Assessment of Ecological Condition and Stressor Impacts within Great Lakes Rivers and Harbors: Milwaukee Estuary, Wisconsin

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Executive Summary

The Great Lakes, the largest surface freshwater resource in the world, has long been recognized for its valuable natural resources and services vital to the wellbeing of our nation. In 2012 a probabilistic sampling component was included under an expanded version of NOAA's National Status and Trends/Mussel Watch Program in the Great Lakes as a basis for assessing the status of ecological condition and potential stressor impacts in targeted river and harbor systems of this important region. The probabilistic sampling is intended to provide managers and other stakeholders with information on the spatial extent of healthy versus unhealthy condition within these areas and the ability to quantify potential changes in their quality over time. Accordingly, in August 2012 a survey was conducted within a Great Lake's sub-system, the Milwaukee Estuary in Wisconsin, which had been identified as an Area of Concern (AOC) relative to various Beneficial Use Impairment (BUI) designations. The present report presents results of that Milwaukee Estuary survey.

Sampling was conducted at 18 stations selected randomly among 11 different sampling strata within the outer harbor and adjacent Milwaukee, Menomonee, and Kinnickinnic Rivers. At each station, samples were obtained for characterization of the following core indicators: (1) community structure and composition of benthic macroinfauna (collected with a 0.04-m^2 grab, sieved on 0.5-mm screen); (2) concentration of chemical contaminants in sediments (metals, pesticides, PCBs, PAHs, PBDEs); (3) multiple measures of sediment toxicity (Microtox organic extract assay, Microtox solid-phase assay, amphipod survival assay); and (4) general habitat conditions (water depth, dissolved oxygen, conductivity, temperature, pH, turbidity, % silt-clay versus sand content of sediment, organic-carbon content of sediment). Several human-dimension indicators were recorded as well including presence of surface trash, visual oil sheens in sediments or water, or noxious/oily sediment odors. The synoptic sampling of sediment contamination, sediment toxicity, and condition of ambient benthic fauna provided a Sediment Quality Triad (SQT) approach to assessing potential pollution-induced degradation of the benthos throughout the various stations.

Water depths averaged 4.8 m and ranged from 0.8 – 8.8 m. Measures of bottom-water conductivity, temperature, pH, turbidity, and dissolved oxygen (DO) averaged 471 µS/cm, 22.2 ºC, 8.3 pH units, 8.1 NTU, and 7.1 mg/L respectively across these stations and ranged from 228 - 821 µS/cm, 14.2 – 26.2 ºC, 7.6-8.9 pH units, 1.6 – 22.2 NTU, and 2.1 – 10.7 mg/L respectively. None of the survey area had bottom-water DO levels in the hypoxic range, below 2 mg/L based on the EPA cutpoints, although three stations (M14, M15, M16 representing 18.5% of the survey area) had DO in the moderate range between 2 - 5 mg/L.

The silt-clay content of sediments ranged from 4.3% - 97.0% and averaged 77.6%, with approximately 50% of the survey area composed of muds (>80% silt-clay) while the remainder was composed of sands to intermediate muddy sands. Total organic carbon (TOC) content of sediments averaged 34.0 mg/g and ranged from 8.6 – 74.7 mg/g. Thirty percent of the survey area had relatively low TOC levels of < 20 mg/g, 58% had moderate levels of 20 – 50 mg/g, and the remaining 12% of the area had high levels in excess of the upper threshold associated with a high risk of adverse effects on benthic fauna.

Mean probable-effect-concentration quotients (mean PEC-Qs), used here as an indicator of overall sediment contamination from mixtures of individual chemicals present in a sample, averaged 1.027 across the 18 Milwaukee Estuary stations and ranged from 0.100 (Harbor) to 3.029 (Kinnickinnic River). There was a general trend of lower concentrations of contaminants in the more open-water harbor stratum. One or more individual contaminants exceeded their corresponding PEC values at 15 of the 18 Milwaukee stations. Lower threshold-effect concentrations (TECs) were exceeded at all stations. PAHs and PCBs were the dominant contaminants compared to metals at most stations. Based on the present sampling, an estimated 58% of the survey area contained sediments with high to very high levels of chemical contaminants (mean PEC-Qs > 0.5).

By combining results of the three sediment bioassays into a single toxicity decision, eight of the 18 stations were found to have low to moderate levels of toxicity. Spatially these stations represented 40% of the survey area and tended to be in the more open-water areas (harbor and mouths of tributaries). The remaining 10 stations with high to very high sediment toxicity represented the majority (60 %) of the overall Milwaukee survey area.

A total of 82 benthic taxa were identified to the lowest possible taxonomic level from the 18 Milwaukee stations, of which 48 were identified to the species level. Oligochaeta was the dominant taxonomic group, both by raw abundance (86%) and number of taxa (56%). Insecta was the second-most dominant group, both by raw abundance (9%) and number of taxa (28%). A total of 53,001 individual specimens was collected across the 18 stations (54, 0.04-m^2, grab samples) that were sampled. Densities ranged from 42 to 83,608 m^{-2} and averaged 24,538 m^{-2}. One replicate at station M07 was devoid of benthic fauna while the other two replicates had a total of only 5 individuals. Such density numbers reflect the variety of responses that benthic communities may exhibit in response to pollution, ranging from population irruptions of a few pollution-tolerant taxa to a void of all taxa. Species richness ranged from 1 to 17 taxa per grab and averaged 10 taxa per grab. Diversity values, expressed as H′, ranged from 0.33 to 2.78 per grab and averaged 1.95 per grab. Approximately 50% of the survey area had H′ > 2.07 per grab and 10% of the area had H′ > 2.65 per grab.

Health of resident benthic infaunal communities was assessed based on benthic condition using the species-level modified Hilsenhoff Benthic Index (HBI). HBI scores ranged from 8.5 to 9.9 and averaged 9.5, indicating moderately poor to very poor benthic condition across the 18 stations. Average HBI scores were highest in the Menomonee and Kinnickinnic Rivers and lowest in the Harbor. High HBI scores reflected the high densities of pollution-tolerant taxa relative to sensitive taxa.

Combined results of the sediment quality triad (SQT) provided additional evidence of impaired benthic condition and poor sediment quality throughout the Milwaukee survey area, although to lesser degrees in some areas than others. High HBI scores, > 6.5 indicative of moderately poor to very poor benthic condition, co-occurred with high to very high levels of sediment contamination or toxicity (orange or red codes for corresponding SQT leg) at all but one of the sampling sites (M03 in lower harbor). Hits (orange or red codes) in all three legs of the SQT occurred at seven of these stations, five of which were in the upper portions of the three river strata. The more open-water harbor stratum contained the only station (M02) without significant sediment toxicity in all three bioassays and the only three stations (M01, M03, and M07) without high to very high levels of sediment contamination. The harbor stratum also contained the only station (M03 in lower harbor) with a degraded benthos but without high to very high levels of both sediment contamination and toxicity.

1.0 Introduction

The Great Lakes, the largest freshwater ecosystem in the world, has long been recognized for its valuable natural resources and services vital to the well-being of our nation. The Great Lakes Water Quality Agreement between the United States of America and Canada reaffirmed in 2012 that the nearshore regions of the Great Lakes must be restored and protected to support human use and critical ecological functions (Great Lakes Water Quality Agreement - http://binational.net/2012/09/05/2012-glwqa-aqegl/). NOAA's National Status and Trends Mussel Watch Program (MWP) has been monitoring in the Great Lakes since 1992 with a specific focus on analyzing organic contaminants and trace metals in bivalves and sediment (https://coastalscience.noaa.gov/projects/detail?key=179, Kimbrough et al. 2014). MWP has established sites throughout the Great Lakes to provide biologically-relevant data to aid in the overall understanding of trends within the region as well sites targeted to specific Areas of Concern (AOC). MWP was expanded in 2012 with the addition of a multi-indicator probabilistic sampling component as a basis for assessing the status of ecological condition and potential stressor impacts throughout specific river and harbor systems of the Great Lakes Region. The probabilistic sampling is intended to provide managers and other stakeholders with information on the spatial extent of healthy versus unhealthy condition within these areas and the ability to quantify potential changes over time. Accordingly, in August 2012 a survey was conducted within a Great Lake's sub-system, the Milwaukee Estuary in Wisconsin, which had been identified as an Area of Concern (AOC) relative to various Beneficial Use Impairment (BUI) designations. The present report presents results of that Milwaukee Estuary survey.

The Milwaukee Estuary, located on Lake Michigan, was designated an AOC in 1987 relative to a series of Beneficial Use Impairments (BUIs). In 2008 the geographic boundaries of the Milwaukee AOC were expanded to include more upstream portions of the estuary's tributaries: the Milwaukee River, Menomonee River, and Kinnickinnic River. Contaminants of concern within the Milwaukee AOC include PCBs, PAHs, and heavy metals. BUIs identified for Milwaukee include restrictions on fish and wildlife consumption, eutrophication or undesirable algae, degradation of fish and wildlife populations, beach closings, fish tumors or other deformities, degradation of aesthetics, bird or animal deformities or reproduction problems, degradation of benthos, degradation of phytoplankton and zooplankton populations, restriction on dredging activities, and loss of fish and wildlife habitat. The Milwaukee Estuary currently has a Remedial Action Plan (RAP) in place (WDNR 2014).

Surveys of benthic fauna and other multiple indicators of ecological condition and stressor impacts — including basic habitat characteristics such as depth, conductivity, temperature, dissolved oxygen, pH, sediment grain size and organic content; turbidity levels in the water column; chemical contaminants in sediments and biota; and sediment toxicity — were conducted in these waters at a series of randomly selected stations using a probabilistic sampling design. Specific station locations were selected using a method called the Generalized Random-tessellation Stratified (GRTS) design (Stevens & Olsen 2004). This is a probabilistic survey design from which resulting data can be used to make unbiased statistical estimates of the spatial extent and magnitude of condition relative to various measured indicators and corresponding management thresholds. Sampling sites are dispersed over the area of interest to provide a spatially balanced sample design while still incorporating a true probability approach. The consistent and systematic sampling of the different biological and environmental variables across these sites provides an opportunity for learning more about the spatial patterns of these resources and the processes controlling their distributions. In addition, the synoptic sampling of sediment contamination, sediment toxicity, and condition of ambient benthic fauna provides a "weight-of-evidence" Sediment Quality Triad (SQT) approach to assessing potential pollution-induced degradation of the benthos across these sites (Long and Chapman 1985, Chapman 1990).

2.0 Methods

At each station, samples were obtained for characterization of the following core indicators: (1) community structure and composition of benthic macroinfauna (> 0.5 mm); (2) concentration of chemical contaminants in sediments (metals, pesticides, PCBs, PAHs, PBDEs); (3) multiple measures of sediment toxicity (Microtox organic extract assay, Microtox solid-phase assay, amphipod survival assay); and (4) general habitat conditions (water depth, dissolved oxygen, conductivity, temperature, pH, turbidity, % silt-clay versus sand content of sediment, organic-carbon content of sediment). Several human-dimension indicators were recorded as well including presence of surface trash, visual oil sheens in sediments or water, or noxious/oily sediment odors. The following sections describe methods used for the collection, processing, and analysis of each of these sample types, which were adopted from the protocols developed for EPA's National Coastal Assessment (USEPA 2001a, 2001b) and used previously in coastal systems around the country (Balthis et al. 2009, Balthis et al. 2013, Cooksey et al. 2010, Cooksey et al. 2012, Cooksey et al 2014, Nelson et al. 2008).

2.1 Sampling Design and Field Collections

Samples were collected aboard the NOAA Great Lakes Environmental Research Laboratory's 26-ft Sea Ark research vessel on August 22– 25, 2012. The study design consisted of 18 stations selected randomly among 11 different sampling strata within the outer harbor and adjacent Milwaukee, Menomonee, and Kinnickinnic Rivers (Figure 1, Table 1). These are urbanized, industrial areas supporting multiple uses – both commercial and recreational (Figure 2).

Sediment sampling was conducted using a 0.04-m^2 Young-modified Van Veen grab. Samples for benthic macro-infaunal analysis were collected in triplicate, live-sieved onboard through a 0.5-mm screen, and preserved separately in 10% buffered formalin with Rose Bengal stain. Samples for the analysis of sediment toxicity, sediment contaminants, % silt-clay, % water, and % TOC were sub-sampled from composited surface sediment (upper 2-3 cm) taken from additional grabs (typically three) independent of the macro-infaunal grabs.

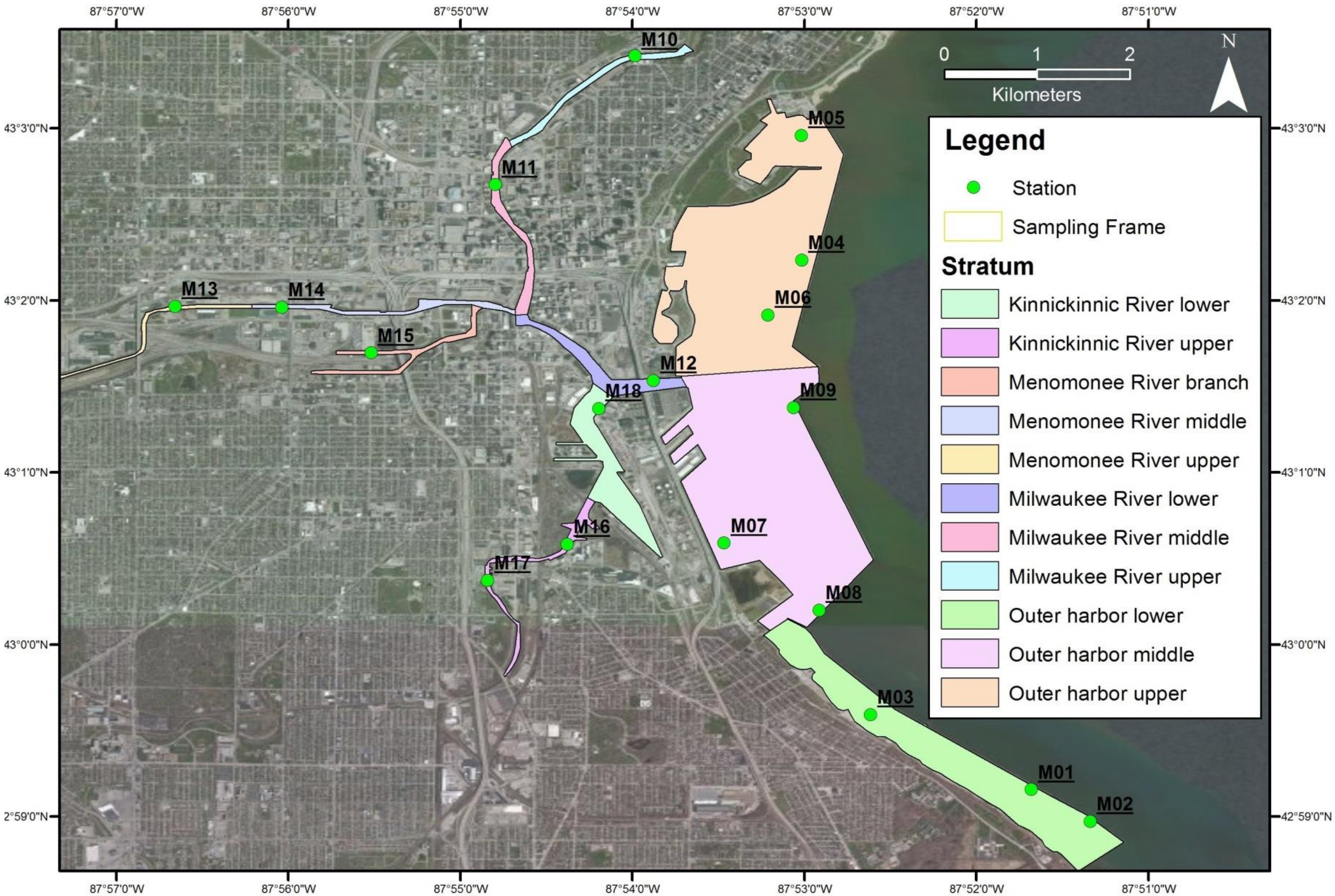

Figure 1. Station locations within the Milwaukee Estuary, Wisconsin. Eleven strata were establised to ensure sites were distributed throughout the length of the river/harbor system.

Figure 2. Milwaukee estuary. Photo Credit: C. Cooksey.

Table 1. Locations, depths, and bottom water characteristics for 18 stations sampled in the Milwaukee Estuary, August 22 – 25, 2012.

Station	Date Sampled	Latitude (DD)	Longitude (DD)	Depth (m)	% Silt-Clay	Near-Bottom Water Temp. (C)	DO (mg/L)	pH	Conductivity (µS/cm)	Turbidity (NTU)
M01	8/23/2012	42.98596	-87.86135	3.02	53.1	21.7	9.43	8.9	279.4	2.9
M02	8/23/2012	42.98289	-87.85565	2.77	51.8	21.6	8.65	8.8	277.5	1.6
M03	8/23/2012	42.99323	-87.87693	3.35	18.9	21.6	8.62	8.6	280.6	2.6
M04	8/22/2012	43.03723	-87.88361	6.71	87.8	22.1	8.98	8.8	349.5	4.5
M05	8/22/2012	43.0493	-87.88362	3.72	77.8	21.9	7.57	8.5	327.9	7.3
M06	8/22/2012	43.03192	-87.88688	6.43	87.3	22.0	8.03	8.7	383.2	3.5
M07	8/23/2012	43.00985	-87.89114	4.08	78.0	21.9	8.50	8.3	381.1	5.2
M08	8/23/2012	43.00335	-87.88193	7.1	88.7	21.4	4.06	8.1	380.3	2.1
M09	8/22/2012	43.02295	-87.88441	8.79	99.2	22.3	9.19	8.6	365.2	2.1
M10	8/24/2012	43.057	-87.89976	1.95	63.6	23.3	5.81	8.5	817.1	11.5
M11	8/24/2012	43.04453	-87.9133	4.15	69.7	23.4	7.84	8.7	815.2	22.2
M12	8/25/2012	43.02557	-87.89796	7.8	63.9	14.2	10.70	8.2	228.0	10.3
M13	8/24/2012	43.03276	-87.94431	0.98	81.5	25.3	7.19	8.1	821.5	11.10
M14	8/24/2012	43.03267	-87.93397	4.39	91.6	25.1	2.09	7.5	819.7	21.2
M15	8/24/2012	43.02826	-87.92531	6.68	81.8	26.2	4.38	7.7	681.6	13.4
M16	8/25/2012	43.00972	-87.90633	6.89	85.1	22.1	4.25	7.6	440.5	19.1
M17	8/25/2012	43.00623	-87.91402	0.82	2.5	24.0	7.01	8.0	548.2	4.1
M18	8/25/2012	43.02287	-87.90327	7.13	93.5	19.0	5.97	8.0	281.7	4.6

2.2 Water Quality Analysis

A Seabird SBE 19 plus CTD was used to acquire continuous profiles of conductivity, temperature, pH, dissolved oxygen, and depth as it was lowered and raised through the water column. Data were processed using the SBE Data Processing software provided by Seabird (version 7.22). A Niskin bottle was used to acquire discrete water samples at two designated water depths (near surface and near-bottom) for analysis of turbidity (in Nephelometric Turbidity Units, NTU). If water depth was ≤ 1m then only one discrete water sample was collected.

