Assessment of Impacts from the Hart-Miller Island Dredged Material Containment Facility, Maryland

Year 30 Exterior Monitoring Technical Report
(September 2011-August 2012)

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Prepared by:
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And Standards Program
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DEFINITION OF TERMS

Aliquot	A portion of a larger whole, (e.g., a small portion of a sample taken for chemical analysis or other treatment).
Amalgamation	In the chemical context amalgamation is the binding or dissolving of two metals to form an alloy with mercury typically being one of the metals.
Amphipod	Crustacean order containing laterally compressed members such as the sand hoppers.
Anion	A negatively charged ion, (e.g., Cl^- and CO_3^{2-}).
Anoxic	Deplete of oxygen, (e.g., groundwater that contains no dissolved oxygen).
Bathymetric	Referring to contours of depth below the water's surface.
Benthic	Referring to the bottom of a body of water.
Benthos	The organisms living in or on the bottom of a body of water.
Bioaccumulation	The accumulation of contaminants in the tissue of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, pore water or dredged material.
Bioaccumulation factor	The degree to which an organism accumulates a chemical compared to the source. It is a dimensionless number or factor derived by dividing the concentration in the organism by that in the source.
Bioassay	A test using a biological system. It involves exposing an organism to a test material and determining a response. There are two major types of bioassays differentiated by response: toxicity tests which measure an effect (e.g., acute toxicity, sublethal/chronic toxicity) and bioaccumulation tests which measure a phenomenon (e.g., the uptake of contaminants into tissues).
Biogenic	Resulting from the activity of living organisms. For example, bivalve shells are biogenic materials.
Biomagnification	Bioaccumulation up the food chain, e.g., the route of accumulation is solely through food. Organisms at higher trophic levels will have higher body burdens than those at lower trophic levels.
Biota	The animal and plant life of a region.

Bioturbation	Mixing of sediments by the burrowing and feeding activities of sediment-dwelling organisms. This disturbs the normal, layered patterns of sediment accumulation.
Box and Whisker Diagram	A graphical summary of the presence of outliers in data for one or two variables. This plot, which is particularly useful for comparing parallel batches of data, divides the data into four equal areas of frequency. A box encloses the middle 50 percent, where the median is represented as a vertical line inside the box. The mean may be plotted as a point. Horizontal lines, called whiskers, extend from each end of the box. The lower (left) whisker is drawn from the lower quartile to the smallest point within 1.5 interquartile ranges from the lower quartile. The other whisker is drawn from the upper quartile to the largest point within 1.5 interquartile ranges from the upper quartile. Values that fall beyond the whiskers, but within 3 interquartile ranges (suspect outliers), are plotted as individual points. Far outside points (outliers) are distinguished by a special character (a point with a + through it). Outliers are points more than 3 interquartile ranges below the lower quartile or above the upper quartile.
Brackish	Salty, though less saline than sea water. Characteristic of estuarine water.
Bryozoa	Phylum of colonial animals that often share one coelomic cavity. Encrusting and branching forms secrete a protective housing (zooecium) of calcium carbonate or chitinous material. Possess lophophore feeding structure.
Bulk sediment chemistry	Results of chemical analyses of whole sediments (in terms of wet or dry weight), without normalization (e.g., to organic carbon, grain-size, acid volatile sulfide).
Cation	A positively charged ion, (e.g., Na^{+} and Mg^{2+}).
Congener	A term in chemistry that refers to one of many variants or configurations of a common chemical structure (e.g., polychlorinated biphenyls [PCBs] occur in 209 different forms with each congener having two or more chlorine atoms located at specific sites on the PCB molecule).
Contaminant	A chemical or biological substance in a form that can be incorporated into, onto or be ingested by and that harms aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment, and includes but is

	not limited to the substances on the 307(a)(1) list of toxic pollutants of the Clean Water Act promulgated on January 31, 1978 (43 FR 4109).
Contaminated material	Material dredged from Baltimore Harbor, originating to the northwest of a line from North Point to Rock Point. Material shows high concentrations of metals, PCBs, organics, etc.
Dendrogram	A branching, diagrammatic representation of the interrelations of a group of items sharing some common factors (as of natural groups connected by ancestral forms).
Depurate	To cleanse or purify something, especially by removing toxins.
Desiccation	The process of drying thoroughly; exhausting or depriving of moisture.
Diversity index	A statistical measure that incorporates information on the number of species present in a habitat with the abundance of each species. A low diversity index suggests that the habitat has been stressed or disturbed.
Dominant (species)	An organism or a group of organisms that by their size and/or numbers constitute the majority of the community.
Dredge	Any of various machines equipped with scooping or suction devices used in deepening harbors and waterways and in underwater mining.
Dredged material containment	A disposal method that isolates the dredged material from the environment. Dredged material containment is placement of dredged material within diked confined disposal facilities via pipeline or other means.
Dredged Material Containment Facility (DMCF)	A diked area, either in-water or upland, used to contain dredged material. The terms confined disposal facility (CDF), dredged material containment area, diked disposal facility, and confined disposal area are used interchangeably.
Effluent	Something that flows out or forth; an outflow or discharge of waste, as from a sewer.
Enrichment factor	A method of normalizing geochemical data to a reference material, which partially corrects for variation due to grain size.
Epifauna	Benthic animals living on the surface of the bottom.
Fine-grained material	Sediments consisting of particles less than or equal to 0.062 mm in diameter.

Flocculation	An agglomeration of particles bound by electrostatic forces.
Flocculent layer	The transition zone between water column and sediment column. The material in the layer is gelatinous and highly mobile; composed primarily of water with organic matter and fine Clay sized particles. The thickness of the layer varies seasonally and as a function of the flow of water over the sediment-water interface. In the Chesapeake Bay, the flocculent layer is generally less than a centimeter thick, and can be absent in areas of high flow.
Freshet	A sudden overflow of a stream resulting from a heavy rain or a thaw. A stream of fresh water that empties into a body of salt water.
Gas chromatography	A method of chemical analysis in which a sample is vaporized and diffused along with a carrier gas through a liquid or solid adsorbent differential adsorption. A detector records separate peaks as various compounds are released (eluted) from the column.
Gravity core	A sample of sediment from the bottom of a body of water, obtained with a cylindrical device, used to examine sediments at various depths.
Gyre	A circular motion. Used mainly in reference to the circular motion of water in each of the major ocean basins centered in subtropical high-pressure regions.
Hydrodynamics	The study of the dynamics of fluids in motion.
Hydrography	The scientific description and analysis of the physical condition, boundaries, flow, and related characteristics of oceans, rivers, lakes, and other surface waters.
Hydrozoa	A class of coelenterates that characteristically exhibit alternation of generations, with a sessile polypoid colony giving rise to a pelagic medusoid form by asexual budding.
Hypoxic	A partial lack of oxygen.
Infauna	Benthic animals living within bottom material.
Isopleths	Lines on a graph or map connecting points that have equal or corresponding values with regard to certain variables.

Leachate	Water or any other liquid that may contain dissolved (leached) soluble materials, such as organic salts and mineral salts, derived from a solid material.
Least-Squares fit	A method to choose the "best" line fit through a cluster of data points. It is possible to fit many different lines through a set of data points. A line that results in the smallest value of the sum of the squares of the differences between observed and expected values is considered the best fit.
Ligand	Lewis bases that bind by coordinate covalent bonds to transition metals to form complexes.
Littoral zone	The benthic zone between the highest and lowest normal water marks; the intertidal zone.
Mesohaline	Moderately brackish estuarine water with salinity ranging from 5 – 18 parts per thousand
Metalloid	An element with properties intermediate between non-metals and metals. There are seven metalloids; Boron, Silicon, Germanium, Arsenic, Antimony, Tellurium, Polonium.
Mixing zone	A limited volume of water serving as a zone of initial dilution in the immediate vicinity of a discharge point where receiving water quality may not meet quality standards or other requirements otherwise applicable to the receiving water. The mixing zone may be defined by the volume and/or the surface area of the disposal site or specific mixing zone definitions in State water quality standards.
Nephelometric turbidity unit (NTU)	A unit of measurement of the amount of light scattered or reflected by particles within a liquid.
Oligohaline	Water with salt concentrations ranging from 0.5 to 5.0 parts per thousand, due to ocean-derived salts
Open water disposal	Placement of dredged material in rivers, lakes or estuaries via pipeline or surface release from hopper dredges or barges.
Polycyclic aromatic hydrocarbons	Polycyclic aromatic hydrocarbons (PAHs) are a group of over 100 different chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances like tobacco or charbroiled meat.

Pollution Sensitive Taxa	Organisms that are sensitive to pollution.
Pore Water	The water filling the space between grains of sediment.
QA	Quality assurance, the total integrated program for assuring the reliability of data. A system for integrating the quality planning, quality control, quality assessment, and quality improvement efforts to meet user requirements and defined standards of quality with a stated level of confidence.
QC	Quality control, the overall system of technical activities for obtaining prescribed standards of performance in the monitoring and measurement process to meet user requirements.
Radiograph	An image produced on a radiosensitive surface, such as a photographic film, by radiation other than visible light, especially by x-rays passed through an object or by photographing a fluoroscopic image.
Reflux	A technique involving the condensation of vapors in a closed system, and the return of this condensate to the system from which it originated. The process allows a solvent and reagent to be heated continuously at or near the boiling point without the loss of the solvent or reagent.
Salinity	The concentration of salt in a solution. Full strength seawater has a salinity of about 35 parts per thousand (ppt). Normally computed from conductivity or chlorinity.
Secchi depth	The depth at which a standard, black and white Secchi disk disappears from view when lowered into water.
Sediment	Material, such as sand, silt, or clay, suspended in or settled on the bottom of a water body.
Seine	A large fishing net made to hang vertically in the water by weights at the lower edge and floats on the top.
Sigma	A measure of standard deviation away from the mean of a normally distributed data set. One sigma accounts for approximately 68 percent of the population that makes up the set. Two sigma accounts for approximately 95 percent of the population while three sigma accounts for 99 percent.
Slag	The fused vitreous material left as a residue by the smelting of metallic ore.

Spectrophotometer	An instrument used in chemical analysis to measure the intensity of color in a solution.
Spillway	A channel for an overflow of water.
Standard Deviation	A statistical measure of the variability of a population or data set. A high standard deviation indicates greater variance around the mean of a data set where as a low standard deviation indicates little variance around the mean.
Substrate	A surface on or in which a plant or animal grows or is attached.
Supernatant	The clear fluid over sediment or precipitate.
Total suspended solids (TSS)	A measurement (usually in milligrams per liter or parts per million) of the amount of particulate matter suspended in a liquid.
Trace metal	A metal that occurs in minute quantities in a substance.
Trawl	A large, tapered fishing net of flattened conical shape, towed along the sea bottom. To catch fish by means of a trawl.
Turbidity	The property of the scattering or reflection of light within a fluid, as caused by suspended or stirred-up particles.
Turbidity maximum	A zone in a water body where turbidity is typically the greatest, resulting from the influx of river-borne sediments, and flocculation of clay particles due to prevailing salinity patterns.
Water Quality Certification	A state certification, pursuant to Section 404 of the Clean Water Act, that the proposed discharge of dredged material will comply with the applicable provisions of Sections 301, 303, 306 and 307 of the Clean Water Act and relevant State laws.
Water quality standard	A law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body.

PROJECT I : SUMMARY REPORT FOR THE HART-MILLER ISLAND DREDGED MATERIAL CONTAINMENT FACILITY YEAR 30

(September 2011 – August 2012)

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MDE thanks Darlene Wells, Elizabeth Sylvia and Stephen Van Ryswick, PIs for Project II with Maryland Geological Survey (MGS); and Dr. Andrew Heyes, PI for Project IV with the Chesapeake Biological Laboratory (CBL).

MDE would like to thank all the members of the HMI Exterior monitoring Program's Technical Review Committee, especially Mr. Thomas Kroen, Chairman of the HMI Citizens Oversight Committee, for their useful comments and suggestions throughout the project year. Special thanks to the Maryland Port Administration for their continued commitment to, and financial support of, the Exterior Monitoring Program. Finally, a special appreciation goes to Mr. David Peters, Ms. Cassandra Carr and their staff with Maryland Environmental Service (MES) for their invaluable work in managing all the necessary dredging operations of HMI.

INTRODUCTION

The HMI-DMCF was designed to receive dredged material from navigation channel maintenance and improvement activities in the Baltimore harbor and its approaches. Construction of HMI, which entailed building a diked area connecting the remnants of Hart and Miller Island, began in 1981 and was completed in 1983. The facility, encompassing approximately 1,100 acres, is divided by a 4,300 foot interior cross-dike resulting in a North and South Cell. In the early years material was mainly placed in the South Cell, which was completed on October 12, 1990 after which efforts were initiated to convert it into an upland-wetland wildlife refuge. Placement of dredged material was then diverted to the North Cell and continued until December 31, 2009 at which time all inflow of dredged material ceased.

The North Cell is no longer receiving dredged material, and as design plans are being finalized, dewatering and crust management will be minimal. The goal is to shape the area creating upland habitat around the northwest side with a gradual slope to the southeast producing a pond ranging in depth from one and a half to six feet in depth with occasional mudflats similar to, but not to the extent of, the South Cell. The current scheduled plan is to use the existing water collected from precipitation events in the cell to form the pond, which allows for minimal discharge during crust management. During this truncated phase of crust management, dredged material could potentially be exposed to air resulting in sulfides becoming oxidized creating acidic conditions during rainfall events. Acidic conditions can mobilize metals, which is cause for concern if discharged to the exterior environment through the spillways. Discharge will continue to be monitored to comply with the permit requirements, and water is not discharged if it does not comply with permit limits. Post closure exterior monitoring will continue to occur to see if any possible concerns do arise during this period.

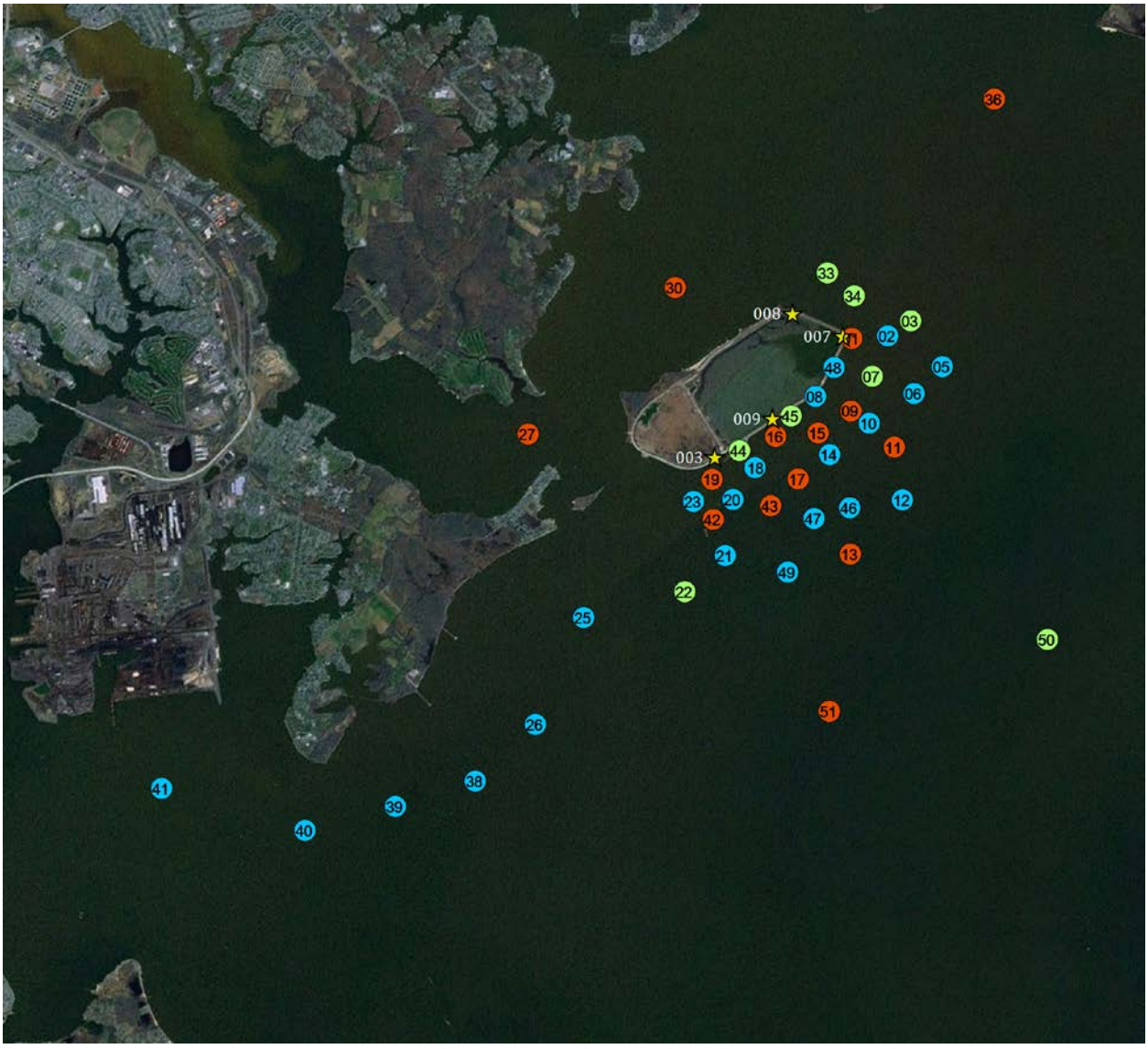
The first sampling cruises for monitoring Year 28 took place in September 2009, while HMI was still receiving dredged material. The April 2010 sampling cruises marked the first sampling after closure. Thus, only the April 2010 monitoring results can be considered post-closure baseline data. Year 30 marks the 2nd full year of post-closure monitoring. It is important that monitoring continues for at least 5 years post-closure during this crucial period of dewatering and crust management, and habitat development of the North Cell to establish a robust post-closure data set. These 5 years of data can then be compared to the thirty years of data collected during dredged material placement. This comparison of pre- and post-closure data will allow the scientists to determine differences, if any, in the exterior environment, and whether the differences were a result of HMI operations. The information learned can be applied to future dredged material containment facilities.

HMI EXTERIOR MONITORING DESIGN

The HMI-DMCF Exterior Monitoring Program is modeled after the Sediment Quality Triad developed in the mid-1980s (Long and Chapman, 1985). This approach consists of three separate components: sediment chemistry, sediment toxicity, and benthic community composition. The sediment chemistry project (Project II) assesses contamination by evaluating metal concentrations in exterior sediments. Project III, benthic community studies, monitors animal communities living in sediments surrounding HMI. As a surrogate for toxicity, Project IV looks at benthic tissue concentrations of both metals and organics in the brackish-water clam *Rangia cuneata*. Whereas sediment contamination thresholds, benthic toxicity benchmarks, and benthic macroinvertebrate indices alone may not conclusively identify pollution impacts, combining them into a triad approach provides a body of evidence for pollution determinations. **Error! Reference source not found.** below illustrates the triad concept.

Summary Table 1: Differential Triad Responses

Scenario	Sediment Contamination (Project II)	Toxicity (Project IV)	Benthic Community Impacts (Project III)	Possible Conclusions
1	+	+	+	Strong evidence for pollution
2	–	–	–	Strong evidence that there is no pollution
3	+	–	–	Sediment pollutants are elevated but not affecting biota
4	–	+	–	Pollutant levels increasing through food chain
5	–	–	+	Benthic community impacts not a result of pollution
6	+	+	–	Pollutants are stressing the system
7	–	+	+	Pollutants increasing through the food chain and altering the benthic community
8	+	–	+	Pollutants are available at chronic, non-lethal levels



Summary Figure 1- 1: Shows the sampling design and the parameters which were monitored. For Year 30, MGS analyzed sediment for physical and chemical properties from all 43 sites, MDE sampled the benthic organisms at 22 sites, and CBL collected the brackish water clam *Rangia cuneata* from 13 sites in the fall and 12 sites in the spring for tissue and sediment analysis of metals and metalloids.

HMI PROJECT SUMMARIES

PROJECT II: Sedimentary Environment and Groundwater Monitoring

The Coastal and Estuarine Geology Program of the Maryland Geological Survey (MGS) has been involved in monitoring the physical and chemical behavior of near-surface sediments around HMI since the early project planning stages. As part of this year's exterior monitoring program, MGS collected bottom sediment samples from 43 stations on both September 22, 2011, and on April 3, 2012. Survey geologists then analyzed the following parameters: (1) grain size composition (relative proportions of sand, silt, and clay) and (2) total elemental concentrations of iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), cadmium (Cd), lead (Pb), phosphorous (P), carbon (C), nitrogen (N), and sulfur (S).

MGS developed a mathematical procedure that normalizes the metals concentrations based on percent composition of sand, silt and clay content. Changes in grain size of the exterior sediments surrounding HMI are largely dependent upon amount, quality, and timing of discharge from particular spillways, the interaction of the discharge with the tides and currents in the receiving waters, and the existing grain size distribution patterns. The depositional environment in the vicinity of HMI is relatively unchanged in the last 3 years. There is only slight variation in grain size composition, mostly due to seasonal changes. In general, sediment distribution is consistent with the findings of previous monitoring years, dating back to 1988, two years following the initial discharge of effluent from HMI.

The metals data are expressed in terms of standard deviation (sigma) units above (enriched) or below (depleted) regional background levels. When normalized, the 30^{th} year data showed that certain sediment samples are significantly enriched with Ni, Pb and Zn. The details on this analysis and can be found in Appendix 1.

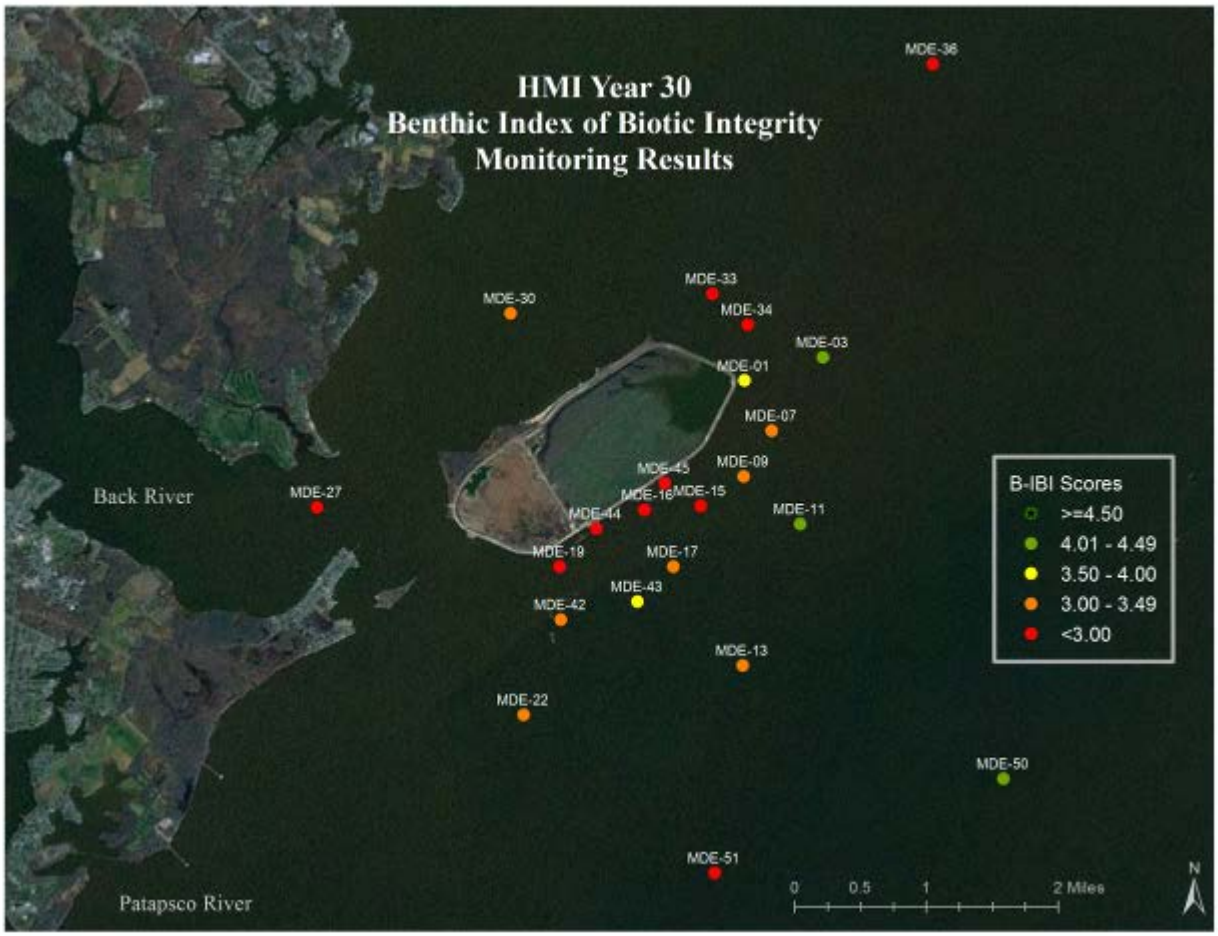
Presented in Appendix 1A, the groundwater monitoring report is a summary of the HMI well data collected from two samplings: December 22, 2011 and June 25, 2012. Discussion of the data includes comparison with previous data collected since June 2006 when MES had adopted new protocols for sampling groundwater monitoring wells (MES, 2010). Data analyses are based on the interpretive methods detailed in the HMI well monitoring report (Hill, 2005). Groundwater sampling continues as part of the on-going HMI external monitoring effort and as a continuation of the groundwater studies completed in 2003 (URS), and 2005 (Hill). The purpose of that study was to identify 1) the direction and rate of groundwater flow from the facility to the surrounding Bay, and 2) physical and chemical reactions controlling the mobilization of contaminants from the facility.

PROJECT III: Benthic Community Studies

The Field Evaluation Division of the Maryland Department of the Environment's Science Services Administration is responsible for macroinvertabrate montitoring around HMI. In Year

30, the benthic macroinvertebrate community was examined under slightly unusual conditions for this region of the Chesapeake Bay. The September 2011 cruise took place two weeks after Hurricane Irene and Tropical Storm Lee passed over the region, leaving historically significant freshwater inputs into the Chesapeake Bay, and resulting in an all-time high total of 52 benthic macroinvertebrate taxa identified during Year 30. The increase in taxa was mainly due to the appearance of several taxa more typically seen in freshwater environments.

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI), a multi-metric index of biotic condition that evaluates summer populations of benthic macroinvertebrates, was calculated for all 22 stations sampled in September 2011.



Summary Figure 1- 2: Year 30 B-IBI Monitoring Results

The mean B-IBI's calculated for all station types during Year 30 were below historic averages. However, the mean B-IBI for Nearfield, and South Cell Exterior stations meet or exceed the benchmark of 3.0. Appendix 2 provides details and statistics of the benthic studies. In general,

both healthy and unhealthy benthic communities exist in the vicinity of the South Cell outfall, off-loading dock, and around HMI.

PROJECT IV: Analytical Services

As part of the HMI annual exterior sediment survey for Y30, the University of Maryland Center for Environmental Science Chesapeake Biological Laboratory (CBL) analyzed target trace elements in surface sediments collected by the MGS in September 2011. Trace element analysis focuses on those parameters not measured by MGS - specifically total mercury (T-Hg), methylmercury (MeHg), silver (Ag), selenium (Se) and arsenic (As). In addition CBL collected the clam *Rangia cuneata* both in the fall 2011 and spring 2012 and analyzed clam soft tissue, along with sediment from the site of collection, for trace elements as a measure of trace element bioavailability. Additional sediment samples were collected in September 2011 and analyzed for polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). With a few exceptions, parameters measured in clams and sediment prove to be similar to historical levels. Appendix 3 details the results and analysis provided by the CBL.

PROJECT I SUMMARY AND RECOMMENDATIONS

This was the second full year of post-closure exterior monitoring for HMI. Therefore, it is important that monitoring continues for a number of years so that a robust data set can be developed with which to conduct statistical analysis against historical data and to determine if any significant trends can be identified. The MGS report indicates that this year's monitoring effort documents lower enrichment of Zn around the HMI facility. However, enrichment for Pb remained above background levels and enrichment for Ni was documented above background levels for the third year at sites within the HMI zone, but not in the Back River or Baltimore Harbor Zones. Overall, CBL observed an increase of some trace elements in sediments from a few sites along the south side of the island and overall increase in PAH and PCBs in clams. However, with the exception of selenium, the other trace elements fall within the range of values found in the Chesapeake Bay as a whole, and no definitive conclusions on the cause or source of the measured increases can be made at this time. Variability in water quality conditions as well as biological communities may be the result of weather (tropical storms) and other naturally occurring anomalous events. The benthic monitoring for Year 30 showed lower than historical average B-IBI scores. The Field Evaluation Division from MDE suggests that this may be due to the presence of lower salinities which resulted in the adoption of oligohaline (salinity range of 0.5 – 5 ppt) metrics to calculate the B-IBIs.

Based on the data collected for this Year 30 report, the sediment triad approach to determining pollution-induced degradation (Summary Table 1 above) suggests that the aquatic habitat near HMI during Year 30 was impacted by pollution (Scenario 1 - Strong evidence for Pollution). Nearly all stations have elevated levels of at least one of the metals analyzed. The Threshold Effects Level (TEL), Effects Range Median (ERM), and Effects Range Lower (ERL), for certain contaminants are exceeded at a number of sites. In addition, low B-IBI scores coincided with elevated contaminant levels at several sites. However, the validity of selecting Scenario – 1 as it relates to whether the cause is strictly a result of the activities at HMI is questionable. Healthy benthic populations were also found in close proximity to HMI. The presence of both healthy and unhealthy benthic communities in the vicinity of HMI raises some doubt. However, the persistent enriched levels of some metals, the variability in benthic scores, and the inconclusive results of trace element analyses indicate a need for continued long-term monitoring. This extended monitoring is particularly important since the facility has experienced water quality issues related to crust management operations in preparation for environmental restoration efforts.

REFERENCES

Long, E.R. and P.M. Chapman. 1985. A sediment quality triad-measures of sediment contamination, toxicity and infaunal community composition in Puget Sound. Marine Pollution Bulletin 16:405-415.

APPENDIX 1: SEDIMENTARY ENVIRONMENT (PROJECT II)

(September 2011 - August 2012)

Technical Report

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EXECUTIVE SUMMARY

The Coastal and Environmental Geosciences Program of the MGS has been involved in monitoring the physical and chemical behavior of near-surface sediments around the Hart-Miller Island Dredged Material Containment Facility (HMI DMCF) from the initial planning stages of construction of the facility to the present. As part of the 30th year exterior monitoring program, MGS collected bottom sediment samples from 43 sites on both September 22, 2011 and April 3, 2012. The sediment samples were analyzed for various physical and chemical properties of the samples: (1) grain size composition (relative proportions of sand, silt, and clay) and (2) total elemental concentrations of iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), cadmium (Cd), lead (Pb), phosphorous (P), carbon (C), nitrogen (N), and sulfur (S).

For exterior bottom sediments sampled during Year 30, average grain size composition, reported as % sand and as clay:mud ratios, varied little compared to the previous two years' data. The pattern of the grain size distribution varied slightly from one cruise to the next, and from the previous years of monitoring. Some of the variation is attributed to seasonal effects. In general, sediment distribution is consistent with the findings of previous monitoring years, dating back to 1988, two years following the initial discharge of effluent from HMI.

MGS used the National Oceanic and Atmospheric Administration (NOAA) Effects Range Low (ERL) and Effects Range Median (ERM) threshold values for certain metals in sediments to access potential impact from HMI. The NOAA ERM and ERL values are proposed criteria put forward by NOAA (Buchman, 2008) to gauge the potential for deleterious biological effects. These criteria are based on a statistical method of termed preponderance of evidence.

The 30th year results of the elemental analyses were statistically similar to the previous two years of data. With regard to the ERL and ERM values, this year's data showed that:

1. At most sampling sites, concentrations of Cr, Cu, and Pb in the sediment exceeded the ERL values; and
2. At most sampling sites, concentrations of Ni exceeded the ERM value; and Zn exceeded the ERM value at some sites.

Because the NOAA threshold criteria method does not allow for unique basin conditions or does not take into account grain size induced variability in metal concentrations in the sediment, MGS utilized a second assessment tool which uses sediment grain size to normalize metal concentrations to assess changes in the sediments that may be attributed to the HMI DMCF. The grain size normalization procedure is a means to correct the deficiencies of the NOAA guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When normalized, metal data are expressed in terms of standard deviation (sigma) units above (enriched) or below (depleted) regional background levels. When normalized, the 30th year data showed that certain sediment samples are significantly enriched with Ni, Pb and Zn.

Based on work done by the University of Maryland during HMI Year 25 monitoring, the most probable conditions where the metals affect the infaunal communities are:

1. When the sigma level (σ) exceeds +2 [indicating enriched metals concentrations over baseline] and;
2. When the metals level exceeds the ERL with increased probability as the level exceeds the ERM [showing absolute concentrations that have exhibited adverse effects in other systems].

Sediments from several sites met these conditions. Samples for both September 2011 and April 2012 cruises from sites within the Baltimore Harbor zone of influence (except MDE-22 and MDE-40) and within the Back River zone contained more than one metal exceeding both ERL or ERM, and sigma level greater than 2. Within the HMI zone of influence (both distal and proximal), the sediments containing multiple metals exceeding ERLs or ERMs, and sigma levels greater than 2 included Sites MDE-8, MDE-9, MDE-13, MDE-14, MDE-20 and MDE-46 from the September 2011 cruise, and sites MDE-3, MDE-8, MDE-9, MDE-11, MDE-13, MDE-18 and MDE-35 from the April 2012 cruise.

Pb and Ni levels within the HMI Zone are higher, in terms of the number of samples exceeding 3σ and overall sigma levels, compared to the previous year. The September 2011 spatial extent of Pb enrichment included three areas: two isolated sites (MDE-34, off northeast tip of the facility, and MDE-20, south of HMI); the third area extending from the facility southeast and encompassing 5 sites (MDE-8, -9, -14, -46, and MDE-13). Ni enrichment was also documented at four sites (MDE-9, -10, -13, and MDE-34). By April 2012, Pb enrichment was documented in the same general areas but shifted slightly to the east. Ni enrichment continued to be significant (>4 sigmas) at site (MDE-34) and increased to a significant level at two sites: MDE-20, located adjacent to SW003, and MDE-11). Zn levels remain low or limited to a few isolated sites, similar to the previous year. In September, 2011, Zn enrichment was documented at one isolated site (MDE-20). In April 2012, Zn enrichment (> 3 sigma) was documented at two sites (MDE- 18 and MDE-11).

September spatial distribution of Pb (and Ni) enriched areas along the eastern end of the facility. There was a non-compliant discharge (pH below permitted limit) for six days from the South Cell spillway (SW003) a week prior to the September 2011 sampling cruise. The low pH discharge was during the peak flow from the Susquehanna River as a result of Tropical Storm Lee. The high flow could have resulted in the northern displacement of any plume coming from SW003. South Cell discharge appeared to have had a minimal effect for both cruises, with regard to Zn enrichment.

The spatial extent and the high enrichment levels for Pb and Zn in the Baltimore Harbor zone of influence, and for Pb in the Back River zone, for both cruises also reflect the impact of Hurricane Irene and Tropical Storm Lee. Commonly the late summer - early fall levels are higher than the spring sampling for the Baltimore Harbor and Back River zones; this is the case for this monitoring year. However, Baltimore Harbor and Back River zones continue to remain separate from the HMI zone.

In terms of number of sites and sigma levels, enrichment of Ni has increased within the HMI zones over the last three years (since 28th year) of monitoring. The persistent enriched levels of Ni and Pb indicate a need for continued monitoring in order to detect if the levels increase to a point where action is required, to document the effect that operations has on the exterior environment (for future project design), and to assess the effectiveness of any amelioration protocol implemented by the Maryland Port Administration (MPA) and MES to counteract the effects of exposing contained dredged material to the atmosphere. Close cooperation with MPA and MES is important in this endeavor.

INTRODUCTION

Since 1981, the MGS has monitored the sedimentary environment in the vicinity of HMI DMCF. HMI is a man-made enclosure in northern Chesapeake Bay, named for the two natural islands that form part of its western perimeter.

Designed specifically to contain material dredged from Baltimore Harbor and its approach channels, the oblong structure was constructed of sediment dredged from the facility interior. The physical and geochemical properties of the older, "pristine" sediment used in dike construction differed from those of modern sediments accumulating around the island. Likewise, material dredged from shipping channels as well as channels in Baltimore Harbor, near commercial docks, which generally have local sources of material of concern, and deposited inside the facility also differ from recently deposited sediments in the region. Much of the material generated by channel deepening is fine-grained and enriched in trace metals and organic constituents. In addition, oxidation of the sediment placed in the facility produces effluent enriched in metals. Oxidation occurs when the sediments are exposed to aerated conditions; this occurs during periods of dewatering and crust management. These differences in sediment properties and discharge from the facility have allowed the detection of changes attributable to construction and operation of the facility. All effluent discharged from HMI facility must meet water quality permit limits for metal concentrations.

Previous Work

Events in the history of the facility can be meaningfully grouped into the following periods:

1. Preconstruction (Summer 1981 and earlier)
2. Construction (Fall 1981 - Winter 1983)
3. Post-construction
    a. Pre-discharge (April 1984 - Fall 1986)
    b. Post-discharge (Fall 1986 - present).
4. Closing of South Cell to new dredged material (Oct. 1990)
5. Closing of North Cell to new dredged material (Dec. 2009)

The nature of the sedimentary environment prior to and during dike construction has been well documented in earlier reports (Kerhin et al. 1982a, l982b; Wells and Kerhin 1983; Wells et al. 1984; Wells and Kerhin 1985). This work established a baseline against which changes due to operation of the facility could be measured. The most notable effect of dike construction on the surrounding sedimentary environment was the deposition of a thick, light gray to pink layer of "fluid mud" immediately southeast of the facility (Wells and Kerhin, 1983; 1985).

For a number of years after HMI began operating, no major changes were observed in the surrounding sedimentary environment. Then, in April 1989, more than two years after the first release of effluent from the facility, anomalously high Zn values were detected in samples collected near Spillway 007 (Hennessee et al., 1990b). Zn levels rose from the regional average

enrichment factor of 3.2 to 5.5; enrichment factors are normalized concentrations, referenced to a standard material. Enrichment factors are the ratios of concentrations, in this case Zn to Fe, which are in turn normalized to the same ratio in a standard reference material; this number is dimensionless. Effluent discharged during normal operation of the facility was thought to be the probable source of the enrichment of Zn accumulating in the sediments. This was confirmed by use of the Upper Bay Model (Wang, 1993), a numerical, hydrodynamic model, which was used to predict the dispersion of discharge from the facility, coupled with discharge records from the spillways. From the discharge records it was noted that there is a significant increase in metal loading to the exterior sediments during periods of low discharge [<10 million gallons per day (MGD)]; periods of higher discharge rates corresponded to lower metal levels in the exterior sediments.

The factors that influence the metals loadings to the exterior sediments are circulation patterns in the northern Bay and the rate and the nature of discharge from the facility. The results of the hydrodynamic model pertinent to a discussion of contaminant distribution around HMI follow (see the *Year 10 Technical Report* for details):

1. A circulation gyre exists east of HMI. The gyre circulates water in a clockwise pattern, compressing the discharge from the facility against the eastern and southeastern perimeter of the dike.

2. Releases from Spillways 007 and 009 travel in a narrow, highly concentrated band up and down the eastern side of the dike. This explains the location of areas of periodically high metal concentrations east and southeast of the facility.

3. Releases from Spillway 008 are spread more evenly to the north, east, and west. However, dispersion is not as great as from Spillways 007 and 009 because of the lower shearing and straining motions away from the influence of the gyre.

4. The circulation gyre is modulated by fresh water flow from the Susquehanna River. The higher the flow from the Susquehanna, the stronger the circulation pattern and the greater the compression against the dike. Conversely, the lower the flow, the less the compression and the greater the dispersion away from the dike.

5. Discharge from the HMI spillways has no influence on the circulation gyre. This was determined by simulating point discharges of 0-70 MGD from three different spillways. Changes in discharge rate only affect the rate of dilution of species released from the facility; the higher the discharge, the higher the concentration in the plume outside the facility.

The 3-D hydrodynamic model explains the structure of the plume of material found in the exterior sediments, but it does not explain why the level of Zn in the sediments increases at lower discharges. To account for this behavior, the chemistry of the effluent discharged from the facility was examined, as reported in the *Year 11 Technical Report*. As a result of this

examination, a model was constructed to predict the general trend in the behavior of Zn as a function of discharge rate from the facility. The model has two components: (1) loading due to material similar to the sediment in place and (2) loading of enriched material as predicted from a regression line based on discharge data supplied by the MES. The behavior of this model supports the hypothesis of metal contamination during low flow conditions. Sediments discharged from the facility are one of the sources of metals that enrich the exterior sediments. When exposed to the atmosphere, these sediments oxidize in a process analogous to acid mine drainage (i.e., sulfide minerals oxidize to produce sulfuric acid, which leaches acid-soluble metals, nutrients, and organic compounds that are released with the discharged waters). Since the initial detection of Zn, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, higher than expected levels of Zn and Pb have persisted in the vicinity of the facility. Figure 1-1, in addition to showing the sampling sites for Year 30, shows zones which indicate influence of sources of material to the exterior sedimentary environment based on elevated metal levels from previous years' studies. These influences are noted in the figure as:

1. *Reference* - representing the overall blanketing of sediment from the Susquehanna River;

2. *Back River* - Gradients showing the sewage treatment plant as a source carried by the river have varied through time; the sites in this zone encompass the area that has shown the influence from this source. Further documentation of this source was done in the *Year 16 Technical Report*, where samples were collected upstream beyond the sewage treatment plant. These samples clearly showed a continuous gradient from the plant down Back River approaching HMI;

3. *HMI* - The area of influence from the facility is divided into two zones, (a) the proximal zone, which shows the most consistent enrichment levels through time, and (b) the distal zone, which is affected primarily during extended periods of dewatering and crust management, and;

4. *Baltimore Harbor* – Sites in the southern portion of the area have consistently shown a gradient, indicating that Baltimore Harbor is a source of metals in the area south of HMI. The consistent pattern seen in the monitoring studies is base level values near HMI, which increase towards Baltimore Harbor. This pattern supports the results of a hydrodynamic model analyses performed in conjunction with the 1997 sediment characterization of Baltimore Harbor and Back River (Baker et al., 1998). During Year 22 monitoring, near record rainfall levels in the area strongly influenced the hydrodynamic flow, resulting in the incursion of Baltimore Harbor material into the HMI zone. This sampling period was the only time in the 29 years of monitoring that this occurred.

HMI stopped accepting dredged material after December 31, 2009 and facility operations shifted to dewatering and long-term crust management in the North Cell in preparation for environmental restoration activities. Past monitoring studies have shown that, during periods of

extended crust management and dewatering when discharge volume is decreasing, metal concentrations in the discharge tend to increase. Therefore, metals concentrations in the sediments in the region of HMI influence to the east of the facility are expected to increase during the post-closure operation phase. In anticipation of these changes, a modified sediment sampling scheme was implemented during the 27th monitoring year, to provide better coverage in targeted areas south and east of the facility (Rowe and Hill, 2008). The modified sampling scheme was continued during this 30th monitoring year (Figure 1.1).

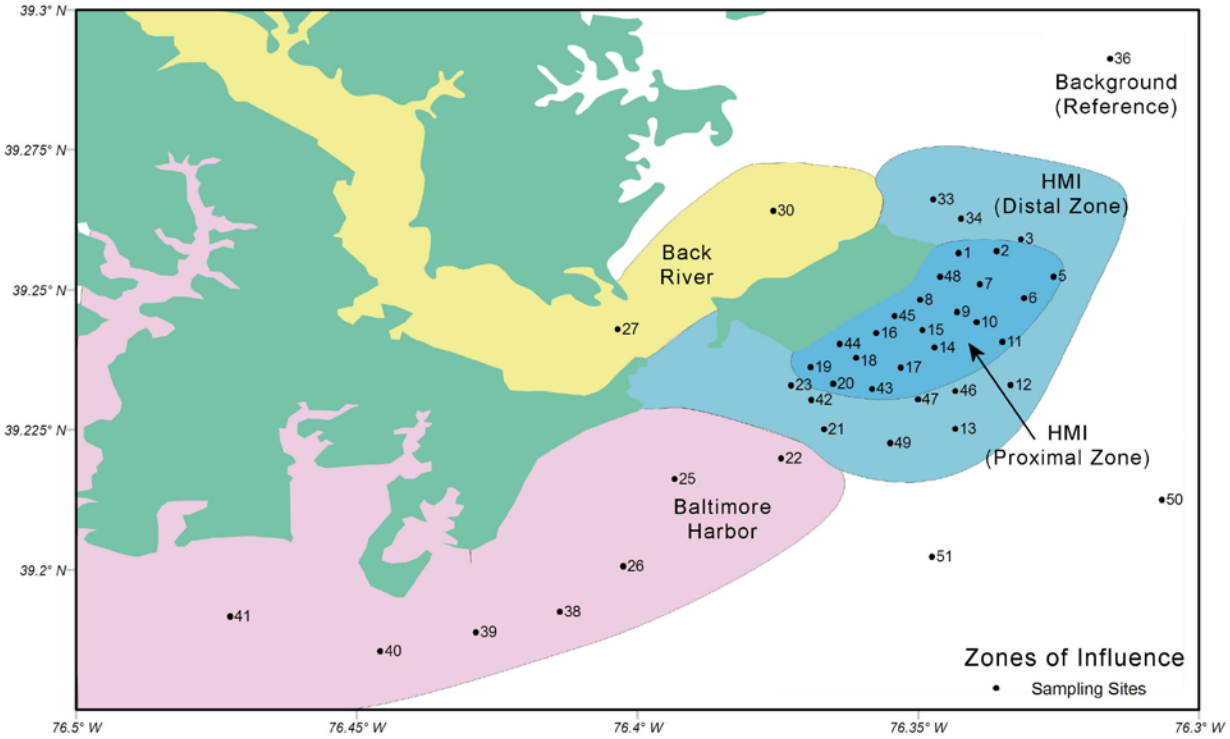

Figure 1- 1: Sampling locations for Year 30. Color areas show zones of influence found in previous studies. Stations 38 – 41 were added in Year 18 to measure the influence of Baltimore Harbor. Starting in Year 27, four stations in the Back River zone were dropped and additional stations added in the proximal zone and southeast of the facility, beyond the HMI zone of influence.

Facility Operations

Certain activities associated with the operation of HMI have a direct impact on the exterior sedimentary environment. Local Bay floor sediments are sensitive, both physically and geochemically, to the release of effluent from the facility. Events or operational decisions that affect the quality or quantity of effluent discharged from the facility account for some of the changes in exterior sediment properties observed over time. For this reason, facility operations during the periods preceding each of the Year 29 cruises are summarized below. Information, which was provided by Carolyn Blakeney, Cassandra Carr and Amanda Peñafiel of MES, covered the period from April 1, 2011 to April 30, 2012.

The facility stopped accepting new dredged material at the end of 2009, after which operations in the North Cell focused on dewatering activities and long-term crust management in preparation for environmental restoration efforts. Precipitation accounted for almost all of the water input in the North and South Cells. The South Cell also received water that flows into the holding pond used for controlling the interior waterfowl pond and spray irrigation.

Figure 1-2 compares the monthly rainfall for HMI and Baltimore Washington International Airport (BWI) for the period between February 2011 and May 2012. The trend in monthly total precipitation recorded at HMI generally tracked that of BWI. The differences in HMI and BWI monthly amounts illustrate the variations in precipitation on a local scale. Two major storm systems, Hurricane Irene and Tropical Storm (TS) Lee, contributed significant rainfall to the region in August and September, 2011 (Figure 1-3). The total inches recorded at BWI for September exceeded the record set for that month. Overall, September 2011 was the wettest month since August 1955 and the third wettest month on record at BWI. Precipitation amounts were at or below normal for the rest of the monitoring year.

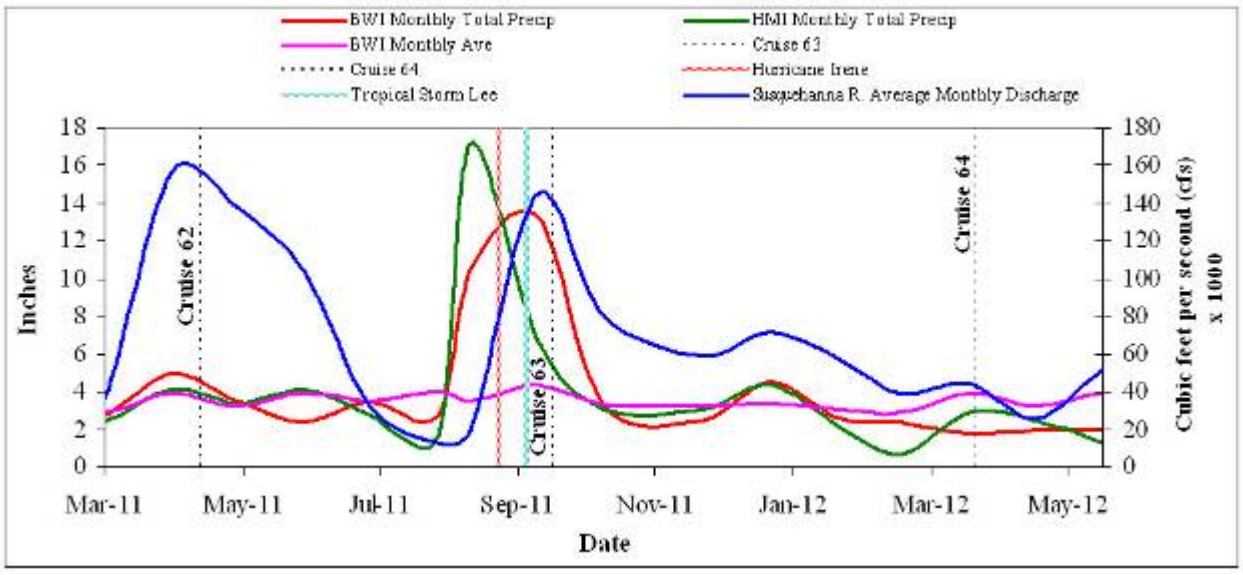

Figure 1- 2: Comparison of monthly precipitation data collected at HMI Facility and at the National Weather Service (NWS) Station at BWI (NOAA, 2012) with the average monthly discharge of the Susquehanna River. BWI monthly averages were based on monthly precipitation data from 1981 to 2011. Susquehanna River data were obtained from the USGS website (U.S.G.S, 2012).

Also shown in Figure 1-2 is the average monthly discharge for the Susquehanna River at the Conowingo Dam. As noted earlier, flow from the Susquehanna River influences the dispersion of material around HMI. Normally, the River flow is largely seasonal, with higher

flow during the winter and spring (wet) and low flow during the summer and fall (dry). However, for this monitoring year, the flow rate was influenced by unusual regional weather patterns. From January to April, 2011, the northeast United States received well above normal precipitation resulting in the very high flows in March and April; daily flow rates reached as high as 414,000 cubic feet per second (cfs) (March 12, 2011). During the following summer the flow dropped, to a monthly mean of 12,500 cfs in July, 2011. However, average flow increased to 144,660 cfs in September due to TS Lee. Compared to Hurricane Irene, TS Lee contributed significantly higher amounts of rainfall throughout the Susquehanna River Watershed (Figure 1-3). On September 9, 2011, the river flow peaked at 778,000 cfs, the second highest recorded rate since TS Agnes on June 24, 1972. For this monitoring period, the May-October average, which normally represents the low or dry season, was 75,036 cfs, higher than the November-April (normally high flow season) average of 58,436 cfs. These seasonal averages were significantly higher compared to the high and low flow rates (40,878 cfs and 9,376 cfs, respectively) used in the hydrodynamic model to predict the dispersion of discharge from the facility (Wang, 1993).

During the 30th year monitoring, there were no discharges from the North Cell due to continued water quality issues within the cell (MES, 2012). In order to stay within the schedule for the 5-year North Cell Habitat development plan, water from crust management (dewatering efforts) was diverted into the South Cell, on an as-needed basis, from February, 2011 to July, 2011. Diversion of water from the North Cell stopped when the South Cell began its drawdown to lower the elevation of the pond in order to expose mudflats for migratory birds. The drawdown took place during the latter half of July, 2011; during which 30 million gallons of water was discharged from SW003 (Figure 1-4). In August, 2011, the water quality in the South Cell pond deteriorated, with a precipitous drop in pH and increases in metal concentrations. Rainfall from Hurricane Irene and TS Lee resulted in the South Cell pond level rising to within 6-inches of overtopping SW003 (Figure 1-5) (MES, 2011). In order to lower the pond level, water, with pH below the discharge permit limit of 6.0, was discharged from SW003 for 6 days (Sept. 7 – Sept. 11, 2011); the period coinciding with the Susquehanna River peak flow from TS Lee. SW003 discharge rates were below 10 million gallons per day (mgd). Water from the South Cell was also pumped into the North Cell in September and December, 2011. There were no additional discharges from SW003 until the following April (2012). By then, water quality had improved in the South Cell to levels within the discharge permit criteria. Between April 1, 2011 and April 30, 2012, total cumulative discharge from the South Cell into the Bay was 91 million gallons, the lowest volume since discharge from the South Cell began.

At the end of 2011, the North Cell contained nearly 600 million gallons. In addition, water quality monitoring in the North Cell indicated a decreasing pH and increasing metal concentrations; no discharge occurred from the North Cell. To mitigate the pH, a lime doser was set into operation in the North Cell in May, 2012 (MES, 2012).

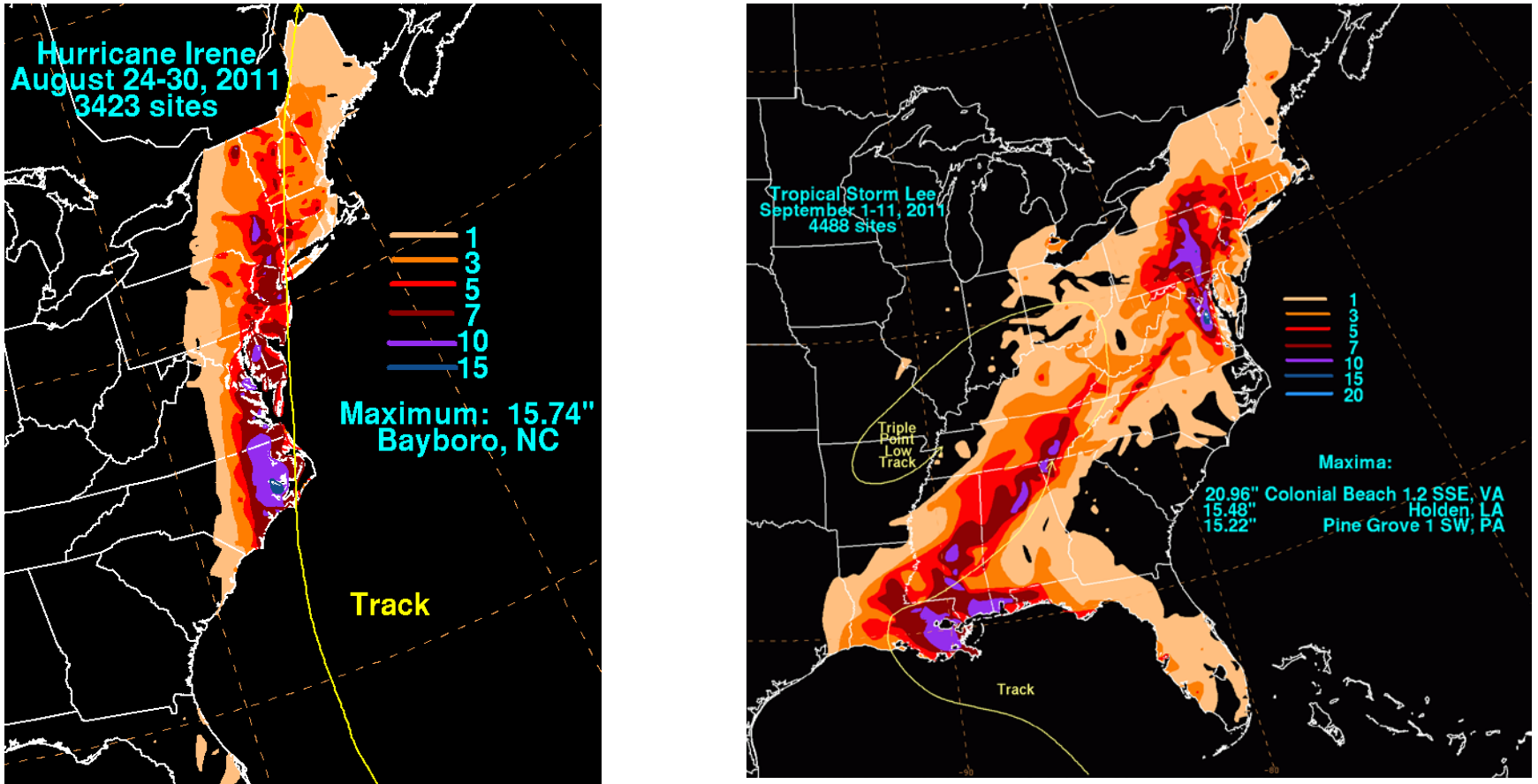

Figure 1- 3: Maps showing areal extent and amounts of rainfall produced by Hurricane Irene during August 2011 (shown at left), and Tropical Storm Lee (above). Maps downloaded from NOAA's Weather Prediction Service web site (Roth, 2011).

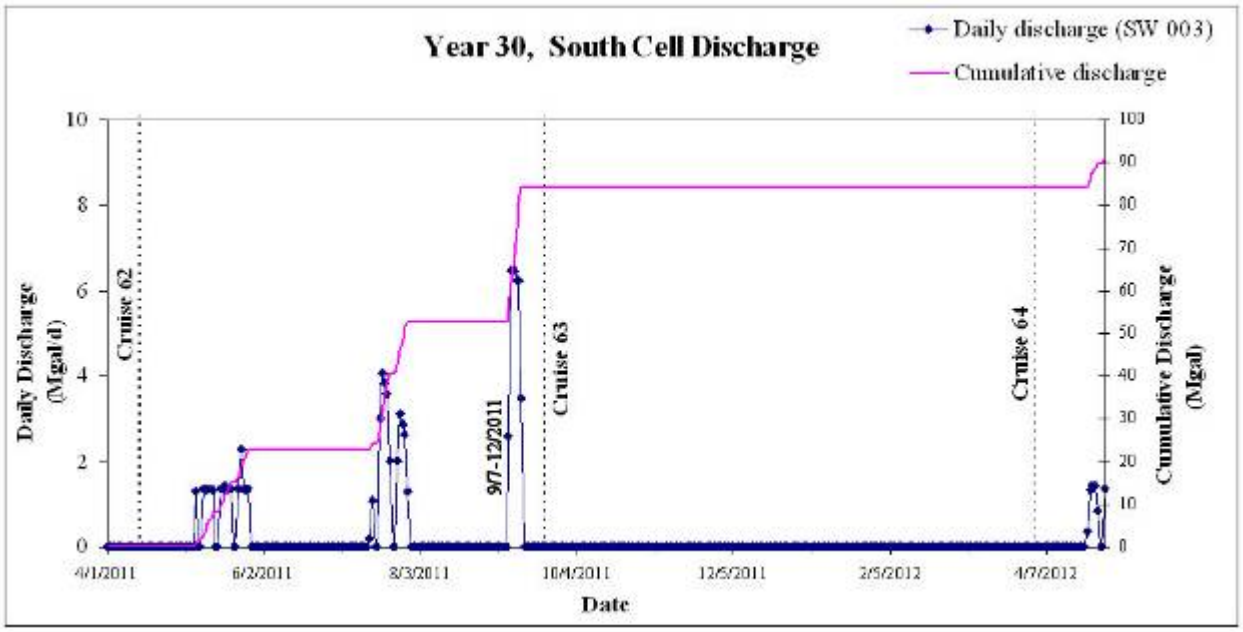

Figure 1- 4: Daily and cumulative discharge from the South Cell. The discharge from the South Cell is from SW003, which is the only discharge point for the Cell. The exterior sediment sampling events are marked by the vertical lines.

OBJECTIVES

As in the past, the main objectives of the Year 30 study were (1) to measure specific physical and geochemical properties of near-surface sediments around HMI and (2) to assess detected changes in the sedimentary environment. Tracking the extent and persistence of the area of historically elevated metals concentrations was again of particular interest.

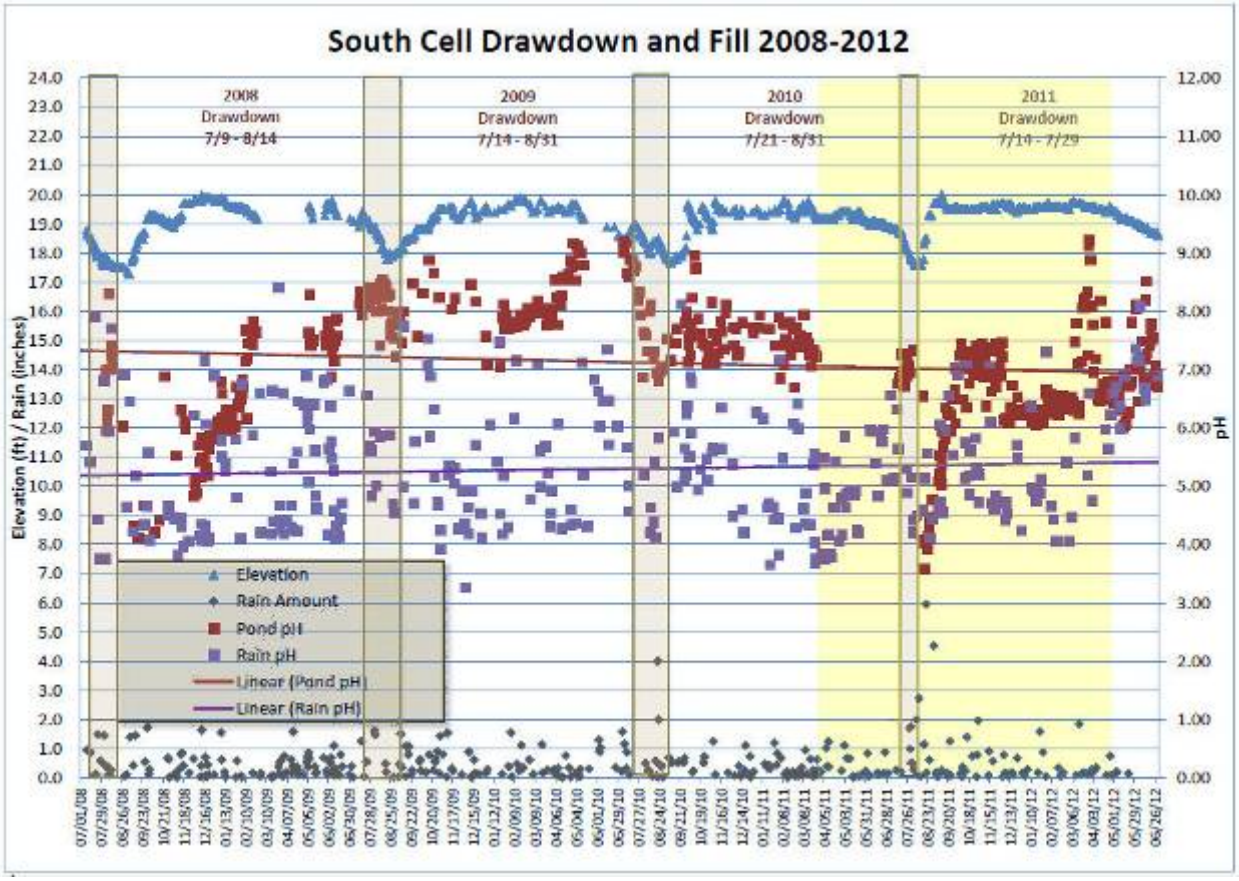

Figure 1- 5: Graph showing the South Cell pond elevation (blue triangles) and pond pH (red squares) for 2008 to 2012. The 30th year monitoring period is indicated by yellow shading. Drawdown periods are indicated by tan shading. Also shown are HMI daily precipitation amounts and rain pH. Graph was modified from MES, 2012.

METHODS AND MATERIALS

Field Methods

The information presented in this report is based on observations and analyses of surficial sediment samples collected around HMI during two cruises aboard the *R/V Kerhin.* The first cruise took place on September 22, 2011 (Cruise 63), within two weeks after TS Lee, and the second, on April 3, 2012 (Cruise 64).

Sampling sites (Figure 1-1) were located in the field by means of a Leica Model MX412B differential global positioning system (GPS) with a built-in beacon receiver.

According to the captain, Rick Younger, the repeatability of the navigation system, that is, the ability to return to a location at which a navigation fix has previously been obtained is between 5-10 m (16-33 ft). Where replicates were collected, the captain repositioned the vessel between samples to counteract drifting off the station during sample retrieval. The captain recorded station coordinates and water depth at each site. Target and actual coordinates (latitude and longitude - North American Datum of 1983, or NAD83) of Year 30 sample locations are reported in the companion *Year 30 Data Report*.

Using a dip-galvanized Petersen sampler (maximum depth of penetration = 38 cm or 15 inches), crewmembers collected undisturbed samples, or grabs, of surficial sediments at 43 sites for both Year 30 cruises. The stations were identical to those sampled during previous three monitoring years.

At 39 stations for both the September and April cruises, a single grab sample was collected, described lithologically, and split. Triplicate grab samples were collected at the remaining four stations (MDE-2, MDE-7, MDE-9 and MDE-31) and, likewise, described and split. MGS analyzed one split for grain size composition, a suite of metals, and phosphorus, carbon, sulfur and nitrogen. The Chesapeake Biological Laboratory (CBL) analyzed the second split collected for a different suite of metals. Field descriptions of samples are included as appendices in the *Year 30 Data Report*.

Using plastic scoops cleaned with deionized water, the crew took sediment sub-samples from below the flocculent (floc) layer, usually several centimeters from the top, and away from the sides of the sampler to avoid possible contamination by the sampler itself. MGS's sub-samples were placed in 18-oz Whirl-Pak™ bags and refrigerated. They were maintained at 4°C until they could be processed in the laboratory. CBL's splits were handled in much the same way, except that they included the floc layer and were frozen instead of refrigerated. CBL's samples are only collected for the fall sampling of each monitoring year. Therefore, the spring sampling procedure does not include a split.

Laboratory Procedures

Textural Analyses

In the laboratory, sediment samples were analyzed for water content and grain size composition (sand-silt-clay content). Water content was calculated as the percentage of the water weight to the total weight of the wet sediment:

$$Wc = \frac{Ww}{Wt} \times 100 \qquad \text{Equation (1)}$$

where: Wc = water content (%)
Ww = weight of water (g)

Wt = weight of wet sediment (g)

Water weight was determined by weighing approximately 25 g of the wet sample, drying the sediment at 65°C, and reweighing it. The difference between total wet weight (Wt) and dry weight equals water weight (Ww). Bulk density was also determined from water content measurements.

