sample has the highest PCB and OCP concentration, and the Riverbend benthic sample has the highest concentration of total PAH. The comparison of the total PCB, OCP, and PAH concentration in benthic and tuna samples is shown in Figure 28 (Appendix I.).

The total PCB concentration in benthic samples is higher than that in canned tuna samples. There is no significant difference between benthic samples and tuna samples whne it comes to OCP and PAH concentrations..

IV.2.3 Benthic Results

Tables 31 and 32 (Appendix I.) list~~s~~ the abundant taxa at each sampling station for Riverbend Wetland Preserve (RB), Anderson Creek Marsh (AC), and Secaucus High School Marsh (SHS). Data processing and statistical analysis of the data will be carried out under MERI-Rutgers.

IV.2.4. Statistical Analysis

IV.4.1 Summary statistics

Figures 29 to 31 (Appendix I.) show histograms of the variables in the data set. Summary statistics are shown in Tables 33 and 34 (Appendix I.). Most of the distributions are non-symmetric and positively skewed. There are no observations for Sb in the tissue samples

The distributions of the contaminants from the tissue and sediment samples are different. Many of their ranges are different as well, e.g. for As, Ba, Cd, and Cr, to name a few.

Some of the contaminant concentrations are correlated.Tables 35 and 36 shows the correlation coefficients, with values greater than 0.8 shown in bold. We note that more of the correlations between contaminant concentrations in tissue samples are greater than 0.8, compared with sediment samples, and they tend to be higher as well. Also, the pairs of contaminants with high correlations do not match between the tissue and sediment samples. For example, the correlations of V with Th and with Ti are greater than 0.9 in tissue samples, but quite a bit smaller in sediment samples.

Also Al and Ti are highly correlated in tissue samples (0.9977, round to 1.00 in Table 36, Appendix I.), but is 0.68 in sediment samples. However, this could be due to the small sample sizes.

The correlation coefficient between diversity index and tissue contaminants, between diversity and sediment contaminants and between tissue and sediment contaminants are list in the Table 37 (Appendix I.). Most correlations are small. The largest correlations between diversity and tissue contaminants are with Cr, Co and Th, each about -0.50. The largest correlations between diversity and sediment contaminants are with Ag and PAH, at -0.56 and 0.57 respectively. Finally, Mo, Hg, Cr and V in tissue and sediment have correlations of 0.63, 0.59, 0.54 and 0.53 respectively. It appears that contaminants in tissue and sediment tend to be positively correlated, and negatively correlated with diversity. There are exceptions to this general statement, however, and quite a range in variability in the correlations. Figure 33 (Appendix I.) shows pairwise scatterplots of said variables, while Figure 34 (Appendix I.) shows similar plots for the water variables. Sand and silt seems to be highly negatively correlated, but the other variables do not seem to be correlated.

Most water samples have pH around 7, however, one sample had very high pH which is an outliner.

IV.2.4.2 Analysis of Variance

We next examine whether the measured variables show differences between sites. We do this using Analysis of Variance (with equal and unequal variances, which has a normality assumption) and also the non-parametric Kruskal test. Table 38 (Appendix I.) shows the p values obtained for each variable, for tissue and sediment samples separately. Since the data set is small and may not be normally distributed, we use p values of 0.05 or less for the non-parametric Kruskal test to assess signifcance. Based on this criterion, we find that for the tissue samples, only Mn exhibits differences between sites (the ANOVA tests agree with the Kruskal test). For the sediment samples, salinity as well as the contaminants Cr, Hg, Pb, Sb, Ti, V and U exhibit differences between sites. These are indicated in Table 38 (Appendix I.) with an asterisk at the contaminant name. Note that As and Ag were signi_cant using the ANOVA tests, but not with the Kruskal non-parametric test.

Figures 34 and 35 (Appendix I.) show plots of the contaminant measurements, separated by site, with tissue and sediment data points colored green and maroon respectively.

IV.2.3 Regression models – biodiversity vs contaminant concentrations

Finally, we consider how variations in biodiversity and contaminant concentrations can be explained by other variables, including site, using regression models.

(a) We explore whether biodiversity is related to contaminant concentrations. We fit the model with each contaminant, to assess if it is significant. We then gather any significant variables into a combined model, and remove any resulting non-significant variables one at a time. We also consider site as a variable. At the 0.05 significance level, we find that neither site or any of the contaminants is significant. All the correlations with biodiversity are small, with the largest ones (in absolute value) being with Cr, Co and Th (-0.498, -0.493 and -0.492 respectively). We note that 16 out of the 24 correlations are negative, which means that biodiversity is negatively correlated to contaminant concentration.

We can also study the relationship, if any, between diversity and sediment soil and water variables., and found that Percent silt is inversly related to diversity with the fitted model

$$\text{Diversity} = 2{:}36 - 0{:}019(\text{PercentSilt})$$

where the coeficient of Percent silt has standard error 0.005, a p value of about 0.001, and the model has a coeficient of determination R2 = 0.556. Since percent silt and sand are negatively correlated, a model with Percent sand alone is also significant (R2 = 0.54, coefficient estimate of 0.016, standard error 0.004, and a p value of 0.002).

Diagnostics using residuals plots (not shown) do not indicate any serious misfit.

(b) When considered variations of contaminant concentrations by site alone, for tissue samples, site did not explain variations in contaminant concentration, except for Mn.

Since there are water and soil variables associated with the sediment samples, we can explore the relationships between sediment contaminant concentrations and these variables, with or without site. For this, we consider regression models. We use a log transformation for the contaminant concentrations to make the distributions more normal.

The coefficient estimates and standard errors for the regression models with only water and soil variables considered are shown in Table 39 (Appendix I.). Many of the sediment contaminant concentrations have a significant association with percent organic matter.

With the addition of percent organic matter, site became not significant in many of the cases. The contaminants with site as a significant factor in the log-regression model, together with the coefficient estimates and standard errors, are shown in Table 40. These are Ag, Hg, Pb, Sb and PCB. The positive association with percent organic still exists. For most of these contaminants, Riverbend had the lowest concentrations, with Anderson significantly higher for all except PCB, and Secaucus significantly higher for Ag, Hg and PCB. We note that Riverbend has the highest mean salinity. However, salinity was not significant in the regression models.

V. Discussion

V.1. Component 1 (Ross Feltes, Drew McQuade)

The intent of this component was to compare diversity and population density of the benthic invertebrate communities at two enhanced wetland sites as represented by past and recent collections. Collections in 1999 through 2002 were made during several months in each of those years. In this study benthic comparisons were made between collections taken in each year closest to the same calendar date in late summer or fall. The physical and biotic conditions at several of the stations had changed from the time of the earlier to the recent collections. Some stations may receive now less tidal flow due to siltation or accretion and much more vegetation is present around several stations. One station was dropped from the study because it was dry.

Collections made over the years at Harrier included a total of 26 taxa, with 16 in 2000 and 2001 as the largest number in a given year. The majority of the categorized taxa fell into two of five defined ecological groups, where species are very sensitive to organic enrichment and another group where species are tolerant to excess organic matter enrichment. The taxa that were more abundant in collections differed between the three habitats and in those habitats between years. Nematoda was significant in all years in the Mudflat habitat. *Manayunkia aestuarina* and Capitelellidae were each important in some years. In the Channel habitat Copepoda, Nematoda, and Capitellidae were prominent in collections in some years. Collections from the Impoundment were dissimilar to the other two habitats because Ostracoda dominated three of the years.

This study did not compare collections made before and after ecological enhancement. This was a comparison between collections made after a differing number of years following enhancement. Few noteworthy trends in the composition of the invertebrate fauna, or the abundance of particular taxa, across the two sites and through the years were apparent. In 2015 at all habitats Nematoda and Capitellidae dominated, or co-dominated collections. There is a greater likelihood of finding Ostracoda in the Impoundment habits of both sites, than in the other habitats. The greatest density at both Harrier and Mill Creek was observed in 2001. The lowest density at Harrier was in 2015, while it was 2002 at Mill Creek. There was no trend across years in density of organisms at either site. The greatest variation in densities between years at both sites was in the collections from the Mudflat habitat. The highest density at Harrier was in the

Mudflat habitat in 2001 and the lowest at Impoundment in 2015. At Mill Creek the highest density was in Mudflat in 2000 and lowest in Impoundment collections of 2002.

There was much variability in abundance. Over the years, Nematoda and Capitellidae were often among the most abundant taxa for both sites. A given taxon may be absent in a particular year and then one of the most abundant in another. A taxon may be dominant at one habitat type, but not present at others.

Nematoda conspicuously dominated some collections. At Harrier in 1999 nematodes made up 82% of the collection in Mudflat, and 87% in Channel in 2001. The greatest contribution by Nematoda at Mill Creek was 60% in 2015 at the Channel stations.

Capitellidae comprised 44% of the collection made at the Harrier Impoundment stations in 1999, but were minor percentages of the total at the other habitats that year. At Harrier in 2015 Capitellidae were 42% and 69% of the specimens respectively at the Mudflat and Channel stations, but only 6% in at the Impoundment stations. A lack of consistence in abundance is shown at Mill Creek in the Mudflat habitat where capitellids were less than 1% of the total in 2000, 37% in 2001, 22% in 2002, and as high as 71% in 2015.

Oligochaeta was one of the more abundant taxa in the Mudflat habitat at Harrier, 13% in 1999 and 18% in 2000, but less than 5% in the other habitats for all other years. At Mill Creek in 2000 67% of the specimens were oligochaetes for Mudflat, 39% for Channel, and 15% for Impoundment. But in all other years they were less than 5% or absent.

There were relatively high numbers of *Manayunkia aestuarina* in the Mudflat samples at Harrier for 2000 at 48% and 2001 at 22%, but never as abundant at Mill Creek. Spionidae was 75% of the organisms collected at the Mill Creek Impoundment habitat in 2000, 32% that year in the Channel habitat, but only 8% at the Mudflat habitat, and had little presence in other years at Mill Creek or at Harrier. Copepoda was in high numbers at Harrier for the Channel stations at 58% in 1999, 42% in 2000, and 43% in 2002. The only high numbers of Copepoda found at Mill Creek (34%) from the Mudflat in 2002.

Some taxa showed higher numbers in only one of the habitat types. Ostracods usually made up less than 10% of the abundance at Harrier for Mudflat and Channel stations, except for the latter with 17% in 2002 and 23% in 2015. The Impoundment habitat at that site had *Ostracoda* equaling 12% of the collection in 1999, 78% in 2000, 91% in 2001, and 98% in 2015. Mudflat stations at Mill Creek had *Ostracoda* contributing 19% in 2001, 22% in 2002; 23% at Channels in 2000; and at Impoundments 31% in 2001 and 75% in 2002. The peak for numbers of ostracods at the two sites was in different years, as was the case for some other taxa.

Some taxa typically made minor contributions, with the exception of collections in one year for particular habitats. At Harrier in 2002 Anthozoa was present at Mudflat stations with 18% and 24% of the abundance at Channel stations.

The top three major taxa reported by Angradi et al. (2001) for collections made in southern New Jersey were oligochaetes, polychaetes, and nematodes. Combined these three taxa made up 81% to 91% of the total abundance. Kneib (1984) reported nematodes as the dominant taxa in salt marshes in both a macrofaunal study in Georgia and a meiofauna study in South Carolina. *Polychaeta* typifies higher salinity habitats (Cammen 1979), while Oligochaeta are a major part of freshwater and oligohaline habitats (Cuomo and Zinn 1997, Sacco et al. 1994).

The greater New York and New Jersey harbor area, including the Hackensack River estuary containing the Meadowlands is within the biogeographic designation of the Virginian Province. The taxa, and even at the species level, collected in this study are common in surveys of benthic invertebrates in this region. For example Gallagher and Grassle (1997) report specimens designated only as *Spionidae* in their study, but included those identified as *Streblospio benedicti*, are typically numerically dominant in intertidal zones with intermediate salinities throughout the Virginian Province. They also stated *Cyathura polita* is geographically widespread and Heteromastus filiformis is common to lower salinity habitats.

There have been previous studies on the benthic invertebrate fauna of the Meadowlands. Most were collections from the bottom substrate of the Hackensack River and not directly comparable to those biological samples taken on marsh surfaces.

Collections were made by Ichthyological Associates, Inc. in 1972 and 1973 on behalf of PSEG in the Hackensack River near the Bergen Generating Station (Anselmini 1974). They reported *Limnodrilus hoffmeisteri (Oligochaeta)* was particularly abundant. They also note the presence of *L. cervix, L. udekemianus, and L. maumeensis*. Several insect specimens of *Ceratopogonidae*, *Glyptotendipes sp.*, and *Chironmonus riparious, Procladius culiciformis* were collected. Included in their list of taxa collected in the Upper Hackensack River were the *Crustacea* species

Balanus improvisus, *Cyathura polita* and *Chiridotea alymra*.

Other collections were made on behalf of PSE&G in 1986 (E. A. Science and Technology. 1988). Ponar and Peterson grabs were used to sample the bottom of the river. *Streblospio benedicti* was the dominant species, comprising as much as 97% of the density of some stations in the lower and middle part of the Hackensack River estuary. *Limnodrilus spp*. were dominant further upriver in lower salinities. Twenty-four taxa were collected near Kearny, including four taxa in *Oligochaeta*. Densities near Kearny were 30,845 specimens/m2.

A fisheries resource survey of the Hackensack River and major tributaries was conducted by the Hackensack Meadowlands Development Commission from 1987 to 1988 (Kraus and Bragin 1989). As part of that study benthic invertebrates were collected on a quarterly basis. Samples were taken using a 23 cm x 23 cm Ponar grab. Fifty-three different taxa of invertebrates were collected during the 1987 survey. Approximately 36% of taxa were polychaetes, 15% were molluscs, and 11% were amphipods. The remaining 38% include taxa from 13 other classes. The benthic community was dominated by *Gastropoda* (50.4% of all specimens) and *Oligochaeta* (26.5%). Eighteen species of *Polychaeta* made up 8.3% of the collections, followed by five species of *Bivalvia* at 7.7%. Together, these four invertebrate groups comprised 93% of those collections. The habitat and collection methods were very different from those in the present study.

A similar survey of benthic invertebrates within the Hackensack Meadowlands, using the same grab gear, was conducted by the New Jersey Meadowlands Commission in 2002

(Bragin et al. 2009). Sixty-seven different taxa of invertebrates were collected during the 2002 survey. This included twenty-two species of Polychaeta worms (45% of specimens) and 10 species of Amphipoda (35.5%). These, plus Oligochaeta (6%) and Insecta (3.7%) made up approximately 90% of the 2002 benthic collections. The taxa with the highest diversity were Polychaeta, Amphipoda, Bivalvia, and Gastropoda. The highest density of benthic organisms were at Mill Creek during both 1987 and 2002 collections throughout the lower Hackensack River and tributaries.

An environmental impact report (Empire Ltd. 1999) refers to results of a 1997 benthic invertebrate study at Moonachie and Bashes Creeks within Empire Tract and the adjacent Hackensack River. An Ekman grab was used for sampling. *Oligochaeta*, *Chironomidae*, *Ceratopgonidae, Amphipoda, Physella sp. (Gastropoda)*, and *Libellulidae* (*Odonata*) were taken in 45 samples. *Oligochaetes* dominated the collections. The collections in the Hackensack River at that time were similar, but with a lesser abundance of oligochaetes than on the marsh.

In 1999 and 2000 Raichel et al. (2003) used shallow pit traps to collect invertebrates on the marsh surface near Mill Creek, including in Western Brackish Marsh. She identified 39 invertebrate taxa. Her study included a comparison of the fauna in areas vegetated by Spartina alterniflora and others covered by Phragmites australis. The Spartina habitat yielded 13,109 individuals and 7,182 specimens in the Phragmites habitat. Major taxa differed in abundance between these two habitats. Harpacticoid copepods, oligochaetes, ostracods, and the sabellid polychaete Manayunkia aestuarina were all significantly greater in abundance within the Spartina pit trap collections. Chironomids, gastropods, predominantly Hydrobia spp., and gammarids were significantly more abundant in the *Phragmites* dominated marsh areas.

Yuhas (2001, 2005) compared the benthic invertebrate fauna in *Phragmites australis* and *Spartina alterniflora* stands at Sawmill Creek and Mill Creek in the Meadowlands. She used a core sampler with a 3.9 cm diameter to collect the top 5 cm of substrate. A 300 µm sieve was used. The methods are the same as used in this study. Yuhas recognized 25 taxa in collections taken over four months at all stations at both sites. Nematoda made up 77% to 80% of all specimens at Mill Creek. She found no clear pattern of difference in taxa abundance and richness between *Phragmites* and *Spartina* marshes in her study. The numerically dominant taxa in Yuhas' study were Oligochaeta, Nematoda, and *Manayunkia aestuarina*. In her study, Sawmill Creek had a greater abundance, taxa richness, and diversity than Mill Creek. She cites studies that state lower salinity decreases these measures. Mill Creek has lower salinity than Sawmill Creek. Her collections at Sawmill Creek were dominated by Oligochaeta, Nematoda, *Manayunkia aestuarina*, and Copepoda. The most numerous taxa in her Mill Creek collections were Nematoda, Oligochaeta, Ostracoda, and Copepoda.

The collection methods, especially sieve mesh size for retaining specimens, varies between studies and these result in the capture of different taxa and the number of specimens. Sieve mesh size particularly affects the species richness and abundance of the smaller organisms. The degree of taxonomic resolution in identification of specimens greatly influences the number of taxa recognized and thus conclusions about diversity and ecological relationships. This differs greatly between studies. Like other studies nematodes and oligochaetes are very abundant, but taxonomic resolution requires specialized examination and is very seldom performed. This is also true for ostracods (Feltes 2003).

In this study and as previously reported for the monitoring of Harrier Meadow and Mill Creek (Feltes, 2003; Learn et al. 2004) densities of organisms were high compared to other studies of macrofauna elsewhere that used 500 µm sieves (Kneib 1984, Levin et al. 1998) as opposed to 300 µm used here. Some of the densities observed in this study are high even compared to Angradi et al. (2001) where a 300 µm sieve was used to process collections made in the Mullica River of southern New Jersey yielding combined densities as high as 96,885 m-2.

V.2. Component 2 (Cheryl Yao, Francisco Artigas)

Most studies on benthic pollutant loads (e.g. Burrows and Whitton 1983; Oremo et al. 2019 and Perelo 2010) are conducted on benthic macroinvertebrates where individuals have much larger biomass compared to our study where all organism retained by a 300 um sieve were included. Although picking out and sorting the benthos from a 300 um sieve took significantly more effort, this approach better captures the benthic community and its associated contaminant loads.

The three study sites of Component II (i.e. Riverbend, Anderson and Secaucus High School (SHS)) are distributed along a salinity gradient between 15.5 ppt at Riverbend closest to the ocean and 11.1 ppt at SHS about 8 kilometers upriver. Values for temperature, pH and dissolved oxygen from channels near these sites are not significantly different. Sediment characteristics, including the particle size distribution, % organic matter, and % moisture are also not significantly different among the three sites.

Anderson Creek which is the intermediate site along the salinity gradient shows the highest concentration of trace metals in sediments followed by SHS and the lowest concentrations were found at Riverbend. Andreson Creek has been treated with herbicides to remove the invasive common reed and as a result the vegetation cover is less than 25% which in turn leeds to less sediment deposition and restricted attenuation. Trace metal levels at these sites are comparable to levels found in similarly industrialized estuaries elsewhere (e.g. North-East England, Burrows and Whitton 1983), and levels are much higher compared to areas less developed and with lower population densities (Oremo et al. 2019).

The spatial patterns of organic pollutant levels in sediments among our three sites are different to the patterns of trace metals levels. Total PCBs are highest at SHS and lowest at Riverbend, while total PAHs are exactly the reverse. Total OCPs on the other hand are similar in all three sites (40.5 µg/kg at Riverbend, 36.9 µg/kg at Anderson Creek, and 40.7 µg/kg at SHS). Differences in levels of pollutants among sites have been explained by in the past by their proximity to sources (Artigas et al. 2017). SHS is a recently enhanced wetland site where legacy PCB contaminant levels remain relatively high deep in the sediment. The sources of these PCBs are from known hot spots in the Hudson river (Fowler 1990) and from local sources such as superfund sites in the towns of Moonachie, Little Ferry and Carlstadt (EPA super fund site citation). PCB congeners and OCPs can rapidly desorb from sediment binding sites and remain tightly adsorbed to mobile suspended organic matter and hence their wide distribution (Lamoureux and Brownawell 1999). The major source of PAHs are from the incomplete combustion of gasoline from transportation sources, coal burning and wood burning (Abdel-Shafy and Mansour 2016). PAHs have high hydrophobicity which promotes their adsorption and accumulation in sediment (Perelo 2010). The Riverbend site is located closely to the NJ Turnpike, one of the busiest highways in the country and Newark Bay (Port Newark) one of the busiest ports in the country and the most likely sources of PAHs.