2.3 Sediment TOC and Grain Size Analysis

Sediment characterization included analysis for total organic carbon (TOC) content and silt-clay content. TOC analysis followed USEPA Method 9060. A minimum of 5g (wet weight) of sediment was initially dried for 48 h. Weighed subsamples were ground to a fine consistency and acidified to remove inorganic carbon (e.g., shell fragments). The acidified samples were ignited at 950ºC and the carbon dioxide that evolved was measured with an infrared gas analyzer. Silt-clay samples were prepared by sieve separation followed by timed pipette extractions as described in Plumb (1981).

2.4 Chemical Contaminant Analysis

Collected sediments were delivered frozen to the NOAA Hollings Marine Laboratory. Upon receipt, samples were logged into an electronic tracking database and stored at -40°C until extraction and analysis for a suite of organic compounds (PCBs, PAHs, Organochlorine Pesticides, PBDEs) and inorganic elements (Table 2). For organic compound analysis, sediments were thawed overnight at 4°C. Thawed samples were well-mixed and roughly 10g wet sediment were added to ~24g anhydrous sodium sulfate and ground in a glass mortar bowl. Simultaneous to chemical extraction, an additional 2-5g aliquot of wet sediment was dried for 24 hours at 90°C to determine the dry fraction of each sample. The contents of each mortar bowl were added to 33mL extraction cells and a known mass of carbon or deuterated labeled internal standards was added. Sediments were extracted by Accelerated Solvent Extraction (ASE200, Dionex Inc.) using an acetone:dichloromethane solution (1:1 v/v). Samples were further processed using gel permeation chromatography and solid-phase extraction (activated alumina). Final sample extracts were analyzed using GC/MS (Agilent 6890GC with 5973 Mass Selective Detector). Data quality was ensured by analyzing a series of standard reference materials (NIST 1944), spikes and blanks. A second extract was prepared in a similar manner for Microtox analysis, except without added internal and recovery standards.

Sediments (~5g) for inorganic analysis (except Hg) were pre-dried and powdered. Approximately 0.25g of dried sediment were digested by microwave in 5-mL nitric acid for analysis of the following metals: Li, Be, Al, Fe, Mg, Ni, Cu, Zn, Cd, and Ag. A second ~0.25g aliquot was digested by microwave in 5-mL nitric acid with added hydrofluoric acid for analysis of the following metals: V, Cr, Co, As, Sn, Sb, Ba, Tl, Pb and U. Selenium (~0.25g) was digested in nitric acid using a hot plate. Digested samples were diluted with deionized water and analyzed using ICP/MS (Perkin Elmer Elan 6100). A 0.1-0.3g wet sediment sample was analyzed using a direct mercury analyzer (DMA80; Milestone, Inc). Data quality was ensured using certified reference materials (NRC MESS-3; Marine Sediment), spikes, and blanks.

Chemical results were compared statistically, using Tukey-Kramer HSD Pairwise comparisons (JMP, version 11), to test for significance of mean differences in contaminant response variables among the various strata (segments) within a system.

Table 2. List of target contaminant analytes analyzed in sediment and tissue samples.

Polycyclic Aromatic Hydrocarbons (PAHs)	***Polychlorinated Biphenyls (PCBs)***
1-Methylnaphthalene[1]	PCB 1 (2-Chlorobiphenyl)
1-Methylphenanthrene[1]	PCB 103 (2,2',4,5',6-Pentachlorobiphenyl)
2,3,5-Trimethylnaphthalene[1]	PCB 104 (2,2',4,6,6'-Pentachlorobiphenyl)
2,6-Dimethylnaphthalene[1]	PCB 105 (2,3,3',4,4'-Pentachlorobiphenyl) [2]
2-Methylnaphthalene[1]	PCB 106/118 Mixture[2]
Acenaphthene[1]	PCB 107/108 Mixture
Acenaphthylene[1]	PCB 110 (2,3,3',4',6-Pentachlorobiphenyl)
Anthracene[1]	PCB 114 (2,3,4,4',5-Pentachlorobiphenyl)
Benz[a]anthracene[1]	PCB 119 (2,3',4,4',6-Pentachlorobiphenyl)
Benzo[a]pyrene[1]	PCB 12 (3,4-Dichlorobiphenyl)
Benzo[b]fluoranthene[1]	PCB 123 (2,3',4,4',5'-Pentachlorobiphenyl)
Benzo[e]pyrene[1]	PCB 126 (3,3',4,4',5-Pentachlorobiphenyl)
Benzo[g,h,i]perylene[1]	PCB 128/167 Mixture[2]
Benzo[k]fluoranthene[1]	PCB 130 (2,2',3,3',4,5'-Hexachlorobiphenyl)
Biphenyl[1]	PCB 132/168 Mixture
Chrysene +Triphenylene[1]	PCB 138/163/164 Mixture[2]
Dibenz[a,h]anthracene[1]	PCB 141 (2,2',3,4,5,5'-Hexachlorobiphenyl)
Dibenzothiophene[1]	PCB 146 (2,2',3,4',5,5'-Hexachlorobiphenyl)
Fluoranthene[1]	PCB 149 (2,2',3,4',5',6-Hexachlorobiphenyl)
Fluorene[1]	PCB 15 (4,4'-Dichlorobiphenyl)
Indeno[1,2,3-c,d]pyrene[1]	PCB 151 (2,2',3,5,5',6-Hexachlorobiphenyl)
Naphthalene[1]	PCB 153 (2,2',4,4',5,5'-Hexachlorobiphenyl) [2]
Perylene	PCB 154 (2,2',4,4',5,6'-Hexachlorobiphenyl)
Phenanthrene[1]	PCB 156 (2,3,3',4,4',5-Hexachlorobiphenyl)
Pyrene[1]	PCB 157 (2,3,3',4,4',5'-Hexachlorobiphenyl)
	PCB 158 (2,3,3',4,4',6-Hexachlorobiphenyl)
Pesticides	PCB 159 (2,3,3',4,5,5'-Hexachlorobiphenyl)
2,4'-DDD	PCB 165 (2,3,3',5,5',6-Hexachlorobiphenyl)
2,4'-DDE	PCB 169 (3,3',4,4',5,5'-Hexachlorobiphenyl)
2,4'-DDT	PCB 170/190 Mixture[2]
4,4'-DDD	PCB 172 (2,2',3,3',4,5,5'-Heptachlorobiphenyl)
4,4'-DDE	PCB 174 (2,2',3,3',4,5,6'-Heptachlorobiphenyl)
4,4'-DDT	PCB 177 (2,2',3,3',4,5',6'-Heptachlorobiphenyl)
Aldrin	PCB 18 (2,2',5-Trichlorobiphenyl) [2]
Alpha-chlordane	PCB 180 (2,2',3,4,4',5,5'-Heptachlorobiphenyl) [2]
Gamma-chlordane	PCB 183 (2,2',3,4,4',5',6-Heptachlorobiphenyl)
Cis-nonachlor	PCB 184 (2,2',3,4,4',6,6'-Heptachlorobiphenyl)
Trans-Nonachlor	PCB 187 (2,2',3,4',5,5',6-Heptachlorobiphenyl) [2]
Oxychlordane	PCB 188 (2,2',3,4',5,6,6'-Heptachlorobiphenyl)
Chlorpyrifos	PCB 189 (2,3,3',4,4',5,5'-Heptachlorobiphenyl)
Dieldrin	PCB 193 (2,3,3',4',5,5',6-Heptachlorobiphenyl)
Endosulfan I	PCB 194 (2,2',3,3',4,4',5,5'-Octachlorobiphenyl)
Endosulfan II	PCB 195 (2,2',3,3',4,4',5,6-Octachlorobiphenyl) [2]

Endosulfan Sulfate
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
alpha-Hexachlorocyclohexane (alpha-BHC)
beta-Hexachlorocyclohexane (beta-BHC)
Lindane
Mirex

Metals

Aluminum
Antimony
Arsenic
Barium
Beryllium
Cadmium
Chromium
Cobalt
Copper
Iron
Lead
Lithium
Manganese
Mercury
Nickel
Selenium
Silver
Thallium
Tin
Uranium
Vanadium
Zinc

Polybrominated Diphenyl Ethers (PBDEs)

PBDE 17 (2,2',4-Tribromodiphenyl Ether)
PBDE 28 (2,4,4'-Tribromodiphenyl Ether)
PBDE 47 (2,2',4,4'-Tetrabromodiphenyl Ether)
PBDE 66 (2,3',4,4'-Tetrabromodiphenyl Ether)
PBDE 71 (2,3',4',6-Tetrabromodiphenyl Ether)
PBDE 85 (2,2',3,4,4'-Pentabromodiphenyl Ether)
PBDE 99 (2,2',4,4',5-Pentabromodiphenyl Ether)
PBDE 100 (2,2',4,4',6-Pentabromodiphenyl Ether)
PBDE 138 (2,2',3,4,4',5'-Hexabromodiphenyl Ether)
PBDE 153 (2,2',4,4',5,5'-Hexabromodiphenyl Ether)
PBDE 154 (2,2',4,4',5,6'-Hexabromodiphenyl Ether)
PBDE 183 (2,2',3,4,4',5',6-Heptabromodiphenyl Ether)
PBDE 190 (2,3,3',4,4',5,6-Heptabromodiphenyl Ether)

PCB 198 (2,2',3,3',4,5,5',6-Octachlorobiphenyl)
PCB 2 (3-Chlorobiphenyl)
PCB 20 (2,3,3'-Trichlorobiphenyl)
PCB 200 (IUPAC 201)
PCB 201 (IUPAC 199)
PCB 202 (2,2',3,3',5,5',6,6'-Octachlorobiphenyl)
PCB 203/196 Mixture
PCB 206 (2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl) [2]
PCB 207 (2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl)
PCB 208 (2,2',3,3',4,5,5',6,6'-Nonachlorobiphenyl)
PCB 209 (2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl)
PCB 26 (2,3',5-Trichlorobiphenyl)
PCB 28 (2,4,4'-Trichlorobiphenyl) [2]
PCB 29 (2,4,5-Trichlorobiphenyl)
PCB 3 (4-Chlorobiphenyl)
PCB 31 (2,4',5-Trichlorobiphenyl)
PCB 37 (3,4,4'-Trichlorobiphenyl)
PCB 44 (2,2',3,5'-Tetrachlorobiphenyl) [2]
PCB 45 (2,2',3,6-Tetrachlorobiphenyl)
PCB 47/48 Mixture
PCB 49 (2,2',4,5'-Tetrachlorobiphenyl)
PCB 5/8 Mixture[2]
PCB 50 (2,2',4,6-Tetrachlorobiphenyl)
PCB 52 (2,2',5,5'-Tetrachlorobiphenyl) [2]
PCB 56/60 Mixture
PCB 61/74 Mixture
PCB 63 (2,3,4',5-Tetrachlorobiphenyl)
PCB 66 (2,3',4,4'-Tetrachlorobiphenyl) [2]
PCB 69 (2,3',4,6-Tetrachlorobiphenyl)
PCB 70/76 Mixture
PCB 77 (3,3',4,4'-Tetrachlorobiphenyl)
PCB 81 (3,4,4',5-Tetrachlorobiphenyl)
PCB 82 (2,2',3,3',4-Pentachlorobiphenyl)
PCB 84 (2,2',3,3',6-Pentachlorobiphenyl)
PCB 87/115 Mixture
PCB 88 (2,2',3,4,6-Pentachlorobiphenyl)
PCB 89/90/101 Mixture[2]
PCB 9 (2,5-Dichlorobiphenyl)
PCB 92 (2,2',3,5,5'-Pentachlorobiphenyl)
PCB 95 (2,2',3,5',6-Pentachlorobiphenyl)
PCB 99 (2,2',4,4',5-Pentachlorobiphenyl)

[1]-Used to calculate Total PAHs.
[2]-Used to calculate Total PCBs as $[2.19 * \Sigma(18 \text{ congeners})] + 2.19$.

2.5 Toxicity Analysis

Overall sediment toxicity at each station, based on three bioassays (Microtox solid-phase assay, Microtox solvent-extract assay, amphipod assay), was characterized as low (0 of 3 assay hits = Green in Figure 11, moderate (1 of 3 hits = yellow), high (2 of 3 hits = orange), and very high (3 of 3 hits = red).

2.5.1 Microtox Solid Phase Assay

Sediment samples were collected in pre-cleaned 4-oz jars and placed in 4ºC storage until time of analysis. Microtox assays were conducted according to the standardized solid-phase protocols with the Microtox Model 500 analyzer (Modern Waters, Inc., DE). All materials and reagents were purchased from Modern Waters. In this assay, sediment was homogenized and a 7.0-7.1g sediment sample was used to make a series of sediment dilutions with 3.5% NaCl diluent. Test samples were placed in a 15ºC water bath for a 10-minute incubation. Luminescent bacteria (*Vibrio fisheri*) were then added to the test concentrations for a 20-minute incubation. At the end of the incubation period a column filter was used to separate the liquid phase from the sediment phase, and bacterial post-exposure light output was then measured using Microtox Omni Software. An EC50 value (the sediment concentration that reduces light output by 50% relative to the controls) was calculated for each sample. Triplicate samples were analyzed simultaneously. Sediments were considered toxic when EC50s were significantly ($p \leq 0.05$) lower than Reference site (Willow Hall Pond, SC) sediments.

2.5.2 Microtox Solvent Extract Assay

A 10-g sediment sample was placed into a solvent-rinsed mortar bowl containing 27 g of anhydrous sodium sulfate. Samples were thoroughly ground via mortar and pestle and then placed into solvent-rinsed, accelerated solvent extraction (ASE) cells (Dionex Corporation, CA). Samples were extracted using a Dionex ASE 200 system with a 50/50 mixture of dichloromethane and acetone. After extraction, samples were filtered through sodium sulfate into 200-mL TurboVap tubes (Biotage, NC) and concentrated under a stream of nitrogen using a TurboVap II Concentration Workstation (pressure = ~1 bar, water bath temperature = 40°C [Zymark Corporation, MA]). Samples were concentrated to 0.5 mL and solvent-exchanged to acetone twice. Samples were then further concentrated to a minimal volume (100-150 µL) and transferred to 2-mL silanized amber auto sampler vials (ASVs) (Thermo Scientific, NC). TurboVap tubes were rinsed three times with dimethyl sulfoxide (DMSO) and added to the sample extract (Final volume=1 mL). Samples were then stored at 4ºC until time of analysis.

Microtox assays were conducted according to the basic test protocol with the Microtox Model 500 analyzer (Modern Waters, Inc., DE). All materials and reagents were purchased from Modern Waters. In this assay, solvent-extract samples were used to make a series of dilutions with 1% DMSO saline (2%NaCl) diluent. Cuvettes containing 1% DMSO diluent were placed in the analyzer for a 5-minute incubation at a constant temperature of 15°C. Freeze-dried luminescent bacteria, *Vibrio fischeri*, were reconstituted then added to the test cuvettes for a 15-minute incubation. At the end of incubation, bacterial luminescence was measured prior to sample addition (0 min reading), then 5 and 15 min after sample addition, using the Microtox Omni Software. An EC50 value (the sample concentration that reduces light output by 50% relative to the controls) was calculated for each sample at each time point. Triplicate samples were analyzed simultaneously. Sediments were considered toxic when EC50s were significantly ($p \leq 0.05$) lower than reference-site sediments (Willow Hall Pond, SC).

2.5.3 Amphipod sediment bioassay

The 10-day *Hyalella* sediment bioassay was based on methods developed by USEPA (2000). The test consisted of a laboratory-formulated sediment control (USEPA, 2000) and the field-site sediments. Tests were run in 300-mL glass beakers with 100 mL (by weight) of homogenized sediment in each beaker and 175 mL of reconstituted water (USEPA, 2000). Each beaker was covered with a pre-drilled plastic lid, placed in a water bath (23ºC) at predetermined random positions and aerated (>90% dissolved oxygen saturation) for 24 h before the addition of amphipods. There were eight replicates for each control and field site. Amphipods used for testing were purchased from Aquatic BioSystems, Inc. (Fort Collins, CO) and were held in-house at least 48 h prior to testing. Prior to adding the amphipods, an 80% water renewal was performed in each beaker. Ten juvenile amphipods were then added to each beaker. Exposure was static with a daily 80% water renewal. After daily renewal, 1.05 mL of YTC (yeast-trout chow-cerophyll; Aquatic BioSystems, Inc.) was added to each beaker with ground Tetramin (0.7g, <250 um) also added on days 0 and 6. Photoperiod was 16 h light: 8 h dark using wide-spectrum fluorescent lights. Water-quality parameters (conductivity, pH, temperature, and dissolved oxygen concentration) from the pooled water removed from each control and field site were measured daily. On days 0 and 9, the hardness, alkalinity, and ammonia levels in the pooled water were measured from each control and field site. On day 10, each beaker was gently sieved through a 300-µm sieve to isolate the test animals. The numbers of live, missing, and dead amphipods were recorded. Sediments were considered toxic when survival relative to control sediments was significantly different ($p \leq 0.05$) and less than 80% of control survival.

2.6 Benthic Community Analysis

Once in the laboratory, benthic samples were transferred from formalin to 70% ethanol. Macroinfaunal invertebrates were sorted from the sample debris under a dissecting microscope and identified to the lowest practical taxon (usually species). Data were used to compute density (m^{-2}) of total fauna (all species combined), densities of numerically dominant species (m^{-2}), numbers of taxa, and diversity (Shannon H' derived with base-2 logarithms and Hill’s N1). The species-level, modified Hilsenhoff Benthic Index (HBI) was used to assess overall benthic condition (Hilsenhoff 1982, 1987; Mandaville 2002).