The relative proportions of sand, silt, and clay were determined using the sedimentological procedures described in Kerhin et al. (1988). The sediment samples were pre-treated with hydrochloric acid and hydrogen peroxide to remove carbonate and organic matter, respectively. Then the samples were wet sieved through a 62-µm mesh to separate the sand from the mud (silt plus clay) fraction. The finer fraction was analyzed using the pipette method to determine the silt and clay components. Each fraction was weighed; percent sand, silt, and clay were determined; and the sediments were categorized according to Pejrup's (1988) classification (Figure 1-6).

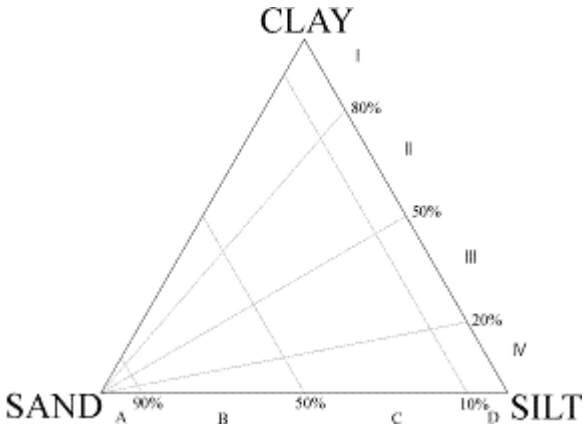

Figure 1- 6: Pejrup's Diagram (1988) classification of sediment type.

Pejrup's diagram, developed specifically for estuarine sediments, is a tool for graphing a three-component system summing to 100%. Lines paralleling the side of the triangle opposite the sand apex indicate the percentage of sand. Each of the lines fanning out from the sand apex represents a constant clay:mud ratio (the proportion of clay in the mud, or fine, fraction). Class names consist of letter-Roman numeral combinations. Class D-II, for example, includes all samples with less than 10% sand and a clay:mud ratio between 0.50 and 0.80.

The primary advantage of Pejrup's classification system over other schemes is that the clay:mud ratio can be used as a simple indicator of hydrodynamic conditions during sedimentation. (Here, hydrodynamic conditions refer to the combined effect of current velocity, wave turbulence, and water depth.) The higher the clay:mud ratio, the quieter the depositional environment. Sand content cannot be similarly used as an indicator of depositional environment; however, it is well suited to a rough textural classification of sediment.

Although the classification scheme is useful in reducing a three-component system to a single term, the arbitrarily defined boundaries separating classes sometimes create artificial differences between similar samples. Samples may be assigned to different categories, not because of marked differences in sand-silt-clay composition, but because they fall close to, but on opposite sides of, a class boundary. To avoid that problem, the results of grain size analysis are discussed in terms of percent sand and clay:mud ratios, not Pejrup's classes themselves.

Elemental Analysis

The sediment samples were analyzed for elements by *Activation Laboratories Inc*. (ActLabs). The quality assurance and quality control of ActLabs has proved to meet MGS standards and requirements. In addition to the nine elements historically measured by MGS (Fe, Mn, Zn, Cu, Cr, Ni, Pb, Cd, and total P), forty-one (41) additional elements were analyzed. Samples were prepared and ground in-house and sent to ActLabs for analyses using both Neutron Activation Analysis (NAA) and a four acid "near total" digestion technique followed by analysis on an Inductively Coupled Argon Plasma Spectrometer (ICAP). In addition to the standards and blanks used by ActLabs, National Institute for Standards and Technology (NIST) and Canadian Research Council (CRC) standard reference materials (SRM) were inserted as blind samples for analyses; one in every nine samples.

Results of the analyses of the SRMs reported by ActLabs are presented in the *Year 30 Data Report.* Both the accuracy and precision of the Actlabs analyses are in good agreement with the SRMs.

Carbon-Sulfur-Nitrogen Analysis

Sediments were analyzed by MGS for total carbon, nitrogen, and sulfur (CNS) contents using a Carlo Erba NA1500 analyzer. This analyzer uses complete combustion of the sample followed by separation and analysis of the resulting gasses by gas chromatographic techniques employing a thermal conductivity detector. The NA1500 Analyzer was configured for CNS analysis using the manufacturer's recommended settings. As a primary standard, sulfanilamide was used. Blanks (tin capsules containing only vanadium pentoxide) were run at the beginning of the analyses and after 12 to 15 unknowns (samples) and standards. Replicates of every seventh sample were also run. As a secondary standard, one of several NIST SRMs was run after every six to seven sediment samples. The recovery of the SRMs was good with the agreement between the NIST certified values and MGS's results well within the two standard deviations of replicate analyses. Results of the SRMs are presented in the *Year 30 Data Report.*

RESULTS AND DISCUSSION

Sediment Distribution

The monitoring effort around HMI is based on the identification of long-term trends in sediment distribution and on the detection of changes in those trends. The sampling scheme, revised in Year 17 and expanded in Year 18, established a new baseline against which any future changes in the sedimentary environment will be measured. Through Year 19, results of all cruises beginning with Year 17 were reported and compared. Starting with Year 20, results of the current year were discussed with respect to the preceding year. For this report, the current Year 30 results are discussed with respect to the preceding Year 29 results, and where appropriate, with references to earlier monitoring year results.

All sampling sites visited during Year 30 yielded results that can be compared to those measured during Year 29. The grain size composition (proportions of sand, silt, and clay) of the samples is depicted as a series of Pejrup's diagrams in Figure 1-7. Within a diagram, each solid circle represents one sediment sample. Related statistics, by cruise, are presented in Table 1-1.

Table 1-1: Summary statistics for Years 29 and 30, for 43 sediment samples common to all four cruises.

Variable	Sept 2010 Cruise 61	Apr 2011 Cruise 62	Sept 2011 Cruise 63	Apr 2012 Cruise 64
Sand (%)				
Mean	22.98	21.67	21.61	20.93
Median	5.30	3.70	4.21	4.34
Minimum	0.84	0.72	0.88	0.66
Maximum	98.89	97.14	96.83	96.46
Range	98.05	96.42	95.95	95.79
Count	43	43	43	43
Clay:Mud				
Mean	0.58	0.54	0.54	0.54
Median	0.57	0.55	0.54	0.55
Minimum	0.42	0.36	0.44	0.42
Maximum	0.99	0.82	0.64	0.62
Range	0.57	0.46	0.20	0.20
Count	43	43	43	43

The ternary diagrams show similar distributions of sediment type compared to the previous year. The samples range widely in composition, from very sandy (>90% sand) to very muddy (<10% sand). Muddy sediments predominate; at least three-fourths of the samples contain less than 10% sand. All of the points fall fairly close to the line that extends from the sand apex and bisects the opposite side of the triangle (clay:mud = 0.50 or 50%). For both the September 2011 and April 2012 samplings (Cruises 63 and 64, respectively), points lie above the 50% line, indicating that the fine (muddy) fraction of the sediments contains more clay than silt.

However, the number of points shifts slightly away from the Sand apex (especially in September, 2011), indicating an overall decrease in the sand fraction. This shift is attributed to the effect of the two storms (Hurricane Irene and TS Lee).

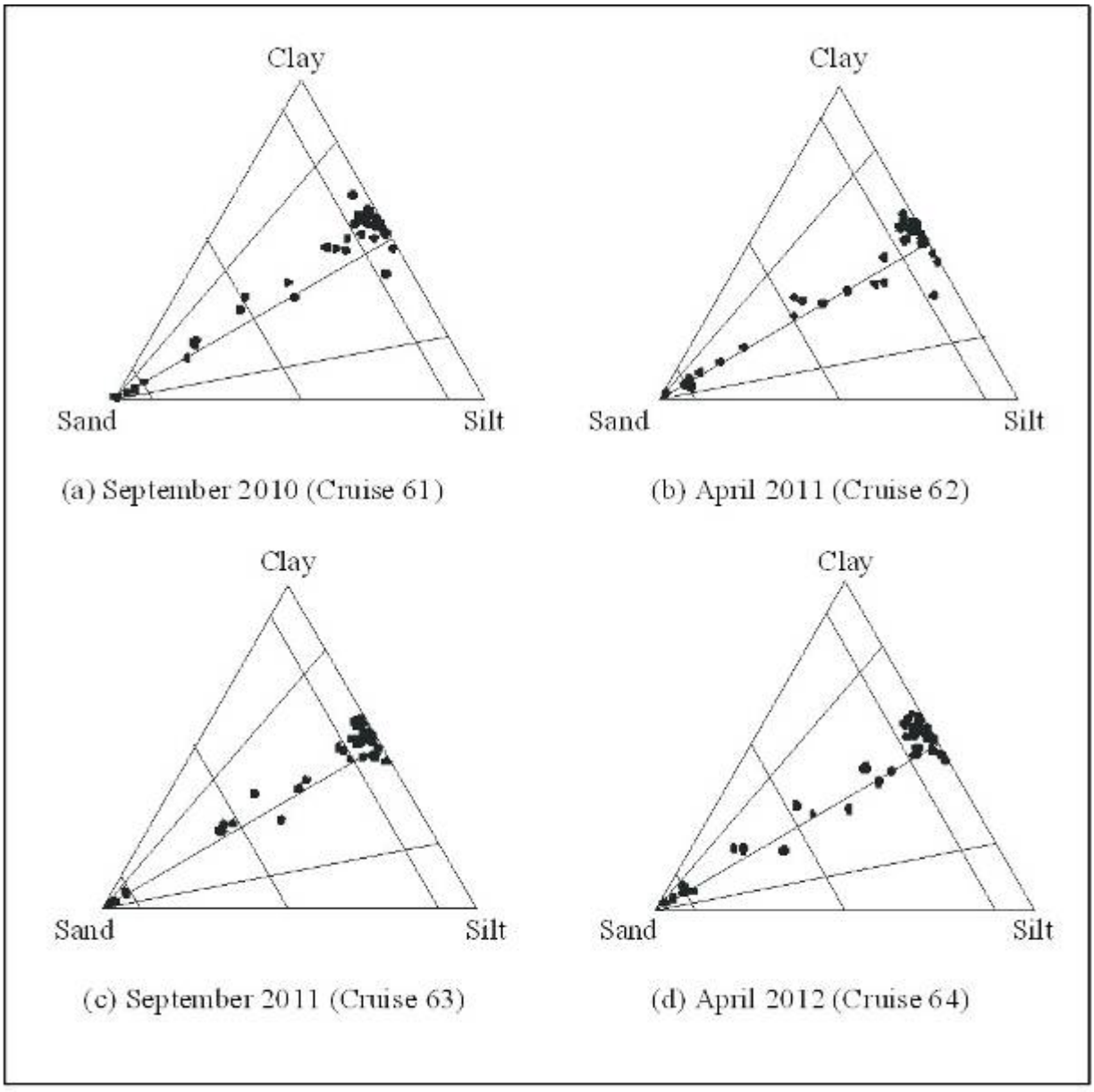

Figure 1- 7: Pejrup diagrams showing the grain size composition of sediment samples collected in Years 29 and 30 from the 43 sampling sites common to all four cruises: (a) September, 2010, (b) April, 2011, (c) September, 2011, and (d) April, 2012.

Based on the summary statistics (Table 1-1), average grain size composition, reported as % sand and as clay:mud ratios, varied little over the four sampling periods. The mean percentage of sand varied approximately 2 % for the four samplings. The mean clay:mud ratio was 0.58 for sampling Cruise 61 and decreased to 0.54 for Cruises 62, 63 and 64.

Sandy sediments are associated with the shallower areas around the diked facility (Figure 1-8). The grain-size distribution of bottom sediments around HMI is depicted in contour maps showing (1) the percentage of sand in bottom sediments and (2) the clay:mud ratios. In Figures 1-9 and 1-10, three contour levels represent 10%, 50%, and 90% sand, coinciding with the parallel lines in Pejrup's diagram (Figure 1-6). Generally, sand content diminishes with distance from the containment facility. Scattered around the perimeter of the dike, the sandiest sediments (>50% sand) are confined to relatively shallow (<15 ft) waters.

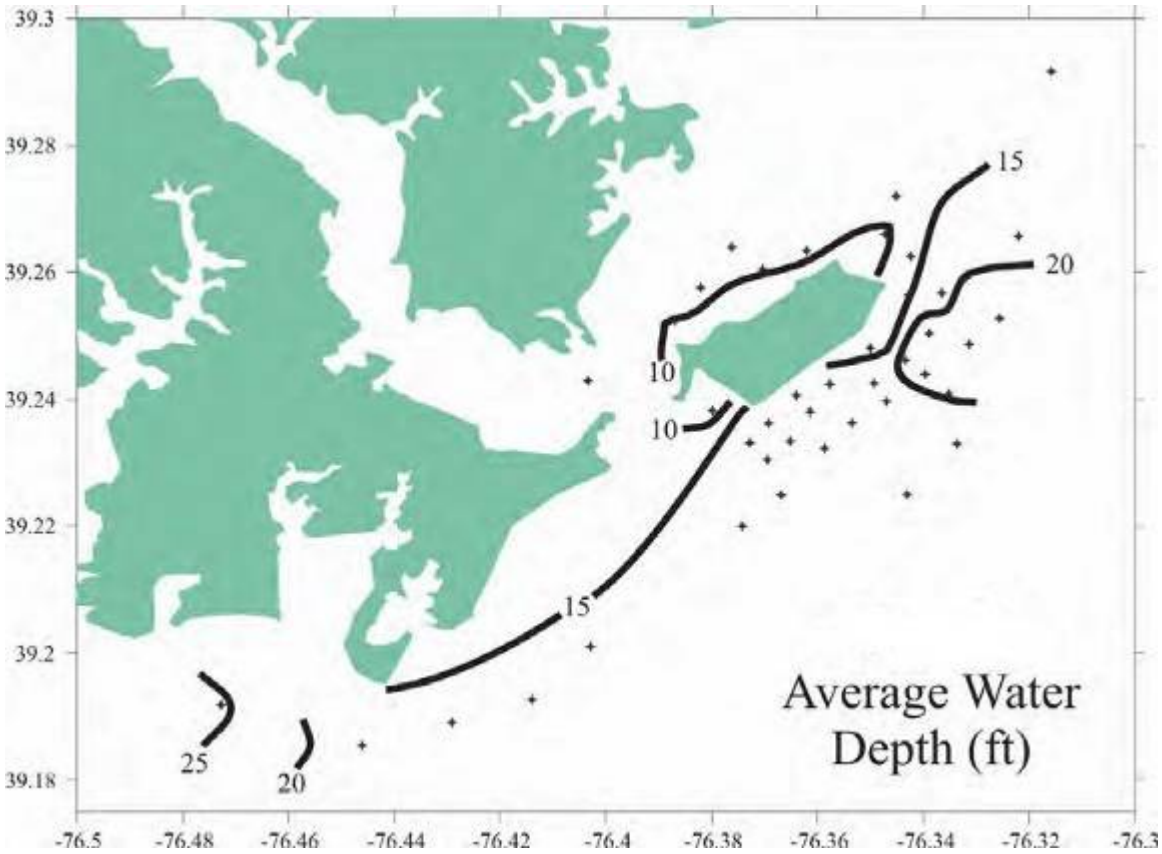

Figure 1- 8: Average water depths around HMI and vicinity. Contour interval = 5 ft.

Broadest north and west of the facility, the shoals are the erosional remnants of a larger neck of land. The once continuous landmass has been reduced to a series of islands, including Hart and Miller, extending from the peninsula that now forms the south shore of Back River. However, not all shallow water samples are sandy. In particular, several of the shallow water samples from Hawk Cove (*e.g.*, MDE-30) contain less than 10% sand. Sand distribution maps for Years 29 and 30 are very similar in appearance (Figures 1-9 and 1-10). Sand contents continue to be highest near the perimeter of HMI in shallow water depths. At the northeast end of the facility, the broad sand area, as defined by the 90% contour, underwent subtle seasonal shifts. The September, 2011 distribution changed very little from the previous April, indicating minimal effect from the Hurricane Irene and TS Lee. In general, the distribution of sand around

HMI has remained largely unchanged since November 1988, two years after the first release of effluent from the dike.

Compared to the distribution of sand, the distribution of clay:mud ratios has tended to be slightly more variable over time (Figures 1-11 and 1-12). The fine (mud) fraction of the sediments around HMI is generally richer in clay than in silt. That is, the clay:mud ratio usually exceeds 0.50, as shown in the ternary diagrams in Figure 1-7. However, slight variations in the most clay-rich (clay:mud ratio ≥ 0.60) and in the most silt-rich (clay:mud ratio < 0.50) of the fine fractions are evident at the mouth of Baltimore Harbor, which continued to be clay-rich for all of the four samplings. A broad clay-rich area north of HMI was present in September 2010 and diminished in size by following April sampling and into this year. A clay-rich area south of HMI (in proximal zone) present in September 2010, all but disappeared in the following sampling cruises. These patterns of change are most likely due to the effects of the storms as opposed to seasonal changes. In previous monitoring years, the April samplings occur during a period of higher turbulence due to weather, whereas the September samplings take place after a comparatively quiet, low flow summer during which more clay size sediment accumulated on the bottom. The September 2011 sampling took place within days after TS Lee. During the storm, the study area was subjected to high turbulence, preventing the settling of the finer clay size sediment.

Based on the overall similarities between the fine fraction results from the past four years, one may conclude that the depositional environment in the vicinity of HMI has not changed significantly over this period. The depositional environment continues to be very stable despite the major storm events.

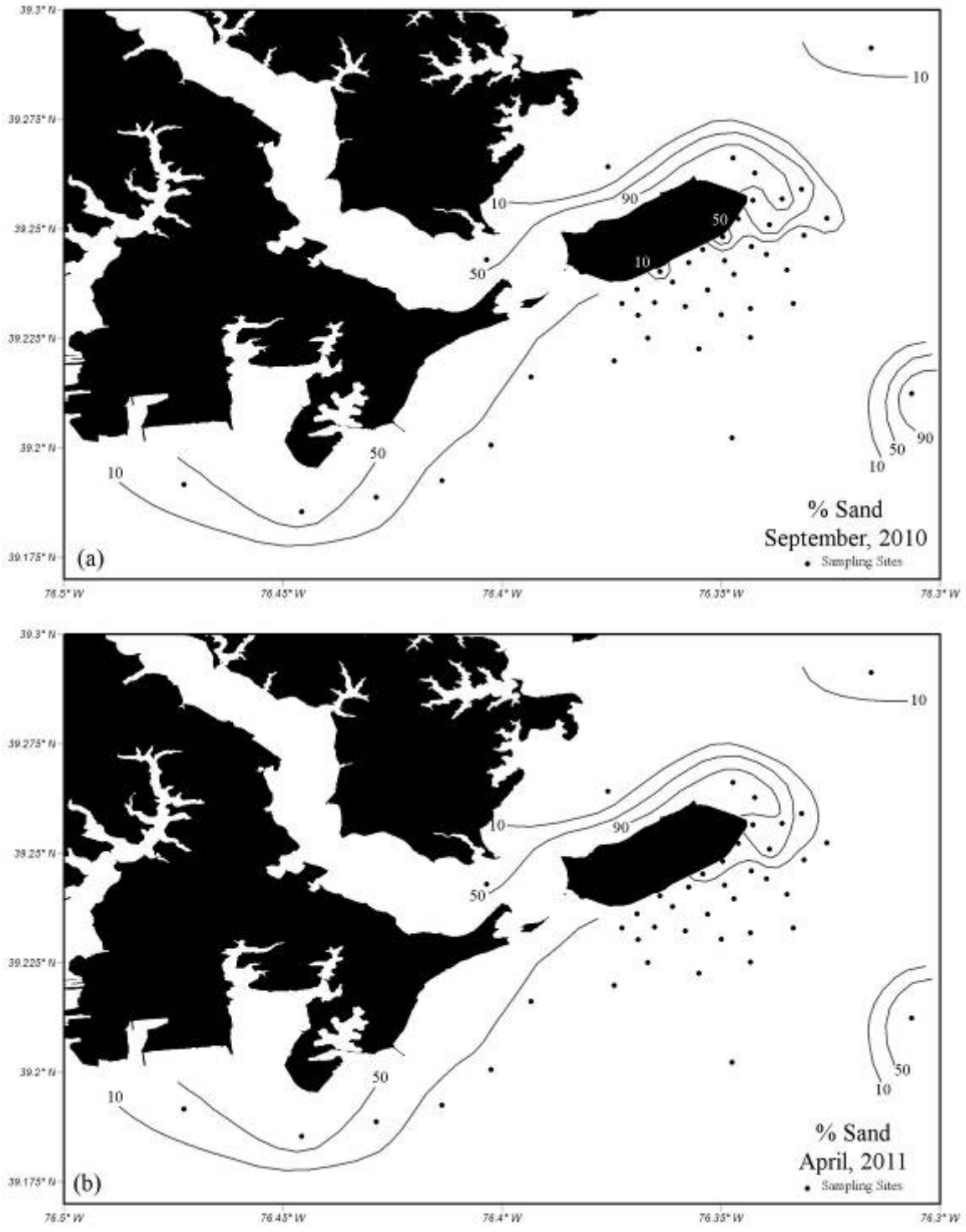

Figure 1- 9: Sand distribution for Monitoring Year 29: (a) September, 2010 (Cruise 61), (b) April, 2011 (Cruise 62). Contour intervals are 10%, 50%, and 90% sand.

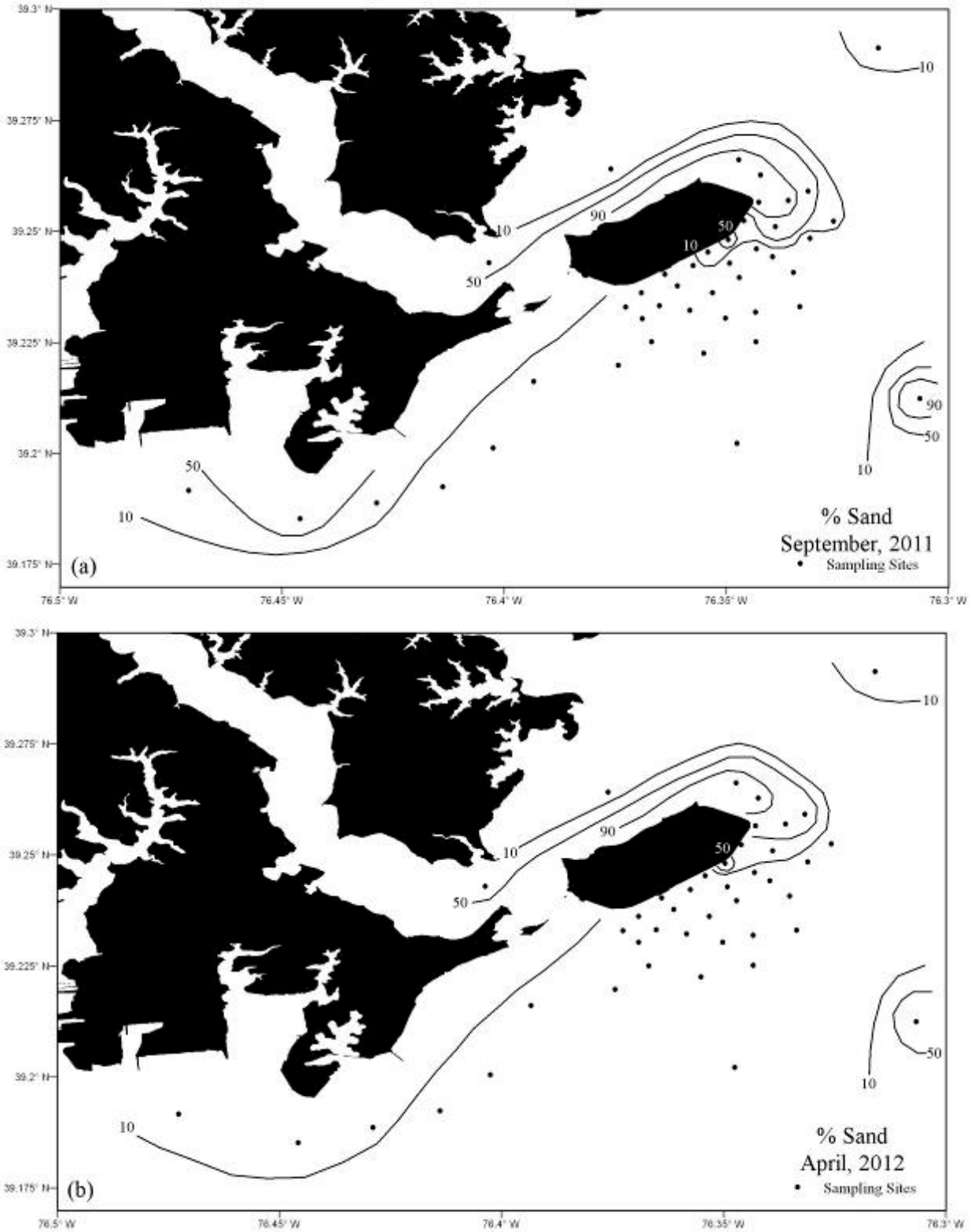

Figure 1- 10: Sand distribution for Monitoring Year 30: (a) September, 2011 (Cruise 63), (b) April, 2012 (Cruise 64). Contour intervals are 10%, 50%, and 90% sand.

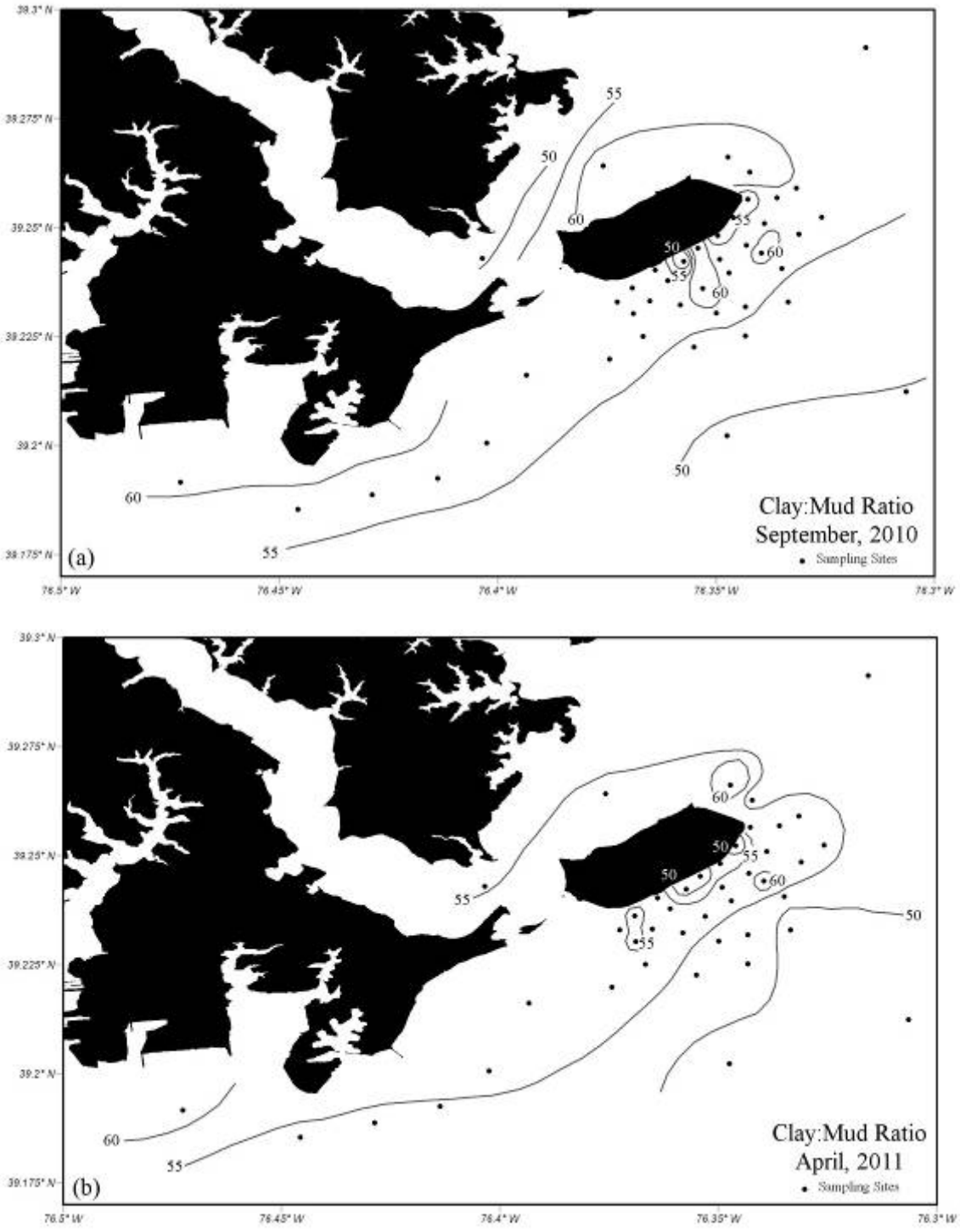

Figure 1- 11: Clay:Mud ratios for Monitoring Year 29: (a) September, 2010 (Cruise 61), (b) April, 2011 (Cruise 62). Contour intervals are 50%, 55%, and 60% (clay:mud ratio expressed as %).

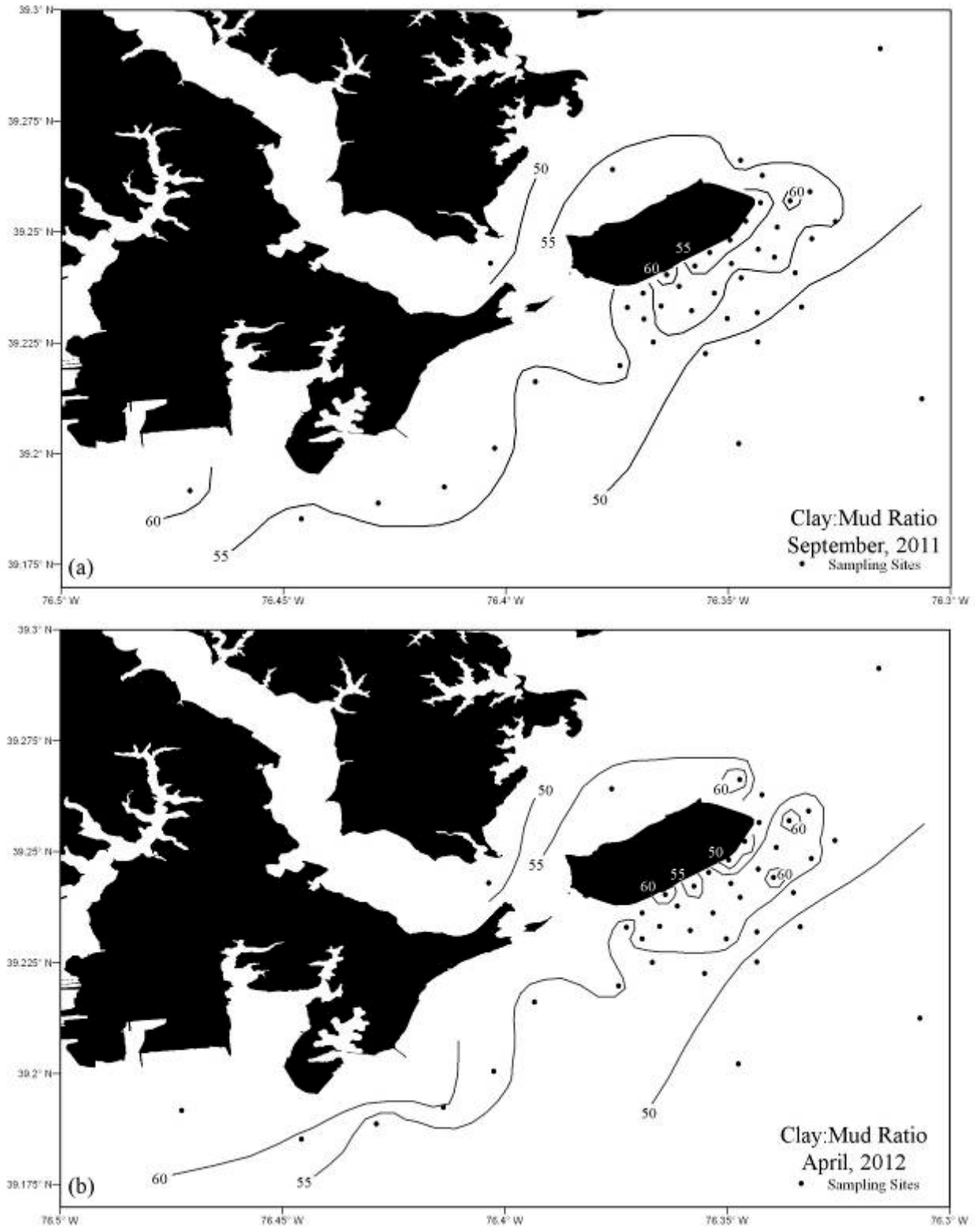

Figure 1- 12: Clay:Mud ratios for Monitoring Year 30: (a) September, 2011 (Cruise 63), (b) April, 2012 (Cruise 64). Contour intervals are 50%, 55%, and 60% (clay:mud ratio expressed as %)

Elemental Analyses

Interpretive Technique for Metals

Previous monitoring years have focused on eight metals as part of the ongoing effort to assess the effects of operation of the containment facility on the surrounding sedimentary environment. The method used to interpret changes in the observed metal concentrations takes into account grain size induced variability and references the data to a regional norm. The method involves correlating metal levels with grain size composition on a data set that can be used as a reference for comparison. For the HMI study area, data collected between 1983 and 1988 are used as the reference. Samples collected during this time showed no aberrant behavior in metal levels. Normalization of grain size induced variability of metal concentrations was accomplished by fitting the data to the following equation:

$$X = a(\text{Sand}) + b(\text{Silt}) + c(\text{Clay}) \qquad \text{Equation (2)}$$

where X = the metal of interest
a, b, and c = the determined coefficients
Sand, Silt, and Clay = the grain size fractions of the sample

A least squares fit of the data was obtained by using a Marquardt (1963) type algorithm. The results of this analysis are presented in Table 1-2. The correlations are excellent for Cr, Fe, Ni, Pb, and Zn, indicating that the concentrations of these metals are directly related to the grain size of the sediment. The correlations for Mn and Cu are weaker, though still strong. In addition to being part of the lattice and adsorbed structure of the mineral grains, Mn occurs as oxy-hydroxide chemical precipitate coatings. These coatings cover exposed surfaces, that is, they cover individual particles as well as particle aggregates. Consequently, the correlation between Mn and the disaggregated sediment size fraction is weaker than for metals, like Fe, that occur primarily as components of the mineral structure. The behavior of Cu is more strongly influenced by sorption into the oxy-hydroxide than are the other metals. The poor relationship with regard to Cd is due to the baseline being established at or near the detection limit; however, the relationship is still significant. Baseline levels for Cd and Pb were determined from analyses of 30 samples collected in a reference area on the eastern side of the Northern Bay. The baseline was established as part of a study examining toxic loading to Baltimore Harbor.

Table 1-2: Coefficients and R^2 for a best fit of metal data as a linear function of sediment grain size around HMI. The data are based on analyses of samples collected during eight cruises, from May 1985 to April 1988.

X = [a*Sand + b*Silt + c*Clay]/100 Equation (2)								
	Cd	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
a	0.32	25.27	12.3	0.553	668	15.3	6.81	44.4
b	0.14	71.92	18.7	1.17	218	0	4.1	0
c	1.373	160.8	70.8	7.57	4158	136	77	472
R^2	0.12	0.733	0.61	0.91	0.36	0.82	0.88	0.77

The strong correlation between the metals and the physical size fractions makes it possible to predict metal levels at a given site if the grain size composition is known. A metal concentration can be predicted by substituting the least squares coefficients from Table 1-2 for the constants in equation 2, and using the measured grain size at the site of interest. These predicted values can then be used to determine variations from the regional norm due to deposition; to exposure of older, more metal-depleted sediments; or to loadings from anthropogenic or other enriched sources.

The following equation was used to examine the variation from the norm around HMI.

$$\% \text{ excess Zn} = \frac{(\text{measured Zn} - \text{predicted Zn})}{\text{predicted Zn}} * 100 \qquad \text{Equation (3)}$$

Note: Zn is used in the equation because of its significance in previous studies; however any metal of interest could be used.

In Equation 3, the differences between the measured and predicted levels of Zn are normalized to predicted Zn levels. This means that, compared to the regional baseline, a value of zero percent excess metal is at the regional norm, positive values are enriched, and negative values are depleted. Direct comparisons of different metals in all sediment types can be made due to the method of normalization. As useful as the % Excess Metal values are, alone they do not give a complete picture of the loading to the sediments; natural variability in the samples as well as analytical variations must be taken into account. As result of the normalization of the data, Gaussian statistics can be applied to the interpretation of the data. Data falling within $\pm 2\sigma$ (± 2 standard deviations) are within normal background variability for the region. Samples with a value of $\pm 3\sigma$ can be within accepted background variability, but are considered marginal depending on the trends in the distribution. Any values falling outside this range indicate a significant perturbation to the environment. The standard deviation (σ) of the baseline data set (the data used to determine the coefficients in Equation 2) is the basis for determining the sigma level of the data. Each metal has a different standard deviation, as reflected in the R^2 values in Table 1-2. The sigma level for Zn is ~30% (e.g. $1\sigma = 30\%$, $2\sigma = 60\%$, etc.).

General Results

The summary statistics for the concentrations of the elements analyzed are given in Table 1-3. Generally, the statistics are very similar to the previous two years, including an anomalously high Cr value of 3060 ppm which was measured from MDE-41 sampled during the April 2012 cruise. The sample also contained some of the highest values for Cu, Fe and Mn. This sampling site is the upstream-most sample in the Baltimore Harbor Zone of influence and has consistently been high in metals. The sample collected at this site in April contained significant gravel (>30%), a portion of which may have been 'slag' from Sparrows Point, which would explain the high Cr content as well as the high sigma levels for the metals (see next section).

With regard to Effects Range Low (ERL) and Effects Range Median (ERM) values list in Table 1-3, the following, which is very similar to the previous year's findings, should be noted:

1. At most sampling sites, concentrations of Cr, Cu, Ni, Pb, and Zn in the sediment exceed the ERL values; and
2. At most sampling sites, concentrations of Ni exceed the ERM values; and concentrations of Zn exceed the ERM values at some sites.

Table 1-3: Summary statistics for elements analyzed. Both sampling cruises are included in summary. All concentrations are in ug/g (ppm) unless otherwise noted. '*n*' is the total number of values reported above detection limits.

	%P	Cd	Cr	Cu	%Fe	Mn	Ni	Pb	Zn
Ave	0.072	0.78	124	42	4.10	2679	81	50	291
Std	0.030	0.31	323	17	1.53	1443	34	23	139
Min	0.003	0.40	9	4	0.28	324	8	7	21
Max	0.162	2.00	3060	77	6.39	8190	168	99	673
n	86	70	86	86	86	86	86	86	86
ERL	n/a	1.3	81	34	n/a	n/a	21	47	150
#>ERL		4	60	64			80	55	72
ERM	n/a	9.5	370	270	n/a	n/a	52	218	410
#>ERM		0	1	0			72	0	13

ERL and ERM are proposed criteria put forward by NOAA (Buchman, 2008) to gauge the potential for deleterious biological effects. Sediments with concentrations below the ERL are considered baseline concentrations with no expected adverse effects. Concentrations between the ERL and ERM may have adverse impacts to benthic organisms, while values greater than the ERM have probable adverse biological effects. These criteria are based on a statistical method of termed preponderance of evidence. The method does not allow for unique basin conditions and does not take into account grain size induced variability in metal concentrations in the sediment. The values are useful as a guide, but are limited in applicability due to regional differences. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of

Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, certain samples are significantly enriched in Pb and to a lesser extent in Zn and Ni, compared to the baseline.

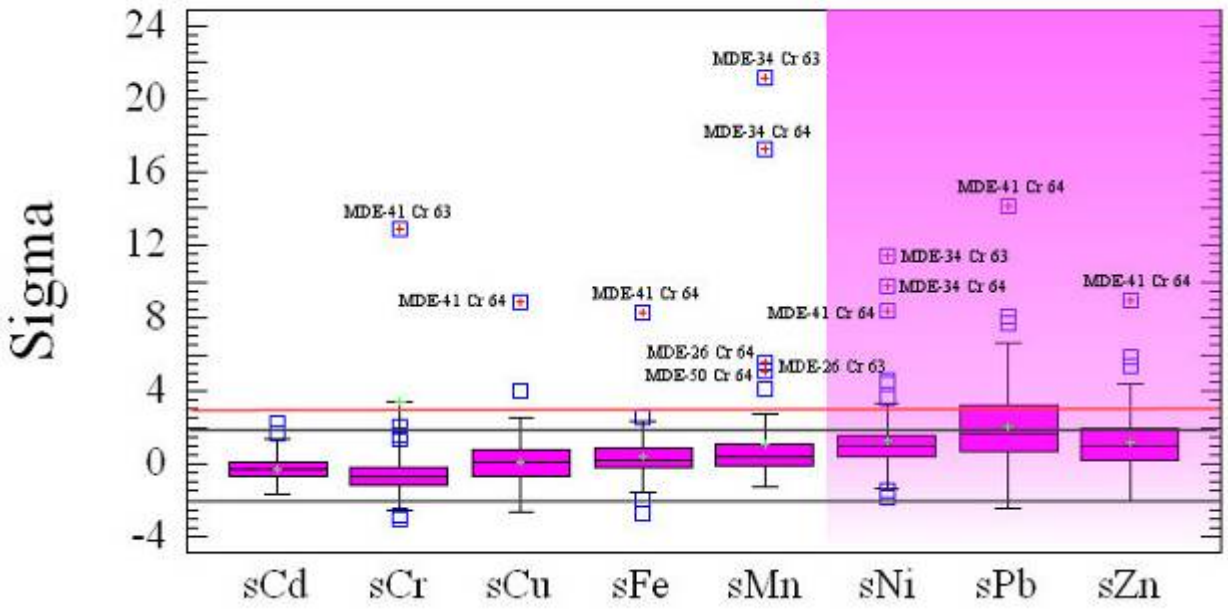

Figure 1- 13: A box and whisker diagram showing the range of the sigma levels for both the September and April cruises for Year 30. The box encloses the middle 50% of the sigma level values for each metal (interquartile range, IQR); the median is indicated by the black line within each box; the mean is indicated by the green +. The vertical lines, or whiskers, bracket the +/- 1.5 IQR. Inside outliers (between 1.5 and 3 IQR) and outside outliers (> 3 IQR), are plotted as individual points (shown as open blue squares, and blue squares with red +, respectively). An extreme outside outlier for sCr (sigma of 337 corresponding to MDE-41 Cr. 64), is not shown; this outlier explains the high mean shown.

The values presented in Table 1-3 are the measured concentrations of metals in the sediment, not normalized with respect to grain size variability, as outlined in the preceding *Interpretive Techniques* section. Figure 1-13 shows the variation of the data from the predicted baseline behavior for each of the elements measured. The values are in units of multiples of standard deviations from the norm; zero values indicate measurements that are identical to the predicted baseline behavior, values within plus or minus two (2) sigma (indicated by grey lines in Figure 1-13) are considered to be within the natural variability of the baseline values. Cd, Cr, Cu and Fe, at most sites for both sampling cruises are within the range expected for normal baseline behavior in the area. Approximately 29% of the samples contain Pb significantly exceeding the baseline levels (*i.e.*, >3 sigma levels, indicated by red line), 12% of the samples contain Zn levels exceeding the baseline and 9% of the samples contain Ni levels exceeding the baseline. Overall sigma levels for Ni, Pb and Zn have increased slightly over the previous monitoring year. Most of the samples with elevated Pb and Zn sigma levels are in the Baltimore Harbor Zone of Influence (Stations MDE-26 and MDE-41), whereas most of the samples with elevated Ni sigma levels were found in the HMI Zone of Influence. Both fall and spring samples for MDE-34 yielded outside outlier values for Mn and Ni. The spring sample for MDE-41 (in

the Baltimore Harbor Zone of Influence) yielded elevated sigma levels for Ni as well as Cu, Cr, Pb and Zn.

Based on work done by the University of Maryland during Year 25 monitoring year, the most probable conditions where the metals affect the infaunal communities are:

1. When the sigma level exceeds +2 [indicating enriched metals concentrations over baseline] and;
2. When the metals level exceeds the ERL with increased probability as the level exceeds the ERM [showing absolute concentrations that have exhibited adverse effects in other systems].

Sediments from several sites met these conditions. Samples for both September 2011 and April 2012 cruises from sites within the Baltimore Harbor Zone of influence (except MDE-22 and MDE-40) and within the Back River Zone contained more than one target metal exceeding both ERL and ERM and sigma greater than 2. Within the HMI Zone of influence (both distal and proximal), the sediments containing multiple metals exceeding ERLs and ERMs, and sigma levels greater than 2 included Sites MDE-8, MDE-9, MDE-13, MDE-14, MDE-20, MDE-34, and MDE-46 from the September 2011 cruise, and sites MDE-3, MDE-8, MDE-9, MDE-11, MDE-13, MDE-18, and MDE-34 from the April 2012 cruise.

Metal Distributions

Since Year 8, increased metal levels (specifically Zn) have been noted in bottom sediments east and south of Spillway 007; similarly since the Pb was added to the monitoring protocol (Year 15), elevated levels of Pb have been found in the same areas, but with generally higher relative loadings. In the last two monitoring years, elevated levels of Ni have been noted at several sites within the HMI zone of influence. The results of previous monitoring studies have shown that the areal extent and magnitude of metals loadings to the exterior sedimentary environment is controlled by three primary factors. These factors are:

1. *Discharge rate* - Controls the amount of metals discharged to the external sedimentary environment. Discharge from HMI at flows less than 10 MGD contribute excess metals to the sediment (see *Year 12 Interpretive Report*). The high metal loading to the exterior environment may be the result of a low pond level, which allows exposure of the sediment to the atmosphere. When the sediments are exposed to atmospheric oxygen, naturally occurring sulfide minerals in the sediment oxidize to produce sulfuric acid, which leaches metals and other acid-soluble chemical species from the sediment. At discharge rates greater than 10 MGD, the water throughput (input from dredge disposal to release of excess water) submerges the sediment within the facility, minimizing atmospheric exposure, and dilutes and buffers any acidic leachate. As a result, higher discharge rates produce metal loadings that are close to background levels.

2. *Flow of freshwater into the Bay from the Susquehanna River* - The hydrodynamic environment of the Bay adjacent to HMI is controlled by the mixing of freshwater and brackish water south of the area. Details of the hydrodynamics of this region

were determined by a modeling effort presented as an addendum to the *Year 10 Interpretive Report* (Wang, 1993). The effects of Susquehanna flow to the contaminant distribution around HMI follow;

a. A circulation gyre exists east of HMI. The gyre circulates water in a clockwise pattern, compressing the discharge from the facility against the eastern and southeastern perimeter of the dike;
b. The circulation gyre is modulated by fresh water flow from the Susquehanna River. The higher the flow from the Susquehanna, the stronger the circulation pattern and the greater the compression against the dike. Conversely, the lower the flow, the less the compression and the greater the dispersion away from the dike; and
c. Discharge from the facility has no influence on the circulation gyre. This was determined by simulating point discharges of 0-70 MGD from three different spillways. Changes in discharge rate only modulated the concentration of a hypothetical conservative species released from the facility; the higher the discharge, the higher the concentration in the plume outside the facility.

3. *The positions of the primary discharge points from the facility* - The areal distribution of the metals in the sediment also depends on the primary discharge locations to the Bay. The effects of discharge location were determined as part of the hydrodynamic model of the region around HMI. The effects of discharge location are:
   a. Releases from Spillways 007 and 009 travel in a narrow, highly concentrated band up and down the eastern side of the dike. This explains the location of the areas of periodic high metal enrichment to the east and southeast of the facility; and
   b. Releases from Spillway 008 are spread more evenly to the north, east, and west. However, dispersion is not as great as from Spillways 007 and 009 because of the lower shearing and straining motions.

The 3-D hydrodynamic model explains the structure of the plume of material found in the exterior sediments, and the functional relationship of contaminants to discharge rate accounts for the magnitude of the loading to the sediments.

Figure 1-14 shows distribution of the sigma levels for Pb for Year 30 monitoring periods in the study area adjacent to HMI; sigma levels for Zn are shown in Figure 1-15. Sigma levels are the multiple of the standard deviation of the baseline data set. Data that falls within +/-2 sigma are considered within normal baseline variability. Data within the 2 -3 sigma range are transitional; statistically one sample in 100 would normally be expected to occur, in a small data set. The occurrence of two or more spatially contiguous stations in this range is significant. Any sample >3 sigma is significantly elevated above background. As shown in Figure 1-1, there are three primary areas of interest that will be referred to as: Back River, Baltimore Harbor, and HMI Zones of Influence.

Back River - The Back River influence is seen for Pb even though only two sites within this zone were sampled this monitoring year. As with previous years, Pb continues to be

discharged by Back River during both of the sampling periods. Based on the two sites, Ni and Zn concentrations were within background levels for both sampling cruises.

Baltimore Harbor - Elevated levels of Pb and Zn extend into the area southwest of HMI. The levels for these metals are isolated from the HMI Zone of Influence adjacent to the island. Pb and Zn showed similar enrichment values as compared to Year 29. The higher number of contours between MDE-41 and MDE-40 for both Pb and Zn in April 2012 is attributed to the anomalous nature of the sediment collected at MDE-41; the sample consisted of 30% gravel and high concentration of metals. MDE-41 also yielded a high Ni sigma level.

HMI – Pb and Ni levels within the HMI Zone are higher, in terms of the number of samples exceeding 3σ, and overall sigma levels, compared to the previous year. The September 2011 spatial extent of Pb enrichment included three areas: two isolated sites (MDE-34, off northeast tip of the facility, and MDE-20, south of HMI); the third area extending from the facility southeast and encompassing 5 sites (MDE-8, -9, -14, -46, and MDE-13). Ni enrichment was also documented at four sites (MDE-9, -10, -13, and MDE-34) (Figure 1-16). By April 2012, Pb enrichment was documented in the same general areas but shifted slightly to the east. Ni enrichment continued to be significant (>4 sigma) at site MDE-34 and increased to a significant level at MDE-20, located adjacent to SW003, and MDE-11. Zn levels remain low or limited to a few isolated sites, similar to the previous year. In September, 2011, Zn enrichment was documented at one isolated site (MDE-20). In April 2012, Zn enrichment (> 3 sigma) was documented at two sites (MDE- 18 and MDE-11).

September spatial distribution of Pb (and Ni) enriched areas along the eastern end of the facility. There was a non-compliant discharge (*i.e.*, pH < 6) from the South Cell (SW003) for six days just before the September 2011 sampling. This discharge, at flow rates less than 10 MGD, occurred during a peak flow period of the Susquehanna River, a result of rainfall from TS Lee (Figure 1-3). The flow from the Patapsco River also peaked during this time (USGS, 2012). The high flow from the Susquehanna and Patapsco Rivers could have distorted and intensified the circulation gyre located east of the facility. As a result, most of the SW003 discharge may have been compressed close to the dike and moved northward before dispersing out into the Bay, explaining the dispersal pattern and extent of the Pb enrichment. The higher Pb persisted through the winter.

The HMI zone, prior to Year 22 monitoring, was clearly independent of Baltimore Harbor and Back River inputs. In the monitoring Years 22 and 23, an enriched area extended into the HMI region. In Year 22 near record rainfall caused the Baltimore Harbor influence to extend into the HMI region for the first time since the construction of the dike. This effect intensified during Year 23, due to continuing climatic factors. The influence of the Harbor diminished in the Year 24 monitoring, with the separation complete in the April 2006 sampling period. During Year 24 rainfall was below normal thus minimizing flow from Baltimore Harbor. The separation of the Baltimore Harbor zone from the HMI zone was maintained for Years 26 and 27 by the low to average rainfall in the periods prior to sampling. During Years 28 and 29 monitoring, rainfall was above average but the Baltimore Harbor and Back River zones remained separate from the HMI zone. Precipitation amounts during Year 30 were even higher than previous years due to a hurricane followed by a tropical storm in the fall. However, Baltimore Harbor and Back River zones continue to remain separate from the HMI zone.

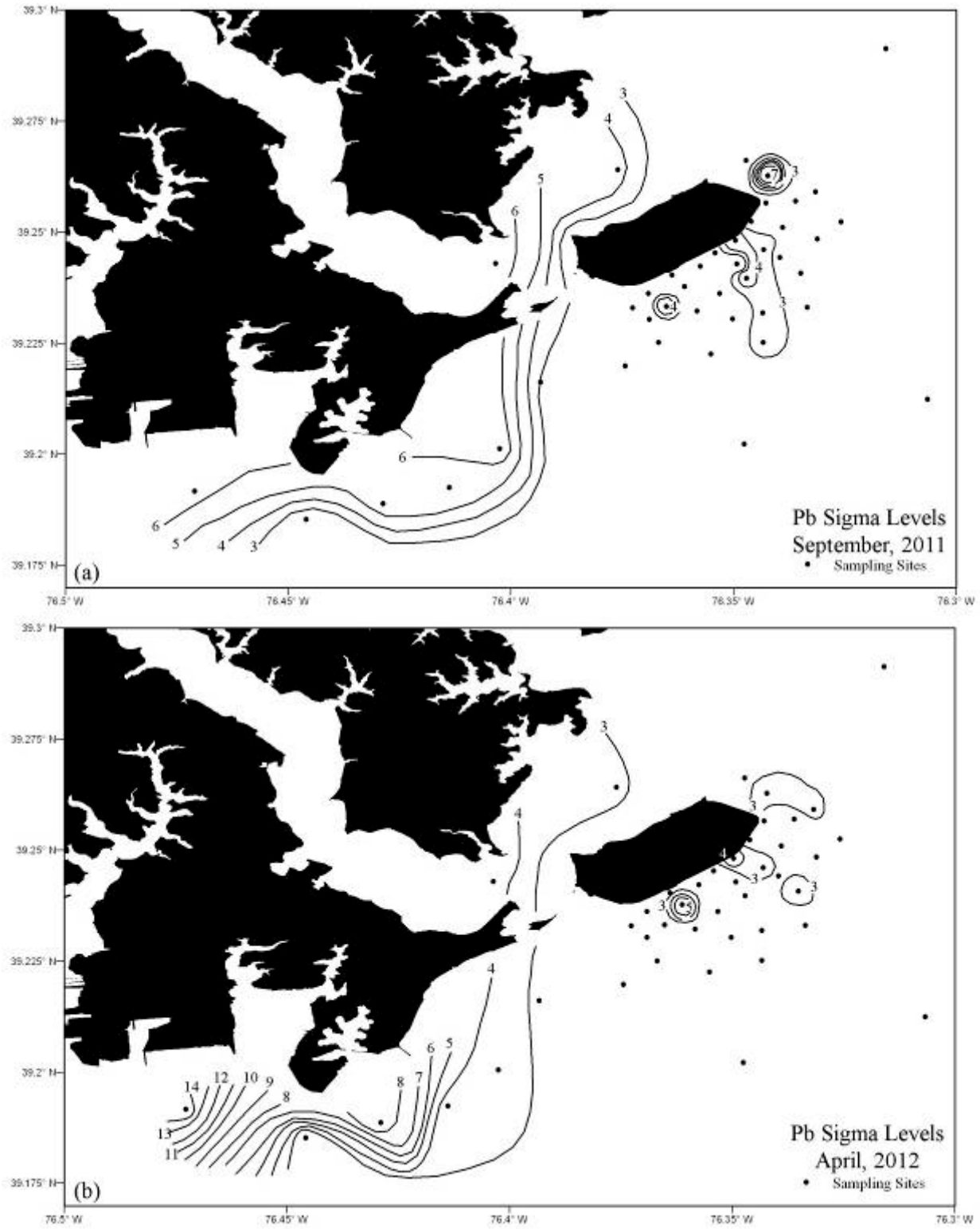

Figure 1- 14: Distribution of Pb in the study area for the September, 2011 and April, 2012 sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (values less than 3 not shown), >3 = significantly enriched.

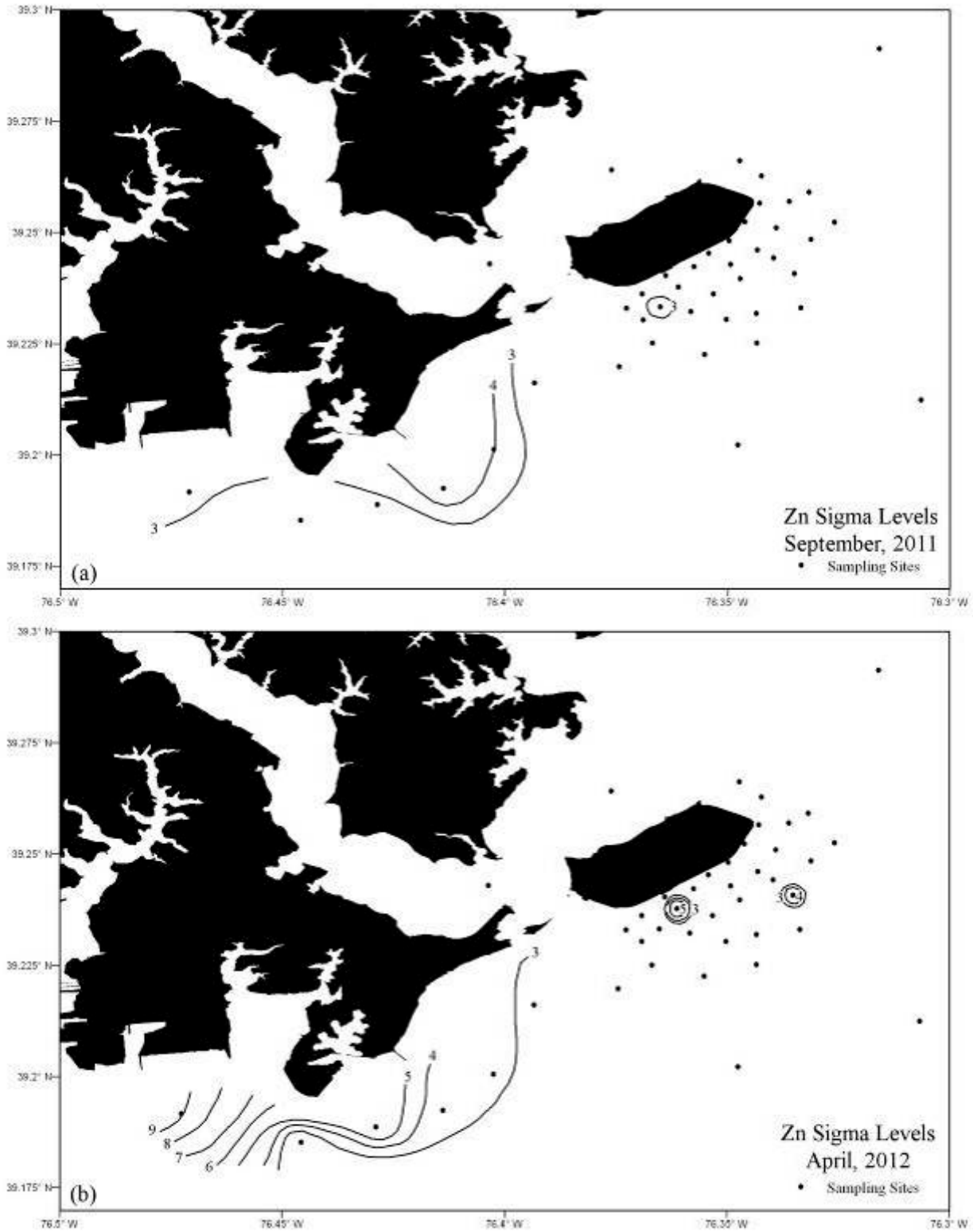

Figure 1- 15: Distribution of Zn in the study area for the September, 2011 and April, 2012 sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (values less than 3 not shown), >3 = significantly enriched.

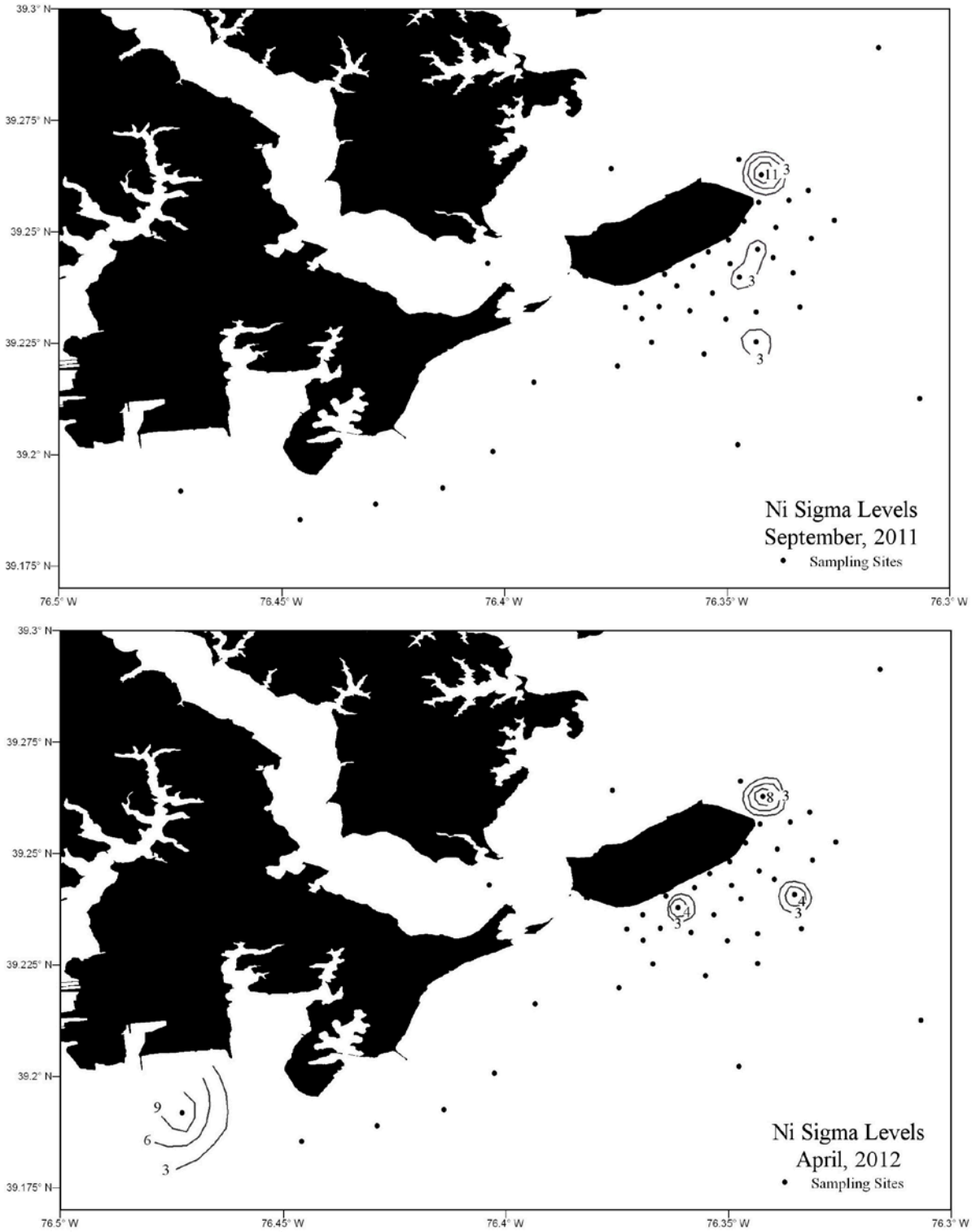

Figure 1- 16 :Distribution of Ni in the study area for the September, 2011 and April, 2012 sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (values less than 3 not shown), >3 = significantly enriched

CONCLUSIONS AND RECOMMENDATIONS

The grain size distribution of the Year 30 sediment samples does not show any clear trends in sedimentation patterns from cruise to cruise, other than that attributed to seasonal effects and the two major storms that passed through the region during the fall of 2011. The clay:mud ratios show that the depositional environment was similar during the last four monitoring years. The general sediment distribution pattern is consistent with the findings of previous monitoring years dating back to 1988 (the second year after the start of release from HMI) and no significant changes occurred during Year 30.

Elemental analyses data indicate that the sediments are very similar to the previous year including the anomalously high Cr value measured at a sampling site in the Baltimore Harbor Zone of influence; the same site had consistently been high in metals in previous years. Based on summary statistics, the elemental data show that:

1. At most sampling sites, concentrations of Cr, Cu, and Pb in the sediment exceed the ERL values; and
2. At most sampling sites, concentrations of Ni exceed the ERM values; and at some sites, Zn exceeds the ERM values.

ERL and ERM are proposed criteria put forward by NOAA (Buchman, 2008) to gauge the potential for deleterious biological effects. Sediments with concentrations below the ERL are considered baseline concentrations with no expected adverse effects. Concentrations between the ERL and ERM may have adverse impacts to benthic organisms, while values greater than the ERM have probable adverse biological effects. These criteria are based on a statistical method of termed preponderance of evidence. The method does not allow for unique basin conditions and does not take into account grain size induced variability in metal concentrations in the sediment. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, Pb, Ni, and Zn are significantly enriched in some samples compared to the baseline.

In regard to potential adverse benthic effects the overlap of enrichment and concentration can be used as an indicator of potential biological impacts: based on the intensity of the effect (enrichment based on sigma level, and concentrations exceeding ERL or ERM), Ni>Zn>Pb; in regard to the number of samples, Pb>Zn>Ni. From the preliminary toxicology work done in Year 25, enrichments of Zn and Pb are probably the most significant in influencing benthic communities as a result of HMI operations. Pb enriched samples are associated with the three local sources HMI, Baltimore Harbor and Back River. Zn on the other hand shows enrichment from Baltimore Harbor and a decreasing enrichment from HMI. The two sampling sites in Back River showed no enrichment for Zn. Prior to Year 28 monitoring, most of the samples with potential benthic effects due to high concentrations of Ni were in the Back River and Baltimore Harbor Zones of Influence. Since the 28 year monitoring, sigma levels of Ni have increased in the HMI Zone. Material from the Baltimore Harbor generally did not influence the sediments in the HMI zone.

Sediments were slightly enriched (3 sigma levels) with Zn at one site in the HMI zone during the fall; two sites were enriched with Zn in the spring. Pb showed higher enriched levels, both in terms of the number of sites and extended spatial distribution, compared to the previous year. The higher enrichment of Pb in the HMI zone was attributed to certain HMI facility operational activities. There were no discharges from the North Cell during the monitoring period because of water quality issues within the cell. Total discharge from the South Cell was 90 million gallons, the smallest volume since discharge began. Discharge from the South Cell was limited due to water quality issues as well. A non-compliant discharge due to pH below permit limits from the South Cell was permitted on an emergency basis just before the Fall 2011 sampling.