The highest number of benthic organisms (5448 n/m2) was collected at the SHS site. The abundance of benthic fauna at this site was almost twice as large compared to Riverbend (2628 n/m2) and Anderson (3172 n/m2). The number of species was also twice as high in SHS and Riverbend (29 and 30 respectively) compared to Anderson (13). According to the Shannon diversity index, the most diverse benthic community was found at the Riverbend site (H = 2.25) and the lowest diversity was found at SHS (H= 1.18) where 68% of the benthic organisms corresponds to *Hobsonia florida*. Riverbend represents the site with the least human intervention while SHS represents the most intervened site.

Concentration levels of the contaminants in benthic tissues are important parameters that can help evaluate the health of the ecosystem (Perelo, 2010). For most trace metals, the concentration in tissue is positively correlated to the concentration in the sediment. The largest correlations between benthic tissue and sediment were found for trace metals: Mo, Hg, Cr, and, V. Thirty to thirty five percent of the concentration of Hg and Cr in benthic tissue can be explained by the concentration levels of these elements in the sediment. Trace metal concentration mirroring between tissue and sediment occurs among all three sites with the expection of Ag, Cd, Se, Ba, Be, Cu, Pb, and Fe.

Cd and Pb concentrations are the lowest in Riverbend sediments compared to the other two sites, however concentrations of Cd and Pb in the benthic tissue are the highest at Riverbend (Figure 34, Appendix I.). One particular benthic tissue sample at Riverbend (RB01) contains very high concentration of Cd and Pb. This same sample contained a significantly larger number of Capitellidae *sp.* indicating an ability of this species to accumulate larger amounts of Cd and Pb in their body. Capitellidae is a clear example of bioaccumulation taking place where the rate of ingestion exceeds that rate of excretion (Chen et al. 2008).

Statistical analysis of the data for the most part show a negative correlation between diversity index and tissue and sediment trace metal concentrations, though the realationship is not significant. This implies that higher sediment or tissue contamiant levels results in low biodiversity in the benthic community.

Contrary to trace metals, PCBs, OCPs and PAHs are not significantly correlated between benthic tissue and sediment (Figure 37, Appendix I.). In general PCBs and OCPs concentrations in tissue and sediment do not follow a clear pattern. For PAHs, levels in sediment were consistently higher than levels in tissue in all three sites (Figure 34). Benthic organisms have limited mobility and are exposed to a variety of stresses and can integrate the effects of multiple natural stresses and pollutants over time (Hartwell et al. 2011). According to Akinsanya et al (2018). Two possible ways to explain the difference of PAH levels in sediments and tissue are (a.)- Benthic fauna selectively avoids PAHs or (b.)- The rate of PAH excretion is greater than the rate of ingestion. The actual mechanisms operating in this case would have to be investgated further.

Canned tuna samples serve as an overall reference on the amount of trace metals and organic pollutants in tissue of secondary consumers. In our case, compared to our benthic samples, concentrations of PCB in benthic tissue was three to four times higherthan in commercial tuna cans. Concentrations of OCPs and PAHs on the other hand were similar between canned tuna and the benthic organisms sampled. It is somewhat expected as the area is known to be highly impacted by PCB contamination originating from the Hudson river and industrial sites within the estuary. Assuming that tuna tissue represents the global levels of priority organic contaminants in secundary consumers, we can conclude, contrary to PCBs, that OCP and PAH levels in benthic issue in the estuary are comparable to the global average in secondary consumers.

VI. Conclusion

VI.1 Component I

A total of 20 taxa were reported from Mill Creek, with the greatest number of taxa occurring in 2001. A total of 26 taxa were reported from Harrier Meadow, with the greatest number of taxa (16) occurring in 2000 and 2001. Overall Harrier Meadow showed the greatest diversity (1.8) compared to Mill Creek. For all habitat types the year 2000 was the most different in species composition. There were no consistent trends in terms of species abundance between sites, among site types and among years. For both sites the most abundtant taxas were Nematoda and Capitellidae.The majority of categorized taxa fell into the ecological sensitivity groups 1 (tolerant) and 3 (sensitive).

(1.5

When comparing habitat types in terms of organism density, mudflat showed the highest density, followed by channel and impoundment. At both sites the abundance of organisms peaked in 2001 and decreased thereafter. This peak coinsided with 2001 being a very dry year. In terms of abundance the least intervened site (Mill Creek) showed more stable abundances over time compares to the more impacted Harrier site.

VI.2. Component II

Water quality, grain size and organic matter content in sediment are comparable among the three sites. Salinity gradient was not a factor in determining contaminant levels in sediment or benthic tissue. There is no statistically significant correlation between contaminant levels in sediment and tissue samples. In all three sites the majority of trace metal in tissue mirrored the sediment concentration. Mercury and chromium showed the strongest correlation between sediment and tissue. Similarly PCB, OCP, and PAH levels are not strongly corralated between the sediment and benthic tissue. In most cases trace metal concentrations in sediments were higher than those in the tissue. Benthic diversity was usually negatively correlated with contaminat levels in the sediments and in the benthos, however this relationship is not significant.

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VII. Acknowledgements

Report completion:

The report was completed by Ross Feltes, Drew McQuade from the New Jersey Sports and Exposition Authority; Cheryl Yao and Joseph Grzyb from the Meadowlands Environmental Research Institute (MERI).

The report was reviewed by Ildiko C. Pechmann (QA/QC officer), and Francisco Artigas (PI).

Field work:

The authors wish to thank Joseph Grzyb and Saleh Kojak from MERI for their help in the field work. A special thank you goes to Brett Bragin, Gabrielle Bennett-Meany and Drew McQuade from NJSEA for their valuable help with the sediment sampling and invertebrate sorting.

VIII. Appnedix I- Figures and Legends

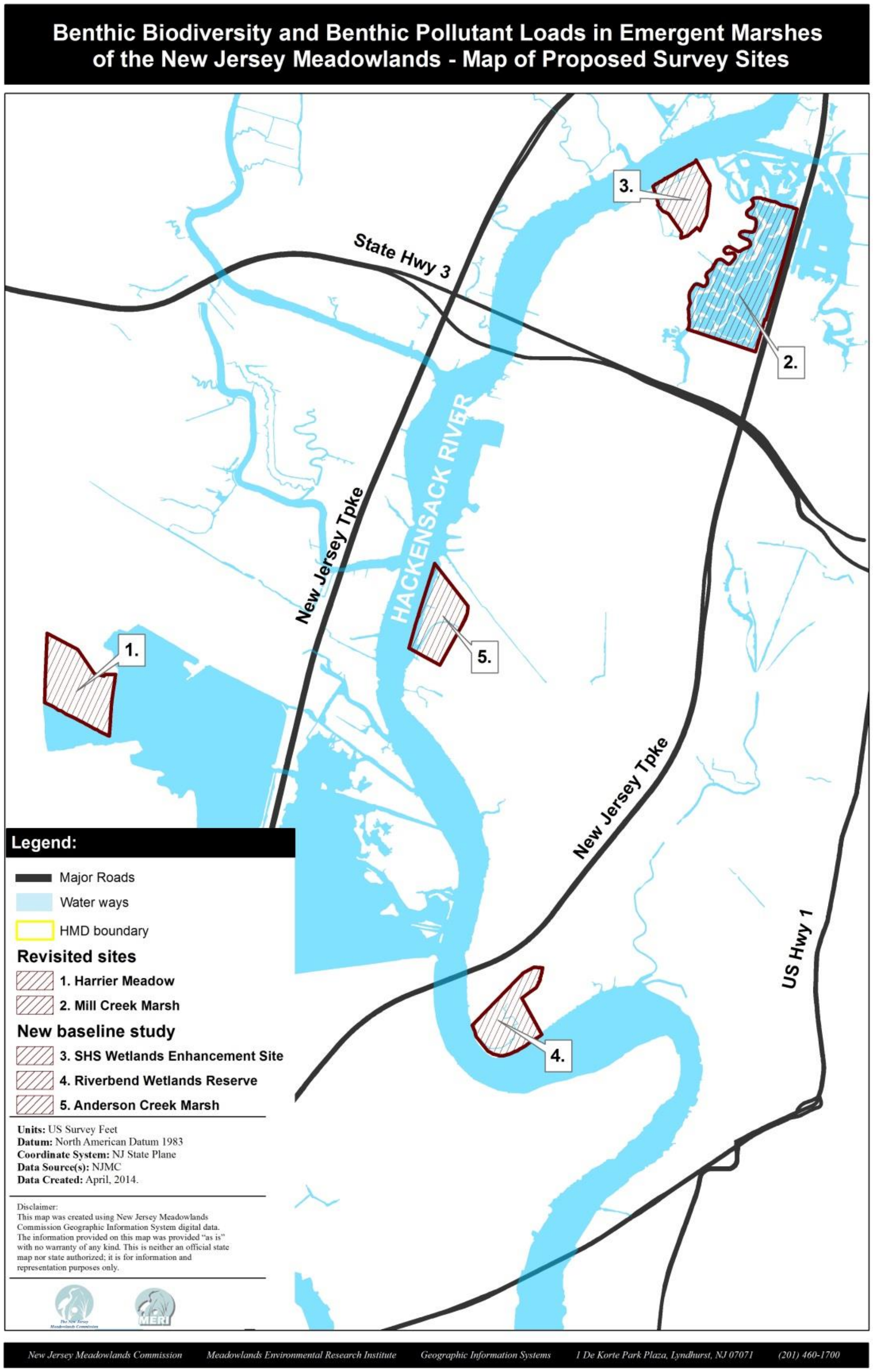


Figure 1 – Study sites and waterways within the Hackensack Meadowlands District

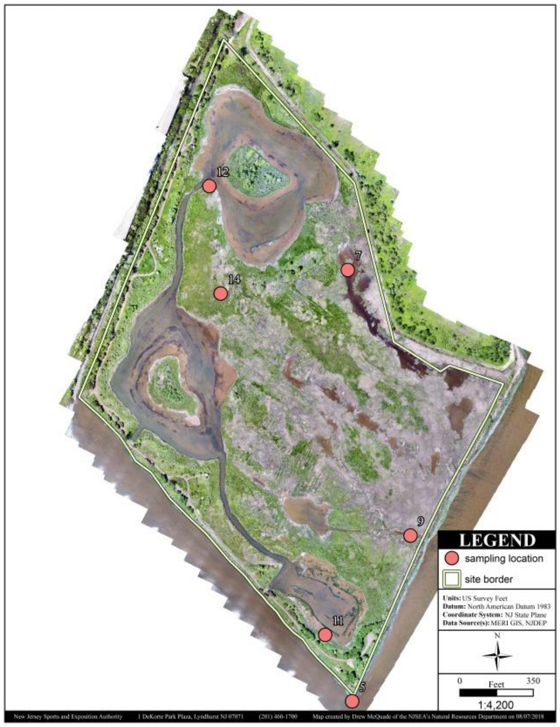
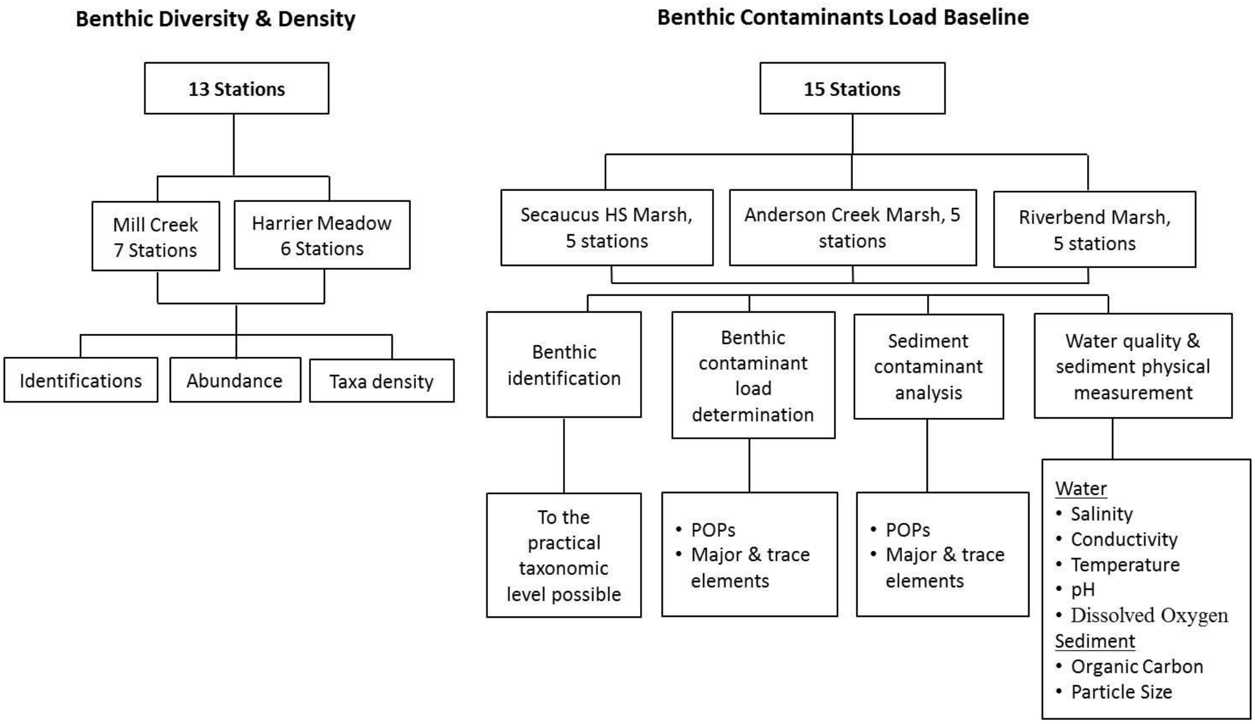


Figure 2 – Sampling locations for monitoring benthic invertebrates at Harrier Meadow Wetland Mitigation Site in 1999

Figure 3 - Sampling locations for monitoring benthic invertebrates at Mill Creek Marsh Wetland Mitigation Site in 2000.

Figure 4. Example of Benthic and Sediment sampling – Component 2



Major elements: Fe, K, Ca, Mg, Na, and Sr
Trace elements: Ag, Al, As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, Ti, Th, V, U, and Zn
Persistent organic pollutants (POPs): 16 polycyclic aromatic hydrocarbons (PAHs),
114 polychlorinated biphenyl (PCBs) congeners and 20 organochlorine pesticides (OCPs)

Figure 5 Sampling design for Component I: Benthic Diversity and Density and for Component II: Benthic Contaminant Load Baseline and contaminants of interest

Table 1. Benthic invertebrate taxa collected at Harrier Meadow and Mill Creek Marsh, 1999 through 2002 and 2015, with ecological group classifications

	Phylum	**Class**	**Subclass**	**Superorder**	**Order**	**Family**	**Genus and species**	**ecological group classifications**
1	Cnidaria	**Anthozoa**						I
2	Plathelminth	**Turbellaria**						I
3	**Nematoda**							III
4	**Nemertea**							III
5	Annelida	Polychaeta	Errantia		Phyllodocida	Nereidae	***Alitta succinea***	III
6	Annelida	Polychaeta	Errantia		Phyllodocida	Nereidae	***Nereis* sp.**	II
7	Annelida	Polychaeta	Errantia		Phyllodocida	**Phyllodocidae**		II
8	Annelida	Polychaeta	Sedentaria		Capitellida	**Capitellidae**		V
9	Annelida	Polychaeta	Sedentaria		Scolecida	Capitellidae	***Heteromastus filiformis***	IV
10	Annelida	Polychaeta	Sedentaria		Orbiniida	**Orbiniidae**		not listed
11	Annelida	Polychaeta	Sedentaria		Sabellida	Sabellidae	***Manayunkia aestuarina***	II
12	Annelida	Polychaeta	Sedentaria		Spionida	**Spionidae**		not listed
13	Annelida	Polychaeta	Sedentaria		Terebellida	Ampharetidae	***Hobsonia florida***	III
14	Annelida	Clitellata	**Oligochaeta**					V
15	Mollusca	**Gastropoda**						not listed
16	Arthropoda	Arachnida	**Acari**					not listed
17	Arthropoda	Branchiopoda	Phyllopoda	**Cladocera**				III
18	Arthropoda	Collembola				Neanuridae	***Anurida maritima***	not listed
19	Arthropoda	Collembola				**Entomobryidae**		not listed
20	Arthropoda	**Ostracoda**						I
21	Arthropoda	Hexanauplia	**Copepoda**					not listed
22	Arthropoda	Malacostracea	Eumalacostraca	Peracarida	Amphipoda	**Gammaridae**		I
23	Arthropoda	Malacostracea	Eumalacostraca	Peracarida	Decapoda	Palaemonidae	***Palaemon pugio***	I
24	Arthropoda	Malacostracea	Eumalacostraca	Peracarida	Isopoda	Corophiidae	***Corophium* sp.**	III
25	Arthropoda	Malacostracea	Eumalacostraca	Peracarida	Isopoda	Cyathuridae	***Cyathura polita***	I
26	Arthropoda	Insecta	Pterygota	Endopterygota	**Coleoptera**			not listed
27	Arthropoda	Insecta	Pterygota	Endopterygota	**Diptera**			IV
28	Arthropoda	Insecta	Pterygota	Endopterygota	Diptera	**Ceratopogonidae**		not listed
29	Arthropoda	Insecta	Pterygota	Endopterygota	Diptera	**Chironomidae**		III
30	Arthropoda	Insecta	Pterygota	Endopterygota	Diptera	**Dolichopodidae**		II
31	Arthropoda	Insecta	Pterygota	Endopterygota	Diptera	**Ephydridae**		not listed
32	Arthropoda	Insecta	Pterygota	Exopterygota	Hemiptera	**Corixidae**		not listed

Taxa names used in calculations and in text are in bold font.

Primary reference for nomenclature was WORMS (World Register of Marine Species) http://www.marinespecies.org/index.php

Ecological group classification values for taxa from Gillett (2015) Supplemental Material 1 using groupings of Grall and Glémarec (1997) as described in Borja et al. (2000).

Table 2. Benthic invertebrate taxa collected at Harrier Meadow and Mill Creek Marsh by year

		Harrier					**Mill Creek**			
	taxa collected	1999	2000	2001	2002	2015	2000	2001	2002	2015
1	Anthozoa	x	x	x	x			x		
2	Turbellaria	x	x					x		
3	Nematoda	x	x	x	x	x	x	x	x	x
4	Nemertea	x								
5	*Alitta succinea*					x				
6	*Nereis* sp.	x	x	x		x				
7	Phyllodocidae				x					
8	Capitellidae	x	x		x	x	x	x	x	x
9	*Heteromastus filiformis*					x				
10	Orbiniidae		x							
11	*Manayunkia aestuarina*		x				x	x	x	
12	Spionidae	x	x				x			
13	*Hobsonia florida*	x	x		x	x	x	x	x	x
14	Oligochaeta	x	x	x	x		x	x	x	
15	Gastropoda	x		x	x		x	x	x	x
16	Acari			x			x	x	x	
17	Cladocera						x			
18	*Anurida maritima*						x	x		
19	Entomobryidae						x			
20	Ostracoda	x	x	x	x	x	x	x	x	x
21	Copepoda	x	x	x	x	x				
22	Gammaridae			x			x	x		
23	*Palaemon pugio*			x						
24	*Corophium* sp.						x			
25	*Cyathura polita*		x	x	x					
26	Coleoptera			x						
27	Diptera							x	x	
28	Ceratopogonidae		x		x				x	
29	Chironomidae	x	x	x	x	x	x	x	x	
30	Dolichopodidae							x	x	
31	Ephydridae			x						
32	Corixidae		x							

Table 3. Diversity of benthic invertebrates at Harrier Meadow for all the stations.

	Harrier Meadow - all stations				
	1999	**2000**	**2001**	**2002**	**2015**
N	2281	5725	5032	4150	634
S	13	16	16	12	10
H'	1.1841	1.8272	1.4255	0.6973	1.4549
D	2.2051	4.9131	3.4448	1.3931	3.2352
J'	0.4616	0.6590	0.5141	0.2806	0.6319
	Hutchenson's t-test vs. 2015 collections				
Significant at α=0.05	Yes	Yes	No	Yes	

Table 4. Diversity of benthic invertebrates at Harrier Meadow for Mudflat stations.