2.7 Data Analysis

A probabilistic, stratified-random sampling design was used in this study in order to provide a basis for making unbiased statistical estimates of the spatial extent (% area) of condition within the survey area based on the status of various measured ecological indicators. A similar approach has been applied throughout EPA's EMAP, related NCA programs, and other estuarine and coastal-ocean surveys (e.g., Summers et al. 1995; Strobel et al. 1995; Hyland et al. 1996; USEPA 2004, 2006; Nelson et al. 2008). Results are presented throughout this report as the percentage of survey area within specified ranges of a particular indicator. Additional data summaries representing key distributional properties (e.g., mean, range) and other basic data tabulations are provided as well. Data presented graphically in this report are primarily in the form of cumulative distribution functions (CDFs), pie charts and maps. In some cases, maps represent data analyzed in ArcMap's Geostatisical Analyst using Kernel Smoothing with Barriers. Such analyses are useful for portraying the percentage of coastal area corresponding to varying levels of a given indicator across the full range of its observed values and for estimating the percentage of area falling below or above some designated threshold of interest. This can be a useful feature for management applications as well; for example, if valid thresholds can be defined for a particular indicator or suite of indicators, they could be used as ecosystem quality targets for monitoring the system and triggering any necessary management actions.

The biological significance of sediment contamination was evaluated by comparing measured chemical concentrations in samples to corresponding consensus-based threshold effect concentration (TEC) and probable effect concentration (PEC) sediment quality guideline (SQG) values that are listed in Table 3 (from MacDonald et al. 2000, Ingersoll et al. 2001). The TEC values are lower-threshold limits, below which adverse effects on sediment–dwelling organisms are not expected to occur. PEC values represent higher-threshold limits, above which bioeffects are likely to occur in some sediment-dwelling species. Overall sediment contamination from multiple chemicals in a sample was expressed as the mean PEC quotient (mean PEC-Q), which is the average of three PEC-Qs using only contaminants with reliable PECs: mean PEC-Q for metals, PEC-Q for Total PAHs and PEC-Q for Total PCBs (Table 3) (MacDonald et al. 2000, Ingesoll et al. 2001). For the purposes of the present analysis, mean PEC-Qs ≤ 0.1, > 0.1 to ≤ 0.5, > 0.5 to ≤ 1.5, and > 1.5 are considered to have a low, moderate, high, to very high likelihood of observing sediment toxicity respectively (based on toxicity occurrences presented in MacDonald et al. 2000).

Table 3. Consensus-Based TEC and PEC sediment quality guidelines (MacDonald et al. 2000, Ingersoll et al. 2001). Cells highlighted in yellow indicate values used to calculate mean PEC-Qs.

Chemical	Consensus-Based TEC	Consensus-Based PEC
Metals (in mg/kg Dry Wt.)		
Arsenic	9.79	33.0[b]
Cadmium	0.99[a]	4.98[b]
Chromium	43.4	111[b]
Copper	31.6[a]	149[b]
Lead	353.8[a]	128[b]
Mercury	0.18	1.06
Nickel	22.7	48.6[b]
Zinc	121[a]	459[b]
Polycyclic Aromatic Hydrocarbons (in µg/kg Dry Wt.)		
Anthracene	57.2[a]	845
Fluorene	77.4	536
Naphthalene	176[a]	561[b]
Phenanthrene	204[a]	1,170[b]
Benzo[a]anthracene	108[a]	1,050[b]
Benzo[a]pyrene	150[a]	1,450[b]
Chrysene	166[a]	1,290[b]
Dibenz[a,h]Anthracene	33.0	--
Fluoranthene	423[a]	2,230
Pyrene	195[a]	1,520[b]
Total PAHs	1,610[a]	22,800[b]
Polychlorinated Biphenyls (in µg/kg Dry Wt.)		
Total PCBs	59.8[a]	676[b]
Organochlorine Pesticides (in µg/kg Dry Wt.)		
Chlordane	3.24[a]	17.6
Dieldrin	1.90[a]	61.8
Sum DDD	4.88[a]	28.0
Sum DDE	3.16[a]	31.3[b]
Sum DDT	4.16[a]	62.9
Total DDTs	5.28[a]	572
Endrin	2.22	207
Heptachlor epoxide	2.47[a]	16.0
Lindane (gamma-BHC)	2.37	4.99

[a] - Reliable for predicting lack of toxicity

[b] - Reliable for predicting probable toxicity

3.0 Results and Discussion

3.1 Depth and Water Quality

Water depths at the 18 Milwaukee Estuary stations averaged 4.8 m and ranged from 0.8 – 8.8 m (Table 1, Figure 3). Measures of bottom-water conductivity, temperature, pH, turbidity, and dissolved oxygen (DO) averaged 471 µS/cm, 22.2 ºC, 8.3 pH units, 8.1 NTU, and 7.1 mg/L respectively across these stations and ranged from 228 - 821 µS/cm, 14.2 – 26.2 ºC, 7.5-8.9 pH units, 1.6 – 22.2 NTU, and 2.1 – 10.7 mg/L respectively (Table 1, Figure 3). None of the survey area had bottom-water DO levels in the hypoxic range, below 2 mg/L based on the EPA (2008) cutpoints, although three stations (M14, M15, M16 representing 18.5% of the survey area) had DO in the moderate range between 2 - 5 mg/L (Figures 3 and 4). These latter stations were spatially concentrated within upstream portions of the tributaries (Figure 5).

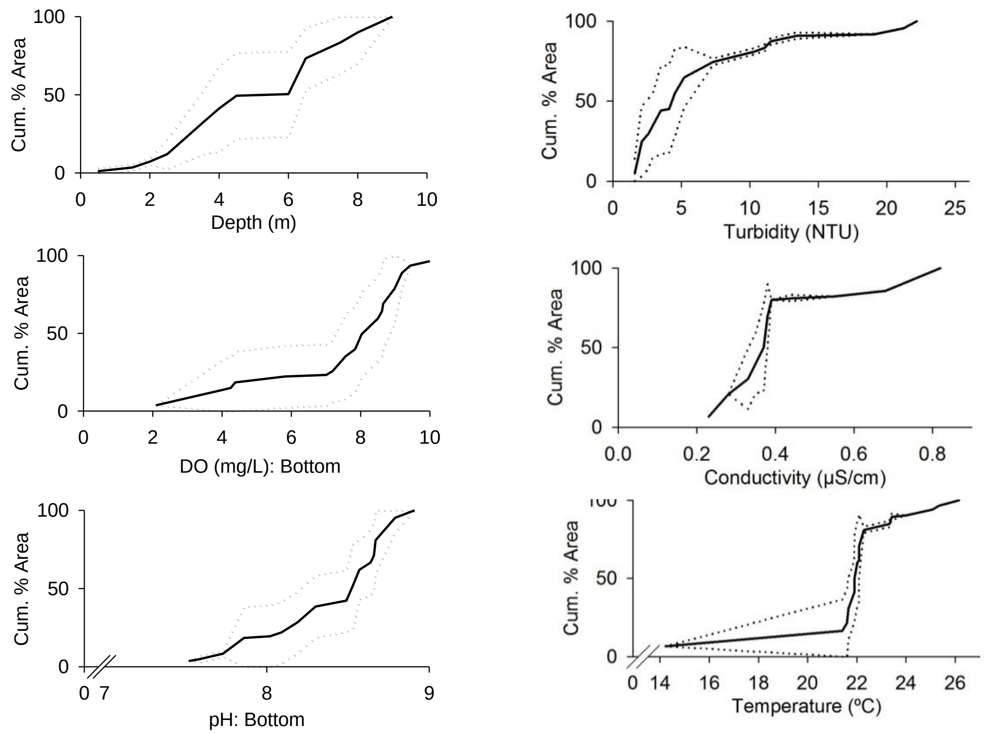

Figure 3. Cumulative distribution functions for key bottom-water characterisitics for the Milwaukee Estuary. Dotted lines are 95% confidence intervals.

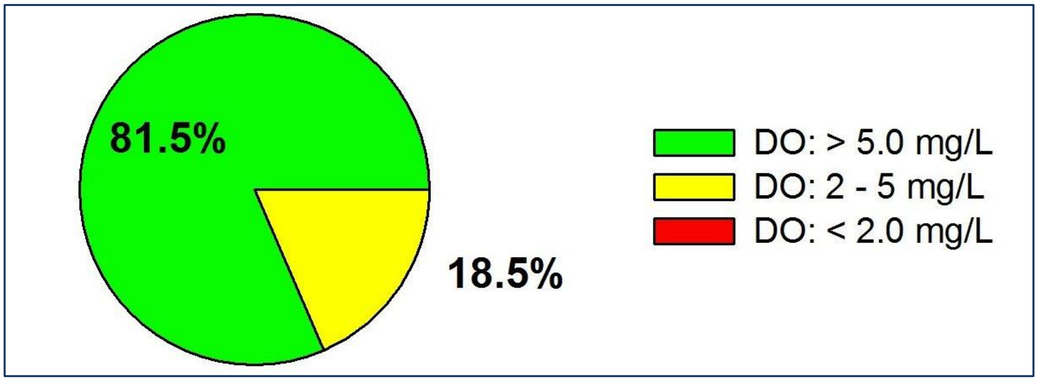

Figure 4. Percent area of the Milwaukee Estuary within specified ranges of DO.

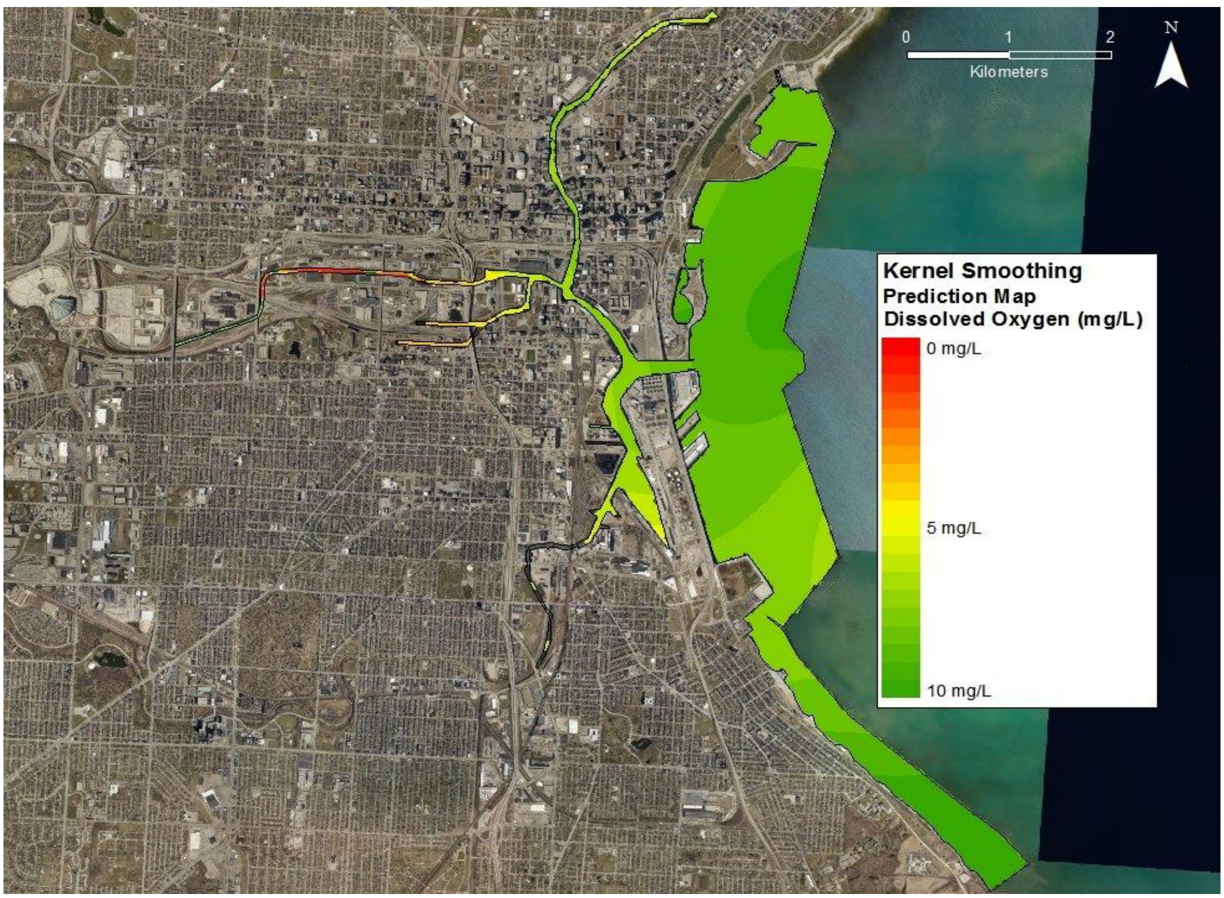

Figure 5. Spatial distribution of dissolved oxygen (DO) levels within the Milwaukee Estuary. DO data were analyzed in ArcMap's Geostatisical Analyst using Kernel Smoothing with Barriers.

3.2 Sediment Quality

3.2.1 Grain Size and TOC

The silt-clay content of sediments in the Milwaukee estuary ranged from 2.5% - 99.2% and averaged 70.9% (Table 4). Approximately 50% of the survey area was composed of muds (>80% silt-clay) while the remainder was composed of sands to intermediate muddy sands (Figure 6). Total organic carbon (TOC) content of sediments averaged 34.0 mg/g and ranged from 8.6 – 74.7 mg/g (Table 4). Thirty percent of the survey area had relatively low TOC levels of < 20 mg/g, 58% had moderate levels of 20 – 50 mg/g, and the remaining 12% of the area had high levels in excess of the upper threshold associated with a high risk of adverse effects on benthic fauna (> 50 mg/g cutpoint from USEPA 2008) (Figure 6). High levels of TOC were found in the upper reaches of the Menomonee and Milwaukee Rivers, with TOC gradually lowering towards the harbor area (Figure 7).

Table 4. Summary of Milwaukee Estuary sediment characteristics (TOC and grain size).

	Mean	Range	CDF 10th%	CDF 50th%	CDF 90th%
TOC (mg/g)	34.0	8.6 – 74.7	11.1	25.3	58.2
% silt-clay	70.9	2.9 – 99.2	61.7	81.1	95.5

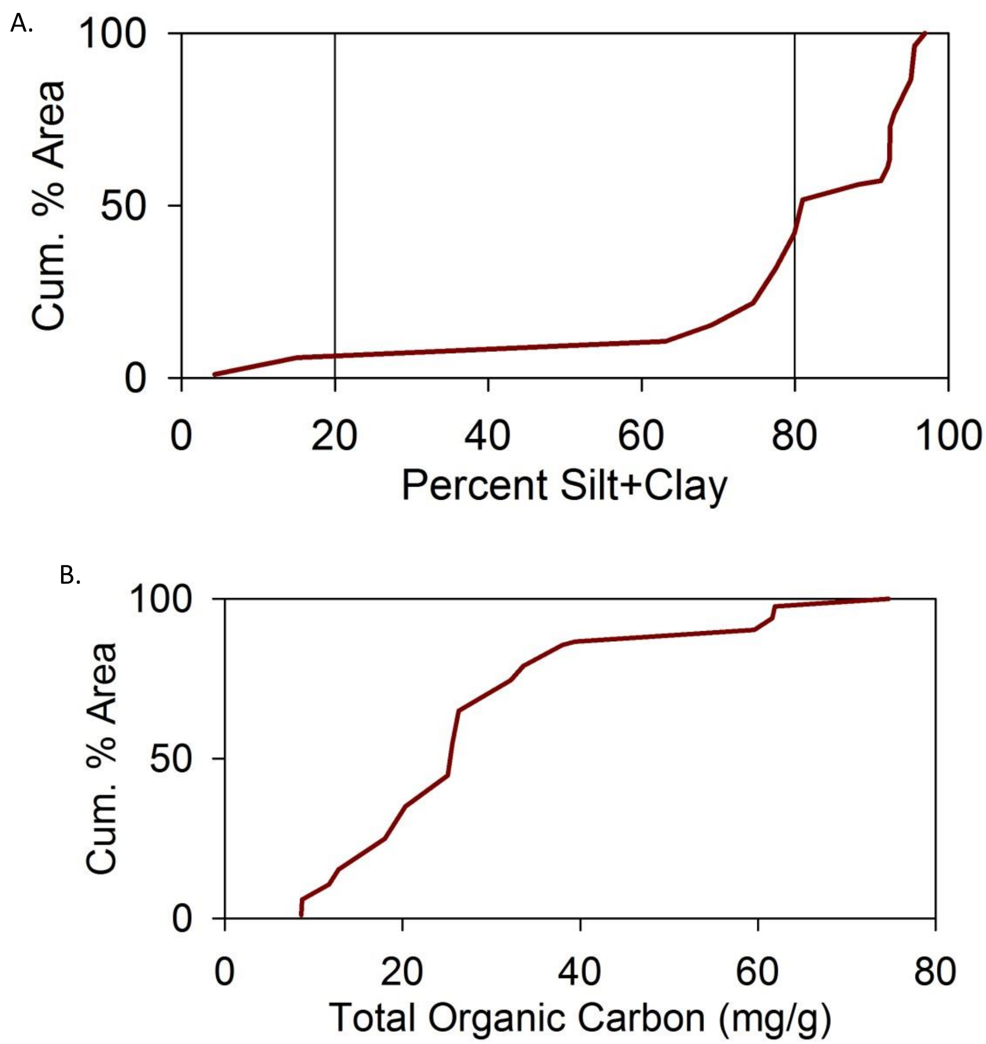

Figure 6. Percent area of Milwaukee Estuary vs. percent silt+clay of sediment (A) and Total Organic Carbon (B).