This year's monitoring documents lower enrichment of Zn around the HMI facility. However, enrichment for Pb remained above background levels and enrichment for Ni was documented above background levels for the third year at sites within the HMI Zone. This persistent enriched level indicates a need for continued monitoring, particularly since the facility has experienced water quality issues related to crust management operations in preparation for environmental restoration efforts. MES documented very low pH as well as high metals in the North Cell on several occasions during this monitoring year, but water was not discharged directly from the North Cell spillways. North Cell water was diverted to the South Cell from February through early July 2011 for discharge. In late July, the South Cell pond was discharged to an elevation to expose mudflats for migratory birds. Due to the soil oxidation that occurred during exposure of the mudflats and low pH precipitation in August from Hurricane Irene and TS Lee that followed, South Cell water quality deteriorated. Monitoring should continue in order to document the effect that operations has on the exterior environment and to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of crust and water management inside the facility. Close cooperation with MES is important in this endeavor.

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APPENDIX 1A: HMI GROUNDWATER MONITORING WELLS 2011-2012 (PROJECT II)

INTRODUCTION

Groundwater samples from six wells were collected by MES on December 22, 2011, and June 25, 2012. MES analyzed the water samples for the following parameters: pH, temperature, conductivity, dissolved oxygen (DO), oxygen-reduction potential (ORP), salinity, alkalinity, chloride (Cl^-), sulfate, total Kjeldahl nitrogen (TKN), total nitrogen (TN), nitrates/nitrites (NO_3^- /NO_2^-), P, aluminum (Al), arsenic (As), Cd, calcium (Ca), Cr, Cu, Fe, Pb, magnesium (Mg), Mn, potassium (K), silver (Ag), sodium (Na), and Zn. The groundwater sampling and analyses were done as part of the on-going HMI external monitoring effort and as a continuation of the groundwater studies completed in 2003 (URS, 2003), and 2005 (Hill, 2005). The number of wells was equally divided between the North and South Cells as seen in Figure 1A-1: North Cell 2A, 4A & 6A; South Cell 8A, 10A & 12A. These wells were part of 34 wells installed around the facility dike between 2001 and February 2002 for a groundwater study (URS, 2003). The purpose of that study was to identify 1) the direction and rate of groundwater flow from the facility to the surrounding Bay, and 2) physical and chemical reactions controlling the mobilization of contaminants from the facility. The 6 wells (*i. e.,* 'A' wells) were installed to depths to monitor the shallow saturated groundwater zone; depths of the wells range from -4 ft to -16.6 ft North America Vertical Datum of 1988 (NAVD88) (Table 1A-1).

Table 1A- 1: Elevation and depth of well data for the HMI Wells sampled for groundwater monitoring. Data is from URS, 2003. Elevation is referenced to NAVD88 datum which is approximately mean sea level.

Well ID	Date Installed	Elevation, ft (Top of well casing)	Depth of well, ft	Elevation, ft (Bottom of well)
2A	12/12/2001	19.28	35	-15.72
4A	1/6/2002	21.48	30	-8.52
6A	1/4/2002	21.41	30	-8.59
8A	12/19/2001	21.07	30	-8.93
10A	12/18/2001	20.98	25	-4.02
12A	12/15/2001	13.6	25	-11.4

The South Cell, which was closed to new dredged material in 1990, has been converted to upland and wetlands. Activities within the South Cell are specific to the management of the different habitats. The North Cell was closed to dredged material in December, 2009. Since then, activities within the North Cell consisted primarily of crust management (dewatering of sediments) as part of habitat development; in 2012, the North Cell contained over 500 million gallons of stormwater. A summary of the Facility operations for the Year 30 monitoring period are presented in the Technical Report for Sedimentary Environment. Presented in this

groundwater monitoring report is a summary of the well data collected from two samplings: December 2011 and June 2012. Discussion of data includes comparison with previous data collected since June 2006 when MES had adopted new protocols for sampling groundwater monitoring wells (MES, 2010). Data analyses are based on the interpretive methods detailed in the HMI well monitoring report (Hill, 2005).

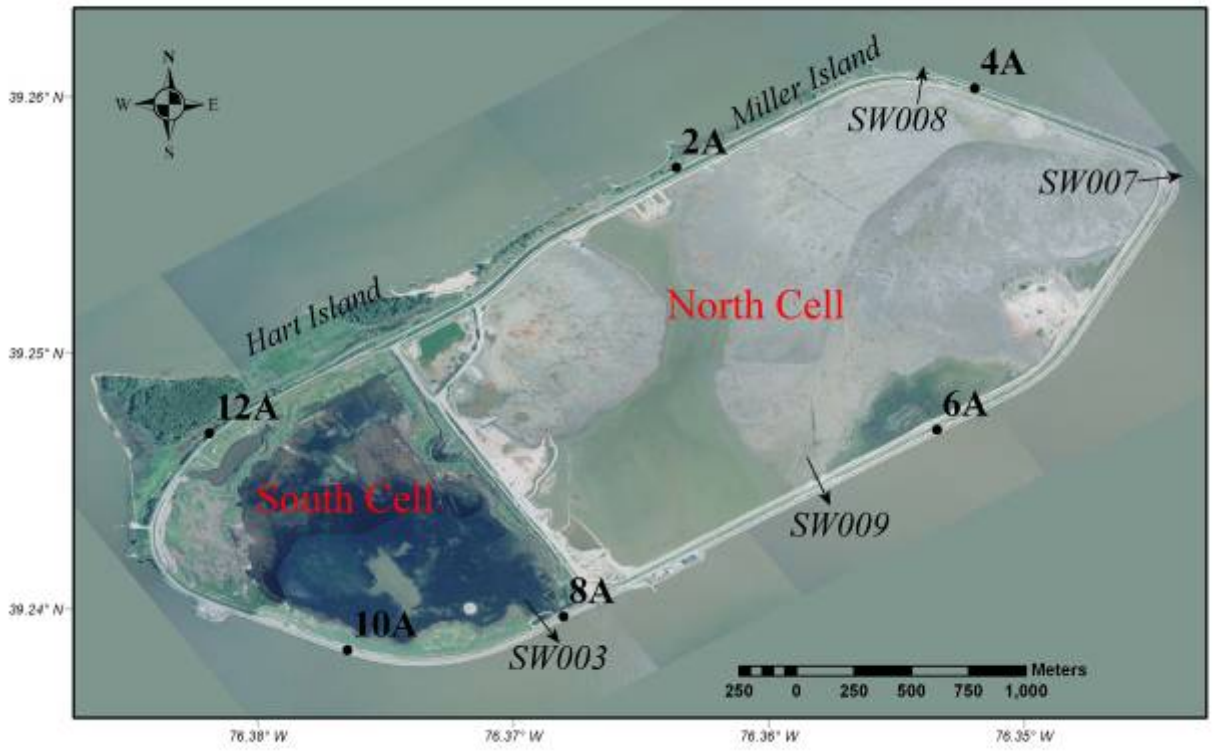

Figure 1A- 1: Aerial photograph of the HMI DMCF, taken on Sept. 15, 2009, showing the locations of the groundwater monitoring wells (black dots) and the spillways (*SW; black arrows*).

SUMMARY OF WELL DATA

Trend plots of select field parameters and metal concentrations measured in well water samples collected since 2006 are presented in Figures 1A-2 through 1A-5. All of the wells continue to be anoxic or hypoxic with DO levels less than 1.0 mg/L. DO levels have been consistently below 2 mg/L since 2006.

Due to limitations in the instrumentation used to get *in-situ* measurements, no sulfide measurements were taken. These measurements are not necessary, but their absence limits the information on the degree of anoxia and the processes occurring. URS (2003) found that sulfide concentrations in HMI groundwater were consistently at or below detection. The low levels were attributed to loss by precipitation, based on the relatively high Fe concentrations (Figures 1A-4 and 1A-5). Dissolved sulfide binds with many metals and restricts their mobility, and is preferentially used as a metal ligand releasing mineralized phosphate into the water.

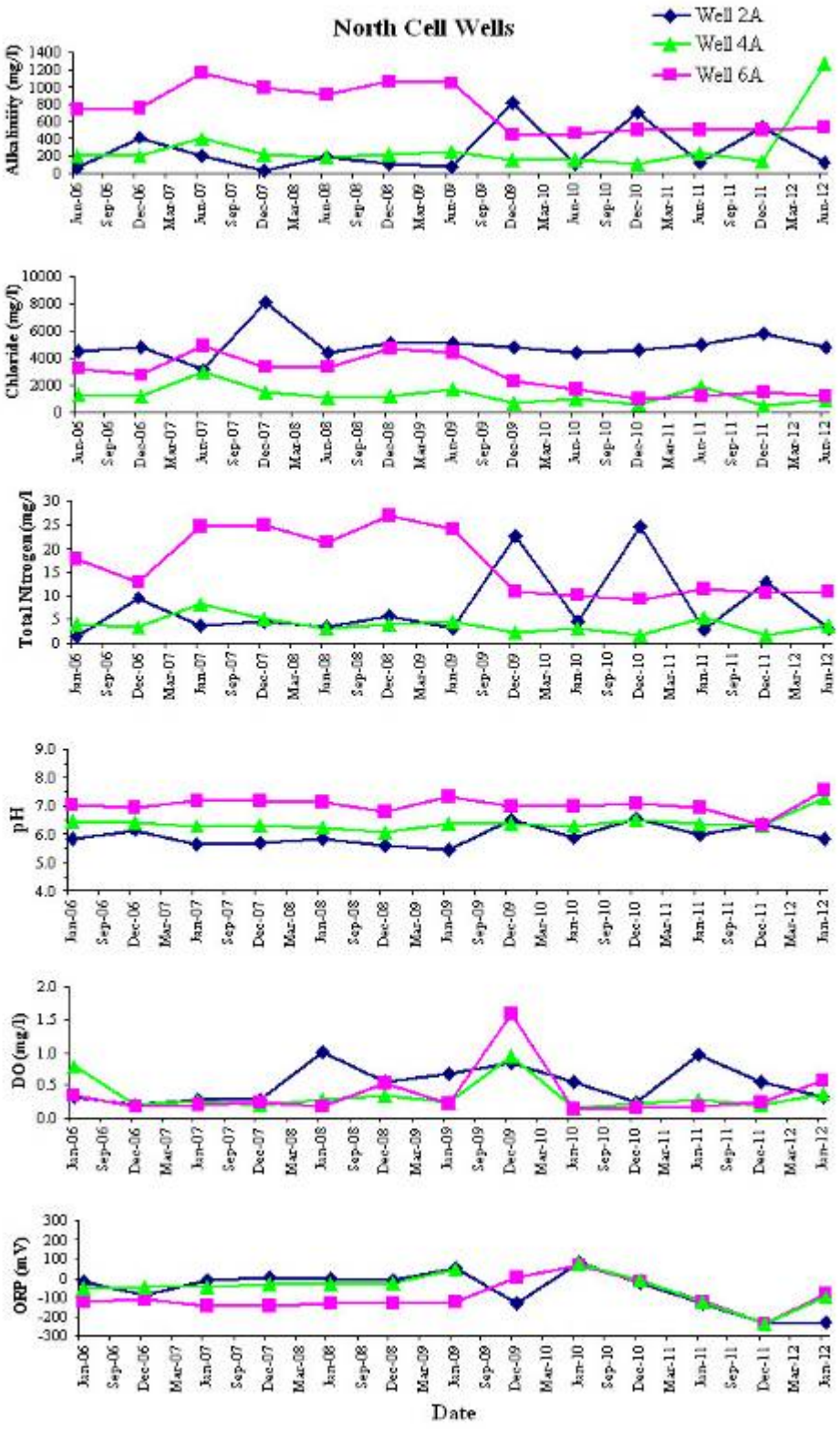

Figure 1A- 2: Trend plots for field parameters measured in groundwater samples collected since 2006 from North Cell wells. The Oxidation-Reduction Potential (ORP) value reported for Dec. 2009, for Well 4A was -1533 mV, which was considered an anomaly and not plotted.

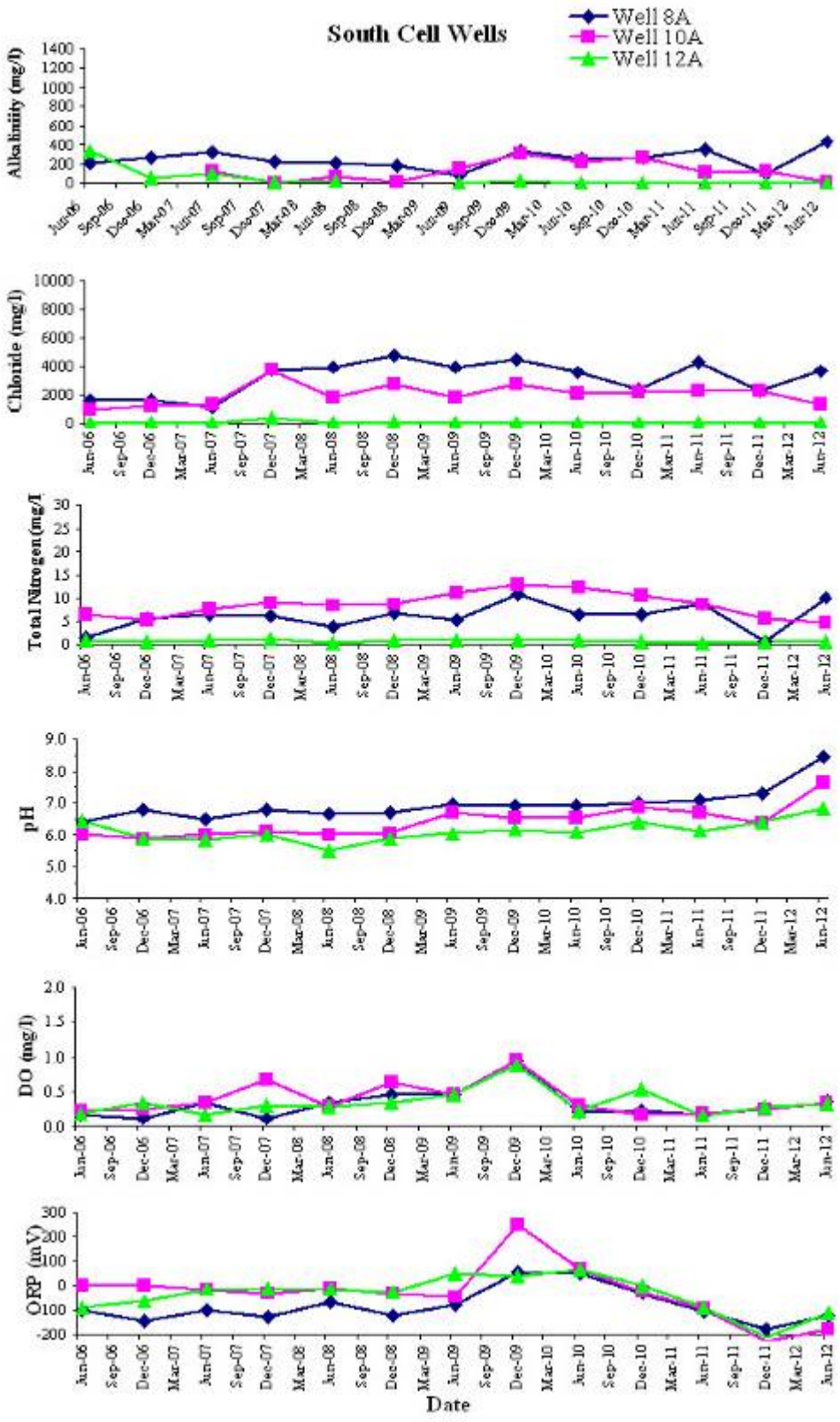

Figure 1A- 3: Trend plots for field parameters measured in groundwater samples collected since 2006 from South Cell wells.

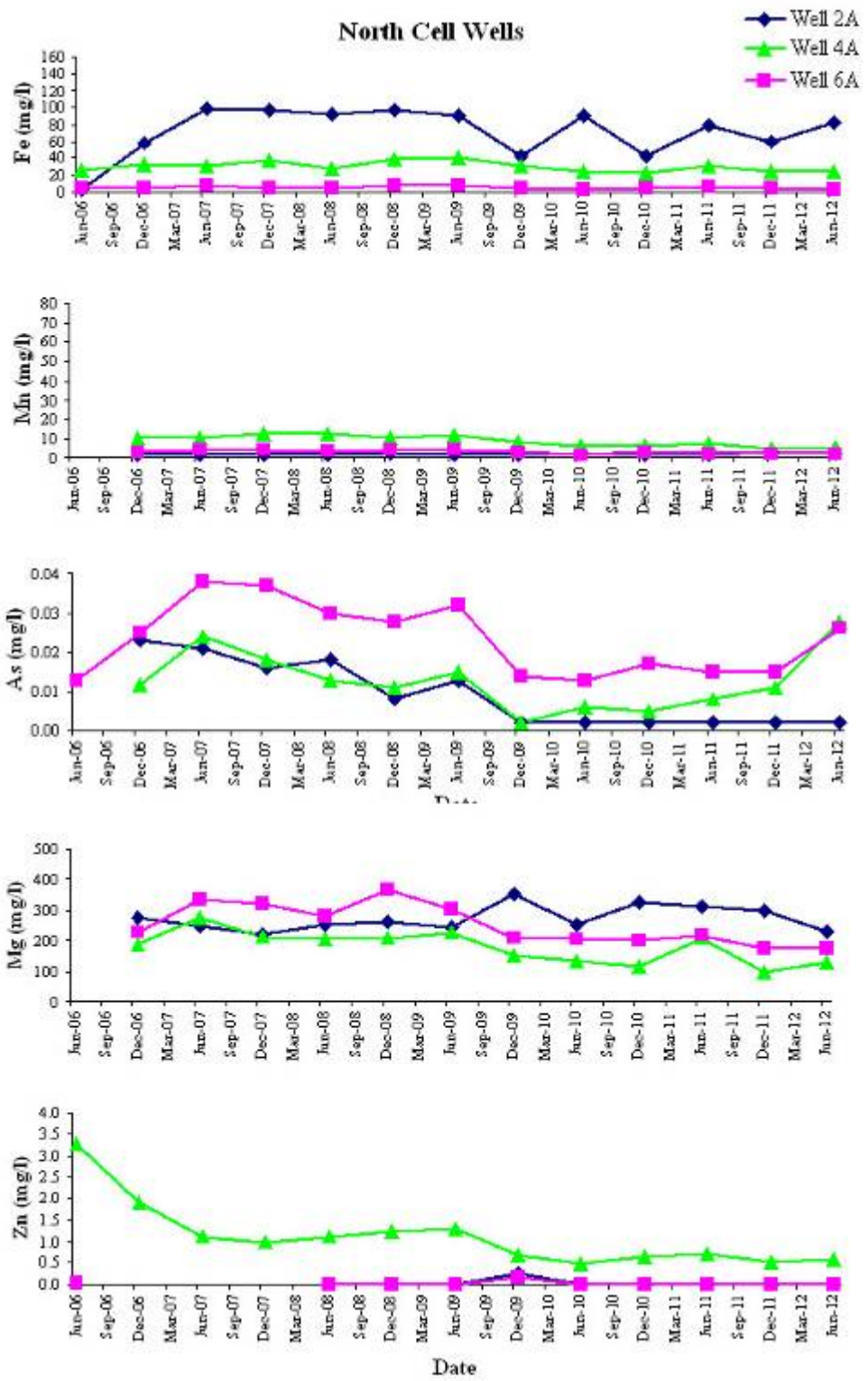

Figure 1A- 4: Trend plots for select metals measured in groundwater samples collected since 2006 from North Cell wells.

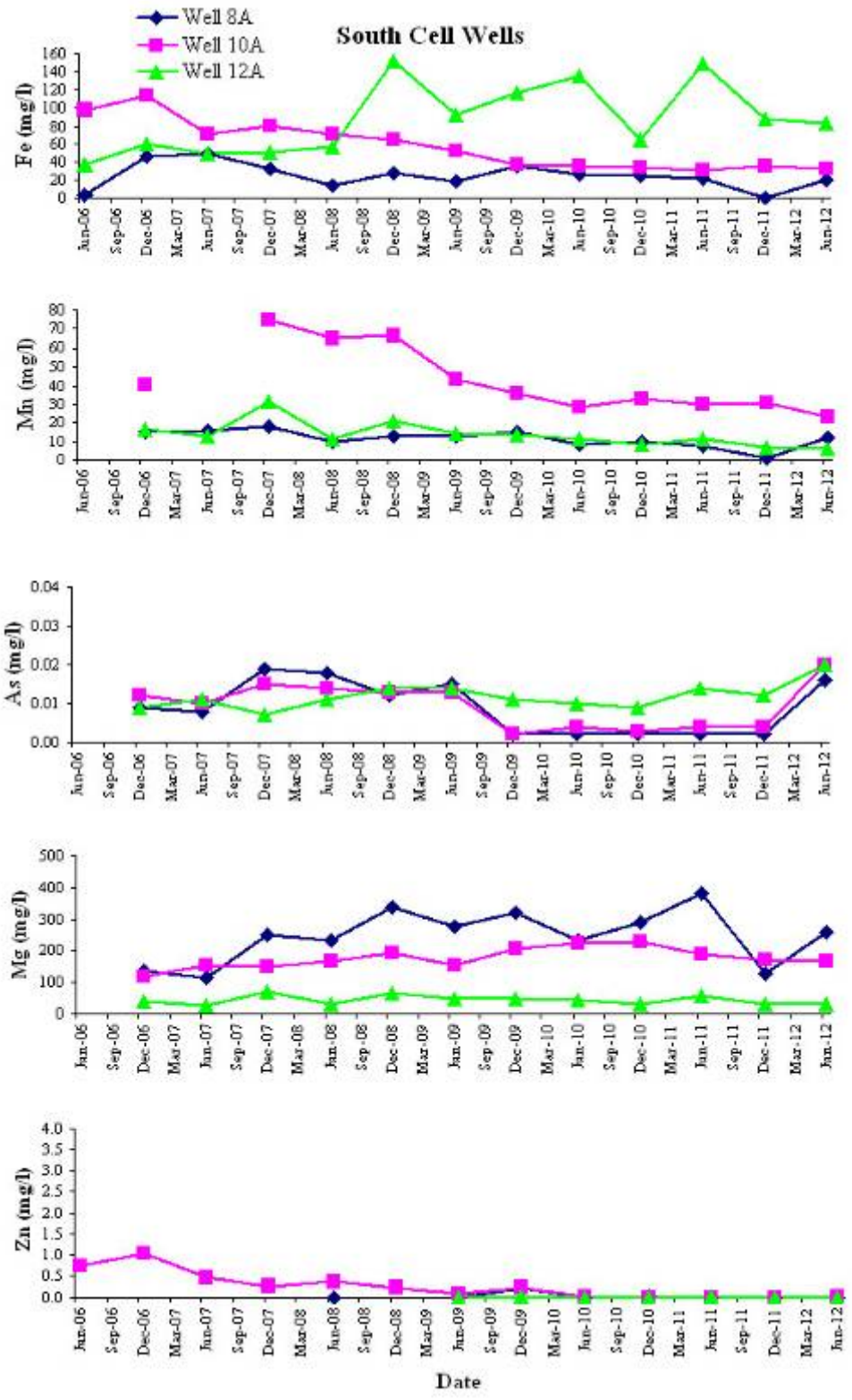

Figure 1A- 5: Trend plots for select metals measured in groundwater samples collected since 2006 from South Cell wells.

The dominant form of nitrogen in all of the wells appears to be ammonium, since most nitrate readings are below detection. Nitrate is used preferentially once oxygen is consumed as the primary oxidant, and ammonium ion is a by-product of anaerobic respiration. This is consistent with the anoxic/hypoxic nature of the groundwater.

North Cell Wells 2A, 4A and 6A

Figure 1A-6 shows the chloride (Cl^-) concentration from the December 2011 and June 2012 samplings as a function of the amount of excess sulfate, either removed from the water as a result of sulfate reduction (– excess sulfate) or added to the water as the result of sulfide oxidation in the sediment solids (+ excess sulfate). The predicted sulfate levels are calculated from the chloride concentration based on conservative mixing between rainwater and seawater. Based on the depletion in sulfate in comparison to predicted concentrations, North Cell Well 2A is the only well that continues to have a reducing environment, whereas Wells 4A and 6A are more similar to the oxidizing environment seen in the South Cell wells. Well 2A, which is the deepest of the six monitoring wells (Table 1A-1), is located on the remnant of Miller Island. Well 2A also is the only well exhibiting seasonal oscillations in alkalinity, total nitrogen, pH and Fe concentrations (Figures 1A-2 and 1A-4) and phosphorus (not shown). These seasonal oscillations become obvious starting at the end of 2009, about the same time the North Cell stopped receiving dredged material and operations focused on crust management (dewatering) activities.

Figure 1A-7 shows ratios of K^+/Cl^- and Ca^{++}/Cl^- as a function of the amount of excess sulfate. The major cations are near the predicted conservative mixing concentrations. Since acid generally is not being generated in the vicinity of Well 2A, there is minimum mineral dissolution (specifically calcium carbonate) or ion exchange. In the rest of the wells,the hydrogen ion from acid is preferentially bound on ion exchange sites in the sediment releasing other adsorbed cations (*e.g.* K^+, Ca^{++}). The linear relation in the positive excess sulfate region is due to the process of acid production being directly related to neutralization and ion exchange.

Prior to December 2009, alkalinity in Well 6A had been consistently higher compared to other wells. After December 2009, alkalinity dropped and leveled off but continued to be higher than the other two wells in the North Cell (except for December 2009, 2010 and 2011 samplings for Well 2A and June 2012 for Well 4A) and the wells in the South Cell (Figures 1A-2 and 1A-3). The higher concentrations suggest that the alkalinity in this well still has not been neutralized by acid production and may be buffered somewhat. This is supported by the pH values for Well 6A, which generally have been higher than the other wells (both North and South Cell wells). In June 2012, pH increased to highest levels in all wells except Well 2A. Also, the behavioral trend of alkalinity in Well 6A matches those of total nitrogen and arsenic.

Chloride concentrations in Wells 4A and 6A have dropped slightly, indicating higher rainwater mixing.

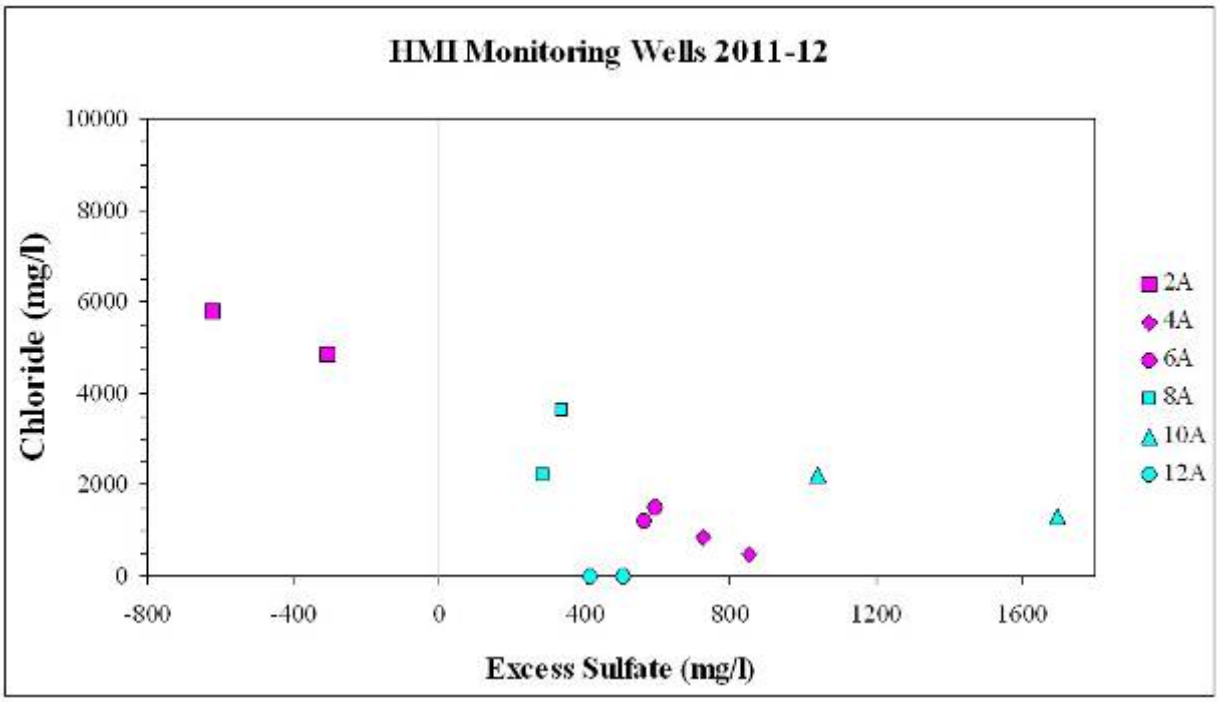

Figure 1A- 6: Groundwater chloride concentrations as a function of excess sulfate (the difference of the measured sulfate concentrations minus the predicted concentrations). Monitoring wells are grouped by general location; North Cell (pink) or South Cell (light blue). The data shown in this graph include December 2011 and June 2012 samplings only.

The groundwater from the North Cell Well 2A continues to exhibit behavior typical of anoxic pore waters that have minimum exposure to oxidized sediment. It may be that Well 2A is the least affected by operations in the North Cell compared to Wells 4A and 6A due to its location. Generally the behavior of measured parameters in each of the North Cell wells is different reflecting a number of factors. The recharge area for the monitoring wells is the North Cell, the surface conditions of which have been constantly changing due to dredge material management and dewatering operations. Another factor is the heterogeneous material contained in the dike wall and the North Cell substrate, both of which affect transport rates and chemistry of the groundwater.

South Cell Wells 8A, 10A & 12A

The waters in these wells have been exposed to oxidized sediments, thus the higher levels of excess sulfate (Figure 1A-6). Chloride concentrations generally are low. Rainwater appears to be a major source of water to these wells, particularly Well 12A, the waters of which appear to be entirely fresh water. The lowest level of chloride was observed in June, 2010 (Cl^- = 6.5 mg/L). Well 12A is located in a stand of mixed hardwood and conifer trees on a portion of the dike underlain by a remnant of Hart Island.

Total nitrogen (ammonium) and alkalinity are slightly lower, while metals and cations are higher than in the waters in the North Cell wells. Overall, water chemistry in the South Cell

wells tends to be more stable, showing less fluctuation, compared to the North Cell wells. The sediments in the South Cell are to some extent exposed to the atmosphere. The exposure of the sediment is providing the oxygen to oxidize the sulfide in the sediments that are the source of water for the wells. The entire South Cell has on-going sediment oxidation.

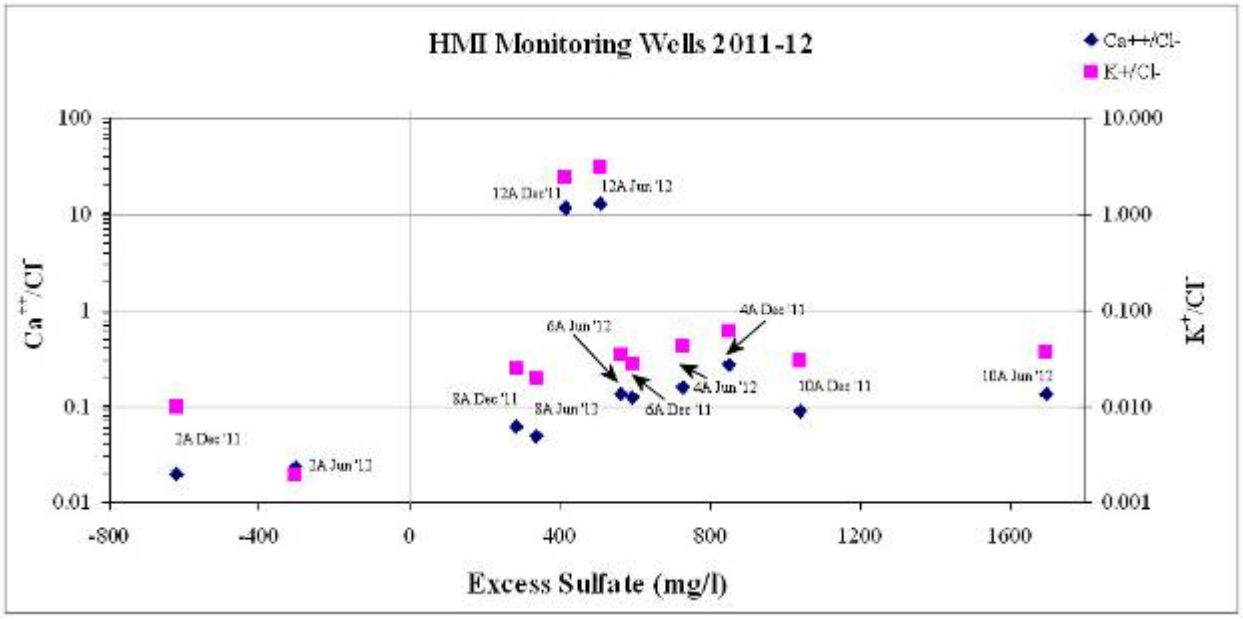

Figure 1A- 7: The ratios of K^+/Cl^- and Ca^{++}/Cl^- as a function of excess sulfate. The data shown in this graph include December 2011 and June 2012 samplings only. For reference, the ratio for both of these cations in seawater is ~0.02. Note that scale of the y-axes are logarithmic to accommodate the relatively large ratios calculated for Well 12A; the ratios were very high due the extremely low chloride concentrations (Ca^{++}/Cl^- = 11.5, and 12.9; K^+/Cl^- = 2.5 and 3.0 for December 2011 and June 2012 sampling, respectively).

PROCESSES OPERATING IN HMI GROUNDWATER

Figure 1A-8 shows a hypothetical cross section of HMI at the South Cell. Hydrodynamically, there are four areas to consider:

1. *The surface sediments of the interior of the cell*. Here ***if*** the sediment is kept inundated the sediment and the associate pore fluids would be anoxic and would have the characteristics of normal Bay sediments. This is the situation in the North Cell. However in the South Cell circumstance, the material for the most part is sub-areal with rain water being the primary source of water to the system. The occluded water native to the dredged material is diluted by the fresh rain water; this lowers the dissolved load derived from dilution of sea water in the Bay waters. Since the hydrated sediment is exposed to atmospheric oxygen, the aerobic process is in operation. One of the most significant reactions is the oxidation of the naturally occurring sulfide minerals (primarily iron monosulfides and pyrite) that produces sulfuric acid. The acidified waters have sulfate concentrations in excess of conservative mixing. The oxidation of the sulfide minerals significantly increases the levels of Fe and Mn, and the free acid can react with the sediment to release other metals, acid soluble nutrients, and trace organic compounds. This acidified water is either entrained in surface water runoff or infiltrates into the sediment in the dike forming the groundwater flow through the dike. The surface water is monitored and controlled by MES.

2. *Dredged sediment in the dike.* When the acidified waters infiltrate into the dredged sediment they enter an organic rich environment that is isolated from the atmosphere. Here several processes occur: the acid is neutralized by naturally occurring material such as shell material which contains calcium carbonate; acid and metals are bound by ion exchange processes; the reduction in acidity causes precipitation of insoluble metal compounds (with anions such as phosphate, and carbonate), and; reduction occurs which removes oxygen and changes the environmental conditions waters are in. The flow of water through the dike is relatively fast compared to the rate of reduction since the concentrations of sulfate are high relative to conservative mixing (this is shown as the positive Excess Sulfate in the preceding figures). If strongly reducing conditions existed all of the sulfate would be reduced and the sulfide produced would be significantly removed by sulfide mineral formation as in the North Cell.

3. *Movement through the dike walls.* The dike walls are made of clean sands, thus are relatively inert; however they act as a mechanical filter. As a filter, the dike retains the fine sediment placed in the dike, and removes the precipitates that form as the water reacts in the contained sediment. Eventually as with any filter, it would be expected that the filter (*i.e.* the dike walls) will become plugged as material is trapped along the flow lines. This is the area where the sampling wells are located. The groundwater sampled at this point reflects changes in the water chemistry resulting from transport through the three zones outlined above.

4. *Mixing with Bay water*. As the groundwater travels the dike as a result of the hydraulic gradient, it will encounter and mix with Bay water within the dike wall. The water from the dike is more dilute than Bay water so there will be some degree of floating, or riding over, of the less dense dike water on top of the more saline Bay water. The Bay water is aerated and slightly alkaline. This water will react with the dike water oxidizing the reduced water and precipitating iron oxy-hydroxides and other redox sensitive species. These precipitates are effective in scavenging trace metals and phosphate.

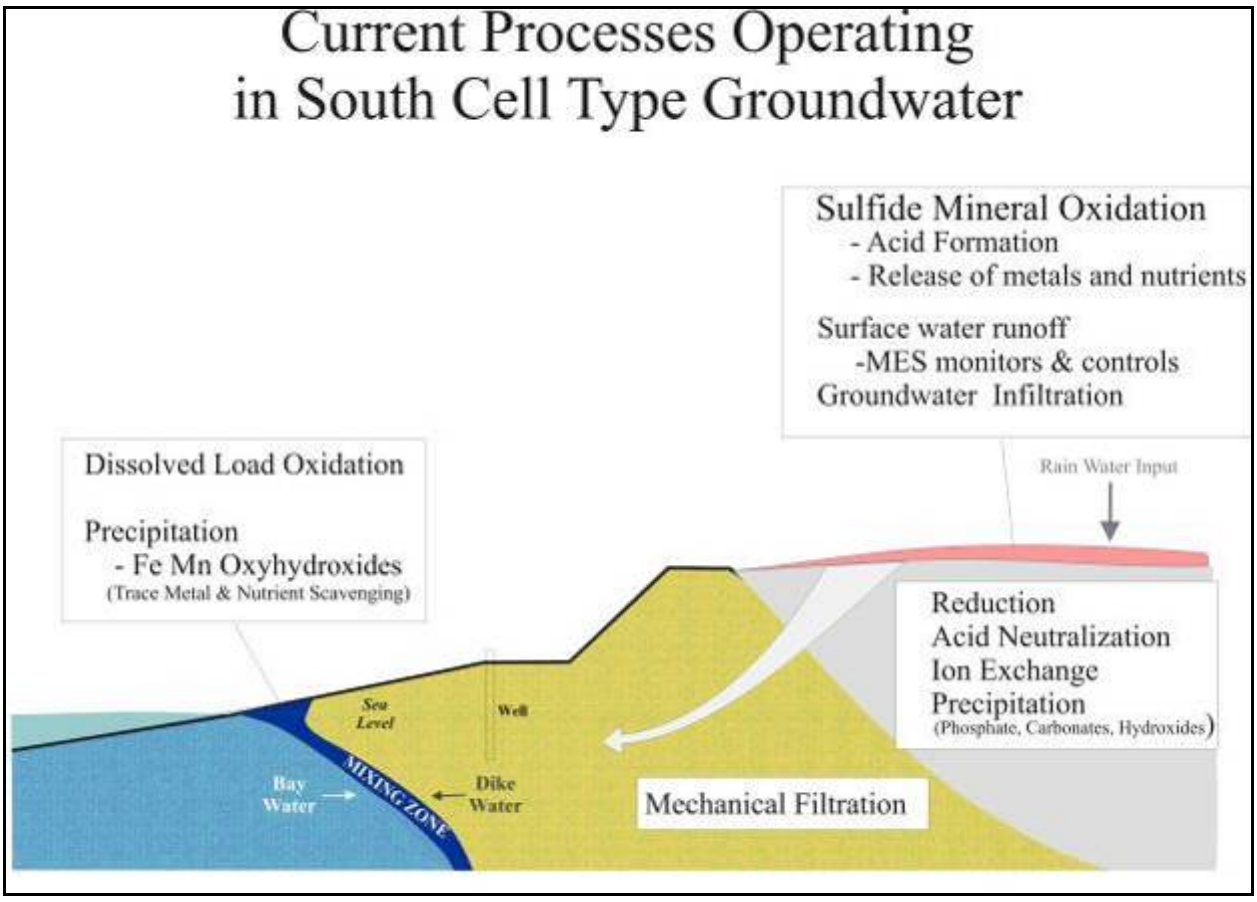

Figure 1A- 8: Schematic presentation of the processes which produce the groundwater similar to those found in the South Cell wells.

As noted the sampling wells are located in the sandy matrix of the dike walls which act as a filter for the groundwater. Groundwater is anaerobic for all of the sampling wells; the South Cell type wells have undergone an initial oxidation stage. Results of the most recent sampling suggest that portions of the North Cell are undergoing the initial oxidation, as evident in Wells 4A and 6A. However, it should be noted that the behavior of measured parameters in each well within the two cells is different reflecting the heterogeneous material contained in the dike wall and source material that effected transport rates and chemistry of the groundwater.

Table 1A-2 is a summary of the trace metal data for the groundwater sampled in December 2011 and June 2012; listing the number of samples, the number below detection, the mean, maximum and minimum concentration and the EPA Maximum Concentration Level in drinking water (MCL) (U.S. EPA, 2002). For the most part, the concentrations of the metals remain low. Generally, Cd, Cu, Pb and Ag were below detection limit for all well samples. Result for Al were the below detection limit for all except December 2011 sample from Well 4A and June 2012 sample from Well 8A. Concentrations of Zn were at the lowest since well monitoring began.

Table 1A- 2: Monitoring wells trace metal analyses for 2011 and 2012 (two sampling periods). Values in mg/L, unless otherwise indicated. Detection limits (*dl)* for Fe and Mn were not reported.

North Cell Type							
	n	***n>dl***	***dl***	***Mean***	***Min***	***Max***	***MCL***
Al	6	1	0.05	0.268	<dl	0.268	0.05 - 0.2*
As	6	4	0.01	0.014	<dl	0.028	0.01
Cd	6	0	0.001	<dl	<dl	<dl	0.005
Cr (total)	6	0	0.005	<dl	<dl	<dl	0.1
Cu	6	0	0.005	<dl	<dl	<dl	1.3
Fe	6			33.5	3.7	82.2	0.3*
Pb	6	0	0.02	<dl	<dl	<dl	0
Mn	6			3.3	1.9	5.6	0.05*
Zn	6	5	0.005	0.186	<dl	0.560	5*
Ag	6	0	0.001	<dl	<dl	<dl	0.1*
South Cell Type							
	n	***n>dl***	***dl***	***Mean***	***Min***	***Max***	***MCL***
Al	6	1	0.05	0.061	<dl	0.113	0.05 - 0.2*
As	6	4	0.01	0.012	<dl	0.020	0.01
Cd	6	0	0.002	<dl	<dl	<dl	0.005
Cr (total)	6	1	0.005	0.005	<dl	0.007	0.1
Cu	6	0	0.005	<dl	<dl	<dl	1.3
Fe	6			43.6	0.70	88.6	0.3*
Pb	6	0	0.02	<dl	<dl	<dl	0
Mn	6			13.2	0.4	30.8	0.05*
Zn	6	5	0.005	0.013	<dl	0.028	5*
Ag	6	0	0.001	<dl	<dl	<dl	0.01*

Note:
MCL – EPA Maximum Concentration Levels for Inorganic in Drinking Water
*Values followed by * are Secondary Maximum Concentration Levels (SMCL)*
North Cell Type – Maintained Pore water behavior
South Cell Type – Oxidation at Surface followed by neutralization and partial reduction

Overall, the North Cell samples were slightly lower in metal concentrations, with a significant number of metals below detection limits. The South Cell samples have more metals at detectable concentrations; however they are still low with respect to the MCL. Fe and Mn are the only metals with concentration that exceed the SMCL. These two metals are not considered a health risk but affect the taste and quality of the water. These metals precipitate from solution in aerobic conditions, so as the water mixes with Bay water further down the flow path, these metals will precipitate out as metal oxyhydroxides. The metal-rich precipitate will cement the sands and make the dike more impermeable with time.

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APPENDIX 2: BENTHIC COMMUNITY STUDIES (PROJECT III)

(September 2011 – August 2012)

Technical Report

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January 2013

EXECUTIVE SUMMARY

The benthic macroinvertebrate community in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI-DMCF) was studied for the thirtieth consecutive year under Project III of the HMI Exterior Monitoring Program. Benthic communities living close to the facility [Nearfield, South Cell Exterior Monitoring (formerly called South Cell Restoration Baseline), and Back River/Hawk Cove stations] were compared to communities located at some distance from the facility (Reference Stations). Water quality parameters, including dissolved oxygen concentrations, salinity, temperature, pH, conductivity, and Secchi depth were measured *in situ.* Twenty-two stations (12 Nearfield, 5 Reference, 2 Back River/Hawk Cove, and 3 South Cell Exterior Monitoring stations) were sampled on September 23, 2011 and on April 4, 2012.

In Year 30, the benthic macroinvertebrate community was examined under slightly unusual conditions for this region of Chesapeake Bay. The September 2011 cruise took place two weeks after Hurricane Irene and Tropical Storm Lee passed over the region, leaving historically significant freshwater inputs into the Chesapeake Bay. This depressed the salinity in the vicinity of HMI from the typical low mesohaline regime into the olighohaline regime, necessitating the adoption of oligohaline metrics to calculate the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI).

An all-time high total of 52 benthic macroinvertebrate taxa were identified during Year 30. The increase in taxa was mainly due to the appearance of several taxa more typically seen in freshwater environments. Several taxa were clearly dominant. The worms *Marenzelleria viridis, Streblospio benedicti,* and Naididae sp., the clam *Rangia cuneata,* and the arthropods *Leptocheirus plumulosus* and *Cyathura polita* were among the dominant taxa on both sampling dates. Taxa abundance varied greatly for certain taxa between the two seasons in Year 30. As in past years, abundances for many species were much higher in the spring than in the fall, due to spring recruitment. Abundances typically decrease for many of the dominant species by the following fall due to predation. This general rule is most reflected in the difference in abundances for the species *Leptocheirus plumulosus*, *Marenzelleria viridis*, and Naididae. During September 2011 the species *Streblospio benedicti,* and *Rangia cuneata* were actually more abundant than the 2012 spring samples, possibly due to reduced predation or low recruitment for the former species and winter die-off for the latter. Overall, abundances for many organisms were below historic averages.

The Chesapeake Bay B-IBI, a multi-metric index of biotic condition that evaluates summer populations of benthic macroinvertebrates, was calculated for all stations sampled in September 2011. The mean B-IBI's for all station types during Year 30 were below historic averages. However, the mean B-IBI for Nearfield, and South Cell Exterior Monitoring stations met or exceeded the benchmark of 3.0. In contrast, the mean B-IBI for Back River/Hawk Cove and Reference stations failed to meet the benchmark of 3.0. Overall, ten of the twenty-two stations failed to meet the benchmark criteria of 3.0. Five of these stations were contiguous to each other, and located near the South Cell outfall and former offloading dock area. Analysis

indicates that the mean B-IBI for this station cluster was lower than the means of all station types except Back River/Hawk Cove. However, based on prior performance there is little evidence to suggest that this station cluster is a persistent concern.

Multivariate cluster analysis of benthic invertebrate communities indicates that there were four distinct station groups along the southern side of the island. These stations displayed benthic invertebrate communities that differed from the larger, more wide-spread benthic community on the northern and eastern sides of HMI. However, these distinct groups did not coincide with a cluster of poorly performing stations identified in the B-IBI analysis. Friedman's non parametric ANOVA did not support singling out the groups identified in the Multivariate cluster analysis or the group identified as poorly performing in the B-IBI analysis. This supports the premise that both healthy and unhealthy benthic communities exist in the vicinity of the South Cell outfall, off-loading dock, and around HMI in general.

In addition, at the request of the Maryland Port Administration, post closure benthic monitoring was conducted at Site 92 during the Fall HMI sampling cruise for Year 30. Since Site 92 is located in close proximity to HMI, these results are briefly incorporated into this report for comparison.

INTRODUCTION

Annual dredging of the shipping channels leading to the Port of Baltimore is necessary to maintain safe navigation. On average 4-5 million cubic yards of Bay sediments is dredged each year to maintain access to the Port. This requires the State of Maryland to develop environmentally responsible placement sites for dredged material. In 1981, the Hart-Miller Island Dredged Material Containment Facility (HMI-DMCF) was constructed to accommodate the dredged material management needs for the Port of Baltimore and specifically the need to manage contaminated sediments dredged from Baltimore's Inner Harbor.

HMI is a 1,140-acre artificial island surrounded by a 29,000-foot long dike constructed along the historical footprints of Hart and Miller Islands at the mouth of the Back River. A series of four spillways are located around the facility's perimeter that discharge excess water released from on-site dredged material disposal operations.

As part of the environmental permitting process for dredged material containment facilities, an exterior monitoring program was developed to assess environmental impacts associated with HMI. Various agencies have worked together since the inception of this program to monitor for environmental impacts resulting from facility construction and operation. Studies were completed prior to and during the early construction period to determine baseline environmental conditions in the HMI vicinity. Since Year 17, the Maryland Department of the Environment (MDE) has been responsible for all aspects of benthic community monitoring. The results of the post-construction monitoring are compared to the baseline monitoring data, as well as to inter-seasonal and inter-annual data.

Midway through Year 28, on December 31, 2009, HMI stopped accepting dredged material. The fall of Year 28 represented the final monitoring data collected while HMI received dredged material. However, during the capping and stabilization aspect of this project, which could take several more years, HMI management will continue to move sediment and manage stormwater run-off, resulting in periodic discharge into the Chesapeake Bay. As the island gradually stabilizes post closure exterior benthic monitoring will be necessary to support long-term statistical trends. Discussions are continuing to determine how much post monitoring is necessary to document that the island has stabilized. Year 30 represents the second full year of post closure data.

The goals of the Year 30 benthic community monitoring were:

- To monitor the benthic community condition; using, among other analytical tools, the Chesapeake Bay Benthic Index of Biological Integrity (B-IBI; Llanso 2002), and to compare the results at Nearfield stations to present local reference conditions;

- To monitor other potential sources of contamination to the HMI region by sampling transects along the mouth of Back River;

- To facilitate trend analysis by providing data of high quality for comparison with HMI

monitoring studies over the operational phase of the project; and,

- To monitor benthic community conditions in areas near all functioning spillways, particularly South Cell Spillway 003. This will help the State to assess any environmental effects resulting from the South Cell closure and restoration.

METHODS AND MATERIALS

MDE staff collected all macroinvertebrate and water quality samples in Year 30. Field sampling cruises were conducted on board the Maryland Department of Natural Resources vessel "*R/V Kerhin"*. Twenty-two fixed benthic stations were monitored during both fall and spring. Environmental parameters recorded at the time of sample collection are included in Tables 2-2 through 2-5.

All stations sampled during Year 29 were again sampled for Year 30. Over the years, the list of stations sampled has changed several times. Occasionally old stations were deleted and new stations were added to suit monitoring needs. Year 30 is the third year without changes to the list of sampling stations[1]. Stations were classified by location and dominant sediment type. Stations were divided into four location groups (Nearfield stations, Reference stations, Back River/Hawk Cove stations, and South Cell Exterior Monitoring stations) and five sediment types (silt/clay, shell, detritus, gravel, and sand). All benthic community stations coincided with stations sampled by the Maryland Geological Survey (MGS) for sediment analysis.

Temperature, depth, salinity, pH, conductivity, and dissolved oxygen (DO) were measured *in situ* using a Hydrolab Surveyor 4a multi-parameter water quality meter in September 2011 and April 2012. Water quality parameters were measured at approximately 0.5 m (1.6 feet) below the surface and 0.5 m above the bottom. The Secchi depth was measured at all stations during both seasons.

All macroinvertebrate samples were collected using a Ponar grab sampler, which collects approximately 0.05 m^2 (0.56 ft^2) of bottom substrate. Three replicate grab samples were collected at each station. A visual estimate of the substrate composition [percent contributions of detritus, gravel, shell, sand, and silt/clay (mud)] was made at each station and the dominant sediment type for each station was derived from these estimates. Each replicate was individually rinsed through a 0.5 mm sieve on board the vessel and preserved in a solution of 10 percent formalin and Bay water, with Rose Bengal dye added to stain the benthic organisms.

[1] For a detailed explanation of the new sampling design see "Scientific Rationale for Relocating Hart-Miller Island Exterior Monitoring Stations in Advance of Facility Closure"

Table 2- 1: Sampling stations (latitudes and longitudes in degrees, decimal minutes), 7-digit codes of stations used for Year 30 benthic community monitoring, and predominant sediment type at each station for September and April.

Station #	Latitude	Longitude	Sediment Type		Maryland 7-Digit Station Designation
			Fall	Spring	
Nearfield Stations					
MDE-01	39° 15.3948	-76° 20.5680	Sand	Sand	XIF5505
MDE-03	39° 15.5436	-76° 19.9026	Silt/clay	Silt/clay	XIG5699
MDE-07	39° 15.0618	-76° 20.3406	Silt/clay	Silt/clay	XIF5302
MDE-09	39° 14.7618	-76° 20.5842	Silt/clay	Silt/clay	XIF4806
MDE-11	39° 14.4432	-76° 20.104	Silt/clay	Silt/clay	XIG4501
MDE-15	39° 14.5686	-76° 20.9526	Silt/clay	Silt/clay	XIF4609
MDE-16	39° 14.5368	-76° 21.4494	Silt/clay	Silt/clay	XIF4615
MDE-17	39° 14.1690	-76° 21.1860	Shell	Shell	XIF4285
MDE-19	39° 14.1732	-76° 22.1508	Silt/clay	Silt/clay	XIF4221
MDE-33	39° 15.9702	-76° 20.8374	Sand	Sand	XIF6008
MDE-34	39° 15.7650	-76° 20.5392	Silt/clay	Silt/clay	XIF5805
MDE-45	39° 14.7198	-76° 21.2538	Silt/clay	Silt/clay	N/A
Reference Stations					
MDE-13	39° 13.5102	-76° 20.6028	Silt/clay	Silt/clay	XIG3506
MDE-22	39° 13.1934	-76° 22.4658	Silt/clay	Silt/clay	XIF3224
MDE-36	39° 17.4768	-76° 18.9480	Silt/clay	Silt/clay	XIG7589
MDE-50	39° 12.7488	-76° 18.3954	Sand	Sand	N/A
MDE-51	39° 12.1392	-76° 20.853	Silt/clay	Silt/clay	N/A
Back River/Hawk Cove Stations					
MDE-27	39° 14.5770	-76° 24.2112	Silt/clay	Silt/clay	XIF4642
MDE-30	39° 15.8502	-76° 22.5528	Silt/clay	Silt/clay	XIF5925
South Cell Exterior Monitoring Stations					
MDE-42	39° 13.8232	-76° 22.1432	Silt/clay	Silt/clay	XIF3879
MDE-43	39° 13.9385	-76° 21.4916	Silt/clay	Silt/clay	XIF3985
MDE-44	39° 14.4229	-76° 21.8376	Silt/clay	Silt/clay	XIF4482

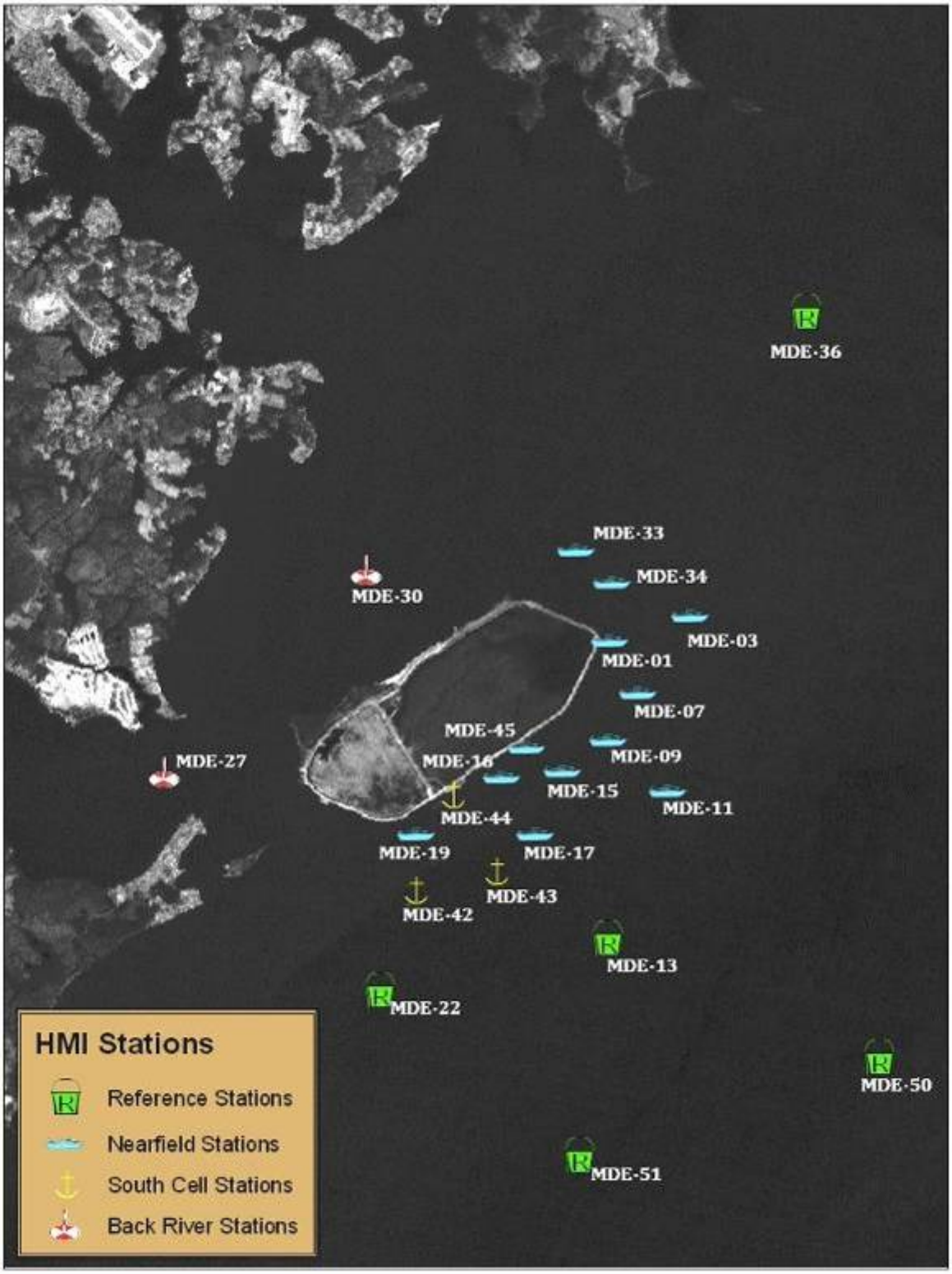

Figure 2- 1: Year 30 benthic sampling stations for the HMI exterior monitoring program.

In the laboratory, each benthic macroinvertebrate replicate was placed into a 0.5 mm sieve and rinsed to remove field preservative and sediment. Organisms were sorted from the remaining debris, separated into vials by major taxonomic groups, and preserved in 70 percent ethanol. All laboratory staff were required to achieve a minimum baseline sorting efficiency of 95 percent and quality control checks were performed for every sample to ensure a minimum 90 percent recovery of all organisms in a replicate sample.

Most organisms were identified to the lowest practical taxon using a stereo dissecting microscope. The number of specimens for each taxon collected in each replicate (raw data) is presented in the *Year 30 Data Report.* Members of the insect family Chironomidae (midges) were identified using methods similar to Llanso (2002). Where applicable, chironomids were slide mounted and identified to the lowest practical taxon using a binocular compound microscope. In cases where an animal was fragmented, only the head portion was counted as an individual taxon. All other body fragments were discarded. Individuals of the most common clam species (*Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli*) were measured to the nearest millimeter. An independent taxonomist verified 10 percent of all samples identified.

Nine major measures of benthic community condition were examined, including: total infaunal abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance of pollution-sensitive infaunal taxa, the Shannon-Wiener diversity index (SWDI), taxa richness, total abundance of all taxa (excluding Bryozoa and Copepoda), tolerance score, abundance of carnivore and omnivores, and Tanypodinae to Chironomidae abundance ratio. Six of these measures (total infaunal abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance of pollution-sensitive infaunal taxa, tolerance score, abundance of carnivore and omnivores, and Tanypodinae to Chironomidae abundance ratio) were used to calculate the B-IBI for September 2011. The B-IBI is a multi-metric index of biotic integrity used to determine if benthic populations in different areas of the Chesapeake Bay are stressed (Llanso 2002). The B-IBI has not been calibrated for periods outside the summer index period (July 15 through September 30) and thus was not used with the April 2012 data. In addition to the above metrics, the numerically dominant taxa during each season and the length frequency distributions of the three most common clams (*R. cuneata*, *M. balthica*, and *M. mitchelli*) were examined.

Abundance measures were calculated based on the average abundance of each taxon from the three replicate samples collected at each station. Total abundance was calculated as the average abundance of epifaunal and infaunal organisms per square meter (#/m^2), excluding Bryozoa, which are colonial. Qualitative estimates (i.e., rare, common, or abundant) of the number of live bryozoan zooids are included in the *Year 30 Data Report*. Total infaunal abundance was calculated as the average abundance of infaunal organisms per square meter (#/m^2). Two different measures of total abundance were calculated because epifaunal organisms are not included in the calculation of the B-IBI (Ranasinghe et al. 1994).

For each station, data was converted to the base 2 logarithm in order to calculate the SWDI (H') (Pielou 1966). Taxa richness (number of taxa) was calculated for each station as the total number of taxa (infaunal and epifaunal) found in all three replicates combined. Infaunal

taxa richness was calculated as the number of infaunal taxa found in all three replicates combined. The most abundant taxa at reference and monitoring stations were also determined.

To evaluate the numerical similarity of the infaunal abundances among the 22 stations, a single-linkage cluster analysis was performed on a Euclidean distance matrix comprised of station infaunal abundance values for all 22 stations. This analysis was performed for September 2011 data. Friedman's nonparametric test was used to analyze the differences of the 10 most abundant infaunal species among the Nearfield, Reference, Back River/Hawk Cove, and South Cell Exterior Monitoring stations for both September 2011 and April 2012. The statistical analyses were performed using SAS, Version 9.1 and Statistica, Version 6.0.

RESULTS AND DISCUSSION

Water Quality

Minimal variations between surface and bottom values for salinity, temperature, DO, conductivity, and pH values during the September 2011 (Table 2-3) and April 2012 cruises indicated that water column stratification was not prevalent.

Secchi depths were lower in September 2011(range=0.30 m-0.45 m, average = 0.33 m ± 0.04 m) than those in April 2012 (range=0.50 m-1.6 m, average=1.2 m ± 0.35 m). Water quality and Secchi depth measurements provide a snapshot of the conditions prevalent at the time of sampling, but do not necessarily reflect the dominant conditions for the entire season. September 2011 mean Secchi depth is 0.52 m less than the 14-year historic average of 0.85 m and an all-time fall low for this monitoring project. This is due to high sediment discharges from the Susquehanna River which occurred during Hurricane Irene and Tropical Storm Lee.

The following discussion will be limited to bottom values for the first three parameters as bottom water quality measurements are most relevant to benthic macroinvertebrate health. In Year 30, bottom water temperatures did not vary much between stations during both sampling seasons. The September 2011 mean bottom water temperature (mean=20.36°C ± 0.22°C, range= 20.13°C – 21.11°C) was 3.85ºC lower than the 25-year fall average of 24.21ºC. Bottom water temperatures were seasonably lower in April 2012 with a range of 11.25°C –13.52°C and an average of 12.22°C ± 0.63°C. April 2012 mean temperature was 0.12°C higher than the 15-year spring average of 12.10ºC.

The mean bottom DO concentration exceeded the water quality standard (5.0 ppm) to protect aquatic life (Maryland Code of Regulations COMAR) during both seasons. The September 2011 mean bottom DO (mean=7.63 ppm ± 0.32 ppm, range=6.94 ppm – 8.48 ppm) was 0.32 ppm higher than the 15-year fall average of 7.31 ppm. The April 2012 mean bottom DO (mean=10.17 ppm ± 0.99 ppm, range=8.15 ppm – 12.31 ppm) was 0.22 ppm higher than the 15-year spring average of 9.95 ppm. Historically fall DO is 2.64 ppm lower than spring DO due to reduced oxygen solubility with elevated seasonal temperatures. This year there was a 2.54 ppm difference in spring vs. fall mean bottom DO concentration.

This region of the Bay typically ranges between the oligohaline (0.5 ppt – 5 ppt) and mesohaline (>5 ppt – 18 ppt) salinity regimes (Lippson and Lippson 1997). The 26-year mean bottom salinity is 4.46 ppt. Oligohaline conditions (≥0.5-5 ppt) were found during the fall 2011 and spring 2012 sampling seasons.

In Year 30 mean salinity values varied slightly between September (mean=1.28 ppt $\pm$ 0.49 ppt, range = 0.45 ppt – 2.45 ppt) and April (mean=4.81 ppt $\pm$ 1.48 ppt, range 2.13 ppt – 7.15 ppt). The mean fall salinity was 4.79 ppt lower than the historical average (mean =6.07 ppt, ± 2.92 ppt). However, mean spring salinity was 1.97 ppt higher than the historical mean (2.84 ppt $\pm$ 2.33 ppt). This region of the Bay is subject to significant salinity fluctuations resulting from

large inter-annual variation in rainfall in the watershed. In general, the Bay experiences relatively higher salinity values during the fall, because of dry summer conditions. However, the reverse was true for Year 30 due to the effects of a strong 2011 spring freshet and Hurricane Irene and Tropical Storm Lee two weeks prior to the fall 2011 benthic sampling cruise.

Table 2- 2: Year 30 physical parameters measured *in situ* at all HMI stations on September 23, 2011.

MDE Station	Time	Tide	Water Depth (m)	Wave Height (m)	Wind Direction	Wind Speed (knots)		Air Temp. (°C)	Cloud Cover (%)	Weather		Observed Bottom Sediment (%)				
						Min.	Max			Past 24 hrs.	Today	silt/clay	sand	shell	gravel	detritus
MDE-01	12:39	Flood	5.74	0.1	SE	0	5	22	100	0	2	0	90	10	0	0
MDE-03	11:34	Flood	7.21	0.2	SE	8	10	22	100	0	2	70	0	30	0	0
MDE-07	12:25	Flood	5.24	0.2	SE	8	10	22	100	0	2	70	0	30	0	0
MDE-09	12:10	Flood	7.18	0.2	SE	8	10	22	100	0	2	70	0	30	0	0
MDE-11	11:56	Slack	6.76	0.0	LV	0	1	22	100	0	2	70	0	30	0	0
MDE-13	10:56	Ebb	6.05	0.0	LV	0	1	22	100	0	2	70	0	30	0	0
MDE-15	10:31	Ebb	7.0	0.0	LV	0	1	22	100	0	2	60	0	40	0	0
MDE-16	10:10	Ebb	6.48	0.0	LV	0	1	22	100	0	2	70	0	30	0	0
MDE-17	9:32	Ebb	6.80	0.0	LV	0	1	22	100	0	2	25	0	75	0	0
MDE-19	9:38	Ebb	6.73	0.0	LV	0	1	22	100	0	2	80	0	20	0	0
MDE-22	8:52	Ebb	7.0	0.0	LV	0	1	22	100	0	2	75	0	25	0	0
MDE-27	13:52	Flood	5.54	0.1	SE	0	5	22	100	0	2	75	0	15	0	10
MDE-30	13.34	Flood	5.17	0.1	SE	0	5	22	100	0	2	60	0	40	0	0
MDE-33	13.22	Flood	4.40	0.1	SE	0	5	22	100	0	2	0	90	10	0	0
MDE-34	12:53	Flood	4.27	0.1	SE	0	5	22	100	0	2	90	0	10	0	5
MDE-36	14:22	Flood	5.06	0.1	SE	0	5	22	100	0	2	70	0	30	0	0
MDE-42	9:07	Ebb	6.98	0.0	LV	0	1	22	100	0	2	90	0	10	0	0
MDE-43	9:23	Ebb	7.13	0.0	LV	0	1	22	100	0	2	85	0	15	0	0
MDE-44	10:00	Ebb	7.09	0.0	LV	0	1	22	100	0	2	70	0	30	0	0
MDE-45	10:25	Ebb	8.56	0.0	LV	0	1	22	100	0	2	70	0	0	0	30
MDE-50	11:40	Slack	5.88	0.0	LV	0	1	22	100	0	2	0	95	5	0	0
MDE-51	11:16	Slack	5.11	0.0	LV	0	1	22	100	0	2	80	0	20	0	0

Note: The Weather code 0 stands for “Clear”, code 2 stands for “Continuous Cloud Cover”. Wind Direction code LV stands for “Light and Variable”

Table 2- 3: Year 30 water quality parameters measured *in situ* at all HMI stations on September 23, 2011.