	Harrier Meadow - Mudflat				
	1999	**2000**	**2001**	**2002**	**2015**
N	1473	2558	3476	423	429
S	7	12	15	9	7
H'	0.6652	1.4157	1.1935	1.6093	1.3661
D	1.4603	3.1170	2.5989	3.6440	3.1948
J'	0.3419	0.5697	0.4407	0.7324	0.7020
	Hutchenson's t-test vs. 2015 collections				
Significant at α=0.05	Yes	No	Yes	Yes	

Sample size=N, number of species=S, Shannon-Weiner Index=H′, Simpson's Dominance=D, and Pielou's Evenness=J′.

Table 5. Diversity of benthic invertebrates at Harrier Meadow for Channel stations.

	Harrier Meadow - Channel				
	1999	**2000**	**2001**	**2002**	**2015**
N	704	1255	165	217	173
S	8	9	8	8	5
H'	1.0200	1.1087	0.6117	1.4253	0.8666
D	2.2262	2.5208	1.3232	3.4525	1.8872
J'	0.4905	0.5046	0.2942	0.6854	0.5385
	Hutchenson's t-test vs. 2015 collections				
Significant at α=0.05	Yes	No	Yes	Yes	

Sample size=N, number of species=S, Shannon-Weiner Index=H′, Simpson's Dominance=D, and Pielou's Evenness=J′.

Table 6. Diversity of benthic invertebrates at Harrier Meadow for Impoundment stations.

	Harrier Meadow - Impoundment				
	1999	**2000**	**2001**	**2002**	**2015**
N	104	1912	1391	3510	32
S	8	11	8	10	6
H'	1.4671	0.8624	0.4240	0.1179	1.5875
D	3.3424	1.6010	1.2121	1.0391	4.4138
J'	0.7055	0.3596	0.2039	0.0512	0.8860
	Hutchenson's t-test vs. 2015 collections				
Significant at α=0.05	No	Yes	Yes	Yes	

Sample size=N, number of species=S, Shannon-Weiner Index=H′, Simpson's Dominance=D, and Pielou's Evenness=J′.

Figure 6. Abundance of taxa in all habitats at Harrier by year. Abundance represented as average of counts in replicates.

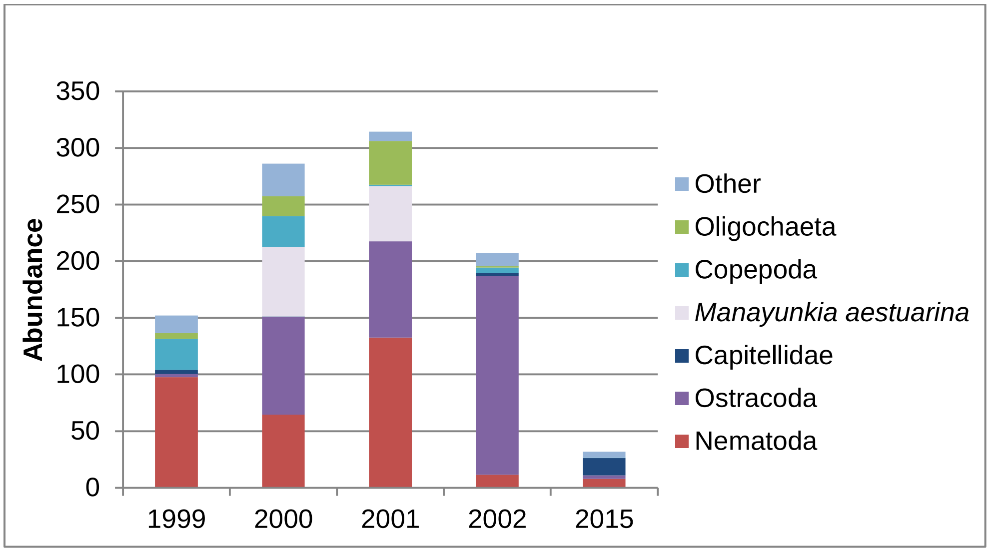


Figure 7. Relative abundance of taxa in all habitats at Harrier by year. Abundance represented as percentage of all specimens.

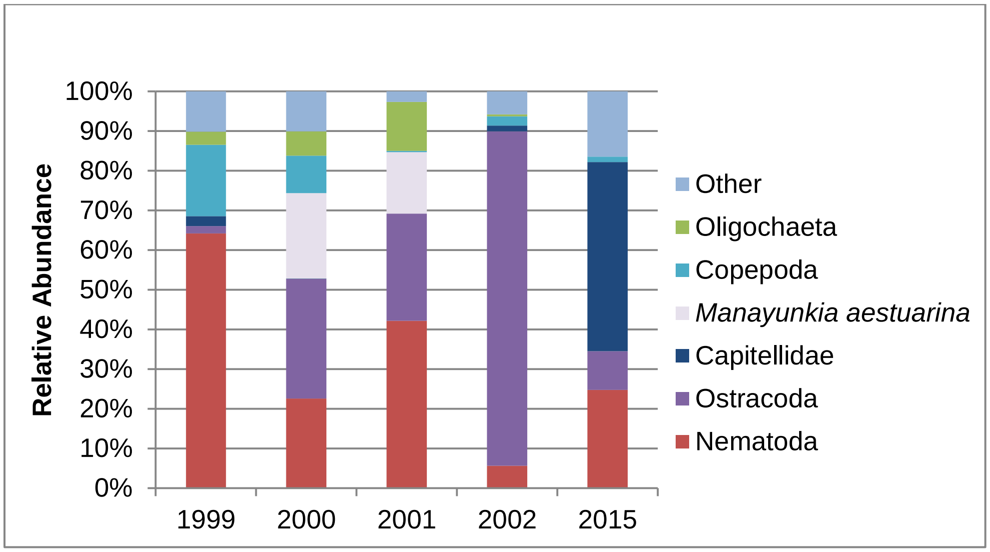


Figure 8. Abundance of taxa in Mudflat habitat at Harrier by year. Abundance represented as average of counts in replicates.

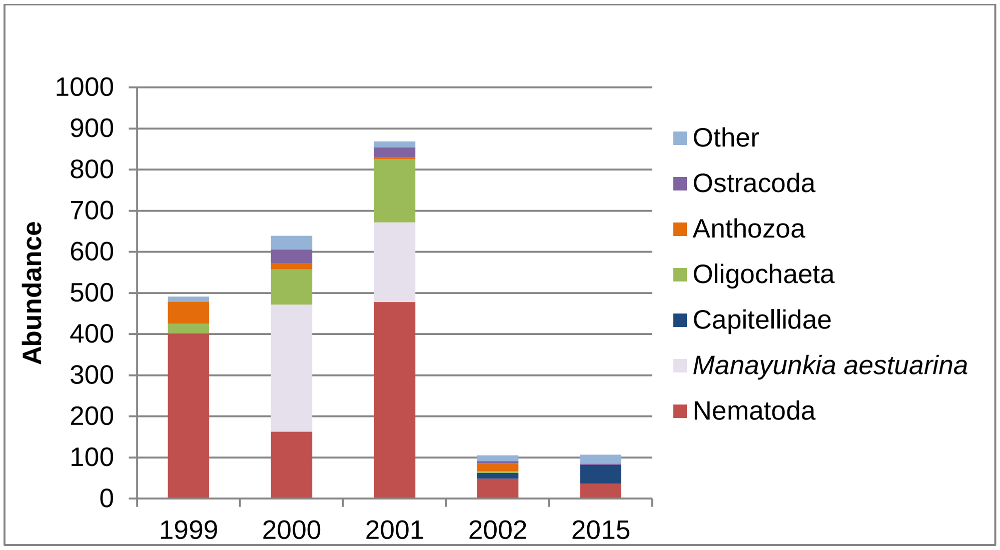


Figure 9. Relative abundance of taxa in Mudflat habitat at Harrier by year. Abundance represented as percentage of all specimens.

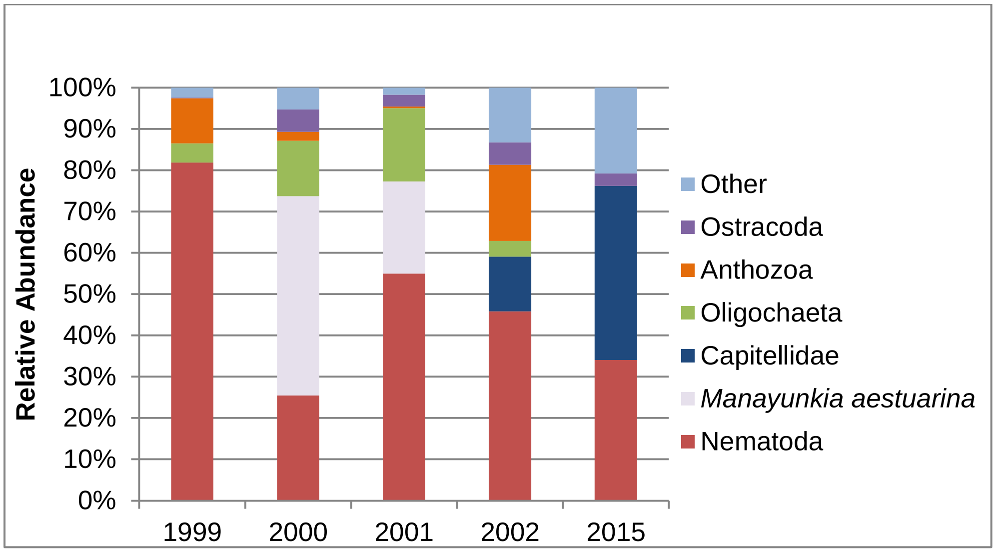


Figure 10. Abundance of taxa in Channel habitat at Harrier by year. Abundance represented as average of counts in replicates.

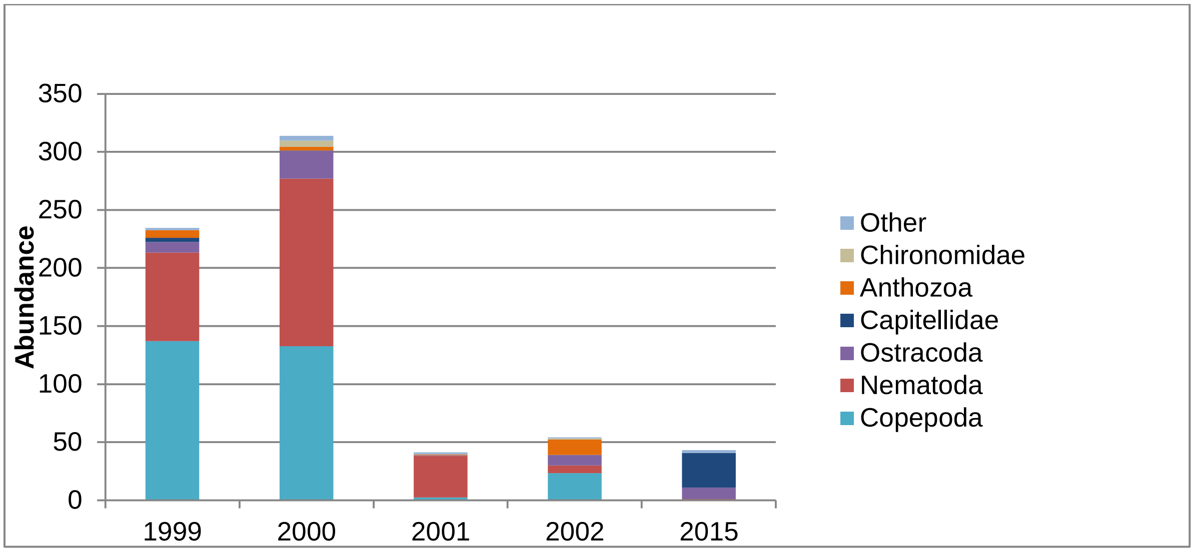


Figure 11. Relative abundance of taxa in Channel habitat at Harrier by year. Abundance represented as percentage of all specimens.

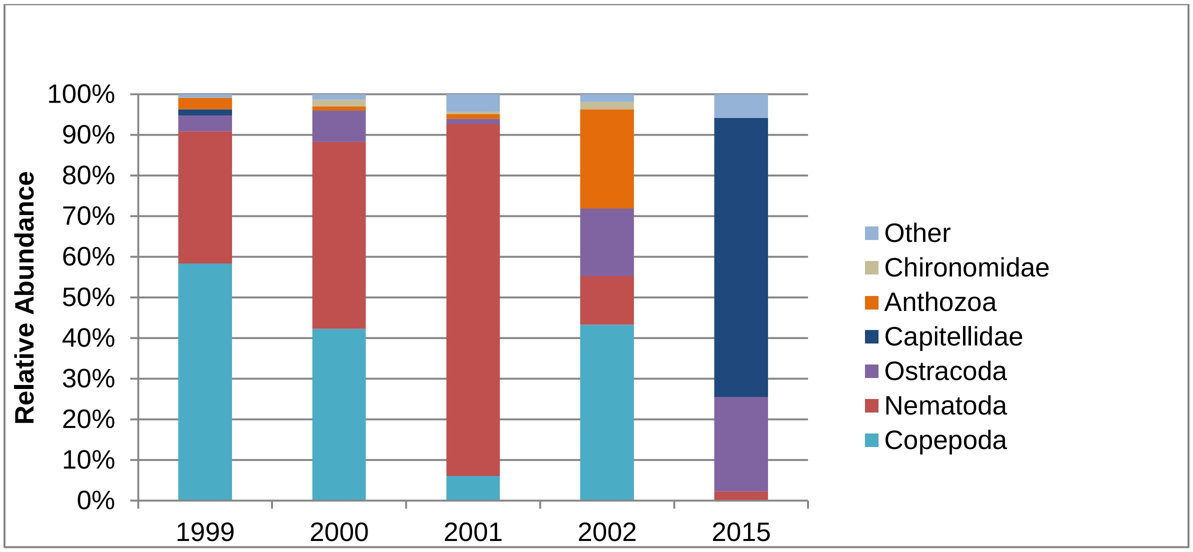


Figure 12. Abundance of taxa in Impoundment habitat at Harrier by year. Abundance represented as average of counts in replicates.

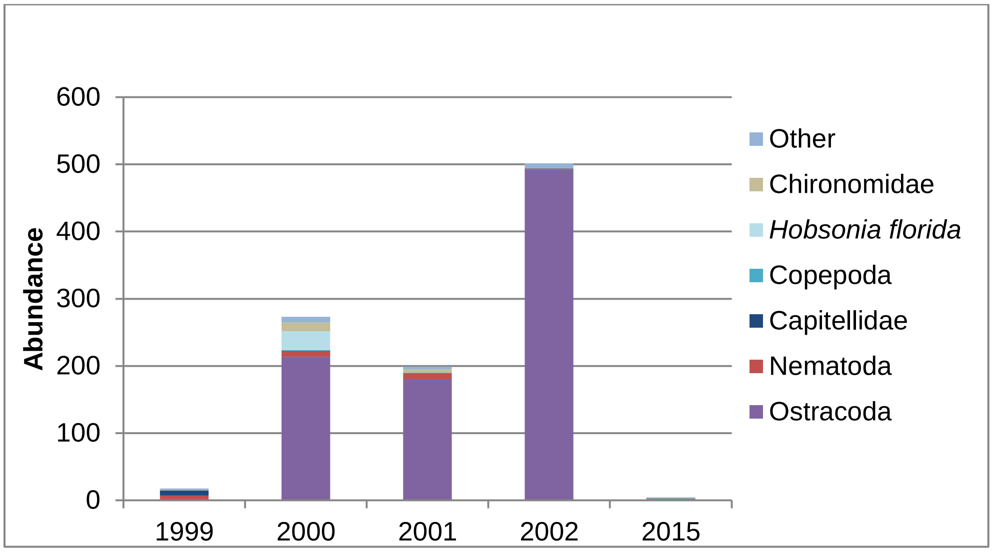


Figure 13. Relative abundance of taxa in Impoundment habitat at Harrier by year.

Abundance represented as percentage of all specimens.

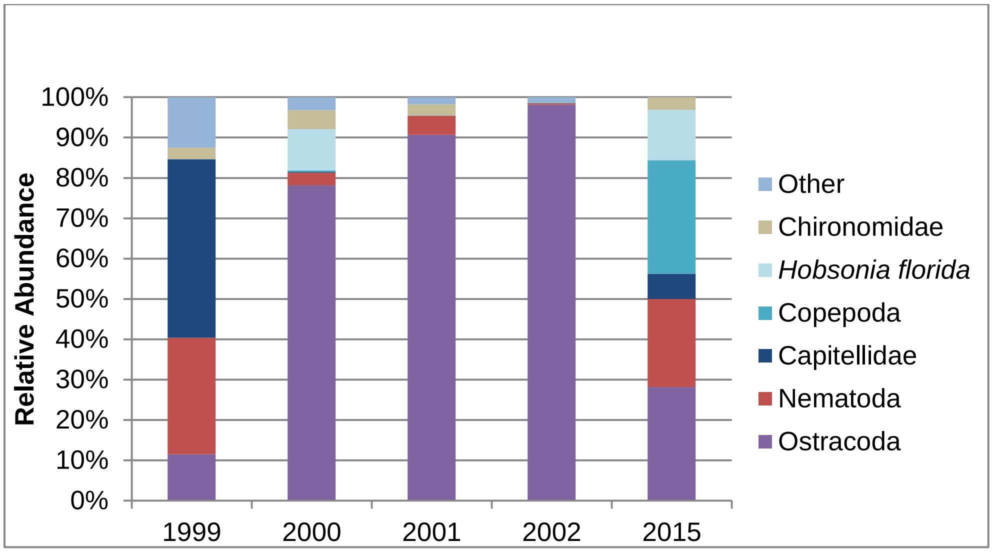


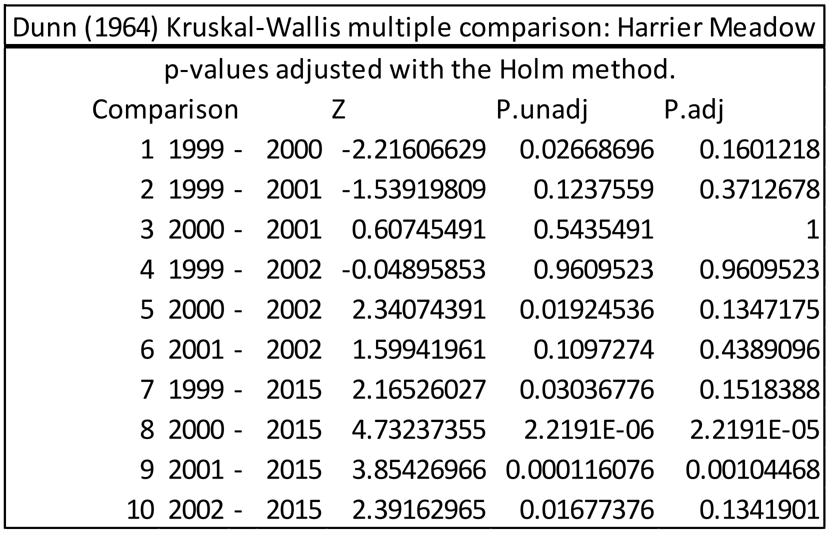
Table 11. Shapiro-Wilk test results for benthic invertebrate density at Harrier Meadow by year, pooled across all habitats.

year	W statistic	p-value
1999	0.77807	3.089E-04
2000	0.68204	1.658E-05
2001	0.81663	2.128E-04
2002	0.72902	7.529E-06
2015	0.78872	1.507E-10

Table 12. Average benthic invertebrate densities at Harrier Meadow by year in n/m2.

year	average	standard error
1999	134084	49190
2000	252399	54949
2001	277308	88042
2002	182962	74918
2015	28039	8012

Table 13. Results of the Dunn test for Kruskal-Wallis multiple comparisons of benthic invertebrate density at Harrier Meadow by year, including p-values adjusted with Holm method.



Dunn (1964) Kruskal-Wallis multiple comparison: Harrier Meadow

p-values adjusted with the Holm method.

	Comparison	Z	P.unadj	P.adj
1	1999 - 2000	-2.21606629	0.02668696	0.1601218
2	1999 - 2001	-1.53919809	0.1237559	0.3712678
3	2000 - 2001	0.60745491	0.5435491	1
4	1999 - 2002	-0.04895853	0.9609523	0.9609523
5	2000 - 2002	2.34074391	0.01924536	0.1347175
6	2001 - 2002	1.59941961	0.1097274	0.4389096
7	1999 - 2015	2.16526027	0.03036776	0.1518388
8	2000 - 2015	4.73237355	2.2191E-06	2.2191E-05
9	2001 - 2015	3.85426966	0.000116076	0.00104468
10	2002 - 2015	2.39162965	0.01677376	0.1341901

Table 14. Results of the Shapiro-Wilk test of normality for benthic invertebrate density at Harrier Meadow by habitat.

habitat	W statistic	p-value
Mudflat	0.86204	1.060E-02
Channel	0.57042	8.365E-09
Impoundment	0.62997	1.464E-08

Table 15. Average benthic invertebrate densities at Harrier Meadow by year and habitat.

