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

Year 29 Exterior Monitoring Technical Report (September 2010-August 2011)





Contract No. 293644; PIN No. 50030020

THIS PAGE INTENTIONALLY LEFT BLANK

Prepared by:
Environmental Assessment Division
Maryland Department of the Environment

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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 ~~28~~29

(September ~~2009~~ 2010 – August ~~2010~~2011)

Prepared by
John L. Hill

Ecological Assessment Division
Science Services Administration
Maryland Department of the Environment
1800 Washington Blvd
Baltimore, MD 21230

Prepared for
Maryland Port Administration
Maryland Department of Transportation
World Trade Center
401 East Pratt Street
Baltimore, Maryland 21202

March 2012

ACKNOWLEDGMENTS

The Hart-Miller Island Dredged Material Containment Facility (HMI DMCF) is a large and complex operation and its success goes to the credit of many individuals within numerous organizations. Within the Science Service Administration of the Maryland Department of the Environment (MDE) a special thanks is offered to Mr. Matthew Rowe, Program Manager of the Environmental Assessment Division; Mr. John Hill, Technical Coordinator; and Mr. Jeff Carter, Mr. Nicholas Kaltenbach and Ms. Patricia Brady, Principle Investigators (PIs). Mr. Rowe was responsible for making sure that the project work was done efficiently in a coordinated manner and met all the technical goals set by the Technical Review Committee for Year 29. Mr. Hill was responsible for assuring that all project related budgetary products, services, and activities had been implemented by each Principal Investigator. Mr. Hill is responsible for reviewing the three individual technical reports of Projects II, III and IV; preparing the Project I Summary Report; and compiling all four into the Year 29 Exterior Monitoring Report. He is also responsible for archiving Year 29 data from each of the Projects into the Environmental Protection Agency's national data base STORET (STORage and RETrieval). The PIs were responsible for all the benthic laboratory work to include identifying organisms, assembling the data and performing the necessary calculations, and writing the Project III Technical and Data reports. For their technical support to the PIs a special thanks is given to Mr. Charles Poukish, biologist and Manager of the Field Evaluation Division, and Mr. Chris Luckett, biologist and taxonomist. Last but not least a special thanks to the Towson University interns Kelsea Croteau and Chris Marshall for their most important work of patiently sorting the benthic samples and helping with identifications. It must be noted that all the calculations that assumptions and conclusions are drawn from are based on the work of the individuals sorting the organisms. Their work is the foundation for all subsequent work.

MDE thanks Ms. Darlene Wells, PI for Project II with Maryland Geological Survey (MGS) and Stephen Ryswick; and Dr. Andrew Heyes, PI for Project IV with the Chesapeake Biological Laboratory (CBL). Ms. Wells is responsible for analyzing for metals and characterizing physical parameters in surficial sediment samples and writing the Project II report. Mr. Ryswick assists with the report, compiles the Project II data report and schedules and conducts the field work. Dr. Heyes is responsible for analyzing tissue samples for metals and organic contaminants. In addition to tissue analysis his laboratory analyzes sediment samples for organic contaminants and a suite of ancillary metals not analyzed by MGS. Dr. Heyes interprets the data and writes the Project IV Technical report and compiles the data report.

MDE would like to thank all the members of the HMI Exterior monitoring Program's Technical Review Committee and Mr. Thomas Kroen, Chairmen of the HMI Citizens Oversight Committee and the Committee members 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.

Now that the North Cell is no longer receiving dredged material, and 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. However, 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 29 marks the first 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. The 5 years of data can then be compared to the thirty years of data collected during which placement of dredged material took place. This comparison of pre and post-closure data will allow the scientist to determine differences, if any, in the exterior environment, and whether the differences, if any, were a result of HMI operations. The information learned can be applied to future dredged material containment facilities.

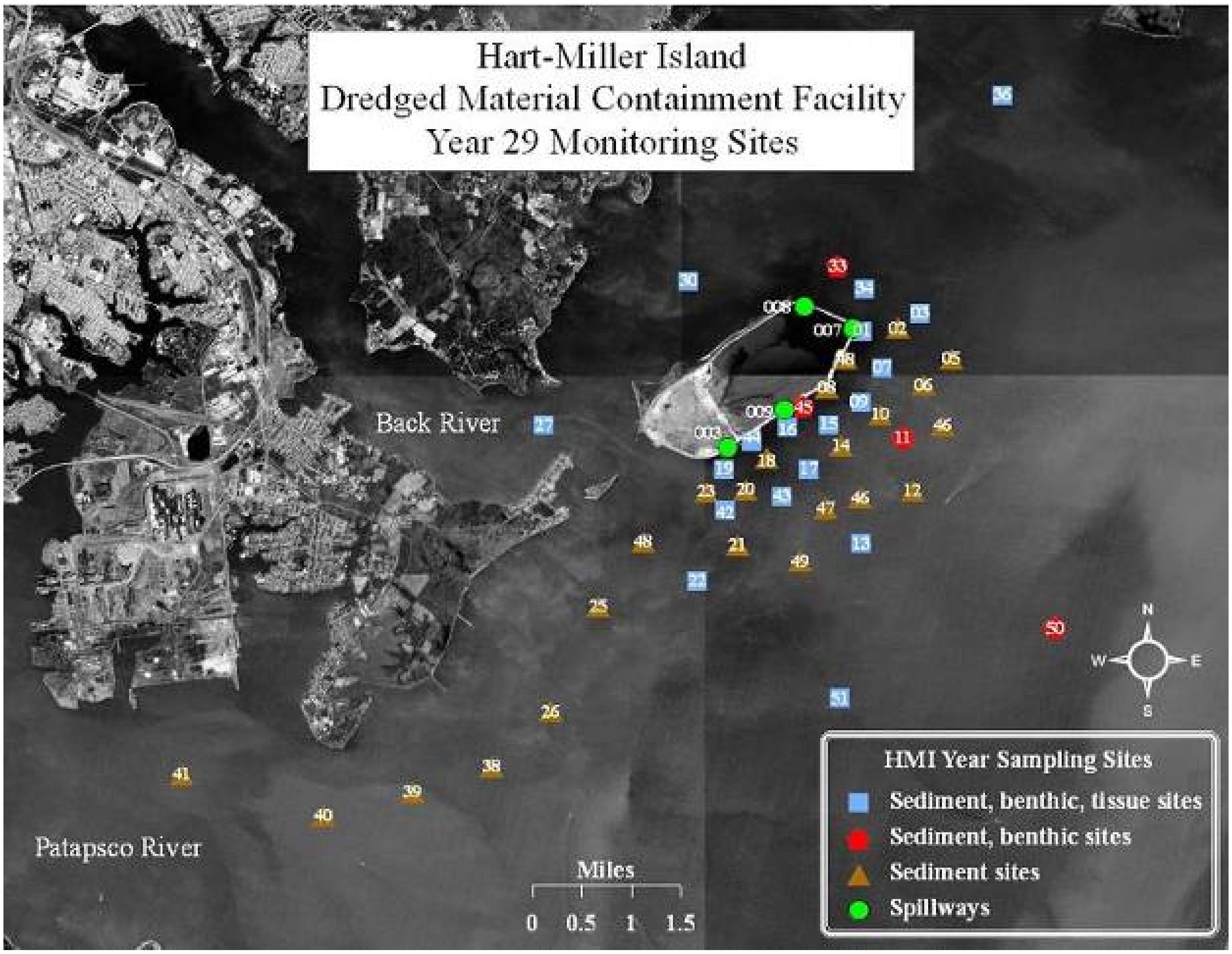
HMI EXTERIOR MONITORING DESIGN

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. Summary Table 1-1 below illustrates the triad concept.

Summary Table 1-1. 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 29, MGS analyzed sediment for physical and chemical properties, MDE sampled the benthic organisms at 22 sites, and from 18 sites CBL collected the brackish water clam *Rangia cuneata* for tissue analysis and sediment for analysis of metals and metalloids.



Summary Figure 1-1. Year 29 HMI post-closure monitoring locations.

HMI PROJECT SUMMARIES

PROJECT II: Sedimentary Environment

The Coastal and Estuarine Geology Program of the 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 14, 2010, and on April 14, 2011. 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).

Sediment Grain Size Composition

Changes in grain size of the exterior sediments surrounding HMI are largely dependent upon amount, quality, and timing of discharge from particular spillways, and the interaction of the discharge with the tides and currents in the receiving waters and the existing grain size distribution patterns. Basically, the depositional environment in the vicinity of HMI was unchanged between Year 28 and Year 29, i.e., there was only slight variations in grain size composition mostly due to seasonal change. The areas of high sand content are generally found around the perimeter of the dike in shallow waters and diminish with distance from HMI. The area extending off the northeast tip of HMI typically has the highest sand content; in September 2010 sites MDE-33, 34, and 02 had sand content greater than 90 percent. In April 2011 sites MDE-33 and 34 remained above 90 percent; however MDE-02 decreased below 90 percent. This shift is likely due to seasonal change. Sites on the east side of HMI with the exception of MDE-08, 45, and 48 (which are close to the dike) were below 10 percent sand content both in September 2010 and April 2011.

The mud portion of sediment is made up of very fine particles of clay, and the slightly larger particles of silt. The fine (mud) fraction of the sediments around HMI is generally richer in clay than in silt. Muddy sediments predominate around HMI; however, compared to the distribution of sand, the distribution of clay:mud ratios has tended to be more variable over time. The reason for this variability is due to the fact that the silt and especially the clay fractions remain suspended for longer periods of time resulting in greater opportunity to eventually settle far removed from the actual source. Also, the finer grains are more likely to become re-suspended and re-located as a result of storm events. Sand, being larger, heavier particles will settle more quickly, closer to the source, and is less likely to become re-suspended.

A broad clay-rich area (clay:mud ratio >0.60) north of HMI, including sites MDE-30, 33, and 34, was present in September 2010 and diminished in size, confined to only MDE-33 by the following April sampling. A likely reason for the change is that sites MDE-33 and 34 are high percent sand sites with mud (silt and clay mix) representing only a small percent of the total sample, and MDE-30 although has a low percent of sand typically is a silty site. Thus, with seasonal changes the clay portion of the sample can easily be altered. A clay-rich area south of HMI (in the proximal zone) was present in both September 2009 and September 2010, but diminished in size in the April sampling of both years. These patterns of change are most likely due to seasonal changes. For example, the spring time period often has higher turbulence due to weather while the late summer early fall period preceding sampling events are comparatively calm with lower flow. The less turbulent waters offer greater opportunity for the finer silt-clay particles to settle on the bottom.

Silt-rich sediments (clay:mud ratio < 0.50) are generally found immediately adjacent to the walls of the dike, commonly in the vicinity of spillways. In September 2010 a silt-rich area was confined to site MDE-16 between Spillways 003 and 009. By April 2011, the silt-rich area expanding to three stations (MDE-16, 45, and 48) south and adjacent to the dike wall (Summary Figure 1-1).