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt)	Temp. (C)	Dissolved Oxygen (ppm)	pH	Secchi Depth (m)	Conductivity (µmos/cm)
Nearfield Stations									
MDE-01	XIF5505	Surface	0.50	0.54	20.43	7.93	7.57	0.3	1,099
		Bottom	5.24	0.65	20.37	7.85	7.66		1,235
MDE-03	XIG5699	Surface	0.50	1.29	20.37	7.80	7.49	0.3	2,407
		Bottom	6.71	1.35	20.30	7.67	7.55		2,512
MDE-07	XIF5302	Surface	0.50	0.66	20.47	8.08	7.56	0.3	1,261
		Bottom	7.11	1.24	20.27	7.74	7.60		2,310
MDE-09	XIF4806	Surface	0.50	0.62	20.43	8.11	7.64	0.3	1,211
		Bottom	6.68	1.38	20.22	7.63	7.55		2,570
MDE-11	XIG4501	Surface	0.50	1.31	20.46	7.96	7.51	0.3	2,418
		Bottom	6.26	1.64	20.35	7.43	7.44		3,038
MDE-15	XIF4609	Surface	0.50	0.85	20.21	7.68	7.45	0.3	1,710
		Bottom	6.5	1.24	20.13	7.60	7.49		2,313
MDE-16	XIF4615	Surface	0.50	0.68	20.24	7.78	7.49	0.35	1,477
		Bottom	5.98	1.25	20.19	7.53	7.46		2,358
MDE-17	XIF4285	Surface	0.50	1.02	20.27	7.79	7.57	0.35	1,967
		Bottom	6.30	1.41	20.21	7.49	7.47		2,631
MDE-19	XIF4221	Surface	0.50	0.96	20.26	7.68	7.48	0.35	1,748
		Bottom	6.23	1.27	20.21	7.47	7.42		2,375
MDE-33	XIF6008	Surface	0.50	0.63	20.57	7.89	7.57	0.3	1,204
		Bottom	3.9	0.63	20.52	7.80	7.61		1,190
MDE-34	XIF5805	Surface	0.50	0.64	20.52	8.02	7.60	0.3	1,271
		Bottom	3.77	0.79	20.44	7.89	7.73		1,293
MDE-45	N/A	Surface	0.50	0.59	20.30	7.96	7.59	0.35	1,105
		Bottom	8.06	1.15	20.20	7.75	7.63		2,146
Reference Stations									
MDE-13	XIG3506	Surface	0.50	1.36	20.40	7.78	7.47	0.3	2,575
		Bottom	5.55	1.67	20.31	7.45	7.47		3,092
MDE-22	XIF3224	Surface	0.50	0.85	20.59	8.14	7.42	0.4	1,751
		Bottom	7.0	1.9	20.22	6.94	6.98		3,500
MDE-36	XIG7589	Surface	0.50	1.00	20.42	7.61	7.48	0.3	1,875
		Bottom	4.56	1.01	20.46	7.65	7.56		1,897
MDE-50	N/A	Surface	0.50	2.43	20.67	7.32	7.42	0.35	4,463
		Bottom	5.38	2.45	20.67	7.29	7.45		4,483
MDE-51	N/A	Surface	0.50	1.91	20.54	7.64	7.45	0.3	3,516
		Bottom	4.61	2.08	20.45	7.39	7.44		3,857
Back River/Hawk Cove Stations									
MDE-27	XIF4642	Surface	0.50	0.58	21.22	8.40	7.83	0.35	1,111
		Bottom	5.04	0.62	21.11	8.29	7.89		1,171
MDE-30	XIF5925	Surface	0.50	0.43	20.72	8.84	7.87	0.4	826
		Bottom	4.67	0.45	20.54	8.48	7.88		880
South Cell Exterior Monitoring Stations									
MDE-42	XIF3879	Surface	0.50	1.03	20.31	7.80	7.46	0.45	1,840
		Bottom	6.48	1.39	20.31	7.54	7.42		2,589
MDE-43	XIF3985	Surface	0.50	1.14	20.21	7.52	7.41	0.35	2,155
		Bottom	6.63	1.43	20.22	7.47	7.46		2,649
MDE-44	XIF4482	Surface	0.50	0.60	20.34	8.06	7.59	0.35	1,123
		Bottom	6.59	1.19	20.19	7.42	7.41		2,141

Table 2- 4: Year 30 physical parameters measured *in situ* at all HMI stations on April 04, 2012.

MDE Station	Time	Tide	Water Depth (m)	Wave Height (m)	Wind Direction	Wind Speed (knots)		Air Temp (ºC)	Cloud Cover (%)	Weather		Observed Bottom Sediment (%)				
						Min.	Max.			Past 24 hrs.	Today	silt/clay	sand	shell	gravel	detritus
MDE-01	12:18	Ebb	3.52	0.2	N	2	5	18	65	0	2	0	95	5	0	0
MDE-03	12:10	Ebb	6.27	0.2	N	2	5	18	65	0	2	70	0	30	0	0
MDE-07	12:00	Ebb	5.63	0.0	N	2	5	18	65	0	2	75	0	25	0	0
MDE-09	11:44	Ebb	5.94	0.0	N	2	5	18	65	0	2	70	0	30	0	0
MDE-11	11:37	Ebb	4.84	0.0	N/A	0	0	18	65	0	2	75	0	25	0	0
MDE-13	10:26	Ebb	4.75	0.0	N/A	0	0	18	70	0	2	75	0	25	0	0
MDE-15	10:16	Ebb	5.02	0.0	N/A	0	0	18	70	0	2	65	0	35	0	0
MDE-16	10:02	Ebb	4.68	0.0	N/A	0	0	17	70	0	2	80	0	20	0	0
MDE-17	9:11	Ebb	6.30	0.0	N/A	0	0	15	70	0	2	30	0	70	0	0
MDE-19	9:31	Ebb	6.16	0.0	N/A	0	0	17	70	0	2	85	0	15	0	0
MDE-22	8:27	Ebb	6.75	0.0	N/A	0	0	15	100	0	2	75	0	25	0	0
MDE-27	13:32	Ebb	4.36	0.2	N	2	5	19	60	0	2	70	0	20	0	10
MDE-30	13:00	Ebb	3.31	0.2	N	2	5	19	60	0	2	60	0	40	0	0
MDE-33	12:49	Ebb	2.56	0.2	N	2	5	19	65	0	2	0	90	10	0	0
MDE-34	12:44	Ebb	2.58	0.2	N	2	5	19	65	0	2	90	0	10	0	0
MDE-36	13:59	Ebb	3.41	0.2	N	2	5	19	65	0	2	75	0	25	0	0
MDE-42	8:39	Ebb	6.89	0.0	N/A	0	0	15	100	0	2	80	0	20	0	0
MDE-43	9:02	Ebb	6.85	0.0	N/A	0	0	15	70	0	2	90	0	10	0	0
MDE-44	9:39	Ebb	5.80	0.0	N/A	0	0	17	70	0	2	75	0	25	0	0
MDE-45	10:10	Ebb	4.82	0.0	N/A	0	0	17	70	0	2	70	0	0	0	30
MDE-50	11:09	Ebb	4.25	0.0	N/A	0	0	18	65	0	2	0	90	10	0	0
MDE-51	10:54	Ebb	4.91	0.0	N/A	0	0	18	70	0	2	80	0	20	0	0

Note: The weather code 0 stands for “Clear”, 2 stands for “Continuous Cloud Cover”.

Table 2- 5: Water quality parameters measured *in situ* at all HMI stations on April 04, 2012.

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt)	Temp. (C)	Dissolved Oxygen (ppm)	pH	Secchi Depth (m)	Conductivity (µmos/cm)
Nearfield Stations									
MDE-01	XIF5505	Surface	0.50	2.09	13.86	12.10	8.30	1.2	3,844
		Bottom	3.02	2.13	13.52	12.31	8.36		3,863
MDE-03	XIG5699	Surface	0.50	3.67	12.94	11.20	7.74	1.5	6,607
		Bottom	5.77	4.09	12.46	10.85	7.79		7,346
MDE-07	XIF5302	Surface	0.50	3.04	13.19	11.35	8.04	1.5	5,510
		Bottom	5.13	3.55	12.61	11.12	7.99		6,422
MDE-09	XIF4806	Surface	0.50	2.38	13.25	11.51	8.13	1.0	4,335
		Bottom	5.44	4.36	12.27	10.49	7.81		7,799
MDE-11	XIG4501	Surface	0.50	4.12	12.69	10.97	7.89	1.0	7,401
		Bottom	4.34	5.45	12.48	10.37	7.79		9,760
MDE-15	XIF4609	Surface	0.50	3.38	12.50	10.81	7.97	1.5	6,233
		Bottom	4.52	5.15	11.98	10.01	7.70		9,153
MDE-16	XIF4615	Surface	0.50	4.15	12.34	10.03	7.84	1.6	7,348
		Bottom	4.18	5.22	12.02	9.71	7.71		9,284
MDE-17	XIF4285	Surface	0.50	2.69	12.79	11.14	8.11	1.2	4,870
		Bottom	5.8	6.00	11.75	9.40	7.71		10,562
MDE-19	XIF4221	Surface	0.50	4.17	12.38	10.68	7.89	1.6	7,320
		Bottom	5.66	5.99	11.66	9.18	7.65		10,668
MDE-33	XIF6008	Surface	0.50	2.11	13.82	11.93	8.30	0.9	3,893
		Bottom	2.06	3.42	12.92	11.48	8.11		4,355
MDE-34	XIF5805	Surface	0.50	2.33	13.64	11.76	8.25	1.0	4,272
		Bottom	2.08	2.43	13.41	11.81	8.23		4,740
MDE-45	N/A	Surface	0.50	3.89	12.36	10.56	7.86	1.5	6,976
		Bottom	4.32	5.14	12.04	9.90	7.71		9,122
Reference Stations									
MDE-13	XIG3506	Surface	0.50	4.30	12.64	10.86	7.95	1.5	7,556
		Bottom	4.25	5.50	12.00	10.38	7.79		9,646
MDE-22	XIF3224	Surface	0.50	3.35	12.80	11.49	8.03	0.8	6,049
		Bottom	6.18	6.89	11.42	8.92	7.45		12,051
MDE-36	XIG7589	Surface	0.50	1.86	13.65	12.09	8.31	0.6	3,437
		Bottom	2.91	2.46	13.06	10.99	8.13		4,032
MDE-50	N/A	Surface	0.50	4.68	12.36	10.88	7.87	1.5	8,439
		Bottom	3.75	5.63	11.77	10.28	7.75		9,981
MDE-51	N/A	Surface	0.50	3.16	12.84	11.43	8.14	1.5	5,753
		Bottom	4.41	7.15	11.25	8.15	7.49		12,510
Back River/Hawk Cove Stations									
MDE-27	XIF4642	Surface	0.50	2.69	13.83	13.32	8.58	0.5	4,896
		Bottom	3.86	4.00	12.92	9.58	7.92		7,199
MDE-30	XIF5925	Surface	0.50	2.14	13.73	12.24	8.39	0.7	3,927
		Bottom	2.81	3.21	12.00	10.36	7.83		5,788
South Cell Exterior Monitoring Stations									
MDE-42	XIF3879	Surface	0.50	4.06	12.65	10.52	7.91	1.0	6,894
		Bottom	6.39	6.52	11.61	9.21	7.64		11,428
MDE-43	XIF3985	Surface	0.50	4.30	12.67	10.70	7.93	1.4	7,724
		Bottom	6.35	6.45	11.62	9.42	7.68		11,315
MDE-44	XIF4482	Surface	0.50	4.45	12.22	10.35	7.81	1.5	7,894
		Bottom	5.3	5.06	12.03	9.85	7.71		8,991

BENTHIC MACROINVERTEBRATE COMMUNITY

Taxa Richness and Dominance

A total of 52 taxa were found over the two seasons of sampling during Year 30. This is higher than the 14-year average of 40.79 taxa and more than the all-time high of 45. This is due to a large increase in taxa normally associated with freshwater communities (additional consequences of the strong spring freshet and tropical storms).

The most common taxa groups were members of the phyla Arthropoda (joint-legged organisms), Annelida (segmented worms), and Mollusca/Bivalvia (shellfish having two separate shells joined by a muscular hinge). Thirty-three taxa of Arthropoda were found in Year 30. This is higher than the 14-year mean of 19.29 taxa (range= 12-33 taxa). The most common types of arthropods were the amphipods (including *Leptocheirus plumulosus*) and the isopods (including *Cyathura polita*). Six taxa of annelid worms in the Class Polychaeta were found. This is similar to the 14-year mean of 7.36 taxa (range= 6-10 taxa). Five species of bivalve mollusks were found. This is similar to the 14-year mean of 5.71 taxa (range= 4-7 taxa). Overall, bivalve average abundance was lower in April 2012 than in September 2011.

During the spring, Ostracoda, *Eteone heteropoda, Balanus improvisus, Balanus subalbidus, Balanus* sp. A, *Rheotanytarsus* sp., *Polypedillum* sp., *Chironomus* sp., *Harnischia* sp., *Thienemanniella* sp., *Nanocladius* sp., *Brillia* sp., *Gyratryx hermaphrodites, Cladocera, Pisicola* sp., and Copepoda were exclusively found, while Odonata, Chaoboridae, Terrestrial Collembolla, *Oribatida* sp., Culicidae pupae, and Hydrobiidae were only found in fall samples. *G. solitaria* and *Mulinia lateralis* have not been observed since the Year 21 sampling season. These species (and a few rarer ones) tended to only be found at Harbor Stations (MDE-38, MDE-39, MDE-40, and MDE-41), which have not been sampled since Year 21. The cessation of sampling Harbor stations usually accounts for occasional reductions in the numbers of taxa found. Additionally, small inter-annual and inter-seasonal differences in taxa richness are likely a result of natural variation in salinity and spawning/recruitment typical in this dynamic region of the Chesapeake Bay.

Table 2- 6: Average and total abundance (individuals per square meter) of each taxon found at HMI during the September 2011 sampling; by substrate and station type. Taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

Taxon	Average Abundance, All stations	Total Abundance, All stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Nemata	70.98	1561.60	80.51	12.80	10.67	46.93	74.24	249.60	42.67
Carinoma tremophoros	55.85	1228.80	60.29	38.40	27.73	55.47	75.52	12.80	53.33
Bivalvia	7.85	172.80	1.01	0.00	51.20	13.87	0.00	3.20	0.00
Macoma sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macoma balthica	1.16	25.60	1.35	0.00	0.00	0.00	5.12	0.00	0.00
Macoma mitchelli	7.56	166.40	8.42	12.80	2.13	5.87	12.80	3.20	8.53
Rangia cuneata	432.87	9523.20	362.78	115.20	876.80	643.20	227.84	60.80	181.33
Ischadium recurvum	0.29	6.40	0.00	0.00	2.13	0.53	0.00	0.00	0.00
Mytilopsis leucophaeata	223.42	4915.20	118.57	6.40	887.47	408.00	3.84	0.00	0.00
Amphicteis floridus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capitellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heteromastus filiformis	4.07	89.60	4.04	0.00	4.27	2.67	10.24	0.00	2.13
Spionidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marenzelleria viridis	**368.87**	**8115.20**	**371.20**	**44.80**	**354.13**	**387.20**	**373.76**	**492.80**	**204.80**
Streblospio benedicti	566.98	12473.60	605.98	979.20	320.00	580.27	517.12	643.20	546.13
Polydora cornuta	0.58	12.80	0.67	0.00	0.00	1.07	0.00	0.00	0.00
Boccardiella ligerica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nereidae	0.58	12.80	0.67	0.00	0.00	1.07	0.00	0.00	0.00
Neanthes succinea	4.36	96.00	3.71	0.00	8.53	4.80	5.12	6.40	0.00

Table 2-6 (continued)

Taxon	Average Abundance, All stations	Total Abundance, All stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Eteone heteropoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naididae sp.	364.51	8019.20	415.33	339.20	42.67	200.00	656.64	601.60	377.60
Amphipoda	29.38	646.40	25.94	25.60	51.20	27.73	24.32	70.40	17.07
Gammaridea	2.33	51.20	2.36	0.00	2.13	4.27	0.00	0.00	0.00
Ameroculodes spp complex	14.55	320.00	13.47	12.80	21.33	17.07	12.80	0.00	17.07
Leptocheirus plumulosus	381.38	8390.40	361.77	44.80	505.60	326.40	377.60	867.20	283.73
Gammarus sp.	20.07	441.60	13.81	0.00	59.73	19.73	6.40	0.00	57.60
Melitadae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Melita nitida	20.95	460.80	22.91	6.40	8.53	28.27	11.52	3.20	19.20
Corophiidae	2.33	51.20	0.67	0.00	12.80	4.27	0.00	0.00	0.00
Apocorophium lacustre	146.04	3212.80	21.89	12.80	932.27	263.47	3.84	3.20	8.53
Cyathura polita	319.13	7020.80	324.38	320.00	285.87	325.33	358.40	284.80	251.73
Edotea triloba	0.58	12.80	0.00	0.00	4.27	0.00	2.56	0.00	0.00
Chiridotea almyra	**3.78**	**83.20**	**1.01**	**0.00**	**21.33**	**6.40**	**1.28**	**0.00**	**0.00**
Ciripedia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Balanus improvisus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Balanus subalbidus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rhithropanopeus harrisii	6.69	147.20	7.07	12.80	4.27	10.13	1.28	0.00	6.40
Membranipora sp	+	+	+	+	+	+	+	0	+
Chironomidae	0.29	6.40	0.34	0.00	0.00	0.00	1.28	0.00	0.00

Table 2-6 (continued)

Taxon	Average Abundance, All stations	Total Abundance, All stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Coelotanypus sp.	12.51	275.20	14.48	0.00	0.00	10.13	5.12	54.40	6.40
Procladius sp.	2.91	64.00	3.37	0.00	0.00	2.13	7.68	0.00	0.00
Cryptochironomus sp.	0.29	6.40	0.34	0.00	0.00	0.00	0.00	3.20	0.00
Chironominae	0.29	6.40	0.34	0.00	0.00	0.00	0.00	3.20	0.00
Gammmaridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copepoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gobiosoma bosci	0.29	6.40	0.34	0.00	0.00	0.53	0.00	0.00	0.00
Mysidacea	1.16	25.60	1.35	0.00	0.00	1.07	2.56	0.00	0.00
Cassidinea ovalis	0.58	12.80	0.67	0.00	0.00	1.07	0.00	0.00	0.00
Odonata	0.29	6.40	0.34	0.00	0.00	0.00	0.00	0.00	2.13
Chaoboridae	1.16	25.60	1.35	0.00	0.00	1.60	0.00	0.00	2.13
Hydrobiidae	0.87	19.20	0.00	0.00	6.40	1.60	0.00	0.00	0.00
Terrestrial Collembola	0.29	6.40	0.34	0.00	0.00	0.00	0.00	3.20	0.00
Oribatida sp.	0.29	6.40	0.34	0.00	0.00	0.00	0.00	0.00	2.13
Hydrozoa	0.58	12.80	0.00	0.00	4.27	1.07	0.00	0.00	0.00
Culicidae pupae	0.29	6.40	0.34	0.00	0.00	0.00	0.00	0.00	2.13

Note: Presence of *Membranipora* sp. is indicated by +

Table 2- 7: Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 30 spring sampling, April 2012, by substrate and station type. Taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Nemata	189.44	3788.80	204.80	38.40	21.33	132.07	57.60	490.67	230.40
Carinoma tremophoros	26.88	537.60	32.71	38.40	12.80	19.20	51.20	36.27	21.33
Bivalvia	0.96	19.20	1.07	0.00	0.00	0.58	0.00	0.00	4.27
Macoma sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macoma balthica	8.00	160.00	14.58	0.00	0.00	2.33	17.07	25.60	2.13
Macoma mitchelli	0.64	12.80	1.07	0.00	0.00	0.00	0.00	4.27	0.00
Rangia cuneata	71.36	1427.20	68.98	140.80	51.20	86.69	102.40	8.53	46.93
Ischadium recurvum	0.32	6.40	0.00	0.00	2.13	0.58	0.00	0.00	0.00
Mytilopsis leucophaeata	8.96	179.20	4.62	0.00	32.00	16.29	0.00	0.00	0.00
Capitellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heteromastus filiformis	3.20	64.00	3.20	6.40	12.80	2.33	8.53	2.13	2.13
Spionidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marenzelleria viridis	**271.68**	**5433.60**	**298.31**	**140.80**	**266.67**	**287.42**	**170.67**	**174.93**	**411.73**
Streblospio benedicti	46.08	921.60	59.73	12.80	2.13	19.78	29.87	136.53	68.27
Polydora cornuta	0.32	6.40	0.36	0.00	0.00	0.58	0.00	0.00	0.00
Boccardiella ligerica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2-7 (continued)

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Nereidae	0.96	19.20	0.00	0.00	6.40	1.75	0.00	0.00	0.00
Neanthes succinea	4.16	83.20	0.71	0.00	23.47	6.40	4.27	0.00	0.00
Naididae sp.	834.56	16691.20	929.07	300.80	356.27	309.53	424.53	3118.93	885.33
Amphipoda	16.32	326.40	8.53	19.20	51.20	17.45	10.67	14.93	19.20
Gammaridea	3.52	70.40	3.56	0.00	2.13	2.91	0.00	2.13	10.67
Ameroculodes spp complex	16.00	320.00	16.36	12.80	14.93	17.45	19.20	10.67	12.80
Leptocheirus plumulosus	138.88	2777.60	148.98	102.40	44.80	94.84	96.00	234.67	247.47
Gammaridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gammarus sp	38.40	768.00	32.71	38.40	49.07	27.93	14.93	4.27	134.40
Melitadae	1.60	32.00	1.07	6.40	2.13	1.75	2.13	0.00	2.13
Melita nitida	40.64	812.80	28.80	6.40	96.00	47.13	8.53	19.20	70.40
Corophiidae	1.28	25.60	0.71	6.40	2.13	1.75	2.13	0.00	0.00
Apocorophium sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apocorophium lacustre	42.24	844.80	20.62	44.80	142.93	68.07	19.20	0.00	12.80
Cyathura polita	141.44	2828.80	156.44	230.40	91.73	145.45	181.33	123.73	104.53
Edotea triloba	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00
Chiridotea almyra	**1.28**	**25.60**	**1.42**	**0.00**	**0.00**	**2.33**	**0.00**	**0.00**	**0.00**
Balanus improvisus	18.24	364.80	6.04	0.00	85.33	33.16	0.00	0.00	0.00
Balanus subalbidus	2.56	51.20	0.00	0.00	17.07	4.65	0.00	0.00	0.00

Table 2-7 (continued)

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Balanus sp. A	25.28	505.60	10.67	0.00	104.53	45.96	0.00	0.00	0.00
Rhithropanopeus harrisii	12.80	256.00	5.69	0.00	51.20	20.36	8.53	0.00	2.13
Membranipora sp	+	+	+	+	+	+	+	0	+
Chironomidae	4.48	89.60	3.20	0.00	10.67	4.65	2.13	2.13	8.53
Chironominae	1.28	25.60	1.42	0.00	0.00	1.75	0.00	0.00	2.13
Tanypodinae	0.32	6.40	0.36	0.00	0.00	0.58	0.00	0.00	0.00
Coelotanypus sp.	11.84	236.80	12.80	6.40	0.00	3.49	2.13	49.07	14.93
Procladius sp.	9.28	185.60	10.31	6.40	0.00	10.47	10.67	6.40	6.40
Tanytarsini	14.72	294.40	6.40	0.00	59.73	26.76	0.00	0.00	0.00
Rheotanytarsus sp.	10.56	211.20	2.13	0.00	57.60	18.62	2.13	0.00	0.00
Polypedillum sp.	0.32	6.40	0.36	0.00	0.00	0.00	0.00	2.13	0.00
Cryptochironomus sp.	5.12	102.40	5.69	0.00	4.27	2.33	4.27	14.93	6.40
Chironomus sp.	3.52	70.40	3.91	0.00	0.00	1.16	0.00	2.13	17.07
Harnischia sp.	1.28	25.60	1.42	0.00	0.00	1.16	2.13	0.00	2.13
Thienemanniella sp.	0.64	12.80	0.00	0.00	4.27	1.16	0.00	0.00	0.00
Nanocladius sp.	2.24	44.80	1.07	0.00	8.53	4.07	0.00	0.00	0.00
Brillia sp.	0.32	6.40	0.00	0.00	2.13	0.58	0.00	0.00	0.00
Copepoda	+	+	+	0.00	0.00	0.00	0.00	+	+
Ostracoda	4.48	89.60	4.98	0.00	0.00	0.00	0.00	0.00	29.87
Mysidacea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gyratrix hermaphrodites	0.32	6.40	0.36	0.00	0.00	0.58	0.00	0.00	0.00

Cladocera	22.08	441.60	24.53	0.00	0.00	0.00	0.00	147.20	0.00
Eteone heteropoda	0.32	6.40	0.36	0.00	0.00	0.58	0.00	0.00	0.00
Cassidinea ovalis	3.84	76.80	0.71	0.00	21.33	6.98	0.00	0.00	0.00
Hydrozoa	13.44	268.80	12.80	0.00	12.80	7.56	4.27	0.00	57.60
Pisicola sp.	0.32	6.40	0.36	0.00	0.00	0.00	0.00	2.13	0.00
Gobiosoma bosci	0.64	12.80	0.00	0.00	4.27	1.16	0.00	0.00	0.00

Note: Presence of *Membranipora* sp. and Copepoda is indicated by +

Of the 52 taxa found in Year 30, fifteen were considered truly infaunal, twenty-three were considered epifaunal, and the remaining fourteen were considered too general to classify as either infaunal or epifaunal (see Ranasinghe et al. 1994). The most common infaunal species found during Year 30 were worms from the family Naididae, the amphipod *L. plumulosus*, the polychaete worms *M. viridis* and *S. benedicti*, the bivalve *R. cuneata*, and the isopod *C. polita*. The most common epifaunal species was the bivalve *M. leucopheata*.

Nearfield station MDE-09 had the highest number of taxa in September 2011 (19 taxa). The station with the fewest number of taxa (6 taxa) in September was Back River/Hawk Cove station MDE-30. Overall, average taxa richness was highest at the Nearfield and South Cell Exterior Monitoring stations but did not vary greatly between station types (average taxa richness: Nearfield=15.25 taxa, South Cell Exterior Monitoring=15 taxa, Reference=14.6 taxa, Back River/Hawk Cove=11.5 taxa). It is important to note that there are 12 Nearfield stations, 5 Reference stations, 3 South Cell Exterior Monitoring stations and 2 Back River/Hawk Cove stations. So, historic higher taxa abundances at Nearfield stations may simply be an artifact of sample size. No trend of increasing/decreasing taxa richness associated with distance from HMI could be discerned.

Table 2- 8: Summary of metrics for each HMI benthic station surveyed during the Year 30 September 2011 cruise. Total infaunal abundance and total abundance, excluding Polycladida, Nematoda, and Bryozoa, are individuals per square meter.

Station	Total Infauna	Total All	All Taxa	Infaunal Taxa	Shannon-Wiener	PSTA (%)	PITA (%)	Tolerance Score	% Carnivore/ Omnivore	Tanypodinae: Chironomidae	B-IBI
Nearfield Stations											
MDE-01	2195.2	2259.20	16	12	3.01	23.62	18.95	6.95	23.51	N/A	3.80
MDE-03	1900.8	1945.60	14	10	2.41	38.72	18.18	6.99	28.29	N/A	4.20
MDE-07	2355.2	2368.00	15	11	2.47	9.24	39.13	6.45	20.00	100.00	3.00
MDE-09	2067.2	2227.20	19	10	2.10	1.55	65.33	8.13	21.84	100.00	3.00
MDE-11	1657.6	1670.40	11	10	2.51	36.68	10.42	6.50	24.90	N/A	4.20
MDE-15	2028.8	2067.20	13	9	2.62	14.51	50.47	8.08	12.69	100.00	2.67
MDE-16	2297.6	2361.60	16	10	2.59	11.70	38.44	8.19	10.84	100.00	2.67
MDE-17	1945.6	1971.20	15	10	2.12	2.30	67.76	8.84	18.18	N/A	3.40
MDE-19	1824	1913.60	13	10	2.52	10.53	32.28	8.84	12.71	100.00	2.67
MDE-33	7046.4	9913.60	16	9	2.20	7.27	7.27	6.11	2.32	N/A	2.60
MDE-34	7206.4	9491.20	17	13	2.50	17.85	12.17	6.17	9.24	N/A	2.60
MDE-45	1926.4	2073.60	18	11	2.12	0.66	62.46	8.71	8.64	100.00	2.67
MEAN	**2870.93**	**3355.20**	**15.25**	**10.42**	**2.43**	**14.55**	**35.24**	**7.50**	**16.10**	**100.00**	**3.12**
Reference Stations											
MDE-13	1888	1894.40	14	11	2.56	9.83	51.86	8.17	22.64	N/A	3.40
MDE-22	1107.2	1139.20	12	10	2.66	24.28	12.14	6.72	28.65	100.00	3.33
MDE-36	4499.2	4601.60	18	10	2.62	24.75	28.73	7.41	13.91	88.89	2.00
MDE-50	1280	1305.60	14	11	2.24	7.50	15.50	6.00	20.59	N/A	4.20
MDE-51	4563.2	4582.40	15	12	1.98	4.63	74.61	9.60	13.27	100.00	1.67
MEAN	**2667.52**	**2704.64**	**14.6**	**10.8**	**2.41**	**14.20**	**36.57**	**7.58**	**19.81**	**96.30**	**2.92**
Back River/Hawk Cove Stations											
MDE-27	4672.00	4748.80	14	10	2.40	16.71	49.04	9.44	10.51	80.00	1.67
MDE-30	1420.80	1484.80	9	6	2.15	14.41	22.52	7.78	15.52	100.00	3.33
MEAN	**3046.40**	**3116.80**	**11.5**	**8**	**2.28**	**15.56**	**35.78**	**8.61**	**13.01**	**90.00**	**2.50**
South Cell Exterior Monitoring Stations											
MDE-42	1396.60	1433.60	14	10	2.75	3.74	32.24	8.63	21.88	100.00	3.00
MDE-43	1779.20	1792.00	16	12	2.97	19.78	26.62	7.39	19.64	N/A	3.80
MDE-44	2880.00	2918.40	15	9	2.33	7.33	65.33	9.21	9.21	N/A	2.60
MEAN	**2018.60**	**2048.00**	**15**	**10.3**	**2.68**	**10.28**	**41.40**	**8.41**	**16.91**	**100.00**	**3.13**

In April 2012, the greatest taxa richness (24 taxa) occurred at Nearfield station MDE-03 (Table 2-9). The lowest taxa richness (10 taxa) from spring 2012 sampling was recorded at Back River/Hawk Cove station MDE-30 and Reference station MDE-50. Overall, average taxa richness varied between station types. The average taxa richness was highest at Nearfield stations (17.58 taxa), followed by South Cell Exterior Monitoring stations (16.67 taxa), Back River/Hawk Cove Stations (14.50 taxa), and Reference stations (12.20 taxa).

Table 2- 9: Summary of metrics for each HMI benthic station surveyed during the Year 30 April 2012 cruise. Total infaunal abundance and total abundance, excluding Polycladida, Nematoda, and Bryozoa, are individuals per square meter.

Station	Total Infauna	Total All	All Taxa	Infaunal Taxa	Shannon-Wiener	PSTA (%)	PITA (%)
Nearfield Stations							
MDE-01	1849.60	3539.20	23	7	1.95	8.65	52.94
MDE-03	1740.80	2515.20	24	11	2.64	21.69	29.04
MDE-07	864.00	883.20	15	10	2.58	7.41	38.52
MDE-09	825.60	896.00	19	10	2.59	15.50	40.31
MDE-11	1248.00	1324.80	19	12	2.59	21.03	38.97
MDE-15	761.60	800.00	18	12	2.70	30.25	42.02
MDE-16	1344.00	1440.00	19	9	2.17	49.52	31.43
MDE-17	1094.40	1120.00	16	11	2.82	12.87	39.77
MDE-19	1203.20	1267.20	13	8	2.29	11.70	73.94
MDE-33	582.40	608.00	14	10	3.08	16.48	29.67
MDE-34	563.20	608.00	14	9	2.55	28.41	29.55
MDE-45	1420.80	1491.20	17	9	2.12	45.50	42.79
MEAN	**1124.80**	**1374.40**	**17.58**	**9.83**	**2.51**	**22.42**	**40.75**
Reference Stations							
MDE-13	614.40	633.60	12	9	2.73	15.63	54.17
MDE-22	2182.40	2208.00	13	10	2.24	9.97	73.61
MDE-36	1888.00	1971.20	13	9	1.89	56.61	25.42
MDE-50	960.00	972.80	10	9	2.07	56.67	17.33
MDE-51	2547.20	2560.00	13	11	2.23	13.07	62.56
MEAN	**1638.40**	**1669.12**	**12.20**	**9.60**	**2.23**	**30.39**	**46.62**
Back River/Hawk Cove Stations							
MDE-27	8774.40	9420.80	19	10	0.75	2.63	96.43
MDE-30	736.00	800.00	10	6	1.73	10.43	80.00
MEAN	**4755.20**	**5110.40**	**14.50**	**8.00**	**1.24**	**6.53**	**88.21**
South Cell Exterior Monitoring Stations							
MDE-42	1113.60	1152.00	15	10	2.31	9.77	72.41
MDE-43	1440.00	1465.60	15	11	2.50	16.89	58.22
MDE-44	3078.40	3654.40	20	11	2.08	11.23	74.01
MEAN	**1877.33**	**2090.67**	**16.67**	**10.67**	**2.30**	**12.63**	**68.22**

Since the first benthic survey studies of the Hart-Miller Island area in 1981, a small number of taxa have been dominant. Year 30 was no exception. During both seasons, 8 taxa were consistently dominant (in the top ten taxa in terms of total average abundance): oligochaete worms of the family Naididae, the amphipods *L. plumulosus*, and *A. lacustre*, the bivalve *R. cuneata*, the isopod *C. polita*, and the polychaete worms *M. viridis*, and *S. benedicti,* and worms of the phylum Nemata.

Several other taxa were among the most dominant in only one season. In September 2011, the nemertea *C. tremaphoros* and the bivalve *M. leucopheata* were within the top ten most dominant taxa, but not in April 2012. Likewise, the amphipods *M. nitida* and *Gammarus* sp. were among the most dominant in April 2012, but not in September 2011. The average abundance of each taxon (individuals per square meter) found at each station during September and April are provided in Table 2-10 through 2-13. These trends, both in overall abundance and seasonal variation are very consistent with historic data.

Table 2- 10: Average number of individuals collected per square meter at each station during HMI Year 30 late summer sampling, September 2011, stations MDE-1 to MDE-22. Because the mean bottom salinity regime was oligohaline, taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

Taxon	Station										
	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Nemata	0	6.4	32	19.2	0	6.4	25.6	102.4	12.8	307.2	0
Carinoma tremaphoros	57.6	115.2	57.6	76.8	64	76.8	38.4	25.6	38.4	32	51.2
Bivalvia	0	0	0	0	0	0	0	0	0	0	0
Macoma sp.	0	0	0	0	0	0	0	0	0	0	0
Macoma balthica	0	0	0	0	0	0	0	0	0	0	0
Macoma mitchelli	0	0	0	12.8	0	25.6	0	6.4	12.8	12.8	12.8
Rangia cuneata	172.8	256	563.2	211.2	275.2	153.6	236.8	224	115.2	115.2	160
Ischadium recurvum	0	0	0	0	0	0	0	0	0	0	0
Mytilopsis leucophaeata	12.8	0	0	25.6	0	0	0	0	6.4	0	0
Amphicteis floridus	0	0	0	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	6.4	0	0	6.4	6.4	12.8	0	0	0	6.4	6.4
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	480	736	217.6	32	608	185.6	294.4	268.8	44.8	192	268.8
Streblospio benedicti	345.6	230.4	838.4	1043.2	128	755.2	678.4	544	979.2	192	83.2
Polydora cornuta	0	12.8	0	0	0	0	0	0	0	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereidae	0	0	12.8	0	0	0	0	0	0	0	0
Neanthes succinea	6.4	12.8	0	12.8	0	6.4	6.4	0	0	0	0
Eteone heteropoda	0	0	0	0	0	0	0	0	0	0	0
Naididae sp.	57.6	89.6	76.8	268.8	38.4	204.8	313.6	313.6	339.2	377.6	38.4
Amphipoda	0	0	12.8	12.8	6.4	25.6	19.2	57.6	25.6	44.8	0
Gammaridea	0	0	0	0	0	0	0	0	0	0	0

Table 2- 10 (continued)

Station											
Taxon	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Ameroculodes spp complex	44.8	0	25.6	0	38.4	12.8	32	12.8	12.8	0	0
Leptocheirus plumulosus	204.8	19.2	140.8	0	134.4	83.2	217.6	633.6	44.8	646.4	211.2
Gammarus sp.	121.6	0	0	0	6.4	0	0	0	0	0	0
Melitadae	0	0	0	0	0	0	0	0	0	0	0
Melita nitida	0	6.4	6.4	44.8	12.8	6.4	12.8	32	6.4	76.8	25.6
Corophiidae	0	0	0	12.8	0	0	0	0	0	0	0
Apocorophium lacustre	268.8	6.4	6.4	0	0	0	0	6.4	12.8	0	6.4
Cyathura polita	428.8	422.4	396.8	377.6	352	345.6	192	204.8	320	198.4	268.8
Edotea triloba	0	0	0	0	0	0	0	0	0	0	0
Chiridotea almyra	**38.4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Ciripedia	0	0	0	0	0	0	0	0	0	0	0
Balanus improvisus	0	0	0	0	0	0	0	0	0	0	0
Balanus subalbidus	0	0	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	12.8	38.4	0	51.2	0	0	0	0	12.8	0	0
Membranipora sp	+	+	+	+	0	+	+	+	+	0	0
Chironomidae	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	6.4	6.4	0	0	25.6	19.2	0	12.8	6.4
Procladius sp.	0	0	0	12.8	0	0	0	6.4	0	0	0
Cryptochironomus sp.	0	0	0	0	0	0	0	0	0	0	0
Chironominae	0	0	0	0	0	0	0	0	0	0	0
Gammmaridae	0	0	0	0	0	0	0	0	0	0	0
Copepoda	0	0	0	0	0	0	0	0	0	0	0
Gobiosoma bosci	0	0	0	6.4	0	0	0	0	0	0	0
Mysidacea	0	0	0	0	0	0	0	6.4	0	0	0
Cassidinea ovalis	0	0	6.4	0	0	0	0	0	0	6.4	0

Note: Presence of *Membranipora* sp. is indicated by +

Table 2- 10 (continued)

Station											
Taxon	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Odonata	0	0	0	0	0	0	0	0	0	0	0
Chaoboridae	0	0	0	12.8	0	0	0	0	0	0	0
Hydrobiidae	0	0	0	0	0	0	0	0	0	0	0
Terrestrial Collembola	0	0	0	0	0	0	0	0	0	0	0
Oribatida sp.	0	0	0	0	0	0	0	0	0	0	0
Hydrozoa	0	0	0	0	0	0	0	0	0	0	0
Culicidae pupae	0	0	0	0	0	0	0	0	0	0	0

Table 2- 11: Average number of individuals collected per square meter at each station during the HMI Year 30 late summer sampling, September 2011, stations MDE-27 to MDE-51. Taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

	Station										
Taxon	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Nemata	204.8	294.4	32	0	364.8	19.2	6.4	102.4	25.6	0	0
Carinoma tremaphoros	25.6	0	19.2	128	115.2	38.4	44.8	76.8	12.8	6.4	128
Bivalvia	6.4	0	153.6	12.8	0	0	0	0	0	0	0
Macoma sp.	0	0	0	0	0	0	0	0	0	0	0
Macoma balthica	0	0	0	0	0	0	0	0	0	0	25.6
Macoma mitchelli	6.4	0	0	19.2	0	6.4	19.2	0	6.4	6.4	19.2
Rangia cuneata	64	57.6	2393.6	3078.4	537.6	83.2	326.4	134.4	76.8	64	224
Ischadium recurvum	0	0	6.4	0	0	0	0	0	0	0	0
Mytilopsis leucophaeata	0	0	2649.6	2201.6	19.2	0	0	0	0	0	0
Amphicteis floridus	0	0	0	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	0	0	0	6.4	0	0	6.4	0	0	6.4	25.6
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	780.8	204.8	492.8	1267.2	1113.6	51.2	352	211.2	12.8	89.6	211.2
Streblospio benedicti	1120	166.4	441.6	704	940.8	211.2	281.6	1145.6	838.4	172.8	633.6
Polydora cornuta	0	0	0	0	0	0	0	0	0	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereidae	0	0	0	0	0	0	0	0	0	0	0
Neanthes succinea	12.8	0	0	19.2	0	0	0	0	0	19.2	0
Eteone heteropoda	0	0	0	0	0	0	0	0	0	0	0
Naididae sp.	1107.2	96	70.4	147.2	300.8	211.2	185.6	736	307.2	0	2739.2
Amphipoda	51.2	89.6	121.6	12.8	64	12.8	19.2	19.2	19.2	32	0
Gammaridea	0	0	6.4	44.8	0	0	0	0	0	0	0

Table 2- 11: (continued)

Taxon	Station										
	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Ameroculodes spp complex	0	0	0	19.2	12.8	0	44.8	6.4	19.2	19.2	19.2
Leptocheirus plumulosus	1100.8	633.6	704	659.2	928	377.6	121.6	352	512	608	57.6
Gammarus sp.	0	0	38.4	64	6.4	115.2	57.6	0	6.4	19.2	6.4
Melitadae	0	0	0	0	0	0	0	0	0	0	0
Melita nitida	0	6.4	19.2	44.8	12.8	38.4	6.4	12.8	76.8	6.4	6.4
Corophiidae	0	0	38.4	0	0	0	0	0	0	0	0
Apocorophium lacustre	6.4	0	2528	326.4	12.8	6.4	12.8	6.4	6.4	0	0
Cyathura polita	396.8	172.8	192	710.4	467.2	256	307.2	192	108.8	236.8	473.6
Edotea triloba	0	0	0	0	0	0	0	0	0	12.8	0
Chiridotea almyra	**0**	**0**	**19.2**	**19.2**	**0**	**0**	**0**	**0**	**0**	**6.4**	**0**
Ciripedia	0	0	0	0	0	0	0	0	0	0	0
Balanus improvisus	0	0	0	0	0	0	0	0	0	0	0
Balanus subalbidus	0	0	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	0	0	0	6.4	6.4	0	0	19.2	0	0	0
Membranipora sp	+	0	0	0	+	0	+	+	+	0	0
Chironomidae	0	0	0	0	6.4	0	0	0	0	0	0
Coelotanypus sp.	51.2	57.6	0	0	19.2	19.2	0	0	51.2	0	0
Procladius sp.	0	0	0	0	32	0	0	0	6.4	0	6.4
Cryptochironomus sp.	6.4	0	0	0	0	0	0	0	0	0	0
Chironominae	6.4	0	0	0	0	0	0	0	0	0	0
Gammmaridae	0	0	0	0	0	0	0	0	0	0	0
Copepoda	0	0	0	0	0	0	0	0	0	0	0
Gobiosoma bosci	0	0	0	0	0	0	0	0	0	0	0
Mysidacea	0	0	0	0	6.4	0	0	0	6.4	0	6.4
Cassidinea ovalis	0	0	0	0	0	0	0	0	0	0	0

Note: Presence of *Membranipora* sp. is indicated by +

Table 2- 11: (continued)

Station											
Taxon	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Odonata	0	0	0	0	0	0	6.4	0	0	0	0
Chaoboridae	0	0	0	0	0	6.4	0	0	6.4	0	0
Hydrobiidae	0	0	19.2	0	0	0	0	0	0	0	0
Terrestrial Collembola	6.4	0	0	0	0	0	0	0	0	0	0
Oribatida sp.	0	0	0	0	0	0	0	6.4	0	0	0
Hydrozoa	0	0	12.8	0	0	0	0	0	0	0	0
Culicidae pupae	0	0	0	0	0	0	0	6.4	0	0	0

Table 2- 12: Average number of individuals collected per square meter at each station during the HMI Year 30 spring sampling, April 2012, stations MDE-1 to MDE-22. Taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

Taxon	Station										
	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Nemata	25.6	32	51.2	12.8	12.8	25.6	121.6	89.6	38.4	352	0
Carinoma tremaphoros	0	25.6	32	32	44.8	38.4	6.4	12.8	38.4	44.8	70.4
Bivalvia	0	0	0	0	0	0	6.4	0	0	0	0
Macoma sp.	0	0	0	0	0	0	0	0	0	0	0
Macoma balthica	0	0	6.4	0	25.6	0	6.4	0	0	12.8	76.8
Macoma mitchelli	0	0	0	0	0	0	0	0	0	0	12.8
Rangia cuneata	25.6	300.8	140.8	108.8	160	38.4	51.2	32	140.8	0	19.2
Ischadium recurvum	6.4	0	0	0	0	0	0	0	0	0	0
Mytilopsis leucophaeata	89.6	64	0	6.4	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	0	6.4	0	0	19.2	0	6.4	0	6.4	0	0
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	**160**	**377.6**	**64**	**128**	**262.4**	**96**	**230.4**	**665.6**	**140.8**	**140.8**	**217.6**
Streblospio benedicti	0	12.8	6.4	0	6.4	51.2	6.4	0	12.8	140.8	204.8
Polydora cornuta	0	0	0	6.4	0	0	0	0	0	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereidae	19.2	0	0	0	0	0	0	0	0	0	0
Neanthes succinea	57.6	0	0	0	12.8	0	0	0	0	0	0
Naididae sp.	921.6	454.4	217.6	281.6	416	204.8	179.2	230.4	300.8	505.6	1164.8
Amphipoda	147.2	0	0	0	12.8	6.4	6.4	0	19.2	25.6	12.8
Gammaridea	0	6.4	0	6.4	0	0	0	0	0	12.8	0
Ameroculodes spp. complex	0	6.4	25.6	6.4	38.4	19.2	19.2	6.4	12.8	0	12.8
Leptocheirus plumulosus	0	19.2	102.4	32	12.8	64	121.6	160	102.4	224	230.4

Table 2- 12: (continued)

Station											
Taxon	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Gammaridae	0	0	0	0	0	0	0	0	0	0	0
Gammarus sp	108.8	57.6	0	19.2	6.4	6.4	25.6	19.2	38.4	6.4	0
Melitadae	6.4	6.4	0	6.4	0	0	0	0	6.4	0	0
Melita nitida	275.2	128	6.4	19.2	6.4	6.4	6.4	19.2	6.4	44.8	19.2
Corophiidae	6.4	6.4	0	0	0	0	0	6.4	6.4	0	0
Apocorophium sp.	0	0	0	0	0	0	0	0	0	0	0
Apocorophium lacustre	345.6	192	6.4	32	0	0	12.8	51.2	44.8	0	0
Cyathura polita	57.6	275.2	262.4	172.8	230.4	89.6	89.6	160	230.4	89.6	160
Edotea triloba	0	0	0	0	0	0	0	0	0	0	0
Chiridotea almyra	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Balanus improvisus	256	108.8	0	0	0	0	0	0	0	0	0
Balanus subalbidus	51.2	0	0	0	0	0	0	0	0	0	0
Balanus sp. A	313.6	192	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	153.6	44.8	0	12.8	25.6	0	12.8	0	0	0	0
Membranipora sp	+	+	+	+	+	0	+	+	+	+	+
Chironomidae	32	19.2	0	0	6.4	0	0	0	0	0	0
Chironominae	0	6.4	6.4	0	0	0	0	6.4	0	0	0
Tanypodinae	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	0	6.4	0	0	6.4	12.8	6.4	12.8	0
Procladius sp.	0	12.8	6.4	6.4	19.2	12.8	0	12.8	6.4	0	6.4
Tanytarsini	172.8	108.8	0	6.4	0	0	0	0	0	0	0
Rheotanytarsus sp.	172.8	25.6	0	0	6.4	0	0	6.4	0	0	0

Note: Presence of Copepoda and *Membranipora* sp. is indicated by +

Table 2- 12: (continued)

Taxon	Station										
	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Polypedillum sp.	0	0	0	0	0	0	0	0	0	0	0
Cryptochironomus sp.	0	0	0	0	0	0	0	12.8	0	0	0
Chironomus sp.	0	0	0	0	0	0	0	6.4	0	6.4	0
Harnischia sp.	0	6.4	0	0	0	0	0	6.4	0	0	0
Thienemanniella sp.	12.8	0	0	0	0	0	0	0	0	0	0
Nanocladius sp.	25.6	19.2	0	0	0	0	0	0	0	0	0
Brillia sp.	6.4	0	0	0	0	0	0	0	0	0	0
Copepoda	0	0	0	0	0	0	0	0	0	0	0
Ostracoda	0	0	0	0	0	0	0	0	0	0	0
Mysidacea	0	0	0	0	0	0	0	0	0	0	0
Gyratrix hermaphrodites	0	0	0	0	0	0	0	0	0	0	0
Cladocera	0	0	0	0	0	0	0	0	0	0	0
Eteone heteropoda	0	0	0	0	0	0	0	0	0	0	0
Cassidinea ovalis	64	6.4	0	6.4	0	0	0	0	0	0	0
Hydrozoa	38.4	25.6	0	0	12.8	0	6.4	12.8	0	0	0
Pisicola sp.	0	0	0	0	0	0	0	0	0	0	0
Gobiosoma bosci	12.8	0	0	0	0	0	0	0	0	0	0

Table 2- 13: Average number of individuals collected per square meter at each station during the HMI Year 30 spring sampling, April 2012, stations MDE-27 to MDE-51. Taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

Taxon	Station										
	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Nemata	876.8	595.2	38.4	6.4	697.6	121.6	12.8	486.4	192	0	0
Carinoma tremaphoros	38.4	0	12.8	6.4	0	70.4	25.6	19.2	19.2	25.6	102.4
Bivalvia	0	0	0	0	0	0	12.8	0	0	0	0
Macoma sp.	0	0	0	0	0	0	0	0	0	0	0
Macoma balthica	0	0	0	0	0	25.6	6.4	0	0	0	102.4
Macoma mitchelli	0	0	0	0	0	0	0	0	0	0	6.4
Rangia cuneata	6.4	0	76.8	96	83.2	6.4	51.2	19.2	70.4	51.2	57.6
Ischadium recurvum	0	0	0	0	0	0	0	0	0	0	0
Mytilopsis leucophaeata	0	0	6.4	6.4	6.4	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	0	6.4	0	0	12.8	0	0	6.4	0	38.4	0
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	**230.4**	**76.8**	**96**	**134.4**	**1068.8**	**108.8**	**243.2**	**345.6**	**646.4**	**544**	**332.8**
Streblospio benedicti	204.8	0	0	0	0	70.4	64	108.8	32	6.4	166.4
Polydora cornuta	0	0	0	0	0	0	0	0	0	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereidae	0	0	0	0	0	0	0	0	0	0	0
Neanthes succinea	0	0	12.8	0	0	0	0	0	0	0	0
Naididae sp.	7801.6	390.4	102.4	0	307.2	556.8	627.2	1638.4	390.4	44.8	1356.8
Amphipoda	6.4	25.6	6.4	0	0	0	0	57.6	0	0	0
Gammaridea	6.4	0	6.4	0	0	0	19.2	6.4	6.4	0	0
Ameroculodes spp. complex	19.2	0	32	70.4	6.4	6.4	25.6	6.4	6.4	12.8	19.2
Leptocheirus plumulosus	300.8	172.8	57.6	166.4	96	172.8	140.8	441.6	160	76.8	64

Table 2- 13: (continued)

Taxon	Station										
	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Gammaridae	0	0	0	0	0	0	0	0	0	0	0
Gammarus sp	6.4	6.4	38.4	19.2	6.4	0	64	339.2	0	0	6.4
Melitadae	0	0	0	0	0	0	0	6.4	0	0	0
Melita nitida	32	6.4	12.8	0	0	12.8	6.4	192	12.8	0	0
Corophiidae	0	0	0	0	0	0	0	0	0	0	0
Apocorophium sp.	0	0	0	0	0	0	0	0	0	0	0
Apocorophium lacustre	0	0	83.2	6.4	19.2	12.8	6.4	25.6	6.4	0	0
Cyathura polita	153.6	57.6	57.6	57.6	288	83.2	166.4	64	83.2	160	332.8
Edotea triloba	0	0	0	0	0	0	0	0	0	0	6.4
Chiridotea almyra	**0**	**0**	**0**	**25.6**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Balanus improvisus	0	0	0	0	0	0	0	0	0	0	0
Balanus subalbidus	0	0	0	0	0	0	0	0	0	0	0
Balanus sp. A	0	0	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	0	0	0	0	0	0	0	0	6.4	0	0
Membranipora sp	0	0	0	0	0	0	+	0	+	0	0
Chironomidae	6.4	0	0	0	0	0	0	19.2	6.4	0	0
Chironominae	0	0	0	0	0	0	0	6.4	0	0	0
Tanypodinae	0	0	0	0	6.4	0	0	0	0	0	0
Coelotanypus sp.	128	19.2	0	0	0	0	0	25.6	19.2	0	0
Procladius sp.	12.8	0	0	0	64	6.4	6.4	6.4	6.4	0	6.4
Tanytarsini	0	0	6.4	0	0	0	0	0	0	0	0
Rheotanytarsus sp.	0	0	0	0	0	0	0	0	0	0	0

Note: Presence of Copepoda and *Membranipora* sp. is indicated by +

Table 2- 13: (continued)

Taxon	Station										
	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Polypedillum sp.	6.4	0	0	0	0	0	0	0	0	0	0
Cryptochironomus sp.	44.8	0	0	6.4	6.4	12.8	0	6.4	12.8	12.8	0
Chironomus sp.	6.4	0	0	0	0	0	0	51.2	0	0	0
Harnischia sp.	0	0	0	0	0	6.4	0	0	6.4	0	0
Thienemanniella sp.	0	0	0	0	0	0	0	0	0	0	0
Nanocladius sp.	0	0	0	0	0	0	0	0	0	0	0
Brillia sp.	0	0	0	0	0	0	0	0	0	0	0
Copepoda	+	0	0	0	0	0	0	+	0	0	0
Ostracoda	0	0	0	0	0	0	0	89.6	0	0	0
Mysidacea	0	0	0	0	0	0	0	0	0	0	0
Gyratrix hermaphrodites	0	0	0	6.4	0	0	0	0	0	0	0
Cladocera	403.2	38.4	0	0	0	0	0	0	0	0	0
Eteone heteropoda	0	0	0	6.4	0	0	0	0	0	0	0
Cassidinea ovalis	0	0	0	0	0	0	0	0	0	0	0
Hydrozoa	0	0	0	0	0	0	0	172.8	0	0	0
Pisicola sp.	6.4	0	0	0	0	0	0	0	0	0	0
Gobiosoma bosci	0	0	0	0	0	0	0	0	0	0	0

Infaunal Taxa Abundance

Average total infaunal abundance was higher in the fall (September 2011) than in the spring (April 2012). Typically spring abundance is much higher than the fall due to recruitment. This trend has been repeated in each of the past 13 years (excluding Year 23, which had an unusually large winter die-off of *R. cuneata*). In Year 30 the lower spring abundance is primarily due to low recruitment of many of the taxa, particularly *M. viridis*, whose abundance was about 15% of its historic mean. In September 2011, total infaunal abundance ranged from 1,107.2 to 7,206.4 organisms per square meter (individuals/m^2) and averaged 2,723.2 individuals/m^2 . The highest September 2011 abundance was found at the Nearfield station MDE-34, due primarily to large numbers of *M. viridis*, *R. cuneata*, and *M. leucopheata*. The lowest infaunal abundance in September 2011 was found at the Reference station MDE-22. The average total infaunal abundance was highest at Back River/Hawk Cove stations (3,046.4 individuals/m^2) followed by Nearfield stations (2,870.9 individuals/m^2), Reference stations (2,667.5 individuals/m^2), and South Cell Exterior Monitoring stations (2,018.6 individuals/m^2) in September. Based on station type, no trend of increasing/decreasing abundances associated with distance from HMI could be discerned. However, Nearfield stations MDE-33 and MDE-34 had especially high abundances, driven by large numbers of the bivalve, *R. cuneata*. These two stations are in close proximity, located off the northeast corner of the North Cell. The 30-year mean (4,756.7 individuals/m^2) of fall abundance for the Back River stations is much higher than the Reference (1,953.3individuals/m^2) and Nearfield (2,210.8 individuals/m^2) means. Mean abundance in the South Cell stations has an eight-year average of 1,359.3 individuals/m^2.

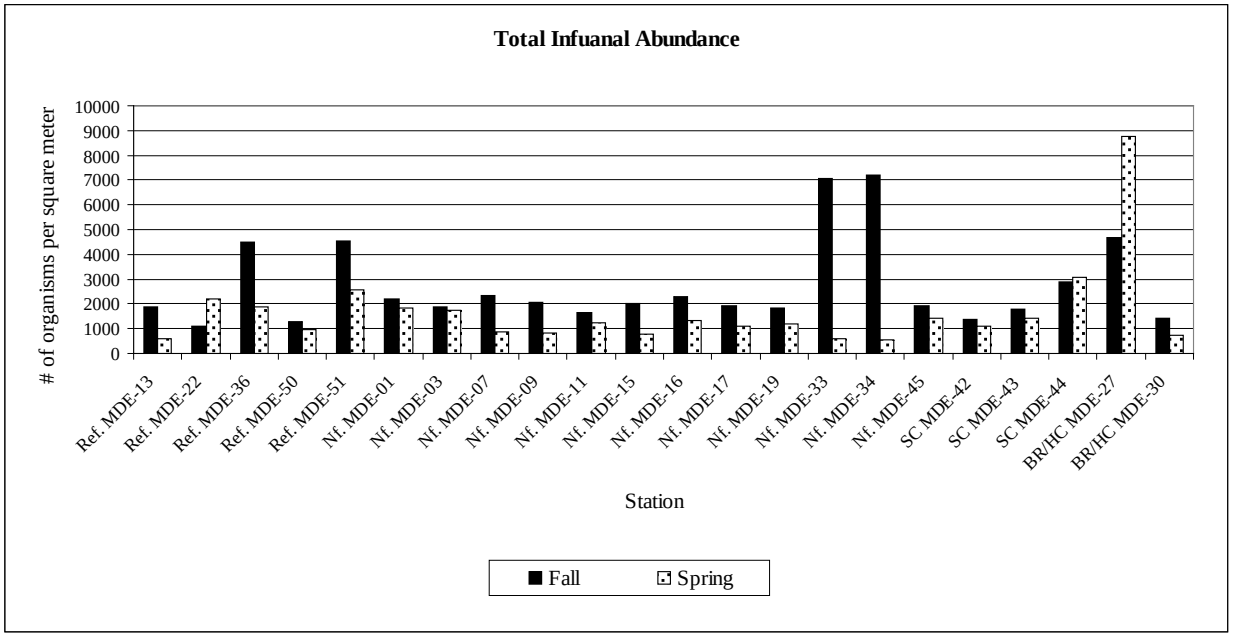

Figure 2- 2: Total abundance of infaunal taxa collected at each HMI station in Year 30, September 2011 and April 2012 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

In April 2012, total infaunal abundance ranged from 563.2 to 8,774.4 individuals/m^2 and averaged 1,674.2 individuals/m^2. The station with the highest abundance was the Back River/Hawk Cove station MDE-27, due primarily to a large number of worms of the family Naididae. The lowest spring abundance occurred at the Nearfield station MDE-34. This was due to depressed abundances of many common species (, 2-12) and a sharp drop in the bivalve *R. cuneata*, which had been found in unusually high numbers in the previous fall. The average total infaunal abundance was lowest at Nearfield stations (1,124.8 individuals/m^2), followed by Reference stations (1,638.4 individuals/m^2), South Cell Exterior Monitoring stations (1,877.3 individuals/m^2), and highest at Back River/Hawk Cove stations (4,755.2 individuals/m^2). No consistent trend of increasing/decreasing abundances associated with distance from HMI could be discerned. Comparisons of mean spring station type abundances to historical averages were not made due to historically high variable and often intense spring recruitment.

Total infaunal abundance and epifaunal abundance are subsets of total abundance. Infaunal abundance excludes certain organisms that have been omitted from the calculation of the B-IBI (see *Methods*). In Year 30, total infaunal abundance was similar to total abundance, typically accounting for ≥85 percent of all organisms at all stations during both seasons. This ratio is historically typical for this project.

Diversity

Species diversity was examined using the Shannon-Wiener Diversity Index (SWDI), which measures diversity on a numerical scale from zero to four. A lower score indicates an unbalanced benthic community dominated by only one or two species whereas a higher score suggests a balanced, diverse benthic community. Pfitzenmeyer et al. (1982) suggested that diversity, as measured by SWDI, would be higher in the summer when recruitment decreased and predation increased as opposed to spring, thus reducing the numbers of the dominant taxa. Correspondingly, diversity has often been lowest at most stations in spring (April or May) due to an influx of juveniles, especially of the dominant species (Duguay et al. 1998, Duguay et al. 1995a, Duguay et al. 1995b, Duguay 1992, Duguay 1990, Pfitzenmeyer and Tenore 1987). Diversity values for Year 30 are presented in and 2-9. In Year 30, SWDI was calculated in spring for general seasonal comparisons, but is not analyzed further in this report.

SWDI values in Year 30 averaged 2.45± 0.27 in September 2011. The fall average diversity of 2.45 was slightly higher than the 14-year mean fall diversity of 2.30. The lowest diversity value in September 2011 occurred at Reference station MDE-51 (1.98). This was due to the large percentage of Naididae worms, which accounted for 60 percent of total infaunal abundance at this station. The highest September 2011 diversity value (3.01) occurred at Nearfield station MDE-01.

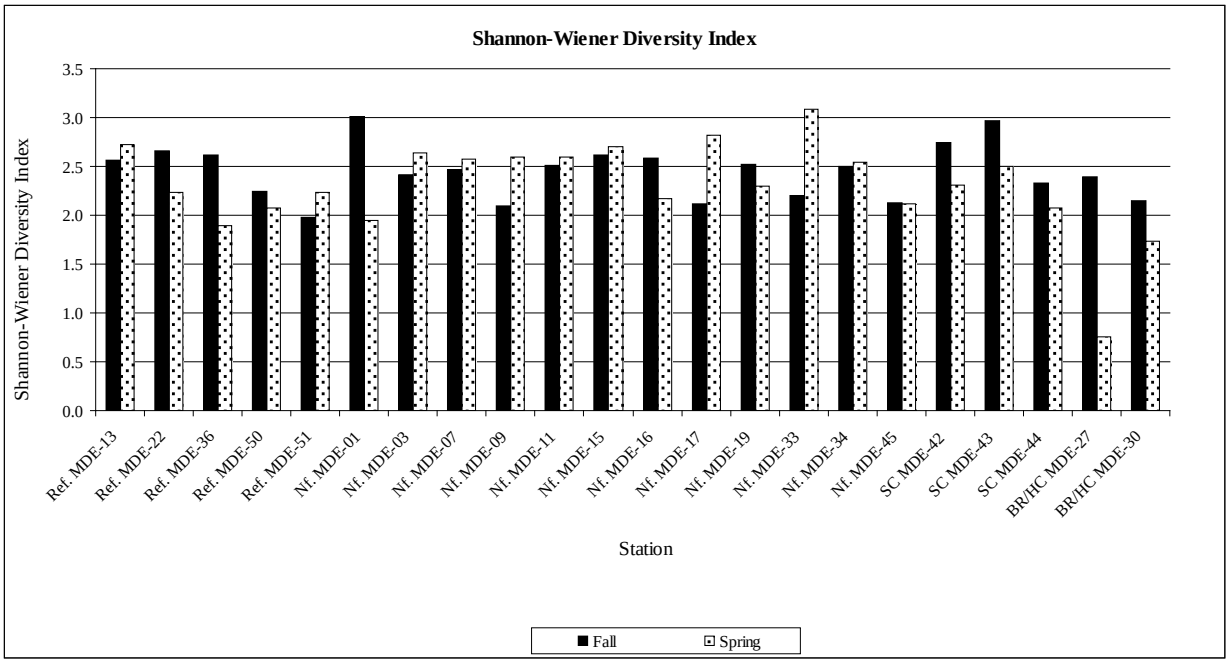

Figure 2- 3: Shannon-Wiener Diversity Index (SWDI), HMI Year 30, September 2011 and April 2012 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell; BR/HC = Back River Hawk Cove).

On average, Nearfield stations had diversity values similar to Reference stations in September 2011. Comparing station types from the fall only, the lowest average SWDI was 2.28 at the Back River/Hawk Cove stations followed by the Reference stations at 2.41, and Nearfield stations at 2.43. The highest average SWDI occurred at the South Cell Exterior Monitoring stations at 2.68. Historically, the 24-year mean SWDI values, ranked from lowest to highest, are associated with the following station types: Back River/Hawk Cove (2.14), Nearfield (2.34), Reference (2.40), and South Cell Exterior Monitoring (2.58, n=8 yrs). No trend of increasing/decreasing diversity associated with distance from HMI could be discerned.

Pollution Sensitive Taxa Abundance (PSTA)

Two taxa found during the September 2011 and April 2012 sampling cruises were designated as "pollution-sensitive" according to Alden et al. (2002). These were the polychaete worm *M. viridis* and the isopod crustacean *C. almyra.* The calculation of the PSTA is a ratio of the relative PSTA abundance to total infaunal abundance.