	Mudflat		Channel		Impoundment	
	Average (N/m^2)	Standard error (N/m^2)	Average (N/m^2)	Standard error (N/m^2)	Average (N/m^2)	Standard error (N/m^2)
1999	432936.70	114634	103458	48535	15283	3487
2000	563875.80	97269	138323	57744	210737	78039
2001	766236.23	179522	36371	12835	153313	53495
2002	93244.51	17339	23917	10317	386865	166695
2015	94567.13	5343	19067	4088	3747	924

Tables 16. Kruskal-Wallis test results by habitat at Harrier Meadow.

habitat	chi-squared	df	p-value
Mudflat	13.97	4	7.4E-03
Channel	15.11	4	4.5E-03
Impoundment	24.81	4	5.5E-05

Tables 17. Results of the Dunn test for multiple comparisons by habitat at Harrier Meadow.

Dunn (1964) Kruskal-Wallis multiple comparison: Mudflat

p-values adjusted with the Holm method.

	Comparison	Z	P.unadj	P.adj
1	1999 - 2000	-0.4071725	6.84E-01	1
2	1999 - 2001	-0.8725126	3.83E-01	1
3	2000 - 2001	-0.5026247	6.15E-01	1
4	1999 - 2002	1.7450252	8.10E-02	0.48588295
5	2000 - 2002	2.3246392	2.01E-02	0.16073009
6	2001 - 2002	2.8272639	4.69E-03	0.04694762
7	1999 - 2015	1.7450252	8.10E-02	0.40490245
8	2000 - 2015	2.3246392	2.01E-02	0.14063883
9	2001 - 2015	2.8272639	4.69E-03	0.04225286
10	2002 - 2015	0	1.00E+00	1

Dunn (1964) Kruskal-Wallis multiple comparison: Channel

p-values adjusted with the Holm method.

	Comparison	Z	P.unadj	P.adj
1	1999 - 2000	-0.6936147	4.88E-01	0.97584775
2	1999 - 2001	0.86885853	3.85E-01	1
3	2000 - 2001	1.52756798	1.27E-01	0.75971903
4	1999 - 2002	2.22421697	2.61E-02	0.2090708
5	2000 - 2002	3.1516184	1.62E-03	0.01623683
6	2001 - 2002	1.04571767	2.96E-01	1
7	1999 - 2015	2.16609283	3.03E-02	0.21212866
8	2000 - 2015	3.08883716	2.01E-03	0.01808474
9	2001 - 2015	0.994457	3.20E-01	1
10	2002 - 2015	-0.06278124	9.50E-01	0.9499407

Dunn (1964) Kruskal-Wallis multiple comparison: Impoundment

p-values adjusted with the Holm method.

	Comparison	Z	P.unadj	P.adj
1	1999 - 2000	-2.4510822	1.42E-02	0.099699192
2	1999 - 2001	-2.2011135	2.77E-02	0.166367943
3	2000 - 2001	0.2699971	7.87E-01	1
4	1999 - 2002	-2.2011135	2.77E-02	0.138639952
5	2000 - 2002	0.2699971	7.87E-01	1
6	2001 - 2002	0	1.00E+00	1
7	1999 - 2015	1.2463718	2.13E-01	0.850511665
8	2000 - 2015	3.9937068	6.50E-05	0.000650483
9	2001 - 2015	3.7237097	1.96E-04	0.00176685
10	2002 - 2015	3.7237097	1.96E-04	0.001570533

Figure 20. Abundance of taxa in Impoundment habitat at Mill Creek by year. Abundance represented as average of counts in replicates.

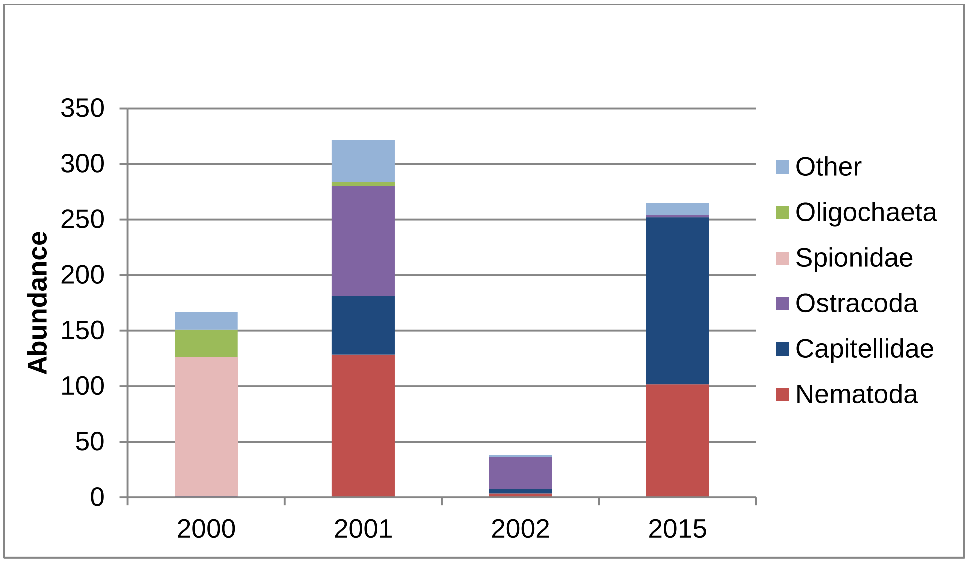
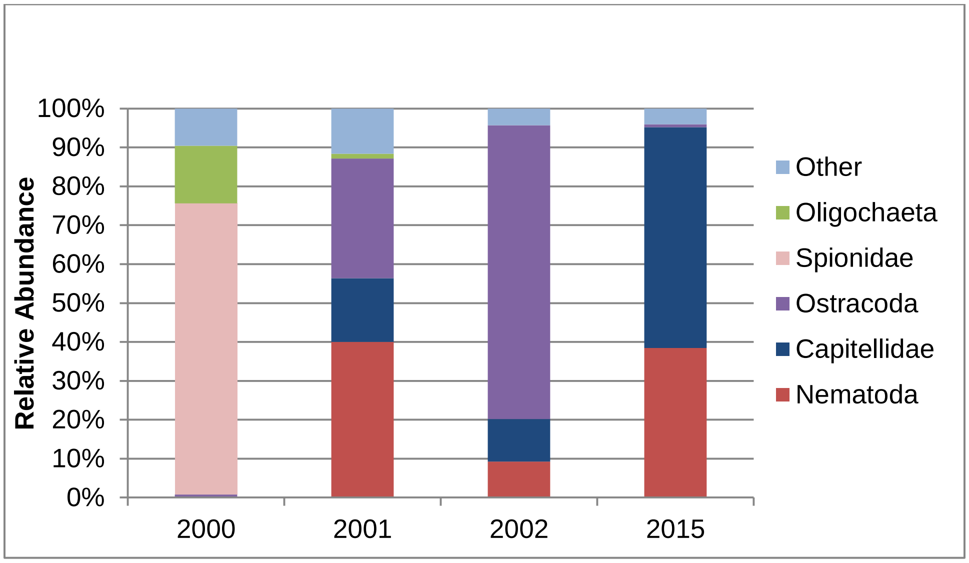


Figure 21. Relative abundance of taxa in Impoundment habitat at Mill Creek by year.

Abundance represented as percentage of all specimens.



Tables 18. Results of the Shapiro-Wilk test of normality for benthic invertebrate density by individual years, and the pooled Mill Creek (MC) data.

year	W statistic	p-value
2000	0.778	3.1E-04
2001	0.682	1.7E-05
2002	0.817	2.1E-04
2015	0.729	7.5E-06
pooled MC	0.788	1.5E-10

Table 19. Average benthic invertebrate densities at Mill Creek by year in n/m2.

year	average	standard error
2000	217035	54949
2001	243739	88042
2002	135221	74918
2015	197479	8012

Table 20. Results of the Dunn test for the comparison of density between years, α=0.05.

Dunn (1964) Kruskal-Wallis multiple comparison

	Comparison	Z	P.unadj	P.adj
1	2000 - 2001	-0.7353358	0.462135007	0.92427001
2	2000 - 2002	1.9043516	0.056864413	0.28432206
3	2001 - 2002	2.6904586	0.007135389	0.04281233
4	2000 - 2015	0.3401146	0.733770244	0.73377024
5	2001 - 2015	1.1262216	0.260071724	0.78021517
6	2002 - 2015	-1.689569	0.091110432	0.36444173

p-values adjusted with the Holm method.

Table 21. Results of the Shapiro-Wilk test of normality for benthic invertebrate density by habitat pooled over all years.

habitat	W statistic	p-value
Mudflat	0.762	1.744E-03
Channel	0.884	5.055E-03
Impoundment	0.70858	3.075E-09

Table 22. Average benthic invertebrate densities at Mill Creek by year and habitat.

	Mudflat		Channel		Impoundment	
	average	standard error	average	standard error	average	standard error
2000	544918	154702	195747	35149	145708	45644
2001	147545	27791	212794	32924	283260	84087
2002	214925	38179	298801	58788	33506	9615
2015	109336	40776	169515	79119	233497	51548

Tables 23. Results of the Kruskal-Wallis tests by habitat at Mill Creek Marsh.

habitat	chi-squared	df	p-value
Mudflat	8.02	3	4.55E-02
Channel	5.99	3	1.11E-01
Impoundment	25.5	3	1.22E-05

Tables 24. Results of the Dunn test for Kruskal-Wallis multiple comparisons of benthic invertebrate density at Mill Creek by year, including p-values adjusted with Holm method.

Dunn (1964) Kruskal-Wallis multiple comparison: Mudflat

Comparison	Z	P.unadj	P.adj
1 2000 - 2001	2.1469802	0.031794861	0.15897431
2 2000 - 2002	1.3041013	0.192199036	0.57659711
3 2001 - 2002	-0.991117	0.321628449	0.6432569
4 2000 - 2015	2.6342847	0.008431476	0.05058886
5 2001 - 2015	0.3390663	0.734559751	0.73455975
6 2002 - 2015	1.4367622	0.150785565	0.60314226

p-values adjusted with the Holm method.

Dunn (1964) Kruskal-Wallis multiple comparison: Channel

Comparison	Z	P.unadj	P.adj
1 2000 - 2001	-0.07018624	0.94404543	0.94404543
2 2000 - 2002	-0.96604018	0.33402407	1
3 2001 - 2002	-0.89100794	0.37292491	0.74584982
4 2000 - 2015	1.28492724	0.19881771	0.79527085
5 2001 - 2015	1.35995948	0.17384275	0.86921373
6 2002 - 2015	2.4313227	0.01504381	0.09026286

p-values adjusted with the Holm method.

Dunn (1964) Kruskal-Wallis multiple comparison: Impoudment

Comparison	Z	P.unadj	P.adj
1 2000 - 2001	-1.35799491	0.1744653	0.3489306
2 2000 - 2002	2.72120928	0.006504357	0.02601743
3 2001 - 2002	4.1729669	3.00659E-05	0.000150329
4 2000 - 2015	-1.39823661	0.162042	0.4861261
5 2001 - 2015	0.05352102	0.9573168	0.9573168
6 2002 - 2015	-4.4495101	8.60664E-06	5.16398E-05

p-values adjusted with the Holm method.

Figure 22. Average benthic invertebrate density at Harrier Meadow by year

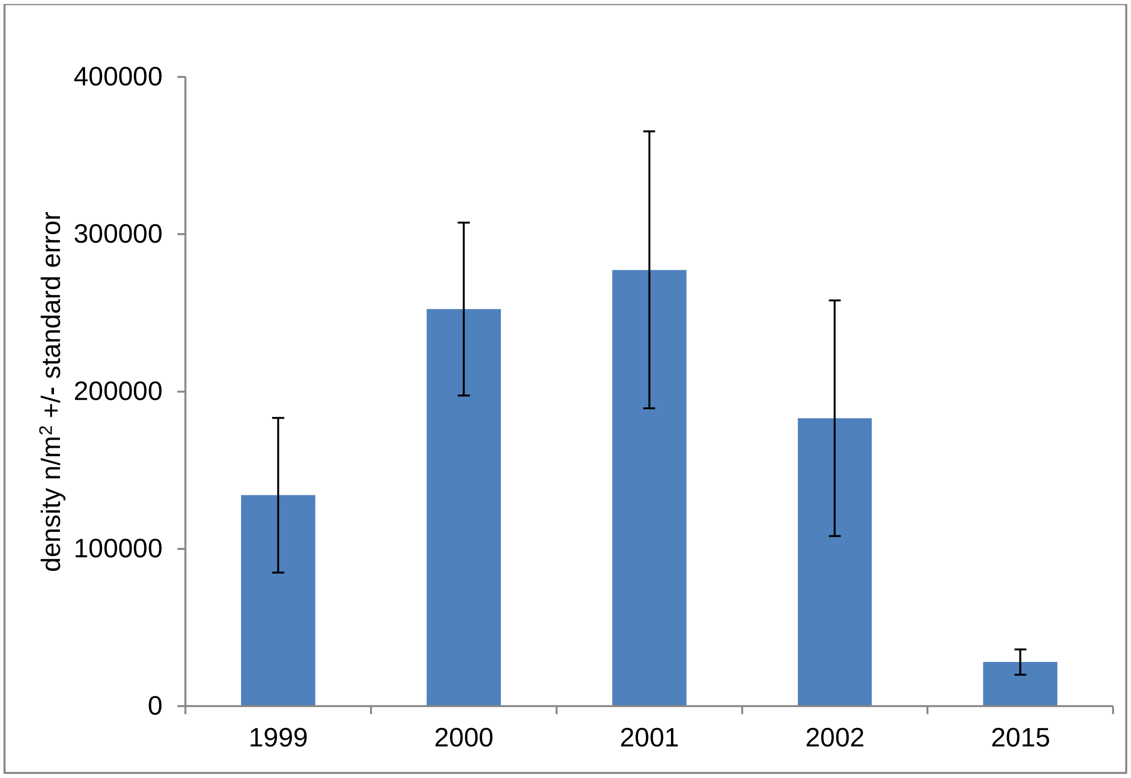


Figure 23. Average benthic invertebrate density for habitat type at Harrier Meadow by collection years

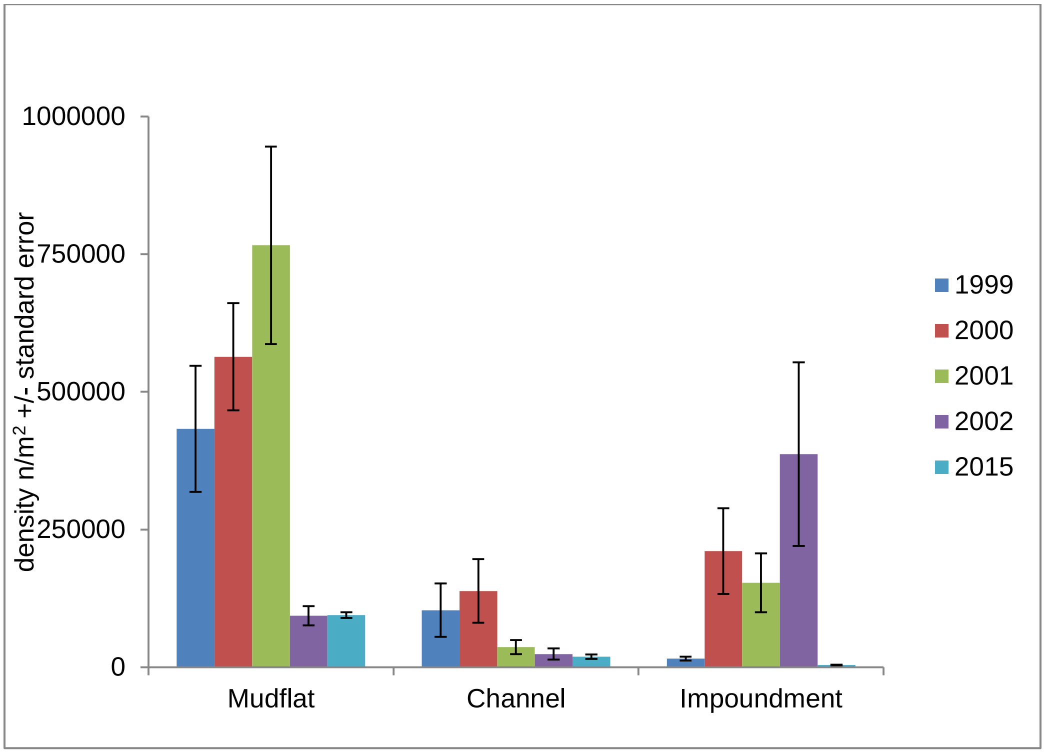


Figure 24. Average benthic invertebrate density for collection years at Harrier Meadow by habitat type

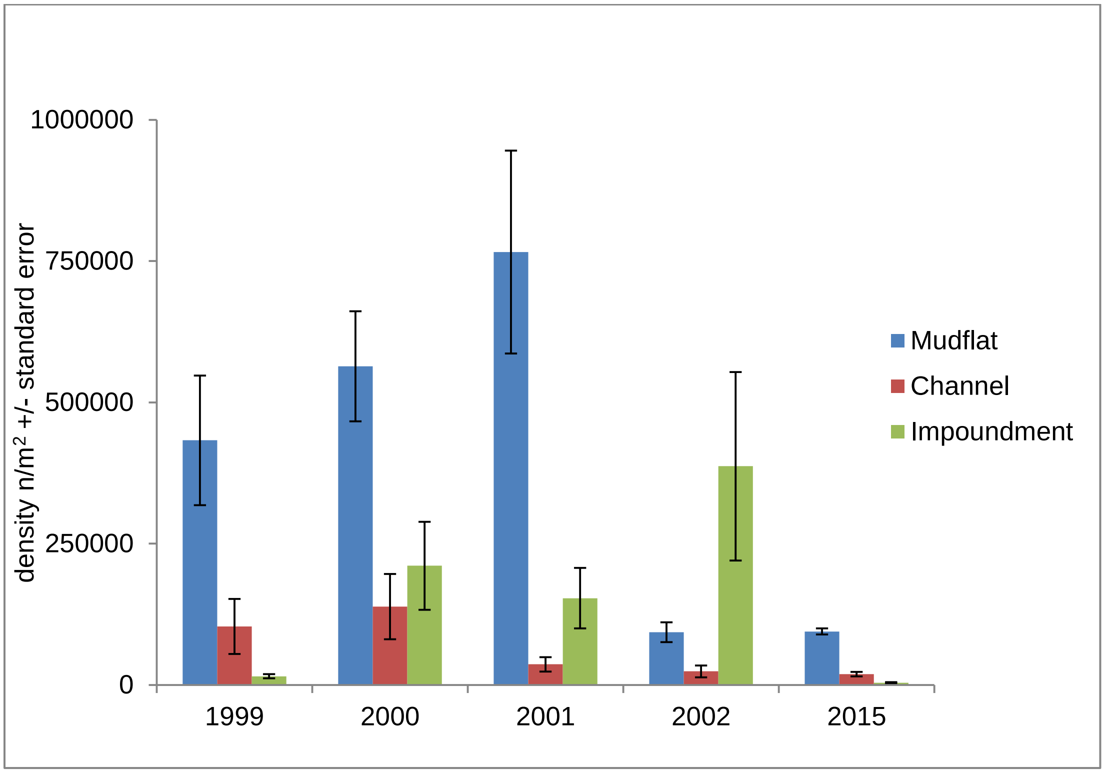


Table 23 Target compounds and their monitored ions

Retention Order	PAH	Primary	Secondary	Molecular weight
1	Naphthalene	128	129	128.18
2	Acenaphthene	152	153	152.2
3	Acenaphthylene	153	154	154.2
4	Fluorene	166	165	166.23
5	Phenanthrene	178	176	178.24
6	Anthracene	178	176	178.24
7	Fluoranthene	202	101	202.26
8	Pyrene	202	101	202.26
9	Benz[a]anthracene	228	114	228.3
10	Chrysene	228	114	228.3
11	Benzo(b)fluoranthene	252	126	252.32
12	Benzo(k)fluoranthene	252	126	252.32
13	Benzo[a]pyrene	252	126	252.32
14	Indeno[1,2,3-cd]pyrene	276	138	276.34
15	Dibenzo[a,h+a,c]anthracene	278	139	278.35
16	Benzo[g,h,i]perylene	276	138	276.34

Table 24 Water quality parameters for the three wetland site

Anderson Creek	Temperature	Salinity	pH	DO	DO	Conductivity	TDS	Turbidity
	C	ppt	pH	%	ppm	mS/cm	mg/L	NTU
AC03	27.55	9.14	7.51	52.3	3.86	15.71	N/A	24.8
AC04	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
AC10	32.2	13.29	7.86	46.3	2.88	22.27	14482	N/A
AC52	27.7	12.95	7.75	64.3	4.72	21.62	N/A	64.3
AC59	27.7	12.95	7.75	64.3	4.72	21.62	N/A	64.3

Riverbend	Temperature	Salinity	pH	DO	DO	Conductivity	TDS	Turbidity
	C	ppt	pH	%	ppm	mS/cm	mg/L	NTU
RB01	25	16.07	7.47	73.2	5.45	26.33	N/A	N/A
RB02	24.4	11.69	7.42	60.9	4.75	19.65	N/A	21.5
RB07	24	16.91	8.02	44.3	3.26	27.43	17875	N/A
RB37	26.7	16.72	7.86	57.3	3.8	27.31	17751.5	N/A
RB47	25.3	16.26	7.91	64.8	4.83	26.60	17294	N/A

Secaucus High School	Temperature	Salinity	pH	DO	DO	Conductivity	TDS	Turbidity
	C	ppt	pH	%	ppm	mS/cm	mg/L	NTU
SHS04	26	10.39	7.67	47	3.5	17.65	11472	N/A
SHS03	21.4	11.65	7.46	26.6	2.23	19.52	12694.5	N/A
SHS08	29.2	12.11	7.1	80.8	5.7	20.38	13260	N/A
SHS17	29.1	10.21	6.71	57.1	4.1	17.43	11329.5	N/A
SHS01	20.2	11.46	7.62	48	4.3	19.23	12493	N/A

Where data are not shown, field records were incompatible and thus omitted from the statistical analysis.