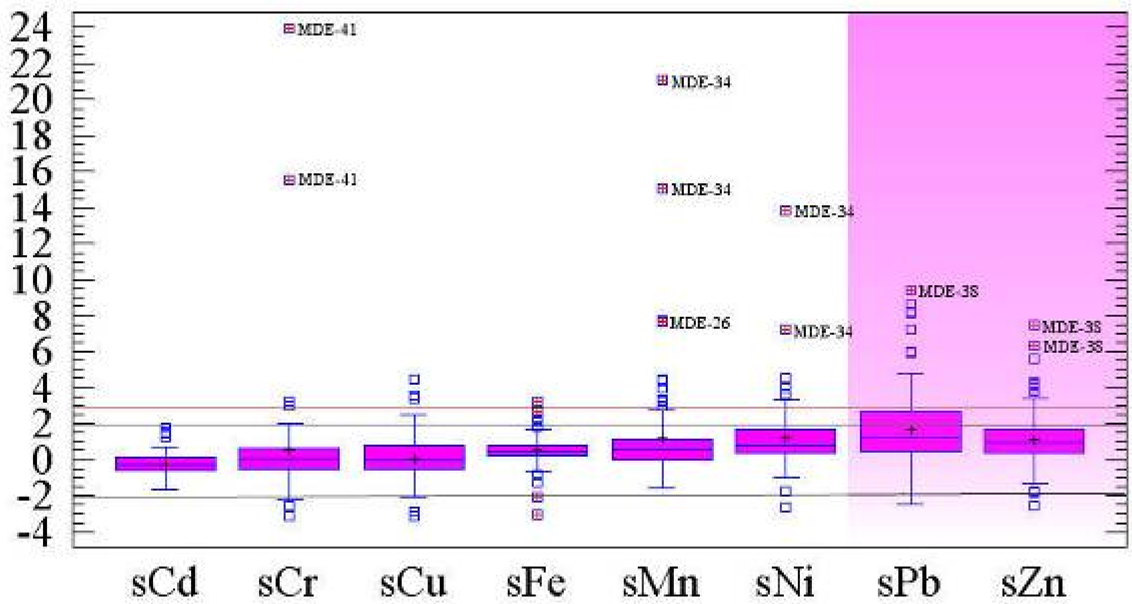
In general, the grain size distribution (i.e., sand, silt and clay) of Year 29 samples was found to be consistent with the findings of previous monitoring years.

Analysis of Trace Metals

The sediment samples collected by MGS were analyzed for metals including Fe, Mn, Zn, Cu, Cr, Ni, Cd, and Pb. The concentrations were then compared to the Effects Range Low (ERL) and Effects Range Median (ERM), which are proposed criteria put forward by the National Oceanic and Atmospheric Administration (NOAA) (Buchman, 2008) to gauge the potential for deleterious biological effects. The ERL and ERM are explained in detail in Appendix I. Basically, concentrations between the ERL and ERM may have adverse effects on benthic organisms and those exceeding the ERM are likely to have adverse biological effects. Of the eight metals, Cr, Cu, Ni, Pb and Zn were found at some sites with concentrations that exceeded the ERLs while at other sites concentrations for Zn and Ni were high enough to exceed the ERMs. This comparison is somewhat useful; however, it does not take into consideration the unique characteristics and composition (i.e., grain size) of the Bay sediments around HMI.

MGS developed a mathematical procedure that normalizes the metals concentrations based on percent composition of sand, silt and clay content. The resulting values are expressed as multiples of sigma levels (standard deviation) above and below zero, which is a reference baseline for background levels typical of the Bay region around HMI. When the data are normalized, Pb and to a lesser extent Mn, Ni, and Zn, have samples significantly exceeding 3 sigma, indicated by the red line in (Summary Figure 1-2). Based on work done by the University of Maryland during Year 25 monitoring the most probable conditions where the metals affect the infaunal communities are:

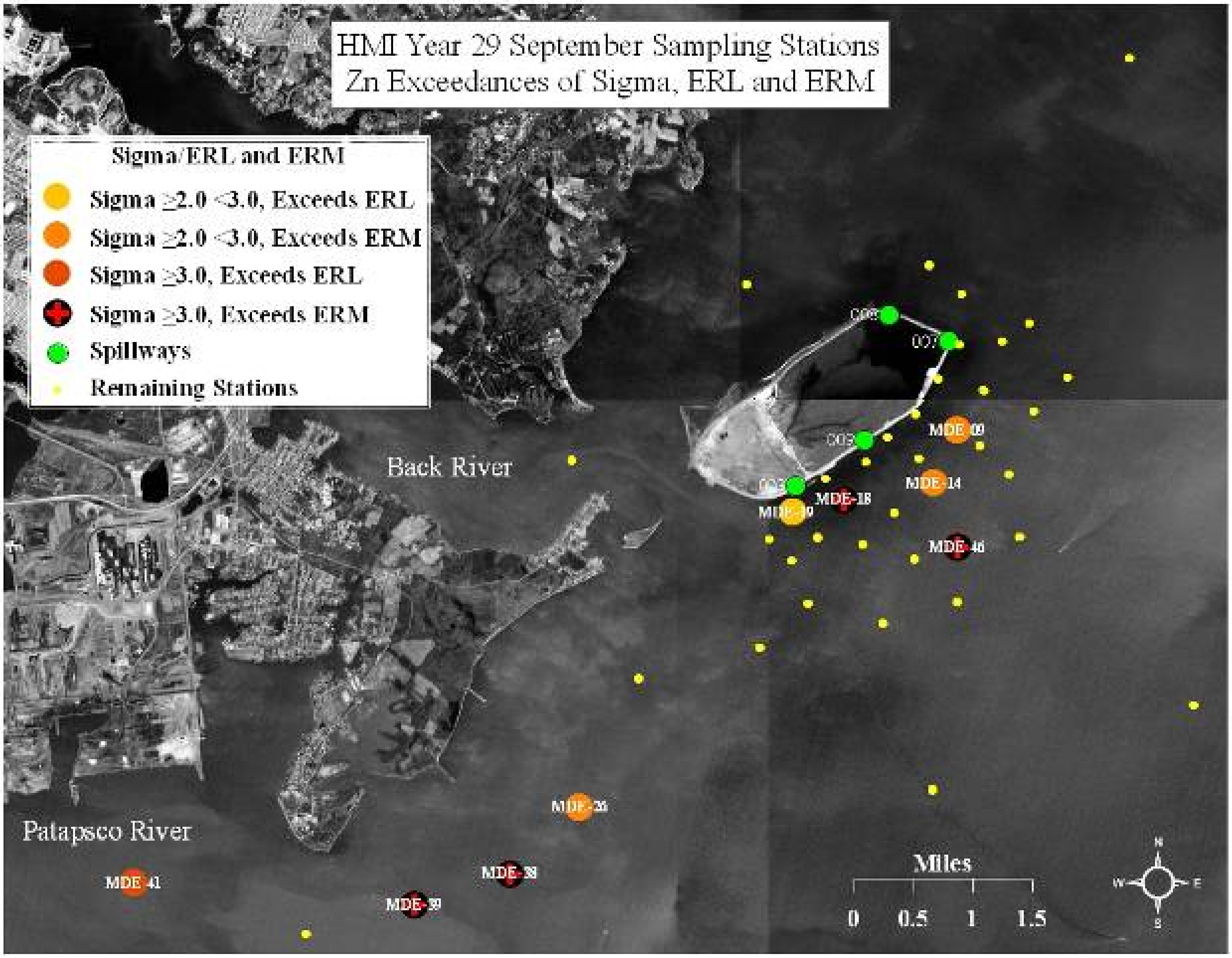
1. When the sigma level exceeds +2 [indicating enriched metals concentrations over baseline] and;
2. When the metals level exceeds the ERL with increased probability as the level exceeds the ERM [showing absolute concentrations that have exhibited adverse effects in other systems].



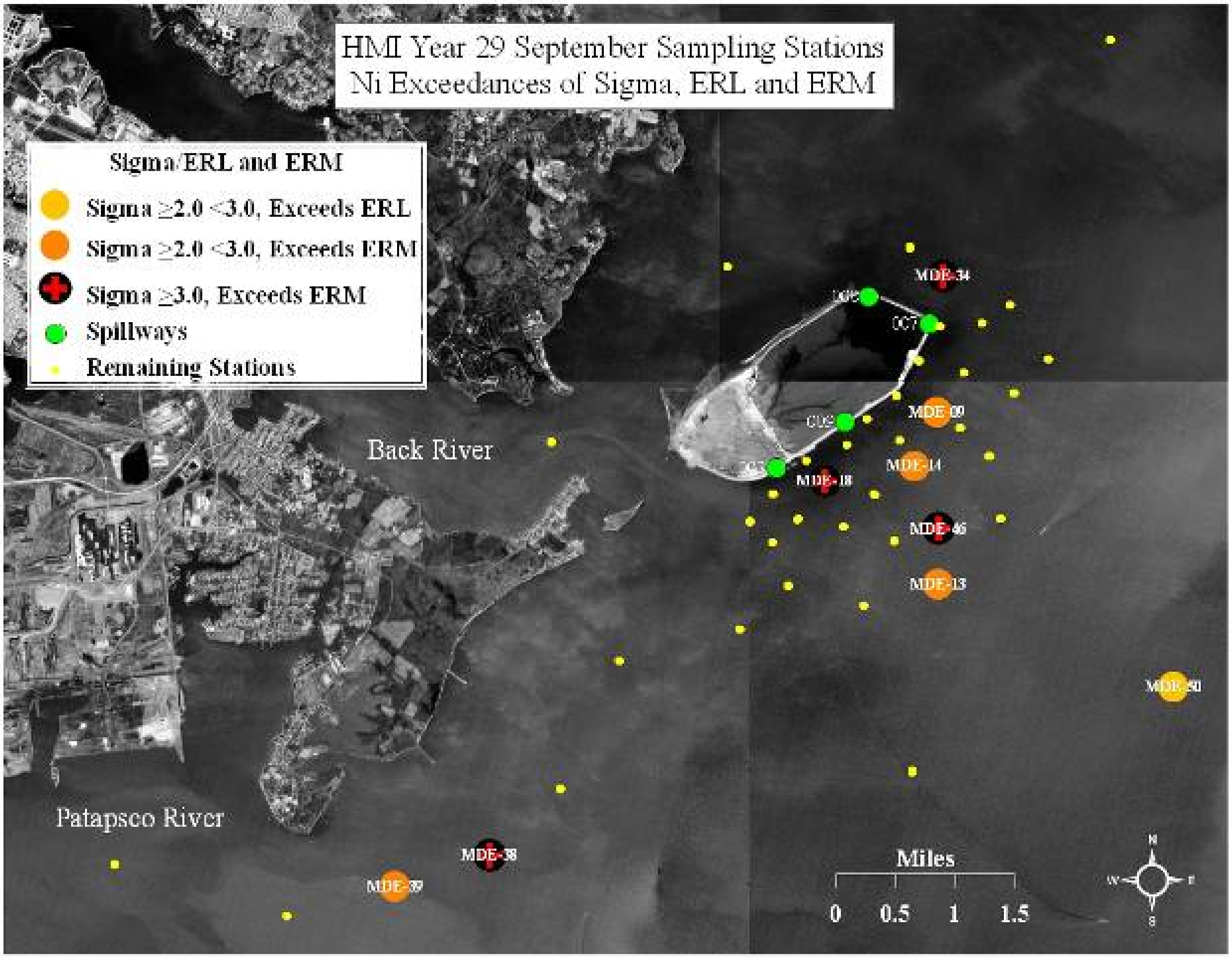
Summary Figure 1-2. Year 29 concentration of metals at HMI relative to baseline values. Metal concentrations greater than 2 standard deviations (horizontal grey lines) are considered elevated above baseline.