Small changes in salinity (causing conditions to be either above or below 5.0 ppt) can greatly affect the sensitivity/tolerance designation of several organisms, and correspondingly alter calculated abundances. Because this metric is, in part, salinity driven, and salinity varies from year to year, salinity must be controlled for historical analyses of PSTA fall data. In Year 30, the fall salinity regime was oligohaline, the last time the fall salinity regime was oligohaline was Year 25.

In Year 30, pollution sensitive taxa occurred at all station types. In September 2011, PSTA ranged from 0.66 percent at MDE-45 (Nearfield station) to 38.72 percent at MDE-03 (Nearfield station). The average PSTA for all stations in September 2011 was 13.98 percent. Comparing station types, the lowest average PSTA was 10.29 percent at the South Cell Exterior Monitoring stations, followed by the Reference stations at 14.20 percent, followed by the Nearfield stations at 14.55 percent. The highest average PSTA was 15.56 percent at Back River/Hawk Cove stations. Historically, the 30-year mean fall PSTA values, ranked from lowest to highest, are associated with the following station types: South Cell Exterior Monitoring (27.83 percent, n=7 years), Back River/Hawk Cove (30.63 percent), Nearfield (38.46 percent), and Reference (41.87 percent).

In April 2012, PSTA ranged from 2.63 percent at MDE-27 (Back River/Hawk Cove station) to 56.67 percent at MDE-50 (Reference station - 9). The average PSTA for all stations in April 2012 was 21.45 percent. Comparing station types, the lowest average PSTA was 6.53 percent at the Back River/Hawk Cove stations, followed by the South Cell Exterior Monitoring stations at 12.63 percent, followed by the Nearfield stations at 22.42 percent. The highest average PSTA was 30.39 percent at Reference stations.

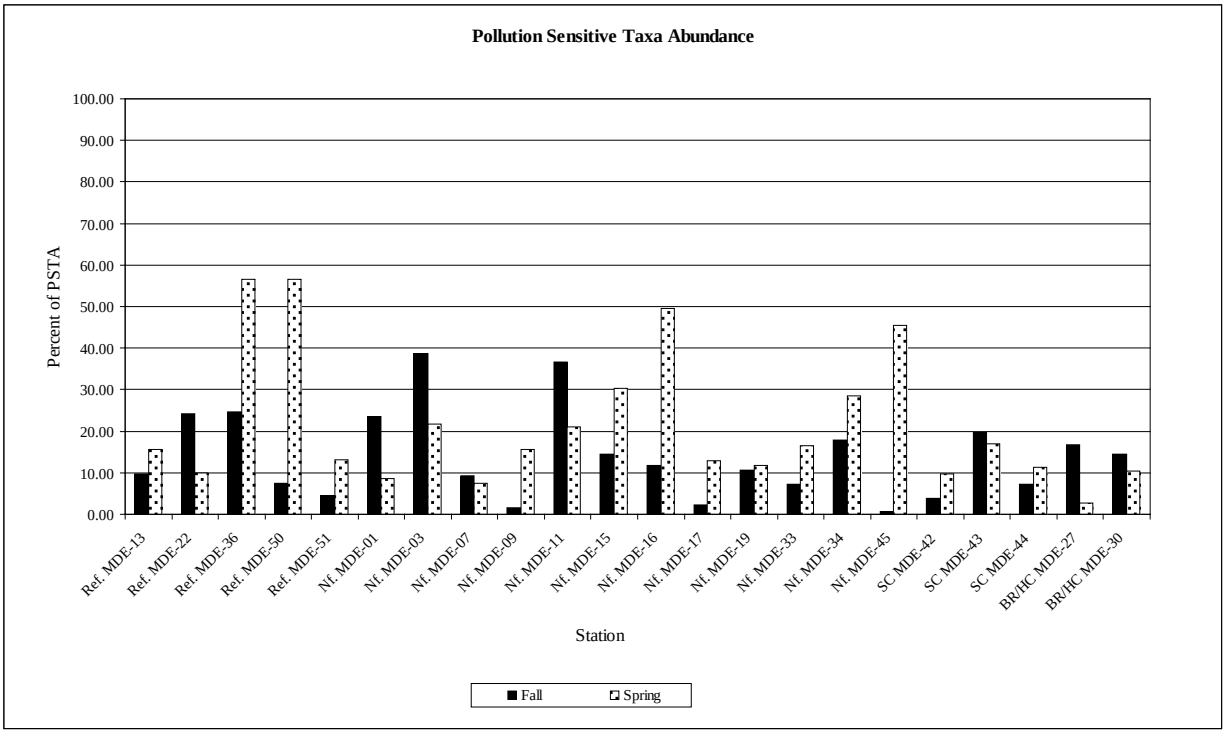

Figure 2- 4: Percent abundance comprised of pollution sensitive species (PSTA), HMI Year 30 September 2011 and April 2012 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

Pollution Indicative Taxa Abundance (PITA)

Eight taxa found during the September 2011 sampling of Year 30 benthic monitoring were designated as "pollution-indicative" according to Alden et al. (2002): the Chironomids *Coelotanypus* sp., *Procladius* sp., the polychaete worms *S. benedicti*, *H. filiformis*, *N. succinea*, and *P. cornuta*, the amphipod *L. plumulosus,* and oligochaete worms of the family Naididae. Ten taxa found during the April 2012 sampling cruise were designated as "pollution-indicative" according to Alden et al. (2002): the Chironomids *Coelotanypus* sp., *Chironomus* sp., *Polypedillum* sp., *Procladius* sp., the polychaete worms *S. benedicti*, *H. filiformis*, *N. succinea*, and *P. cornuta*, the amphipod *L. plumulosus*, and oligochaete worms of the family Naididae. The calculation of the PITA is a ratio of the relative PITA abundance to total infaunal abundance.

In Year 30, pollution indicative taxa occurred at all station types. In September, the PITA ranged from 7.27 percent at MDE-33 (Nearfield station) to 74.61 percent at MDE-51 (Reference station). The average PITA for all stations in September 2011 was 36.43 percent. Comparing station types, the lowest average PITA was 35.24 percent at the Nearfield stations, followed by 35.78 percent at the Back River/Hawk stations, and 36.57 percent at Reference stations. The highest average PITA occurred at the South Cell Exterior Monitoring stations at 41.40 percent. Historically, the 30-year mean fall PITA values, ranked lowest to highest, are associated with the following station types:

Reference (21.37 percent), Nearfield (23.57 percent), South Cell Exterior Monitoring (36.83 percent, n = 8 years) and, Back River/Hawk Cove (36.95 percent).

In April 2012, the lowest PITA was 17.33 percent at MDE-50 (Reference station) and the highest was 96.43 percent at MDE-27 (Back River/Hawk Cove station - 2-9). The average PITA for all stations in April was 50.14 percent. Nearfield stations had the lowest average PITA at 40.75 percent, followed by the Reference stations at 46.62 percent, and the South Cell Exterior Monitoring stations at 68.22; the Back River/Hawk Cove had the highest average PITA of 88.21 percent.

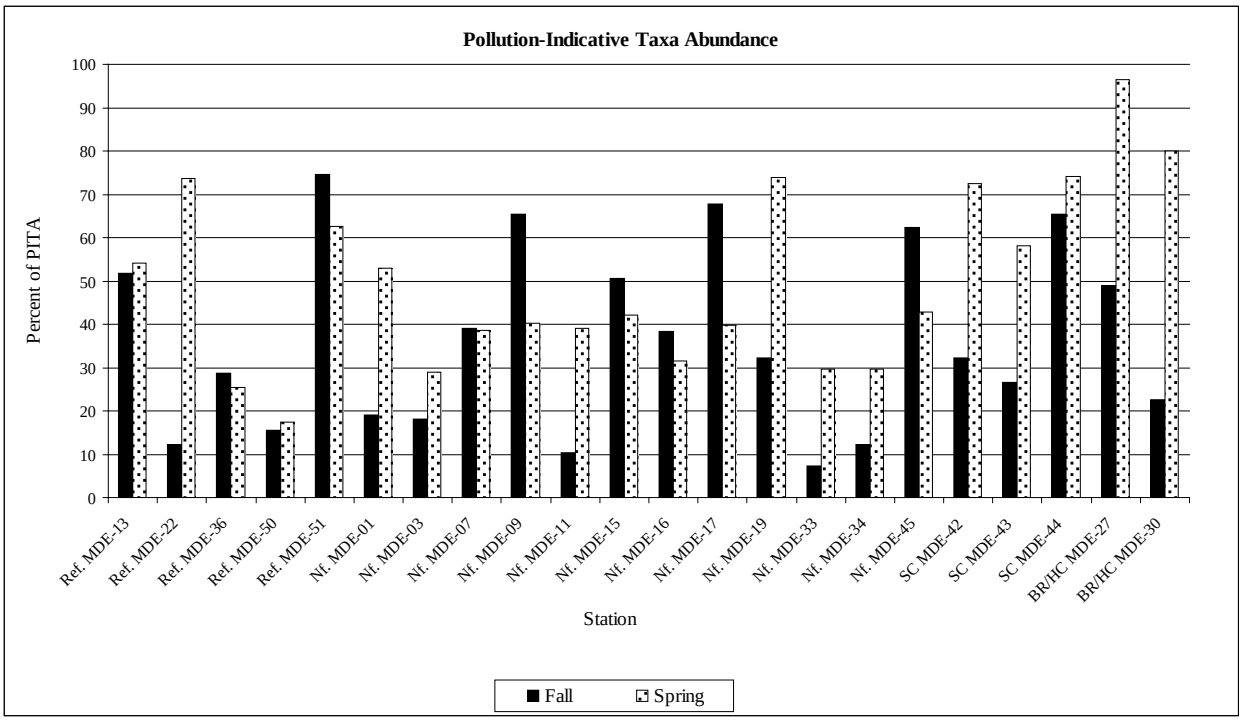

Figure 2- 5: Percent abundance comprised of pollution indicative species (PITA), HMI Year 30 September 2011 and April 2012 grouped by station type (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

Benthic Index of Biotic Integrity

The B-IBI was calculated for all stations based on September 2011 data only (see *Methods and Materials*). Six metrics were used to calculate the B-IBI for stations under the oligohaline classification (0.5 - 5 ppt). These metrics were total infaunal abundance, relative abundance of pollution-indicative taxa, relative abundance of pollution-sensitive taxa, tolerance score, abundance of carnivores and omnivores, and Tanypodinae to Chironomidae abundance ratio. The specific scoring criteria for the oligohaline metrics are presented in. The B-IBI was developed as a benchmark to determine whether any given benthic sample taken from the Bay either approximates (B-IBI score = 5), deviates

slightly (B-IBI score = 3), or deviates greatly (B-IBI score = 1) from conditions at the best Reference sites (Weisberg et al., 1997). A B-IBI score greater than or equal to 3.0 represents a benthic community that is not considered stressed by *in situ* environmental conditions. The 22 benthic stations studied during Year 30 were compared to this benchmark.

Table 2-14: Oligohaline scoring criteria for measures used in calculating the Chesapeake Bay B-IBI in September 2011 (Weisberg et al. 1997).

Measure	Score		
	5	3	1
Total Abundance (individuals per square meter)	≥ 450-3350	180-450 **or** > 3350-4050	< 180 **or** ≥ 4050
% Pollution-indicative Taxa	≤ 27%	27-95%	> 95%
% Pollution-sensitive Taxa	≥26%	0.2-26%	<0.2%
% Abundance of carnivores and omnivores	≥35%	15-35%	<15%
Tolerance Score	≤6	6-9.05	>9.05
% Tanypodinae to Chironomidae abundance ratio	≤17%	17-64%	>64%

Compared to Year 29, individual station B-IBI Scores decreased at 9 stations, remained the same at 1, and increased at 12 stations. Twelve of the twenty-two stations met or exceeded the benchmark criteria of 3.0 in Year 30. In Year 30, Back River/Hawk Cove station MDE-27 (1.67), Reference stations MDE- 36 (2.00) and MDE-51 (1.67), Nearfield Stations MDE-15 (2.67), MDE-16 (2.67), MDE-19 (2.67), MDE-33 (2.60), MDE-34 (2.60), and MDE-45 (2.67), and South Cell Exterior Monitoring Station MDE-44 (2.60) failed to meet the benchmark criteria of 3.0. Sixteen stations were below their historic averages and six stations (three Nearfield, one South Cell Exterior Monitoring, one Back River/Hawk Cove, and one Reference) were above their historic averages for B-IBI. In addition to sixteen stations being below their historic average one was equal to a historic low (Nearfield station MDE-09). Three stations (Nearfield station MDE-16, Reference station MDE-51, and South Cell Exterior Monitoring station MDE-44) set new historic lows; however this is only the fourth year station MDE-51 has been sampled. No stations set new historic highs.

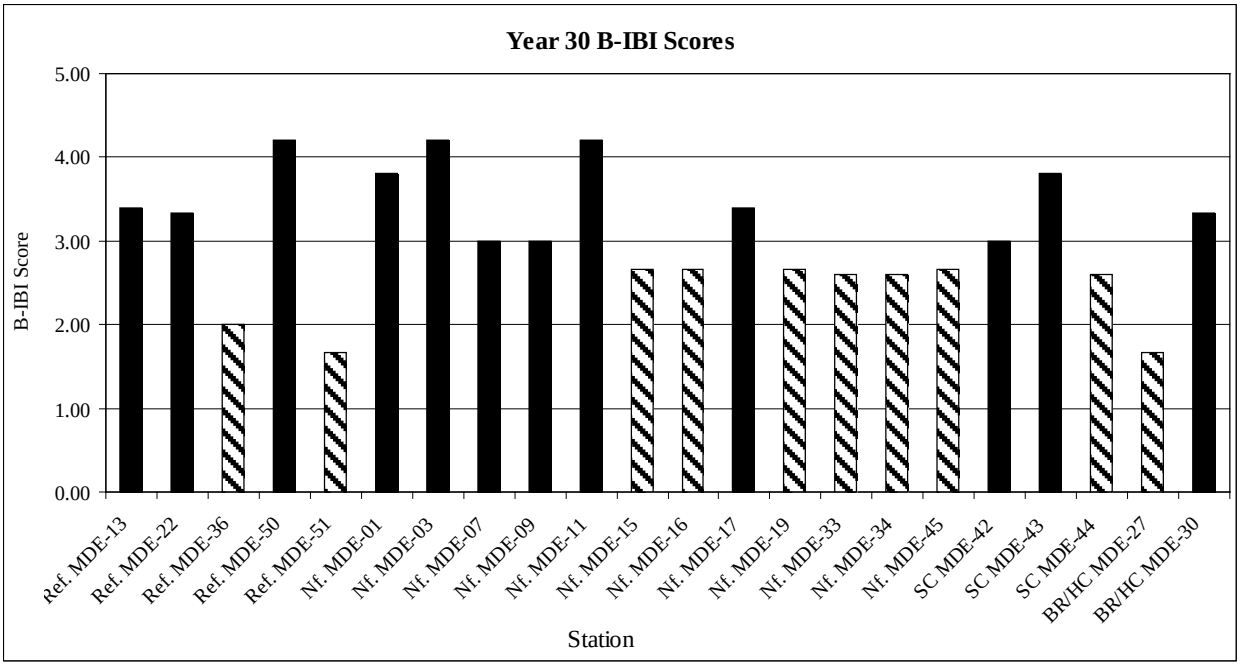

Figure 2- 6: B-IBI Scores for all stations in September 2011 grouped by station type (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

The mean B-IBI for Nearfield and South Cell Exterior Monitoring stations met or exceeded the benchmark of 3.0. The mean B-IBI for Back River/Hawk Cove and Reference stations failed to meet the benchmark of 3.0. Average B-IBI scores by station type are shown in. Compared to Year 29, the mean B-IBI decreased for all HMI station types. The Year 30 mean B-IBI's for all station types were below their historic averages (eight year average for South Cell Exterior Monitoring Stations).

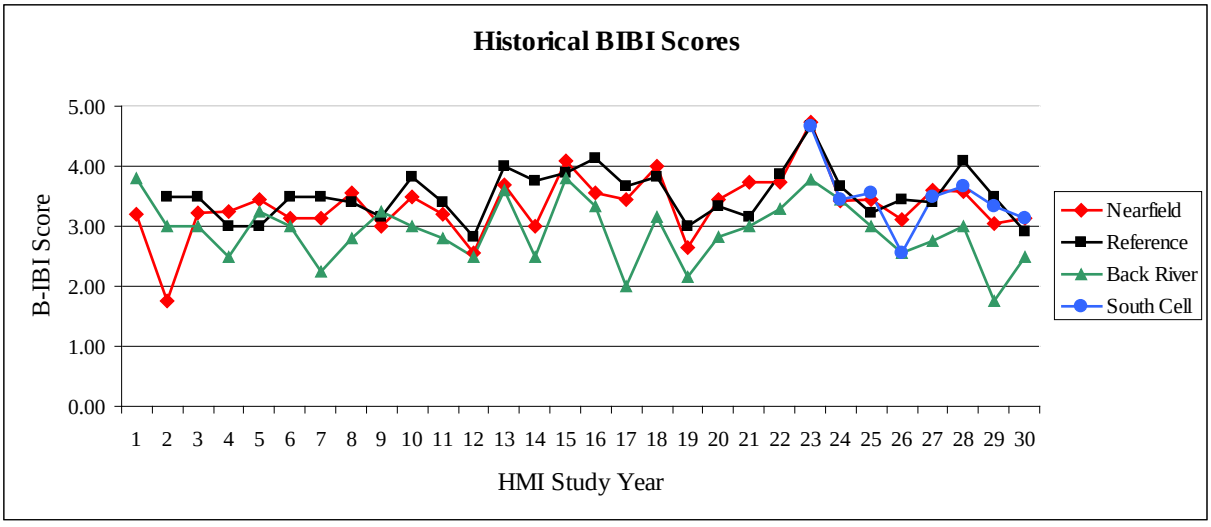

Figure 2- 7: Average B-IBI Scores at HMI for Monitoring Years 1-30.

There was no trend of increasing or decreasing B-IBI scores associated with proximity to HMI in Year 30. Back River/Hawk Cove stations had the lowest mean in Year 30 and have had the lowest average for 25 of 30 years. There is a group of contiguous stations, located near the South Cell outfall and former offloading dock that performed poorly in Year 30. This group consists of Nearfield stations MDE-15, MDE-16, MDE-19, and MDE-45, and South Cell Exterior Monitoring station MDE-44. These sites are closer to the island than the passing stations in the South Cell Exterior Monitoring group. This station cluster failed because of poor metric scores for Tanypodinae/Chironomidae ratio (midges) and % Carnivores and Omnivores. Midge presence always caused poor scores for the first metric. Depressed salinity around HMI increased the presence of midges and contributed to the poor scores for this station cluster. Low B-IBI scores were also attributable to below average abundances of the isopod, *Cyathura polita*, which is the primary organism contributing to the second metric. Of the seven stations with the lowest abundance for *C. polita*, five were found within this cluster. Lower salinity may have contributed to the reduced abundance for *C. polita* in this area. For comparison, *C. polita* was found at higher abundances at Site 92, where the salinity was nearly twice as high. Alternatively, explanations for this cluster of poorly performing stations could relate to conditions unique to the proximity to the dike or to the South Cell outfall and barge offloading dock.

The mean B-IBI for the cluster of contiguous stations near the South Cell outfall was 2.66 which is slightly more than the mean for the Back River/Hawk Cove stations (2.50) and less than the means for South Cell Exterior Monitoring (3.10), Nearfield (3.10), Reference (2.90), and Site 92 (3.80). Since Year 27, the year of the most recent station reconfiguration (incorporating the addition of MDE-45, 19 and 15), the four-year mean B-IBI for this station cluster is 3.11. This is lower than the four-year means for Nearfield stations (3.33), full set of South Cell Exterior Monitoring stations (3.41), and Reference stations (3.48). The mean B-IBI for this cluster is, however, still above 3 and only deviates slightly from undisturbed reference conditions. In this respect, the historic performance of this cluster is more comparable to the Nearfield, Reference, or South Cell Exterior Monitoring stations than the Back River/Hawk Cove station group, which, on average (2.50) shows greater deviation from undisturbed conditions.

To determine if the low performing benthic station cluster near the HMI outfall is statistically significant, it was further analyzed using Friedman's non-parametric ANOVA.

Clam Length Frequency Distribution

In September 2011, 1,488 *R. cuneata* were collected. The greatest average abundance of *R. cuneata* occurred at the Nearfield stations (100.50 clams/station), followed by the Reference stations (35.60 clams/station), the South Cell Exterior Monitoring stations (28.33 clams/station), and the Back River/Hawk Cove stations (9.50 clams/station). The greatest abundance of *R. cuneata* during the fall was found in the 1-5 and 6-10 mm size classes. In April 2011, 243 *R. cuneata* were collected. The greatest average abundance for this species occurred at the Nearfield stations (15.92

clams/station), followed by the Reference and South Cell Exterior Monitoring stations (7.80 and 4.00 clams/station, respectively), and the Back River/Hawk Cove stations (0.50 clam/station). The greatest abundance of *R. cuneata* during the spring was found in the 11-15 and 16-20 mm size classes.

Historically, *R. cuneata* tends to be the most abundant bivalve mollusk found in this benthic monitoring project. It is classified as pollution sensitive during higher salinity years (≥5ppt). The population has historically been very dynamic in terms of overall abundance and distribution by size or station type. The main drivers of *R. cuneata* variability appear to be temperature and salinity. In the Chesapeake Bay, this species exists at the northern extent of its range. Because of this, it is subject to high winter mortality during cold winters (Hopkins, et al., 1973). Additionally, ideal salinity conditions for reproduction and recruitment do not occur regularly. The reduction in *Rangia* abundance from September 2011 to April 2012 (83.7 %) is greater than the typical winter die-off which usually ranges between 5 and 68%. This is probably explained by the fact that the bulk of the *Rangia* were in the smallest size classes. Reproduction in the Year 29 clams was especially high (accounting for a 32-fold increase in population), resulting in a population of mostly small clams, which were more prone to predation, siltation, and cold stress. In Maryland, *R. cuneata* rarely if ever reaches its reported maximum age (15-20 years) or size (79 mm). Looking at 14 years of frequency distribution data around HMI, it is difficult to identify more than four age classes of clams at any time. This implies very few clams survive longer than five years.

In September 2011, 4 *M. balthica* were collected, with all 4 coming from Reference station MDE-51. The *M. balthica* found during the fall were all larger than 18 mm. In April 2012, 43 *M. balthica* were collected with 28 coming from Reference stations, 8 from Nearfield stations, 7 from South Cell Exterior Monitoring stations, and 0 from Back River/Hawk Cove stations. The greatest abundance of *M. balthica* during the spring was found in the 19-22 mm size class.

M. balthica has been commonly observed in low to moderate abundances throughout this benthic monitoring project. It is classified as pollution sensitive during higher salinity years (≥ 5 ppt). The population has historically been somewhat dynamic in terms of overall abundance and size distribution. The main driver of *M. balthica* variability appears to be salinity. In the Chesapeake Bay, this species exists at salinities as low as about 5 ppt (Gosner, 1978), and is generally not found much more than 10-15 miles north of HMI. Fifteen years of monitoring data indicates that strong freshets are responsible for causing wide population fluctuations. After high mortality occurred during a strong freshet in Year 23 the population gradually recovered to previous densities only after the upper bay became more salty during Year 29. A second freshet induced mortality was documented in 2011 as MDE confirmed a major die-off in the northern part of the bay, in late June, as a result of low salinity.

In September 2011, 26 *M. mitchelli* were collected, with 11 coming from Nearfield stations, 10 from Reference stations, 4 from South Cell Exterior Monitoring stations, and 1 from Back River/Hawk Cove stations. The greatest abundance of *M.*

mitchelli during the fall was found in the 3-6 mm size class. In April, 3 *M. mitchelli* were collected with all 3 coming from Reference stations MDE-22 and MDE-51. The *M. mitchelli* found during the spring were all in the 5-10 mm size class. Similar to *M. balthica*, *M. mitchelli* populations declined in the spring of Year 22 and remained depressed for several years. Based on 15 years of historical HMI frequency distribution data, a strong freshet in Year 23 caused high mortality in this species; however, by Year 29 it appeared to have recovered to previous densities. The freshet of spring 2011 induced another mass mortality.

MULTIVARIATE AND FRIEDMAN'S ANALYSES

Multivariate Analysis

Multivariate cluster analysis was applied to Year 30 station invertebrate abundances as an initial examination of the variability of taxonomic abundance among the HMI stations. Multivariate methods are used to make sense of large, complex data sets that consist of numerous variables measured on multiple experimental units. In general, the purpose of multivariate methods is to simplify the complex data and identify patterns (Johnson, 1998a). The cluster procedure summarizes and classifies HMI station data by identifying unique groups of stations with similar benthic invertebrate assemblages.

The objective is to identify groups of like stations with benthic communities that are unique from other stations around HMI. This tool can be used to screen unique clusters, if their stations are adjacent and poorly performing for multiple years, for causal evidence of their performance. HMI operations, natural habitat variability, or complex combinations could cause such a trend.

Cluster analysis was applied to the September 2011 data, but not to the April 2012 data due to an unstable spring community associated with reproduction/recruitment that makes the results difficult to interpret.

The multivariate clustering procedure has been conducted twenty-five times since Year 12. Three stations have consistently been identified as outliers: MDE-27 (fifteen times since Year 19), MDE-01 (nine times since Year 19) and MDE-51 (four times since Year 27).

In Year 30, three stations are identified as outlier stations (MDE-33, MDE-34 and MDE-51), while the remaining eight stations (MDE-01, MDE-03, MDE-09, MDE-27, MDE-30, MDE-36, MDE-42 and MDE-50) showed moderate to weak grouping tendencies. Outlier stations were those stations with benthic invertebrate assemblages that were unique enough to be excluded from the multi-station group. In this case, linking the outlier stations to the other stations in the dendrogram was weak because of low data variability ($R^2 < 0.30$).

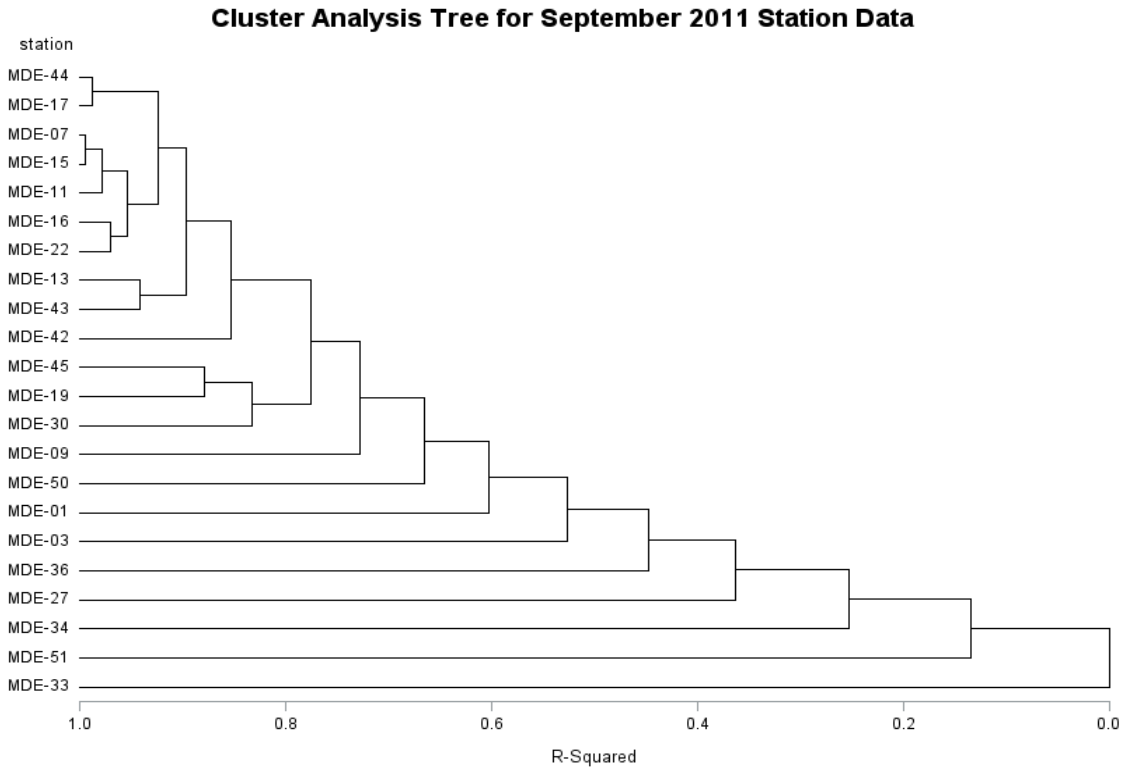

Figure 2- 8: September 2011 Cluster Analysis tree.

The cluster tree figure for September 2011 did not repeat any of the most common historical station pairings. However the figure did show a clear articulation of several HMI station groups (Figure 2-8). Using an $R^2 > 0.95$ as the threshold for identifying the strongest multi-station groups, nine stations formed into three unique station group combinations. The identified station groups were: **Group 1** (MDE-17 and MDE-44), **Group 2** (MDE-07, MDE-11, MDE-15, MDE-16 and MDE-22) and **Group 3** (MDE-13 and MDE-43). One other moderately strong ($R^2 > 0.85$) unique station group was apparent in the dendrogram, adding an additional two stations that showed clear-cut grouping tendencies. **Group 4** was a two station group composed of stations MDE-19 and MDE-45. These four groups were identified by the cluster procedure as having strong to moderately similar benthic invertebrate assemblages that accounted for a high proportion of the variability of the data (high R^2).

The relationship between identified station groups and station type (Nearfield, Reference, Back River and South Cell) was weak. However, the four identified groups did demonstrate good spatial proximity with average distance between stations (Group 1 = 1,054 meters; Group 2 = 2,235 meters; Group 3 = 1,493 meters; Group 4 = 1,640 meters), which is less than the average distance between all stations (mean = 3,790 meters).

The relationship between identified station groups and substrate was inconclusive due to the predominance of silt-clay bottom at all but four stations.

Groups 1 through 4 are depicted in Figure 2-9. The figure suggests that the benthic invertebrate community occurring in the area of Group 1 (MDE-17 and MDE-44), Group 3 (MDE-13 and MDE-43) and Group 4 (MDE-19 and MDE-45) were distinctly different from Group 2, although several of the stations in the groups are intermingled, making them not truly adjacent.

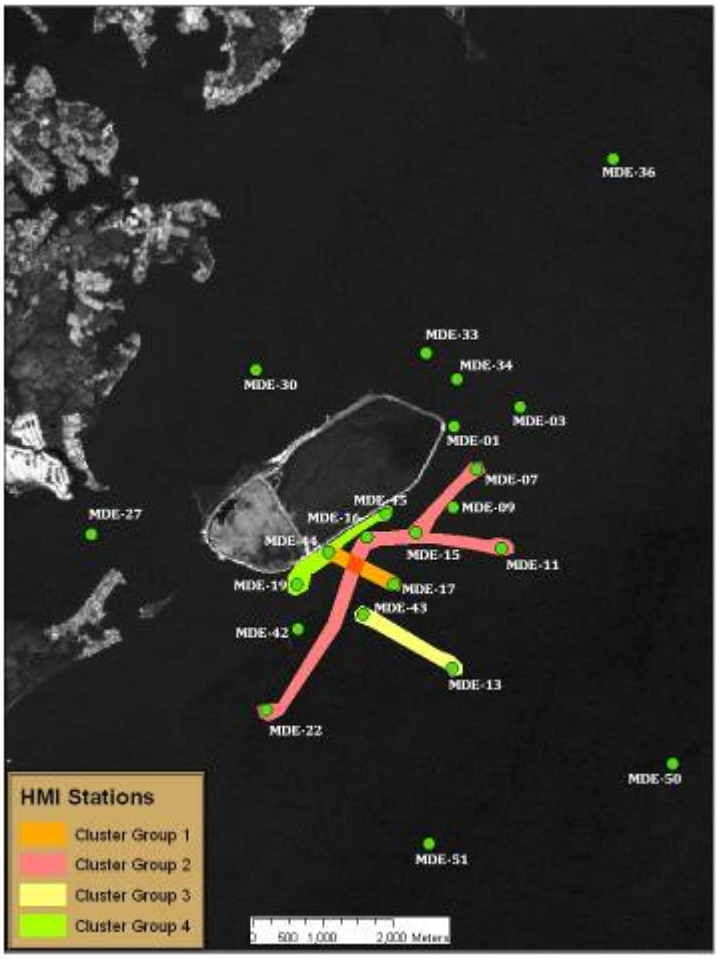

Figure 2- 9: Station Groups 1 – 4 as identified by the cluster analysis of September, 2011 benthic invertebrate data.

Friedman's Analysis

As in previous HMI annual reports (Years 12 – 15; Years 19 - 29), Friedman's nonparametric ANOVA test was applied to Year 30 benthic macroinvertebrate data. The Friedman's nonparametric test determines if significant differences in the top ten most abundant invertebrate taxa occur between station types. For Year 30 the Friedman's test was run on a new set of station groups to better link the test with the B-IBI results and with recent contaminant data that indicated recurring high sediment metal signatures north of the island in the vicinity of stations MDE-33 and MDE-34 and in the vicinity of

the South Cell Outfall.[2] Six groups were tested including the original Reference group (MDE-13, MDE-22, MDE-36, MDE-50 and MDE-51) and the original Back River group (MDE-27 and MDE-30). The new groups include a modified South Cell group of stations MDE-42 and MDE-43, a modified Nearfield station group composed of stations MDE-1, MDE-3, MDE-7, MDE-9, MDE-11 and MDE-17, the Low-performing group identified in the Year 30 B-IBI analysis (MDE-15, MDE-16, MDE-19, MDE-44 and MDE-45) and a north cell group composed of stations MDE-33 and MDE-34. Friedman's analysis of the modified station groups was an adaptive-management strategy designed to more precisely examine possible impacts to the benthic invertebrate community around HMI.

Friedman test results (Tables 2-15 and 2-16) indicated significant differences in the ten most abundant infaunal taxa between the six station types in September 2011 (P = 0.10) but not in April 2012. Significant Friedman results have occurred seven times since Year 12. Significance typically occurs as a result of either unique macroinvertebrate assemblages at Back River and/or South Cell stations.

Table 2- 15: Friedman Analysis of Variance for September 2011's 10 most abundant species among Back River/Hawk Cove, Nearfield, South Cell Exterior Monitoring, and Reference stations. ANOVA Chi-Square. (N = 10, df = 4) = 9.15, p = 0.10.

Station Type	Average Rank	Mean	Std. Dev.
Nearfield	3.5	197	196
Reference	4.0	267	226
Back River	3.5	322	313
South Cell	2.4	145	114
North Cell	4.7	937	967
Low-Performing Group	3.0	225	225

Table 2- 16: Friedman Analysis of Variance for April 2012's 10 most abundant species among Back River/Hawk Cove, Nearfield, South Cell Exterior Monitoring Stations, and Reference stations. ANOVA Chi-Square. (N = 10, df = 4) = 5.77, p = 0.33.

Station Type	Average rank	Mean	Std. Dev
Nearfield	3.9	127	127
Reference	3.6	167	208
Back River	3.7	546	1,267
South Cell	3.4	126	174
North Cell	2.3	52	41
Low-Performing Group	4.1	181	188

[2] From Project II summary of the combined HMI Year 29 report.

A Wilcoxon Signed-Rank post-hoc test was run to identify which station groups differed from each other in September 2011. This test requires a Bonferroni correction applied to determine significance level. The procedure tests significance between pairs of station groups. The Bonferroni corrected level of significance was $p \leq 0.01$. Ten comparisons were tested for significance: Reference stations and Nearfield stations, Reference stations and South Cell stations, Reference stations and North Cell stations, Reference stations and Low-performing group stations, Nearfield stations and South Cell stations, Nearfield stations and North Cell stations, Nearfield stations and Low-performing group stations, South Cell stations and North Cell stations, South Cell stations and Low-performing group stations, and North Cell stations and Low-performing group stations. This represents all possible pair-wise comparisons excluding Back River stations. No pair-wise comparisons were made with Back River stations because it is well-established that river discharge is the dominant environmental factor affecting benthic communities at these sites.

Of all the comparisons tested, results indicate statistical significance only between the modified South Cell and Reference stations ($p = 0.009$). Significantly different benthic communities at South Cell stations occurred in September because they had the lowest average abundance for the ten most abundant invertebrate taxa among all the station groups. The lack of statistically significant difference between the Low-performing group and any other group indicated that the impairment at these stations was not related to the abundance of the most dominant organisms.

CONCLUSIONS

In Year 30, the benthic macroinvertebrate community was examined under slightly unusual conditions for this region of Chesapeake Bay. The September 2011 cruise took place two weeks after Hurricane Irene and TS Lee passed over the region. These events resulted in historically significant freshwater inputs and sediment loading into the Chesapeake Bay. The input resulted in depressing the salinity in the vicinity of HMI into the olighohaline regime. The typical fall salinity is in the low mesohaline regime. While there was an apparent "light dusting" of new fine sediment at the sediment/water interface of the benthic samples, the community (both in terms of abundances and diversity) appeared much like it has in the past. One clear impact of the storms on this study was that the change in salinity resulted in the adoption of oligohaline metrics to calculate the B-IBI.

As usual, little stratification of water quality was evident during either the fall or spring cruises. Dissolved oxygen at all stations exceeded the State standard of 5.0 ppm deemed necessary to support healthy aquatic communities. Concurrent with the drop in salinity after the storms was a marked increase in turbidity. The September 2011 mean Secchi depth (0.33m) was 0.52 m less than the 14-year historic average of 0.85 m and an all-time fall low for this monitoring project.

The health of the benthic macroinvertebrate community around HMI in Year 30 was generally worse than historical averages. The mean B-IBI score for Nearfield stations (3.12) was 0.22 lower than the historic average. The mean South Cell Exterior Monitoring stations were 0.35 below average. The Reference stations were 0.60 below average and Back River/Hawk Cove stations were 0.42 below average. The primary explanation for depressed B-IBI scores lies with the use of oligohaline metrics to calculate the B-IBIs. Two of the metrics not used during low mesohaline conditions (Tanypodinae to Chironomidae ratio and Abundance of carnivores and ominvores) resulted in generally low scores, depressing the B-IBI. When the B-IBI was calculated for comparison, using the typically appropriate low mesohaline metrics, the mean scores increased for all station types to numbers above or near the historic means. All but two stations (MDE-44 and MDE-51) would have met or exceeded the benchmark of 3.00.

Three stations set new historic lows for B-IBI. One was Reference station MDE-51 which was being monitored for only the fourth time. The other two (MDE-16 and MDE-44) are both near the HMI dike, the former offloading dock, and immediately east of the spillway of the South Cell. These two stations are part of a cluster of contiguous stations that performed poorly in Year 30. This larger cluster, consisting of Nearfield stations MDE-15, MDE-16, MDE-19, and MDE-45 and South Cell Exterior Monitoring station MDE-44, is closer to the dike of the island than many of the other stations in their respective station groups. The Year 30 mean B-IBI for this particular cluster was 2.66, slightly more than the mean for the Back River/Hawk Cove stations (2.50) and less than the means for South Cell Exterior Monitoring (3.10), Nearfield (3.10), Reference (2.90), and Site 92 (3.80). Since Year 27, the year of the most recent station reconfiguration (incorporating the addition of MDE-45 and 15), the four-year mean B-IBI for this station

cluster is 3.11. This is lower than the four-year means for Nearfield stations (3.33), full set of South Cell Exterior Monitoring stations (3.41), and Reference stations (3.48). It is, however, still higher than the mean for Back River/Hawk Cove stations (2.50). Explanations for this cluster of poorly performing stations may lie with conditions unique to the proximity to the dike or to the South Cell outfall/ barge offloading dock. The cluster's historic performance is more similar to Nearfield, Reference, or South Cell Exterior Monitoring stations than the Back River/Hawk Cove station group. Hence, there is not convincing historical evidence that this cluster is greatly divergent from undisturbed reference conditions.

During Year 30, MDE also conducted a post-closure study for the former open water dredge disposal site at Site 92, east of HMI and immediately Southeast of Pooles Island (MDE, 2012). Nine stations were sampled for water quality and benthic community on the same day as the fall 2011 cruise at HMI. The mean B-IBI for the nine Site 92 stations was 3.80. This is considerably higher than the mean for any station type at HMI and higher than all but four of the highest performing HMI stations in Year 30. This may be either due to the lee effect of Pooles Island shielding Site 92 from either flow from the Susquehanna River or disturbances caused by northerly winds. Another potential explanation is that Site 92, on the eastern side of the Chesapeake Bay is less exposed to runoff from the urban watersheds of the Greater Baltimore Region (Lower Gunpowder, Middle, Back and Patapsco Rivers).

The multivariate cluster analysis identified unique groups of stations with similar species abundance patterns in the vicinity of the South Cell outfalls and nearby barge dock. Identified cluster groups 1, 3 and 4 were all near this area and had invertebrate assemblages distinct from the general benthic community east of HMI, as represented by identified cluster group 2. However, the multivariate cluster analysis also disassembled the poorly performing cluster of stations identified in the B-IBI section and reorganized it into parts of other groups that were significantly more distinct from one another. The lack of coincidence between the distinct groups identified in the cluster analysis with the distinct cluster group identified in the B-IBI analysis indicated that the impairment of the Low-performing group stations was a function not only of invertebrate abundance but also perhaps more importantly, of invertebrate community composition. Thus, good or poor B-IBI outcomes were not well-correlated to station abundance alone.

The Friedman's nonparametric ANOVA test indicated that South Cell stations were significantly different from Reference stations in September, primarily due to low average abundance of the top ten most abundant invertebrate taxa at station MDE-42 and MDE-43. In addition, lack of significance between the Low-performing group and the other groups provided evidence that invertebrate community composition, especially including the less dominant organisms, was an important factor contributing to the impairment of the invertebrate communities at the stations in this group. The ANOVA did not add to the level of concern about the Low performing group that was identified in Year 30.

Finally, lack of statistical significance between either the Low-performing group stations or the North Cell stations with the other station groups and lack of accord between the statistically significant South Cell group and the Low-performing group indicated that no clear link could be made between sediment metal hotspots and benthic impairment. The transitory nature of sediment contaminant signatures and the naturally varying benthic invertebrate community in this dynamic region of the bay make it very difficult to design monitoring and identify station types that may capture causal relationships between the two. However, continued refinement of "dual-media" (sediment contaminants and invertebrate community characteristics) data analysis should be pursued to provide a more thorough understanding of HMI monitoring.

Future monitoring plans: MDE has proposed to continue benthic monitoring at the current level until stabilization of the island is complete. The current level of support for continued monitoring calls for bi-annual monitoring through Year 31 and then once-annual fall monitoring in each succeeding year through 2017.

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APPENDIX 3: ANALYTICAL SERVICES (PROJECT IV)

(September 2011 – August 2012)

Technical Report

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OBJECTIVES

The 2011-2012 project goals were to continue to measure and evaluate the levels of contaminants in the sediment in the vicinity of HMI and to relate these, as far as possible, to historical data. Continued comparison and correlation of annual data with the historical HMI data, will indicate the extent of any contamination, biological exposure and if any trend in concentrations are developing at locations around the island.

Specific objectives for Year 30 were:

- To collect clams and associated sediment for analyses of trace elements, in the fall of 2011 and spring of 2012. On each occasion a minimum of 10 sites were selected from the larger pool of Maryland Department of the Environment (MDE) biota stations for this work. Sediment and clams were collected at the same time. Both sediment and clams were analyzed for Hg, MeHg, Ag, Se, As, Pb and Cd;

- To determine the concentrations of target trace elements in surface sediments at the larger number of stations around HMI visited by the Maryland Geological Survey (MGS) in September 2011. Metal analysis focused on those metals not measured by MGS, specifically Hg, MeHg, Ag, Se and As; and

- To analyze the sediment and clams collected in the fall of 2011 for PCBs and PAHs.

The results of the quality assurance (QA/QC) procedures and the description of the analytical and field protocols are contained in the *Year 30 Data Report*. Overall, the QA/QC results were acceptable for a study of this nature. No evidence of bias or lack of precision or accuracy was indicated by the QA/QC results. Comparisons of duplicate analyses and comparison of measured values to certified values for the analyzed Standard Reference Materials are also discussed in the *Year 30 Data Report*. Again, the QA/QC objectives were met in this regard.

METHODS AND MATERIALS

Sampling Procedures

A large spatial survey of sediment was conducted by MGS in September 2011. Samples from this survey were collected by MGS personnel for CBL using a Ponar grab sampler. Samples were placed in acid washed plastic containers, frozen and delivered to CBL for trace element analysis. In September 2011 a subset of MDE biota stations was visited by MDE and CBL personnel to collect clams and sediment for trace element, PCB and PAH analyses. The simultaneous collection is required to make the best bioaccumulation calculations. A series of MDE biota stations was visited in April 2012, but sediments and clams were collected only for trace element analysis. Sediment for

trace element and organic contaminants analyses were collected using plastic and stainless steel spatulas, respectively, integrating the top several centimeters and avoiding the sides of the sampler to minimize the possibility of contamination. Sediments for metals were placed in plastic sampling cups and were kept cooled in an ice chest or refrigerator until they could be processed in the laboratory. Sediments for organics were placed in glass jars with foil lined caps.

Sediment was sieved in the field for clams; the whole clams were placed in plastic bags with surface water and held on ice. The clams were frozen to allow easy shucking the next day. Clams for trace metal analysis were removed whole from their shells with a Teflon-coated spatula and the spatula was acid rinsed between each site's samples, to avoid cross contamination. The clam tissues for analyses of organic contaminants were removed using a stainless steel spatula, which was rinsed with solvent between samples from different sites. The clam bodies from each site were homogenized in a plastic blender with a stainless steel blade for trace element analysis, and a glass blender with stainless steel blades, for organic contaminant analysis. Unused samples were returned to their respective bags and stored in the freezer until further analysis.

Procedures for Trace Element Analyses

For trace element analysis other than T-Hg and MeHg, EPA Method 3052 is generally followed. The Milestone EOTHO-EZ uses quartz reaction vessels placed inside Teflon cups, which are pressure sealed during digestion. For digestion, 1-2 grams of sediment is placed in the vessel with 9 ml of concentrated ultra pure Nitric Acid (HNO_3) and 2 ml of concentrated ultrapure Hydrochloric Acid (HCl). The vessel is covered with a loose fitting quartz cap, and placed in the Teflon cup. 5 ml of 30% Hydrogen Peroxide (H_2O_2) is added to the Teflon cup and the cup sealed. The sample is heated to 180°C and allowed to reflux for 15 minutes. The samples are then cooled and filtered through Whatman No. 41 filter paper by suction filtration and diluted to 100 ml with deionized water. Clams are digested in a similar fashion. These extracts are analyzed for Ag, As, Se, Pb and Cd using a Hewlett-Packard 4500 Inductively Coupled Plasma-Mass Spectrometer (ICP-MS).

Samples for the determination of T-Hg (1-3 g wet weight) were placed in Teflon vials along with a solution of 70% sulfuric/30% nitric acid. The Teflon vials are placed in an oven and heated overnight at 60°C (Mason and Lawrence, 1999). The digestate was then diluted to 10 ml with distilled-deionized water. Prior to analysis, the samples were further oxidized for 30 minutes with 2 ml of bromine monochloride solution. The excess oxidant was neutralized with 10% hydroxylamine solution and the concentration of T-Hg in an aliquot of the solution was determined by tin chloride reduction cold vapor atomic fluorescence (CVAFS) detection after gold amalgamation in accordance with protocols outlined in USEPA Method 1631 (Mason et al. 1993).

For the determination of MeHg, clams and sediments were first extracted by sub-boiling distillation (Horvat et al. 1993). Clam or sediment tissue was weighed into Teflon vessels along with 1 ml of 50% sulfuric acid solution, 1 ml of a 20% potassium

chloride solution and 18 ml of ultra pure water. The vessels were heated to approximately 90^{o}C and volatiles and water distilled under a nitrogen stream for three hours. The distillate was reacted with a sodium tetraethylborate solution to convert the nonvolatile MeHg to gaseous MeHg (Bloom 1989). The volatile adduct was purged from solution and recollected on a graphitic carbon column at room temperature. The MeHg was then thermally desorbed from the column and analyzed by gas chromatography with CVAFS detection. Detection limits for T-Hg and MeHg are based on three standard deviations of the blank measurement.

A subsample of each trace metal sample (sediments) was used for dry weight determination. Weighed samples were placed in a VWR Scientific Forced Air Oven at 60^{o}C overnight. Upon drying, samples were then reweighed and a dry/wet ratio was calculated.

Analytical procedures for Organics

The sediment and clam homogenates were extracted and purified using the method described by Kucklick et al. (1996). For this method, a subsample of clam homogenate, 5 g wet weight, is removed and ground with anhydrous sodium sulfate (~50 g). A perdeuterated PAH cocktail (d_8-napthalene, d_{10}-fluorene, d_{10}-fluoranthene, d_{12}-perylene) and a noncommercial PCB solution (IUPAC #'s 14, 65, 166) are added as surrogates to each sample to track extraction efficiency. The mixture is then extracted in a Soxhlet apparatus with 250 ml of dichloromethane (DCM) for 24 hours. The extracts are then concentrated to 2 ml using a vacuum rotary evaporator and transferred into hexane. Each sample is transferred to a 4 ml Waters autosampler vial with sample and rinses amounting to approximately 4 ml. Gravimetric lipid analysis is performed on each sample with subsampled fractions determined gravimetrically (Kucklick et al. 1996). Samples are again concentrated in similar fashion as above, then solvent exchanged to hexane. To remove lipids the extracts are then eluted with 25 ml petroleum ether over 4 g deactivated Alumina [6% (w/w) water]. After concentrating, the extracts are spiked with a perdeuterated PAH mixture (d_{10}-acenapthene, d_{10}-phenanthrene, d_{12}-benz[*a*]anthracene, d_{12}-benzo[*a*]pyrene, d_{12}-benzo[*g,h,I*]perylene) for quantification of PAH's. The samples are then analyzed using a Hewlett Packard 5890 gas chromatograph (GC) with a HP-5MS (cross linked 5% phenyl methyl siloxane) capillary column (30m x 0.25mm x 0.25um film thickness) and a HP-5972 series mass spectrometer (MS) for PAH's (Ko and Baker 1995). Each sample is separated after GC/MS analysis into two fractions with 35 ml of petroleum ether and 50 ml of DCM/PET (1:1), respectively, over 8 g of deactivated Florisil [(2.5% (w/w) water (Kucklick et al.1996)]. The first fraction (F-1), contains PCBs and 1-100%, by weight of the less polar organochlorine pesticides [heptachlor (100%), 4,4-DDT (40%), 4,4-DDE (100%), t-nonachlor (24%), heptachlor (1%), 4,4-DDT(44%)]. The second extracted fraction, (F-2), contains 56-100% of the more polar organochlorine pesticides [a-HCH (100%), g-HCH (100%), c-chlordane (100%), t-chlordane (100%), t-nonachlor (76%), heptachlor (99%), heptachlor epoxide (100%), dieldrin (100%), 4,4-DDD (100%), 4,4-DDT (56%)]. Both fractions are solvent exchanged to hexane and concentrated to ~ 1 ml.

PCB congeners were analyzed by gas chromatography using a J&W Scientific DB-5 capillary column (60m x 0.32mm, 0.25μm film thickness) coupled to an Agilent HP-5972 detector. Individual PCB congeners are identified and quantified using the method of Mullin et al. (1985) using the noncommercial PCB congeners IUPAC 30 and 204 as internal standards.

RESULTS AND DISCUSSION

Trace Elements in Sediment

Concentrations of As in the sediment collected around HMI in Year 30 (fall 2011) are toward the high end of concentrations when compared to previous years (Figure 3-1). At the vast majority of sites, As concentrations were above the historical running mean (calculated for the period 1998 to 2010). Sediment As concentrations at five locations, MDE-6, MDE-42, MDE-43, MDE-49 and MDE-51, were elevated such that they exceeded the standard deviation. Being newer sites, the sample size at sites MDE-49 and MDE-51 are much smaller than at the other locations, hence deviations from the mean are more likely. These stations do not form a cluster but cover an extensive area extending southward from the island. The concentration of As at MDE-6 (27. 4 ug g^{-1}) was also high in 2010 (17.2 ug g^{-1}). This site, located off the east side of the island, is surrounded by sites that do not have unusual concentrations.

In the fall of 2011, concentrations of Se were elevated above the mean and median at approximately half the stations. However, the concentrations were outside the standard deviation of the running mean at only 4 stations (MDE-19, MDE-26, MDE-38 and MDE-40). The fluctuations in Se concentration are common over time, as indicated by the large standard deviation at almost every station. Because Se concentrations in sediment are generally low overall, the proportional changes observed are large. This is important because shifts in Se concentration, from being an essential element to being a toxic element, occur over a small range. However, the link between total Se concentrations in sediment and organism toxicity is not well known. Data for Se concentrations in urban estuaries is also sparse, thus there is little data for which to compare. Sites MDE-6, MDE-26, MDE-30 and MDE-38 are stations with the highest concentrations in Y30. There is a strong potential for external influences on three of these sites, with Baltimore Harbour potentially influencing MDE-26 and MDE-38, and Back River influencing MDE-30.

Concentrations of Ag in the sediment collected from sites MDE-1 to MDE-41in the fall of 2011 were again lower than the median and average concentrations collected around HMI in previous years (Figure 3-2). This same condition, lower than average Ag concentrations in sediment was observed in 2009 and 2010. Sites with a shorter history (sites numbered MDE-42 to MDE-51) have concentrations which are generally higher than average. The variations in concentration between these two groups of sites suggest a system wide reduction in Ag and the mean concentration of Ag is closer to 0.5 ug g^{-1} than the more than 2 ug g^{-1}, when samples from earlier in the decade are included. Data collected from 2000 and 2001 greatly influence the Ag concentration mean of sites with a

long record. Annual fluctuations in the concentration of Ag in sediment are system wide and appear unrelated to HMI operation.

Concentrations of mercury (T-Hg) in sediment were generally close to the running mean of previous years but with most concentrations falling within the standard deviation of measurements made between 1998 and 2010 (Figure 3-2). Sites which fell outside the standard deviation were MDE-9, MDE-11, MDE-14, and MDE-30. Site MDE-30 is close to Back River but MDE 27 did not show the same deviation in concentration. Sites MDE-9, MDE-11 and MDE-14 are close together and lie southeast of the island. The deviations at these sites are not as large as was observed at the MDE-30 location. The concentration at MDE-14 (438 ng g^{-1}) and MDE-30 (538 ng g^{-1}) are far outside the 0.2 to 250 ng g^{-1} dry weight range observed in the main stem of the Chesapeake Bay (Heyes et al. 2006).

Concentrations of MeHg in sediment collected in the fall of 2011 ranged from 0.02 to 2 ng g^{-1} dry weight (Figure 3-3). These concentrations are largely comparable to the rest of the Chesapeake Bay (Heyes et al. 2006). Sites MDE-9, MDE-14 and MDE-30 had concentrations in access of 1.5 ng g^{-1} and MDE-9 and MDE-14 were marginally outside the standard deviation of the sites running mean. Concentrations of MeHg at sites MDE-39 and MDE-46 where substantially above the standard deviation of the running mean for each of the sites. The percent of mercury that occurred as MeHg was less than 1% at all sites except for MDE-8 (Figure 3-3).

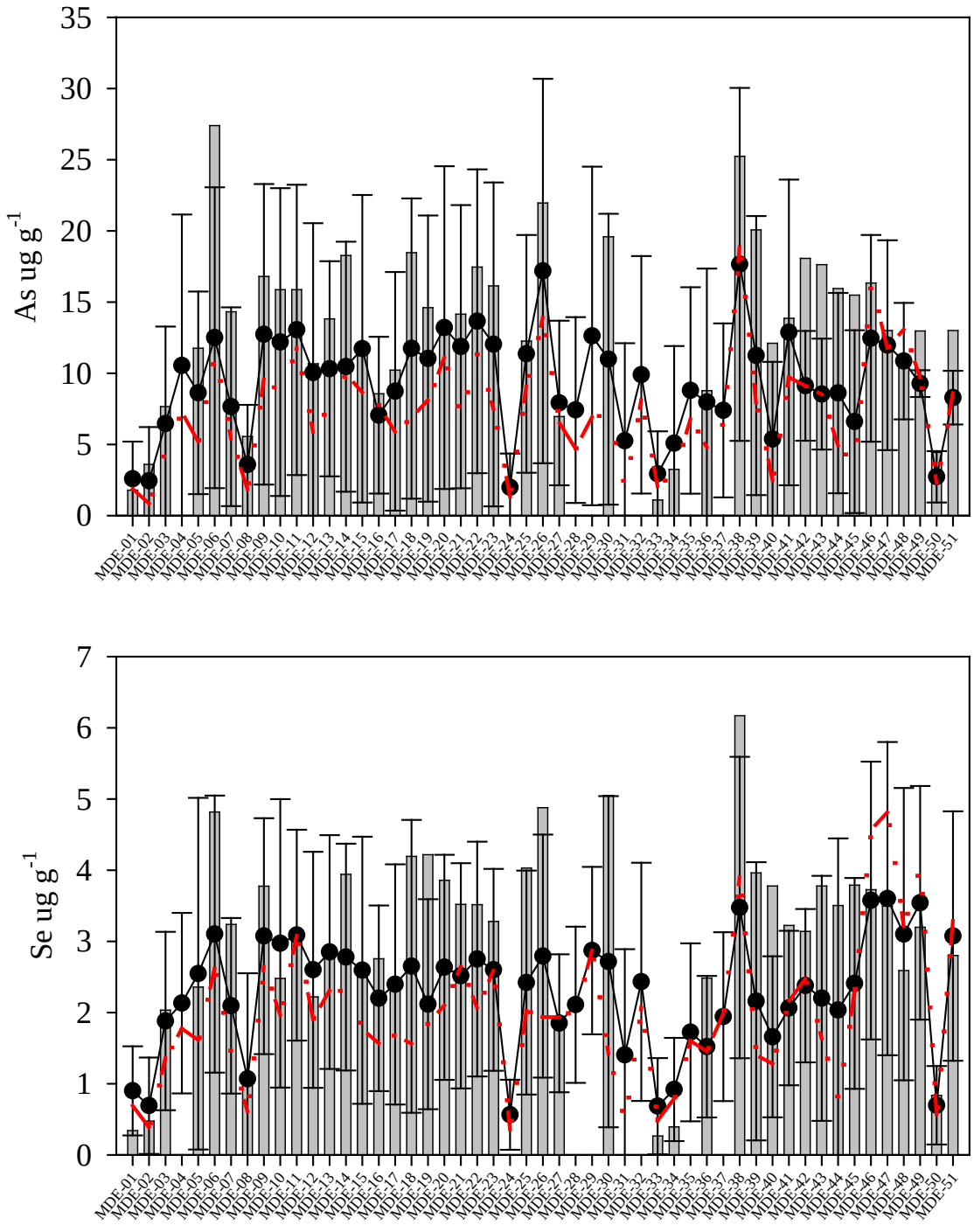


Figure 3- 1. As and Se in sediment, expressed as dry weight concentration, collected by MGS in the fall of 2011 (bars) and the 1998-2010 mean (circles) with standard deviation (error bars) and the 1998-2010 median (dashed line). Sites 4, 24, 28, 29, 31, 32, 35, 37 are no longer sampled.

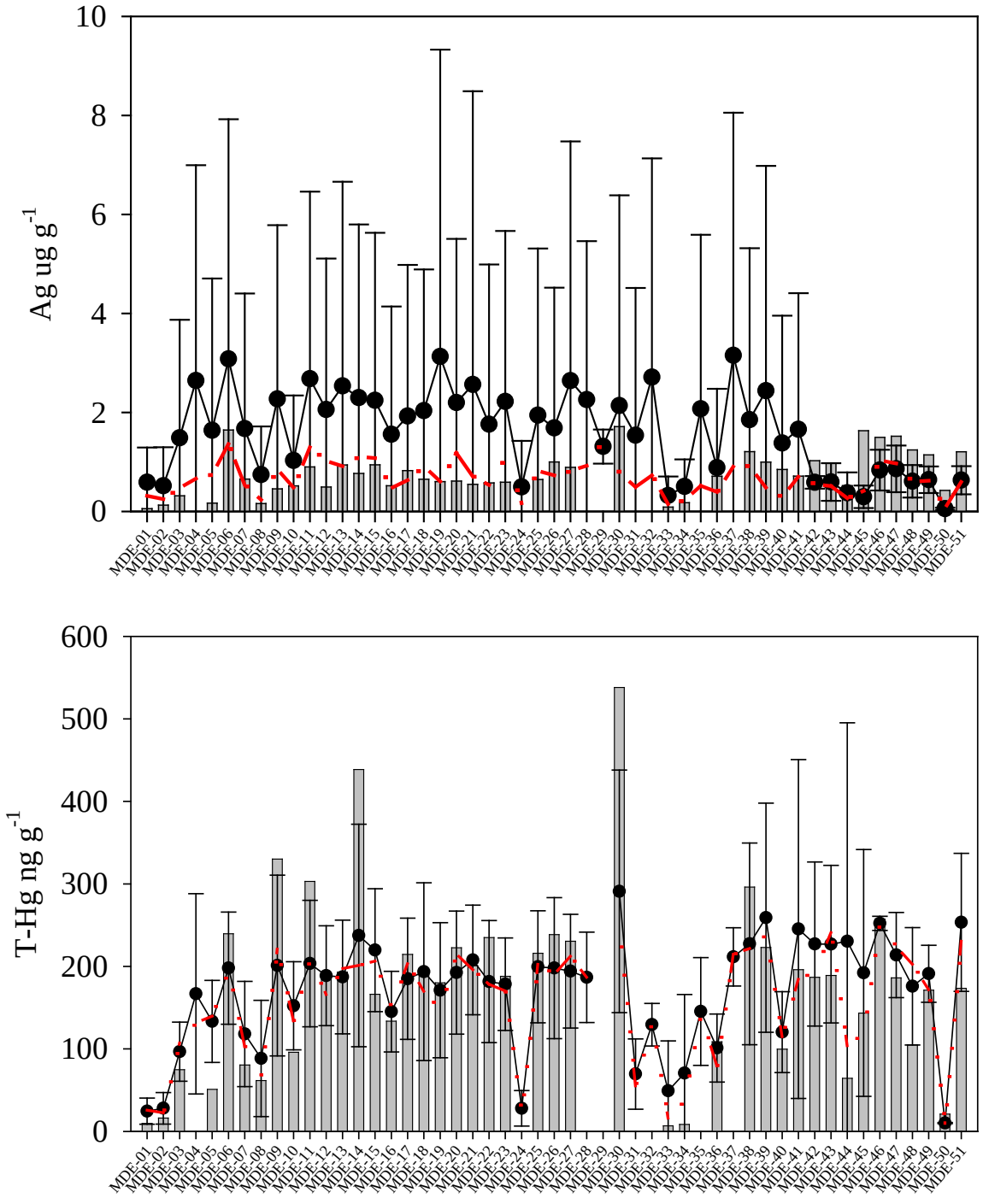


Figure 3- 2. Ag and T-Hg concentrations in sediment, expressed as dry weight concentration, collected by MGS in the fall of 2011 (bars) and the 1998-2010 mean (circles) with standard deviation (error bars) and the 1998-2010 median (dashed line). Sites 4, 24, 28, 29, 31, 32, 35, 37 are no longer sampled.

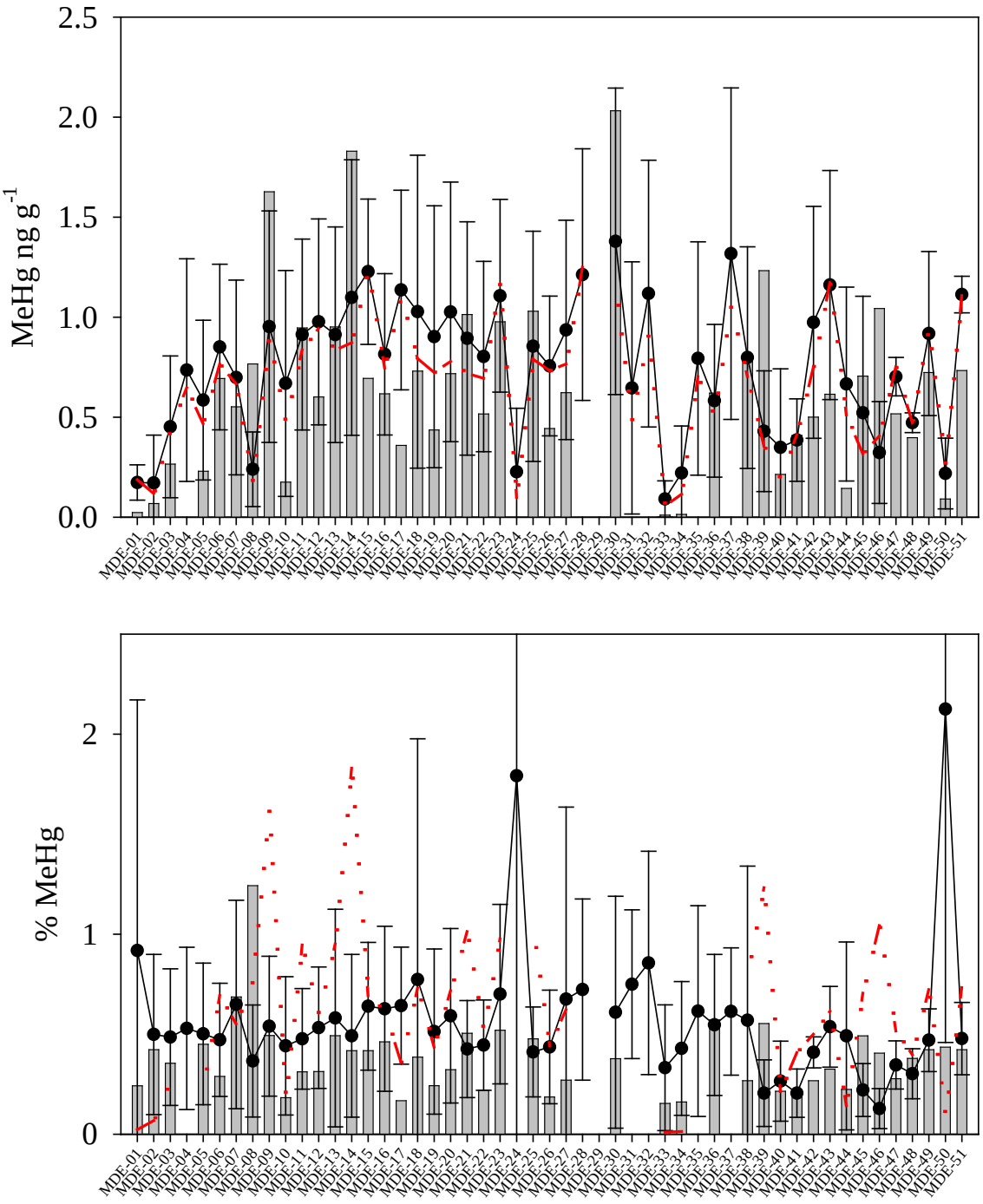


Figure 3- 3 MeHg, expressed as dry weight concentrations, and percent of T-Hg as MeHg in sediment collected by MGS in the fall of 2011 (bars), and the 1998-2010 mean (circles), with standard deviation (error bars), and the 1998-2010 median (dashed line). Sites 4, 24, 28, 29, 31, 32, 35, 37 are no longer sampled.