Table 25. Sediment particle size distribution.

Sample ID	Location	% Sand	% Silt	% Clay
EPA-016-S	RB37	8.2	58.0	33.7
EPA-019-S	RB07	12.0	60.2	27.8
EPA-007-S	RB47	54.3	23.8	21.9
EPA-006-S	RB01	15.9	56.3	27.7
EPA-014-S	RB02	16.0	57.3	26.7
EPA-009-S	AC59	8.4	64.3	27.4
EPA-010-S	AC52	12.1	64.2	23.6
EPA-011-S	AC03	16.2	57.1	26.7
EPA-012-S	AC04	17.9	60.4	21.8
EPA-013-S	AC10	9.9	63.2	26.9
EPA-015-S	SHS04	21.1	53.0	25.9
EPA-017-S	SHS17	5.6	68.6	25.8
EPA-018-S	SHS08	40.8	40.3	18.8
EPA-020-S	SHS01	8.6	64.6	26.8
EPA-021-S	SHS03	6.1	68.0	25.9

Table 26. The percentage of organic matters and percentage of moisture in sediment samples.

Sample #	Location	% OM	% Ash	% Moisture
EPA016-S	RB37	**12.5**	87.5	**60.0**
EPA019-S	RB07	**11.1**	88.9	**58.5**
EPA007-S	RB47	**9.39**	90.6	**54.0**
EPA006-S	RB01	**11.7**	88.3	**62.8**
EPA014-S	RB02	**10.6**	89.4	**59.6**
EPA009-S	AC59	**11.3**	88.7	**58.7**
EPA010-S	AC52	**16.3**	83.7	**69.6**
EPA011-S	AC03	**17.5**	82.5	**60.0**
EPA012-S	AC04	**17.6**	82.4	**69.4**
EPA013-S	AC10	**10.9**	89.1	**60.4**
EPA015-S	SHS04	**12.7**	87.3	**61.8**
EPA017-S	SHS17	**11.4**	88.6	**59.3**
EPA018-S	SHS08	**6.21**	93.8	**44.7**
EPA020-S	SHS01	**14.2**	85.8	**64.6**
EPA021-S	SHS03	**11.2**	88.8	**60.1**
	Average	**12.3**	87.7	**60.2**
	SD	**3.0**	3.0	**6.0**

Table 27 Metal concentrations (mg/kg) in sediment samples.

		Metal concentration of sediment samples, mg/kg																				
Sample #	**Location**	**Ag**	**Al**	**As**	**Ba**	**Be**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Hg**	**Mn**	**Mo**	**Ni**	**Pb**	**Sb**	**Se**	**Ti**	**Th**	**V**	**U**	**Zn**
EPA016-S	RB37	2.1	11536	15.4	85	0.9	2.2	3.2	72	133	30401	6.1	418	3.6	41.3	170	NA	4.1	197	4.4	35.9	2.0	304
EPA019-S	RB07	1.0	8756	10.0	58	0.5	0.8	7.5	97	72	21801	4.0	313	1.0	24.1	81	NA	2.9	136	3.4	22.9	1.0	166
EPA007-S	RB47	0.6	7982	10.6	56	0.5	0.7	7.5	89	58	21412	2.6	455	1.0	21.9	70	NA	3.3	140	3.2	21.8	1.0	142
EPA006-S	RB01	1.2	11034	12.7	74	0.7	1.0	9.5	134	91	28453	3.5	450	1.2	30.7	104	NA	3.2	184	4.4	29.2	1.3	203
EPA014-S	RB02	0.9	10795	12.4	76	0.6	0.8	9.3	122	82	27895	3.1	554	0.9	28.9	95	NA	3.3	180	4.3	27.9	1.2	187
RB Average		**1.2**	**10020**	**12.2**	**69.7**	**0.6**	**1.1**	**7.4**	**103**	**87.0**	**25992**	**3.9**	**438**	**1.5**	**29.4**	**104**	**NA**	**3.4**	**168**	**3.9**	**27.5**	**1.3**	**200**
SD		**0.6**	**1555**	**2.1**	**12.2**	**0.1**	**0.6**	**2.5**	**25**	**28.3**	**4112**	**1.4**	**86**	**1.2**	**7.6**	**39**	**NA**	**0.5**	**27**	**0.6**	**5.6**	**0.4**	**62**
EPA009-S	AC59	1.8	11945	12.6	86	0.6	1.4	8.9	206	107	28181	5.6	327	1.5	33.9	121	NA	5.0	195	4.8	32.5	1.8	233
EPA010-S	AC52	2.5	12535	28.0	80	0.7	2.7	12.5	550	133	34421	9.9	490	6.2	63.2	186	NA	4.3	213	4.9	61.5	2.7	372
EPA011-S	AC03	2.1	10604	46.4	145	0.6	1.0	9.5	284	121	30614	9.2	336	2.7	34.5	249	NA	5.4	202	4.2	36.9	2.2	212
EPA012-S	AC04	2.7	11136	27.1	88	0.9	1.8	9.2	348	149	28352	10.6	298	2.2	34.8	164	NA	4.0	183	3.8	41.3	1.8	263
EPA013-S	AC10	2.0	12178	12.5	78	1.0	1.5	10.5	191	119	29571	5.8	343	2.0	35.9	125	NA	4.2	200	5.0	36.0	2.0	260
AC Average		**2.2**	**11680**	**25.3**	**95.7**	**0.8**	**1.7**	**10.1**	**316**	**126**	**30228**	**8.2**	**359**	**2.9**	**40.5**	**169**	**NA**	**4.6**	**199**	**4.5**	**41.6**	**2.1**	**268**
SD		**0.4**	**791**	**14.0**	**28.1**	**0.2**	**0.6**	**1.5**	**146**	**16**	**2543**	**2.4**	**75**	**1.9**	**12.7**	**52**	**NA**	**0.6**	**11**	**0.5**	**11.5**	**0.4**	**62**
EPA015-S	SHS04	2.2	12014	12.0	103	0.9	1.8	10.9	196	122	32838	6.0	478	1.6	36.3	113	NA	5.0	169	4.7	31.7	1.7	276
EPA017-S	SHS17	2.4	11717	11.6	95	0.7	1.7	9.5	181	108	29666	5.5	442	1.0	32.1	100	NA	4.8	136	4.3	28.4	1.4	245
EPA018-S	SHS08	0.8	7080	7.2	47	0.5	1.0	5.6	93	55	16991	3.5	194	0.8	18.7	55	NA	1.6	120	3.4	18.6	0.9	142
EPA020-S	SHS01	2.0	10796	14.7	108	0.8	1.5	9.4	276	115	27746	8.3	440	1.7	34.3	126	NA	4.1	151	4.2	32.3	1.7	238
EPA021-S	SHS03	2.4	11827	11.9	101	0.9	1.9	10.0	189	117	31175	5.3	437	1.2	34.6	106	NA	4.8	147	4.4	29.4	1.4	266
SHS Average		**2.0**	**10687**	**11.5**	**90.8**	**0.8**	**1.6**	**9.1**	**187**	**103**	**27683**	**5.7**	**398**	**1.2**	**31.2**	**99.9**	**0.0**	**4.1**	**145**	**4.2**	**28.1**	**1.4**	**233**
SD		**0.7**	**2070**	**2.7**	**24.8**	**0.2**	**0.4**	**2.0**	**65**	**28**	**6266**	**1.7**	**116**	**0.4**	**7.2**	**27.2**	**0.0**	**1.4**	**18**	**0.5**	**5.5**	**0.3**	**53**
Overall Average		**1.8**	**10796**	**16.3**	**85.4**	**0.7**	**1.5**	**8.9**	**202**	**105**	**27968**	**5.9**	**398**	**1.9**	**33.7**	**124**	**NA**	**4.0**	**170**	**4.2**	**32.4**	**1.6**	**234**
SD		**0.7**	**1610**	**10.1**	**24.1**	**0.2**	**0.6**	**2.2**	**125**	**28**	**4598**	**2.5**	**93**	**1.4**	**10.1**	**50**	**NA**	**1.0**	**30**	**0.5**	**10.1**	**0.5**	**62**

Table 28 Metal concentrations (mg/kg) in benthic and canned tuna samples.

		Metal concentration of benthic and tuna samples, mg/kg																					
Sample #	**Location**	**Ag**	**Al**	**As**	**Ba**	**Be**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Hg**	**Mn**	**Mo**	**Ni**	**Pb**	**Sb**	**Se**	**Ti**	**Th**	**V**	**U**	**Zn**
EPA 001	RB37	0.3	9641	7.6	64.6	0.4	0.7	3.9	65.3	65.8	13416	1.9	139	1.7	16.3	51.8	NA	1.3	267	2.6	22.7	0.7	159
EPA 019	RB07	0.0	1736	12.5	22.6	0.1	0.3	1.8	17.0	45.2	3987	0.7	109	1.0	5.8	15.3	NA	2.2	55	0.5	4.5	0.2	133
EPA 004	RB47	0.3	700	4.8	33.2	0.0	1.3	0.8	8.0	40.7	2317	0.7	178	0.6	8.6	29.0	NA	1.4	25	0.2	2.7	0.2	108
EPA 005	RB01	0.7	2327	8.7	61.2	0.1	10.9	1.6	19.4	64.2	6427	0.7	148	0.8	5.8	155.6	NA	2.5	69	0.6	7.5	0.3	215
EPA 014	RB02	0.4	909	7.2	34.2	0.1	0.4	1.0	7.7	48.9	2970	0.5	112	0.6	3.0	10.0	NA	1.9	30	0.3	2.8	0.2	120
RB Average		**0.3**	**3063**	**8.2**	**43.2**	**0.1**	**2.7**	**1.8**	**23.5**	**53.0**	**5823**	**0.9**	**138**	**1.0**	**7.9**	**52.4**	**NA**	**1.9**	**89**	**0.8**	**8.0**	**0.3**	**147**
SD		**0.3**	**3735**	**2.8**	**18.6**	**0.2**	**4.6**	**1.2**	**23.9**	**11.4**	**4523**	**0.6**	**29**	**0.4**	**5.1**	**59.9**	**NA**	**0.5**	**101**	**1.0**	**8.4**	**0.2**	**42**
EPA 009	AC59	0.2	4043	12.7	47.4	0.3	0.4	2.7	49.3	52.1	7643	1.4	90	1.4	10.2	29.7	NA	2.3	119	1.3	10.5	0.8	162
EPA 010	AC52	0.3	3733	7.0	28.0	0.2	0.5	2.3	70.1	43.3	6541	1.4	86	2.2	11.1	35.0	NA	1.3	120	1.1	14.8	0.4	150
EPA 011	AC03	0.2	1161	7.0	54.5	0.1	1.2	0.9	14.7	29.0	3349	1.1	79	0.4	3.2	23.8	NA	1.5	37	0.3	3.5	0.2	115
EPA 012	AC04	0.7	3069	11.4	54.4	0.2	0.9	2.4	51.6	62.3	6239	1.5	96	1.0	7.0	35.7	NA	2.6	97	1.0	10.6	0.6	198
EPA 013	AC10	0.6	3908	14.5	43.6	0.2	1.0	3.2	42.4	56.2	9552	1.3	108	1.9	9.3	38.0	NA	3.4	118	1.3	11.6	0.9	177
AC Average		**0.4**	**3183**	**10.5**	**45.6**	**0.2**	**0.8**	**2.3**	**45.6**	**48.6**	**6665**	**1.3**	**91.6**	**1.4**	**8.2**	**32.4**	**NA**	**2.2**	**98.2**	**1.0**	**10.2**	**0.6**	**161**
SD		**0.2**	**1190**	**3.4**	**10.9**	**0.1**	**0.3**	**0.9**	**20.1**	**13.0**	**2263**	**0.2**	**11.0**	**0.7**	**3.1**	**5.7**	**NA**	**0.9**	**35.5**	**0.4**	**4.1**	**0.3**	**31**
EPA 015	SHS04	0.2	2958	6.0	66.0	0.1	0.3	2.2	29.6	36.0	6818	1.0	215	1.0	6.1	20.6	NA	1.8	88	0.9	6.9	0.4	91
EPA 017	SHS17	0.3	2890	6.6	66.6	0.2	4.1	2.2	35.0	32.1	7995	1.2	225	1.0	8.2	54.1	NA	2.0	92	1.1	7.5	0.5	100
EPA 018	SHS08	1.5	2661	10.8	49.1	0.2	0.6	2.5	29.8	70.1	7085	1.2	146	1.4	6.6	21.4	NA	3.6	79	0.9	7.8	0.6	148
EPA 020	SHS01	NA	3475	5.4	65.0	0.1	0.6	2.1	40.0	32.1	6671	1.1	175	1.1	6.2	30.3	NA	1.6	97	1.0	8.3	0.6	85
EPA 021	SHS03	0.4	2749	9.7	48.2	0.2	0.5	2.3	33.3	40.6	7542	1.1	151	1.3	6.8	24.3	NA	3.0	82	1.0	7.5	0.5	127
SHS Average		**0.6**	**2947**	**7.7**	**59.0**	**0.2**	**1.2**	**2.3**	**33.5**	**42.2**	**7222**	**1.1**	**182**	**1.2**	**6.8**	**30.1**	**NA**	**2.4**	**87.5**	**1.0**	**7.6**	**0.5**	**110**
SD		**0.6**	**317**	**2.4**	**9.4**	**0.0**	**1.6**	**0.2**	**4.3**	**16.0**	**544**	**0.1**	**36**	**0.2**	**0.9**	**13.9**	**NA**	**0.9**	**7.3**	**0.1**	**0.5**	**0.1**	**26**
Overall Average		**0.4**	**3064**	**8.8**	**49.2**	**0.2**	**1.6**	**2.1**	**34.2**	**47.9**	**6570**	**1.1**	**137**	**1.2**	**7.6**	**38.3**	**NA**	**2.2**	**91.6**	**0.9**	**8.6**	**0.5**	**139**
SD		**0.4**	**2104**	**3.0**	**14.5**	**0.1**	**2.7**	**0.8**	**19.3**	**13.4**	**2783**	**0.4**	**46.0**	**0.5**	**3.3**	**34.6**	**NA**	**0.7**	**57.5**	**0.6**	**5.2**	**0.2**	**38.4**
Chicken of sea		NA	8.2	2.5	NA	NA	0.1	0.0	0.1	1.6	47.6	1.2	0.8	0.0	0.4	2.9	NA	3.1	0.3	0.0	0.1	0.0	19.4
Skip Jack Tuna		NA	2.7	2.8	NA	0.0	0.1	0.0	0.0	2.0	37.0	1.0	0.2	0.0	0.1	1.3	NA	2.7	0.3	0.0	0.1	0.0	19.1
Wild Selection		NA	10.7	3.1	NA	NA	0.2	0.0	0.1	0.8	11.0	1.0	0.1	0.0	0.1	3.8	NA	1.9	0.4	0.0	0.1	0.0	14.7
Bumble bee		NA	4.4	6.2	NA	0.0	0.9	0.0	0.0	1.1	15.8	1.2	0.8	0.1	0.1	31.0	NA	2.8	0.3	0.0	0.1	0.0	14.3
Average		**NA**	**6.5**	**3.6**	**NA**	**0.0**	**0.3**	**0.0**	**0.1**	**1.4**	**27.8**	**1.1**	**0.5**	**0.0**	**0.2**	**9.7**	**NA**	**2.6**	**0.3**	**0.0**	**0.1**	**0.0**	**16.9**
SD		**NA**	**3.6**	**1.7**	**NA**	**0.0**	**0.4**	**0.0**	**0.0**	**0.5**	**17.3**	**0.1**	**0.4**	**0.0**	**0.2**	**14.2**	**NA**	**0.5**	**0.1**	**0.0**	**0.0**	**0.0**	**2.7**

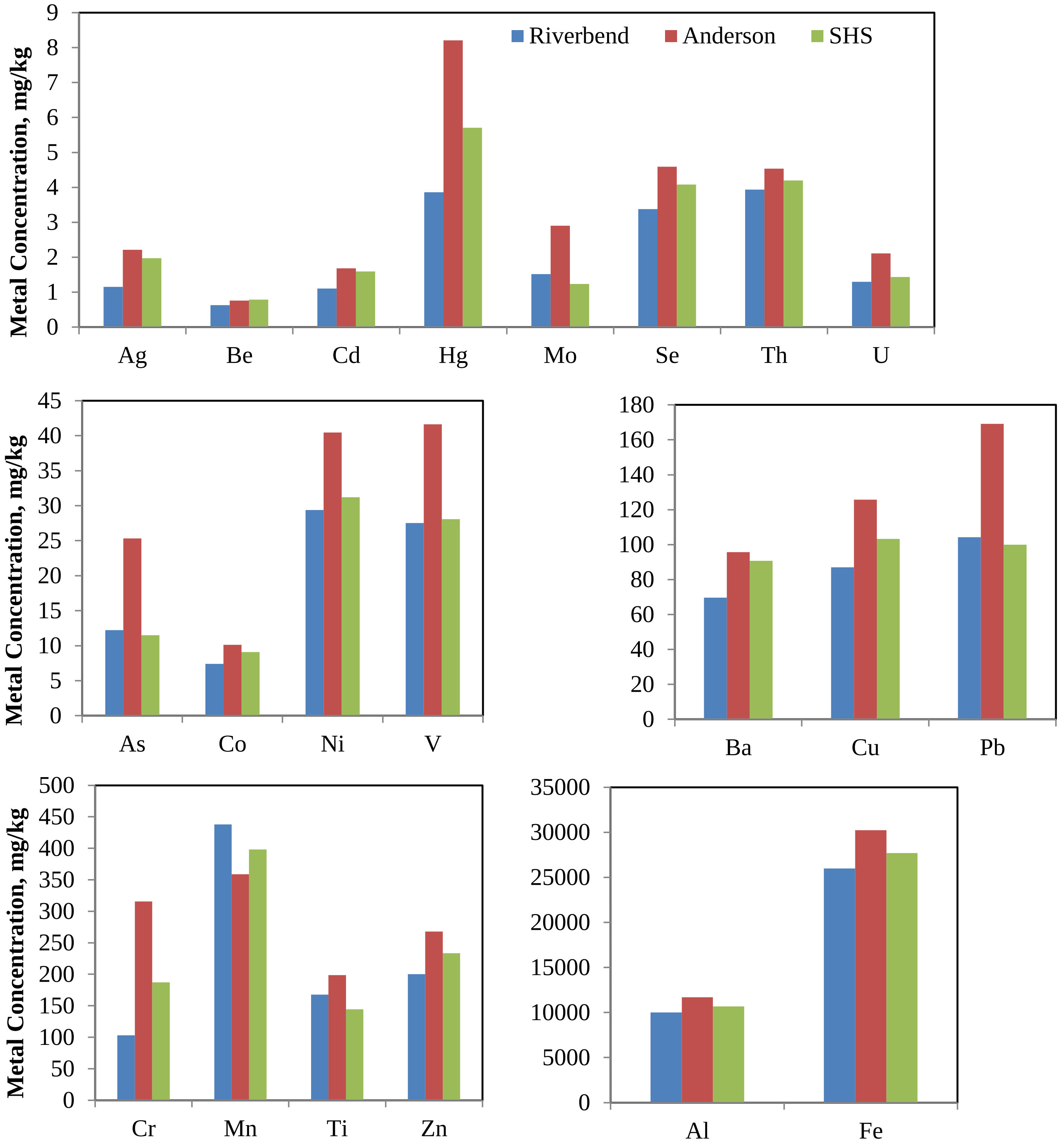


Figure 25 The average metal concentrations in sediment samples.