Concentrations of Zn and Ni were high enough at most sites to exceed either the ERL or the ERM and also had levels at some sites that exceeded 2 and 3 sigma (Summary Figure 1-2). As stated above it is under these conditions when the infaunal communities are likely to be effected. Summary Figures 1-3 and 1-4 show those sites for the September sampling where Zn and Ni (respectively) exceeded some combination of the thresholds. The September results are shown because the Benthic Index of Biotic Integrity (B-IBI), which is part of the Project III study, is calibrated for the time period between July and September; thus, the B-IBI results can be compared and will be discussed later in this summary report.

Sites MDE-38, 39 had high concentration for Zn and Ni that resulted in some combination of exceeding the ERL or ERM, and sigma 3 while MDE-26 and 41 had high levels for only Zn. These sites are within the Baltimore Harbor zone of influence. Sites MDE-13 and 50 both of which are Reference sites only had high concentrations of Ni that exceeded either the ERL or ERM. The remaining sites MDE-34 (near Spillways 007 and 008), MDE-09 and 18 (near Spillway 009) and MDE-19 and 46 are all within the HMI zone of influence. It is difficult to determine the source(s) of Zn and Ni at these sites; however, given the historical data HMI is likely the source or at least a strong contributor.



Summary Figure 1-3. Stations with Zn concentrations exceeding 2 or 3 sigma in addition to exceeding either the ERL or ERM.



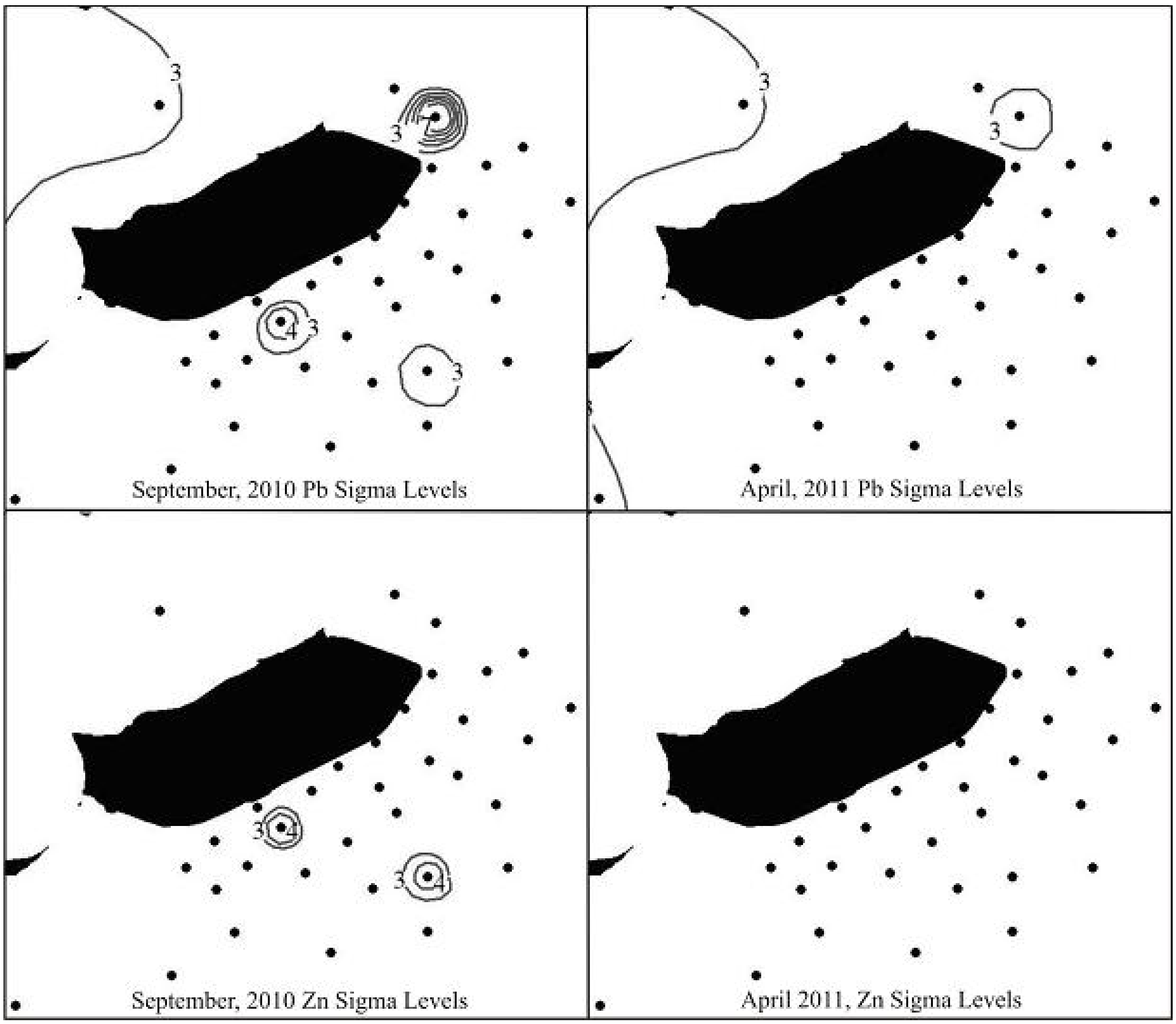
Summary Figure 1-4. Stations with Ni concentrations exceeding 2 or 3 sigma in addition to exceeding either the ERL or ERM.

Although Pb was significantly enriched above the background level (i.e., greater than 2 sigma) at 30 percent of the sites, at no site was the ERM exceeded. The same holds true for Mn which was significantly enriched above the background level at 14 percent of the sites and neither the ERL nor ERM was exceeded.

Pb and Zn distribution around HMI

Since the eighth monitoring year (1988 – 89), increased metal levels (specifically Zn) have been noted in bottom sediments east and south of Spillway 007 (Summary Figure 1-1); similarly since the start of monitoring Pb in Year 15 (1995 – 96), elevated levels of Pb have been found in the same areas, but with generally higher relative loadings.

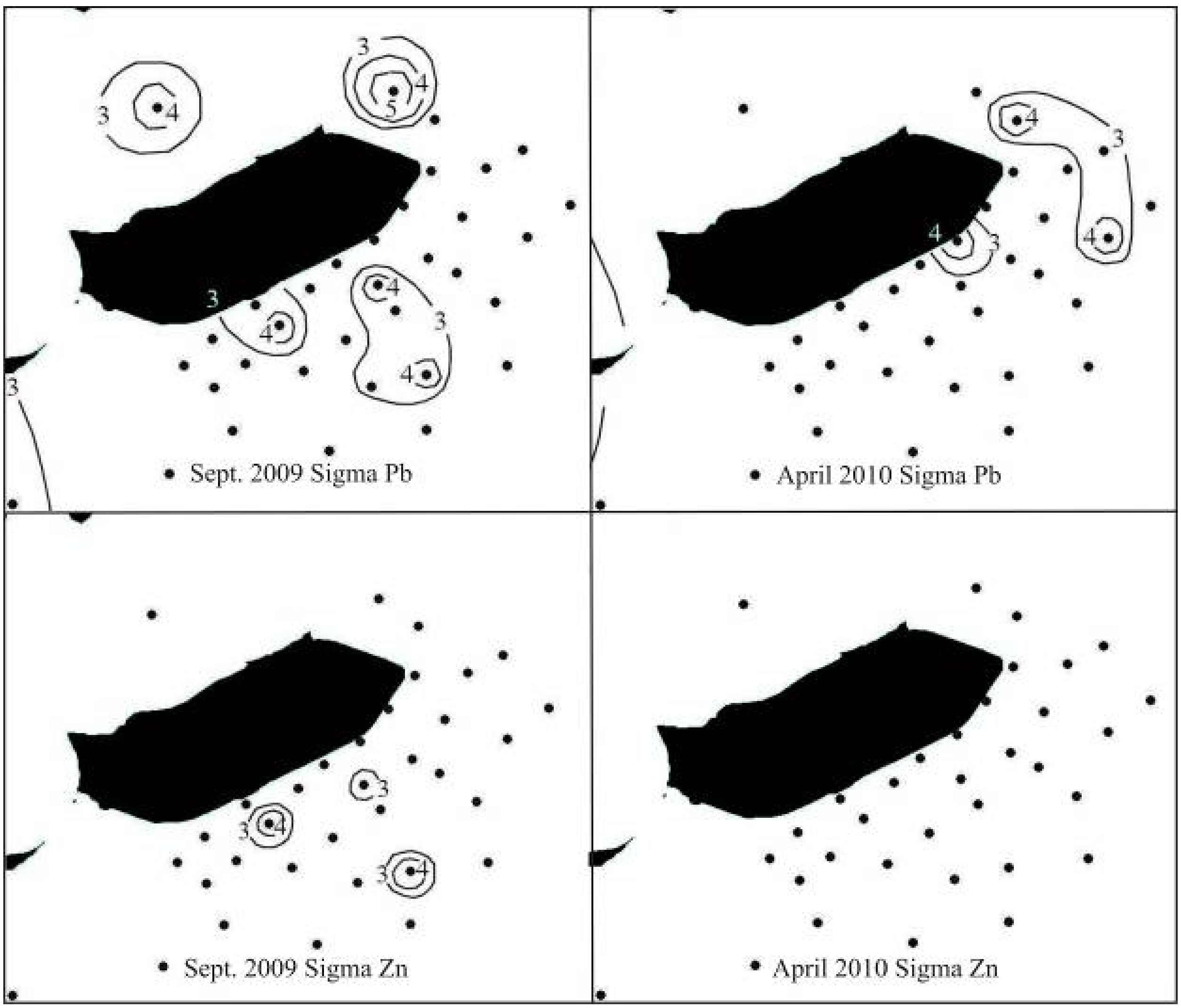
For the purpose of this summary only the distribution of Pb and Zn around HMI will be discussed; the distribution due to the contribution of Baltimore Harbor and Back River are discussed in detail in Appendix II. Summary Figure 1-5 shows the sigma levels for Pb and Zn for Year 29 September and April monitoring events in the area adjacent to HMI. Data that fall within +/-2 sigma are considered within normal baseline variability. Data within the 2 to 3 sigma range are transitional, and data >3 sigma are significantly elevated above background. The isopleths in Summary Figure 1-5 identify those areas that are significantly elevated above baseline levels.



Summary Figure 1-5. Year 29, September 2010 and April 2011 distribution of Pb and Zn around HMI. Values are expressed in multiples of Sigma.