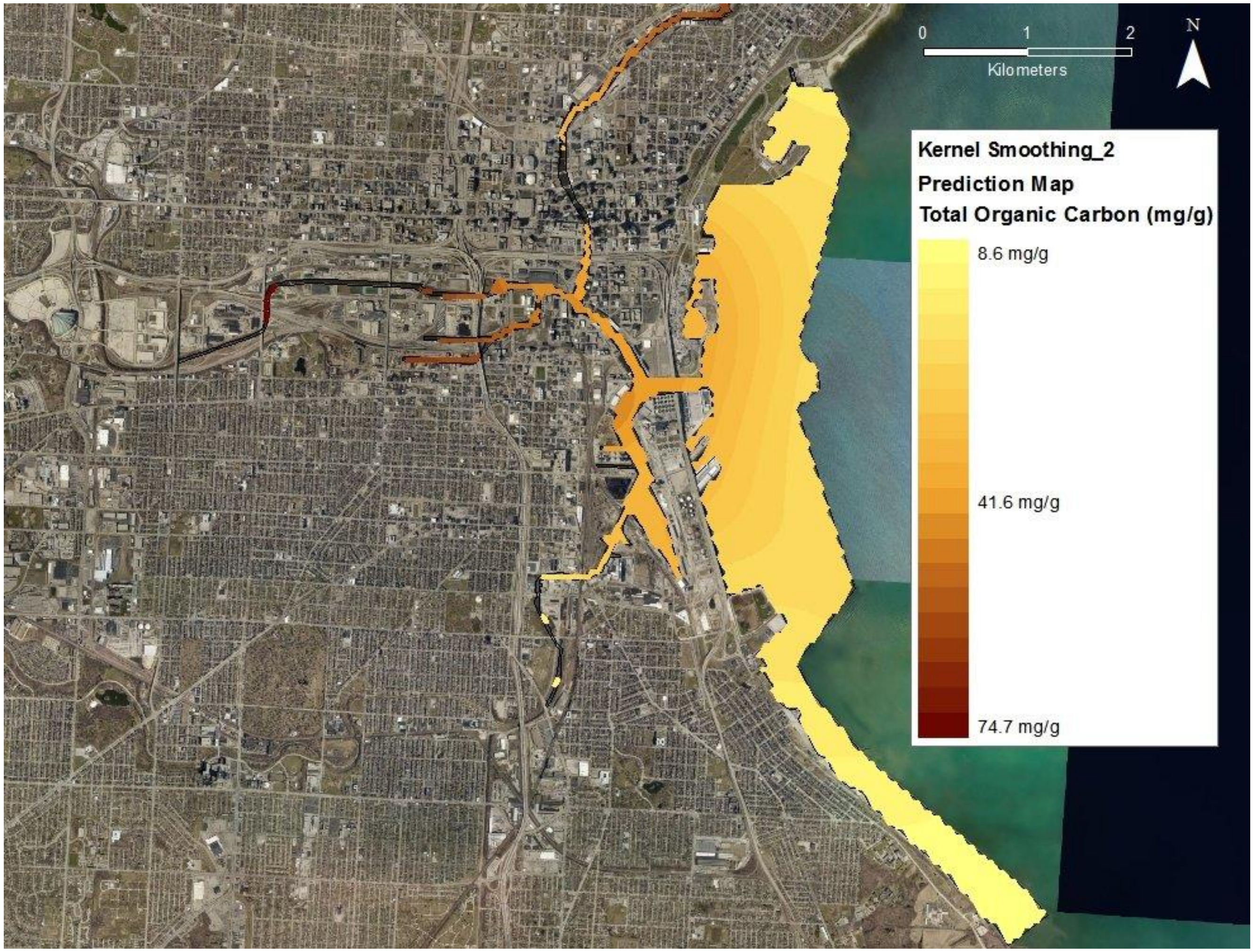

Figure 7. Spatial distribution of Total Organic Carbon (TOC) levels within the Milwaukee Estuary. TOC data were analyzed in ArcMap's Geostatisical Analyst using Kernel Smoothing with Barriers.

Table 5. Summary of contaminant analyses for metals and organic contaminants by strata.

		Metals (mg/kg dry mass)									Organics (µg/kg dry mass)			
Strata		Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	DDTs	PAHs	PBDEs	PCBs
Overall	Average	0.443	4.10	1.12	64.0	54.6	0.110	19.9	67.3	220	40.8	41521	8.35	619
	Min	<MDL	2.12	0.286	19.0	7.18	0.020	7.37	13.2	63.2	1.55	2970	0.463	25.0
	Max	1.19	6.57	2.38	114	222	0.263	32.4	174	533	117	113606	26.4	2334
	Deviation	0.364	1.41	0.624	28.0	51.5	0.064	7.42	42.0	149	32.6	39604	7.96	601
Harbor	Average	0.285	3.47	0.759	54.2	26.3	0.082	17.2	34.4	115	20.6	13457	3.54	258
	Min	<MDL	2.40	0.286	19.0	7.18	0.020	7.37	13.2	63.2	1.55	2970	0.463	25.0
	Max	0.774	4.54	1.48	87.8	46.5	0.144	30.9	60.9	184	58.7	27047	9.53	587
	Deviation	0.310	0.757	0.493	27.5	14.5	0.047	7.68	18.8	43.7	20.5	8781	3.30	226
Milwaukee River	Average	0.676	3.52	1.08	55.9	44.3	0.105	17.8	85.1	178	40.3	47507	8.33	1092
	Min	0.379	3.03	0.850	40.9	33.0	0.089	16.7	59.3	153	33.2	19972	5.35	884
	Max	1.19	4.27	1.53	74.2	59.0	0.133	19.9	106	226	46.2	97212	10.2	1336
	Deviation	0.450	0.665	0.390	16.9	13.4	0.024	1.78	23.8	42.3	6.60	43130	2.61	228
Menomonee River	Average	0.545	5.61	1.36	74.2	138	0.168	26.8	94.1	465	92.4	96147	22.0	343
	Min	0.323	4.68	1.04	69.2	95.0	0.107	26.4	85.6	396	67.5	70922	16.3	176
	Max	0.699	6.27	1.78	79.1	222	0.263	27.1	106	533	117	111002	26.4	636
	Deviation	0.197	0.826	0.382	4.97	72.5	0.084	0.355	10.4	68.0	24.8	21960	5.13	254
Kinnickinnic River	Average	0.582	5.06	1.99	91.4	66.3	0.138	23.1	122	333	50.5	65105	9.13	1504
	Min	<MDL	2.12	1.46	46.4	20.6	0.028	12.3	91.4	241	21.9	37924	0.738	924
	Max	0.950	6.57	2.38	114	104	0.200	32.4	174	455	76.0	113606	18.2	2327
	Deviation	0.510	2.55	0.474	39.0	42.2	0.095	10.1	45.5	110	27.2	42105	8.76	732

Table 6. Summary of chemical contaminant concentrations and TEC/PEC exceedances at Milwaukee Estuary stations (n=18).

Analyte	Mean	Range	#>TEC (and <PEC)	#>PEC
Trace Metals (mg/kg Dry Wt.)				
As	4.10	2.12-6.57	0	0
Cd	1.12	0.286-2.38	11	0
Cr	64.0	18.9-114	12	2
Cu	54.6	7.18-222	11	1
Pb	67.3	13.2-174	1	0
Hg	0.110	0.020-0.263	3	0
Ni	19.9	7.37-32.4	7	0
Zn	220	63.2-533	12	1
PAHs (µg/kg Dry Wt.)				
Anthracene	754	<DL-3123	4	7
Fluorene	297	46.4-826	13	3
Naphthalene	236	<DL-1171	3	3
Phenanthrene	2683	<DL-8041	4	10
Benzo(a)anthracene	2351	205-71778	6	12
Benzo(a)pyrene	2246	175-5790	9	9
Chrysene(+Triphenylene)	3239	<DL-9738	6	11
Dibenz(a,h)anthracene	552	37.6-1594	18	.
Fluoranthene	6885	537-19479	6	12
Pyrene	5872	408-17198	4	14
Total PAHs	41521	2970-113606	8	10
Organochlorine Pesticides (µg/kg Dry Wt.)				
Chlordane	1.9	<DL-7.23	3	0
Dieldrin	0.56	<DL-1.14	0	0
Sum DDE	22.1	0.707-79.5	11	4
Sum DDT	7.24	<DL-38.3	9	0
Sum DDD	11.4	0.842-32.97	13	1
Total DDTs	40.8	1.55-117	15	0
Endrin	0	<DL	0	0
Heptachlor epoxide	0.17	<DL-0.6	0	0
Lindane (gamma-BHC)	0.01	<DL-0.26	0	0
PCBs (µg/kg Dry Wt.)				
Total PCB	619	25-2334	9	6

3.2.2 Chemical Contaminants in Sediments

Total PCB concentrations in the Milwaukee Estuary ranged from 25.0 - 2334 µg/kg dry mass and averaged 619 µg/kg (Tables 5, 6). Of the 18 stations sampled in the Milwaukee Estuary, six had total PCB concentrations in excess of the corresponding PEC value and an additional nine had concentrations that exceeded the lower-threshold TEC value. Mean concentrations among the various strata showed the following pattern: Harbor (258 µg/kg) < Menomonee River (343 µg/kg) < Milwaukee River (1092 µg/kg) < Kinnickinnic River (1504 µg/kg). Tukey-Kramer HSD analysis indicated significant differences (at $\alpha = 0.05$) among strata, with the Harbor and Menomonee River having significantly lower levels than the Kinnickinnic River. Levels in the Harbor were also significantly lower than the Milwaukee River.

Total PBDE concentrations ranged from 0.463 – 26.4 µg/kg dry mass and averaged 8.35 µg/kg (Table 5). Mean concentrations among the various strata showed the following pattern: Harbor (3.54 µg/kg) < Milwaukee River (8.33 µg/kg) < Kinnickinnic River (9.13 µg/kg) < Menomonee River (22.0 µg/kg). Among-strata comparisons based on the Tukey-Kramer HSD revealed that mean concentrations in the Menomonee River were significantly higher than in the remaining strata (at $\alpha = 0.05$). There are currently no published sediment quality guidelines for PBDEs for comparison.

Total PAH concentrations ranged from 2,970 -113,606 µg/kg dry mass and averaged 41,521 µg/kg (Tables 5, 6). Concentrations exceeded the TEC value (4,022 µg/kg) at eight of the 18 stations and the higher-threshold PEC value at 10 stations. Fluoranthene was the individual PAH contaminant with the highest mean concentration (6,885 µg/kg) and exceeded its PEC value at 14 of the 18 stations. Mean concentrations of total PAHs among the various strata showed the following pattern: Harbor (13,457 µg/kg) < Milwaukee River (47,507 µg/kg) < Kinnickinnic River (65,105 µg/kg) < Menomonee River (96,147 µg/kg). Among-strata comparisons based on the Tukey-Kramer HSD revealed that mean concentrations in the Harbor were significantly lower than in the Menomonee and Kinnickinnic Rivers (at $\alpha = 0.05$).

Total DDT concentrations averaged 40.8 µg/kg dry mass and ranged from 1.55 – 117 µg/kg (Tables 5, 6). Concentrations exceeded the TEC value at 15 stations but did not exceed the high-threshold PEC value at any stations. The Menomonee River mean concentration was significantly higher than in the Milwaukee River and Harbor, based on the Tukey-Kramer HSD all-pairwise comparison (at $\alpha = 0.05$). The general pattern in mean total DDT concentrations among the various strata was: Harbor (20.6 µg/kg) < Milwaukee River (40.3 µg/kg) < Kinnickinnic River (50.5 µg/kg) < Menomonee River (92.4 µg/kg). Tukey-Kramer results indicated that the mean DDT concentration in the Menomonee River was significantly higher than the mean DDT concentrations in the other strata.

All but one of the measured metals (arsenic) exceeded corresponding TEC values at one or more of the 18 Milwaukee Estuary stations and three metals (chromium, copper, zinc) exceeded their higher-threshold PEC values (Tables 5, 6). Zinc concentrations, which averaged 220 mg/kg dry mass and ranged from 63.2 - 533 mg/kg, exceeded the lower-threshold TEC value at all 12 stations in addition to the one where the PEC was exceeded. Mean concentrations of zinc were significantly lower in the Harbor (115 mg/kg) and Milwaukee River (178 mg/kg) than in the Kinnickinnic River (333 mg/kg) and Menomonee River (465 mg/kg), based on the Tukey-Kramer HSD all-pairwise comparison (at $\alpha = 0.05$). Chromium and copper were also dominant contaminants, exceeding corresponding consensus-based TEC values at 12 and 11 of the 18 stations respectively, and corresponding PEC values at two and one of the stations respectively.

Li et al (1995) report concentrations of total PAHs and total PCBs from eight sediment cores collected in the Kinnickinnic River. Table 7 provides a comparison of these data (from upper segments of their cores) to concentrations measured in the present study. In general, there is a decrease between the earlier 1995 study and the present survey conducted in 2012.

Table 7. Concentrations of PAHs and PCBs (µg/kg dry wt.) in the Milwaukee estuary reported by Li et al (1995) in comparison to results of the present study.

Analyte	Milwaukee Estuary overall (this study)	Kinnickinnic River Stratum (this study)	Kinnickinnic River (Li et al 1995)
Total PAH	41.5	66.3	227
Total PCB	0.619	1.295	5.71

Mean probable-effect-concentration quotients (mean PEC-Qs), used here as an indicator of overall sediment contamination from mixtures of individual chemicals present in a sample, averaged 1.027 across the 18 Milwaukee Estuary stations and ranged from 0.100 (Harbor) to 3.029 (Kinnickinnic River) (Table 8, Figure 8). For comparison, sediment from a reference site (Willow Hall Pond, SC) had a much lower mean PEC-Q value of 0.009. There was a general trend of lower concentrations of contaminants in the more open-water harbor stratum (M1 – M9). One or more individual contaminants exceeded their corresponding PEC values at 15 of the 18 Milwaukee stations. Lower threshold effect concentrations (TECs) were exceeded at all stations. PAHs and PCBs were the dominant contaminants compared to metals at most stations (Figure 9). Based on the present sampling, an estimated 58% of the survey area contained sediments with high to very high levels of chemical contaminants (mean PEC-Qs > 0.5 as defined here) (Figure 10).

Table 8. TEC, PEC, and mean PEC-Q results by station and stratum.

Station	Stratum	>TEC	>PEC	PEC-Q	Overall Average PEC-Q	Stratum Average PEC-Q
M01	Harbor	8	1	0.208	1.027	0.403
M02	"	7	0	0.100		
M03	"	12	1	0.184		
M04	"	16	0	0.324		
M05	"	11	7	0.661		
M06	"	11	6	0.772		
M07	"	10	0	0.162		
M08	"	19	1	0.536		
M09	"	12	4	0.677		
M10	Milwaukee River	10	7	1.114		1.336
M11	"	11	5	0.822		
M12	"	9	10	2.073		
M13	Menomonee River	12	9	1.801		1.760
M14	"	11	10	1.901		
M15	"	9	13	1.577		
M16	Kinnickinnic River	10	14	3.029		1.857
M17	"	8	9	1.270		
M18	"	12	10	1.271		
	Reference Site (Willow Hall Pond, SC)	0	0	0.009	–	–

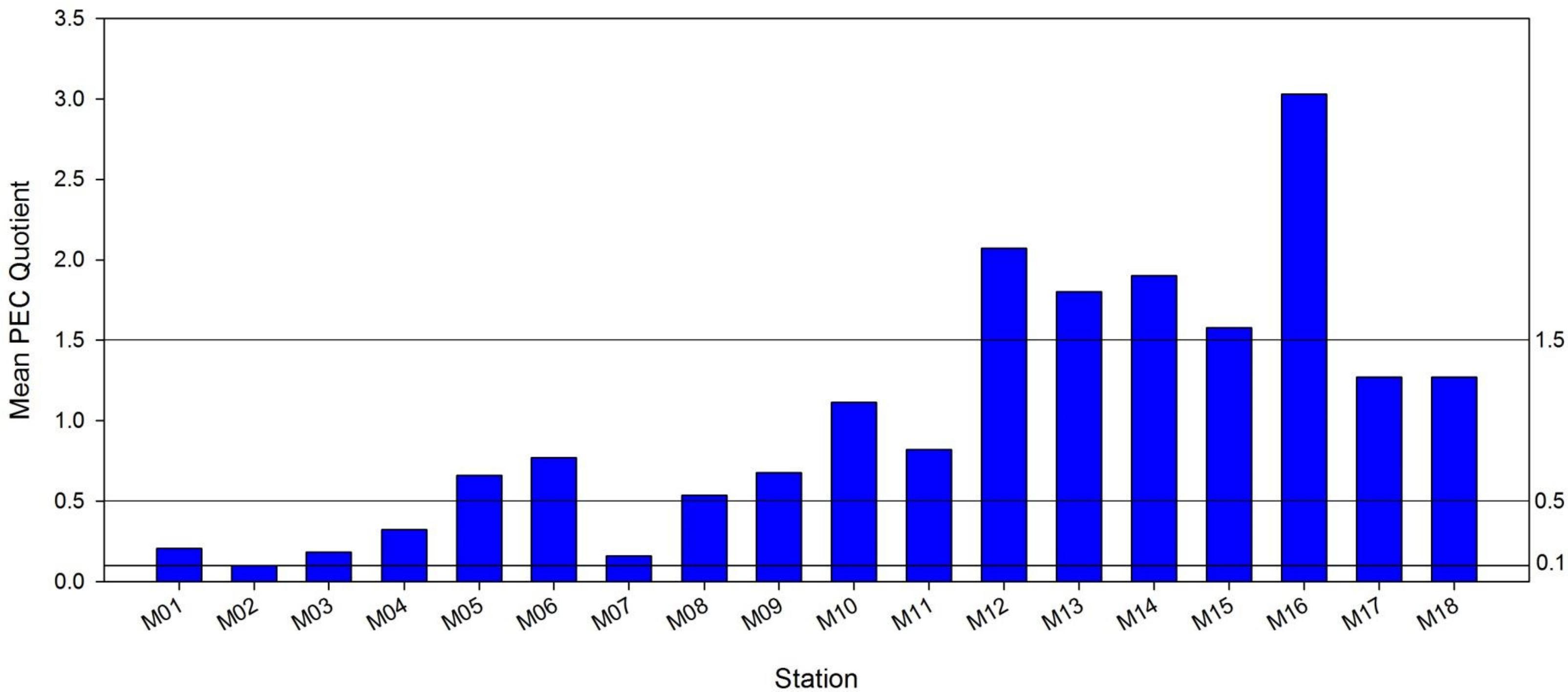

Figure 8. Distribution of PEC-Q values among the various Milwaukee Estuary stations.