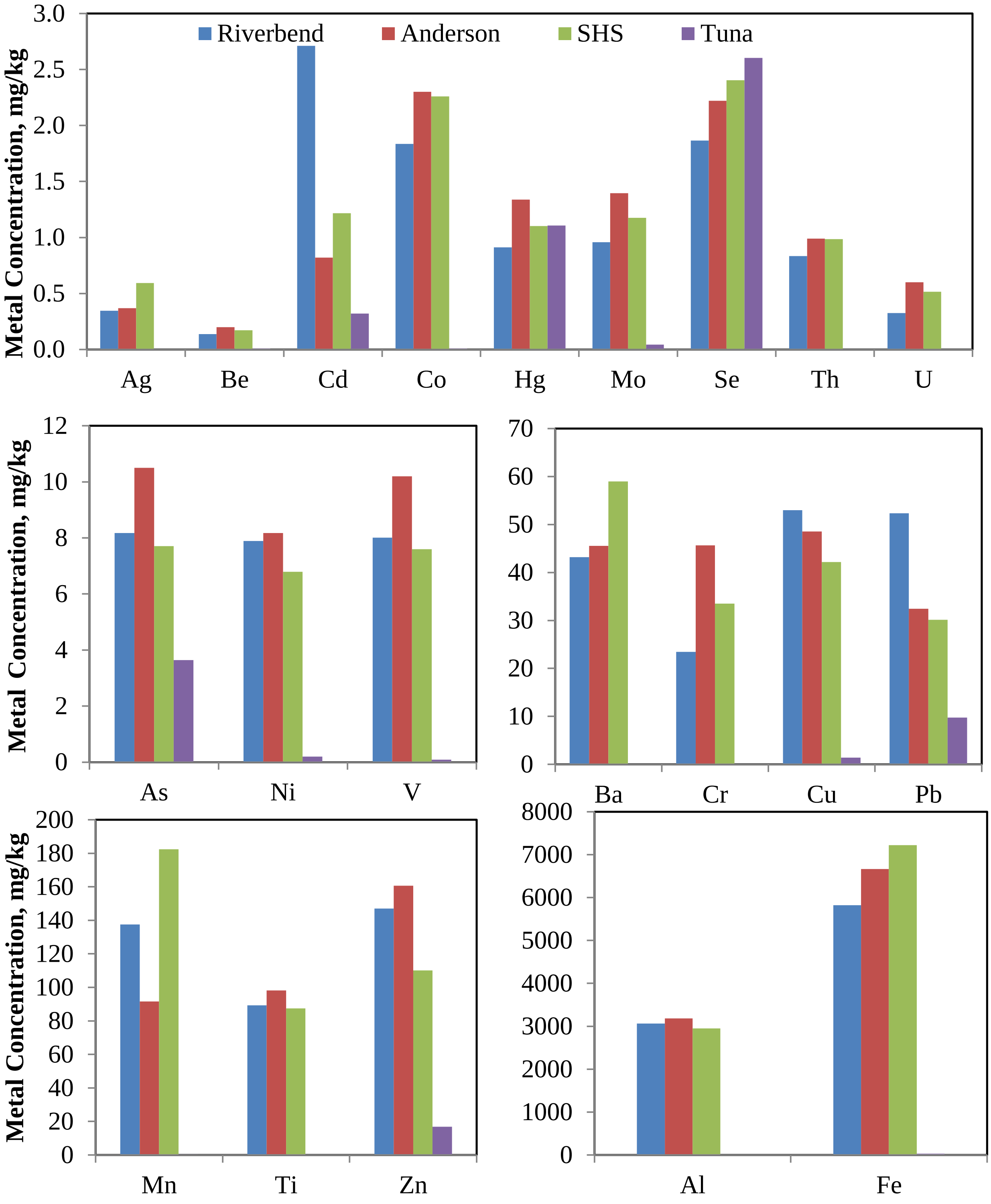


Figure 26 The average metal concentrations in benthic and tuna samples.

Table 29 Total PCB, OCP, and PAH concentrations in sediment samples.

	Total PCB or OCP, µg/kg		**Total PAH, mg/kg**
Sample Location	PCB	OCP	
RB 37	128.3	26.5	3.3
RB 07	113.5	31.1	4.8
RB 47	147.8	36.9	14.7
RB 01	155.8	38.3	5.2
RB 02	95.0	69.8	7.1
RB Average	***128.1***	***40.5***	***7.0***
SD	***24.8***	***17.0***	***4.5***
AC 59	189.4	37.3	3.7
AC 52	217.2	32.1	2.4
AC 03	140.4	37.4	9.1
AC 04	184.5	52.2	5.7
AC 10	153.4	25.3	5.2
AC Average	***177.0***	***36.9***	***5.2***
SD	***30.5***	***9.9***	***2.5***
SHS 04	215.4	53.0	2.7
SHS 17	133.3	25.0	3.1
SHS 08	137.9	22.2	5.9
SHS 01	478.7	65.0	2.3
SHS 03	204.8	38.4	3.0
SHS Average	***234.0***	***40.7***	***3.4***
SD	***141.8***	***18.3***	***1.4***

Table 30 Total PCB, OCP, and PAH concentrations in benthic and tuna samples.

	Total PCB or OCP, µg/kg		Total PAH, mg/kg
Sample Location	PCB	OCP	
RB 37	267.3	32.3	5.5
RB 07	138.3	16.7	2.5
RB 47	144.4	18.2	3.4
RB 01	178.6	34.8	4.5
RB 02	161.8	25.2	2.6
RB Average	**178.1**	**25.4**	**3.7**
SD	**52.3**	**8.1**	**1.3**
AC 59	271.5	36.8	2.2
AC 52	36.2	90.5	0.9
AC 03	42.7	20.0	0.6
AC 04	42.6	42.7	0.7
AC 10	110.3	30.8	0.4
AC Average	**100.7**	**44.1**	**1.0**
SD	**100.2**	**27.3**	**0.7**
SHS 04	380.6	72.1	3.7
SHS 17	37.0	25.2	0.4
SHS 08	37.5	30.7	0.3
SHS 01	286.0	44.2	1.5
SHS 03	356.4	66.8	2.4
SHS Average	**219.5**	**47.8**	**1.6**
SD	**169.9**	**21.0**	**1.4**
Overall Average	**166.1**	**39.1**	**2.1**
SD	**120.4**	**21.4**	**1.6**
Chicken of the Sea	52.3	20.2	2.0
Skip Jack	33.5	27.5	1.5
Wild Selections	44.5	31.9	1.8
Bumble Bees	44.6	54.1	2.2
Average	**43.7**	**33.4**	**1.9**
SD	**7.7**	**14.6**	**0.3**

Table 31 Benthic ID results for Riverbend Wetland Preserve (RB)

Site	Species	N
EPA-001	*Hobsonia florida*	492
RB37	*Streblospio benedicti*	8
	Capitella sp.	28
	Gammarus mucronatus	8
	Leptocheirus plumulosus	8
	Apocorophium lacustre	28
	Chironomidae	172

Site	Species	N
EPA-002	*Hobsonia florida*	218
RB07	*Spio setosa*	1
	Alitta succinea	1
	Capitella sp.	3
	Leptocheirus plumulosus	5
	Littoridinops tenuipes	13
	Chironomidae	51
	Diptera	1
	Coleoptera	1
	Dolichopodidae	1

Site	Species	N
EPA-004	*Hobsonia florida*	16
RB47	*Spio setosa*	12
	Hypereteone lactea	4
	Notomastus latericeus	4
	Capitella sp.	4
	Cyathura polita	48
	Leptocheirus plumulosus	8
	Gammarus mucronatus	12
	Limecola balthica	64
	Streblospio benedicti	24

Site	Species	N
EPA-007	*Spio setosa*	16
RB47	*Alitta succinea*	8
	Leitoscoloplos robustus	12
	Streblospio benedicti	16
	Capitella sp.	4
	Cyathura polita	20
	Leptocheirus plumulosus	8
	Limecola balthica	52

Site	Species	N
EPA-005	*Hobsonia florida*	44
RB01	*Streblospio benedicti*	64
	Alitta succinea	9
	Diadumene leucolena	1
	Capitella sp.	209
	Capitellidae sp.	16
	Cerebratulus lacteus	1
	Cyathura polita	31
	Rhithropanopeus harrisii	3
	Gammarus mucronatus	3
	Leptocheirus plumulosus	13
	Grandidierella japonica	1
	Limecola balthica	21
	Chironomidae	1
	Hypereteone lactea	2

Site	Species	N
EPA-006	*Hobsonia florida*	41
RB01	*Spio setosa*	1
	Alitta succinea	103
	Streblospio benedicti	46
	Capitellidae sp.	256
	Capitella sp.	100
	Leitoscoloplos robustus	1
	Cyathura polita	93
	Edotia triloba	2
	Gammarus sp.	1
	Leptocheirus plumulosus	8
	Grandidierella japonica	2
	Limecola balthica	32

Table 32 Benthic ID results for Anderson Creek Mars (AC) and Seacaucus High School Marsh (SHS)

Site	Species	N
EPA-009 AC59	*Hobsonia florida*	920
	Alitta succinea	864
	Capitella sp.	4
	Cyathura polita	20
	Leptocheirus plumulosus	156
	Littoridinops tenuipes	12
	Chironomidae	8

Site	Species	N
EPA-010 AC52	*Hobsonia florida*	28
	Alitta succinea	28
	Capitella sp.	128
	Chironomidae	52

Site	Species	N
EPA-011 AC03	*Hobsonia florida*	116
	Alitta succinea	140
	Capitella sp.	4
	Capitellidae sp.	4
	Cyathura polita	192
	Gammarus mucronatus	8
	Rhithropanopeus harrisii	4
	Limecola balthica	8

Site	Species	N
EPA-012 AC04	*Hobsonia florida*	96
	Alitta succinea	288
	Capitella sp.	24
	Capitellidae sp.	12
	Streblospio benedicti	4
	Cyathura polita	52

Site	Species	N
EPA-013 AC10	*Hobsonia florida*	1460
	Alitta succinea	756
	Capitella sp.	28
	Cyathura polita	20
	Leptocheirus plumulosus	228
	Chironomidae	344
	Diptera	4

Site	Species	N
EPA-015 SH504	*Hobsonia florida*	136
	Alitta succinea	96
	Capitella sp.	28
	Leptocheirus plumulosus	4
	Littoridinops tenuipes	28
	Chironomidae	52

Site	Species	N
EPA-017 SH517	*Hobsonia florida*	2084
	Spio setosa	8
	Alitta succinea	64
	Capitella sp.	8
	Edotia triloba	4
	Leptocheirus plumulosus	64
	Corophium sp.	4
	Rhithropanopeus harrisii	8
	Amphibalanus eburneus	16
	Modiolus modiolus	32
	Littoridinops tenuipes	28
	Chironomidae	172

Site	Species	N
EPA-018 SH508	*Hobsonia florida*	236
	Spio setosa	96
	Alitta succinea	108
	Cyathura polita	16
	Edotia triloba	16
	Leptocheirus plumulosus	16
	Crassicornis bonelli	16
	Littoridinops tenuipes	8
	Capitellidae sp.	4

Site	Species	N
EPA-021 SH503	*Hobsonia florida*	1128
	Alitta succinea	372
	Spio setosa	20
	Streblospio benedicti	4
	Capitellid sp.	4
	Leptocheirus plumulosus	36
	Crassicornis bonelli	4
	Littoridinops tenuipes	24
	Modiolus modiolus	8
	Chironomidae	100
	Diptera	8
	Tabanidae	4

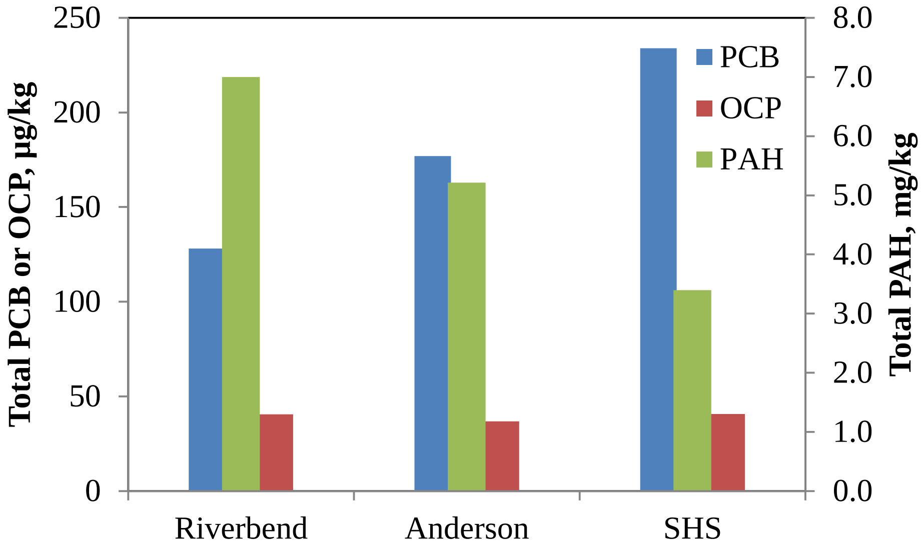


Figure 27The average total PCB, OCP, and PAH concentrations in sediment samples.

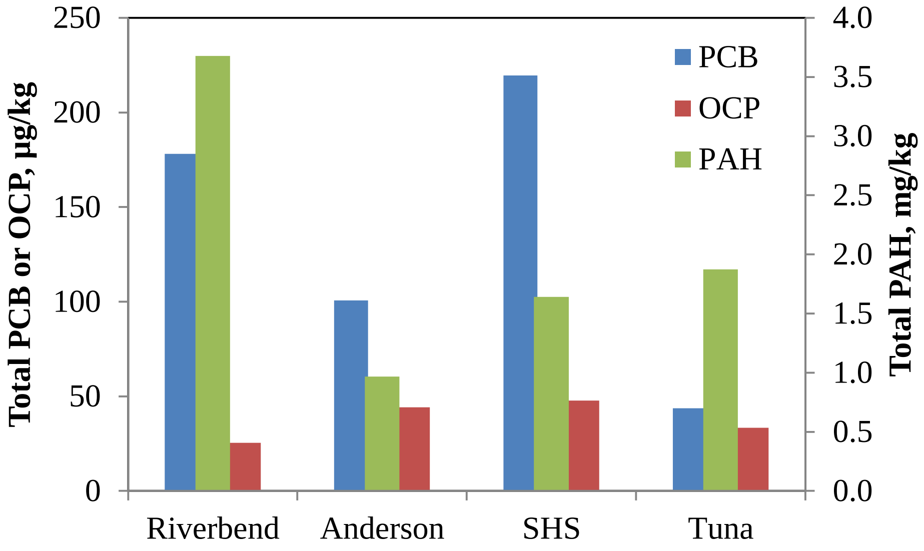


Figure 28) The average total PCB, OCP, and PAH concentrations in benthic and tuna samples.

Table 33: Summary statistics for tissue sample variables

	Min.	1^{st} Qu.	Median	Mean	3^{rd} Qu.	Max.
Ag	0.01	0.235	0.325	0.425	0.505	1.46
Al	700	2032	2890	3064	3604	9641
As	4.83	6.81	7.55	8.794	11.1	14.47
Ba	22.62	38.89	49.13	49.24	62.91	66.55
Be	0.03	0.095	0.18	0.168	0.21	0.42
Cd	0.25	0.47	0.63	1.582	1.125	10.92
Co	0.85	1.7	2.23	2.131	2.445	3.92
Cr	7.73	18.19	33.26	34.21	45.86	70.13
Cu	28.97	38.28	45.22	47.9	59.24	70.12
Fe	2317	5113	6671	6570	7592	13420
Hg	0.5	0.875	1.11	1.117	1.34	1.94
Mn	79	102	139	137.1	163	225
Mo	0.45	0.91	1.01	1.175	1.405	2.24
Ni	2.96	5.925	6.84	7.619	8.955	16.29
Pb	10.03	22.59	29.66	38.31	36.86	155.6
Se	1.31	1.535	2.01	2.163	2.57	3.64
Ti	25.42	62.35	87.95	91.63	107.6	266.7
Th	0.19	0.54	0.96	0.9353	1.085	2.61
V	2.65	5.67	7.52	8.601	10.56	22.67
U	0.16	0.265	0.47	0.4787	0.585	0.92
Zn	85.04	111.3	133.4	139.3	160.6	214.8
PCB	36.25	42.68	153.4	169	269.4	380.6
OCP	16.66	25.19	32.27	38.75	43.42	90.51
PAH	0.28	0.79	2.41	2.413	3.545	5.46
Diversity Index	0.74	1.05	1.24	1.259	1.475	1.81

Table 34: Summary statistics for sediment sample variables

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Ag	0.55	1.085	2.04	1.778	2.295	2.72
Al	7080	10700	11140	10800	11890	12540
As	7.19	11.78	12.47	16.34	15.04	46.45
Ba	47.23	74.81	84.6	85.38	97.94	145.5
Be	0.49	0.58	0.73	0.7267	0.885	0.95
Cd	0.66	1.015	1.49	1.459	1.82	2.73
Co	3.22	8.235	9.43	8.875	9.78	12.55
Cr	72.41	109.4	188.7	201.9	240.7	550.4
Cu	54.82	86.22	114.8	105.3	121.5	148.7
Fe	16990	27820	28450	27970	30510	34420
Hg	2.59	3.75	5.58	5.925	7.175	10.59
Mn	194	331.5	437	398.3	452.5	554
Mo	0.79	0.985	1.46	1.885	2.07	6.23
Ni	18.69	29.8	34.27	33.69	35.39	63.2
Pb	54.55	97.44	113.4	124.5	145	249.2
Sb	-0.05	-0.05	-0.04	-0.033	-0.03	0.02
Se	1.65	3.32	4.13	4.016	4.82	5.36
Ti	119.7	143.6	179.9	170.2	195.8	213
Th	3.19	4.005	4.29	4.221	4.545	4.95
V	18.57	28.12	31.7	32.41	35.94	61.47
U	0.94	1.245	1.71	1.613	1.885	2.75
Zn	141.6	194.7	238.5	233.8	264.7	371.5
PCB	95	130.8	147.8	176.8	197.1	478.7
OCP	22.23	30.96	37.34	39.73	45.27	69.79
PAH	0.42	2.825	3.67	4.885	5.825	14.66
PercentSand	5.6	8.5	12.1	16.87	17.05	54.3
PercentSilt	23.8	56.7	60.2	57.29	64.25	68.6
PercentClay	18.8	24.7	26.7	25.83	27.15	33.7
Salinity.ppt	9	10.92	12.11	12.72	14.68	16.9
pH	6.71	7.465	7.67	8.007	7.86	14
Dissolved.Oxygen.ppm	2.23	3.65	4.1	4.131	4.735	5.7
PercentOrganic	6.21	11	11.4	12.31	13.45	17.6