Relationships between trace elements among sites and years

Of the trace elements analyzed each year by CBL, some correlations exist between these elements in time and space. It is important to assess these trends in order to generate a general understanding of overall trends, so that anomalous stations and years can be identified as it is expected there is a regional signal of trace element deposition captured in the sediment and that any release from the HMI facility recorded at any one site would be in addition to this signal. Stations located near the Back River and Baltimore Harbor need be treated with care because of the potential for contaminants to migrate from these water bodies. MDE sites 1 to 44 have been monitored for gretare than 10 years, a period long enough for a detailed investigation of trends to be initiated.

Arsenic and Selenium

A strong correlation between As and Se has been observed in time and space which is shown in Figure 3-4a, which contains all sites and dates since 1998. There is some variability in the year to year relationship between As and Se, as seen by the range of slopes of the annual As-Se linear regression line over the study period. Variations in the slope of the regression line fitted through the annual data have varied between 0.17 and 0.20 since 1999. The strength of the relationship has also varied. The strength of the As-Se correlation, as shown by the correlation r^2, has ranged from 0.22 to 0.84 between 1999 and 2011. In the fall of 2011 the relationship between As and Se was very strong (r^2 = 0.84) and slope was 0.2 (Figure 3-4b). Such relationships between trace elements are seldom reported in the literature. As and Se are often co-released from coal combustion waste sites, and hence might have the same origin. When the regression relationship between As and Se is examined within a single site over time, the correlation between the two elements is generally weaker with r^2 ranging from 0.30 to 0.86 between 1999 and 2011. No relationship was found between As and Se at 4 sites (MDE-27, MDE-24 (no longer sampled), MDE-8 and MDE-2).

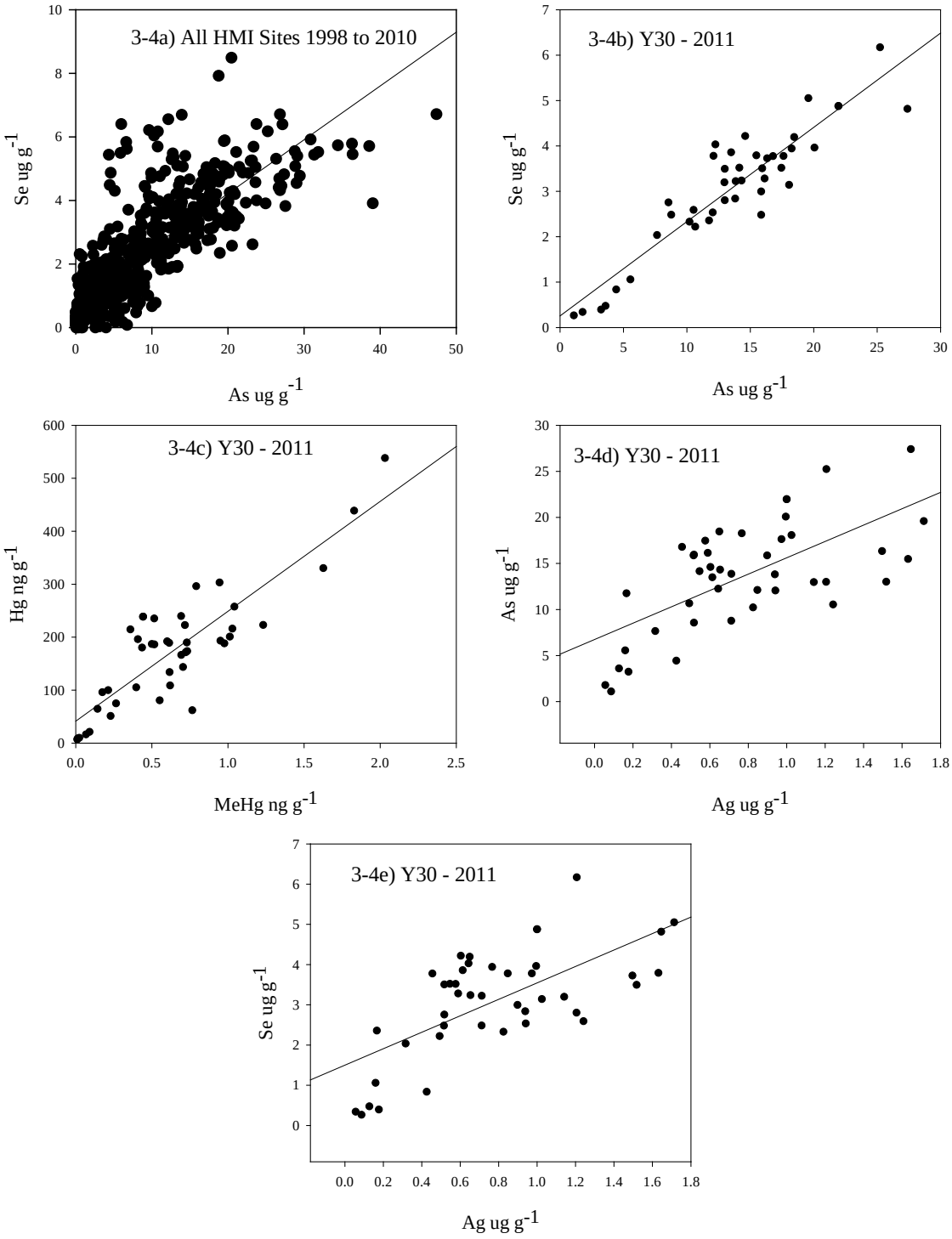


Figure 3- 4 Correlation of concentrations of Se and As in sediment (ug g^{-1} dry weight) for a) all HMI stations sampled from 1998 – 2010; b) sampled in the fall of 2011; c) correlation of T-Hg and MeHg concentration in September 2011, d) As and Ag concentrations in Sepetmber 2011 and e) Se and Ag concentrations in September 2011.

Mercury

T-Hg is not well correlated with Se, As or Ag at the HMI stations in time or space. Only site MDE-44 has strong correlations between T-Hg and As, T-Hg and Se and T-Hg and Ag. T-Hg was weakly correlated with MeHg over most of the years with linear regression r^2 s ranging for 0.11 to 0.48. In 2010, 2008 and 1998, no relationship was observed between T-Hg and MeHg. In 2011, the relationship between T-Hg and MeHg was very strong ($r^2 = 0.74$) (Figure 3-4c). The relationship between T-Hg and MeHg ranges from non-existent at about half the study sites to strong at sites MDE-31, MDE-37, MDE-40, MDE-41, MDE-43, and MDE-44. The dependence of MeHg on T-Hg is expected but in the Chesapeake Bay the relationship is often weak owing to other factors other than T-Hg concentration that influence MeHg production (Heyes et al. 2006).

Silver

At first glance, Ag was poorly correlated with most other elements over the 1998 to 2011 study period. However, high concentrations observed in 2000 and 2001 drastically skew the temporal results. When the data from these two years is removed, correlations between Ag and both As and Se are generally strong. Regressions (r^2) for As and Ag ranged from 0.32 to 0.71 between 2002 and 2010. The exception occurred in 2009 when no relationship between As and Ag existed. In 2011, As was again well correlated with Ag ($r^2 = 0.42$) (Figure 3-4d). Regression r^2 for Ag and Se ranged from 0.47 to 0.7 between 2002 and 2010. In 2011, the relationship was weakest of all the years but having an r^2 of 0.44 the relationship is still strong (Figure 3.4e). At individual sites, concentrations of Ag are not well correlated with concentrations of the other elements over time when all HMI collection dates are examined. However, when the anomalous years of 2000 and 2001 are removed, correlations strengthen at most sites. Interestingly, temporal correlations between Ag and As and Ag and Se are fewest in number from the sites on NE side of the island.

Relationships between trace element concentrations with other site characteristics

As and Se seldom correlate with other variables within a site, thus changes in carbon or clay content do not influence As and Se concentrations at individual sites. This is also true when all sites are examined in a given year or over the entire study period; carbon and clay contents do not influence concentrations of As and Se in sediment.

Mercury is well correlated with carbon and clay content when all sites are examined together and throughout the study period (Figure 3-5).The T-Hg and carbon and T-Hg and clay concentrations are usually well correlated among the 44 sites in a given year; the exception being1998. In 2011, the relationship between T-Hg and carbon was strong (Figure 3-6). However, when T-Hg and carbon and T-Hg and clay content are compared over time at individual HMI sites, mercury is correlated with sediment carbon content at only 8 sites and with clay at only 6 sites. The concentrations of carbon and clay at a single site do not vary a great deal and this weakens the potential for temporal

relationships. Hence, when the range in carbon and clay content are expanded by looking across sites within a year, such relationships strengthen greatly.

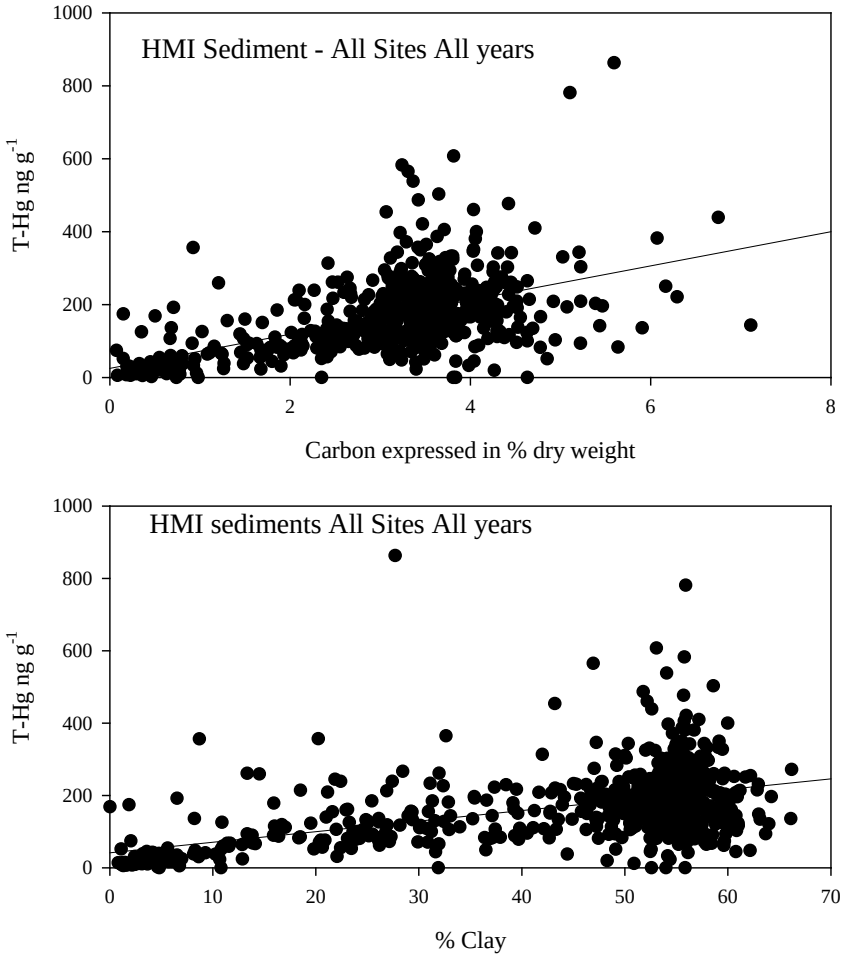


Figure 3- 5 Total-Hg concentration and carbon content (upper) and clay (lower) in sediment for all sites and all years.

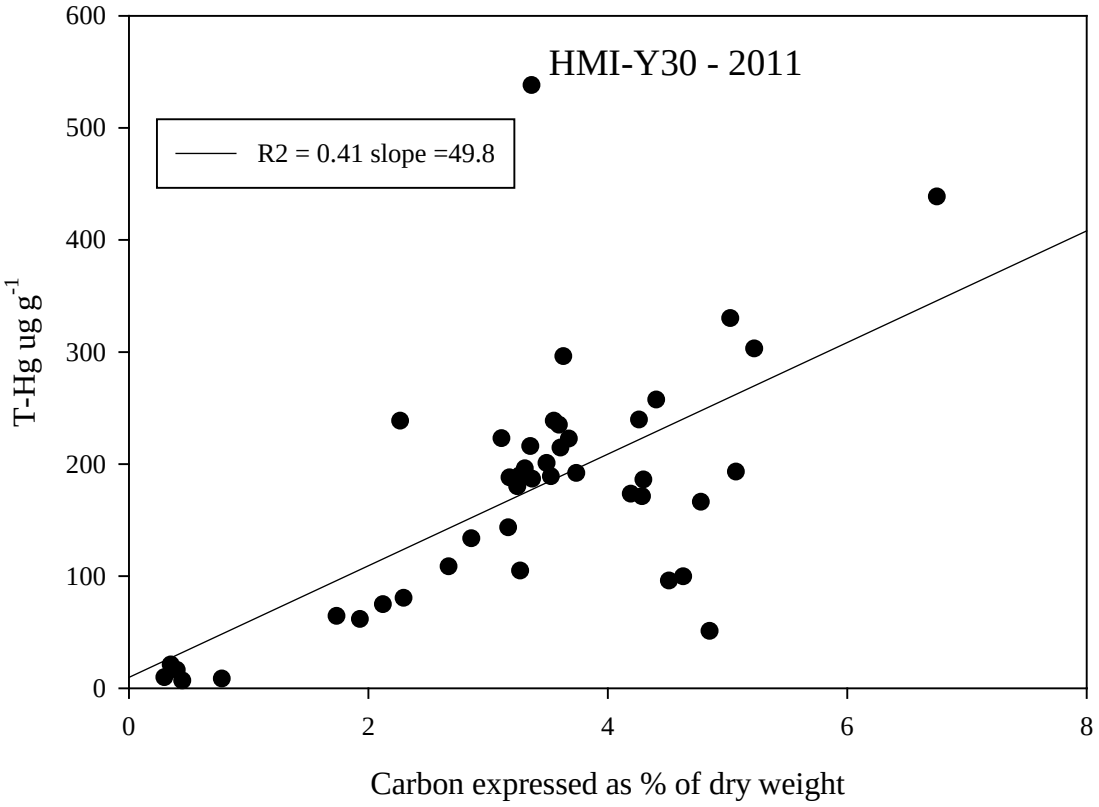


Figure 3- 6 Sediment total mercury and carbon concentration in Y30 – September 2011.

General conclusions from trace element comparisons

The relationships between As, Se and Ag concentrations in sediment suggest either a similar origin or similar diagenetic behavior around HMI complex. The lack of a correlation between Ag and As at sites located NE of the island suggest a different mechanism of delivery or retention in this area. T-Hg appears to act differently than the other trace elements studied as it does not often correlate with other trace elements, and is more dependent on organic matter and clay content of sediment. This might imply a different regional source such as broad scale atmospheric deposition.

Inter-annual variations in the relationships between trace elements, indicated by changing slopes of regression lines are sufficiently great that predicting one element concentration from other element concentrations are not possible. The strength of element to element relationships actually comes from the diversity of sites, not from temporal changes within a site. Spatial and temporal studies of multiple trace elements are rare. Concentrations of Ag, As and Se observed in sediments around HMI are marginally higher than concentrations observed in a study by Moss Landing in 2007 (Sigala et al. 2007) for California Harbors that had seen little industrialization in comparison to Baltimore Harbor.

Trace Elements in Clams

The clam *Rangia* was collected from 13 stations in the fall (September) of 2011 and 12 stations in the spring (April) of 2012. In the fall of 2011, the sites visited were MDE-1, 9, 11, 13, 15, 16, 19, 27, 30, 36, 42, 43 and 51. Concentrations of As, Se, Ag, Cd, and Pb, measured in clams collected in September 2011 were almost ubiquitously lower than previous years when compared to the historical running means for the sampled sites (Figure 3-7). Concentrations of Hg and MeHg were close to the running mean of the station from which they were collected (Figure 3-8). Five new sampling locations were added in 2008 to increase the spatial sample density around the southern side of the island. Of these newer sites, site MDE-51 was sampled for clams in September 2011. Concentrations of trace elements in clams collected from MDE-51 fell in line with concentrations found in clams of the other sites including the reference site MDE-36. The concentrations of T-Hg in the clams collected from MDE-51 again were high relative to previous years sampling; but the site history is short and the T-Hg concentrations are not unusual compared to other HMI stations. Only site MDE-43 had a T-Hg concentration that was outside the historical standard deviation. Elevated % MeHg concentrations are caused by the low T-Hg concentrations in clams at sites MDE-1, 9, 11 and 51.

Sites from which clams were sampled in April 2012 included MDE-9, 13, 16, 17, 19, 27, 30, 36, 42, 43, 44, and 51. In April 2012, concentrations of As, Se, Ag, Cd and Pb were at or below the historical concentrations of the site from which the clams where collected (Figure 3-9). However, concentrations of T-Hg and MeHg were equal to or higher than historical clam concentrations for the sites sampled. Clam concentrations of T-Hg and MeHg have varied greatly over time, but in 2011 many sites had clam concentrations that were 2 times the running mean of previous years. Concentrations above the standard deviation of T-Hg were observed at MDE-9, MDE-16, MDE-30, MDE-43, MDE-44 and MDE-51, but there is no spatial pattern to these increases. Little change in the % MeHg is apparent, as both T-Hg and MeHg increased proportionally, with the exception being site MDE-17.

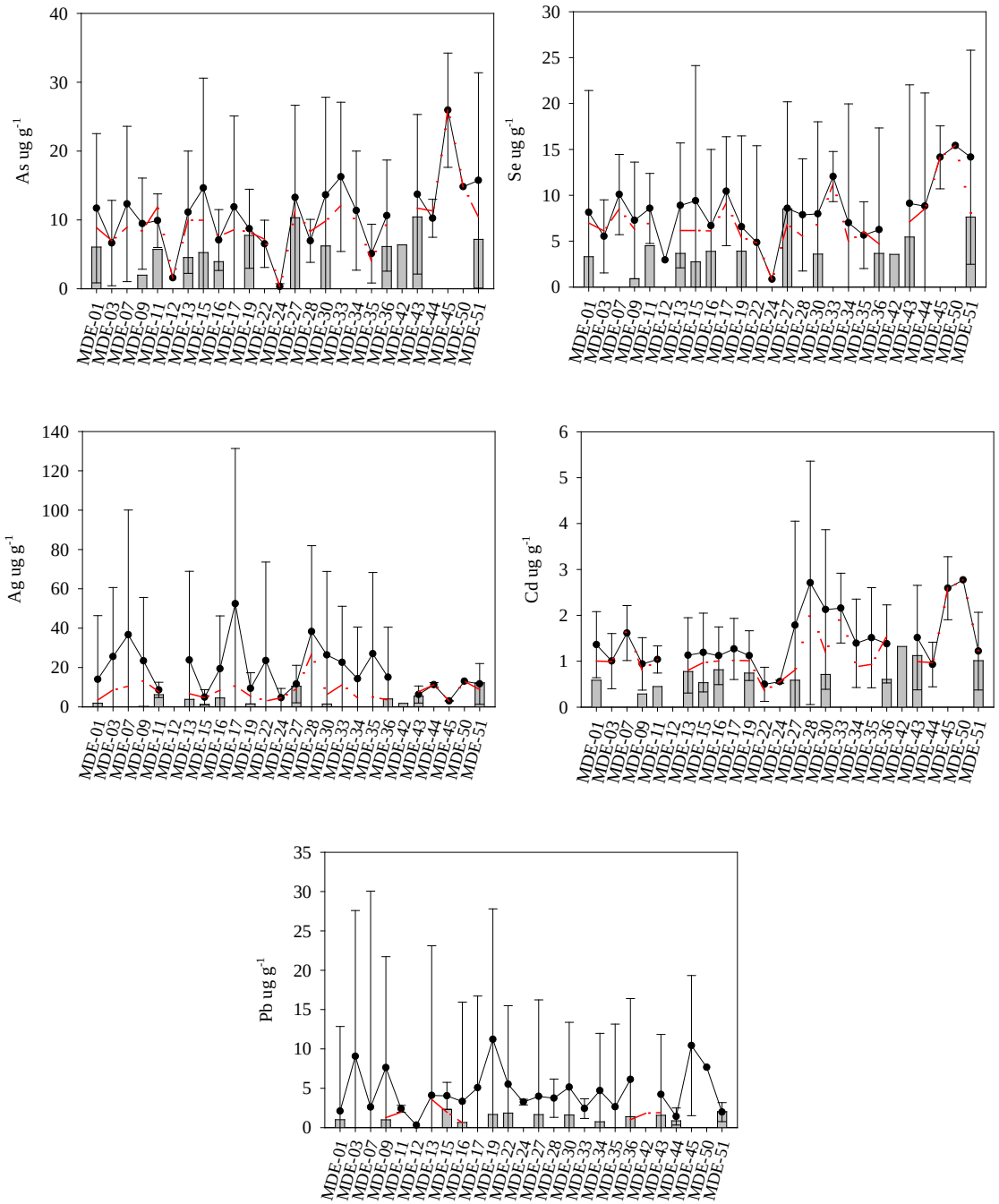


Figure 3- 7 Concentrations of Pb, Cd, As, Se, Ag in clams collected in September 2011. Concentrations (bars) are dry weight based and the 1998-2010 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2010 median (dashed line).

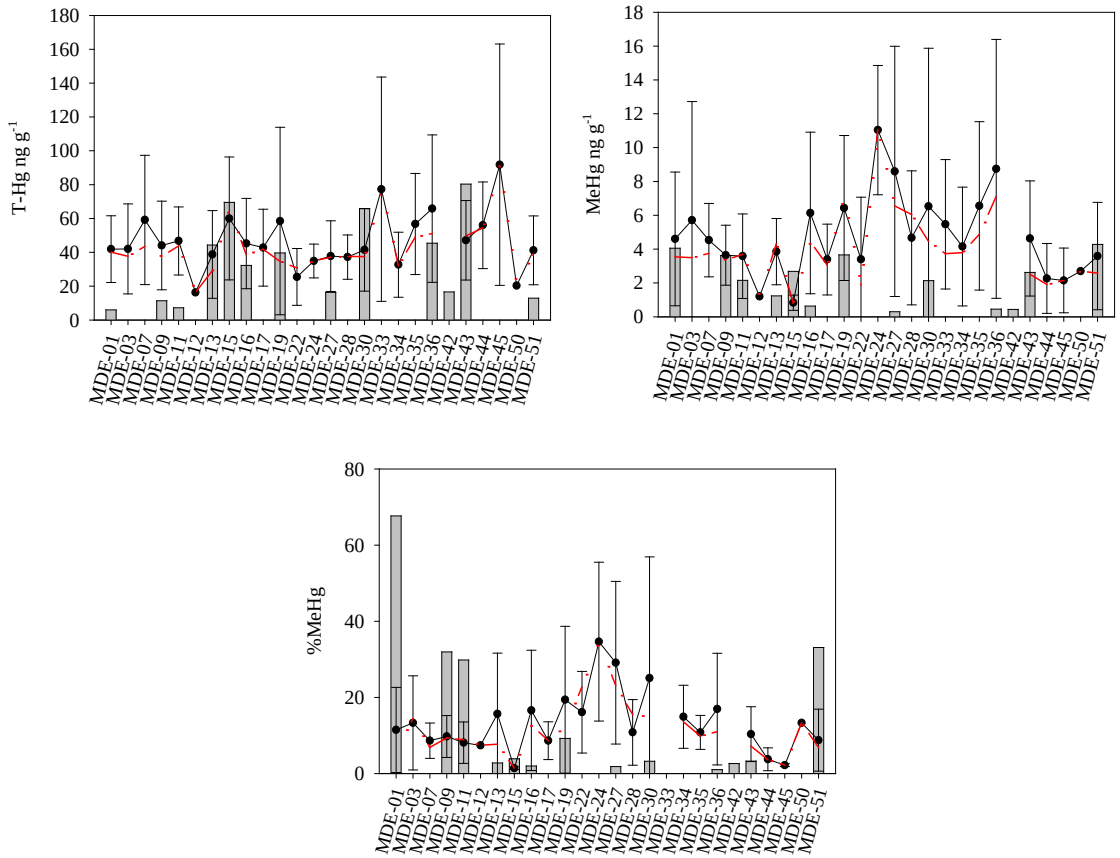


Figure 3- 8 Mercury (Hg) and methylmercury (MeHg) concentrations, expressed on a dry weight basis, and percent of Hg that is MeHg in clams, collected in September 2011 (bars) and the 1998-2010 mean (circles) with standard deviation (error bars) and the 1998-2010 median (dashed line).

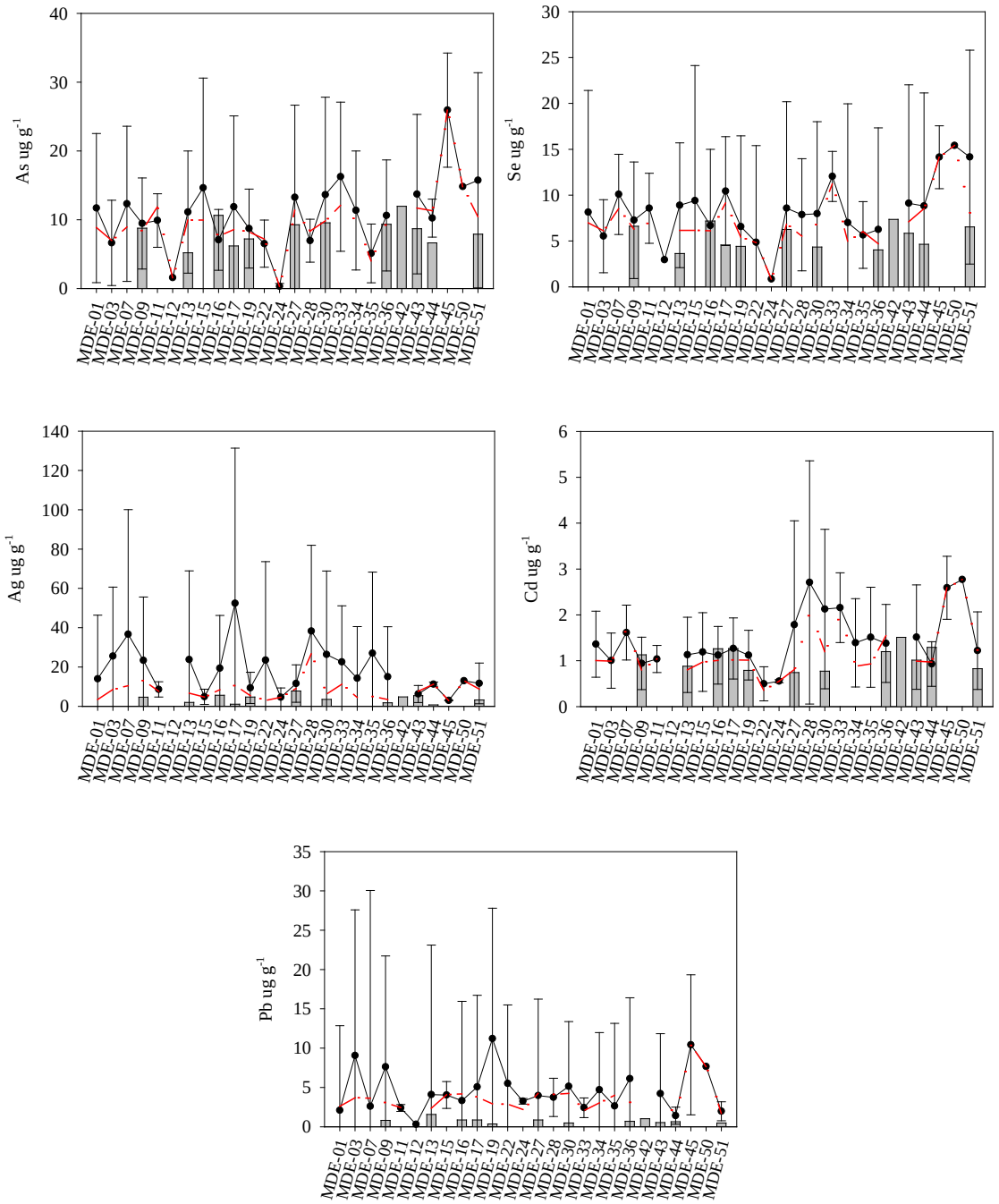


Figure 3- 9 Concentrations of Pb, Cd, As, Se, Ag in clams collected in April 2012. Concentrations (bars) are dry weight based, and the 1998-2010 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2010 median (dashed line).

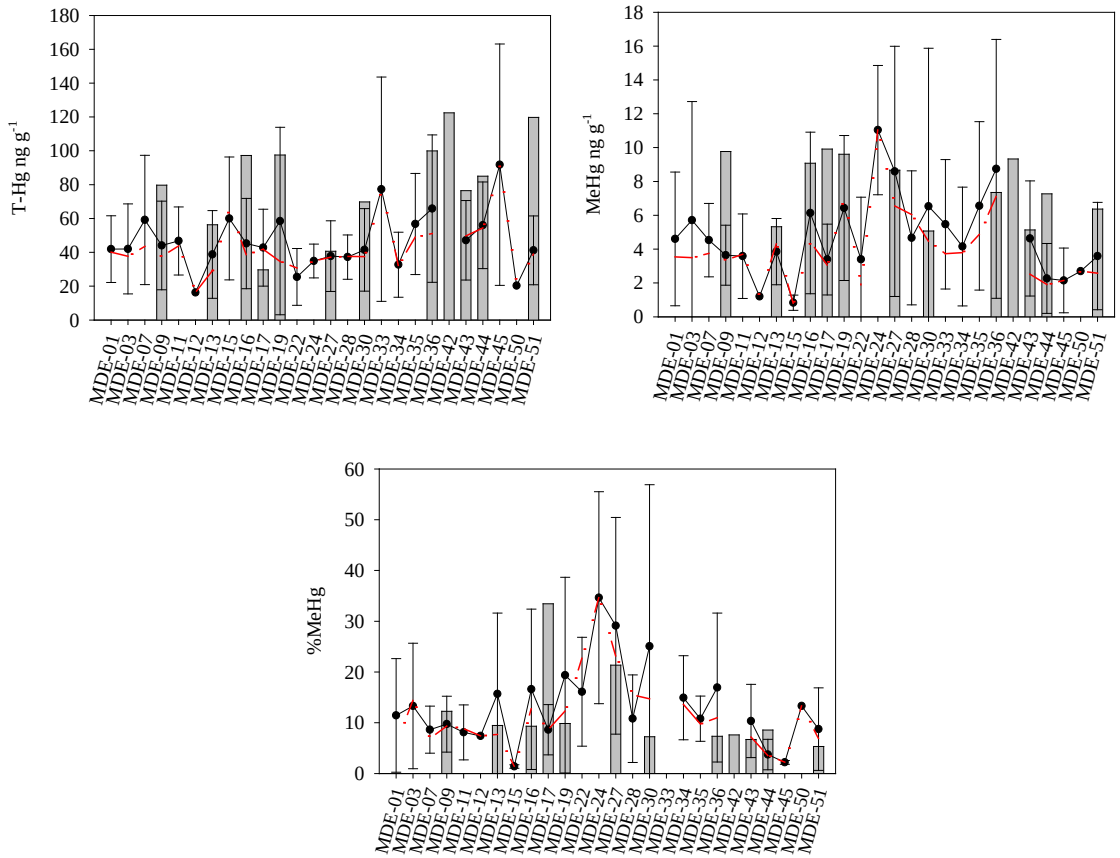


Figure 3- 10 Mercury (Hg) and methylmercury (MeHg) concentrations, expressed on a dry weight basis, and percent of Hg that is MeHg in clams, collected in April 2012 (bars) and the 1998-2010 mean (circles) with standard deviation (error bars) and the 1998-2010 median (dashed line).

Bioaccumulation Factors

Clam bioaccumulation factors (BAFs) for the trace elements Cd, Pb, As, Ag, Se, T-Hg and MeHg (Figure 3-11) were calculated using clam concentrations in Figures 3-4 to 3-7) and sediment concentrations presented in Table 3-1. While the station co-ordinates are the same as MGS, boat drifting might result in poor day to day sample co-ordination. Thus, to ensure the best sediment-clam matching, sediment was collected along with the clam collection.

In both September 2011 and April 2012, the BAFs for Pb (not shown in Figures 3-11 and 3-12) were less than one for all sites, indicating there was no bioaccumulation of Pb from sediment to clams. BAFs of less than 1 for Pb have been occurring for the duration of the study.

In September 2011 little bioaccumulation of As, Cd, T-Hg and Se by the clams was observed (BAFs typically less than 10, Figure 3-11). Moderate bioaccumulation of Ag was generally observed, as BAFs were on the order of 10 or less, except for MDE-1 where Ag concentrations in sediment were very low. While the majority of the stations had BAFs below 10 for MeHg, higher BAFs were calculated for MeHg being above 10 at two stations, MDE-1 and MDE-9. This appears to be driven by low sediment concentrations of MeHg.

In April 2012, little to no bioaccumulation of As, Se, Cd and T-Hg was apparent but moderate accumulation of Ag was observed with BAFs approaching 10 (Figure 3-12). Again bioaccumulation of MeHg was apparent with BAFs near or above 10 at most sites. This pattern is not unusual and consistent with the behavior of MeHg.

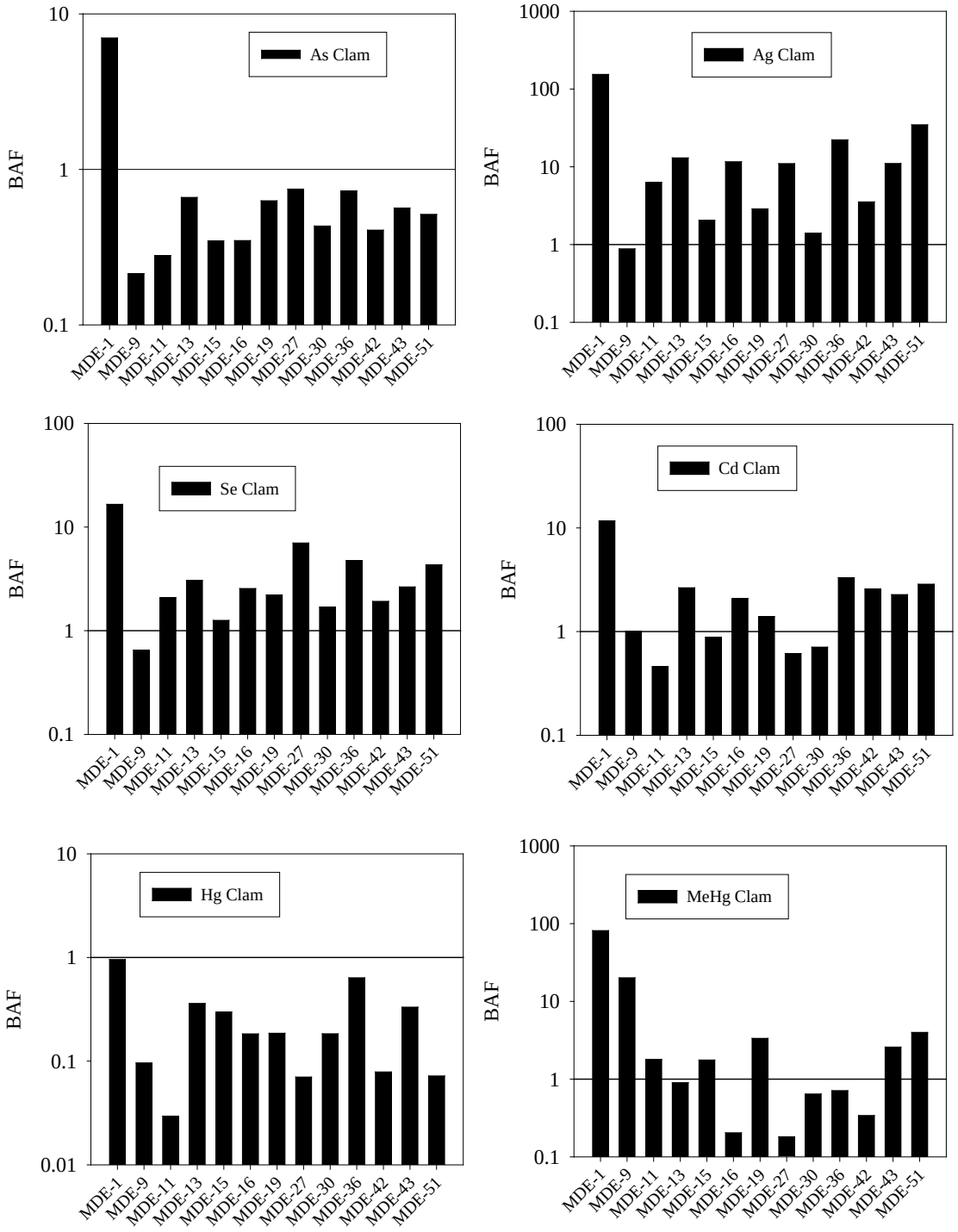


Figure 3- 11 Bioaccumulation factors for the metals As, Ag, Se, Cd, Hg and MeHg September 2011. Note BAF is presented on a log scale.

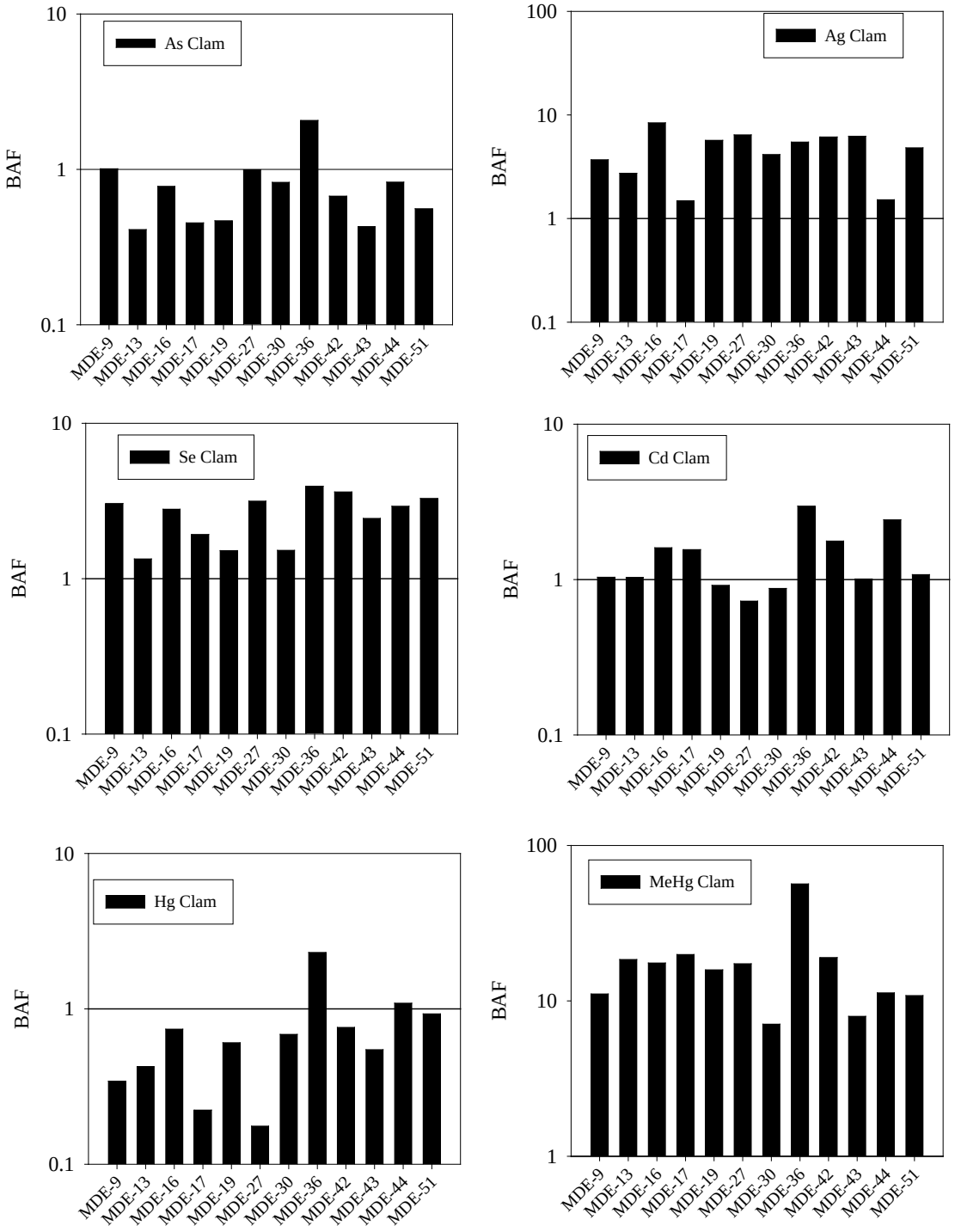


Figure 3- 12 Bioaccumulation factors for the metals As, Ag, Se, Cd, Hg and MeHg April 2012. Note BAF is presented on a log scale.

Table 3- 1 Trace element concentrations in sediment (dry weight) collected along with clams by CBL and MDE in September 2011 and April 2012. The sediment was taken from the same sites but on different dates hence the data is different from what is shown in figures 3-1 to 3-7.

Sediment Sept.	As ug/g dry	Se ug/g dry	Ag ug/g dry	Cd ug/g dry	Pb ug/g dry	T-Hg ng/g dry	MeHg ng/g dry
MDE-1	0.86	UND	0.01	UND	2.26	6.28	UND
MDE-9	9.17	1.39	0.29	0.29	28.30	118.12	0.18
MDE-11	20.42	2.16	0.98	0.98	63.41	245.23	1.21
MDE-13	6.86	1.20	0.29	0.29	28.54	122.81	1.38
MDE-15	15.14	2.18	0.61	0.61	57.52	233.33	1.53
MDE-16	11.29	1.52	0.39	0.39	39.63	176.17	3.10
MDE-19	12.34	1.77	0.53	0.53	52.60	213.15	1.09
MDE-27	13.80	1.21	0.96	0.96	64.88	232.95	1.64
MDE-30	14.38	2.13	1.01	1.01	73.27	358.11	3.31
MDE-36	8.44	0.77	0.18	0.18	22.50	71.24	0.64
MDE-42	15.66	1.86	0.51	0.51	52.98	211.34	1.27
MDE-43	18.48	2.06	0.49	0.49	56.07	241.76	1.02
MDE-51	13.94	1.76	0.35	0.35	35.86	179.39	1.07

Sediment April	As ug/g dry	Se ug/g dry	Ag ug/g dry	Cd ug/g dry	Pb ug/g dry	T-Hg ng/g dry	MeHg ng/g dry
MDE-9	8.71	2.17	1.25	1.09	52.87	232.45	0.88
MDE-13	12.67	2.71	0.73	0.85	37.35	132.66	0.29
MDE-16	13.65	2.57	0.67	0.79	42.76	131.52	0.52
MDE-17	13.69	2.37	0.71	0.81	41.51	133.06	0.50
MDE-19	15.43	2.92	0.83	0.86	53.57	161.07	0.61
MDE-27	9.32	1.98	1.22	1.02	53.33	230.78	0.50
MDE-30	11.57	2.85	0.84	0.88	44.16	101.99	0.72
MDE-36	4.52	1.02	0.32	0.40	14.30	43.32	0.13
MDE-42	17.79	2.04	0.78	0.85	44.64	161.37	0.49
MDE-43	20.28	2.40	0.87	1.01	47.21	140.17	0.65
MDE-44	7.99	1.58	0.50	0.53	26.55	78.10	0.64
MDE-51	14.14	1.99	0.68	0.77	36.88	129.05	0.59

Investigating Potential Metal Toxicity

For some trace metals, toxicological affects criteria or guidelines have been established by the National Oceanic and Atmospheric Agency (NOAA). These guidelines have been used for available elements as a frame of reference for the overall condition of the sediment around HMI. The Probable Effects Levels (PEL) has been plotted along with the concentrations in sediments collected by MGS (Figures 3-13 and 3-14). For the metals As, Ag and Hg; sediment concentrations are below the PEL with the exception of site MDE-6, where the PEL is exceeded for As.

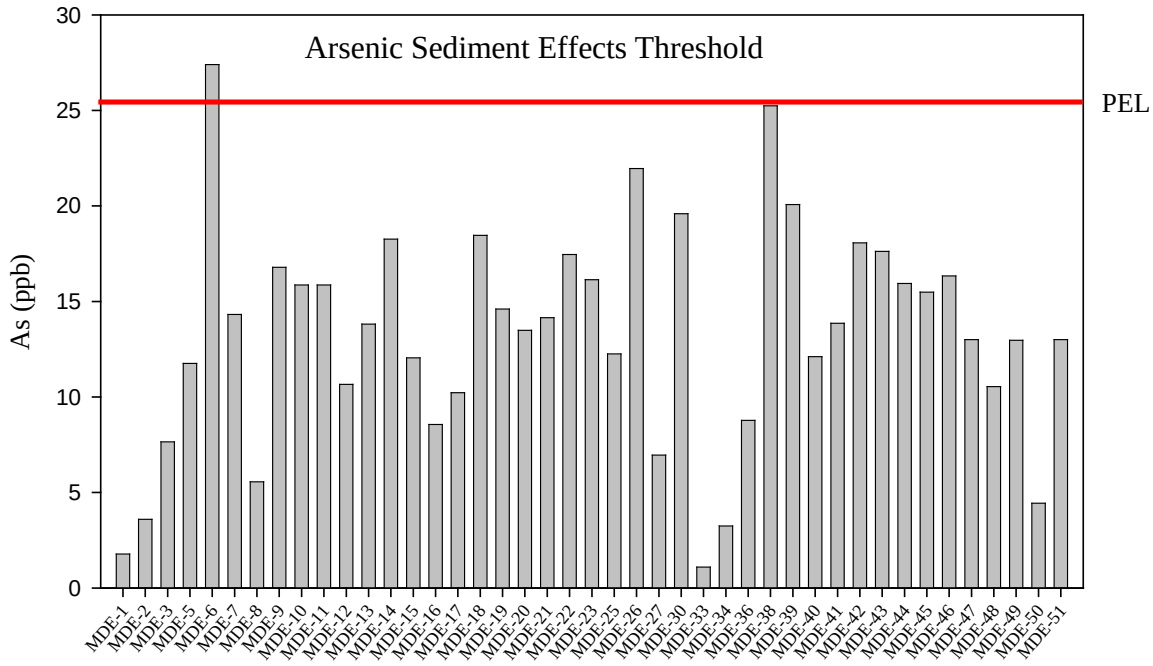


Figure 3- 13 Arsenic (As) concentrations in sediment along with the Probable Effects Level (PEL) as identified by NOAA for marine sediment.

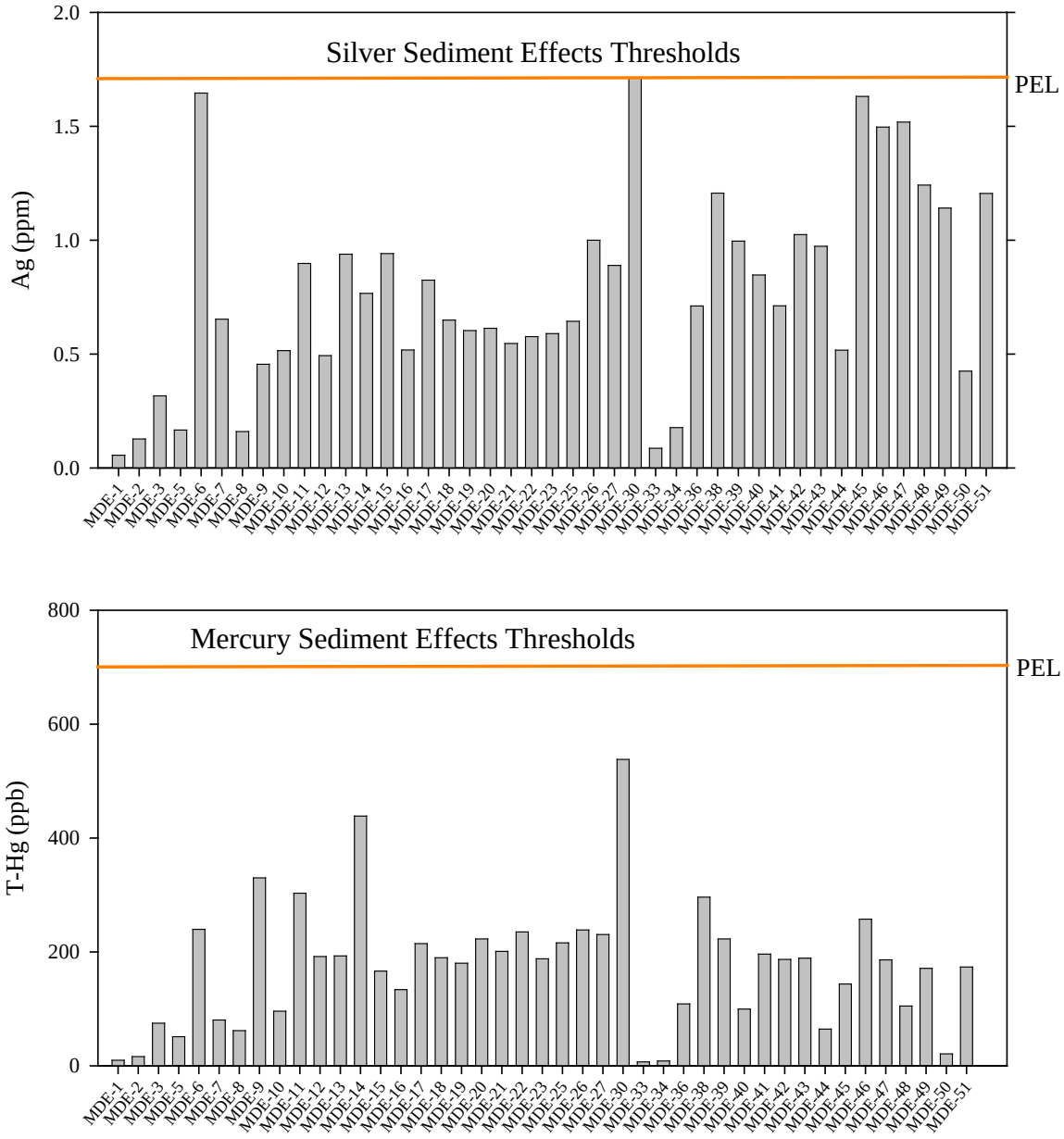
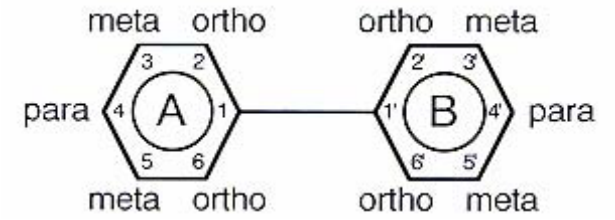


Figure 3- 14 Mercury (Hg) and Silver (Ag) concentrations in sediment along with Probable Effects Level (PEL) as identified by NOAA for marine sediment.

PCBs in Sediment

The PCB congeners analyzed in the sediments collected in September of 2011 are listed in Table 3-2. Each congener number indicates a different biphenyl molecule which has from 1 to 10 chlorine atoms attached at 10 possible sites as seen here.



The number of chlorine atoms attached and the placement around the biphenyl molecule is used in naming (Table 3-2). The degree of chlorination results in 10 groups: mono, tri, di, tetra, penta, hexa, hepta, octa, nona and decachlorobiphenyl. Within each group there exists the potential for a number of positional isomers and the sum of all the combinations is 209. More importantly, with increasing congener number the congeners become less soluble and bioavailable. Microorganisms have difficulty breaking down the more chlorinated molecules (5 or more chlorines). Because of continued refinement of analytical performance, more congeners were able to be measured in 2011 than in 2010. The congeners were regrouped to match previous years in order to perform a historical comparison and the congeners listed in this table match those shown in Figures 3-15 a-m (Table 3-3).The PCB congeners measured around HMI in 2011 are summarized in Figure 3-15 a-m. These figures provide a “signature” from which to investigate trends within and among sites. Not all congeners can be differentiated by CBL analysis, and some congeners must be combined. For example congeners 31 and 38 cannot be separated by the GC column and are said to co-elute and CBL designate the peak 31+28.

The sediments collected in 2011 contain high concentrations of the PCB congeners 31+28, 52, 66+95, 123 + 149, 118, 132+153+105, 163+138, 158, 201, 208+195, 206 and 209. The concentrations of these congeners define the sediment sample signatures in 2011. High concentrations of these congeners occur in most of the previous years, and this is very evident in the plots of the running means and medians for each of the sites. Site MDE-11 has a series of congeners that are not commonly found at other sites. These are Cong 25, Cong 146, Cong pair 77 + 110, Cong 197 and Cong 198. MDE-11 was sampled previously in 2009, at which time a wide range in PCBs was also detected, but the PCB finger print is not entirely the same between the two years. In general, concentrations of many PCB congeners were consistent with site means from previous years. The congener concentrations are weighted toward the higher numbers which is to be expected, as with the increasing degree of chlorination the less soluble they are in water and more likely to stay bound to sediment (Table 3-4). With exception of MDE-11 the congener patterns in sediment from around the island are similar, and no group of congeners indicates the presence of a unique source.

Table 3- 2 Polychlorinated biphenyl congeners measured by CBL in 2011. The congeners that can be detected vary slightly from year to year. In 2011 more congeners could be accurately measured than in 2010 (table 3-3). Most of the additional congeners that could be measured were not detected, hence they add little to the total PCB concentration.

1	Cong-1	Mono	35	Cong-63	Tetra	69	Cong-176	Hepta
2	Cong-2	Mono	36	Cong-74	Tetra	70	Cong-130,137	Hexa,Hexa
3	Cong-3	Mono	37	Cong-70,76	Tetra	71	Cong-164,163,138,158	Hexa,Hexa,Hexa Hexa
4	Cong-4,10	Di	38	Cong-93	Penta	72	Cong-129	Hexa
5	Cong-7,9	Di	39	Cong-66	Tetra	73	Cong-174	Hepta
6	Cong-6	Di	40	Cong-95	Penta	74	Cong-187	Hepta
7	Cong-8,5	Di	41	Cong-91	Penta	75	Cong-183	Hepta
8	Cong-19	Tri	42	Cong-56,60	Tetra	76	Cong-128,167	Hexa
9	Cong-12,13	Di	43	Cong-92	Penta	77	Cong-185	Hepta
10	Cong-18	Tri	44	Cong-84	Penta	78	Cong-174	Hepta
11	Cong-15	Di	45	Cong-101,90,89	Penta,Penta,Penta	79	Cong-177	Hepta
12	Cong-17	Tri	46	Cong-99	Penta	80	Cong-156	Hexa
13	Cong-24	Tri	47	Cong-119	Penta	81	Cong-202	Octa
14	Cong-16,32	Tri	48	Cong-83	Penta	82	Cong-171	Hepta
15	Cong-29	Tri	49	Cong-97	Penta	83	Cong-157	Hexa
16	Cong-26	Tri	40	Cong-81	Tetra	84	Cong-200	Octa
17	Cong-25	Tri	51	Cong-87,115	Penta,Penta	85	Cong-172	Hepta
18	Cong-31,28	Tri	52	Cong-85	Penta	86	Cong-197	Hepta
19	Cong-20.33,41	Tri	53	Cong-136	Hexa	87	Cong-180, 193	Hepta
20	Cong-51	Tetra	54	Cong-77	Tetra	88	Cong-191	Hepta
21	Cong-53	Tetra	55	Cong-110	Penta	89	Cong-199	Octa
22	Cong-22	Tri	56	Cong-82	Penta	90	Cong-170,190	Hepta
23	Cong-45	Tetra	57	Cong-151	Hexa	91	Cong-198	Octa
24	Cong-46	Tetra	58	Cong-135,144	Hexa	92	Cong-201	Octa
25	Cong-52	Tetra	59	Cong-107	Penta	93	Cong-203,196	Octa
26	Cong-49	Tetra	60	Cong-149	Hexa	94	Cong-189	Hepta
27	Cong-47,48	Tetra	61	Cong-118,106	Penta	95	Cong-195	Octa
28	Cong-44	Tetra	62	Cong-134	Hexa	96	Cong-208	Nona, Octa
29	Cong-37	Tri	63	Cong-114	Penta	97	Cong-207	Nona
30	Cong-42	Tetra	64	Cong-146	Hexa	98	Cong-194	Octa
31	Cong-41,64,71	Tetra	65	Cong132,153,105	Hexa,Hexa,Penta	99	Cong-205	Octa
32	Cong-103	Penta	66	Cong-105	Penta	100	Cong-206	Nona
33	Cong-40	Tetra	67	Cong-141	Hexa	101	Cong-209	Deca
34	Cong-100	Penta	68	Cong-179	Hepta			

Table 3- 3 The polychlorinated biphenyl congeners shown in Figure 3-15a-m. For continuity in finger printing only the PCB congeners that have been detected over the life of the project are listed here. Thus, not all the PCB congeners measured (table 3-2), are shown in figures 3-15a-m. This was done to allow inter year comparisons.

1	Cong-1	Mono	30	Cong-63	Tetra	59	Cong-187,182	Hepta
2	Cong-3	Mono	31	Cong-74	Tetra	60	Cong-183	Hepta
3	Cong-4,10	Di	32	Cong-70,76	Tetra	61	Cong-128,167	Hexa
4	Cong-7,9	Di	33	Cong-66,95	Tetra, Penta	62	Cong-185	Hepta
5	Cong-6	Di	34	Cong-91	Penta	63	Cong-174	Hepta
6	Cong-8,5	Di	35	Cong-56,60	Tetra	64	Cong-177	Hepta
7	Cong-19	Tri	36	Cong-89	Penta	65	Cong-202,171,156	Octa,Hepta, Hexa
8	Cong-12,13	Di	37	Cong-101	Penta	66	Cong-157	Hexa
9	Cong-18	Tri	38	Cong-99	Penta	67	Cong-172,197	Hepta
10	Cong-17	Tri	39	Cong-119	Penta	68	Cong-180	Hepta
11	Cong-24	Tri	40	Cong-83	Penta	69	Cong-193	Hepta
12	Cong-16,32	Tri	41	Cong-97	Penta	70	Cong-191	Hepta
13	Cong-29	Tri	42	Cong-81,87	Tetra, Penta	71	Cong-199	Octa
14	Cong-26	Tri	43	Cong-136	Hexa	72	Cong-170,190	Hepta
15	Cong-25	Tri	44	Cong-77,110	Tetra, Penta	73	Cong-198	Octa
16	Cong-31,28	Tri	45	Cong-151	Hexa	74	Cong-201	Octa
17	Cong-33,21,53	Tri	46	Cong-134,144	Hexa	75	Cong-203,196	Octa
18	Cong-51	Tetra	47	Cong-107	Penta	76	Cong-189	Hepta
19	Cong-22	Tri	48	Cong-123,149	Pent, Hexa	77	Cong-208,195	Nona, Octa
20	Cong-45	Tetra	49	Cong-118	Penta	78	Cong-207	Nona
21	Cong-46	tetra	50	Cong-134	Hexa	79	Cong-194	Octa
22	Cong-52	Tetra	51	Cong-114	Penta	80	Cong-205	Octa
23	Cong-49	Tetra	52	Cong-146	Hexa	81	Cong-206	Nona
24	Cong-48,47	Tetra	53	Cong132,153,105	Hexa,Hexa,Penta	82	Cong-209	Deca
25	Cong-44	Tetra	54	Cong-141	Hexa			
26	Cong-37,42	Tri, tetra	55	Cong-137,130,176	Hexa, Hexa, Hepta			
27	Cong-41,64,71	Tetra	56	Cong-163,138	Hexa			
28	Cong-40	Tetra	57	Cong-158	Hexa			
29	Cong-100	Penta	58	Cong-129,178	Hexa,Hepta			

Table 3- 4 Polychlorinated biphenyl homologs and properties.

Number of Chlorines	Homolog Group	Molecular Formula	Molecular Weight	Number of Isomers	Solubility (ug/L)
0	Biphenyl	$C_{12}H_{10}$	154.1	1	7000
1	Mono	$C_{12}H_9Cl$	188.0	3	1200-5500
2	Di	$C_{12}H_8Cl_2$	222.0	12	60-2000
3	Tri	$C_{12}H_7Cl_3$	256.0	24	15-100
4	Tetra	$C_{12}H_6Cl_4$	289.9	42	4.3-100
5	Penta	$C_{12}H_5Cl_5$	323.9	46	4-20
6	Hexa	$C_{12}H_4Cl_6$	357.8	42	0.4-1.0
7	Hepta	$C_{12}H_3Cl_7$	391.8	24	0.45-2.0
8	Octa	$C_{12}H_2Cl_8$	425.8	12	0.2-3.0
9	Nona	$C_{12}HCl_9$	459.7	3	0.018-0.11
10	Deca	$C_{12}Cl_{10}$	493.7	1	0.0012

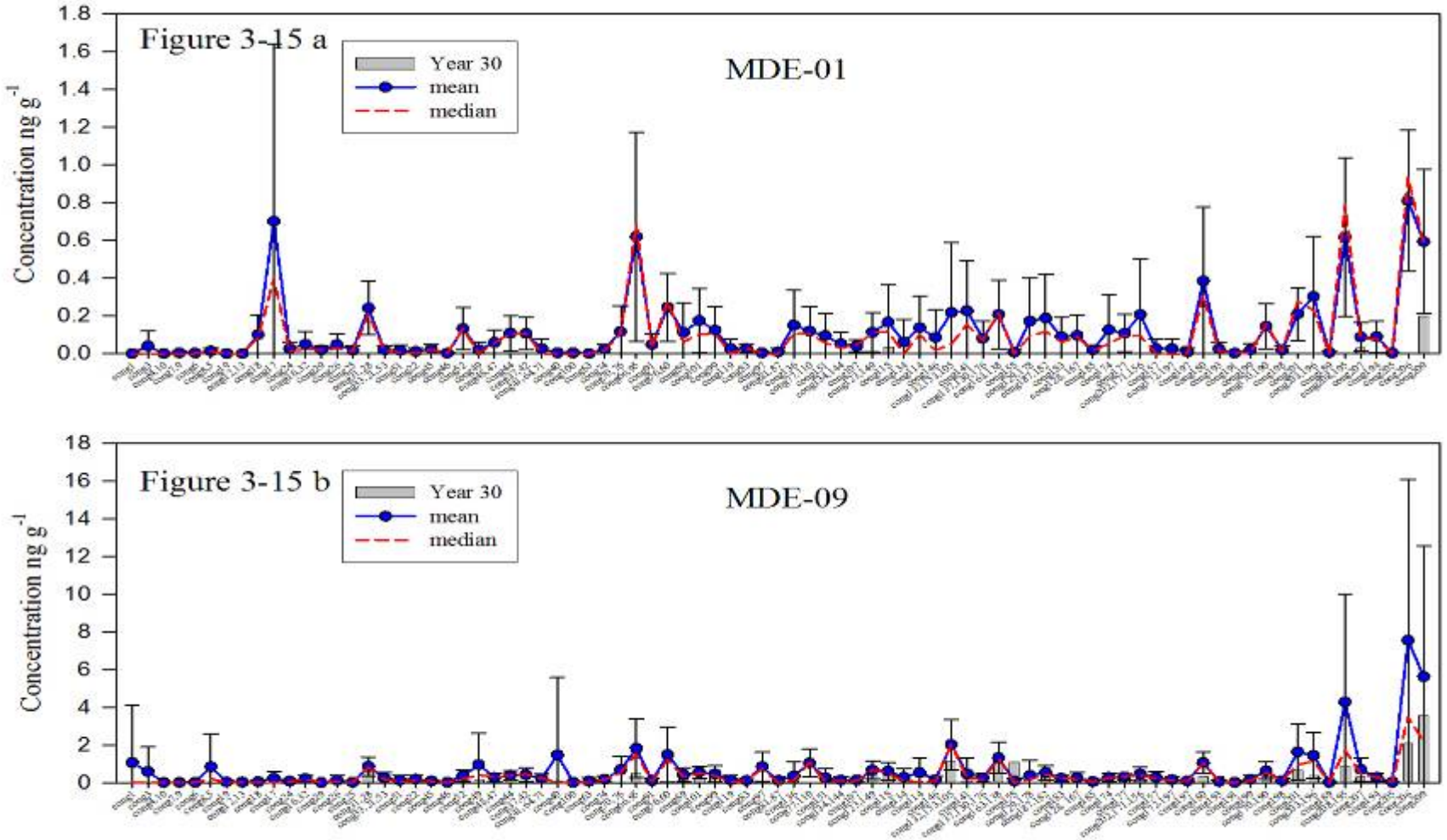


Figure 3- 15 Concentrations of PCB congeners in sediments from sites MDE-01 and MDE-09 from the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line) expressed in ng g^{-1} dry weight.

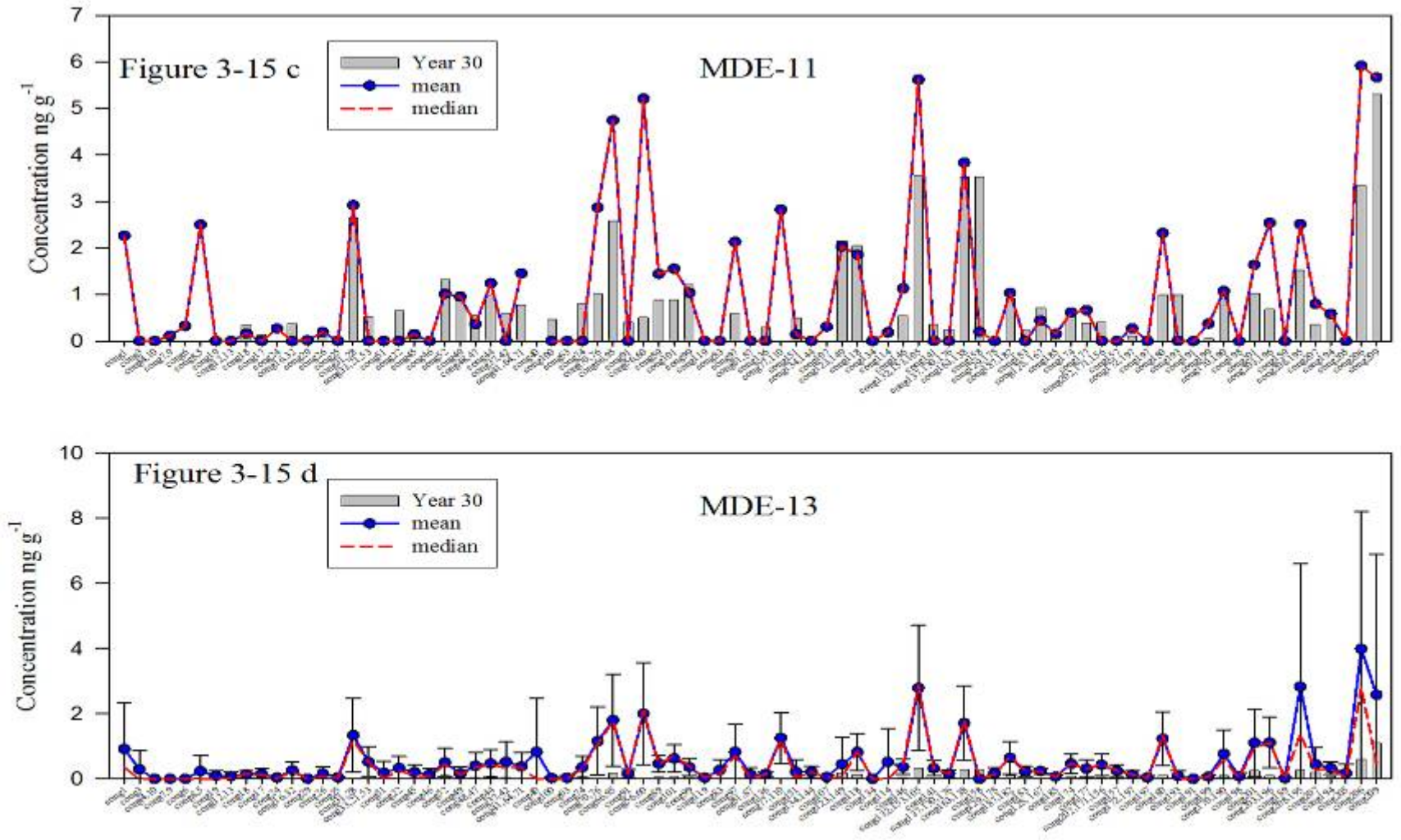


Figure 3-15 continued. Concentrations of PCB congeners in sediments from sites MDE-11 and MDE-13 from the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line) expressed in ng g^{-1} dry weight.