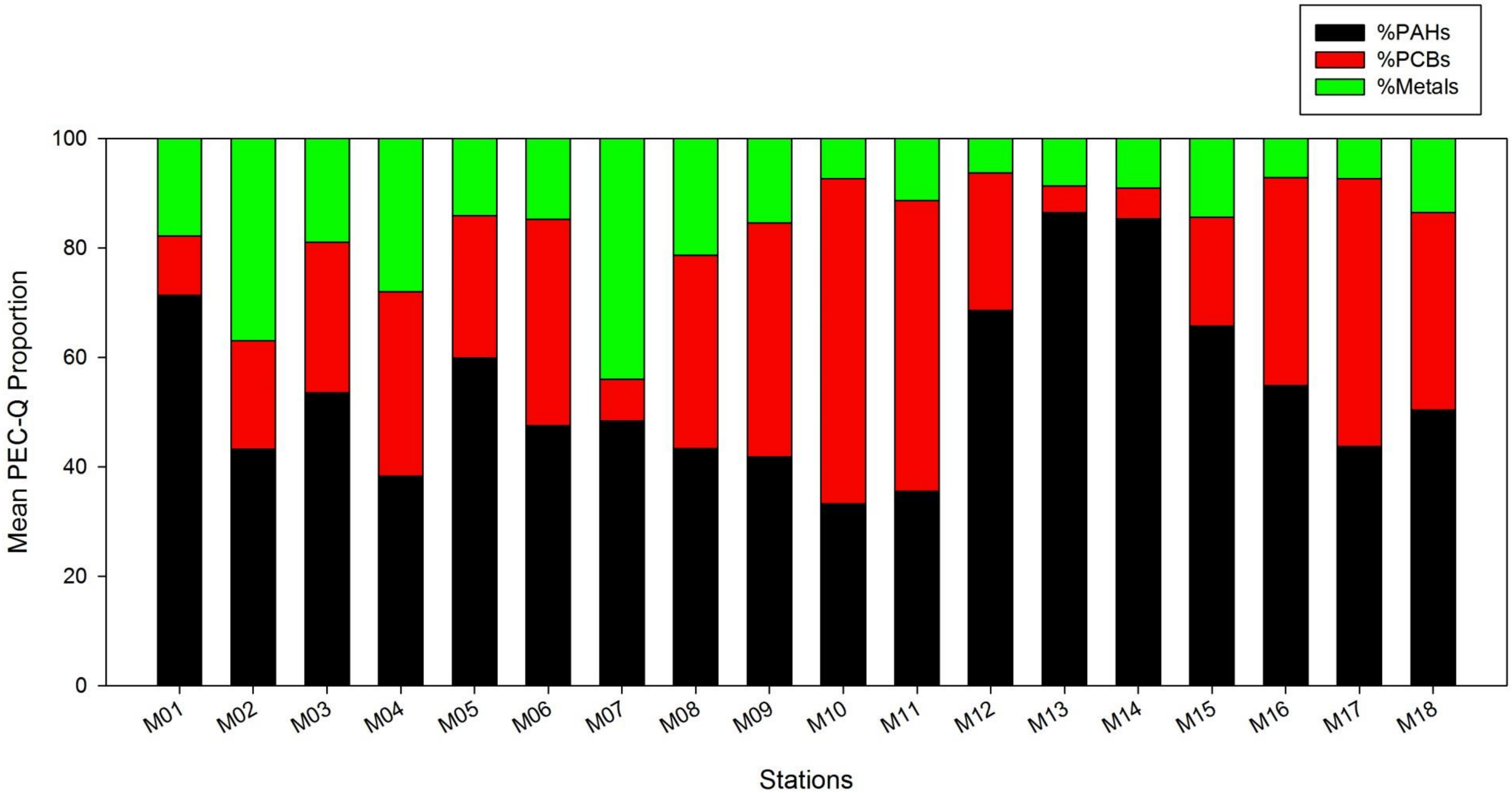

Figure 9. Major contaminant components of mean PEC-Qs for Milwaukee Estuary stations.

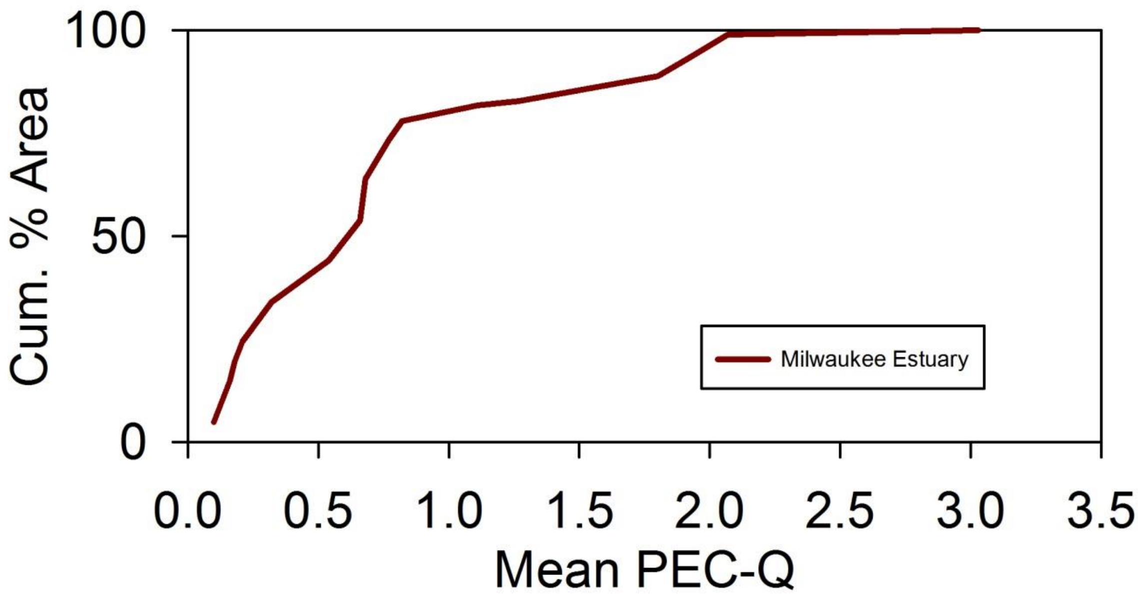

Figure 10. Cumulative Distribution Function (CDF) plot of percent Milwaukee Estuary survey area versus sediment contaminant concentrations (expressed as mean PEC-Qs).

3.2.3 Sediment Toxicity

Three different sediment bioassays were used to establish a weight-of-evidence for evaluating overall sediment toxicity in samples from each of the 18 stations (Figures 11, 15). Based on the three bioassays, sediment toxicity was characterized as either low (none of 3 assay hits = Green in Figure 11), moderate (1 of 3 hits = yellow), high (2 of 3 hits = orange), or very high (3 of 3 hits = red).

Whole-sediment amphipod bioassays, using *Hyalella azteca*, were considered toxic when survival relative to the controls was significantly different ($p \leq 0.05$) and less than 80% of control survival. Sixteen of the 18 stations located in the Milwaukee Estuary were determined to be toxic based on this assay (Table 9).

Microtox solid-phase tests were considered toxic when EC50s were significantly lower ($p \leq 0.05$) than reference-site sediments. Five of the 18 Milwaukee Estuary stations were determined to be toxic relative to reference sediments for this test (Table 9).

Microtox solvent-extract tests were considered toxic when EC50s were significantly lower ($p \leq 0.05$) than reference-site sediments. Nine of the 18 Milwaukee Estuary stations were determined to be toxic relative to reference sediments for this test (Table 9).

By combining results of the three toxicity assays into one overall decision, eight of the 18 Milwaukee Estuary stations were found to have low to moderate levels of toxicity (Table 9).

Spatially these stations represented 40% of the survey area (Figure 11). The remaining 10 stations with high to very high sediment toxicity represented the majority (60%) of the overall Milwaukee survey area and included sites in the harbor and all three rivers (Figures 11, 15).

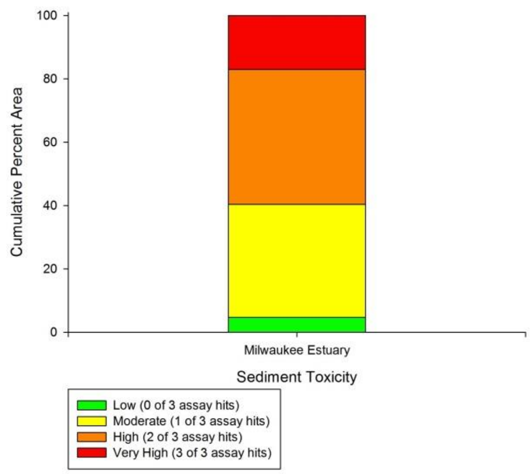

Figure 11. Percent area of the Milwaukee Estuary vs. sediment toxicity scores.

Table 9. Results of three toxicity tests for Milwaukee Estuary stations: Microtox Solid Phase Assay, Microtox Solvent Extract, and *Hyalella azteca* Mean Survival. Gray-shaded cells indicate that the individual toxicity test results for the station sample are considered to be toxic. Overall sediment toxicity at each station, based on the three bioassays combined, was characterized as low (none of 3 assay hits = Green), moderate (1 of 3 hits = yellow), high (2 of 3 hits = orange), and very high (3 of 3 hits = red).

Station	Solid Phase Microtox Mean EC50 (g/mL dry wgt.) (S.D.)	Solvent Extract Microtox 5 Minute Mean EC50 (mg/mL dry wgt.) (S.D.)	*Hyalella azteca* Mean Survival (%) (S.D.)	Overall Toxicity
M01	0.0112 (0.0007)	0.0384 (0.0024)	21.25 (3.9438)	Orange
M02	0.003 (0.0005)	0.0453 (0.0085)	55 (3.8914)	Green
M03	0.0228 (0.0018)	0.09 (0.0051)	18.75 (3.2266)	Yellow
M04	0.0026 (0.0002)	0.0389 (0.0051)	6.25 (1.1877)	Orange
M05	0.0048 (0.0006)	0.0418 (0.0032)	5 (1.4142)	Yellow
M06	0.0052 (0.001)	0.0371 (0.0055)	7.5 (1.165)	Orange
M07	0.0006 (0)	0.06 (0.0021)	40 (2)	Orange
M08	0.0013 (0.0002)	0.0368 (0.0028)	25 (3.295)	Red
M09	0.0048 (0.0007)	0.0782 (0.016)	0 (0)	Yellow
M10	0.0017 (0.0001)	0.0215 (0.0039)	61.25 (2.4165)	Orange
M11	0.0009 (0.0001)	0.0359 (0.0035)	5 (1.069)	Red
M12	0.0075 (0.0009)	0.0551 (0.0029)	57.5 (2.9155)	Yellow
M13	0.0016 (0.0003)	0.0124 (0.0016)	25 (2.5071)	Red
M14	0.0022 (0.0004)	0.0237 (0.0039)	5 (0.7559)	Orange
M15	0.0037 (0.0004)	0.046 (0.0045)	42.5 (2.6049)	Yellow
M16	0.003 (0.0004)	0.0299 (0.0041)	71.25 (2.3566)	Orange
M17	0.014 (0.0025)	0.1173 (0.0158)	30 (2.3905)	Yellow
M18	0.0066 (0.0007)	0.0634 (0.0073)	42.5 (2.6049)	Yellow
Willow Hall Pond, SC	0.0254 (0.0056)	8.05 (0.5883)	N/A	N/A
Formulated Control	N/A	N/A	98.75 (0.336)	N/A

3.3 Status of Benthic Communities

Macroinvertebrate benthic infauna (> 0.5 mm) were sampled from three separate grab samples (0.04 m^2 each) at each of the 18 stations resulting in a total of 36 samples. Replicate samples were averaged for the calculation of CDFs and other analysis purposes. The resulting data were used to assess the status of benthic community characteristics (taxonomic composition, diversity, abundance, and dominant species), spatial patterns, and potential linkages to ecosystem stressors.

3.3.1 Taxonomic Composition

A total of 82 taxa where identified to the lowest possible taxonomic level from 18 stations, of which 48 were identified to the species level. Oligochaeta was the dominant taxonomic group, both by raw abundance (86%) and number of taxa (56%; Figure 12). Insecta was the second most dominant group, both by raw abundance (9%) and number of taxa (28%). Mollusca was the third most dominant group, both by raw abundance (4%) and number of taxa (9%).

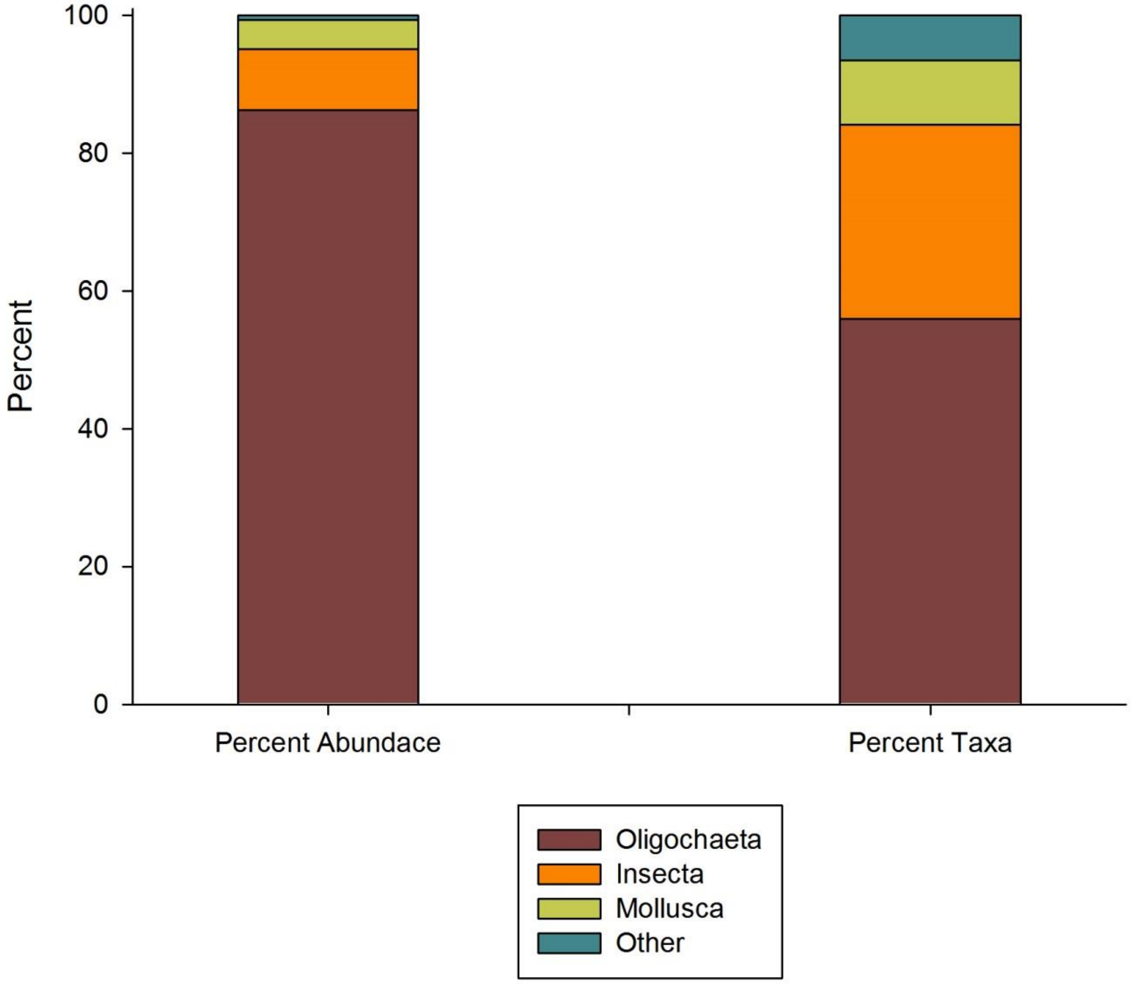

Figure 12. Relative percent composition of major taxonomic groups expressed as percentage of total taxa and of abundance for Milwaukee Estuary invertebrate communities.

3.3.2 Abundance and Diversity

A total of 53,001 individual specimens were collected across the 18 stations (54, 0.04-m^2 grab samples) that were sampled. Densities ranged from 42 to 83,608/m^2 and averaged 24,538/m^2 (Figure 13, Table 10, Appendix B). One replicate at station M07 was devoid of benthic fauna while the other two replicates had a total of 5 individuals. Spatially, 50% of the survey area had densities > 13,379 m^2 and 10% of the area had densities > 31,790 m^2 (Figure 13, Table 10). Such density numbers reflect the variety of responses that benthic communities may exhibit in response to pollution, ranging from population irruptions of a few pollution-tolerant taxa to a void of all taxa.

Species richness ranged from 1 to 17 taxa per grab and averaged 10 taxa per grab (Figure 13, Table 10, Appendix B). Approximately 50% of the survey area had > 8 taxa per grab and 10% of the area had > 11 taxa per grab. Diversity values, expressed as H′, ranged from 0.33 to 2.78 per grab and averaged 1.95 per grab (Figure 13, Table 10, Appendix B). Approximately 50% of the survey area had H′ > 2.07 per grab and 10% of the area had H′ > 2.65 per grab. The lowest taxa richness was observed in the southern portion of the Milwaukee Harbor as well as portions of the Kinnickinnic River (Figure 14).

Table 10. Mean, range, and selected properties of key benthic variables from Milwaukee Estuary stations (3 replicate 0.04 m^2 grab samples per station).

	Mean	Range	CDF 10th%	CDF 50th%	CDF 90th%
H'	1.95	0.33 – 2.78	0.34	2.07	2.65
N1	8.20	1.57 – 16.23	1.72	8.22	14.43
# Taxa	10	1 - 17	2	8	11
Density (#/m^2)	24,538	42 – 83,608	476	13,379	31,790

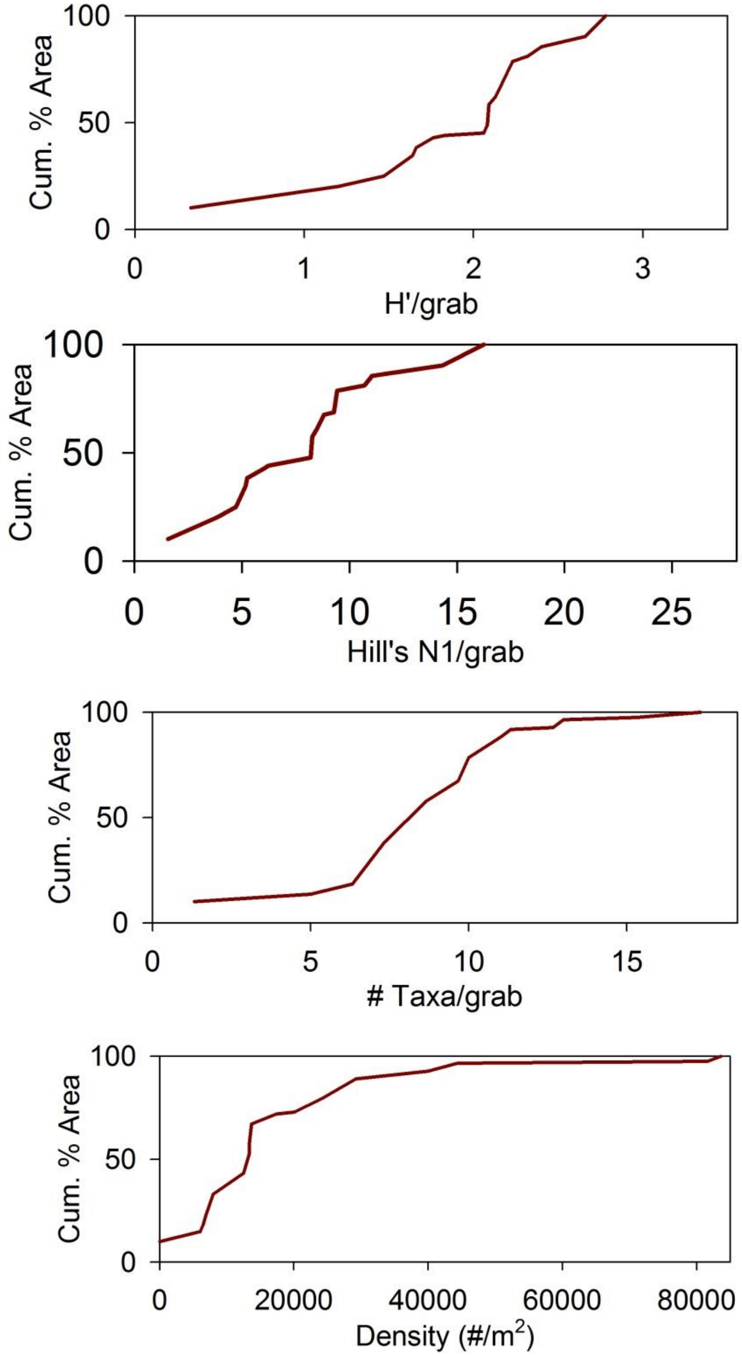

Figure 13. Percent area of the Milwaukee Estuary vs. select benthic community characteristics.