Table 35: Correlation coefficients of tissue variables

	Ag	Al	As	Ba	Be	Cd	Co	Cr	Cu	Fe	Hg	Mn
Al	-0.02											
As	0.22	0.12										
Ba	0.21	0.40	-0.20									
Be	0.13	**0.94**	0.26	0.42								
Cd	0.25	-0.11	-0.12	0.39	-0.16							
Co	0.17	**0.89**	0.44	0.34	**0.93**	-0.17						
Cr	0.01	0.78	0.22	0.18	**0.87**	-0.21	**0.82**					
Cu	0.68	0.45	0.48	**0.08**	0.47	0.20	0.51	0.31				
Fe	0.15	**0.92**	0.26	0.53	**0.93**	0.02	**0.95**	0.75	0.44			
Hg	0.08	**0.85**	0.20	0.40	**0.92**	-0.25	**0.83**	**0.90**	0.33	**0.81**		
Mn	0.08	-0.02	-0.49	0.49	-0.09	0.25	0.00	-0.23	-0.24	0.13	-0.18	
Mo	0.15	0.63	0.36	-0.13	0.70	-0.24	0.78	**0.83**	0.35	0.68	0.65	-0.22
Ni	-0.09	**0.87**	0.05	0.14	**0.83**	-0.14	0.78	0.78	0.33	0.77	0.78	0.02
Pb	0.24	0.14	-0.05	0.42	0.08	**0.96**	0.05	0.03	0.35	0.23	-0.02	0.16
Se	0.68	-0.11	0.73	0.04	0.09	0.07	0.28	-0.04	0.49	0.19	-0.02	-0.05
Ti	-0.02	**1.00**	0.13	0.38	**0.95**	-0.11	**0.90**	**0.82**	0.43	**0.92**	**0.87**	-0.03
Th	0.01	**0.98**	0.18	0.42	**0.97**	-0.16	**0.94**	**0.82**	0.41	**0.96**	**0.87**	0.03
V	0.05	**0.95**	0.16	0.28	**0.93**	-0.08	**0.88**	**0.90**	0.48	**0.88**	**0.89**	-0.16
U	0.22	0.68	0.61	0.31	**0.83**	-0.21	**0.89**	0.72	0.45	**0.81**	0.77	-0.15
Zn	0.41	0.31	0.57	0.06	0.37	0.44	0.38	0.38	0.78	0.34	0.33	-0.48
PCB	-0.33	0.29	-0.01	0.24	0.21	-0.10	0.26	0.01	-0.05	0.31	0.01	0.30
OCP	-0.07	0.19	-0.19	0.04	0.26	-0.14	0.24	0.54	-0.13	0.21	0.28	0.04
PAH	-0.19	0.43	0.07	0.11	0.21	0.20	0.32	0.01	0.29	0.39	0.04	0.14

	Mo	Ni	Pb	Se	Ti	Th	V	U	Zn	PCB	OCP
Ni	0.71										
Pb	-0.03	0.10									
Se	0.20	-0.22	0.05								
Ti	0.67	**0.88**	0.14	-0.11							
Th	0.68	**0.86**	0.08	-0.01	**0.99**						
V	0.77	**0.88**	0.18	-0.09	**0.97**	0.94					
U	0.70	0.61	-0.02	0.46	0.69	0.76	0.70				
Zn	0.33	0.24	0.60	0.41	0.32	0.27	0.44	0.43			
PCB	0.03	0.17	-0.02	-0.02	0.26	0.30	0.13	0.21	-0.15		
OCP	0.51	0.19	-0.04	-0.10	0.22	0.22	0.33	0.15	-0.01	0.31	
PAH	0.15	0.38	0.34	-0.06	0.40	0.36	0.32	0.23	0.24	0.61	-0.10

Table 36: Correlation coefficients of sediment variables

	Ag	Al	As	Ba	Be	Cd	Co	Cr	Cu	Fe	Hg	Mn
Al	-0.02											
As	0.22	0.12										
Ba	0.21	0.40	-0.20									
Be	0.13	**0.94**	0.26	0.42								
Cd	0.25	-0.11	-0.12	0.39	-0.16							
Co	0.17	**0.89**	0.44	0.34	**0.93**	-0.17						
Cr	0.01	0.78	0.22	0.18	**0.87**	-0.21	**0.82**					
Cu	0.68	0.45	0.48	**0.08**	0.47	0.20	0.51	0.31				
Fe	0.15	**0.92**	0.26	0.53	**0.93**	0.02	**0.95**	0.75	0.44			
Hg	0.08	**0.85**	0.20	0.40	**0.92**	-0.25	**0.83**	**0.90**	0.33	**0.81**		
Mn	0.08	-0.02	-0.49	0.49	-0.09	0.25	0.00	-0.23	-0.24	0.13	-0.18	
Mo	0.15	0.63	0.36	-0.13	0.70	-0.24	0.78	**0.83**	0.35	0.68	0.65	-0.22
Ni	-0.09	**0.87**	0.05	0.14	**0.83**	-0.14	0.78	0.78	0.33	0.77	0.78	0.02
Pb	0.24	0.14	-0.05	0.42	0.08	**0.96**	0.05	0.03	0.35	0.23	-0.02	0.16
Se	0.68	-0.11	0.73	0.04	0.09	0.07	0.28	-0.04	0.49	0.19	-0.02	-0.05
Ti	-0.02	**1.00**	0.13	0.38	**0.95**	-0.11	**0.90**	**0.82**	0.43	**0.92**	**0.87**	-0.03
Th	0.01	**0.98**	0.18	0.42	**0.97**	-0.16	**0.94**	**0.82**	0.41	**0.96**	**0.87**	0.03
V	0.05	**0.95**	0.16	0.28	**0.93**	-0.08	**0.88**	**0.90**	0.48	**0.88**	**0.89**	-0.16
U	0.22	0.68	0.61	0.31	**0.83**	-0.21	**0.89**	0.72	0.45	**0.81**	0.77	-0.15
Zn	0.41	0.31	0.57	0.06	0.37	0.44	0.38	0.38	0.78	0.34	0.33	-0.48
PCB	-0.33	0.29	-0.01	0.24	0.21	-0.10	0.26	0.01	-0.05	0.31	0.01	0.30
OCP	-0.07	0.19	-0.19	0.04	0.26	-0.14	0.24	0.54	-0.13	0.21	0.28	0.04
PAH	-0.19	0.43	0.07	0.11	0.21	0.20	0.32	0.01	0.29	0.39	0.04	0.14

	Mo	Ni	Pb	Se	Ti	Th	V	U	Zn	PCB	OCP
Ni	0.71										
Pb	-0.03	0.10									
Se	0.20	-0.22	0.05								
Ti	0.67	**0.88**	0.14	-0.11							
Th	0.68	**0.86**	0.08	-0.01	**0.99**						
V	0.77	**0.88**	0.18	-0.09	**0.97**	0.94					
U	0.70	0.61	-0.02	0.46	0.69	0.76	0.70				
Zn	0.33	0.24	0.60	0.41	0.32	0.27	0.44	0.43			
PCB	0.03	0.17	-0.02	-0.02	0.26	0.30	0.13	0.21	-0.15		
OCP	0.51	0.19	-0.04	-0.10	0.22	0.22	0.33	0.15	-0.01	0.31	
PAH	0.15	0.38	0.34	-0.06	0.40	0.36	0.32	0.23	0.24	0.61	-0.10

Table 37: Table showing the correlations (R value) between diversity index and tissue contaminants, between diversity index and sediment contaminants, and between sediment and tissue contaminants.

	Diversity	Diversity	Sediment contaminant
with	Tissue contaminan	Sediment contaminant	Tissue contaminant
Ag	0.39	-0.56	-0.24
Al	-0.41	-0.41	0.4
As	-0.33	-0.05	-0.17
Ba	-0.05	-0.22	0.51
Be	-0.47	-0.29	0.5
Cd	0.26	-0.46	-0.17
Co	-0.49	0.02	-0.3
Cr	-0.5	-0.18	0.54
Cu	0.15	-0.44	-0.12
Fe	-0.44	-0.29	0.32
Hg	-0.47	-0.34	0.59
Mn	0.11	0.16	0.33
Mo	-0.34	-0.19	0.63
Ni	-0.34	-0.3	0.45
Pb	0.21	-0.22	-0.01
Sb	NA	-0.1	NA
Se	-0.0014	-0.4	-0.38
Ti	-0.44	-0.03	0.37
Th	-0.49	-0.25	0.43
V	-0.39	-0.24	0.53
U	-0.4	-0.23	0.37
Zn	0.03	-0.43	0.12
totalPCB	0.03	0.03	0.38
totalOCP	-0.05	0.3	0.15
totalPAH	0.22	0.57	-0.12

Table 38: p values of ANOVA and non-parametric Kruskal tests for differences in the variables between sites.

	Tissue		
	Unequal var	Equal var	Kruskal
Ag	0.76	0.57	0.74
Al	0.92	0.99	0.21
As	0.38	0.3	0.29
Ba	0.14	0.18	0.11
Be	0.68	0.63	0.14
Cd	0.63	0.55	0.88
Co	0.77	0.66	0.29
Cr	0.37	0.2	0.14
Cu	0.52	0.47	0.33
Fe	0.73	0.76	0.26
Hg	0.08	0.2	0.09
Mn*	0.003	0.001	0.005
Mo	0.51	0.4	0.26
Ni	0.64	0.81	0.47
Pb	0.75	0.57	0.76
Sb	-	-	-
Se	0.5	0.55	0.54
Ti	0.83	0.96	0.21
Th	0.95	0.9	0.25
V	0.47	0.72	0.23
U	0.27	0.15	0.14
Zn	0.07	0.09	0.07
PCB	0.41	0.36	0.45
OCP	0.13	0.24	0.13
PAH	0.11	0.13	0.08
Diversity	0.65	0.61	0.73

	Sediment		
	Unequal var	Equal var	Kruskal
Ag	0.04	0.03	0.11
Al	0.18	0.28	0.16
As	0.18	0.04	0.06
Ba	0.15	0.2	0.08
Be	0.31	0.28	0.25
Cd	0.35	0.26	0.2
Co	0.19	0.15	0.22
Cr*	0.02	0.01	0.01
Cu	0.08	0.08	0.15
Fe	0.22	0.37	0.36
Hg*	0.03	0.01	0.03
Mn	0.38	0.44	0.48
Mo	0.26	0.14	0.07
Ni	0.32	0.18	0.18
Pb	0.09	0.03	0.05
Sb*	-	0.01	0
Se	0.02	0.15	0.07
Ti*	0	0	0.02
Th	0.28	0.21	0.3
V*	0.11	0.03	0.01
U*	0.03	0.01	0.02
Zn	0.31	0.24	0.26
PCB	0.15	0.19	0.16
OCP	0.93	0.95	0.99
PAH	0.32	0.24	0.2
% Sand	0.62	0.65	0.81
% Silt	0.38	0.34	0.23
% Clay	0.51	0.39	0.21
Salinity*	0.02	0.005	0.03
pH	0.18	0.29	0.08
Dissolved O2	0.72	0.73	0.69
% Organic	0.16	0.09	0.23

*note that for Sb due to the limited recovery, negative values were emitted from the analysis.

Table 39: Coefficient estimates and standard errors for regression of sediment contaminant concentration on water and soil variables, and site.

Log	% Organic	% Silt	% Sand	% Clay	pH	Salinity	O2
Ag	.07 (.03)	-	-.02 (.01)	-	-	-	-
Al	-	-	-.010 (.002)	-	-	-	-
As	.14 (.02)	-	-	-	-	-	-
Ba	.05 (.01)	-	-	.04 (.01)	-.04 (.02)	-.07 (.01)	-
Be	-	-	-	-	-	-	-.15 (,05)
Cd	-	.022 (.008)	-	-	-	-	-
Cr	.15 (.02)	-	-.023 (.006)	-.13 (.02)	-.09 (.04)	-	-
Cu	.06 (.01)	-	-.011 (.003)	-	-	-	-
Fe	.03 (.01)	-	-.007 (.003)	-	-	-	-
Hg	.12 (.02)	-	-	-	-	-	-
Mn	-	-	-	-	-	-	-
Mo	.14 (.04)	-	-	-	-	-	-
Ni	.06 (.02)	-	-	-	-	-	-
Pb	.11 (.01)	-	-	.03 (.01)	-	-	-
Sb*	.0051 (.0013)	-	-	-	-	-	-
Se	.06 (.02)	-	-	-	-	-	-
Ti	.04 (.01)	-	-	-	-	-	-
Th	-	-	-.007 (.002)	-	-	-	-
V	.08 (.02)	-	-	-	-	-	-
U	.08 (.02)	-	-	-	-	-	-
Zn	-	.016 (.005)	-	-	-	-	-
PCB	-	-	-	-	-	-	-
OCP	-	-	-	-	-	-	-
PAH	-	-.04 (.02)	-	-	-	-	-

*note that for Sb the original values were used as some of the test results were negative.

Table 40: Coefficient estimates and standard errors for regression of sediment contaminant concentration on water and soil variables, after inclusion of the site variable. Original values used for Sb, since some of them are negative.

Log	% Organic	% Silt	% Sand	% Clay	pH	Salinity	O2	Anderson	Secaucus
Ag	.07 (.02)	-	-.02 (.004)	-	-	-	-	.34 (.14)	.47 (.12)
Hg	.10 (.02)	-	-	-	-	-	-	.38 (.11)	.39 (.09)
Pb	.08 (.01)	-	-	.04 (.01)	-	-	-	.29 (.09)	.09 (.08)
Sb*	.0037 (.0014)	-	-	-	-	-	-	.008 (.01)	-.014 (.008)
PCB	-	-	-	-	-	-	-	.26 (.23)	.50 (.23)

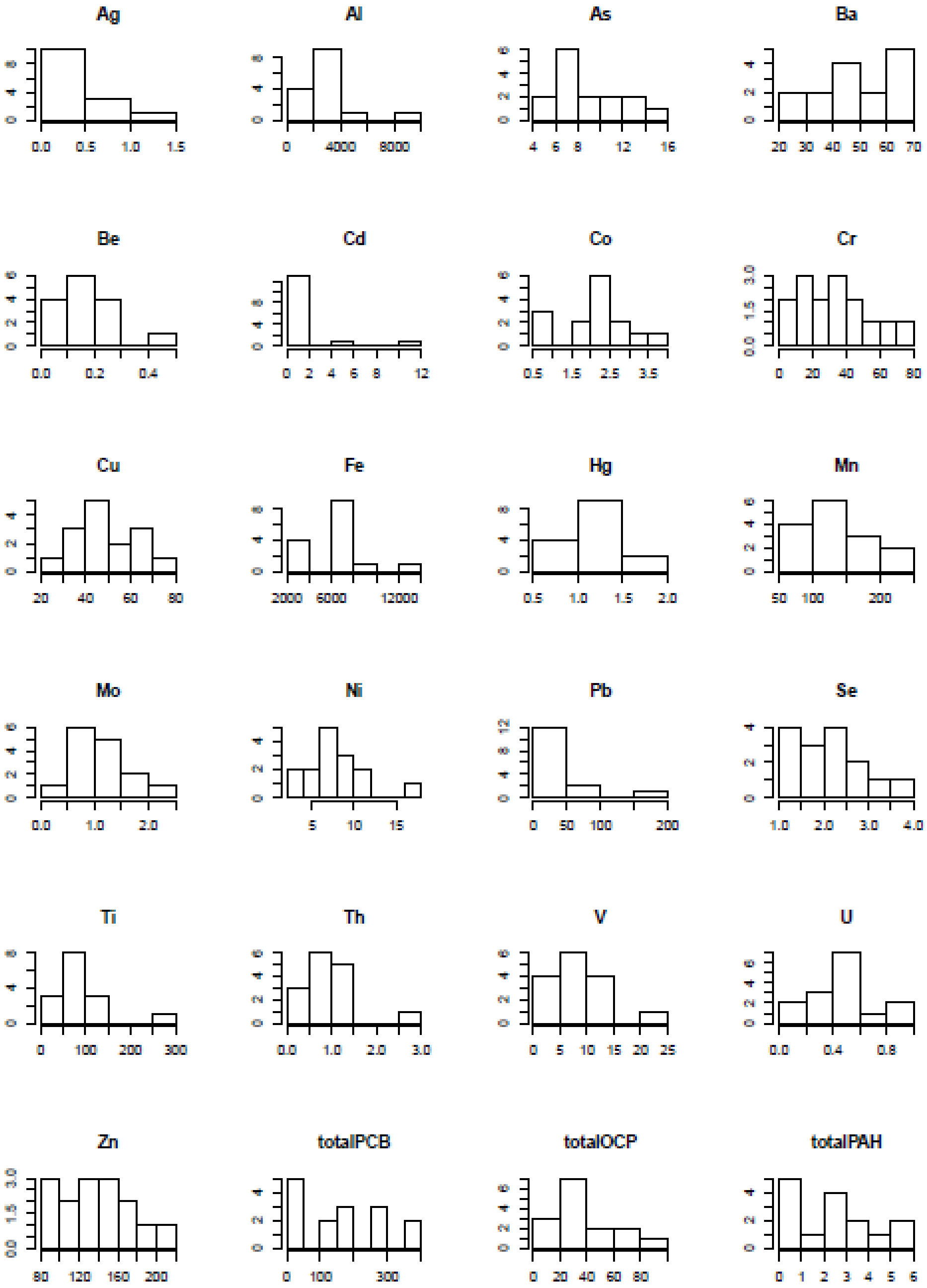


Figure 29: Histograms of contaminant concentrations (μg/L) in tissue samples. Note that the Y axses represent the corresponding metal concentrations

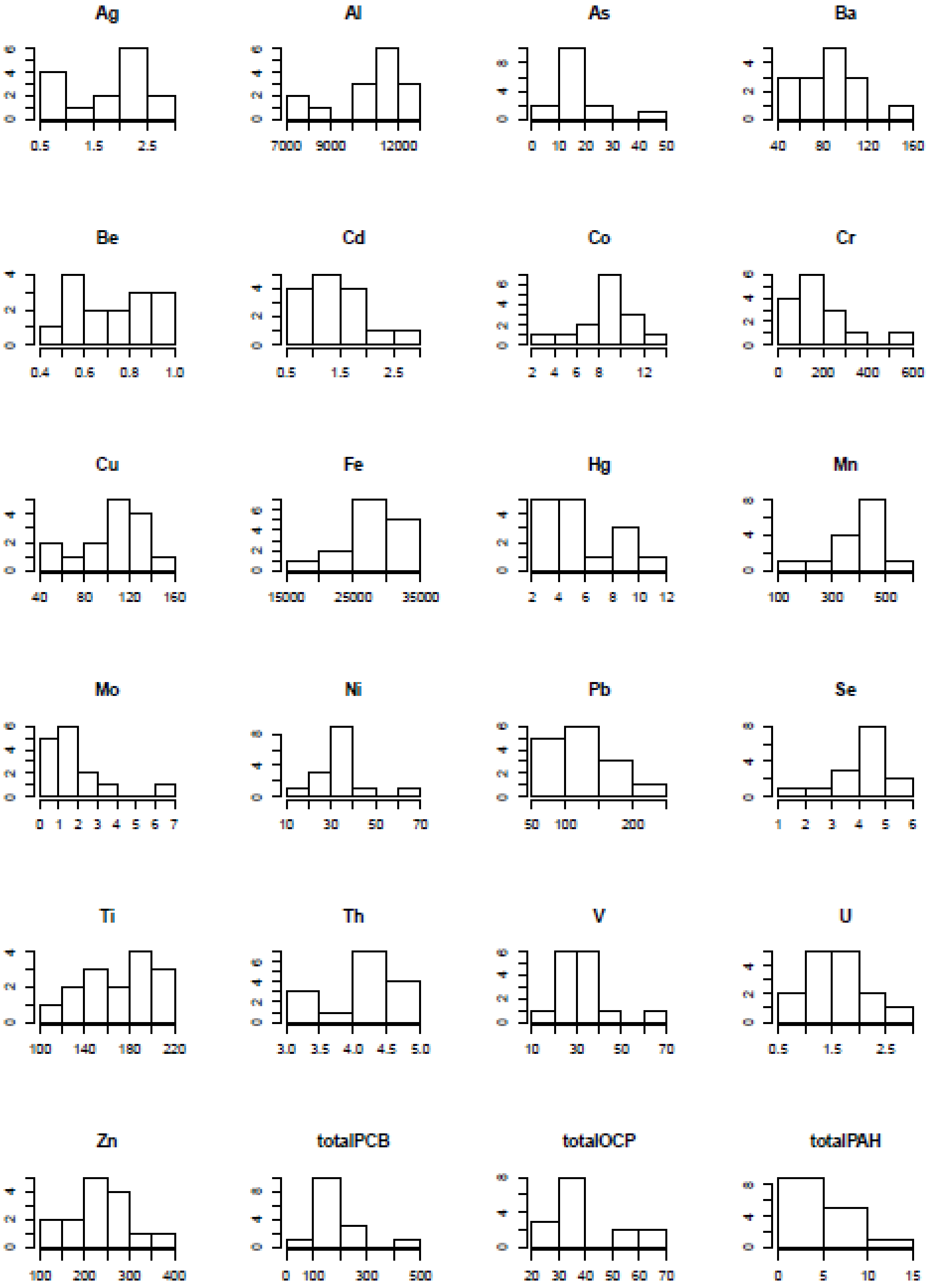


Figure 30: Histograms of contaminant concentrations in sediment samples.