Pb levels in sediments near HMI were lower in terms of the number of sites exceeding 3 sigma. In September Pb enrichment of 3 sigma and greater was found at only three sites; MDE-18 near the South Cell Spillway 003, MDE-46 located southeast of HMI in the distal zone, and MDE-34 located on the north side of HMI between Spillways 008 and 007 (Summary Figure 1-5 top left quadrant). In April Pb enrichment was only found at MDE-34. In September Zn enrichment exceeded 4 sigma at sites MDE-18 and 46; by April concentrations diminished at these two sites and no enrichment greater than 3 sigma within the HMI zone of influence was documented (Summary Figure 1-5 lower left and right quadrants respectively).

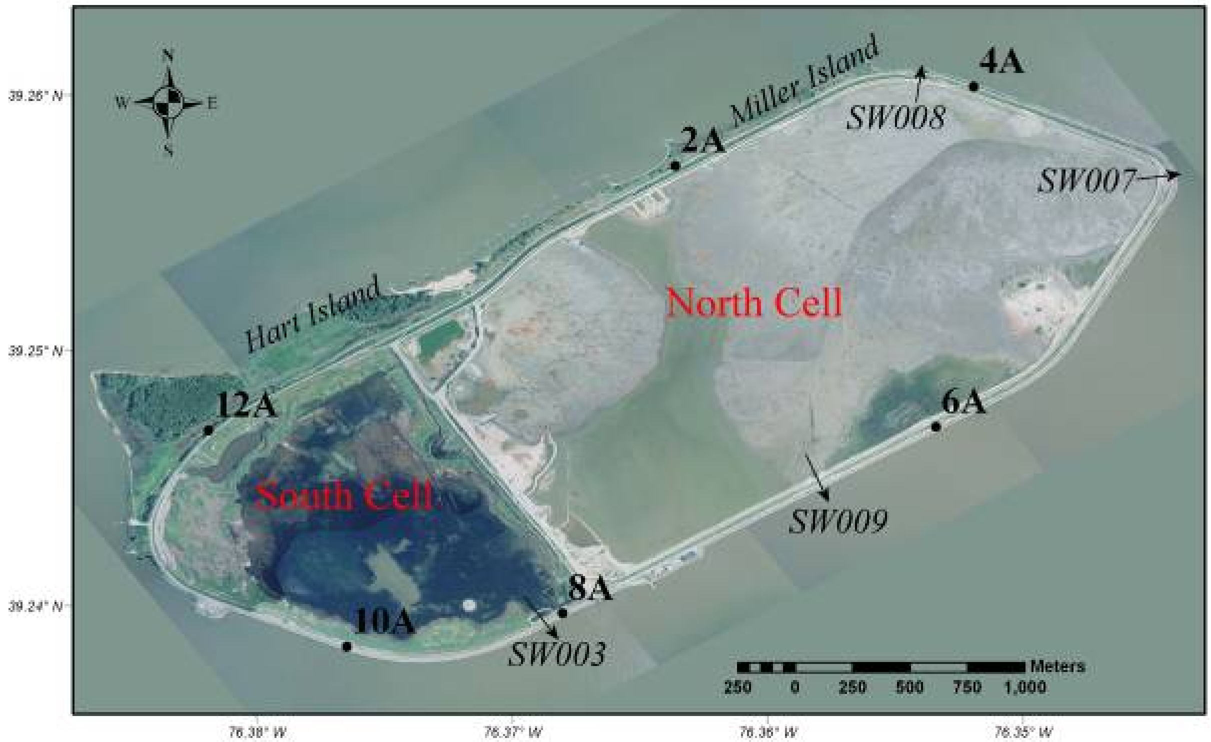
When comparing Year 29 to Year 28, Pb showed slightly lower enrichment levels both in terms of the number of sites and the extent of spatial distribution (Summary Figure 1-5 and Summary Figure 1-6 respectively). In Year 28, Pb distribution was contiguous to the dike around the South Cell Spillway 003 with another rather large spatial area on the east side still within the HMI zone of influence. By April 2010 levels decreased below 3 sigma at these sites; however, by September 2010 levels again increased. This would suggest that the discharge from Spillway 003 occurring in August 2010 prior to the September sampling may be the source. For Zn the distribution of sites exceeding 3 sigma were similar between Year 28 and 29. At least for now there appears to be a diminishing trend in concentration of Zn in sediment around HMI.



Summary Figure 1-6. Year 28, September 2009 and April 2010 distribution of Pb and Zn around HMI. Values are expressed in multiples of Sigma.

Groundwater Monitoring Well

Groundwater samples from six wells were collected on December 17, 2010, and June 21, 2011, 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 North and South Cells each have three monitoring wells (Summary Figure 1-7).



Summary Figure 1-7. Groundwater sampling wells locations.

All wells were found to be anoxic or hypoxic with dissolved oxygen (DO) levels less than 1.0 mg/L. However, due to sulfide interference with the DO probe it is more likely that the wells were anoxic, i.e., without oxygen. When oxygen is not available, anaerobic respiration occurs with nitrates being used preferentially as the primary oxidant and ammonium is formed as a byproduct. Ammonium was found as the dominant form of nitrogen which is consistent with the anoxic nature of the groundwater. In situ sulfides were not measured due to the limitations of the instrumentation.

North Cell Wells 2A, 4A and 6A

Well 2A is the only well still showing a reducing environment based on the depletion in sulfate in comparison to predicted concentrations. Groundwater in Well 6A, which was similar to Well 2A in Year 28, shifted in Year 29 now yielding positive excess sulfate. Thus, indicating an oxidizing environment (i.e., sulfide is oxidized producing sulfate which is then added to the water). The predicted levels of sulfate are calculated from the chloride concentration based on conservative mixing between rainwater and seawater. The amount of sulfate is 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). Oxidation of sulfides can increase the potential for acidic conditions which in turn can mobilize metals and acid soluble nutrients and trace organic compounds in the sediments. Well 4A, like 6A, showed positive excess sulfate for all samplings. Wells 4A and 6A are similar to the oxidizing environment seen in the South Cell.

Alkalinity concentrations have leveled off in Well 6A since declining sharply in December 2009; however, concentrations still remain higher when compared to Wells 2A and 4A, and to all the South Cell wells. The exception is with Well 2A which has fluctuated rather sharply over the last couple of years. Alkalinity in Well 2A was higher than 6A for the December 2009 and December 2010 sampling. The higher concentrations in Well 6A suggest that the alkalinity has not been neutralized by acid production.

Metal concentrations in Well 6A were low and in Well 2A most concentrations except Fe were low. The primary reason is that metals are less likely to be leeched from the sediment by acid or change in oxidation state. Acid produced by sediment oxidation can liberate metals; most of the trace metals measured, except Arsenic (As), were near or below the detection limits. Metals in Well 4A were found to be higher because it has more of an oxidizing environment much like the South Cell wells.

The groundwater from the North Cell Well 2A continues to exhibit behavior typical of anoxic pore waters that have not been exposed to oxidized sediment. In this area of the North Cell, the groundwater is replenished with water from dredged material input, which maintains the anaerobic state of the sediments, which is necessary to keep acidic conditions from developing. However, Wells 4A and now 6A are beginning to show characteristics similar to the South Cell wells. With HMI no longer receiving dredged material and as dewatering and crust management operations begin, the opportunity for sediment to be exposed to the air allowing sulfides to be oxidized is more likely.

South Cell Wells 8A, 10A and 12A

The wells in the South Cell have higher levels of excess sulfate indicating the waters infiltrating them have been exposed to oxidized sediments. Sediments are oxidized when exposed to air during periods of crust management or in the case of the South Cell when the pond is drained down to create mudflats, and with the upland areas (location of Well 12A) that are never submerged. This would indicate that rainwater rather than pond water is the major source of water infiltrating these wells compared to the North Cell. This is also evident in that chloride (typically high in Bay water) is in lower concentrations in these wells, especially Well 12A, which was 7.9 mg/L and 10.0 mg/L for the December 2010 and June 2011 sampling respectively. Wells 8A and 12A were over 2000 mg/L.

In the waters of the South Cell wells, total nitrogen as ammonium and alkalinity are lower, while metals and cations are higher in comparison to the waters in 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 necessary 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.

PROJECT III: Benthic Community Studies

Year 29 was the third year to utilize the revised monitoring station design, which was created to address post-closure needs (Summary Figure 1-1). Twenty-two stations were sampled on September 17, 2010 and on April 19, 2011 to monitor aquatic invertebrate communities surrounding HMI. Organisms living in sediments close to the facility (Nearfield, South Cell Restoration Baseline, and Back River/Hawk Cove stations) were compared to those located away from the influence of the facility (Reference stations). Water quality parameters, including dissolved oxygen (DO) concentrations, salinity, temperature, pH, conductivity, and secchi depth were measured *in situ.*

Water Quality

The water quality parameters measured during the September 2010 and the April 2011 sampling cruises showed minimal variations between surface and bottom conditions indicating that the water column was well mixed and not stratified. The stratification that occurred in April 2010 at stations MDE-50 and MDE-51 was not present in April 2011.

DO is a criterion established to protect aquatic life, and for which a threshold of 5.0 ppm has been determined and published in the Maryland Code of Regulations. During both the September 2010 and April 2011 sampling events, bottom-water DO concentrations exceeded the water quality standard of 5.0 ppm at all stations. In Year 28 the DO concentration was below the water quality standard at both MDE-50 and MDE-51 in September 2009, and in April 2010 only at MDE-51.

Like DO, measures of bottom-water temperature and salinity are important and relevant to benthic macroinvertebrate health. In Year 29, bottom-water temperature did not vary much between stations during both the September 2010 and April 2011 sampling events. In September 2010 the average temperature was 22.52°C, slightly lower than the 25 year average of 24.36°C. In April 2010 the average bottom-water temperature was 12.96°C, slightly higher than the 14-year spring average of 12.10°C. Salinity regimes changed considerably between September and April. Salinity during the fall mainly fell within the low mesohaline regime (>5 ppt – 18 ppt) with a range of 8.15 ppt to 11.30 ppt, and an average of 10.07 ppt. Salinity in the spring was tidal fresh (0.0 ppt – 0.5 ppt) with a range of 0.12 ppt – 1.24 ppt, and an average of 0.38 ppt. The average of all stations is used when determining the salinity regime in which the sampling season falls.

Benthic Macroinvertebrate Community

Taxa Richness and Dominance

A total of 44 taxa were found over the two seasons of sampling during Year 29. The 13 year average is 39.93 taxa. The most common taxa were amphipoda and isopoda of the phyla Arthropoda (joint-legged organisms); twenty-two taxa were found, which is slightly higher than the 13-year average of 18.23. The second most common taxa was Annelida (segmented worms); six taxa of annelid worms in the Class Polychaeta were found. The third most common was Mollusca/Bivalvia (shellfish having two separate shells joined by a muscular hinge); six species were found.

Of the 44 taxa found in Year 29, eighteen were considered infaunal, eighteen were considered epifaunal, and the remaining eight were considered too general to classify as either infaunal or epifaunal (see Ranasinghe et al. 1994). The most common infaunal species found during Year 29 were worms from the family Naididae, the amphipods *L. plumulosus* and *Gammarus* sp., the polychaete worm *M. viridis*, the bivalve *M. balthica*, and the isopod *C. polita*. The most common epifaunal species were the amphipods *A. lacustre* and *M. nitida,* and the isopod *E. triloba.*

Overall, in September 2010 average taxa richness was highest at the Nearfield stations (16.17 taxa) followed by the Reference stations (14.20 taxa). On average 14 taxa were found at the Back River/Hawk Cove stations, and an average of 13 taxa were found at the South Cell Exterior Monitoring stations. 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. Thus, higher taxa abundances at Nearfield stations may simply be an artifact of sample size.