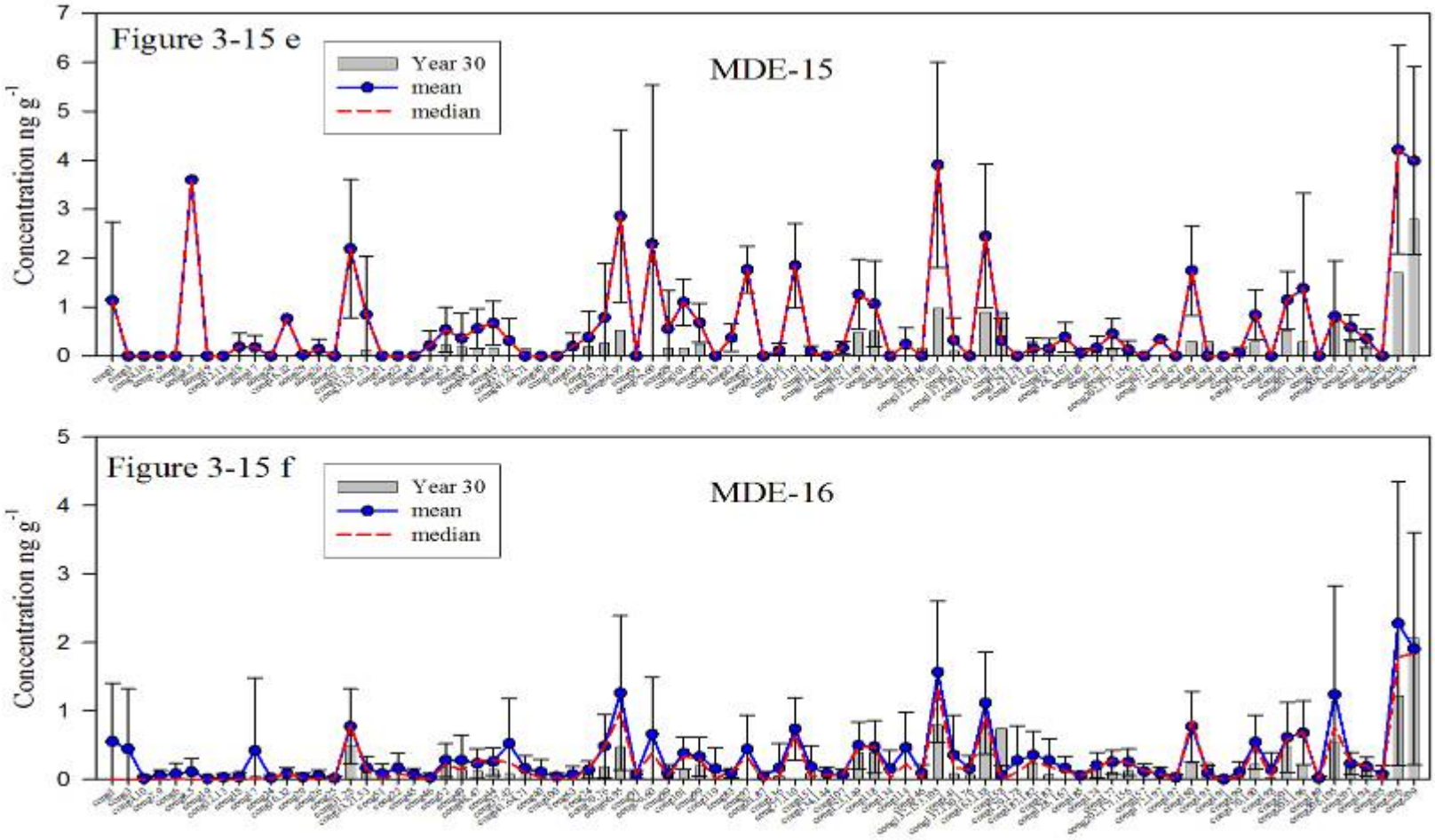


Figure 3-15 continued. Concentrations of PCB congeners in sediments from sites MDE-15 and MDE-16 from the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line) expressed in ng g^{-1} dry weight.

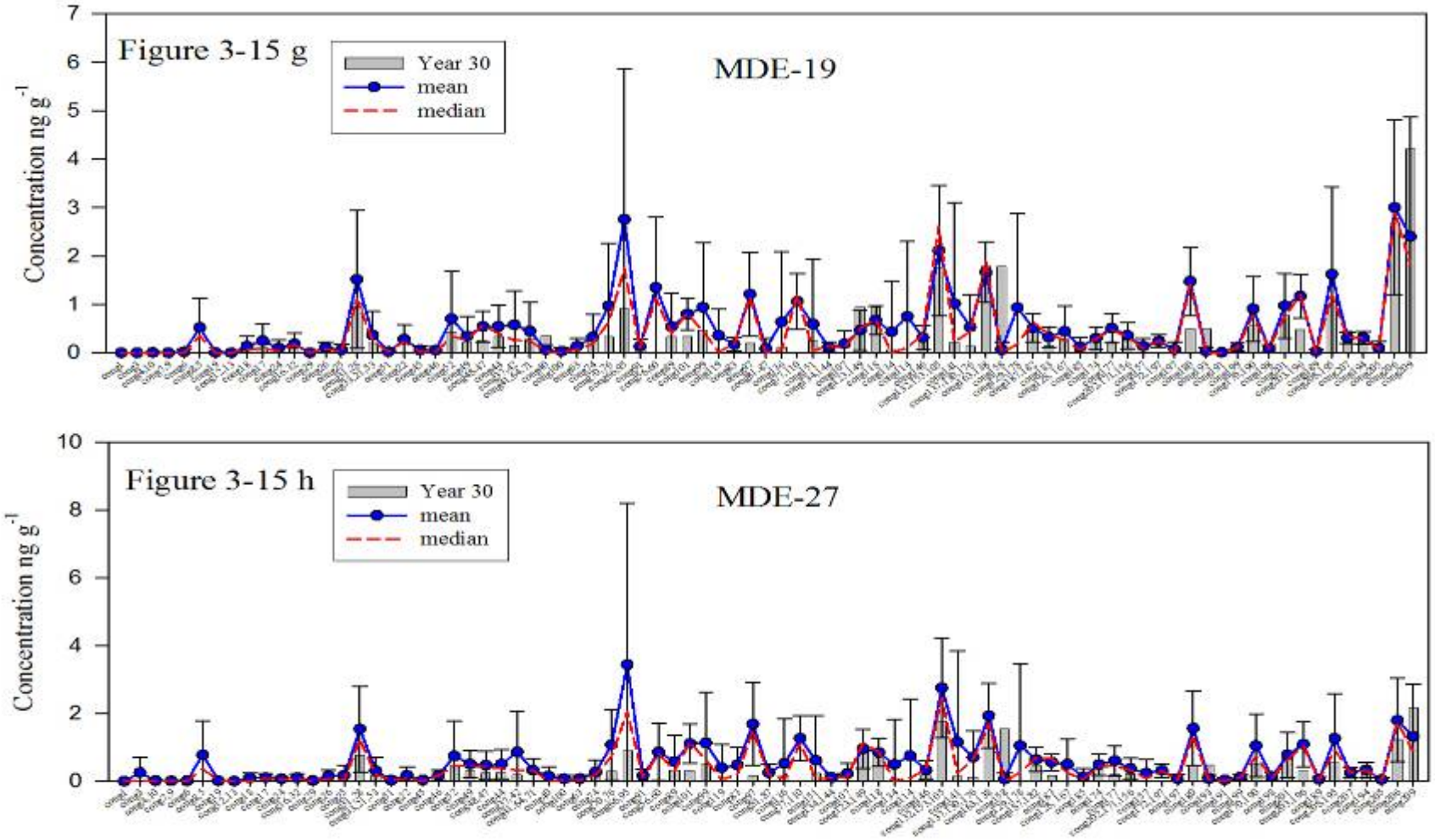


Figure 3-15 continued. Concentrations of PCB congeners in sediments from sites MDE-19 and MDE-27 from the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line) expressed in ng g^{-1} dry weight.

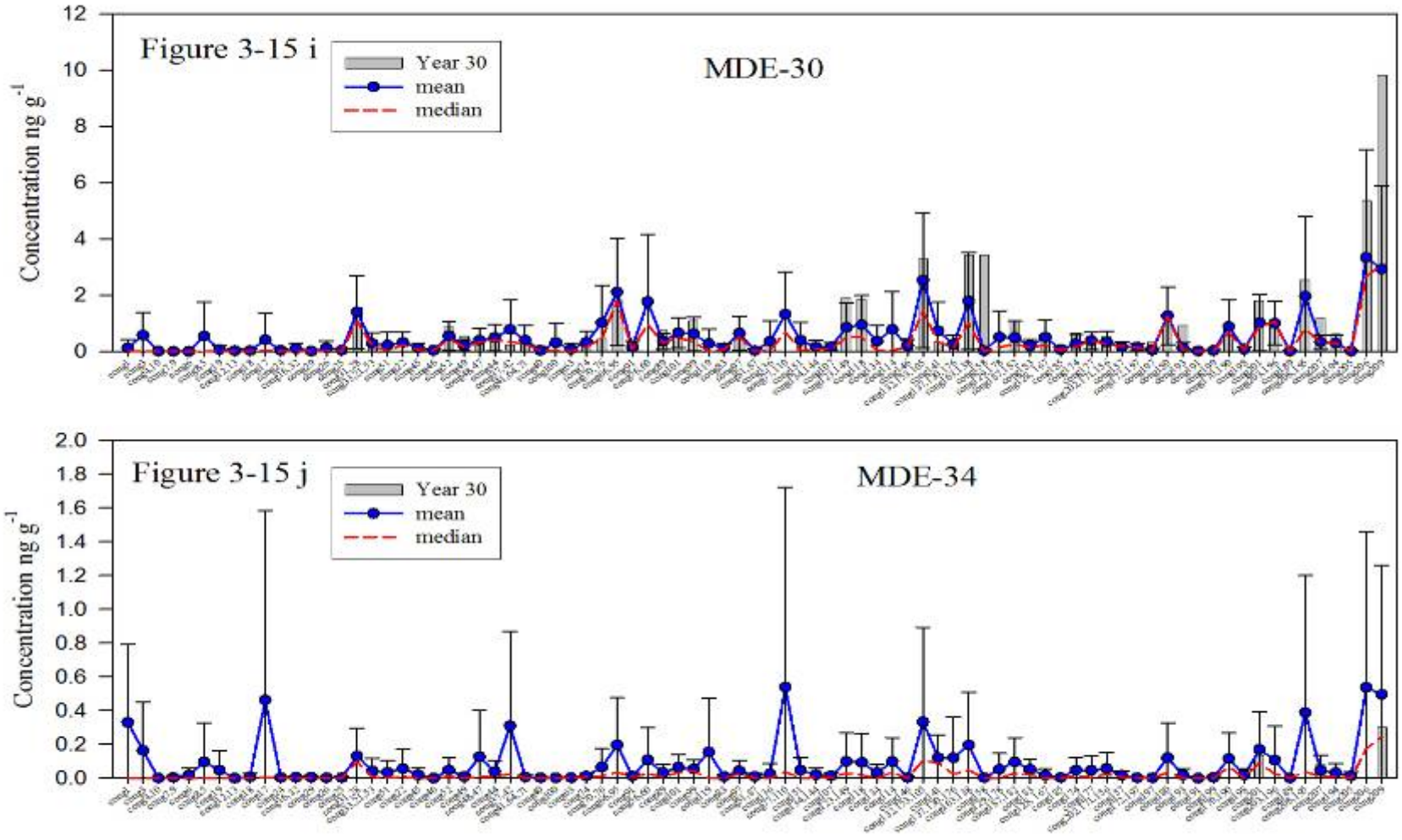


Figure 3-15 continued. Concentrations of PCB congeners in sediments from sites MDE-30 and MDE-34 from the fall of 2011, the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line) expressed in ng g^{-1} dry weight.

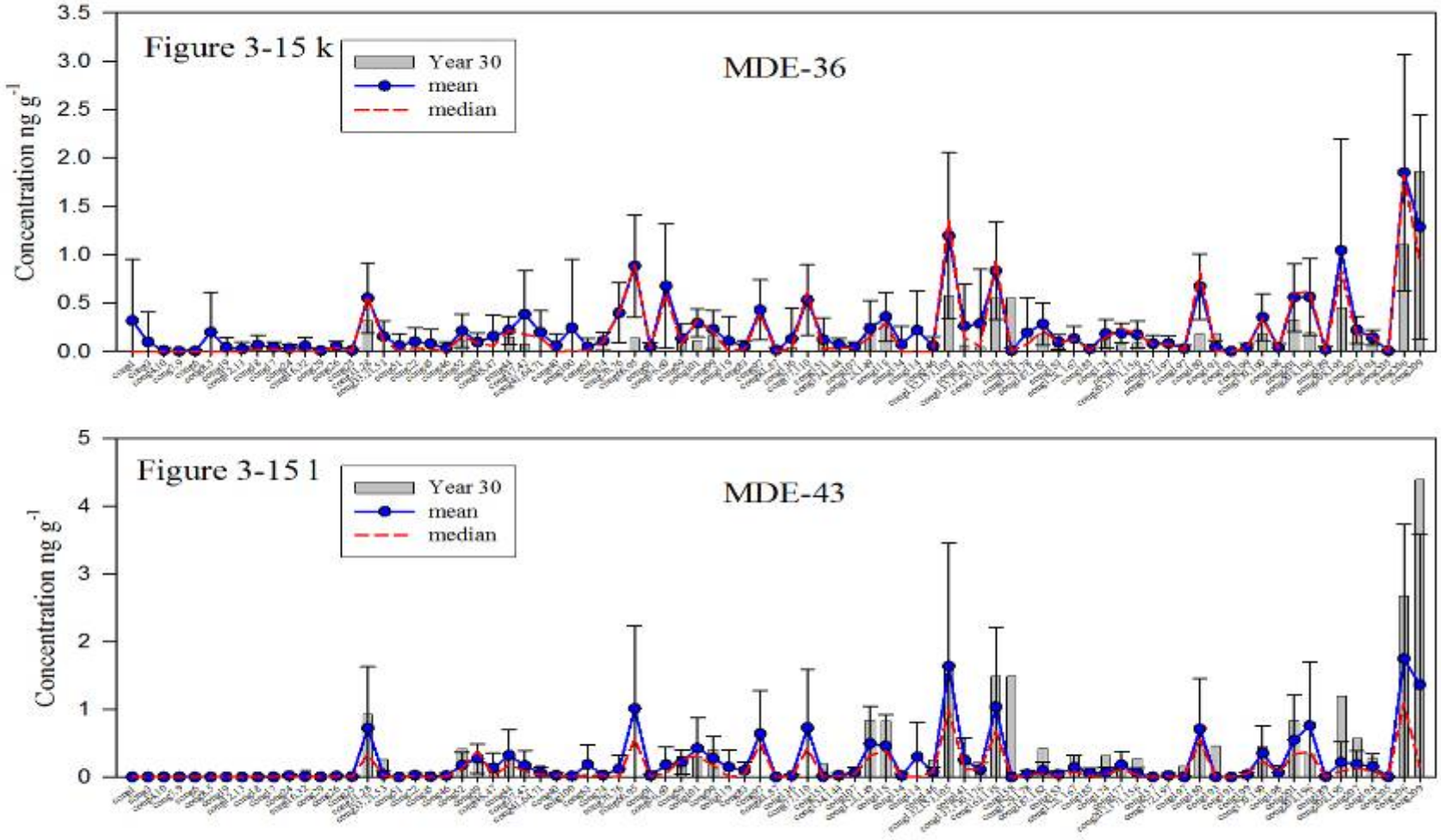


Figure 3-15 continued. Concentrations of PCB congeners in sediments from sites MDE-36 and MDE-43 collected in the fall of 2011. The 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line) expressed in ng g^{-1} dry weight.

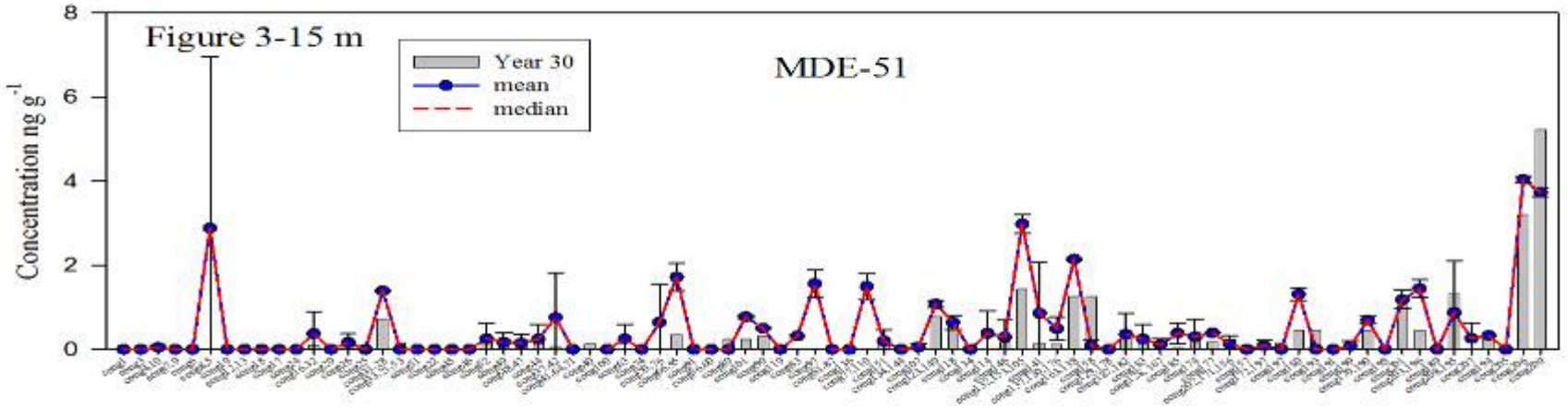


Figure 3-15 continued. Concentrations of PCB congeners in sediments from site MDE-51 collected in the fall of 2011. The 2008-2010 mean with standard deviation (blue circles and error bars) and the 2008-2010 median (dashed line) expressed in ng g^{-1} dry weight

PCB congener profiles in Clams

The PCBs congeners determined in the clams collected in September of 2011 are listed in Table 3-3. As was the case for sediments, for continuity of examining change over time, only the PCBs listed in table 3-4 are plotted in figure 3-16a-k. As in the case of the sediment, these figures provide a "signature" from which to investigate trends in the types and amounts of PCBs within and among the sites. The clams traditionally have contained significant amounts of the congener and congener groups 66+95, 99, 132+153+105, 163+138, 158, 187+182, 203 +196, 208+195, 206, 209. The lower mass congener 18 and the congener pair 31+28 were also commonly found although at very low concentrations. While the amounts of individual congeners change between the sites, the congener pattern is very similar across all the sites. MDE-27 has elevated concentrations in a number of congeners compared to the 8 other past sampling occasions. Concentrations of Congener groups163+138, 32 + 133 + 105, 123 + 149 and the Cong-58 are elevated when compared to other years, so much so that they affect the total concentration see below.

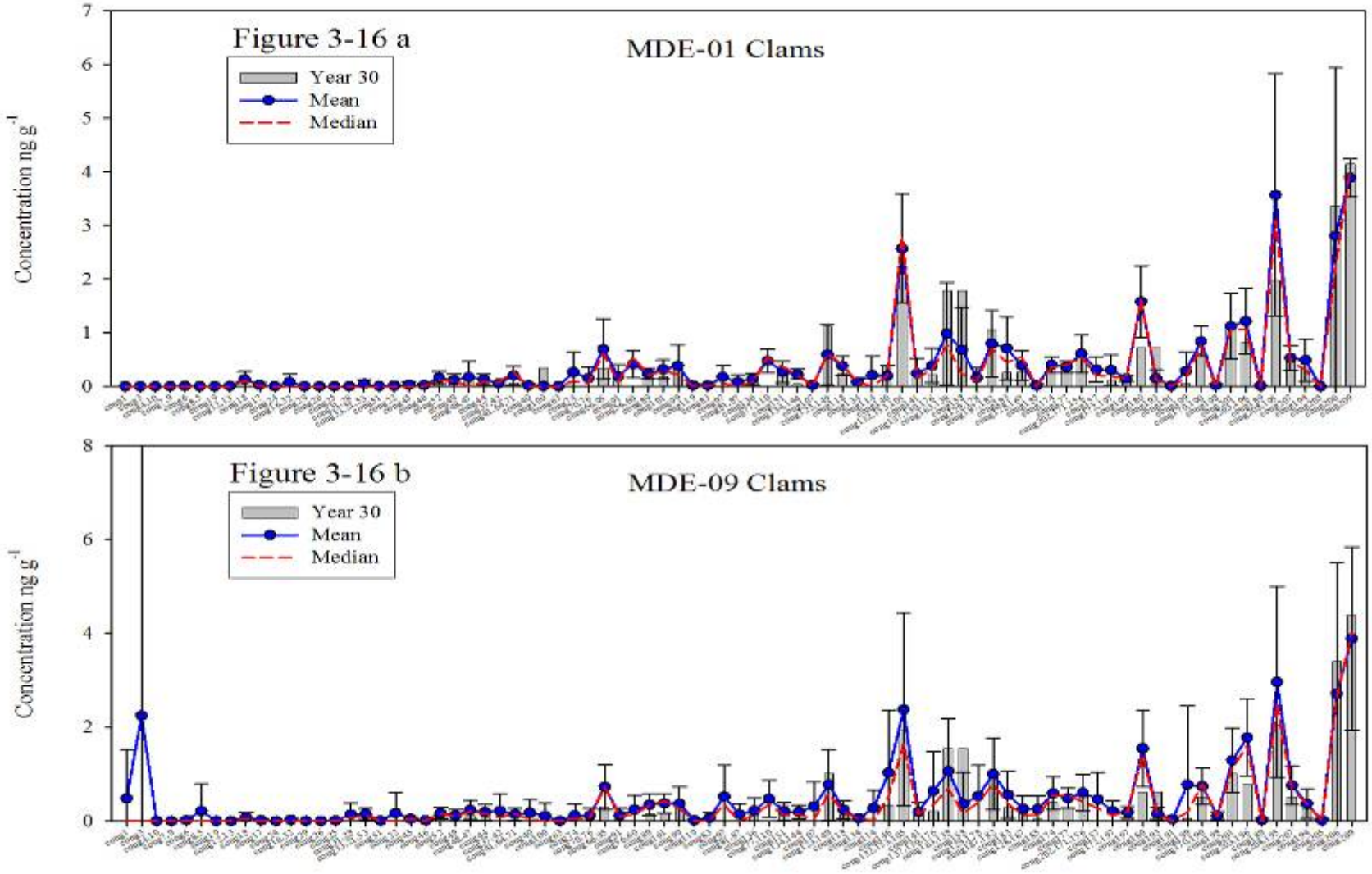


Figure 3- 16 Concentrations of PCB congeners in clams from sites MDE-01 and MDE-09 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line) expressed in ng g^{-1} wet weight.

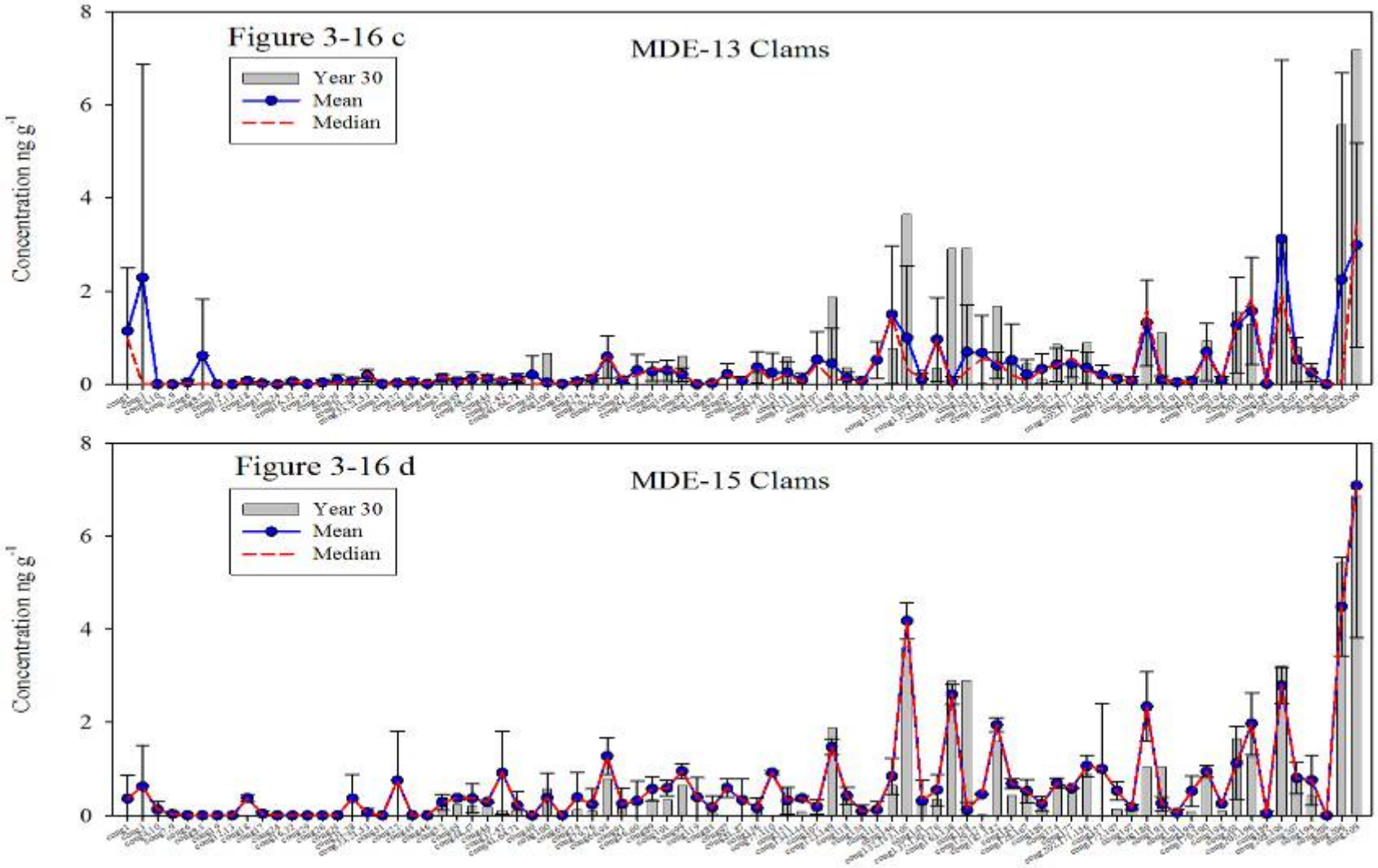


Figure 3-16 continued. Concentrations of PCB congeners in clams from sites MDE-13 and MDE-15 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line) expressed in ng g^{-1} wet weight.

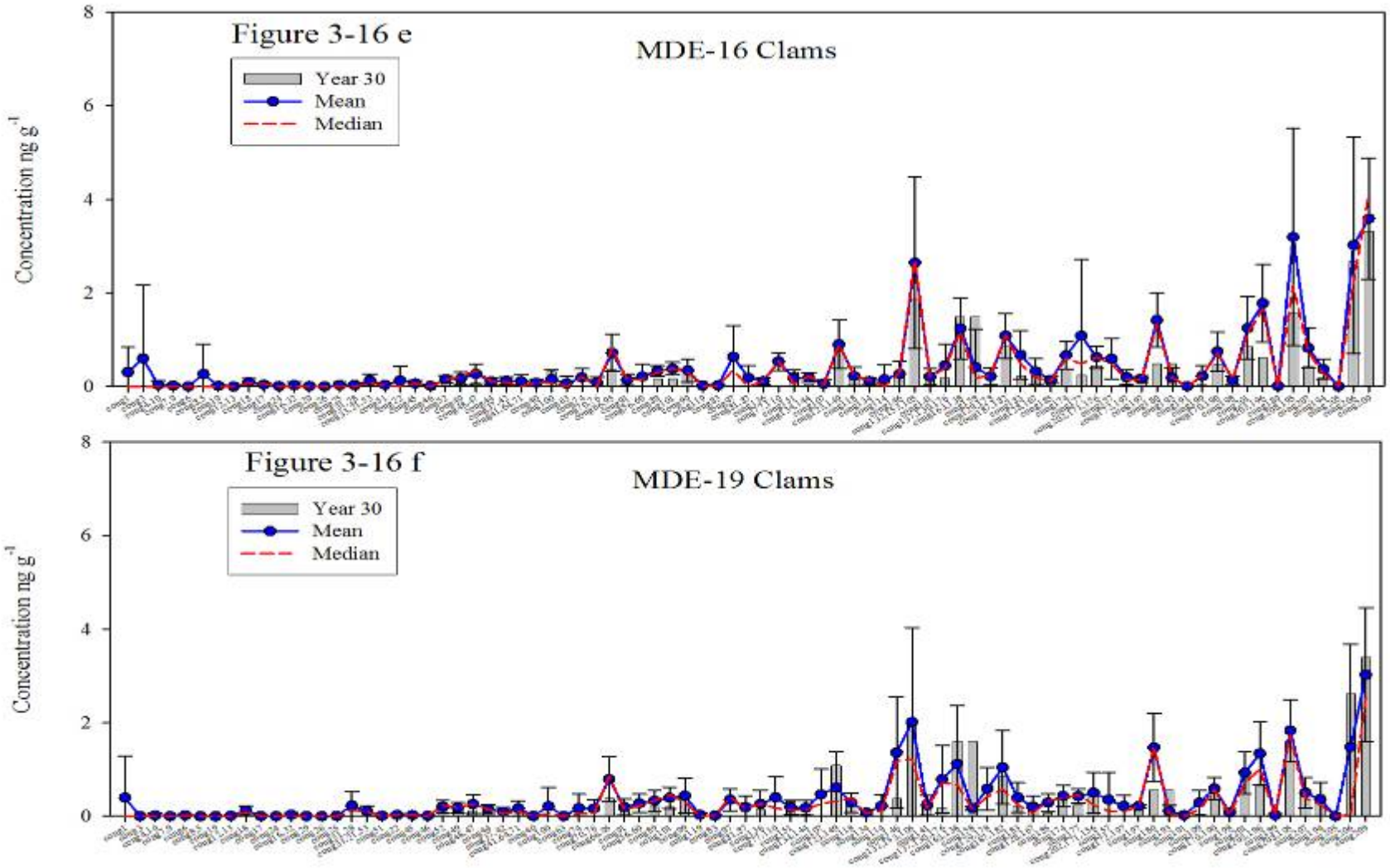


Figure 3-16 continued. Concentrations of PCB congeners in clams from sites MDE-16 and MDE-19 obtained in the fall of 2011(bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line) expressed in ng g^{-1} wet weight.

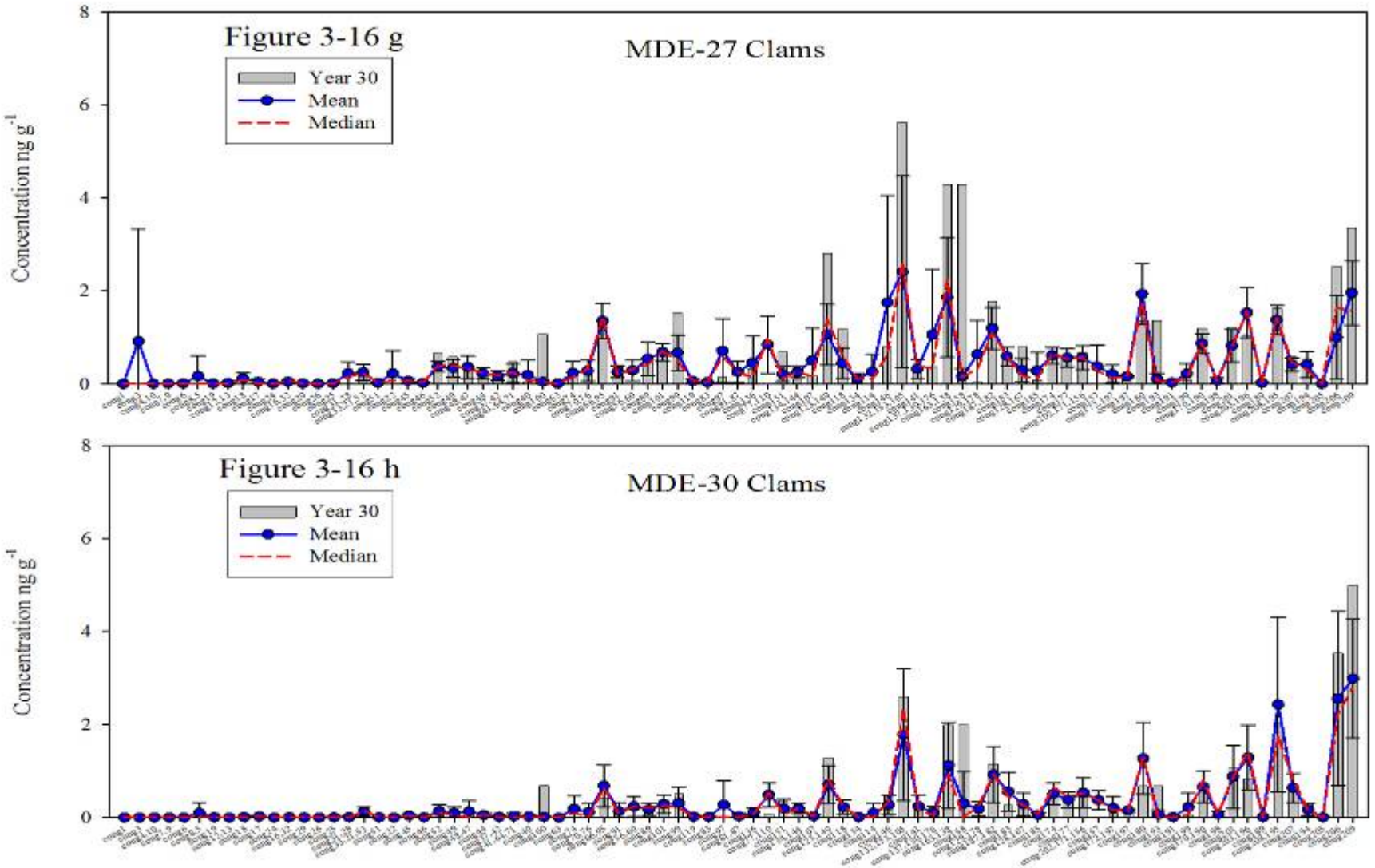


Figure 3-16 continued. Concentrations of PCB congeners in clams from sites MDE-27 and MDE-30 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line) expressed in ng g^{-1} wet weight.

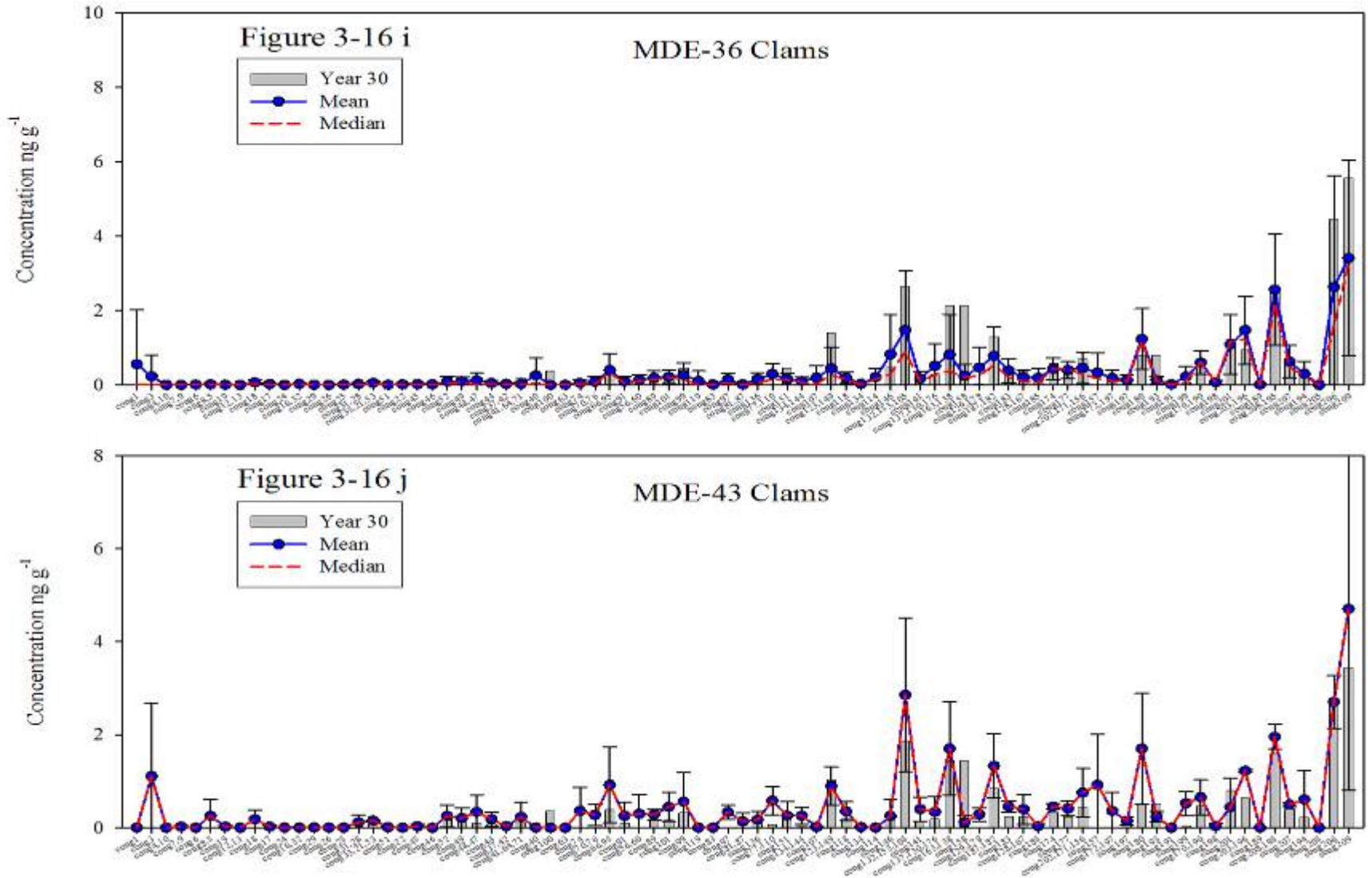


Figure 3-16 continued. Concentrations of PCB congeners in clams from sites MDE-36 and MDE-43 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line) expressed in ng g^{-1} wet weight.

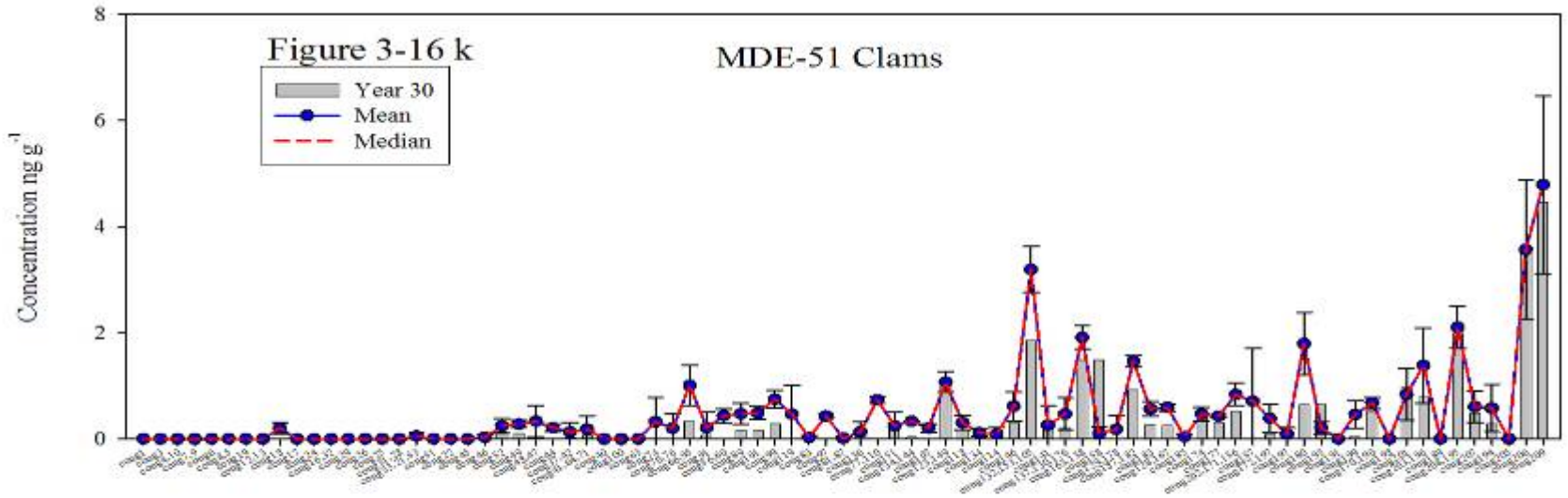


Figure 3-16 continued. Concentrations of PCB congeners in clams from site MDE-51 obtained in the fall of 2011 expressed in ng g^{-1} wet weight (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line) expressed in ng g^{-1} wet weight.

Total PCB concentrations in sediments and clams

The total concentration of PCBs in sediments and clams at each site were calculated by summing the PCB congener concentrations and these totals were compared to previous years (Figure 3-17). The total PCB concentrations in sediment collected in September 2011 were similar to or below the historical site averages, being within the standard deviation of the mean. Total PCB concentrations in clams were similar to the running mean for all sites. Concentrations of PCBs in clams collected from MDE-27 were higher than the running mean and outside the standard deviation of the previous years. As indicated above, 4 conger clusters were largely responsible for the overall increase. The congener distributions in sediment (Figure 3-15) and clams (Figure 3-16) are similar for the same site.

Many older studies have relied on PCB homologs, classes of PCBs with similar structure. The homolog distributions for sediment and clams for each site were plotted as percentage of the total PCB concentration in Figure 3-18, 3-19. In these plots, the reference site (MDE-36) is plotted with each of the other sampled sites as a guide. The homolog distribution is remarkably consistent with all sites following the same pattern as the reference site MDE-36. PCBs in the Hexa class are highest at all sites. The distribution of homologs measured in clams track the control site (MDE-36). While the magnitude of PCB concentrations changes among the sites, the distribution in PCB homologs does not. This suggests source composition is similar and only strength of source or the ability to retain PCBs varies. This is very evident when the clams and sediment concentrations are plotted together, both as homolog concentration and as a homolog percentage of the total (Figure 3-20, 3-21), as the pattern of homologs in sediments and clams are the same. There is however, no relationship between clam and sediment total PCB concentration in Y30 which has been the case in previous years.

At each site the distribution of homologs (Table 3-4) in sediment and clams are very similar with perhaps a little bias to the lower molecular weight complexes in the sediment. The distributions among the sites are similar with the exception of MDE-1 which had very low concentrations of PCBs in the sediment and is unique unto its self (Figure 3-14a). The clams from MDE-1 have a homolog distribution that is similar to other sites but the sediment is bias toward the high molecular weight PCBs. MDE-1 sediment contains little organic matter and thus it is likely to retain fewer PCBs.

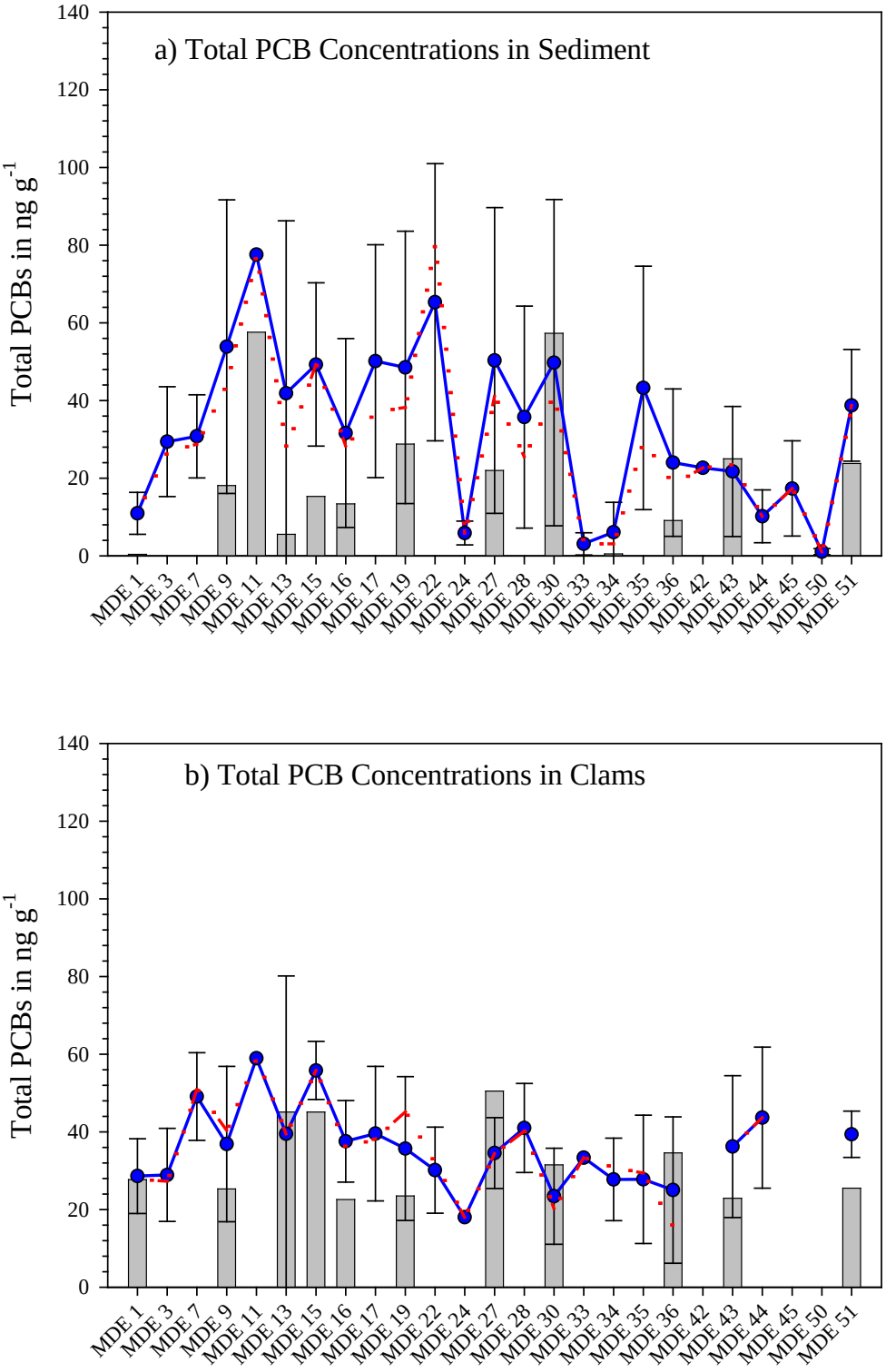


Figure 3- 17 Total PCB concentrations in sediments (a) (ng g^{-1} dry weight) and total PCB concentrations in clams (ng g^{-1} wet weight) collected in September 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line).

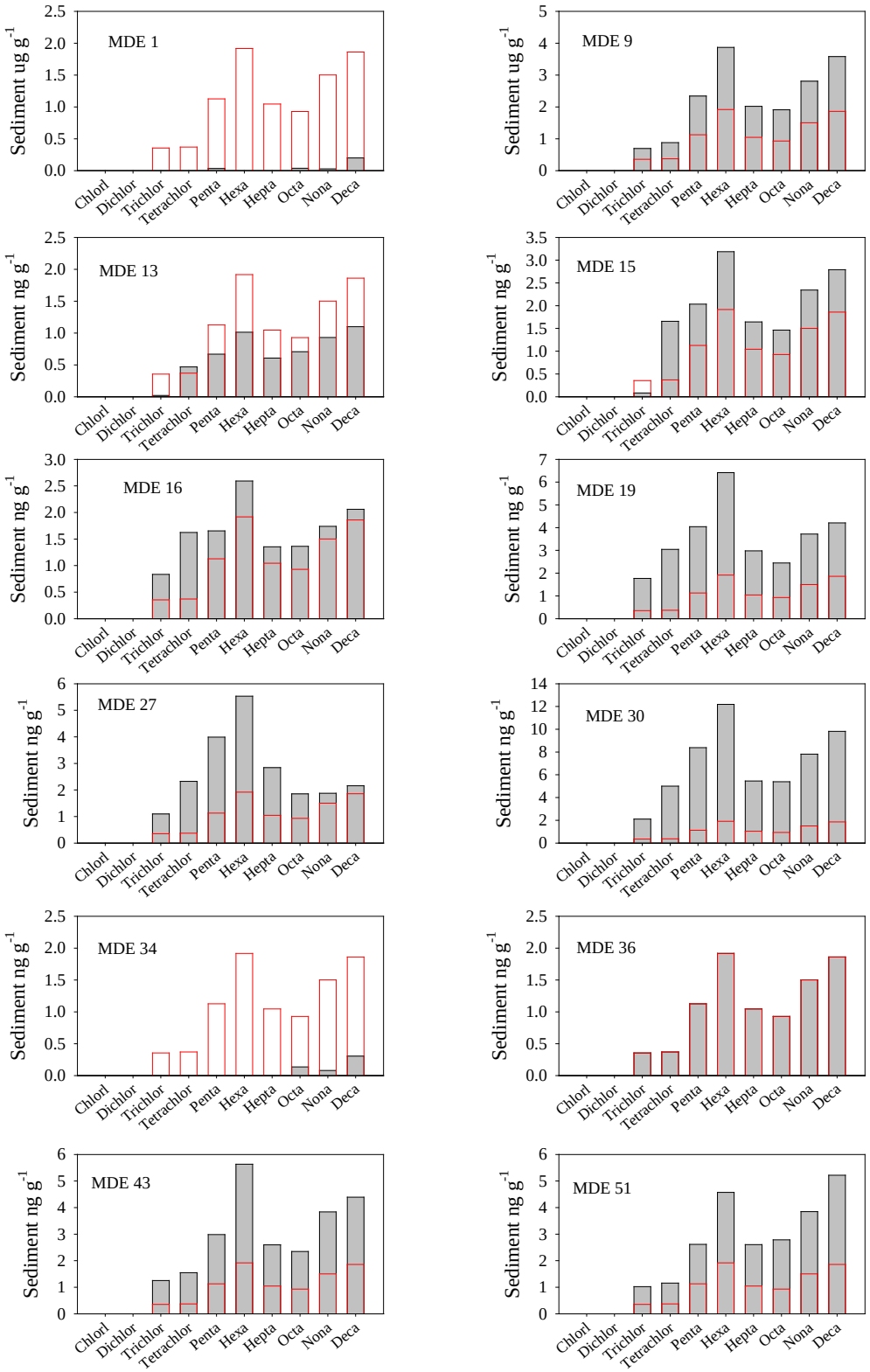


Figure 3- 18 PCB homolog distributions in sediment. The reference site MDE-36 is plotted in red on all plots as guide.

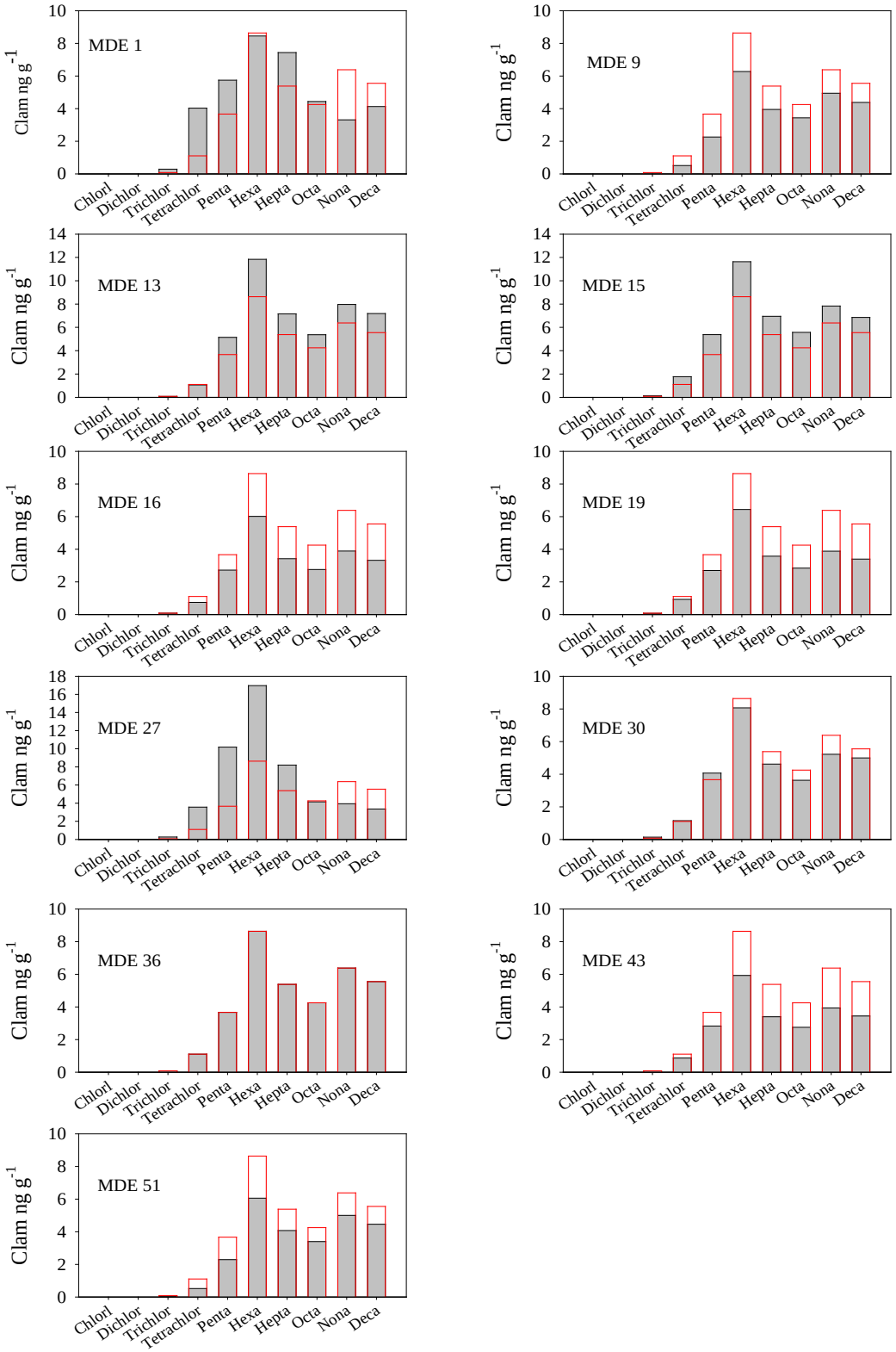


Figure 3- 19 PCB homolog distributions in clams (ng g^{-1}) wet weight. The reference site MDE-36 is plotted in red on all plots as guide.

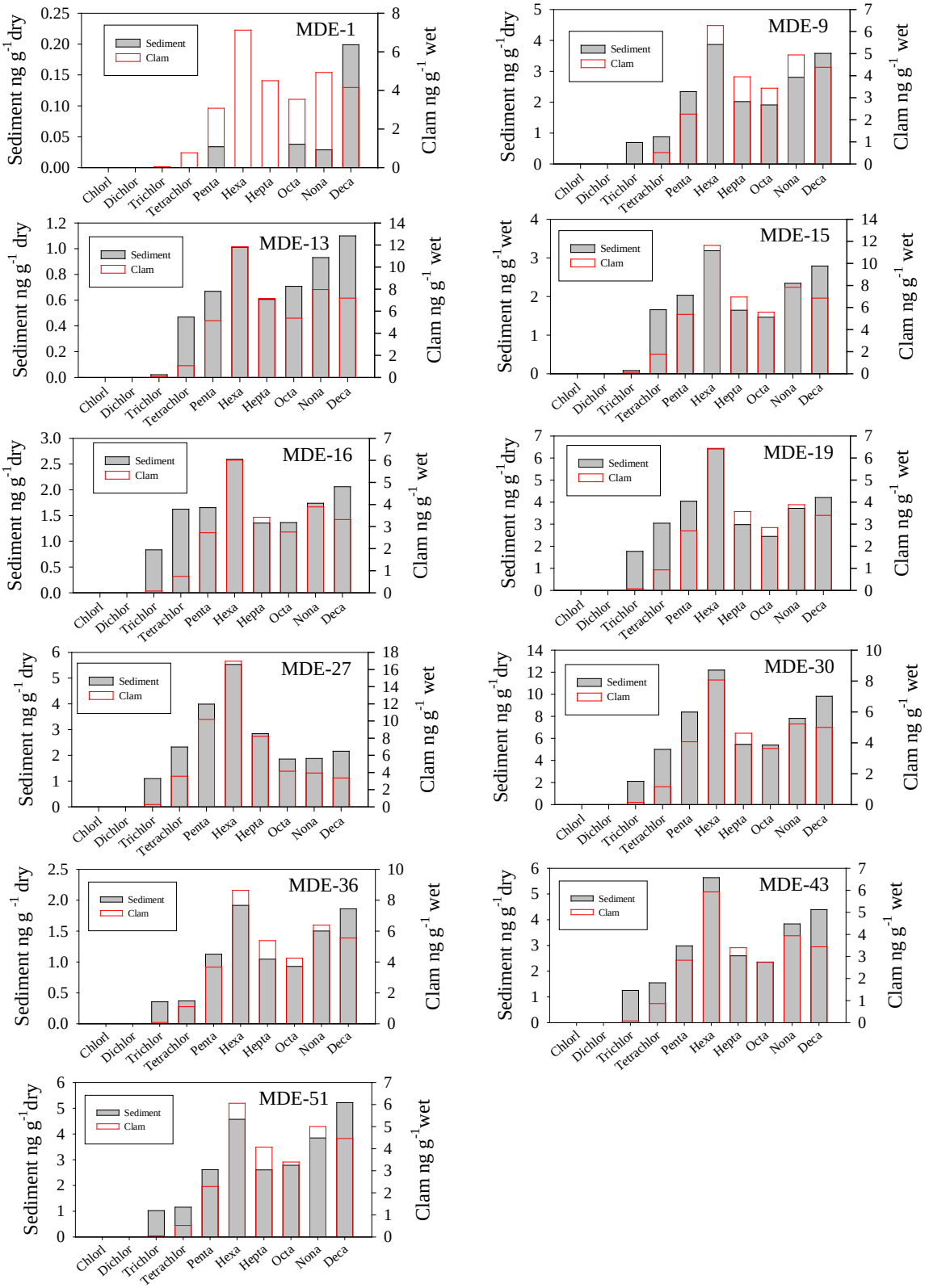


Figure 3- 20 PCB homolog distributions in sediment and clams of each HMI site.

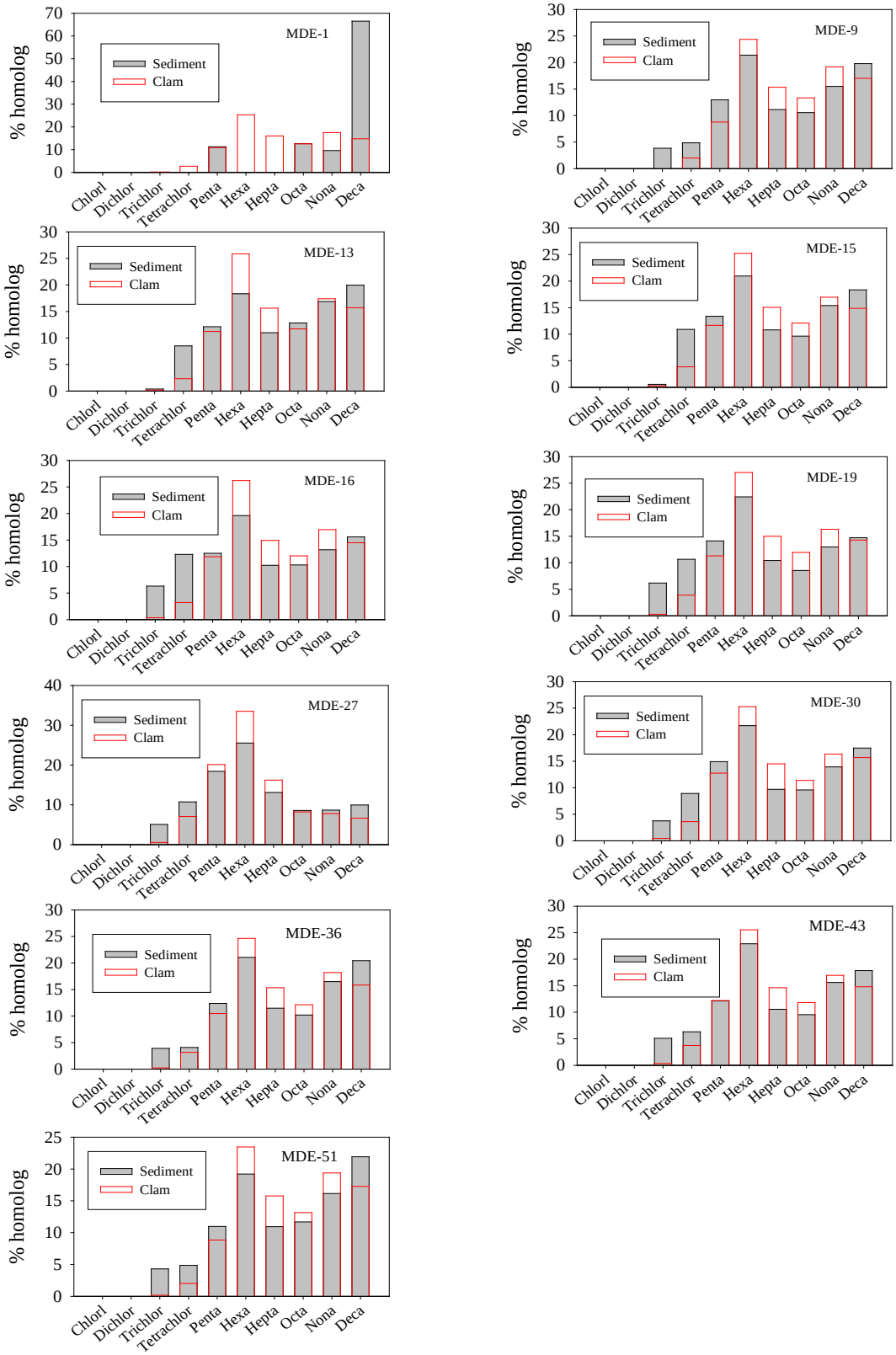


Figure 3- 21 PCB homolog distribution in sediment and clams as a % of total.

Polycyclic Aromatic Hydrocarbons in Sediments

The fingerprints obtained by identifying and measuring the concentrations of a series of polycyclic aromatic hydrocarbons (PAHs) (Table 3-5) from sites in the vicinity of HMI are shown in Figure 3-22a-m. The most common compounds are: naphthalene, 2-methylnaphthalene, phenanthrene, fluoranthene, pyrene, benzo[b]fluoranthene, and perylene. The relative proportions of these compounds together form a distinct pattern that can be found at almost all the HMI sites. With the exception of naphthalene, which originates from coal tar, these compounds are combustion products of gasoline, diesel and municipal waste, mostly delivered via particles or soot. PAH concentrations at sites MDE-1 and MDE-34 were lower than has been observed in past samplings. Site MDE-30 and MDE-43 had higher concentrations of the most common (naphthalene, 2-methylnaphthalene, phenanthrene, fluoranthene, pyrene, benzo[b]fluoranthene, and perylene) compounds but also contained high concentrations of Chrysene + Triphenylene and Corenene. Despite the high PAH concentrations of some compounds observed at MDE-1 and MDE-43, as a whole the 2011 profiles are similar to the historical averages.

Table 3- 5 Polycyclic aromatic hydrocarbons given in the same order as in Figure 3-22 a-m (left to right). Note: 1,4 + 1,5 + 2,3-Dimethylnaphthalene was split into 4-Dimethylnaphthalene and 1,5-Dimethylnaphthalene to enable a historical comparison.