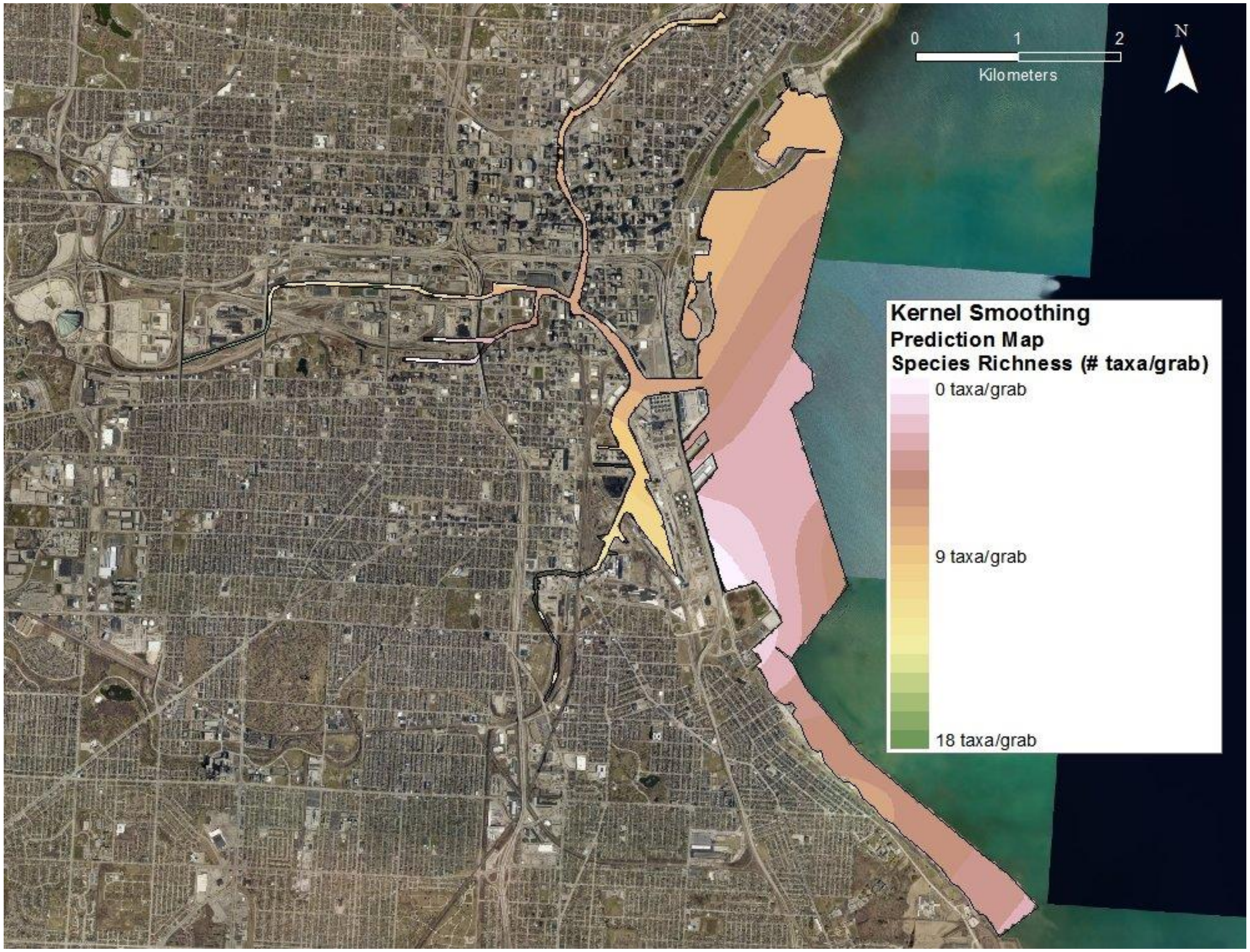

Figure 14. Species Richness (#taxa/grab) within the Milwaukee Estuary. Species Richness data were analyzed in ArcMap's Geostatisical Analyst using Kernel Smoothing with Barriers.

3.3.3 Community Analysis

Health of resident benthic infaunal communities (animals sampled with 0.04 m^2 grab, sieved on a 0.5-mm screen, and identified to species wherever possible) was assessed based on benthic condition using the species-level modified Hilsenhoff Benthic Index (HBI) (Hilsenhoff 1982, 1987; Mandaville 2002). HBI scores can range from 0 (high percentage of pollution-sensitive species) to 10 (high percentage of pollution-tolerant species). HBI scores were ranked as follows: 0.00 - 4.50 = excellent to very good (green in Figure 19); 4.51 – 6.50 = good to fair (yellow); 6.51 – 8.50 = moderately poor to poor (orange); and 8.51 – 10.00 = very poor (red).

HBI scores ranged from 8.5 to 9.9 and averaged 9.5 (Table 11), indicating moderately poor to very poor benthic condition across the 18 stations. Average HBI scores were highest in the Menomonee and Kinnickinnic Rivers and lowest in the Harbor. High HBI scores reflected the high densities of pollution-tolerant taxa relative to sensitive taxa.

3.4 Potential Linkage of Biological Condition to Stressor Impacts

Combined results of the sediment quality triad (SQT, Figure 15) provided evidence of impaired benthic condition and poor sediment quality throughout the Milwaukee survey area, although to lesser degrees in some areas than others. High HBI scores, > 6.5 indicative of moderately poor to very poor benthic condition, co-occurred with high to very high levels of sediment contamination or toxicity (orange or red codes) at all but one of the sampling sites (M03 in lower harbor). Hits (orange or red codes) in all three legs of the SQT occurred at seven of these stations, five of which were in the upper portions of the three river strata. The more open-water harbor stratum contained the only station (M02) without significant sediment toxicity in all three bioassays (green code for corresponding triad leg) and the only three stations (M01, M03, and M07) without high to very high levels of sediment contamination (yellow codes for corresponding triad leg). The harbor stratum also contained the only station (M03 in lower harbor) with a degraded benthos but without high to very high levels of both sediment contamination and toxicity.

Table 11. Mean values of key sediment-quality variables for Milwaukee Estuary stations.

System	# Taxa	Hill's N1	H'	Density (#/m^2)	HBI	TOC (mg/g)	% Silt-Clay	Mean PEC-Q	#TECs exceeded	#PECs exceeded
Overall (n=18)	10	8.2	1.9	24538	9.5	34.0	78	1.027	11	6
Milwaukee River (n=3)	10	9.3	2.2	23661	9.6	43.7	85	1.336	10	7.3
Menomonee River (n=3)	12	8.1	2.0	44831	9.7	66.1	94	1.76	10.7	10.7
Kinnickinnic River (n=3)	13	8.5	2.1	40872	9.7	33.8	64	1.857	10	11
Harbor (n=9)	8	7.7	1.8	12620	9.4	20.1	74	0.403	12	2.2

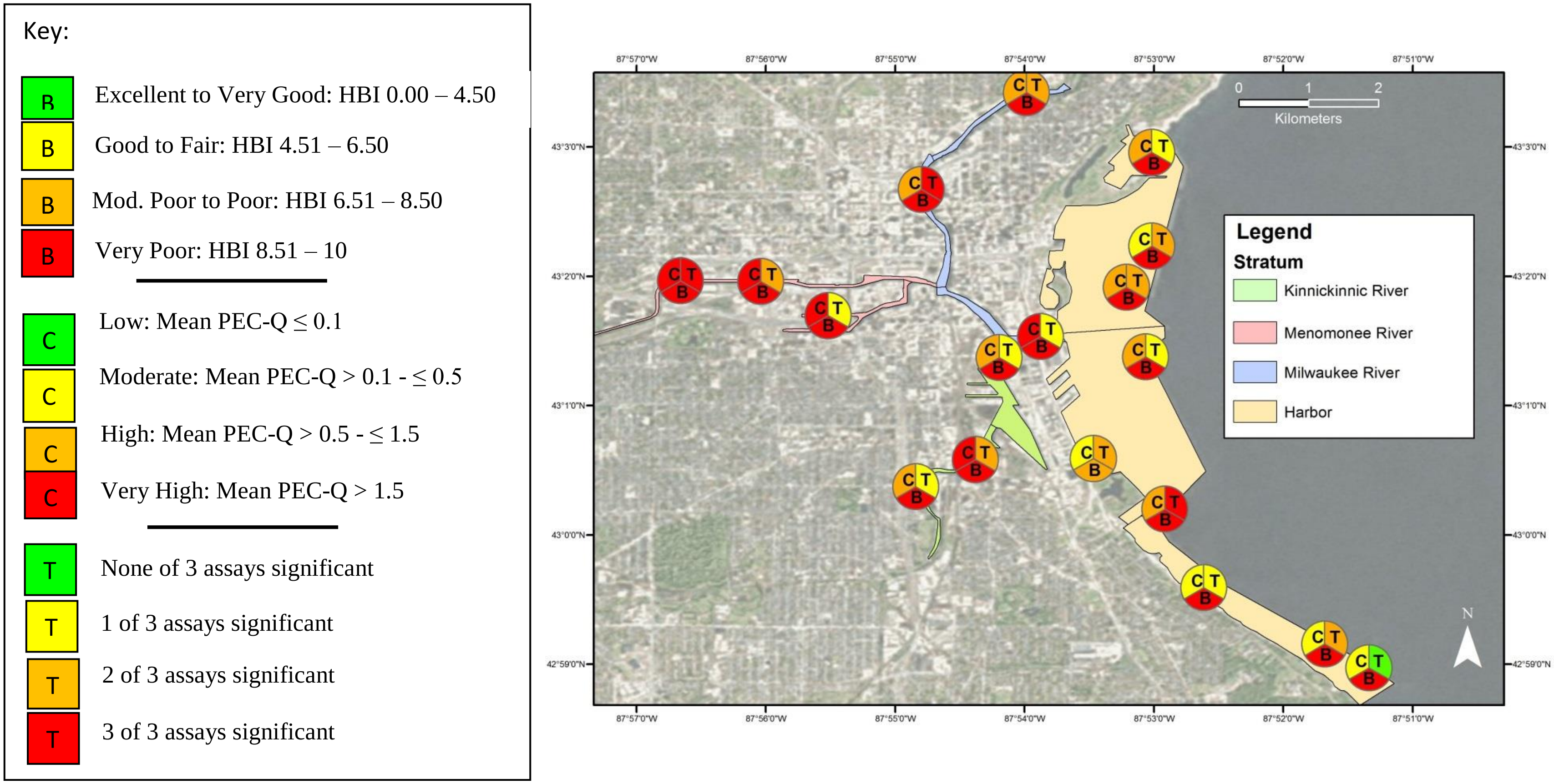

Figure 15. Sediment Quality Triad results for Milwaukee. In the key, B = Benthic condition based on species-level modified Hilsenhoff Benthic Index (HBI); C = Mean PEC-Qs in sediments; T = Toxicity based on 3 sediment bioassays.

4.0 Acknowledgements

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Appendix A. Chemical analysis results for Milwaukee Estuary stations.

Station	Ag ug/g dry	Al ug/g dry	As ug/g dry	Ba ug/g dry	Be ug/g dry	Cd ug/g dry	Co ug/g dry	Cr ug/g dry
M01	< MDL	10690	2.82	280	0.433	0.286	5.06	19.0
M02	< MDL	10645	2.57	271	0.378	0.305	5.79	21.6
M03	< MDL	8367	2.40	312	0.395	0.319	6.09	21.9
M04	0.476	20470	4.02	293	0.733	1.026	8.58	60.8
M05	0.470	15050	3.24	287	0.565	1.365	7.14	70.2
M06	0.774	19888	4.54	304	0.681	1.484	8.31	75.3
M07	0.201	21873	3.76	300	0.812	0.472	8.84	49.2
M08	0.642	28179	4.24	326	1.020	1.152	9.65	87.8
M09	< MDL	52332	3.67	319	1.54	0.420	7.67	82.5
M10	0.379	16855	3.03	278	0.624	0.850	8.80	40.9
M11	0.455	18313	3.25	294	0.632	0.857	8.03	52.8
M12	1.193	15206	4.27	329	0.570	1.529	9.87	74.2
M13	0.323	18567	4.68	292	0.694	1.042	10.14	69.2
M14	0.614	27455	6.27	337	0.867	1.258	10.42	74.2
M15	0.699	37512	5.88	353	0.945	1.785	12.43	79.1
M16	0.796	25171	6.49	332	0.893	2.382	10.90	113.9
M17	< MDL	6119	2.12	184	0.351	1.463	7.47	46.4
M18	0.950	28313	6.57	349	0.916	2.125	12.38	113.9
Hyalella Control	< MDL	30376	< MDL	77	0.419	< MDL	0.532	7.4
EPA Formulated	< MDL	32976	< MDL	112	0.435	< MDL	0.568	8.3
Willow Hall Reference	< MDL	74813	7.35	311	0.128	0.179	2.88	47.2

Appendix A. Contiuned.

Station	Cu ug/g dry	Fe ug/g dry	Hg ug/g dry	Li ug/g dry	Mn ug/g dry	Ni ug/g dry	Pb ug/g dry	Sb ug/g dry
M01	12.0	12255	0.027	9.6	328	9.8	15.5	< MDL
M02	8.9	11389	0.020	10.1	284	9.2	13.2	< MDL
M03	7.2	12990	0.026	7.0	266	7.4	13.5	< MDL
M04	34.1	17721	0.086	22.9	476	18.8	39.9	< MDL
M05	37.2	15673	0.105	16.1	370	14.6	38.5	< MDL
M06	46.5	20761	0.144	19.8	535	19.1	60.9	< MDL
M07	21.7	24863	0.097	26.4	667	21.8	22.5	< MDL
M08	39.8	22897	0.110	29.2	530	23.1	50.1	< MDL
M09	28.9	36220	0.126	50.7	447	30.9	55.3	< MDL
M10	33.0	17230	0.093	15.1	558	16.8	59.3	< MDL
M11	40.8	17243	0.089	16.1	739	16.7	89.6	< MDL
M12	59.0	19133	0.133	16.4	644	19.9	106.4	< MDL
M13	97.7	22512	0.107	18.2	520	26.4	85.6	2.71
M14	95.0	25729	0.133	24.8	560	27.1	91.0	2.65
M15	221.8	28748	0.263	22.2	657	26.8	105.6	1.95
M16	103.9	25783	0.184	24.3	447	32.4	173.9	3.00
M17	20.6	12723	0.028	6.5	408	12.3	91.4	2.95
M18	74.4	26028	0.200	25.9	764	24.6	99.4	1.51
Hyalella Control	1.3	666	0.007	5.2	8.37	2.9	12.0	< MDL
EPA Formulated	1.7	615	0.010	5.1	4.38	3.5	13.0	< MDL
Willow Hall Reference	4.0	25400	0.119	24.0	79	22.5	40.0	1.88

Appendix A. Contiuned.

Station	Se ug/g dry	Sn ug/g dry	Tl ug/g dry	U ug/g dry	V ug/g dry	Zn ug/g dry
M01	0.394	1.28	0.282	1.07	29.4	63.2
M02	0.437	2.07	0.291	1.14	33.0	72.7
M03	< MDL	1.65	0.289	1.04	36.1	73.8
M04	0.606	3.59	0.380	1.62	46.1	137.1
M05	0.501	3.43	0.322	1.28	38.3	131.9
M06	0.681	4.60	0.377	1.52	42.8	184.4
M07	0.394	2.29	0.390	1.80	56.4	86.6
M08	0.641	4.27	0.435	1.89	52.6	166.8
M09	0.585	4.30	0.355	1.47	43.7	121.9
M10	0.649	5.54	0.340	1.23	38.3	153.4
M11	0.615	4.15	0.323	1.18	38.6	152.9
M12	0.589	9.81	0.376	1.32	42.4	226.5
M13	0.592	7.80	0.405	1.54	45.8	396.5
M14	0.662	6.76	0.503	1.73	56.7	467.2
M15	0.766	14.16	0.506	2.02	55.3	532.5
M16	0.626	10.16	0.484	1.93	53.0	454.6
M17	< MDL	9.66	0.195	1.03	33.4	240.5
M18	0.807	7.35	0.509	1.83	52.5	304.7
Hyalella Control	< MDL	0.58	< MDL	3.94	10.1	6.1
EPA Formulated	0.322	0.77	< MDL	4.44	9.3	6.6
Willow Hall Reference	1.429	2.25	0.315	3.51	80.3	47.1

Appendix A. Contiuned.