In April 2011 the average taxa richness did not vary greatly between station types. The average taxa richness was highest at Nearfield stations (13.58 taxa), followed by Back River/Hawk Cove Stations (13.50 taxa), Reference stations (11.80 taxa), and South Cell Exterior Monitoring stations (11.67 taxa).

Benthic Index of Biotic Integrity

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI), (Weisberg et al. 1997), a multi-metric index of biotic condition that evaluates summer populations (specific for July 15th to September 30th timeframe) of benthic macroinvertebrates, was calculated for all stations sampled during the September 2010 cruise.

The B-IBI is calculated using different metrics, and the metrics used are dependent upon the salinity. In September of 2010 the average salinity was 10.07 ppt which is considered low mesohaline and under such conditions the individual metrics used are; 1) Shannon-Wiener species diversity index (SWDI), 2) Total infaunal abundance, 3) Relative abundance of pollution-indicative taxa, and 4) Relative abundance of pollution-sensitive taxa. Relative abundance of pollution-sensitive taxa is used as a substitute to percent biomass of pollution-sensitive taxa. The following is a brief summary of the findings of the four metrics of the September sampling followed by a discussion of the B-IBI results.

Species Diversity

Species diversity was examined using the 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.

SWDI values for the 22 stations sampled in September 2010 ranged from a high of 3.40 at the Nearfield station MDE-17 located approximately three quarters of a mile centrally off the southeast side of HMI to 0.97 at the Back River/Hawk Cove station MDE-27 located at the mouth of Back River. The low diversity at MDE-27 was primarily due to the large percentage of Naididae worms, which accounted for 86.5 percent of total infaunal abundance at this station.

On average, Nearfield stations had diversity values similar to Reference stations in September 2010. Comparing station types from the fall only, the lowest average SWDI was 1.80 at the Back River/Hawk Cove stations followed by the South Cell Exterior Monitoring stations at 2.68, and Nearfield stations at 2.74. The highest average SWDI occurred at the Reference stations at 3.02.

Total Infaunal Abundance

Infaunal organisms are those that live below the surface of the sediment as opposed to on the surface of the sediment, or epifaunal. Total infaunal abundance per meter square ($\#/m^2$) is a calculation derived by multiplying the average infauna of three Ponar grab samples by a conversion factor. In September 2010, total infaunal abundance ranged from 286.8 individuals/m^2 found at the Reference station MDE-50 to 11,763.2 individuals/m^2 at MDE-27, a Back River site located at the mouth of Back River. The high abundance at MDE-27 was due primarily to large numbers of Naididae worms, *S. benedicti, M. mitchelli,* and *L. plumulosus*. Overall, Back River stations had the highest average total infaunal abundance at 6099.2 individuals/ m^2 with Nearfield stations having the second highest average at 2210.7 individuals/m^2. The average total infaunal abundance for South Cell Exterior stations was 1847.5 individuals/m^2 and Reference stations had the lowest average at 1,089.3 individuals/m^2.

Relative abundance of pollution-indicative taxa (PITA)

Pollution-indicative taxa are species that are typically tolerant of pollution. They are often small in size, have rapid growth, high reproductive potential, and short life-span, (Versar, Inc. 2002). In Year 29 during the September sampling four taxa were found that are designated as “pollution-indicative” according to Alden et al. (2002). The four taxa were Chironomid

Coelotanypus, the polychaete worms *S. benedicti* and *E. heteropoda*, and oligochaete worms of the family Naididae.

In September 2010 the Reference site MDE-22 had the lowest percent of pollution-indicative taxa abundance (PITA) at 12.12 percent. MDE-27 at the mouth of Back River had the highest PITA at 91.57 percent while MDE-45 a Nearfield station located near Spillway 009 had the second highest PITA at 73.89 percent. In terms of station type, the lowest average PITA was 32.81 percent for the Reference stations, followed by 39.16 percent for the South Cell stations, and 39.38 percent for Nearfield stations. The Back River/Hawk Cove stations (MDE-27 and 30) had the highest average PITA of 72.99 percent. In Year 28 MDE-30 had the lowest percent PITA; thus, the high percent at MDE-27 was driving the overall high average for the Back River/Hawk Cove stations. This wasn't the case in Year 29. MDE-30 had a high percent PITA (54.41 percent) and was in the 75^{th} percentile for all 22 sites.

Relative abundance of pollution-sensitive taxa (PSTA)

Species identified as being sensitive to pollution are those that tend to grow slowly and are relatively long-lived and thus tend to characterize undisturbed, mature communities, (Versar, Inc. 2002). In September of 2010 the average salinity for all stations was 10.07 ppt, which falls within the low mesohaline regime. The organisms identified as pollution-sensitive are determined based on the salinity regime. Of those organisms collected in September 2010 four taxa were designated as "pollution-sensitive" according to Alden et al. (2002); they were the polychaete worm *M. viridis,* the bivalves *R. cuneata* and *M. balthica,* and the isopod crustacean *C. polita.* PSTA is the ratio of the relative PSTA abundance and the total infuanal abundance.

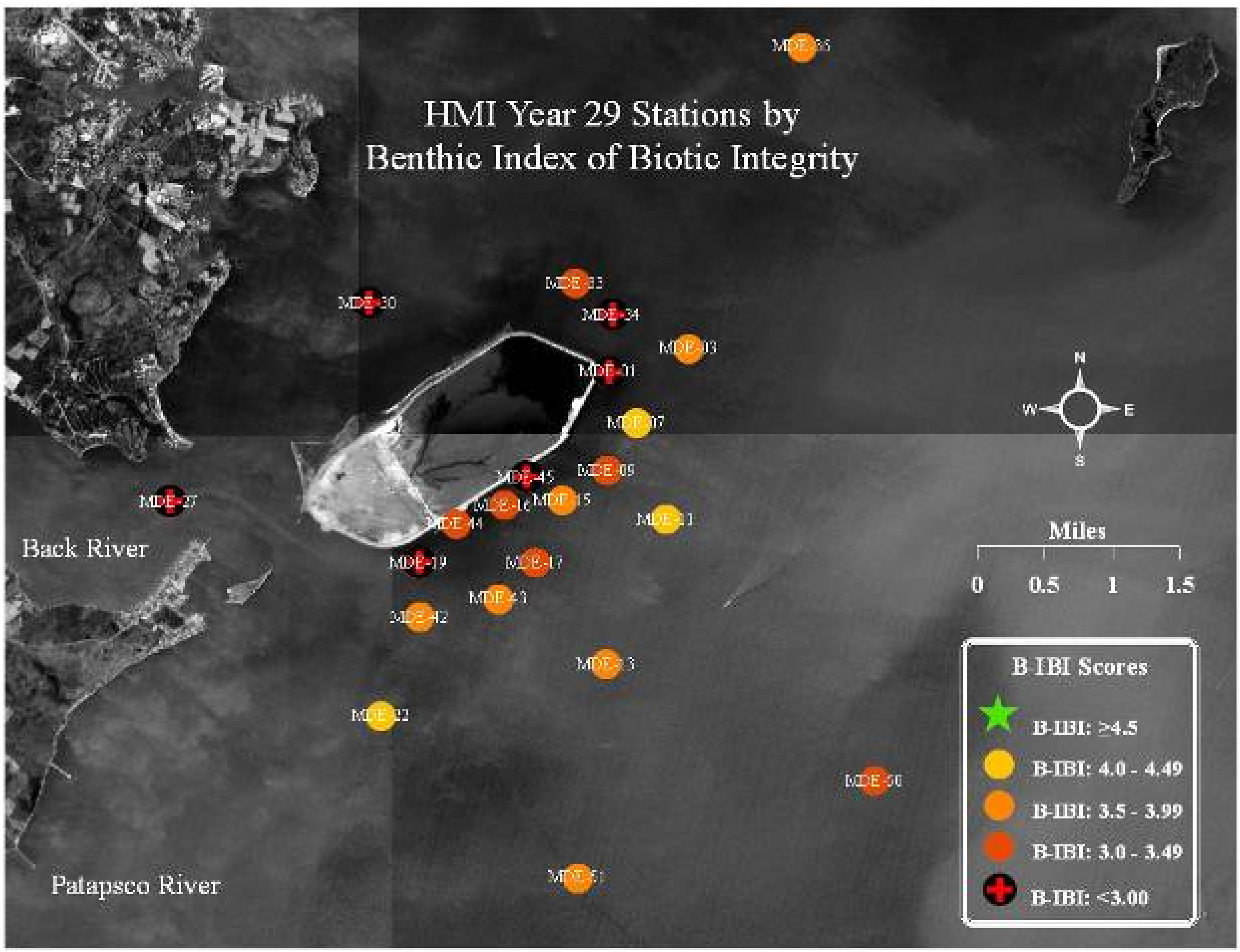
For the September 2010 sampling pollution sensitive taxa were found at all station types. The PSTA ranged from 0.34 percent at MDE-01, a Nearfield station located on northeast side of HMI along the dike near Spillway 007, to 36.36 percent at MDE-22 a Reference station located approximately 1.5 miles south of HMI. The average for all stations was 32.90 percent.

In terms of station types the Back River Hawk Cove stations had the lowest average PSTA at 9.80 percent; Nearfield stations averaged 14.69 percent; South Cell Exterior Monitoring stations averaged 22.46 percent, and the References stations had the highest average of 27.25 percent. Theses percentages are considerably lower than the historical average. The 29-year average fall PSTA percentages for the four station types are: South Cell Exterior Monitoring (30.76 percent, n=6 years), Back River/Hawk Cove (31.15 percent), Nearfield (39.29 percent), and Reference (42.90 percent).

Benthic Index of Biotic Integrity Results

B-IBI scores range from one to five with one considered as deviating greatly from reference conditions, and five approximating reference conditions. A B-IBI score greater than or equal to three represents a benthic community that is not considered stressed by *in situ* environmental conditions. The 22 benthic stations studied during Year 29 were compared to this benchmark. It should be noted that existing conditions at those sites around HMI classified as "Reference" sites are not necessarily equal in high quality to the reference sites originally used for calibrating the B-IBI. The HMI Reference sites were selected and compared to because they were considered outside the potential influence of HMI operations.

B-IBI scores improved in Year 28 over previous monitoring; however in Year 29 B-IBI scores as a whole were lower compared to Year 28. Of the 22 sites sampled, B-IBI scores decrease at 14 sites, remained the same at four sites, and increased at four. In Year 29, Back River/Hawk Cove stations MDE-27 (1.00) and MDE-30 (2.50), Nearfield stations MDE-01 (2.00), MDE-19 (2.50), MDE-34 (2.50), and MDE-45 (2.50) failed to meet the benchmark criteria of 3.0 (Summary Figure 1-8). Eighteen stations were below their historic averages and four stations were above their historic averages for B-IBI. In addition to eighteen stations being below their historic average three tied historic lows (Nearfield stations MDE-01 and MDE-34, and Back River/Hawk Cove station MDE-27).