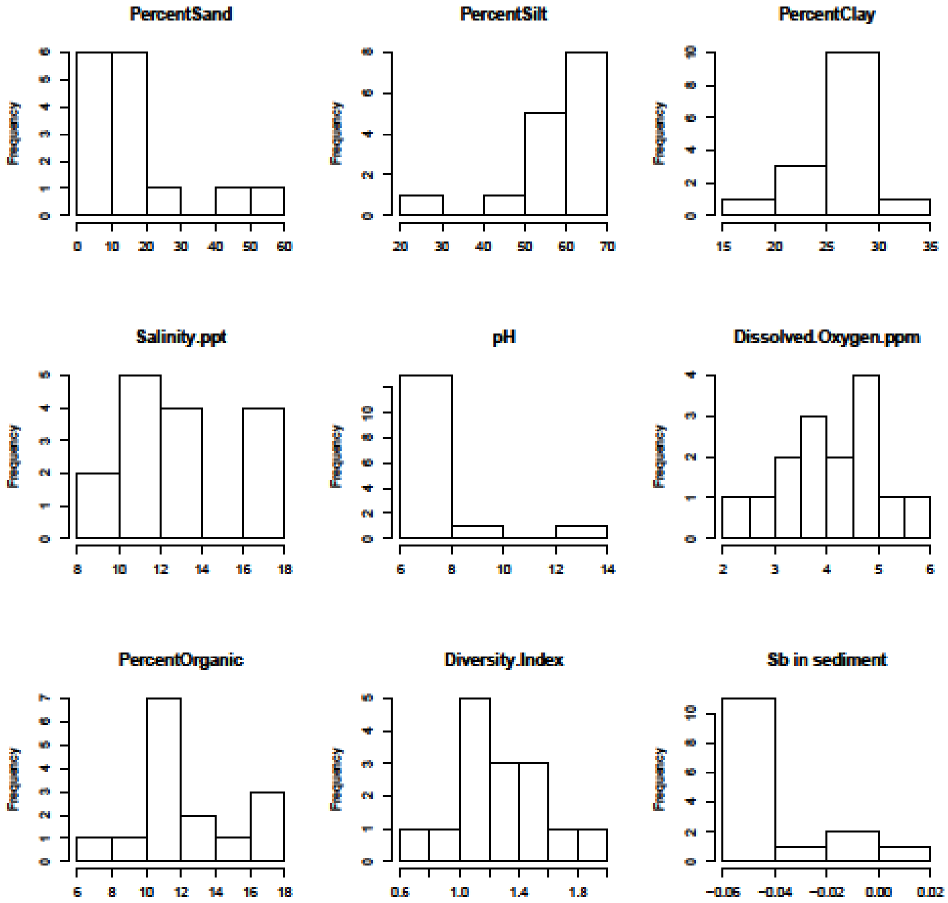


Figure 31: Histograms of soil and water variables, diversity index and Sb in sediment. Note that Sb data was not available in tissue samples. Sediment Sb data is shown here rather than in Figure 2, so that the histograms in Figures 1 and 2 can be more easily compared.

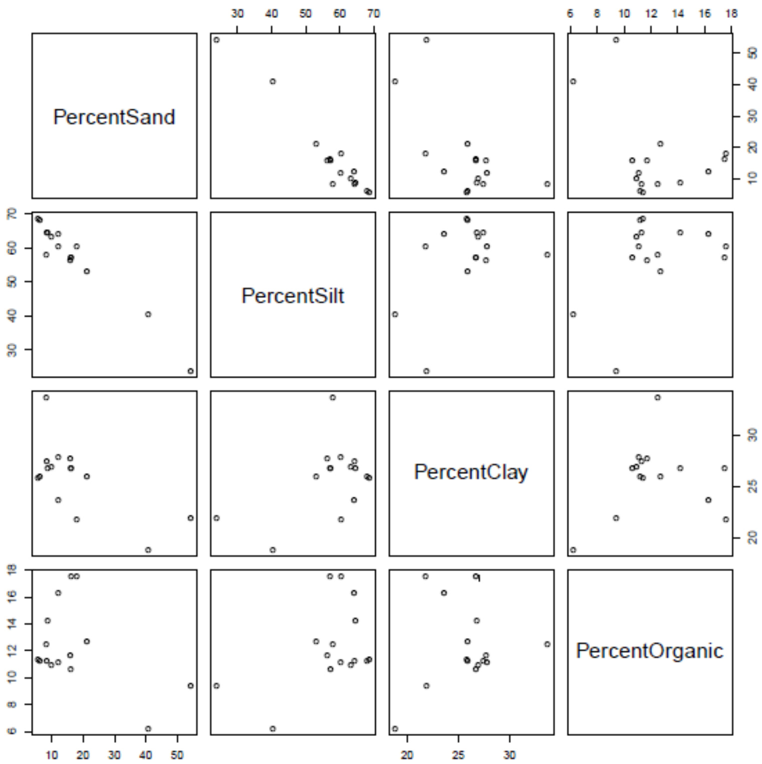


Figure 32: Pairwise scatter plots of soil variables.

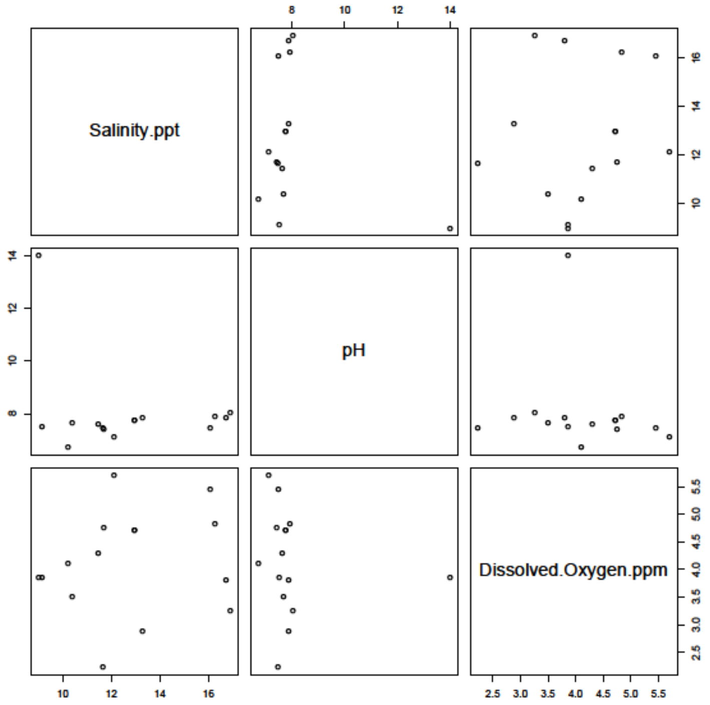


Figure 33: Pairwise scatter plots of water variables.

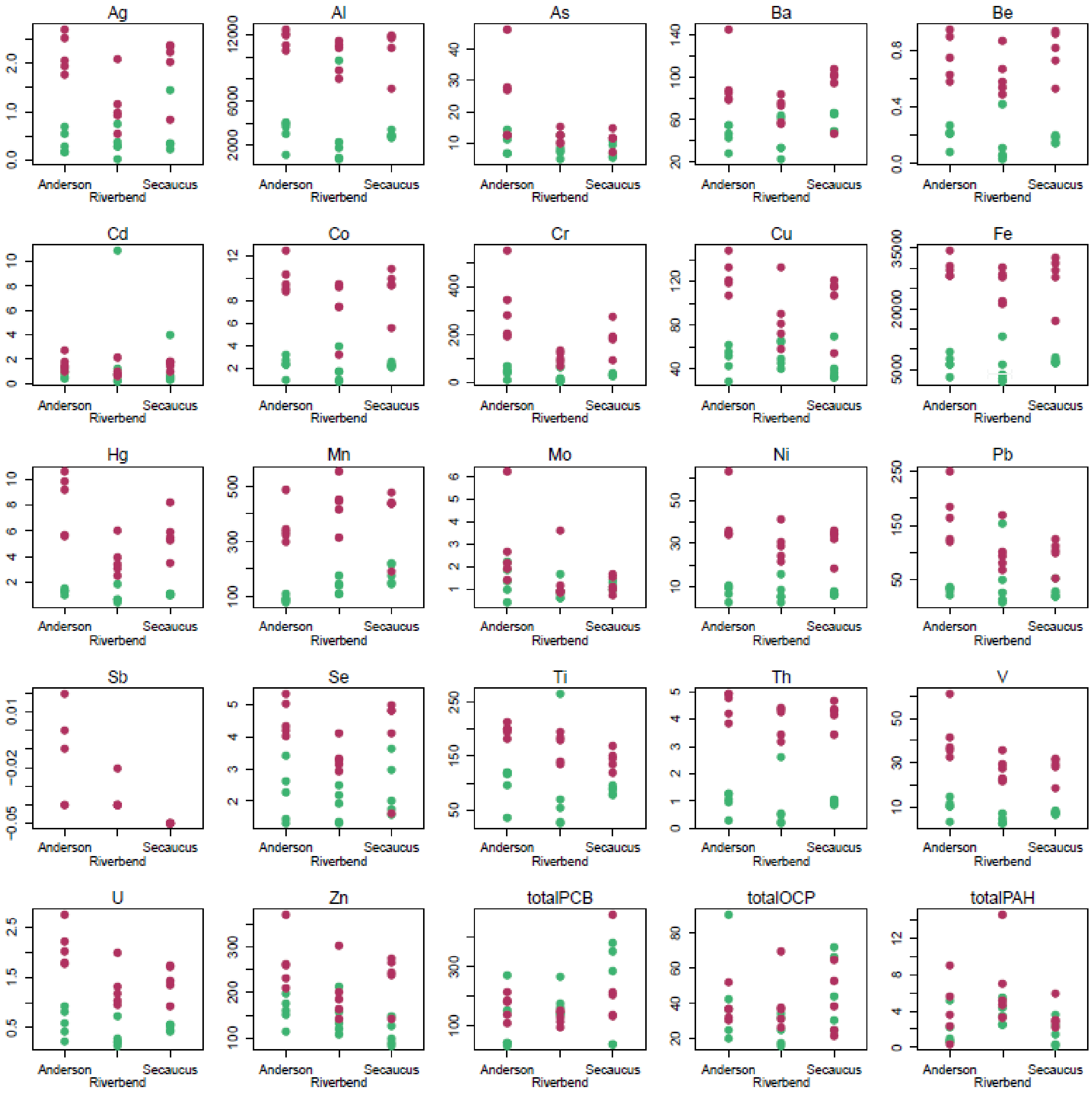


Figure 34: Contaminant concentrations by site, from tissue (green) and sediment (maroon) samples.

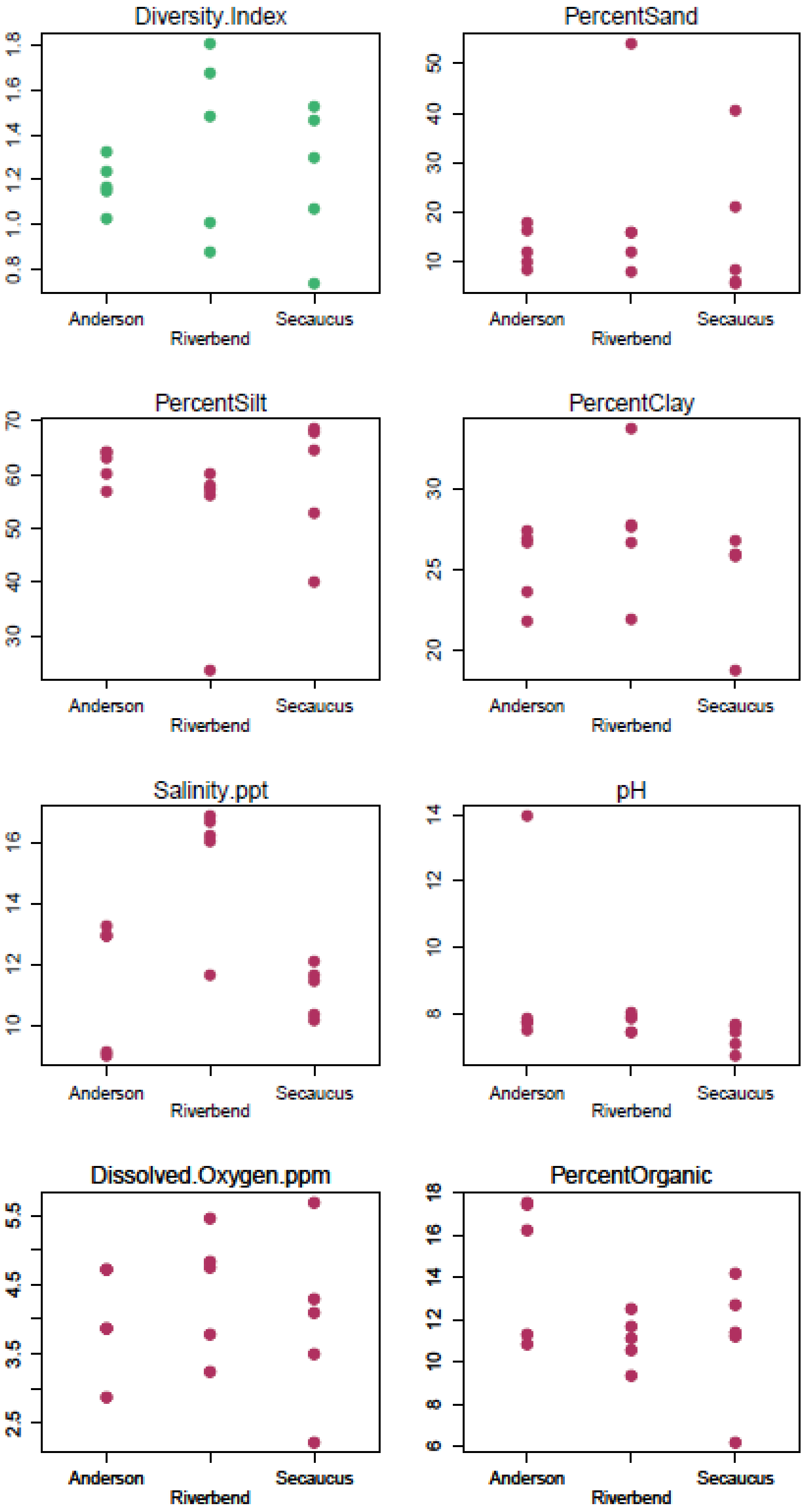


Figure 35: Soil, water and diversity variables by site, from tissue (green) and sediment(maroon) samples.

Table 41 Summary of Component II benthic ID results

Location	Total number of organisms collected	Total number of species collected
Riverbend	2628	30
Anderson	3172	13
SHS	5448	29

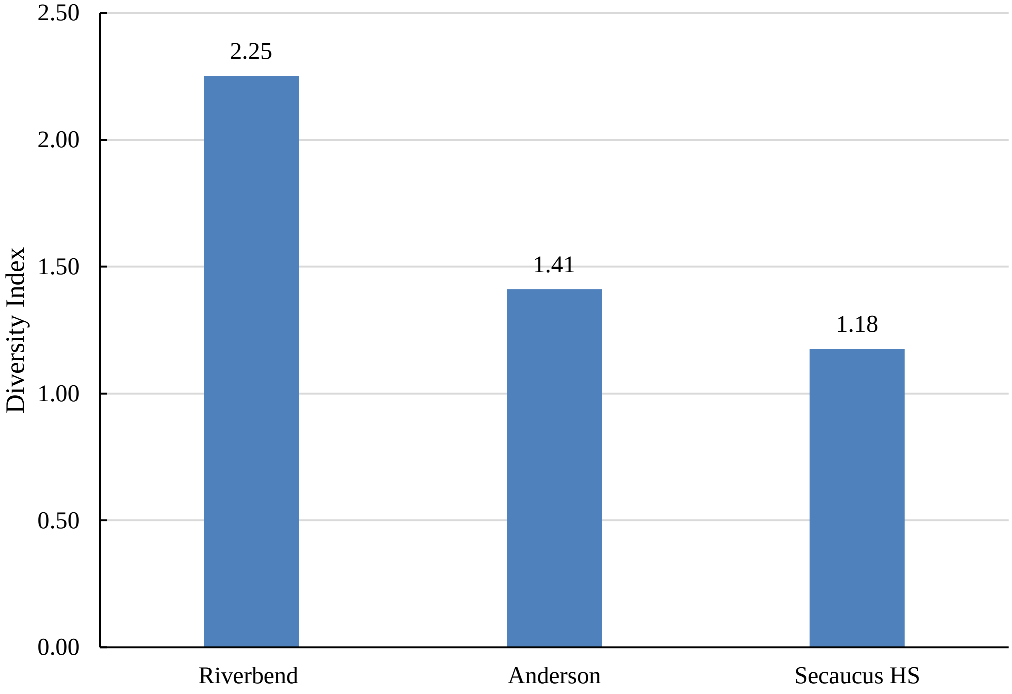


Figure 36 Diversity index of benthic organisms at different location.

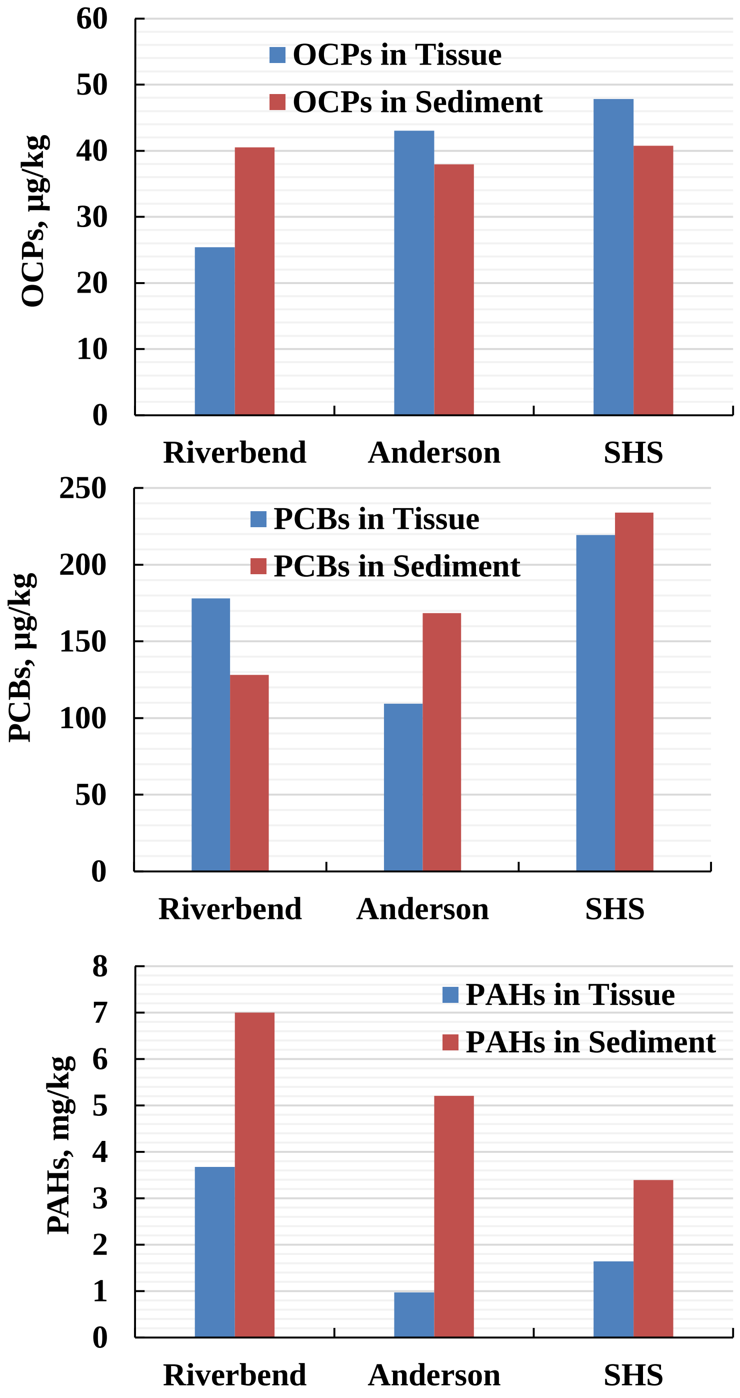


Figure 37 PCBs and OCPs in benthic tissue and in sediment at different sites.