Station	2,4'-DDD ng/g dry	2,4'-DDE ng/g dry	2,4'-DDT ng/g dry	4,4'-DDD ng/g dry	4,4'-DDE ng/g dry	4,4'-DDT ng/g dry	TOTAL DDT ng/g dry	Aldrin ng/g dry	Alpha-HCH ng/g dry
M01	< MDL	< MDL	< MDL	1.68	2.94	0.511	5.13	< MDL	< MDL
M02	0.467	0.074	< MDL	1.53	2.12	< MDL	4.19	0.078	< MDL
M03	< MDL	0.127	< MDL	3.46	4.22	< MDL	7.81	0.053	< MDL
M04	1.25	0.323	< MDL	4.34	9.05	1.478	16.45	0.102	< MDL
M05	< MDL	< MDL	< MDL	5.90	15.56	< MDL	21.46	< MDL	< MDL
M06	2.02	< MDL	17.509	7.48	18.60	4.068	49.68	0.187	< MDL
M07	< MDL	< MDL	< MDL	0.84	0.71	< MDL	1.55	< MDL	< MDL
M08	1.52	< MDL	25.26	6.11	12.81	13.041	58.74	< MDL	< MDL
M09	< MDL	< MDL	< MDL	6.09	14.29	< MDL	20.37	0.120	< MDL
M10	3.01	0.720	< MDL	14.19	20.45	7.785	46.15	0.256	< MDL
M11	2.53	0.272	10.720	7.23	10.58	1.827	33.16	0.272	< MDL
M12	2.74	< MDL	< MDL	11.75	27.22	< MDL	41.71	< MDL	< MDL
M13	3.23	< MDL	< MDL	17.66	61.65	10.012	92.55	< MDL	< MDL
M14	5.19	< MDL	< MDL	19.50	79.52	12.960	117.17	0.297	< MDL
M15	< MDL	< MDL	< MDL	15.98	44.34	7.209	67.54	0.210	< MDL
M16	7.38	< MDL	< MDL	25.58	34.78	8.284	76.03	0.365	< MDL
M17	1.97	< MDL	< MDL	8.77	9.28	1.915	21.94	0.764	< MDL
M18	< MDL	< MDL	< MDL	16.24	29.70	7.711	53.65	0.305	< MDL
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	0.00	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	0.046	0.05	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	Beta-HCH ng/g dry	Chlorpyrifos ng/g dry	Cis-chlordane ng/g dry	Cis-nonachlor ng/g dry	Dieldrin ng/g dry	Endosulfan I ng/g dry	Endosulfan II ng/g dry	Endosulfan Sulfate ng/g dry
M01	< MDL	0.407	0.301	0.089	0.240	< MDL	< MDL	0.050
M02	< MDL	0.269	0.170	0.071	0.311	< MDL	< MDL	0.051
M03	< MDL	0.235	0.185	0.052	0.294	< MDL	< MDL	0.029
M04	< MDL	0.198	0.519	0.180	0.326	< MDL	< MDL	0.065
M05	< MDL	0.229	0.568	0.287	0.337	< MDL	< MDL	0.061
M06	< MDL	0.261	1.227	0.385	0.498	< MDL	0.063	0.094
M07	< MDL	0.126	0.071	0.025	< MDL	< MDL	< MDL	0.023
M08	< MDL	0.268	0.830	0.314	0.454	< MDL	0.061	0.099
M09	< MDL	0.244	1.067	0.333	0.439	< MDL	< MDL	0.066
M10	< MDL	0.475	2.082	0.551	0.773	0.211	0.094	0.140
M11	< MDL	0.369	1.174	0.400	0.603	< MDL	< MDL	0.075
M12	< MDL	0.488	2.340	0.679	0.891	< MDL	0.086	0.148
M13	< MDL	3.502	5.513	1.169	0.960	1.355	0.260	0.352
M14	< MDL	1.871	7.226	1.639	1.141	< MDL	0.277	0.335
M15	< MDL	0.881	3.179	0.911	0.665	< MDL	0.089	0.133
M16	< MDL	1.770	6.479	1.524	1.111	1.968	0.167	0.169
M17	< MDL	0.383	1.191	0.218	0.205	0.746	0.049	0.024
M18	< MDL	0.700	< MDL	0.755	0.838	< MDL	0.087	0.152
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	Endrin ng/g dry	Gamma-chlordane ng/g dry	Gamma-HCH ng/g dry	Heptachlor ng/g dry	Heptachlor epoxide ng/g dry	Hexachlorobenzene ng/g dry	Mirex ng/g dry	Oxychlordane ng/g dry	Trans-nonachlor ng/g dry
M01	< MDL	0.255	< MDL	< MDL	< MDL	0.134	< MDL	< MDL	0.169
M02	< MDL	0.147	< MDL	< MDL	< MDL	0.106	< MDL	< MDL	0.127
M03	< MDL	0.207	< MDL	< MDL	< MDL	0.392	< MDL	< MDL	0.106
M04	< MDL	0.477	< MDL	< MDL	< MDL	0.902	< MDL	< MDL	0.321
M05	< MDL	0.548	< MDL	< MDL	< MDL	0.563	< MDL	< MDL	0.422
M06	< MDL	1.142	< MDL	< MDL	0.264	1.354	< MDL	< MDL	0.713
M07	< MDL	0.066	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	0.041
M08	< MDL	0.806	< MDL	< MDL	0.169	0.984	< MDL	< MDL	0.556
M09	< MDL	1.016	< MDL	< MDL	< MDL	0.722	< MDL	< MDL	0.593
M10	< MDL	1.973	0.260	< MDL	0.309	0.415	< MDL	0.332	1.173
M11	< MDL	1.049	< MDL	< MDL	< MDL	0.216	< MDL	< MDL	0.631
M12	< MDL	2.120	< MDL	< MDL	0.166	0.813	0.035	< MDL	1.325
M13	< MDL	4.195	< MDL	< MDL	0.502	1.040	< MDL	0.707	2.934
M14	< MDL	5.795	< MDL	< MDL	0.598	1.441	0.055	0.536	4.094
M15	< MDL	2.786	< MDL	< MDL	0.278	0.695	0.047	0.290	1.925
M16	< MDL	6.005	< MDL	< MDL	0.460	1.364	0.099	0.383	3.427
M17	< MDL	1.285	< MDL	< MDL	< MDL	0.197	0.014	0.093	0.516
M18	< MDL	2.304	< MDL	< MDL	0.326	0.655	0.024	0.294	1.403
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	0.284	< MDL	< MDL

Appendix A. Contiuned.

Station	PBDE 100 ng/g dry	PBDE 138 ng/g dry	PBDE 153 ng/g dry	PBDE 154 ng/g dry	PBDE 17 ng/g dry	PBDE 183 ng/g dry	PBDE 190 ng/g dry	PBDE 28 ng/g dry	PBDE 47 ng/g dry
M01	0.117	< MDL	0.058	0.054	< MDL	0.045	< MDL	< MDL	0.323
M02	0.097	< MDL	0.060	0.062	< MDL	< MDL	< MDL	< MDL	0.260
M03	0.080	< MDL	0.025	0.027	< MDL	< MDL	< MDL	< MDL	0.317
M04	0.417	< MDL	0.206	0.183	< MDL	0.073	< MDL	< MDL	1.319
M05	0.375	0.034	0.114	0.141	< MDL	< MDL	< MDL	< MDL	1.196
M06	0.740	< MDL	0.377	0.369	< MDL	0.094	< MDL	< MDL	2.917
M07	0.043	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	0.154
M08	1.022	< MDL	0.477	0.506	< MDL	< MDL	< MDL	< MDL	3.001
M09	0.654	< MDL	0.310	0.305	< MDL	0.110	< MDL	< MDL	< MDL
M10	0.498	< MDL	0.158	0.177	< MDL	< MDL	< MDL	< MDL	1.829
M11	0.097	0.087	0.197	0.200	0.187	0.272	< MDL	1.787	1.212
M12	0.813	< MDL	0.394	0.676	< MDL	< MDL	< MDL	< MDL	3.536
M13	1.967	< MDL	0.755	1.029	< MDL	< MDL	< MDL	< MDL	7.037
M14	2.206	< MDL	1.356	1.236	< MDL	0.881	< MDL	0.495	8.083
M15	1.547	< MDL	0.878	0.849	< MDL	0.689	< MDL	< MDL	4.749
M16	1.747	< MDL	0.895	0.910	< MDL	0.355	< MDL	< MDL	5.784
M17	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
M18	0.679	< MDL	0.478	0.464	< MDL	< MDL	< MDL	< MDL	3.585
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	PBDE 66 ng/g dry	PBDE 71 ng/g dry	PBDE 85 ng/g dry	PBDE 99 ng/g dry	1,6,7 Trimethylnaphthalene ng/g dry	1-Methylnaphthalene ng/g dry	1-Methylphenanthrene ng/g dry
M01	< MDL	< MDL	< MDL	0.461	49.6	76.3	123.9
M02	< MDL	< MDL	< MDL	0.347	24.7	25.7	42.2
M03	< MDL	< MDL	< MDL	0.386	79.9	87.5	101.4
M04	< MDL	< MDL	< MDL	2.107	41.7	31.0	63.2
M05	< MDL	< MDL	< MDL	1.187	59.8	< MDL	220.6
M06	< MDL	< MDL	< MDL	3.517	68.1	76.5	170.2
M07	< MDL	< MDL	< MDL	0.266	68.8	22.7	166.1
M08	< MDL	< MDL	< MDL	4.523	76.5	60.9	99.0
M09	< MDL	< MDL	< MDL	2.383	68.4	69.4	159.5
M10	< MDL	< MDL	< MDL	2.689	58.5	< MDL	387.3
M11	2.771	0.762	0.153	1.652	47.0	< MDL	127.6
M12	< MDL	< MDL	< MDL	4.829	245.8	237.4	1340.3
M13	< MDL	< MDL	< MDL	12.500	125.7	< MDL	560.1
M14	< MDL	< MDL	< MDL	12.109	80.0	< MDL	528.4
M15	< MDL	< MDL	< MDL	7.632	2493.8	1651.8	770.4
M16	< MDL	< MDL	< MDL	8.525	329.7	< MDL	671.5
M17	< MDL	< MDL	< MDL	0.738	120.9	< MDL	393.8
M18	< MDL	< MDL	< MDL	3.239	214.7	< MDL	291.3
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	6.6	< MDL	15.3

Appendix A. Contiuned.

Station	2,6 Dimethylnaphthalene ng/g dry	2-Methylnaphthalene ng/g dry	Acenaphthene ng/g dry	Acenaphthylene ng/g dry	Anthracene ng/g dry	Benzo(a)anthracene ng/g dry
M01	42.6	104.5	135.0	293.6	< MDL	685.8
M02	< MDL	38.7	43.4	57.4	< MDL	205.4
M03	64.0	163.2	113.6	180.7	< MDL	383.4
M04	26.2	48.9	44.7	150.2	< MDL	468.2
M05	< MDL	< MDL	209.3	344.1	764.0	2038.0
M06	57.0	115.9	116.1	613.3	< MDL	1968.0
M07	45.6	37.1	220.5	171.4	3.9	344.8
M08	< MDL	91.3	79.9	440.7	314.1	815.8
M09	49.0	104.4	103.7	451.4	471.9	1189.6
M10	< MDL	< MDL	160.6	444.6	758.6	1596.3
M11	< MDL	< MDL	134.1	434.8	< MDL	1357.1
M12	< MDL	< MDL	494.3	2473.8	3122.9	6914.6
M13	< MDL	< MDL	368.9	996.9	1401.2	5207.4
M14	< MDL	< MDL	313.8	1050.8	1212.6	4820.5
M15	787.4	1899.6	401.6	983.2	998.8	2654.0
M16	< MDL	< MDL	663.8	1580.8	2358.7	7177.8
M17	< MDL	< MDL	371.6	580.8	1120.6	2372.4
M18	< MDL	< MDL	174.7	1001.3	1045.0	2134.1
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	Benzo(a)anthracene ng/g dry	Benzo(a)pyrene ng/g dry	Benzo(b)fluoranthene ng/g dry	Benzo(e)pyrene ng/g dry	Benzo(g,h,i)perylene ng/g dry	Benzo(j+k)fluoranthene ng/g dry	Biphenyl ng/g dry
M01	685.8	607.5	715.3	571.7	560.3	622.8	34.2
M02	205.4	174.9	211.0	173.3	161.0	227.3	10.8
M03	383.4	329.6	335.5	264.6	252.8	305.5	41.7
M04	468.2	538.7	770.5	573.1	582.8	611.4	14.2
M05	2038.0	1731.7	1975.8	1713.8	1489.3	2023.6	< MDL
M06	1968.0	1892.7	2821.0	2096.3	1763.1	1323.0	33.9
M07	344.8	243.8	215.1	198.9	183.0	279.4	15.4
M08	815.8	986.8	1695.6	1187.0	1180.1	1091.5	25.3
M09	1189.6	1199.8	1840.2	1061.4	1253.1	1216.5	29.7
M10	1596.3	1435.4	1896.0	1726.5	1284.0	2016.5	< MDL
M11	1357.1	1186.9	2067.7	1592.3	1411.5	1253.3	27.5
M12	6914.6	5309.4	6692.1	5811.3	4996.7	6992.5	105.7
M13	5207.4	4897.3	9664.4	7083.3	7297.5	7737.7	< MDL
M14	4820.5	5411.2	11549.3	8274.2	8214.5	8650.3	< MDL
M15	2654.0	4163.6	6124.7	4750.6	4268.0	4840.1	503.1
M16	7177.8	5790.0	9696.0	7332.7	6977.8	7563.1	< MDL
M17	2372.4	1988.6	2533.3	1947.5	1475.0	2505.0	< MDL
M18	2134.1	2536.3	4272.6	3415.5	3147.9	4154.8	< MDL
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	6.3	2.5	2.0	2.5	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	Chrysene+Triphenylene ng/g dry	Dibenz(a,h)anthracene ng/g dry	Dibenzothiophene ng/g dry	Fluoranthene ng/g dry	Fluorene ng/g dry
M01	843.7	126.4	66.4	1824.3	160.1
M02	247.9	37.6	23.9	537.5	46.4
M03	369.9	63.8	57.8	974.2	148.7
M04	700.8	124.4	34.2	1330.6	66.3
M05	2166.3	352.9	100.6	4523.9	220.7
M06	2292.2	310.6	89.1	4073.0	160.0
M07	319.4	45.4	70.9	825.7	144.5
M08	1225.3	247.5	57.0	2104.5	114.7
M09	1853.4	258.8	67.7	3310.7	134.1
M10	2105.1	316.8	91.2	4287.5	204.5
M11	< MDL	248.0	86.8	3748.8	180.7
M12	7615.7	1223.7	358.9	15285.2	814.7
M13	9072.5	1536.2	382.2	19049.5	495.2
M14	9738.4	1594.0	339.1	19118.9	406.3
M15	5000.6	861.4	285.1	9388.2	538.7
M16	8589.0	1537.4	453.4	19478.6	825.6
M17	2737.0	385.9	263.8	7835.2	378.5
M18	3419.2	670.4	141.3	6242.6	306.4
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	7.8	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	Indeno(1,2,3-cd)pyrene ng/g dry	Naphthalene ng/g dry	Perylene ng/g dry	Phenanthrene ng/g dry	Pyrene ng/g dry
M01	542.9	293.0	205.1	< MDL	1682.8
M02	155.4	117.6	68.0	< MDL	407.6
M03	219.4	566.7	115.0	851.7	799.2
M04	549.2	73.7	184.7	542.3	1093.0
M05	1435.7	< MDL	607.9	1874.3	3802.6
M06	1665.1	169.9	534.6	< MDL	3229.4
M07	147.8	79.2	283.5	576.3	942.1
M08	1023.1	167.1	353.7	818.4	1978.9
M09	1232.0	170.2	381.8	< MDL	3048.2
M10	1299.8	< MDL	558.9	1836.7	3429.4
M11	1323.7	70.3	430.1	1672.8	3001.1
M12	4692.6	347.2	1624.2	7969.1	14168.4
M13	7026.8	< MDL	1790.9	7399.6	16213.5
M14	7429.1	< MDL	1473.5	6382.2	15888.0
M15	4076.6	1171.2	1159.8	4775.2	7534.5
M16	6699.7	641.0	1961.0	8041.1	17198.0
M17	1498.4	< MDL	569.7	3292.8	6122.9
M18	2821.9	382.4	979.8	2257.8	5154.1
Hyalella Control	< MDL	< MDL	24.9	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL
Willow Hall Reference	16.9	< MDL	287.1	< MDL	< MDL

Appendix A. Contiuned.