Summary Figure 1-8. HMI stations by B-IBI scores.

Summary Table 1-2 shows those sites that have failed in one year or another starting with HMI Project Year 25. B-IBI scores overall were poorer in Year 29 with some sites failing that typically have had good scores; these sites were MDE-01, 34, and 45 which have been included in Summary Table 1-2.

MDE-27 and MDE-30, both within the Back River zone of influence had failing B-IBI scores. The scores are quite reduced when compared to previous years, which could be indicative of contaminants of some sort coming from Back River. Of the Nearfield sites MDE-19, which often has a poor B-IBI score, failed this year. Unlike MDE-19 Nearfield sites MDE-01 and MDE-34 typically have good B-IBI scores; however, they also failed in Year 29. These two sites are located on the north side of HMI. Nearfield site MDE-35 was one of the sites relocated with the new post-closure sampling design; thus, is no longer sampled. South Cell Exterior Monitoring stations MDE-44, 43 and 42, established in Year 22 to increase spatial coverage on the south side of HMI to monitor potential effects of effluent from the South Cell Spillway 003, were similar to Year 28 with one improving, one remaining the same, and one with a slight decrease in B-IBI. South Cell Exterior Monitoring station MDE-45, established in Year 27 as part of the new post-closure sampling design, for the first time after being established had a failing B-IBI score of 2.50. MDE-45 is located near Spillway 003.

Summary Table 1-2. Comparison of B-IBI scores of select sites for Years 25, 26, 27, 28 and 29. Failing scores are highlighted in red.

B-IBI Scores For Select Stations					
Stations	Year 25	Year 26	Year 27	Year 28	Year 29
BR/HC MDE-27	2.67	2.33	2.50	2.50	1.00
BR/HC MDE-30	2.33	2.33	3.00	3.50	2.50
Nf. MDE-01	4.67	3.00	3.50	4.00	2.00
Nf. MDE-17	2.67	3.00	3.00	3.00	3.00
Nf. MDE-19	2.67	2.33	3.00	4.00	2.50
Nf. MDE-34	4.00	3.67	3.50	4.50	2.50
Nf. MDE-35	2.67	3.00	Not Sampled	Not Sampled	Not Sampled
Ref. MDE-13	2.67	3.00	3.50	3.50	3.50
SC MDE-42	4.33	2.33	3.00	4.00	3.50
SC MDE-43	3.67	2.33	3.00	3.00	3.50
SC MDE-44	2.67	3.00	4.50	4.00	3.00
SC MDE-45	Not Sampled	Not Sampled	3.00	3.50	2.50

PROJECT IV: Analytical Services

For Year 29 exterior monitoring at HMI, CBL collected the clam *Rangia cuneata* both in September 2010 and April 2011. A total of 19 sites were sampled (see Summary Table 1-3). In addition to clams, sediment samples were concurrently collected and analyzed for trace metals. PCBs and PAHs were analyzed in the sediment and clam samples collected during the September cruise only. Please note sediment only was collected at MDE-50 in September 2010.

As part of the annual sediment survey, CBL conducted analysis for concentrations of target trace elements in surface sediments collected in September 2010 around HMI by MGS. Metal analysis focused on those metals and metalloids not measured by MGS, specifically total mercury (T-Hg), methylmercury (MeHg), silver (Ag), and metalloids selenium (Se) and arsenic (As).

Summary Table 1-3. Clam and sediment stations.

September	April
MDE-1	MDE-1
	MDE-3
	MDE-7
MDE-9	MDE-9
	MDE-13
MDE-15	
MDE-16	MDE-16
	MDE-17
MDE-19	
MDE-22	
MDE-27	
MDE-30	
MDE-34	
MDE-36	MDE-36
	MDE-42
MDE-43	MDE-43
MDE-44	MDE-44
MDE-50	
MDE-51	MDE-51

Metals in Sediment

The following is a summary of the sediment samples collected in September 2010 by MGS and analyzed for As, Se, Ag, T-Hg, and MeHg by CBL.

Concentrations of As in the sediment collected around HMI in September 2010 were similar to concentrations seen in previous years, and were close to the running mean (calculated for the time period 1998 to 2009). The exception was with sites MDE-06, 10, 12, and 15 (see Summary Figure 1-1). Concentration of As in sediments at these sites exceeded the running mean, which is between 10 and 13 ug g^{-1}, by greater than 5 ug g^{-1}.

The concentrations of Se in sediments collected in September 2010 are the same or lower than the running mean from previous years with the exception of sites MDE-6, 10, 12 and 15, which exceeded the stations historic mean Se concentration by greater than 1 ug g^{-1}. To put this into perspective, Se concentrations in sediment around HMI are generally below 3 ug g^{-1}; thus, the increase at the four sites is a large percentage change.

Concentrations of Ag in the sediment collected in September 2010 were lower than the median and average concentrations collected around HMI in previous years. In 2009 this same condition was observed. Annual fluctuations in the concentration of Ag in sediment are system wide and appear unrelated to HMI operation.

Concentrations of T-Hg in sediment were generally greater than the running mean of previous years and concentrations at many sites exceeded the standard deviation of measurements made between 1998 and 2009. Sites MDE-6, 12, 15, 17 18, 39, and 51 considerably exceeded the standard deviation while sites MDE-9, 11, 14, 23, 25, and 36 were marginally above the standard deviation. Concentrations of Hg in the main stem of the Chesapeake Bay range from 0.2 to 250 ng g^{-1} dry weight (Heyes et al. 2006). Concentrations of T-Hg in sediment from all 43 sites sampled ranged from between 9.34 ng g^{-1} and 564.72 ng g^{-1} with 42 percent of the sites exceeding the high range of 250 ng g^{-1} for the main stem of the Chesapeake Bay.

Concentrations of MeHg in sediment collected from 43 sites in September 2010 ranged from 0.06 to 2.5 ng g^{-1} dry weight. These concentrations are mostly comparable to the rest of the Chesapeake Bay (Heyes et al. 2006). However, concentration of MeHg at MDE-25 and MDE-38 was 2.38 and 2.49 ng g^{-1} respectively, which is higher than what has typically been observed (Heyes et al. 2006). Sites MDE-25 and MDE-38 are in the Baltimore Harbor zone of influence. Thus, these high concentrations are not a result of HMI operations.

Metals in Clam Tissue

The clam *Rangia cuneata* was collected from 13 sites in September 2010 and 12 sites in April 2011 (see Summary Table 1-3). Tissue was analyzed for As, Se, Ag, Cd, Pb, Hg and MeHg. Tissue samples collected in the fall only were also analyzed for PCBs and PAHs.

In clam samples collected in September 2010 concentrations of As, Se, Ag, Cd, Pb, T-Hg, and MeHg were nearly all lower than previous years. Concentrations of T-Hg and MeHg were close to the running mean of the stations from which they were collected while concentrations As, Se, Ag, Cd, and Pb were substantially lower than the stations running mean. Sites MDE-44 and 51, which were new stations added in Year 27 as part of the post-closure sampling design, were also sampled for clams in September 2010. Site MDE-44 is adjacent to the south side of HMI and MDE-51, a reference site, is approximately 2 miles south of HMI. Concentrations of trace elements in clams collected from MDE-44 and 51 were similar to concentrations in clams of the other sites including the reference site MDE-36.

In April 2011, concentrations of As Se, T-Hg, MeHg in clams were close to the historical concentrations of the site from which the clams where collected and concentrations of Pb, Ag and Cd in clams were lower than the sites running mean concentration. Clams were again sampled from sites MDE-44 and MDE-51. Concentrations of trace elements were higher in April than September except in the case of Pb but the concentrations were comparable to the those obtained on clams collected from the reference site MDE-36.

Bioaccumulation Factors

A bioaccumulation factor (BAF) is a measure of the degree to which an organism accumulates a chemical compared to the source and in the case of the clams is calculated by dividing the concentration in the tissue by the concentration found in the sediment. It is useful for determining the bioavailability of chemicals.

In both September 2010 and April 2011, the BAFs for Pb by the clams were very low for all sites basically indicating there was no bioaccumulation of Pb from the sediment to the clams. Little bioaccumulation by the clams was observed for As, Cd, T-Hg and Se while moderate bioaccumulation of MeHg was generally observed. However, high BAFs were calculated for Ag. Two sites in particular, MDE-34 and MDE-44, were found to have the highest BAFs for Ag. In September 2010, MDE-34 on the north side of HMI between Spillways 007 and 008 had high BAFs, and April 2011 MDE-44 was found to have high BAFs. These high BAFs are partly the result of very low Ag concentrations in sediment for MDE-34 and MDE-44. Given that the sediment concentration of Ag was low, the source of Ag for the clams was likely suspended organic particulate in the water column. BAF values and figures are given in Appendix III.

Total PCB concentrations in sediments and clams

In Year 29 clams collected during the September 2010 MDE biota cruise, and sediment samples collected concurrently were analyzed for PCBs. In this summary only total PCBs are discussed; individual congeners are reported and discussed in detail in Appendix III.

The total PCB concentrations in sediment collected in September 2010 were similar to or below the historical site averages, being within the standard deviation of the mean with the exception of MDE-43. Total PCB concentrations in clams were on average 2 times higher than the running mean for all sites including the reference site, MDE-36.

Total PAH concentrations in sediments and clams

The total concentrations of PAHs in sediment collected in 2010 from sites around HMI were similar to historical levels. PAH concentrations at the Back River site MDE-27 were above the historical levels of the site but within the range observed at other locations in 2010. Concentrations of PAHs in clams were above historical levels at all but 1 of the sites investigated including at the reference site MDE-36. Site MDE-1 by Spillway 007 was the exception to this trend, where low PAH concentrations in sediment were also observed. The concentrations of PAHs in clams track the sediment concentrations at each site, suggesting a local connection.

The fact that both PCB and PAH concentrations in clams were elevated above historical levels, but sediments were not, might imply a wide spread event that enhanced PAHs and PCBs in the water column particulate load, thus making them more available to uptake by the clams. This could occur by increased sediment resuspension or increased regional delivery of PAH enriched particles from elsewhere in the Bay.

PROJECT I DISCUSSION AND RECOMMENDATIONS

Over all, inYear 29 the areas of enrichment diminished when compared to Year 28. In September 2010 there were three areas around HMI enriched (> 3 sigma) with both Pb and Ni; two of the areas were also enriched with Zn. One of the two areas at which all three metals were enriched was near the South Cell Spillway 003 encompassing only site MDE-18. The second small area was farther from the dike in the distal zone encompassing site MDE-46. A third small area enriched by Pb and Ni was on the north side of HMI between Spillway 007 and 008 encompassing only site MDE-34.