1	Naphthalene	18	Phenanthrene	36	Benzo[a]fluorene
2	2-Methylnaphthalene	19	Anthracene	37	Benzo[b]fluorene
3	1-Methylnaphthalene	20	2-Methyldibenzothiophene	38	Benz[a]anthracene
4	Biphenyl	21	4-Methyldibenzothiophene	39	Chrysene+triphenylene
5	2,6-dimethylnaphthalene	22	2-Methylphenanthrene	40	Naphthacene
6	1,3-Dimethylnaphthalene	23	2-Methylanthracene	41	4 + 6 methylchrysene
7	1,6-Dimethylnaphthalene	24	4H-Cyclopenta[def]phenanthrene	42	Benzo(b)fluoranthene
8	1,4-Dimethylnaphthalene	25	1-Methylanthracene	43	Benzo(k)fluoranthene
9	1,5-Dimethylnaphthalene	26	1-Methylphenanthrene	44	Benzo(e)pyrene
10	Acenaphthylene	27	9-Methylanthracene	45	Benzo(a)pyrene
11	1,2-Dimethylnaphthalene	28	3,6-dimethylphenanthrene	46	Perylene
12	1,8-Dimethylnaphthalene	30	Fluoranthene	47	3-Methylcholanthrene
13	Acenaphthene	31	Pyrene	48	Indeno(1,2,3-cd)pyrene
14	2,3,5-trimethylnaphthalene	32	2,3-dimethylanthracene	49	Dibenz(a,c+a,h)anthracene
15	Fluorene	33	9,10-dimethylanthracene	50	Benzo(g,h,i)perylene
16	1-Methylfluorene	34	1-methylpyrene	51	Anthanthrene
17	Dibenzothiophene	35	2-methylfluoranthene	52	Coronene

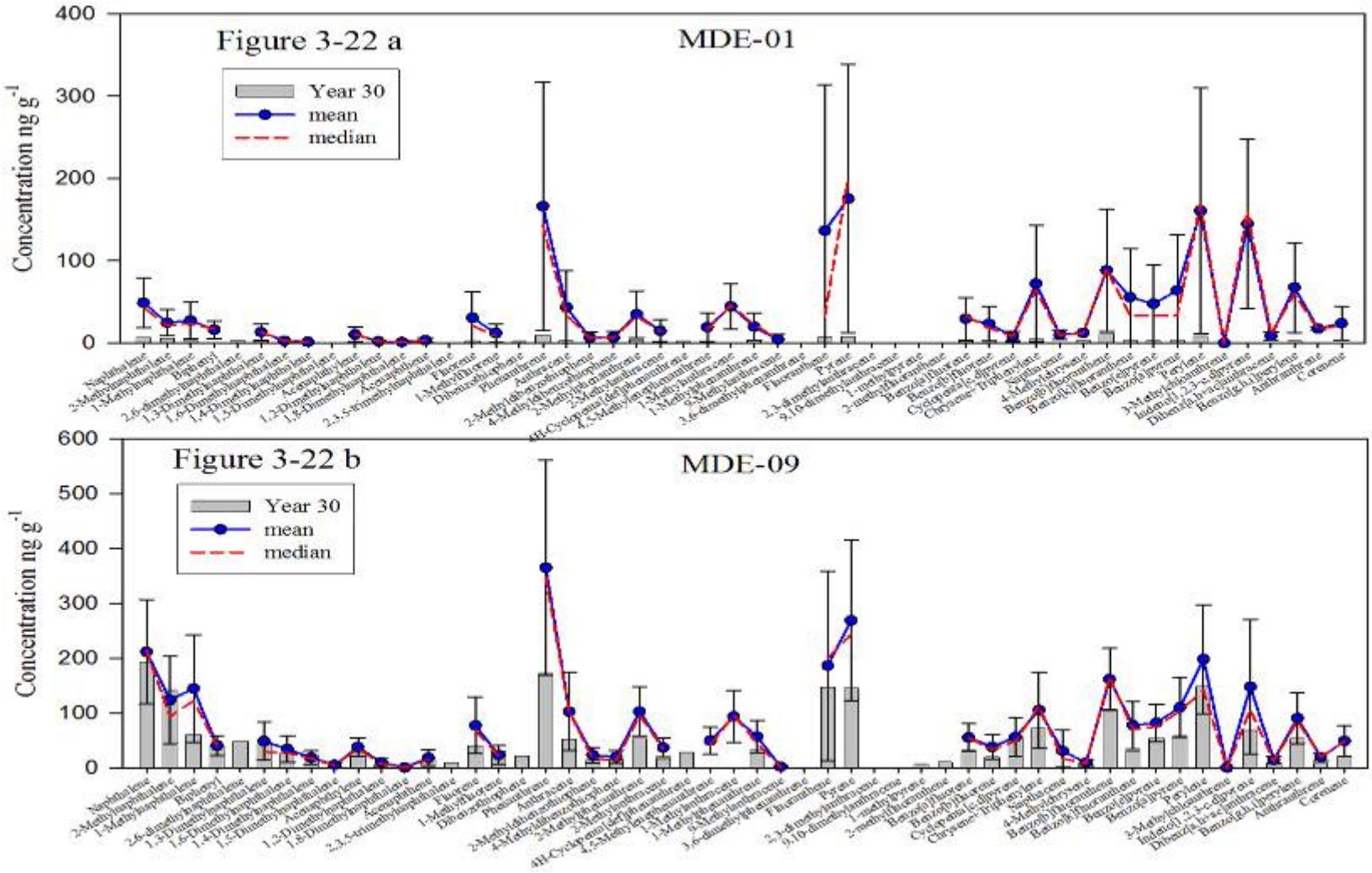


Figure 3- 22 Concentrations of PAHs in sediments from site MDE-01 and MDE-09 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} dry weight.

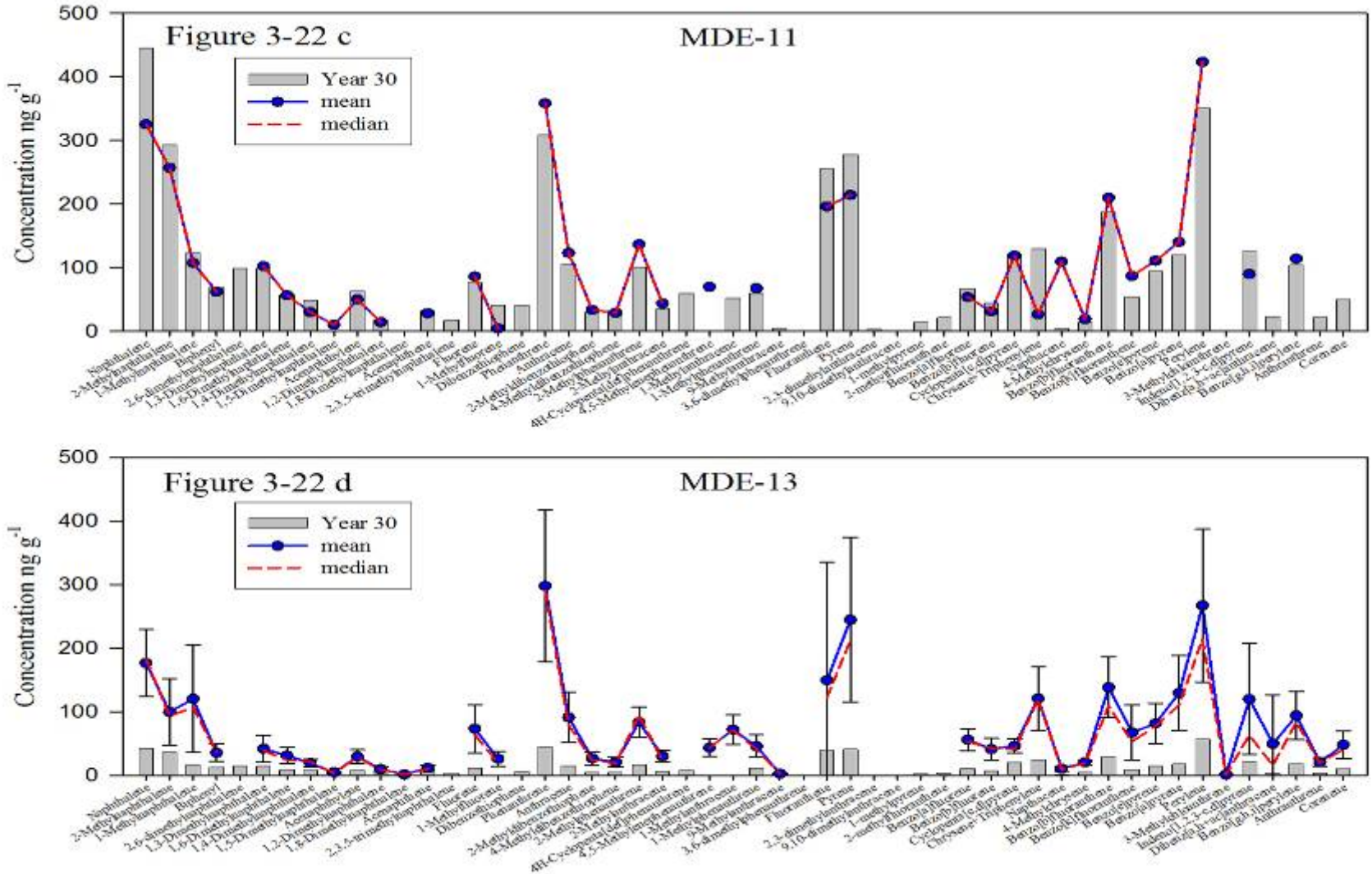


Figure 3-22 continued. Concentrations of PAHs in sediments from site MDE-11 and MDE-13 obtained in the fall of 2010 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} dry weight.

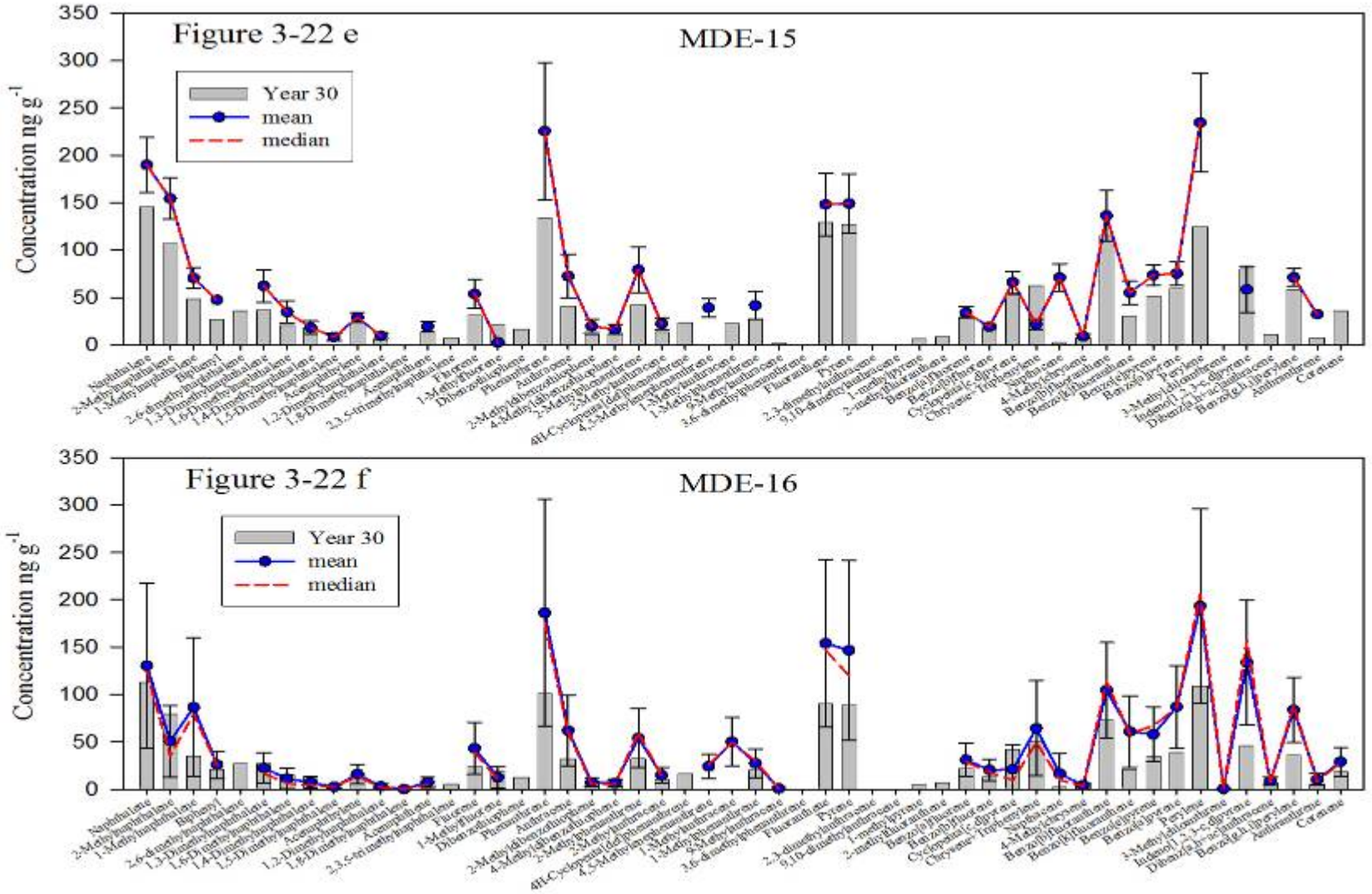


Figure 3-22 continued. Concentrations of PAHs in sediments from site MDE-15 and MDE-16 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} dry weight.

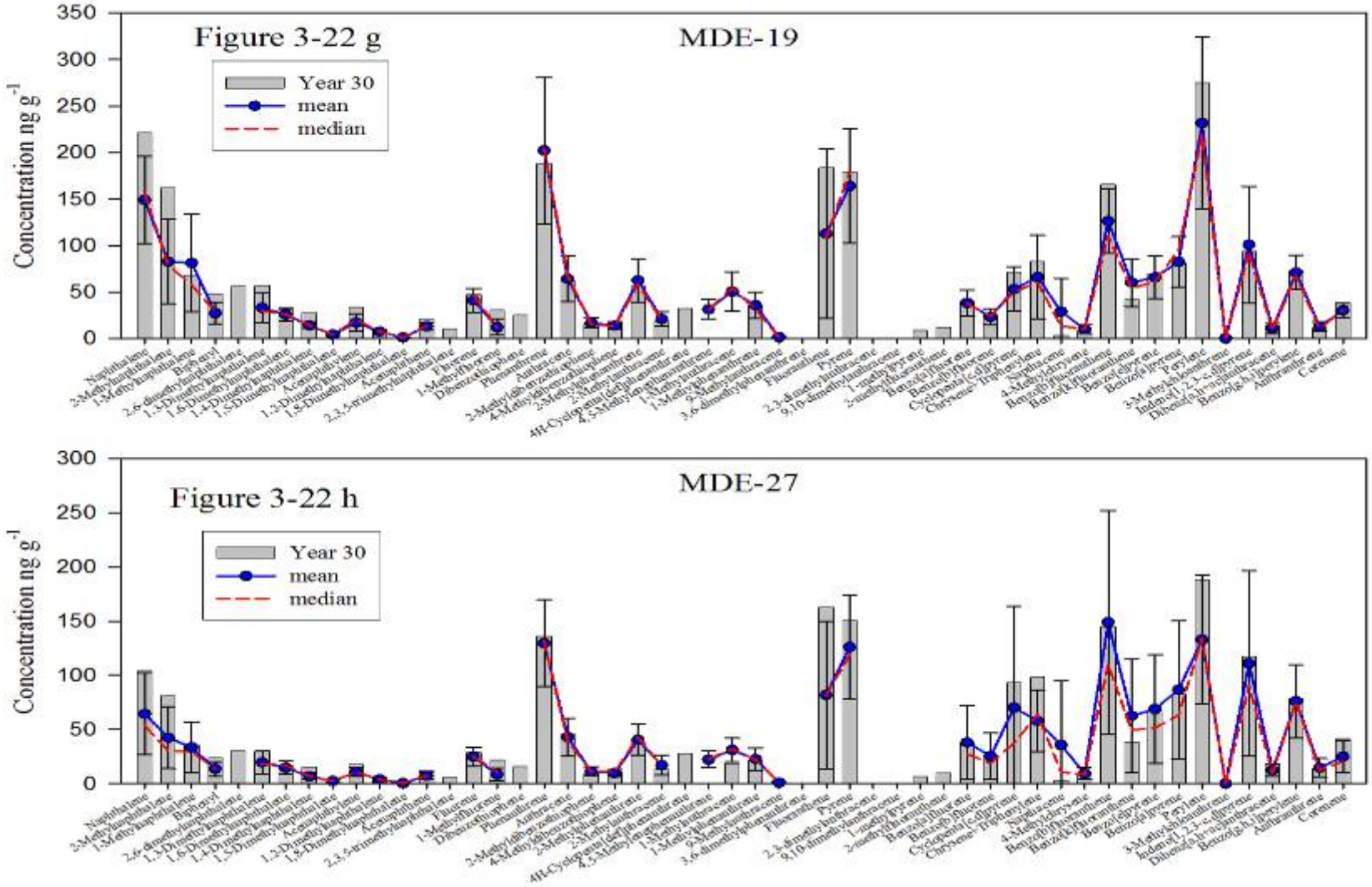


Figure 3-22 continued. Concentrations of PAHs in sediments from site MDE-19 and MDE-27 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} dry weight.

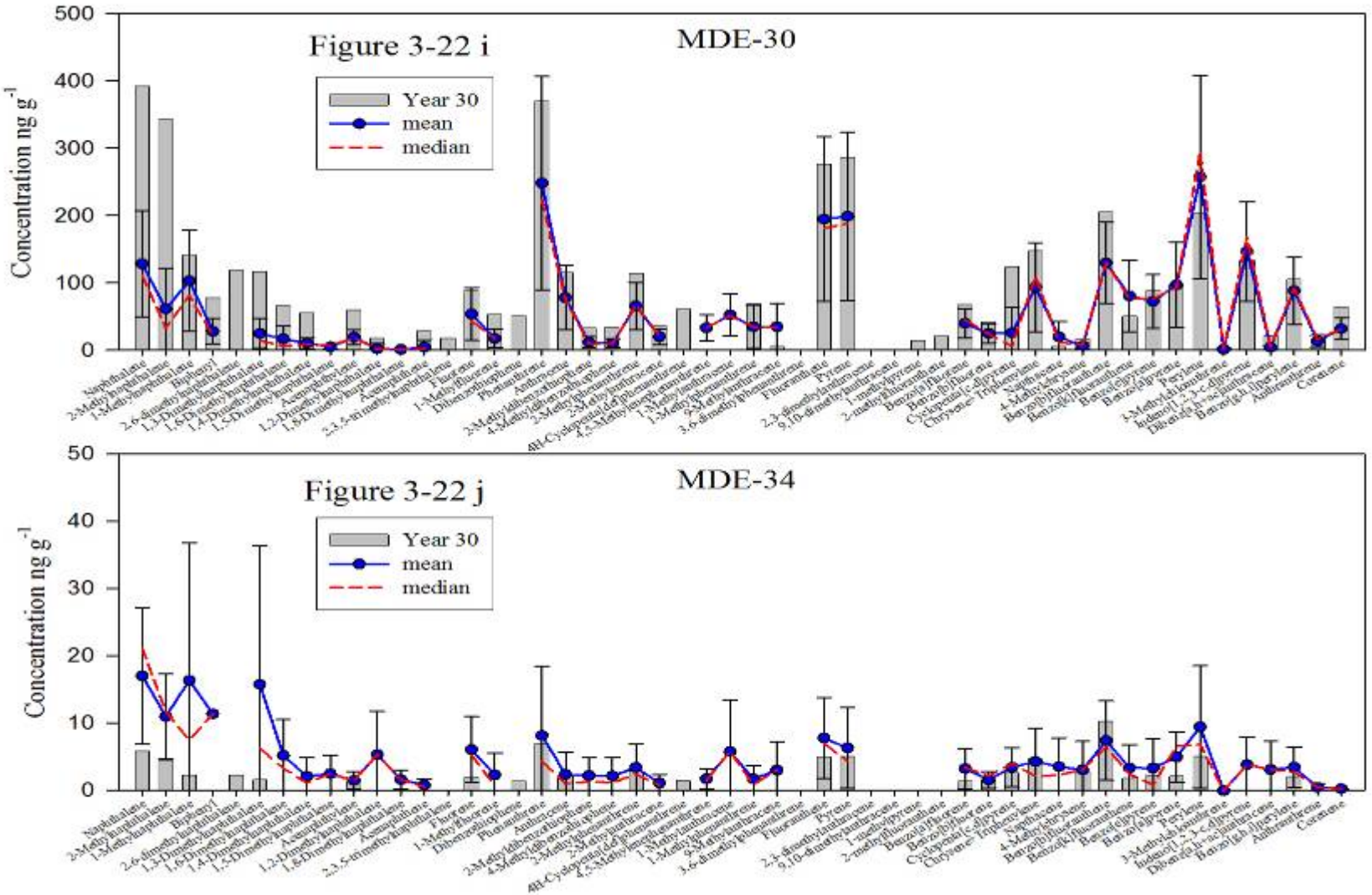


Figure 3-22 i
MDE-30
Year 30
mean
median
Concentration ng g-1
500
400
300
200
100
0
Figure 3-22 j
MDE-34
Year 30
mean
median
Concentration ng g-1
50
40
30
20
10
0

Figure 3-22 continued. Concentrations of PAHs in sediments from site MDE-30 and MDE-34 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} dry weight.

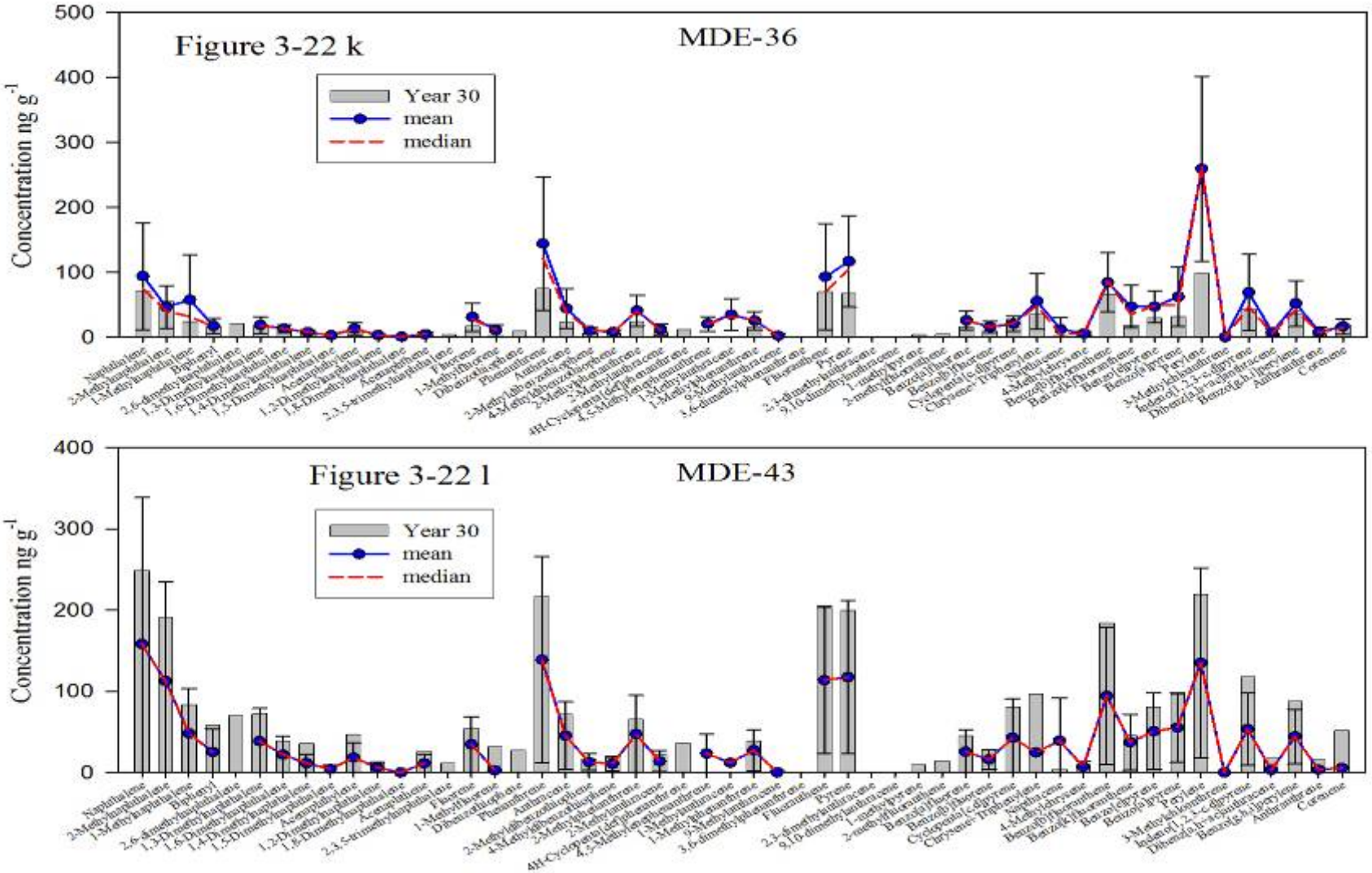


Figure 3-22 continued. Concentrations of PAHs in sediments from site MDE-36 and MDE-43 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} dry weight.

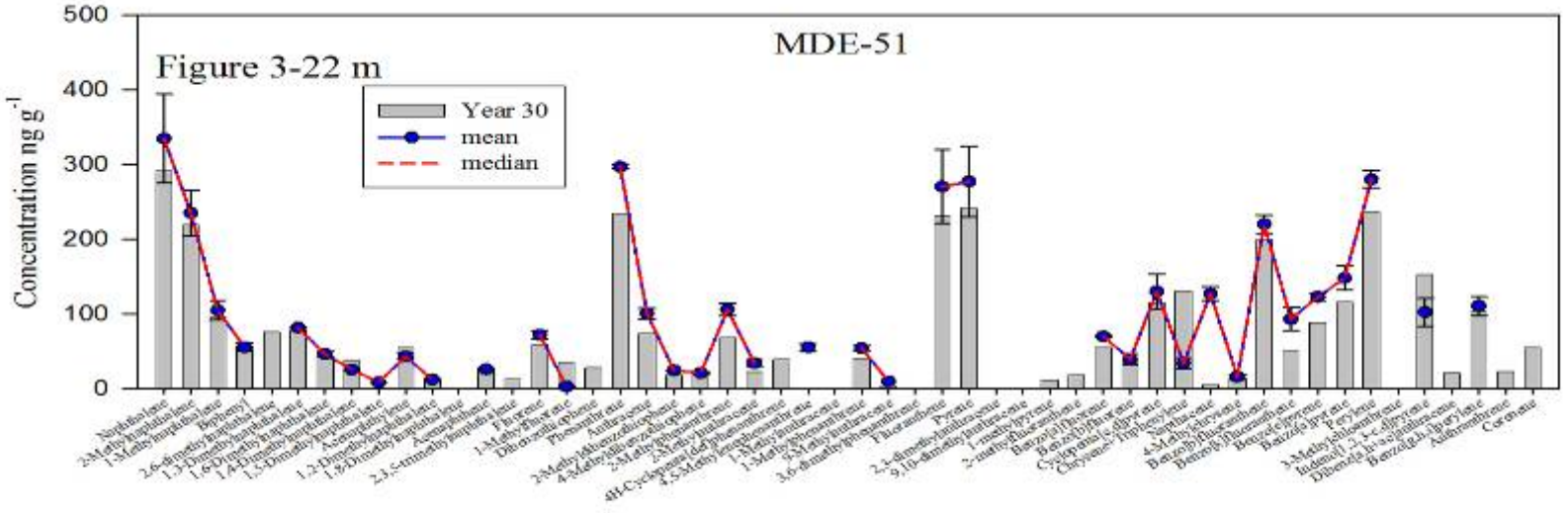


Figure 3-22 continued. Concentrations of PAHs in sediments from site MDE-51 obtained in the fall of 20112011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} dry weight.

Polycyclic Aromatic Hydrocarbons in Clams

The site fingerprints obtained by identifying and measuring the concentrations of a series of PAHs from clams collected in the vicinity of HMI are shown in Figure 3-23 a-m and listed in Table 3-6. The two lists are almost identical but a few compounds could not be separated in sediment chromatograms. The compounds most common in sediments are also found in the clams, those being: Naphthalene, 2-methylnaphthalene, phenanthrene, fluoranthene, pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene and benzo[e]pyrene. Perylene may have been present but it could not be reliably quantified. Chrysene, which could not be separated from triphenylene was present in sediments, but it does not make up such a large component of sediment PAHs. Concentrations of many PAH compounds in were higher clams collected in 2011 than in past years. Most of these compounds are combustion products of coal, wood and oil. Phenanthrene more likely has origins in oil related sources. As in the case of the sediment, together the relative proportions of the PAHs in clams form the same distinct pattern at all the study sites. Sites MDE-43 and 51 have only been sampled enough to calculate mean and median values, hence long term trends from these sites are weak.

When clam PAH signatures are compared to sediment signatures from the same site, ignoring the highest molecular weight compounds (greater than Preylene) which could not be quantified in clams, the patterns are similar, but sediments are orders of magnitude higher in concentration and concentrations of benzo[b]fluoranthene 2-6 dimethylnaphthalene in clams are often proportionally elevated. This effectively creates a different fingerprint. While metabolism of PAHs by clams could be partially responsible for the difference, the elevated concentration and different pattern suggest a waterborne source has influenced the concentrations of individual PAHs in clams. This difference can be seen in clams, where PAH concentrations are lower, but is lost in the larger pool of PAHs in the sediment.

Table 3- 6 Polycyclic aromatic hydrocarbons given in the same order as in Figure 3-23 a-m (left to right). Note: 1,4 + 1,5 + 2,3-Dimethylnaphthalene was split into 4-Dimethylnaphthalene and 1,5-Dimethylnaphthalene to enable a historical comparison

1	Naphthalene	18	Phenanthrene	36	Benzo[a]fluorene
2	2-Methylnaphthalene	19	Anthracene	37	Benzo[b]fluorene
3	1-Methylnaphthalene	20	2-Methyldibenzothiophene	38	Benz[a]anthracene
4	Biphenyl	21	4-Methyldibenzothiophene	39	Chrysene
5	2,6-dimethylnaphthalene	22	2-Methylphenanthrene	40	Naphthacene
6	1,3-Dimethylnaphthalene	23	2-Methylanthracene	41	4-Methylchrysene
7	1,6-Dimethylnaphthalene	24	4H-Cyclopenta[def]phenanthrene	42	Benzo(b)fluoranthene
8	1,4-Dimethylnaphthalene	25	1-Methylanthracene	43	Benzo(k)fluoranthene
9	1,5-Dimethylnaphthalene	26	1-Methylphenanthrene	44	Benzo(e)pyrene
10	Acenaphthylene	27	9-Methylanthracene	45	Benzo(a)pyrene
11	1,2-Dimethylnaphthalene	28	3,6-dimethylphenanthrene	46	Perylene
12	1,8-Dimethylnaphthalene	30	Fluoranthene	47	3-Methylcholanthrene
13	Acenaphthene	31	Pyrene	48	Indeno(1,2,3-cd)pyrene
14	2,3,5-trimethylnaphthalene	32	2,3-dimethylanthracene	49	Dibenz(a,c+a,h)anthracene
15	Fluorene	33	9,10-dimethylanthracene	50	Benzo(g,h,i)perylene
16	1-Methylfluorene	34	1-methylpyrene	51	Anthanthrene
17	Dibenzothiophene	35	2-methylfluoranthene	52	Coronene

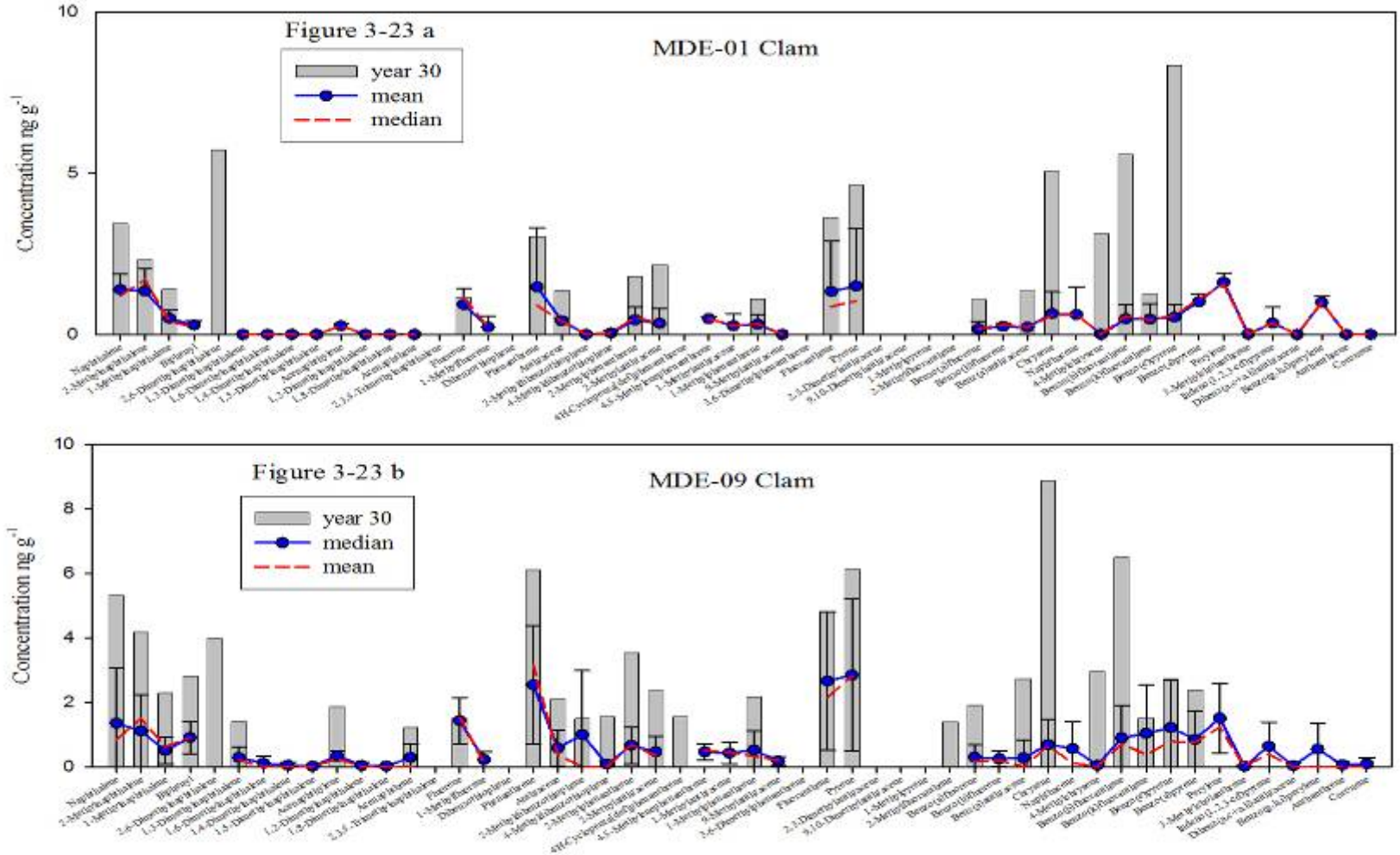


Figure 3- 23 Concentrations of PAHs in clams from site MDE-01 and MDE-09 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} wet weight.

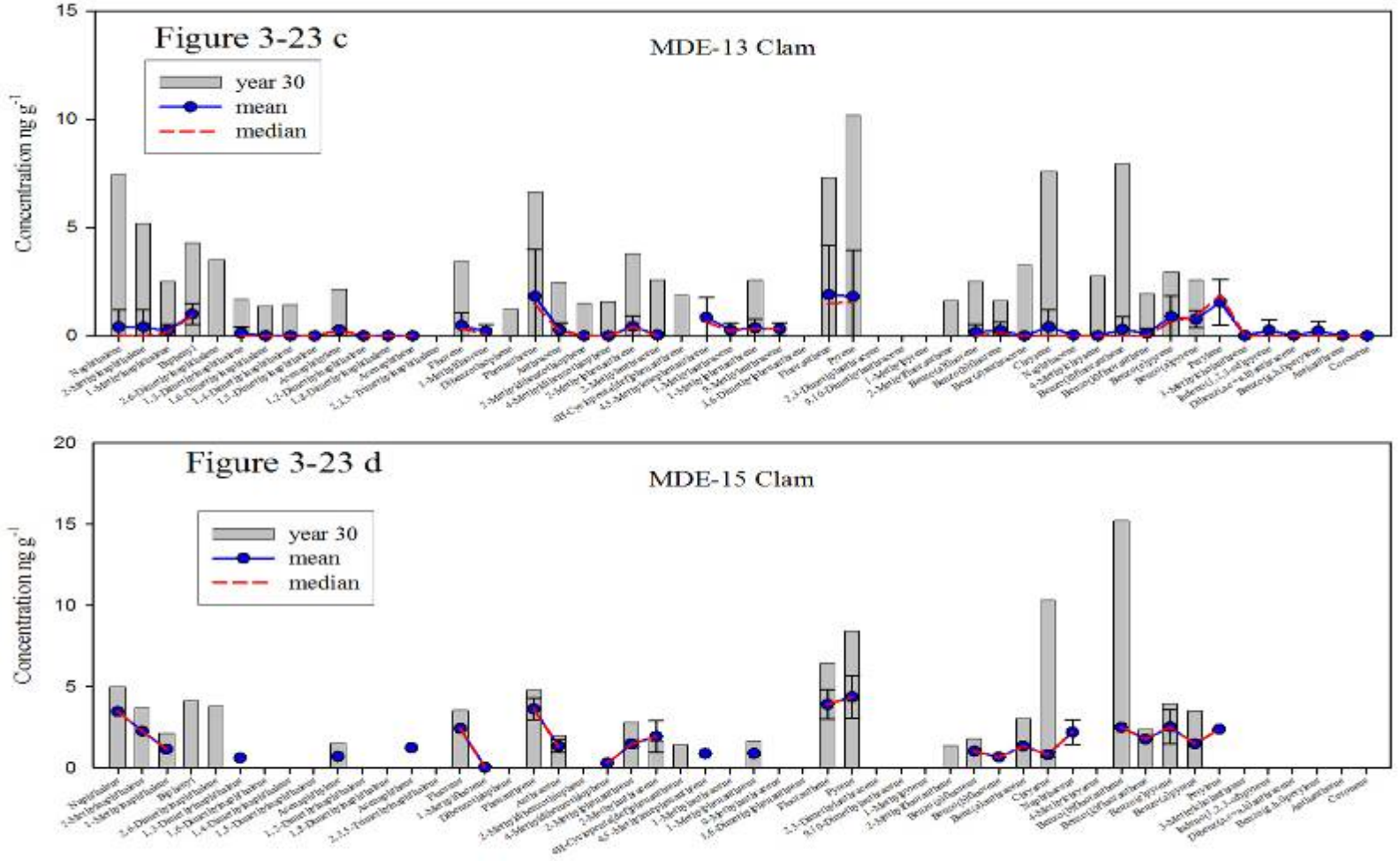


Figure 3-23 continued. Concentrations of PAHs in clams from site MDE-15 and MDE-16 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} wet weight.

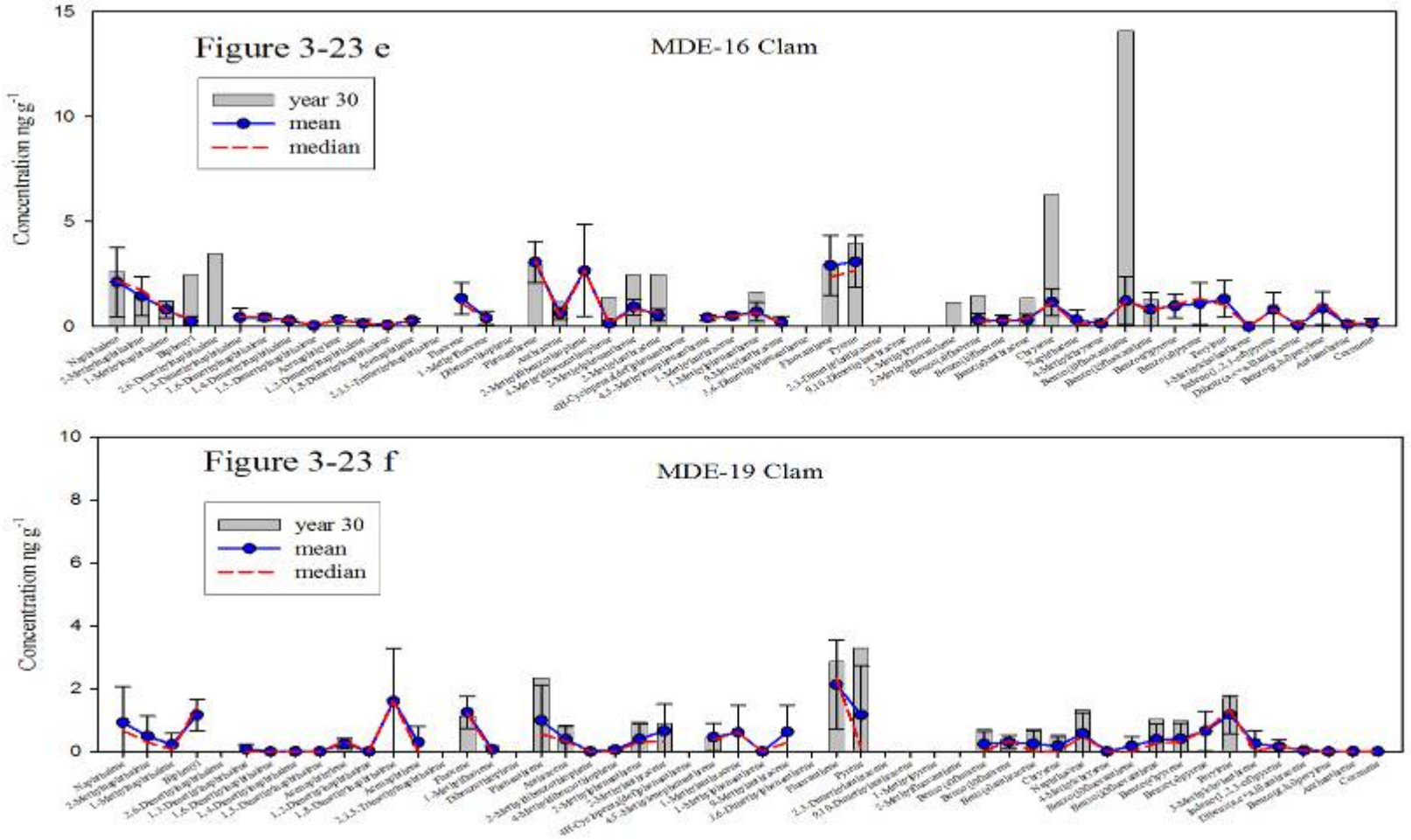


Figure 3-23 continued. Concentrations of PAHs in clams from site MDE-16 and MDE-19 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} wet weight.

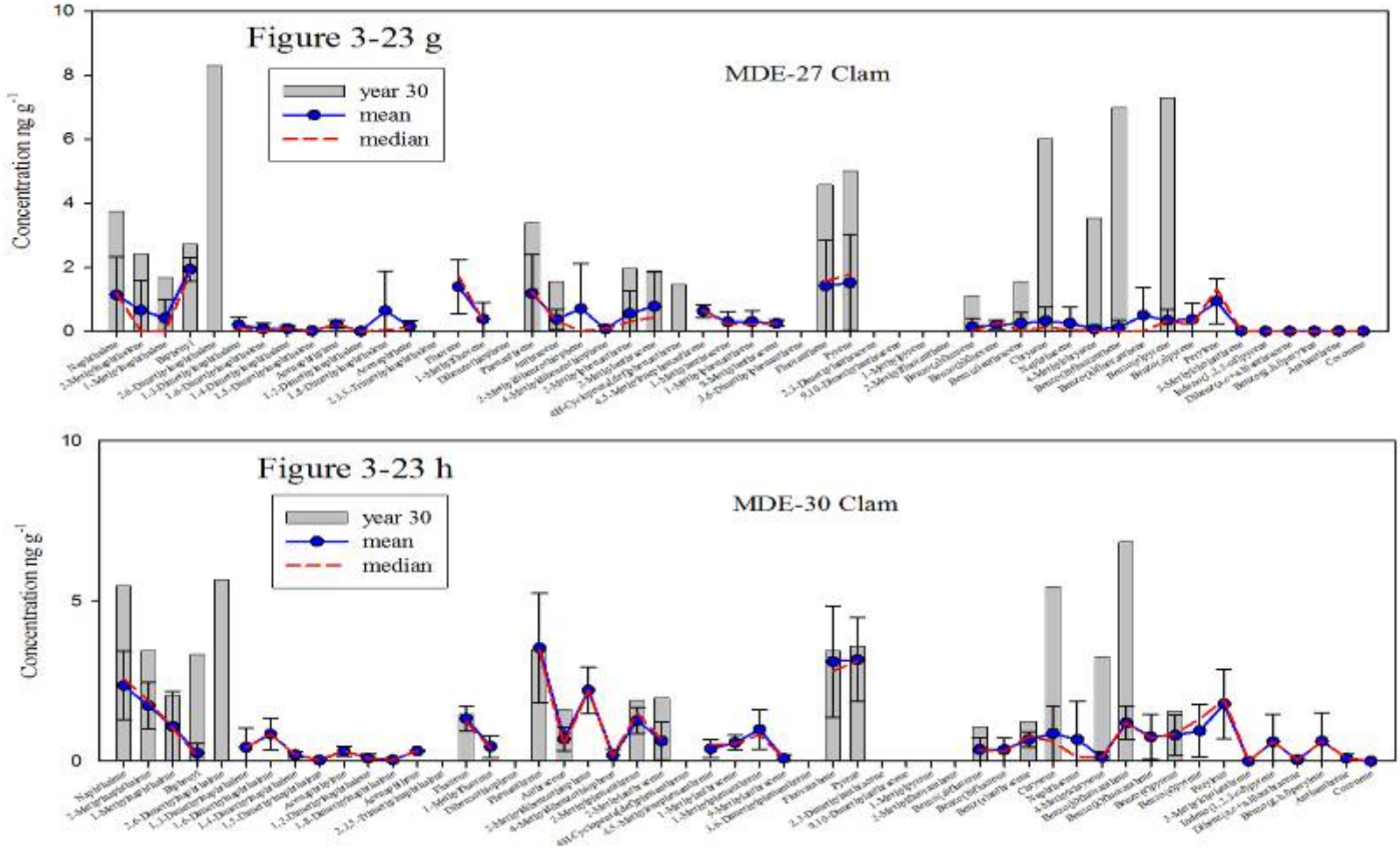


Figure 3-23 continued. Concentrations of PAHs in clams from site MDE-27 and MDE-30 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} wet weight.

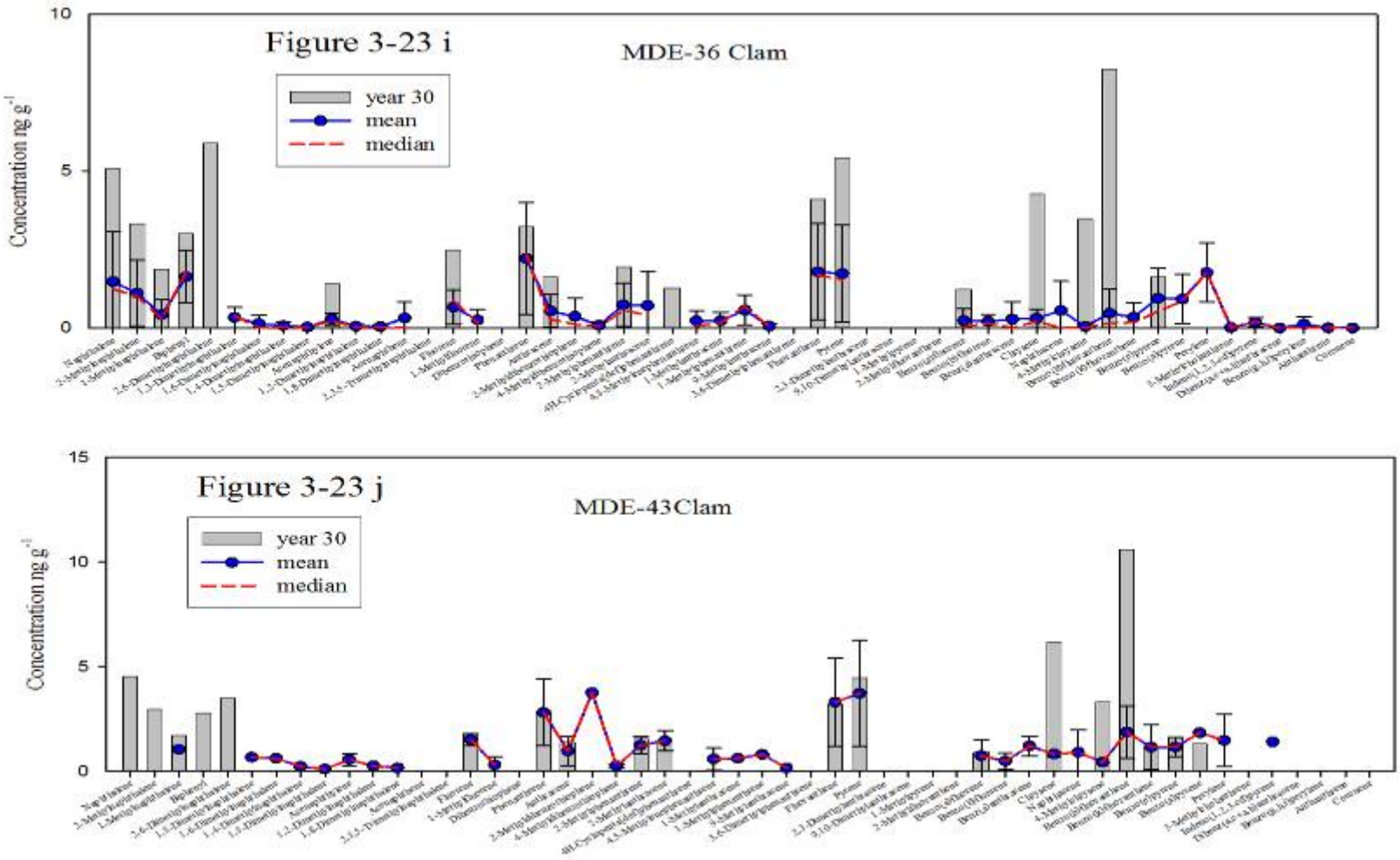


Figure 3-23 continued. Concentrations of PAHs in clams from site MDE-36 and MDE-43 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} wet weight.

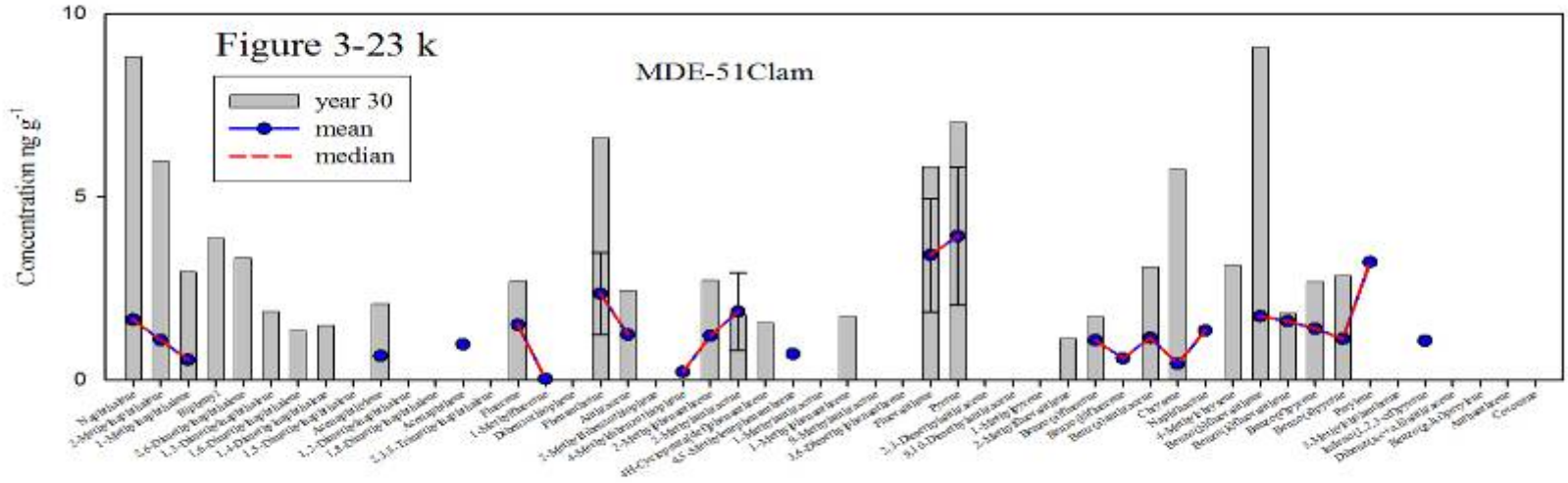


Figure 3-23 continued. Concentrations of PAHs in clams from site MDE-51 obtained in the fall of 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line), expressed in ng g^{-1} wet weight.

Total PAH concentrations in sediments and clams

The total concentrations of PAHs in sediment collected in 2011 from sites around the HMI complex were similar to historical levels (Figure 3-24a). PAH concentrations at site MDE-30 were above the historical levels of the site but within the range observed at other locations in 2011. Site MDE-11 has not been sampled frequently enough to develop a standard deviation. Concentrations of PAHs in clams were above historical levels at all sites, including the reference sites MDE-36 and 51 (Figure 3-24b). The concentrations of PAHs in clams do not track the concentrations in sediment from the same site, suggesting a recent overriding regional signal. While PAH concentrations in clams were elevated above historical levels, PCB concentrations were not which likely indicates that PAHs and PCBs in clams have different sources. As clams metabolize PAHs, the most likely explanation for the presence of the PAHs is a wide spread introduction through burning or oil release.

Figure 3-24 a

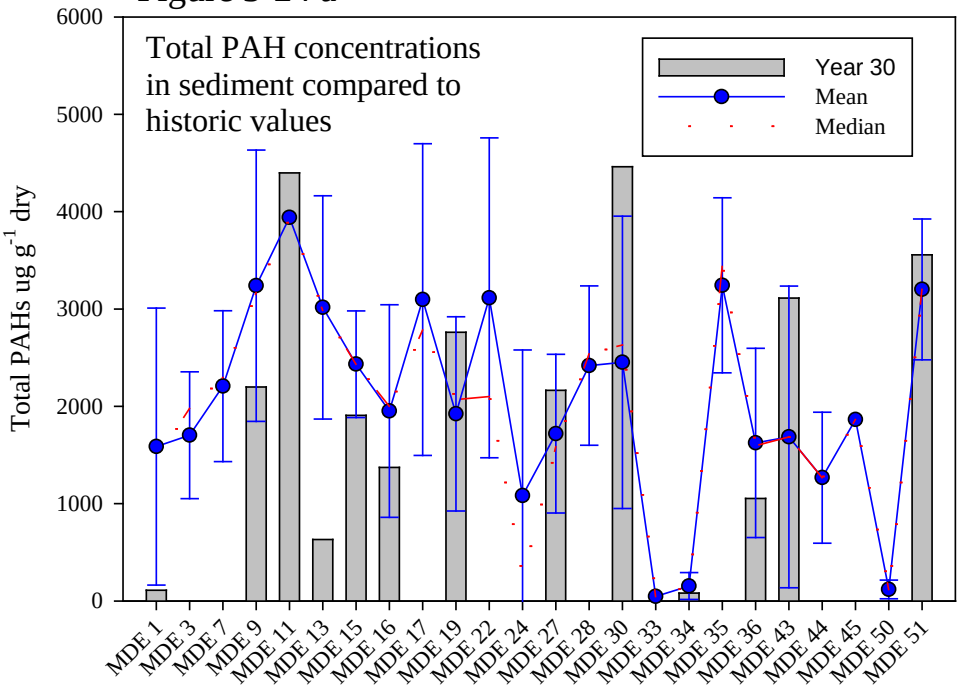


Figure 3-24 b

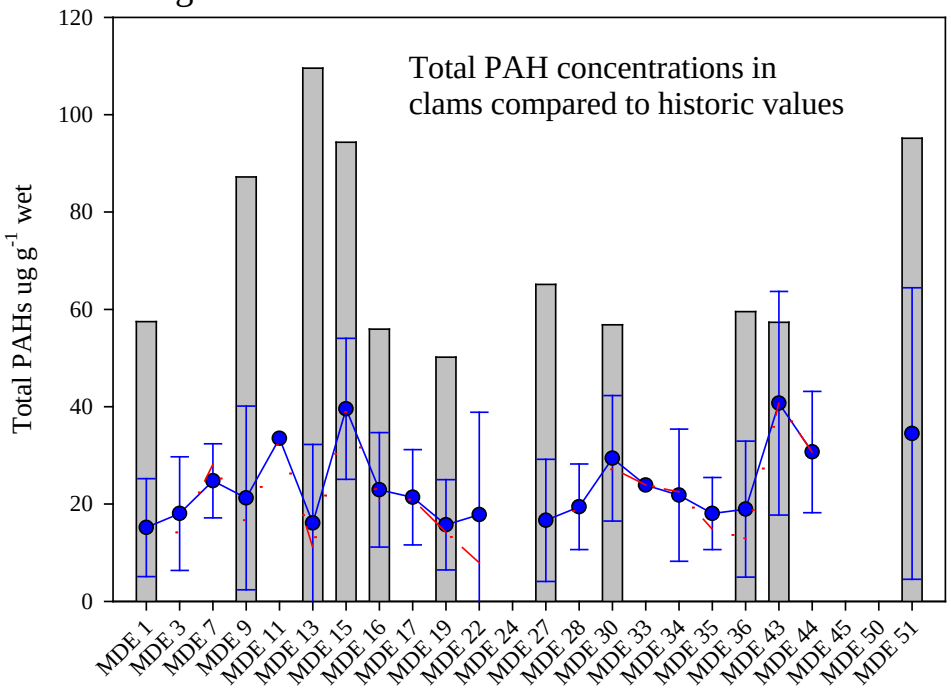


Figure 3- 24 Total PAH concentrations in sediments (a) (ng g^{-1} dry weight) and total PAH concentrations in clams (b) (ng g^{-1} wet weight) collected in September 2011 (bars), the 1998-2010 mean with standard deviation (blue circles and error bars) and the 1998-2010 median (dashed line).

Bioaccumulation Factors for PCBs and PAHs

PAHs are typically not accumulated like PCBs, but rather PAHs are metabolized by organisms at a faster rate but at some metabolic cost and exposure rather than accumulated concentration is responsible for toxicity. However PAHs are transferred in the food web as they are resident in organisms for some time. PAH concentrations in clams are orders of magnitude below the sediment concentrations, hence no bioconcentration is observed in 2011 as has been the case in previous years. PCBs accumulate in organisms because they are metabolized at a rate slower than the rate of accumulation; hence Bioaccumulation Factors (BAFs) can be calculated as a means of assessing the relative bioavailability in a given area. PCB BAFs calculated on a wet weight basis are less than 10 for most of the sites studied in 2011 (Figure 3-25). Site MDE-1 has an accumulation factor of nearly 100, which is driven by the sites much lower than normal level of PCBs in the sediment in 2011.

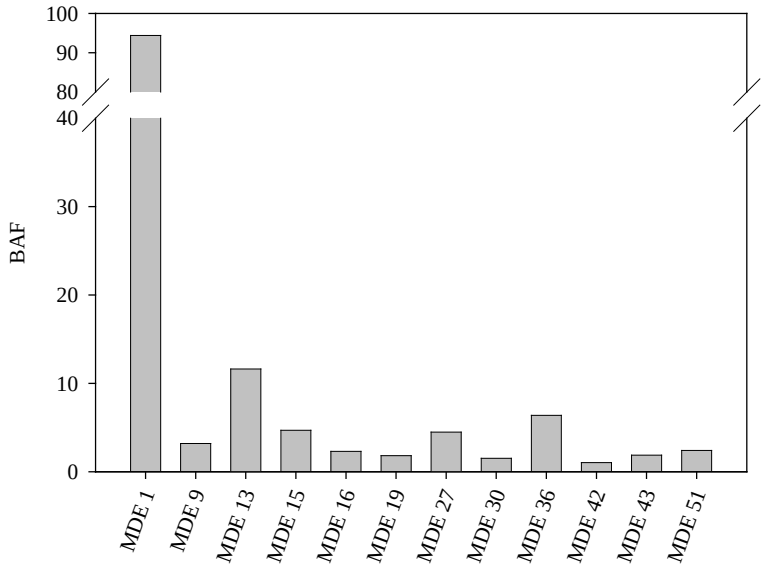


Figure 3- 25 2011 PCB bioaccumulation factors between sediment and clams.

The potential Sediment Toxicity from Organic Contaminants

The potential toxicity of the PAH and PCB concentrations in sediments around HMI was accessed by comparing the total concentrations to the Threshold Effects Level (TEL) and Probable Effects Level (PEL) as developed by NOAA for marine sediments. The TEL is surpassed by a number of the sites, including reference site MDE-51, which is not surprising given Baltimore's industrial and urban influence on sediments (Figure 3-26). The PEL was not surpassed by any of the sites for either PCBs or PAHs (Figure 3-26). Concentrations of individual compounds, for which criteria have been established, fall below the established PELs.

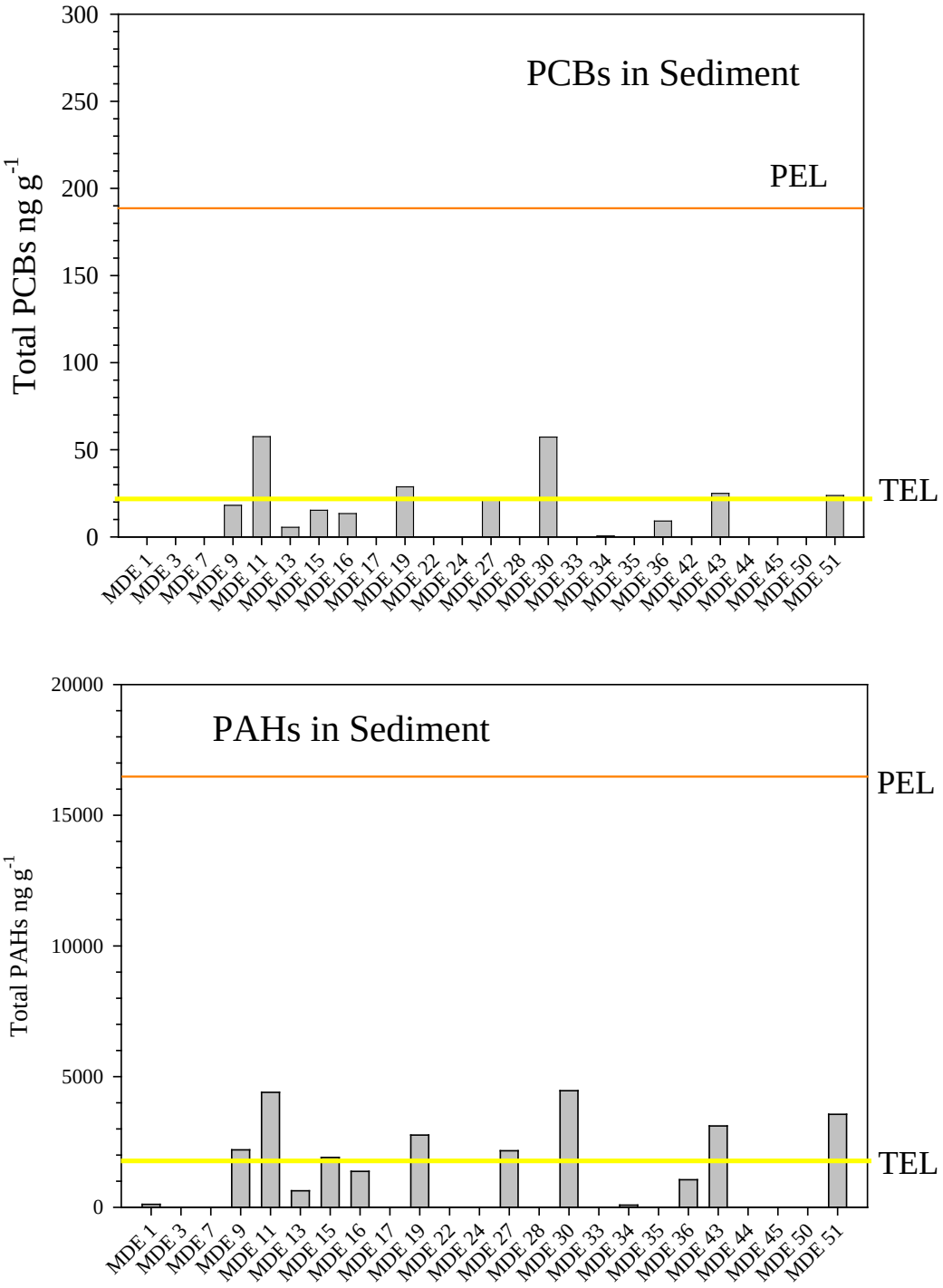


Figure 3- 26 Total PCB and total PAH concentrations in relation to the Threshold Effects Level (TEL) and the Probable Effects Level (PEL) for samples collected in September 2011.

SECTION SUMMARY

Sediment As and Se concentrations were elevated above historic concentrations at a few locations spread across the south and east sides of the island but not often the same site. Station MDE-6 has had elevated As concentrations in 2010 and 2011, and this site was not likely connected to external influences of Back River or Baltimore Harbor, and thus the increases over past years remains unexplained. T-Hg concentrations were elevated at MDE-14 and MDE-30 to levels far outside the 0.2 to 250 ng g^{-1} dry weight range observed in the main stem of the Chesapeake Bay (Heyes et al. 2006). Concentrations of MeHg in sediment were largely comparable to the rest of the Chesapeake Bay (Heyes et al. 2006). Concentrations of MeHg at sites MDE-39 and MDE-46 were substantially above the standard deviation of the running mean for each of the sites. No group of sites appears elevated in trace elements compared to previous years. No site displays elevated concentrations of all trace elements measured.

The relationships between As, Se and Ag suggest the same overall source is delivering the contaminants to the sites around HMI, including Back River and Baltimore Harbor sites. The lack of a correlation between Ag and As at sites located NE of the island suggest a different mechanism of delivery or retention of these elements and warrants further investigation. T-Hg has acted differently than the other elements suggesting a different behavior effecting sediment retention or a difference source. The lack of a correlation with other trace elements was again evident in 2011 as sites showing abnormally high As and Se values were not the same as those showing high T-Hg concentrations. Bioaccumulation factors for trace elements between sediment and clams are similar to previous years.

Inter-annual variations in trace element concentrations, indicated by changing slopes or correlation coefficients are sufficiently great that predicting elements from other elements are not possible. The strength in the relationships comes from the diversity of sites, not from temporal variations within any one site. This may stem from the lack of diversity in the sediment composition at any one site over time. As the study sites change in the concentration of individual trace elements, it would be dangerous to base sediment quality on any one element. The data set for Ag concentrations in HMI sediment is biased by data collected in 2000 and 2001. Concentrations in these years are far different than years post and prior. I have no explanation for the anomalous data. The Ag concentration data from these two years need be treated with care when accessing long term trends.

In the case of the organic contaminants, concentrations of PCBs in sediment and clams are similar to historic values. Sediment and clams display similar distributions of congeners and bioaccumulation factors were low in 2011 when compared to previous years. PAHs in sediments are orders of magnitude higher in sediments than clams, but clam concentrations in 2011 were elevated well above historic means at most sites including the reference sites. The distribution of PAHs in clams is not exactly the same as the sediment. While metabolism of PAHs by clams could be partially responsible for the difference, the elevated concentration and different pattern suggest a waterborne source has influenced the concentrations of individual PAHs in clams. Such a change in source might not be detectable in the sediment which has a very large pool of PAHs. This observation shows the value of examining both organisms and sediments and both

PCBs and clams when searching for changes that maybe assigned to the presence and activities performed at HMI.

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