Station	PCB 1 ng/g dry	PCB 101 ng/g dry	PCB 103 ng/g dry	PCB 104 ng/g dry	PCB 105 ng/g dry	PCB 108/107/123 ng/g dry	PCB 110 ng/g dry	PCB 114 ng/g dry	PCB 118/106 ng/g dry
M01	< MDL	1.756	< MDL	< MDL	0.784	< MDL	1.479	< MDL	1.336
M02	< MDL	1.601	< MDL	< MDL	0.603	< MDL	1.390	< MDL	1.233
M03	< MDL	3.829	0.036	< MDL	1.391	0.320	3.637	0.166	2.650
M04	< MDL	7.543	0.102	< MDL	2.574	0.722	7.110	< MDL	5.700
M05	< MDL	< MDL	0.202	< MDL	4.831	1.205	14.293	< MDL	11.668
M06	< MDL	21.206	0.372	< MDL	6.421	< MDL	20.751	< MDL	15.412
M07	< MDL	1.032	< MDL	< MDL	< MDL	< MDL	0.778	< MDL	0.543
M08	< MDL	14.353	< MDL	< MDL	4.066	< MDL	13.818	< MDL	11.146
M09	< MDL	21.979	0.289	< MDL	6.024	1.705	20.715	< MDL	15.498
M10	< MDL	35.077	0.705	< MDL	11.164	3.477	41.141	0.996	28.310
M11	< MDL	24.226	0.478	< MDL	6.875	2.427	27.308	0.547	19.344
M12	< MDL	38.412	0.649	< MDL	11.236	3.332	37.883	1.500	27.782
M13	< MDL	7.059	< MDL	< MDL	< MDL	< MDL	6.601	< MDL	5.012
M14	< MDL	9.439	< MDL	< MDL	< MDL	< MDL	7.820	< MDL	7.632
M15	< MDL	25.034	< MDL	< MDL	< MDL	< MDL	20.291	< MDL	15.373
M16	< MDL	68.995	0.987	< MDL	21.919	5.898	63.028	2.038	49.788
M17	< MDL	21.050	0.390	< MDL	7.087	1.775	25.835	0.676	13.782
M18	< MDL	37.830	0.578	< MDL	10.818	4.323	34.632	< MDL	27.261
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	PCB 119 ng/g dry	PCB 12 ng/g dry	PCB 126 ng/g dry	PCB 128 ng/g dry	PCB 130 ng/g dry	PCB 132/153/168 ng/g dry	PCB 138/158 ng/g dry	PCB 141 ng/g dry
M01	< MDL	1.282	< MDL	0.173	< MDL	1.468	1.137	0.258
M02	< MDL	< MDL	< MDL	0.159	0.071	1.383	0.909	0.216
M03	0.099	1.305	0.213	0.333	0.088	2.090	1.532	0.345
M04	0.224	0.965	< MDL	1.004	0.318	8.764	5.682	1.340
M05	0.444	< MDL	< MDL	1.578	0.516	13.006	10.371	1.805
M06	0.702	1.060	< MDL	1.726	0.812	24.679	12.795	4.238
M07	< MDL	< MDL	< MDL	< MDL	< MDL	0.670	0.488	< MDL
M08	0.341	< MDL	< MDL	2.433	0.827	17.273	11.489	2.631
M09	0.751	0.927	< MDL	2.252	0.518	20.309	13.673	3.270
M10	1.422	< MDL	< MDL	3.142	1.064	21.800	15.057	3.100
M11	1.056	0.325	< MDL	1.946	0.715	16.267	11.023	2.252
M12	1.583	1.154	< MDL	3.799	1.046	29.523	19.028	4.065
M13	< MDL	< MDL	< MDL	1.484	< MDL	14.053	8.166	3.162
M14	< MDL	< MDL	< MDL	< MDL	< MDL	16.337	10.716	2.742
M15	< MDL	3.383	< MDL	3.673	< MDL	32.480	21.503	5.589
M16	2.684	1.504	< MDL	8.488	2.493	56.126	39.675	8.878
M17	0.769	< MDL	< MDL	1.703	0.507	10.178	7.452	1.633
M18	1.178	1.313	< MDL	4.184	1.379	32.506	19.696	5.037
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	0.056	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	0.120	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	PCB 146 ng/g dry	PCB 149 ng/g dry	PCB 15 ng/g dry	PCB 151 ng/g dry	PCB 154 ng/g dry	PCB 156 ng/g dry	PCB 157 ng/g dry	PCB 159 ng/g dry	PCB 164/163 ng/g dry	PCB 165 ng/g dry	PCB 167 ng/g dry
M01	0.197	0.723	< MDL	0.273	< MDL	< MDL	< MDL	< MDL	0.368	< MDL	< MDL
M02	0.170	0.644	0.630	0.228		0.110	< MDL	< MDL	0.267	< MDL	0.037
M03	0.251	1.067	1.617	0.358	0.012	0.185	< MDL	< MDL	0.479	< MDL	< MDL
M04	1.056	4.407	2.725	1.656	0.089	0.675	0.253	< MDL	2.013	< MDL	< MDL
M05	1.789	6.000	< MDL	2.299	0.207	< MDL	0.965	< MDL	1.351	< MDL	< MDL
M06	2.782	12.718	5.089	5.094	0.286	< MDL	1.362	< MDL	6.922	0.548	< MDL
M07	0.117	0.356	0.495	0.122	< MDL	< MDL	< MDL	< MDL	0.147	< MDL	< MDL
M08	2.113	8.709	3.615	3.147	0.253	1.595	< MDL	< MDL	3.924	< MDL	0.547
M09	2.287	10.605	6.739	4.028	0.209	< MDL	< MDL	< MDL	3.601	0.373	< MDL
M10	3.368	11.240	16.362	4.145	0.539	2.229	< MDL	< MDL	5.005	< MDL	0.728
M11	2.561	8.411	11.129	3.211	0.497	1.502	0.559	< MDL	2.742	< MDL	< MDL
M12	3.963	15.446	9.825	5.701	0.472	3.147	< MDL	< MDL	7.298	< MDL	< MDL
M13	1.399	6.858	< MDL	2.443	< MDL	< MDL	< MDL	< MDL	2.759	< MDL	< MDL
M14	1.742	8.691	< MDL	3.364	0.099	< MDL	< MDL	< MDL	3.852	< MDL	< MDL
M15	3.625	16.896	6.775	6.352	0.248	< MDL	< MDL	< MDL	5.719	< MDL	< MDL
M16	6.457	29.927	9.817	10.444	0.741	5.073	< MDL	< MDL	11.776	< MDL	< MDL
M17	1.298	6.361	18.661	2.274	0.137	0.842	< MDL	< MDL	2.981	< MDL	0.383
M18	3.970	17.060	7.520	6.575	0.582	3.921	< MDL	< MDL	7.319	< MDL	< MDL
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	PCB 169 ng/g dry	PCB 170/190 ng/g dry	PCB 172 ng/g dry	PCB 174 ng/g dry	PCB 177 ng/g dry	PCB 18 ng/g dry	PCB 180/193 ng/g dry	PCB 183 ng/g dry	PCB 184 ng/g dry
M01	< MDL	0.266	< MDL	0.338	0.182	1.074	0.704	0.132	< MDL
M02	< MDL	0.212		0.299	0.161	0.964	0.610	0.097	< MDL
M03	< MDL	0.333	0.027	0.414	0.214	3.296	0.781	0.159	< MDL
M04	< MDL	2.860	0.433	3.045	1.710	4.579	6.047	1.413	< MDL
M05	< MDL	3.733	0.689	4.249	2.537	7.913	8.281	1.872	< MDL
M06	< MDL	8.507	1.255	9.693	5.463	14.644	17.537	4.412	< MDL
M07	< MDL	0.096	< MDL	0.161	0.076	0.764	0.300	0.028	< MDL
M08	< MDL	5.592	0.818	5.682	3.266	5.976	11.227	2.553	< MDL
M09	< MDL	6.282	0.964	6.629	3.542	14.461	12.962	3.049	< MDL
M10	< MDL	4.741	0.739	5.476	3.444	43.650	10.500	2.576	< MDL
M11	< MDL	4.145	0.637	4.582	2.752	24.338	8.858	1.837	< MDL
M12	< MDL	10.686	1.336	8.620	4.921	27.004	17.265	3.842	< MDL
M13	< MDL	4.642	0.865	4.916	2.443	2.301	10.203	2.418	< MDL
M14	< MDL	4.999	0.748	5.201	3.210	3.125	11.044	2.619	< MDL
M15	< MDL	11.447	1.848	12.360	7.088	13.830	24.700	5.988	< MDL
M16	< MDL	14.418	2.393	16.444	8.868	107.079	29.770	7.578	< MDL
M17	< MDL	2.322	0.309	2.744	1.547	86.682	4.988	1.260	< MDL
M18	< MDL	8.338	1.358	8.985	5.445	20.967	17.777	4.209	< MDL
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	PCB 187 ng/g dry	PCB 188 ng/g dry	PCB 189 ng/g dry	PCB 194 ng/g dry	PCB 195 ng/g dry	PCB 198 ng/g dry	PCB 2 ng/g dry	PCB 20 ng/g dry	PCB 200 / IUPAC 201 ng/g dry
M01	0.398	< MDL	< MDL	0.145	0.084	0.197	< MDL	3.843	0.290
M02	0.389	< MDL	< MDL	0.117	0.076	0.168	< MDL	1.035	< MDL
M03	0.500	< MDL	< MDL	0.132	0.080	0.171	< MDL	2.315	< MDL
M04	3.442	< MDL	< MDL	1.332	0.566	1.408	< MDL	3.510	0.229
M05	5.273	< MDL	< MDL	1.720	0.725	0.137	< MDL	5.596	0.409
M06	10.692	< MDL	< MDL	3.495	1.340	0.182	< MDL	9.825	0.303
M07	0.207	< MDL	0.122	0.073	0.034	0.090	< MDL	0.918	0.172
M08	6.354	< MDL	< MDL	2.474	0.894	2.544	< MDL	5.755	0.492
M09	7.518	< MDL	< MDL	2.759	1.105	0.157	< MDL	10.682	0.422
M10	7.483	< MDL	< MDL	2.916	1.422	< MDL	< MDL	26.507	0.615
M11	6.222	< MDL	< MDL	2.536	0.987	< MDL	< MDL	15.486	0.356
M12	10.906	< MDL	< MDL	3.944	1.685	0.220	< MDL	17.638	0.598
M13	5.165	< MDL	< MDL	2.033	0.813	< MDL	< MDL	1.824	0.641
M14	5.700	< MDL	< MDL	2.196	0.843	< MDL	< MDL	1.752	0.854
M15	13.268	< MDL	< MDL	4.681	1.969	< MDL	< MDL	9.031	0.766
M16	17.664	< MDL	< MDL	6.773	2.379	0.363	< MDL	55.942	1.253
M17	3.401	< MDL	< MDL	1.142	0.464	< MDL	< MDL	38.756	0.229
M18	11.459	< MDL	< MDL	4.143	1.867	< MDL	< MDL	14.597	1.209
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	PCB 201 / IUPAC 199 ng/g dry	PCB 202 ng/g dry	PCB 203/196 ng/g dry	PCB 206 ng/g dry	PCB 207 ng/g dry	PCB 208 ng/g dry	PCB 209 ng/g dry
M01	0.173	0.058	0.193	0.067	< MDL	< MDL	0.017
M02	0.143	0.058	0.166	0.046	< MDL	< MDL	0.012
M03	0.154	0.045	0.175	0.049	< MDL	< MDL	< MDL
M04	1.332	0.295	1.455	0.462	0.060	0.112	0.120
M05	1.922	0.418	2.810	0.617	0.099	0.175	0.166
M06	3.487	0.826	4.412	< MDL	0.149	0.344	0.281
M07	0.078	0.037	0.055	< MDL	< MDL	< MDL	< MDL
M08	2.404	0.518	2.626	0.998	< MDL	< MDL	0.282
M09	2.759	0.579	3.406	0.959	0.117	0.188	0.242
M10	3.127	0.845	3.949	0.886	< MDL	< MDL	0.290
M11	2.649	0.584	2.936	0.903	0.100	0.184	0.216
M12	4.059	0.698	4.395	1.229	< MDL	< MDL	0.365
M13	1.832	0.476	2.495	0.733	< MDL	< MDL	0.410
M14	2.626	0.560	4.433	1.059	< MDL	< MDL	0.341
M15	4.332	0.843	5.805	1.724	< MDL	< MDL	0.420
M16	7.397	1.578	9.136	3.072	< MDL	0.587	0.773
M17	1.056	0.300	1.193	0.390	< MDL	< MDL	< MDL
M18	4.711	1.022	5.068	1.819	< MDL	< MDL	0.516
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	PCB 26 ng/g dry	PCB 28/31 ng/g dry	PCB 29 ng/g dry	PCB 3 ng/g dry	PCB 37 ng/g dry	PCB 44 ng/g dry	PCB 45 ng/g dry	PCB 47/48 ng/g dry	PCB 49 ng/g dry	PCB 50 ng/g dry
M01	0.628	3.888	< MDL	< MDL	< MDL	2.111	0.312	1.048	2.260	< MDL
M02	0.716	3.576	1.249	< MDL	0.794	2.048	0.267	0.985	1.873	< MDL
M03	1.471	10.830	1.155	< MDL	1.715	6.026	1.040	2.987	4.792	< MDL
M04	3.502	19.634	3.040	< MDL	3.291	9.243	1.314	4.774	9.778	< MDL
M05	4.921	33.616	< MDL	< MDL	4.032	14.510	2.180	8.995	14.905	< MDL
M06	11.262	56.731	< MDL	< MDL	7.712	25.882	3.801	13.021	25.039	0.143
M07	0.305	2.365	< MDL	< MDL	0.496	1.427	0.277	0.530	1.105	< MDL
M08	5.405	31.839	< MDL	< MDL	6.695	14.187	2.128	8.453	14.714	< MDL
M09	10.190	57.593	< MDL	< MDL	6.964	27.625	4.119	13.633	26.321	< MDL
M10	41.749	182.722	3.383	< MDL	22.355	77.821	11.621	40.010	74.547	0.332
M11	25.241	107.972	1.705	< MDL	11.248	55.088	7.652	28.780	51.581	0.309
M12	22.349	109.411	10.960	< MDL	14.158	56.186	8.065	31.444	54.571	< MDL
M13	1.128	5.400	< MDL	< MDL	< MDL	4.726	0.561	1.432	3.326	< MDL
M14	1.120	8.927	< MDL	< MDL	< MDL	5.215	1.397	3.125	4.743	< MDL
M15	9.273	56.384	< MDL	< MDL	5.485	19.753	2.886	12.416	19.966	< MDL
M16	58.243	281.795	1.479	< MDL	26.646	124.415	24.270	61.027	104.619	0.631
M17	60.098	214.945	< MDL	< MDL	15.411	74.273	14.214	32.398	61.978	0.300
M18	17.936	88.531	9.983	< MDL	8.760	43.947	6.845	24.462	44.598	0.353
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	0.038	< MDL	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	PCB 52 ng/g dry	PCB 56/60 ng/g dry	PCB 61 ng/g dry	PCB 63 ng/g dry	PCB 66 ng/g dry	PCB 69 ng/g dry	PCB 70 ng/g dry	PCB 74 ng/g dry	PCB 76 ng/g dry
M01	2.444	1.422	< MDL	< MDL	1.732	< MDL	1.959	0.775	< MDL
M02	2.151	1.095	0.209	< MDL	1.447	< MDL	2.082	1.164	< MDL
M03	6.894	3.832	< MDL	0.453	4.727	< MDL	5.473	2.807	< MDL
M04	11.027	6.127	< MDL	0.772	8.531	< MDL	8.657	3.817	< MDL
M05	19.631	10.750	< MDL	< MDL	14.964	< MDL	15.898	5.569	< MDL
M06	30.004	13.062	1.321	< MDL	16.114	< MDL	19.485	9.250	< MDL
M07	1.431	0.902	< MDL	< MDL	1.057	< MDL	1.266	0.633	< MDL
M08	19.214	9.763	< MDL	< MDL	14.959	< MDL	15.812	8.066	< MDL
M09	32.490	14.848	2.402	< MDL	21.224	< MDL	24.043	10.680	< MDL
M10	99.557	30.977	< MDL	4.537	55.791	0.098	50.382	22.966	< MDL
M11	67.098	22.445	< MDL	2.942	40.686	< MDL	36.001	16.745	< MDL
M12	69.926	26.188	< MDL	< MDL	41.232	< MDL	44.674	21.748	< MDL
M13	6.554	< MDL	< MDL	< MDL	2.751	< MDL	3.986	< MDL	1.498
M14	7.745	< MDL	< MDL	< MDL	4.593	< MDL	6.680	3.244	< MDL
M15	28.766	9.939	< MDL	< MDL	15.838	< MDL	18.194	8.862	< MDL
M16	156.301	57.585	< MDL	8.381	68.953	< MDL	88.516	51.856	< MDL
M17	95.295	26.277	< MDL	3.337	30.308	0.152	39.815	20.690	< MDL
M18	55.617	21.102	< MDL	< MDL	34.352	< MDL	35.620	19.315	< MDL
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL
EPA Formulated	< MDL	0.054	< MDL	< MDL	0.076	< MDL	0.096	0.046	< MDL
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix A. Contiuned.

Station	PCB 77 ng/g dry	PCB 8/5 ng/g dry	PCB 81 ng/g dry	PCB 82 ng/g dry	PCB 84 ng/g dry	PCB 87/115 ng/g dry	PCB 88 ng/g dry	PCB 89/90 ng/g dry	PCB 9 ng/g dry	PCB 92 ng/g dry	PCB 95 ng/g dry	PCB 99 ng/g dry
M01	< MDL	0.426	< MDL	< MDL	0.751	0.602	1.026	< MDL	< MDL	0.500	0.87	1.33
M02	0.228	0.005	0.269	< MDL	0.391	0.543	0.959	0.078	< MDL	< MDL	0.854	1.33
M03	0.806	0.607	< MDL	0.726	1.95	1.298	< MDL	0.214	< MDL	< MDL	2.13	3.10
M04	1.338	1.536	< MDL	0.897	3.45	2.068	< MDL	0.527	< MDL	< MDL	3.74	6.00
M05	2.420	2.159	< MDL	2.81	< MDL	4.290	6.487	5.437	< MDL	< MDL	1.29	22.71
M06	3.093	3.190	< MDL	2.98	11.10	6.066	14.465	1.332	< MDL	< MDL	< MDL	16.25
M07	< MDL	< MDL	< MDL	< MDL	< MDL	0.255	0.564	< MDL	0.239	0.413	0.53	0.69
M08	3.030	1.316	< MDL	< MDL	3.461	4.075	9.021	0.966	< MDL	2.39	7.52	11.69
M09	3.223	3.931	< MDL	3.65	11.08	5.881	15.001	1.217	< MDL	8.50	12.00	17.17
M10	8.068	9.452	< MDL	5.31	23.01	10.564	< MDL	3.817	< MDL	< MDL	23.49	35.93
M11	4.926	6.381	< MDL	4.64	16.10	6.250	< MDL	1.584	0.219	< MDL	15.52	25.23
M12	7.950	5.573	< MDL	5.67	< MDL	10.949	< MDL	2.415	< MDL	15.52	22.52	33.53
M13	< MDL	0.007	< MDL	< MDL	3.25	2.23	5.50	< MDL	< MDL	< MDL	4.28	4.08
M14	< MDL	0.755	< MDL	< MDL	4.21	2.889	6.878	< MDL	< MDL	< MDL	5.54	5.53
M15	< MDL	3.279	< MDL	< MDL	9.93	6.068	< MDL	< MDL	< MDL	< MDL	13.76	16.14
M16	6.216	9.860	< MDL	10.83	36.92	22.501	< MDL	3.490	1.369		41.29	55.07
M17	3.846	0.003	< MDL	4.34	16.64	7.82	22.50	1.27	< MDL	< MDL	< MDL	17.25
M18	3.817	3.395	< MDL	6.78	7.441	10.409	< MDL	3.218	< MDL	7.64	21.30	31.23
Hyalella Control	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	0.034
EPA Formulated	< MDL	0.112	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	0.070
Willow Hall Reference	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL

Appendix B. Summary by station of mean benthic macroinfauna characteristics for Milwaukee Estuary sites (3 replicate, 0.04-m^2 grabs per site). H′ derived using base-2 logarithms.

Station	Density (#/m^2)	# Taxa	H’	Hill's N1	HBI
M01	17392	10	1.76	6.06	9.62622
M02	6042	6	1.47	4.73	9.29165
M03	13358	10	2.66	14.34	9.57632
M04	29250	7	1.64	5.17	9.89095
M05	13333	11	2.78	16.23	9.79495
M06	13692	9	2.09	8.26	9.66153
M07	42	1	0.33	1.57	8.5
M08	7967	9	2.23	9.42	9.28691
M09	12508	7	1.2	3.85	8.90543
M10	39967	11	2.08	8.2	9.87067
M11	6908	10	2.4	11.05	9.3291
M12	24108	10	2.17	8.8	9.74807
M13	83608	17	2.32	10.69	9.88862
M14	44383	13	2.13	8.49	9.71312
M15	6500	5	1.66	5.25	9.42517
M16	81583	13	1.83	6.24	9.53739
M17	20042	15	2.06	9.28	9.76771
M18	20992	10	2.29	10.05	9.73447

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