The first enriched area, near Spillway 003 and encompassing site MDE-18, was not sampled by MDE for benthics or CBL for tissue; thus, it is not possible to apply the Sediment Quality Triad to determine if there are pollutants. However, some assumptions can be drawn by evaluating those sites in close proximity (within a half mile). The benthic sites in close proximity were MDE-16, 17, 19, 43, and 44 with B-IBI scores of 3.0, 3.0, 2.5, 3.5, and 3.0 respectively. These sites with the exception of MDE-19 had sigma levels below 2 for all metals, with some even below background (0 sigma). At MDE-19, Pb and Zn exceeded 2 sigma with concentrations of Zn exceeding the ERL (see Summary Figure 1-3). Thus, Pb and especially Zn are at concentrations that may affect the faunal community. As noted above the B-IBI score for MDE-19 was 2.5 indicating a stressed faunal community. However, at these same sites, metals in clam tissue analyzed by CBL were found to be generally below the running mean. Bioaccumulation factors for metals, especially Pb, were also low. Based on the triad approach for interpreting results (i.e., comparing results of Projects II, III, and IV), with the exception of site MDE-19 results from all three Projects give strong evidence of no pollution in this vicinity of the South Cell. However, MDE-19 had marginal enrichment of Pb and Zn as well as a stressed faunal community, and MDE-18 had significant enrichment of Pb, Ni, and Zn. It is likely the enrichment of metals at these two isolated sites and the stressed faunal community is due to effluent from the South Cell.

The second area of enrichment encompassed MDE-46 approximately 1.5 miles southeast of Spillway 003. Pb was 3.9 sigma and both Ni and Zn were greater than 4 sigma and exceeded the ERM, which is the most probable condition for metals to affect the faunal community. However, MDE and CBL did not collect samples at this site; thus, the Sediment Quality Triad can not be applied. The sites in close proximity include MDE-12, 13, and 47. Sites MDE-12 and 47, which MDE and CBL did not sample, both had sigma levels below one for all metals and concentrations were below the ERL. MDE sampled the Reference site MDE-13 approximately half a mile away. The sigma level for Ni at MDE-13 was 2.0 and the concentration exceeded the ERM; however, the B-IBI score was good at 3.5 indicating a healthy and diverse faunal community. The Sediment Quality Triad can not really be applied within this area of stations mainly because benthics were only collected at one site and CBL did not collect samples at any of the sites. The enrichment at MDE-46 is likely a localized effect rather than due to effluent from any of the HMI spillways. Regarding MDE-13 it appears the enrichment of Ni and the exceedance of the ERL did not have an effect on the faunal community.

The third and final area of enrichment, on the north side of HMI, encompassed only station MDE-34. Pb was 7.2 sigma while Ni was 13.8 and also exceeded the ERM (see Summary Figure 1-4). MDE and CBL collected samples at MDE-34 and while the B-IBI at 2.5 failed to meet the benchmark of 3.0, CBL reported that concentrations of As, Se, Ag, Cd, Pb, T-Hg and MeHg measured in clams were almost ubiquitously lower than previous years and that they were in line with the running mean. Little bioaccumulation of As, Cd, T-Hg and Se by the clams was observed and only moderate bioaccumulation of MeHg. Bioaccumulation for Ag was high, but in part this was due to the low concentration of Ag found in the sediment (calculation of the BAF is based on sediment and clam metal concentrations). It should be noted that site MDE-34 is a sandy site (90.62 percent) with little organic matter to which Ag can bind. Thus, the source of Ag is likely organic matter suspended in the water column. MDE-34 is close between Spillways 007 and 008 and it is possible that effluent from these spillways is a contributor in addition to regional sources. Regarding sites in close proximity to MDE-34 (MDE-01, 02, 03, and 33), for the most part MGS found metals to be at background level (0 sigma) and lower. MDE collected benthic samples at MDE-01, 03, and 33 while CBL collect clams at MDE-01. At MDE-01 the B-IBI was 2.0, which failed to meet the bench mark. MDE-03 just met the bench mark while MDE-33 was a little more improved at 4.0. CBL found metal concentrations in clam tissue, with the exception of MeHg and T-Hg, to be below the running mean and bioaccumulation factors to be in line with historical values. MeHg was at the running mean and T-Mg was only slightly above it.

With the exception of MDE-34, results from all three Projects give strong evidence of no pollution in this vicinity of the north side of the island. However, MDE-34 is right between Spillway 007 and 008 both of which were used to release effluent. Thus, it is likely the high enrichment of Pb and Ni as well as the stressed benthic community is a result of HMI operations. It should be noted that for the last four years prior to closure of the facility MDE-34 had very good B-IBI scores (see Summary Table 1-2). Regarding MDE-01, it is adjacent to Spillway 007 and although Projects II and IV showed good results for this site it is possible that whatever stressed the benthic community was due to the effluent from the spillway. This site also has had good B-IBI scores for the previous four years (see Summary Table 1-2).

The MGS Year 29 April 2011 results showed no enrichment of Zn which is consistent with Year 28. Enrichment of Pb was only seen at MDE-34 located on the north side of HMI between Spillway 007 and 008. This is a rather significant reduction to the special extent of enrichment when compared to Year 28 when a large spatial area including three stations was delineated on the north side of HMI.

B-IBI scores are not calculated for the spring months. In terms of the individual metrics on which the B-IBI is calculated, results are consistent with previous years. In April 2011, MDE-34 was the only station where enrichment of Pb was found, and results for the individual B-IBI metrics for the site and those sites proximal to it are within range of those sites distanced from the area of enrichment. Thus, there is no conclusive evidence that would suggest any impact to the biota in the area of metal enrichment.

For the Year 29 April sampling cruise, CBL reported that concentrations of As Se, T-Hg, MeHg in clams were close to the historical concentrations of the sites from which clams where collected and concentrations of Pb, Ag and Cd in clams were lower than the sites running mean concentration. Concentrations of trace elements were higher in April than September except in the case of Pb, but the concentrations were comparable to those obtained on clams collected from the reference site MDE-36.

Year 29 was the first full year during which dredged material was not placed in the facility and dewatering and crust management efforts began. During this year there was a slight reduction in the overall spatial extent of enrichment of Pb and Zn, and clam studies conducted by CBL were fairly consistent with previous years. However, when compared to the last four years the biota overall were suppressed with four sites in close proximity to the dike not meeting the B-IBI benchmark of 3.0 (see Summary Figure 1-8). Four of the six sites just meeting the benchmark were also in close proximity to the dike. This being only the first year post-closure it is difficult to say whether or not the suppressed faunal communities are due to HMI operations. Therefore, it is most important that monitoring continues for a number of years to determine if the current trend continues, and so that a robust data set can be developed with which to conduct statistical analysis against historical data.

REFERENCES

Alden, R. W. III, D. M. Dauer, J. A. Ranasinghe, L. C. Scott, and R. J. Llansó. 2002. Statistical verification of the Chesapeake Bay Benthic Index of Biotic Integrity. Environmetrics 13:473-498.

Annotated Code of Maryland, Environment, Title 5, Subtitle 11, Section 5-1103.

Buchman, M.F., 2008, NOAA Screening Quick Reference Tables, NOAA OR&R Report 08-1, Seattle WA, Office of Response and Restoration Division, National Oceanic and Atmospheric Administration, 34 p

Heyes, A., Mason, R.P. Kim, E.H. and Sunderland, E.M. 2006. Mercury methylation in Estuaries: Insights from measuring rates using mercury stable isotopes. Marine Chemistry 102:134-147.

Long, E.R. and P.M. Chapman. 1985. A Sediment Quality Triad: Measures of sediment contamination, toxicity and infaunal community composition in Puget Sound. Mar. Poll. Bull. 10:405-415.

Ranasinghe, J.A., S.B. Weisberg, D.M. Dauer, L.C. Schaffner, R.J. Diaz and J.B. Frithsen. 1994. Chesapeake Bay Benthic Community Restoration Goals. Report CBP/TRS 107/94. U.S. Environmental Protection Agency, Chesapeake Bay Program. Annapolis, Maryland.

Versar, Inc., Revised: 2002. Methods for Calculating the Chesapeake Bay Benthic Index of Biotic Integrity. p 8.

Verween, A., Kerckhof, F., Vincx, M., and Degraer, S., Revised 2006. First European record of the invasive brackish water clam Rangia Cuneata (G.B. Sowerby I, 1831) (Mollusca: Bivalvia). Aquatic Invasions (2006) Volume 1, Issue 4: 198-203.

Weisberg, S.,D. Dauer, L. Schaffner and J. Fithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries* 20(1):149-158.

APPENDIX 1: SEDIMENTARY ENVIRONMENT (PROJECT II)

(September 2010 - August 2011)

Technical Report

Prepared by
Darlene Wells and Stephen Van Ryswick

Coastal and Environmental Geosciences Program
Maryland Geological Survey
2300 St. Paul St.
Baltimore, MD 21218
(410) 554-5500

Prepared for
Maryland Port Administration
Maryland Department of Transportation
World Trade Center
401 East Pratt Street
Baltimore, Maryland 21202

January 2012

ACKNOWLEDGMENTS

For their assistance during the two Year 29 sampling cruises, we would like to thank the Maryland Department of Natural Resources for providing the research vessel *R/V Kerhin*, Captain Rick Younger for piloting the vessel and collecting samples. We would also like to thank our colleagues at the Maryland Geological Survey (MGS), Lamere Hennessee, Richard Ortt, Nicholas Kurtz and Elizabeth Sylvia for their assistance in the field and lab. Finally, we extend our thanks to Carolyn Blakeney, Cassandra Carr and Amanda Peñafiel at Maryland Environmental Service (MES), who provided us with much of the information related to site operations.

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 DCMF) from the initial planning stages of construction of the facility to the present. As part of this year's exterior monitoring program, MGS collected bottom sediment samples from 43 sites on both September 14, 2010 and April 14, 2011. 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), phosphorus (P), carbon (C), nitrogen (N), and sulfur (S)

For exterior bottom sediments sampled during Year 29, average grain size composition, reported as % sand and as clay:mud ratios, varied little compared to previous year data. The pattern of the grain size distribution varied slightly from one cruise to the next, and from the previous years 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 Medium (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 29th year results of the elemental analyses were statistically similar to the previous year's data. With regard to the ERL and ERM values, this year's data showed that:

1. At most sampling sites, concentrations of Cr, Cu, Ni, Pb, and Zn in the sediment exceeded the ERL values; and
2. At most sampling sites, concentrations of Ni exceeded the ERM values; and Zn exceeded the ERM values 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 DCMF. 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 29th year data showed that certain sediment samples are significantly enriched with Pb and Zn.

Based on work done by the University of Maryland during HMI 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 2010 and April 2011 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 ERMs, and sigma levels greater than two. Within the HMI zone of influence (both distal and proximal), the sediments containing multiple metals exceeding ERLs or ERMs, and sigma levels greater than two included Sites MDE-9, MDE-14, MDE-18, MDE-19, and MDE-46 from the September 2010 cruise, and sites MDE-11, MDE-14, MDE-34, MDE-45, and MDE-50 from the April 2011 cruise.

Pb enrichment levels adjacent to the HMI were lower, in terms of the number of samples exceeding 3 sigma levels, compared to the previous year. In September 2010, Pb enrichment was seen at three sites: one adjacent to Spillway 003 (MDE-18); a second southeast of HMI (MDE-46); and the third site north of the facility (MDE-34). By April, Pb enrichment was seen only at MDE-34, and the level had dropped from seven to three. In September, Zn enrichment was seen at two isolated sites (MDE-18 and 46). In April, Zn enrichment was below three sigma at all sites within the HMI Zone of influence.

September spatial distribution of both Pb and Zn enriched areas along the southeast side of the facility suggests that the South Cell discharge may be the source. There was a period of steady discharge from the South Cell spillway a week prior to the sampling cruise as opposed to no discharge from North Cell Spillway 009 during the same period. North Cell Spillway 008 may be the source of Pb enrichment seen at MDE-34 northeast of the facility in the fall and spring. North Cell discharge appeared to have had a minimal effect for both cruises, with regard to Zn enrichment. The lower enrichment levels and reduced spatial extent of the enrichment were attributed to the steps that the HMI facility took to minimize the loadings of these metals.

The spatial extent and the levels found in the Baltimore Harbor and Back River zones of influence vary according to seasonal weather changes, which influence the hydrodynamic conditions and sediment loading, and activity within those sources. 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.

These persistent enriched levels of 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 DCMF. 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.

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 the source 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 29, 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 28 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 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 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 monitoring year (Figure 1-1).

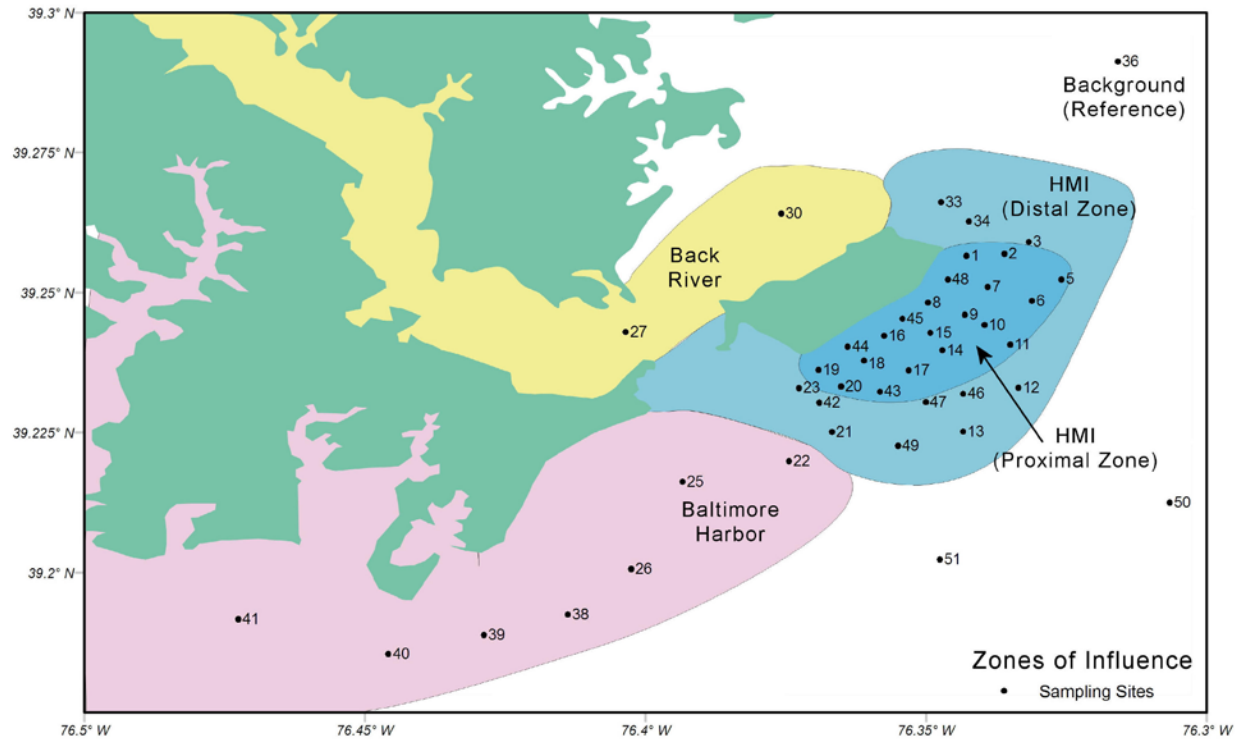


Figure 1-1. Sampling locations for Year 29. Color areas show zones of influence found in previous studies. Stations 38 – 41 were added in Year 18 to measure the influence of Baltimore Harbor. Starting in Year 27, four stations in the Back River zone were dropped and additional stations added in the proximal 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, 2010 to April 30, 2011.

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 most 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 2010 and May 2011. 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. Total amount of precipitation for both HMI and BWI were approximately 7 inches and 12 inches, respectively, lower than recorded for the previous 12-month period (*i.e.*, 28th monitoring year). However, there was a significant rainfall event on September 30, 2010, during which 6.02 inches of rain was recorded at BWI, setting a record high for that day. The rain gages at HMI overflowed on September 30 and Oct. 1, so the monthly totals for those two months were higher than reported.

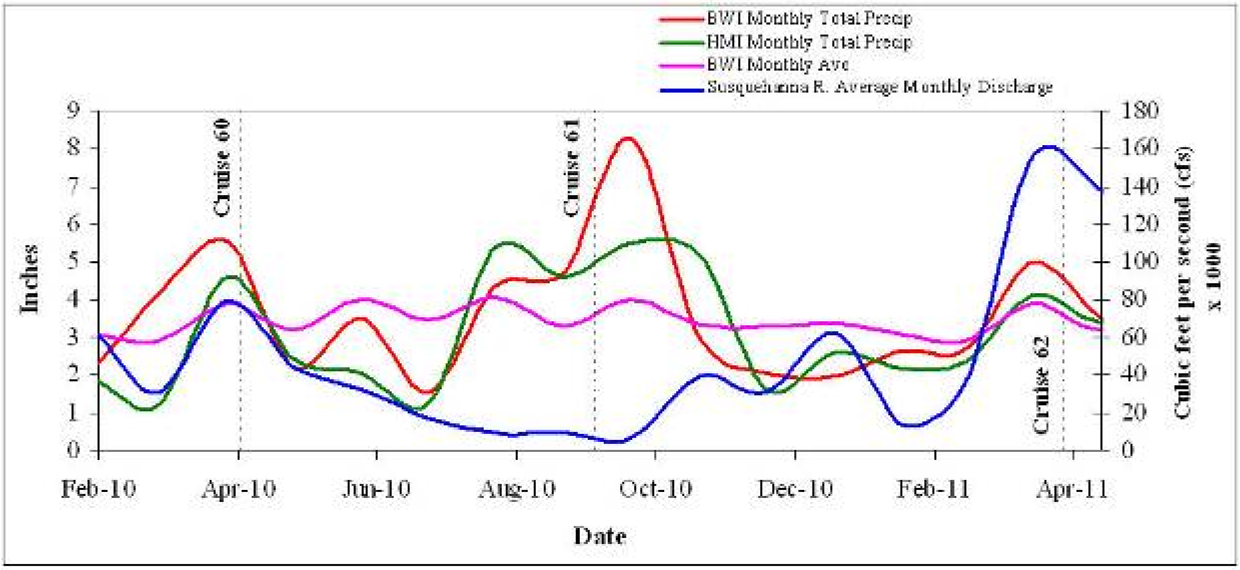
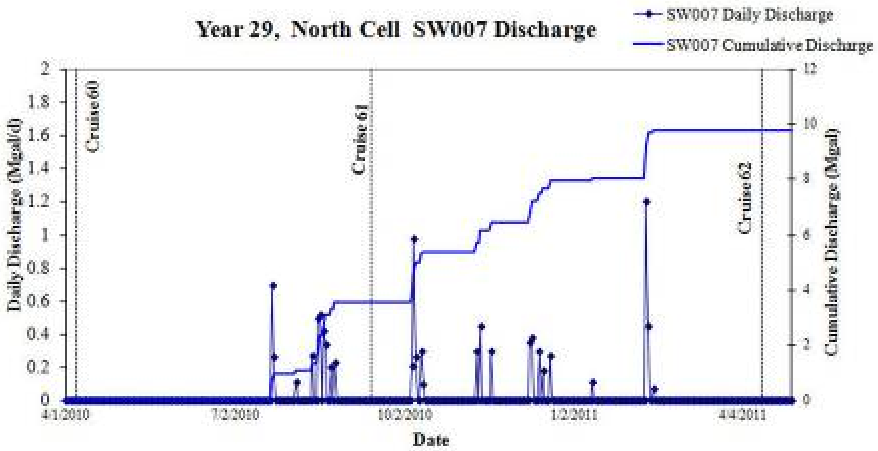


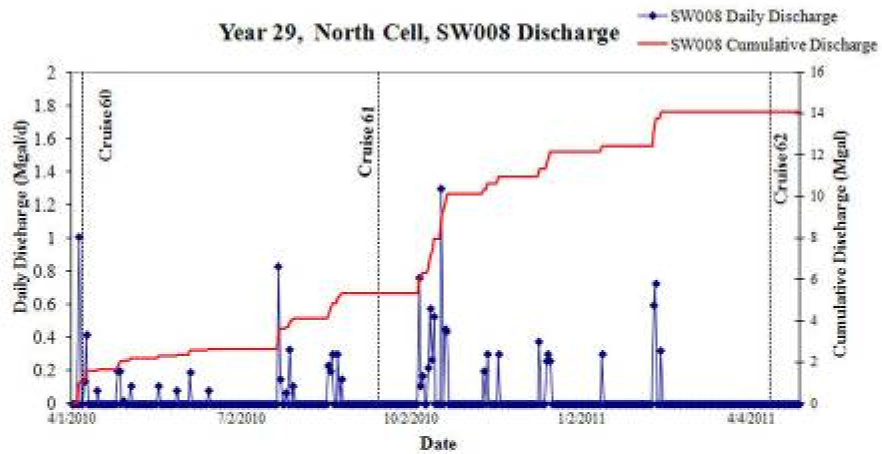
Figure 1-2. Comparison of monthly precipitation data collected at HMI Facility and at the National Weather Service (NWS) Station at BWI with the average monthly discharge of the Susquehanna River. BWI monthly averages were based on monthly precipitation data from 1981 to 2010. Susquehanna River data were obtained from the USGS website.

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. The River flow was largely seasonal, with higher flow during the winter and spring (wet) and low flow during the summer and fall (dry). The flow rate was influenced by regional weather patterns. From January to April, 2011, the northeast United State 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). Conversely, the summer of 2010 was the fourth warmest summer on record (NOAA). Even though there were significant local rainfall events during that time, Susquehanna River daily discharge dropped to 5,620 cfs. During this monitoring period, the high seasonal average was 84,991 cfs and the low seasonal average was 18,795 cfs. The seasonal averages were significantly higher compared to the high and low flow rates (40,878 and 9,376 cfs, respectively) used in the hydrodynamic model to predict the dispersion of discharge from the facility (Wang, 199).

Total discharge from the North Cell for the monitoring year (13 month period, April, 2010 to May, 2011) was 47 million gallons (mgal), which was a fraction of the total (1,804 mgal) for the previous year. Approximately half of the discharge was from Spillway 009 which occurred before May, 2010 (Figure 1-3). At some point after August, 2011, Spillway 009 was bermed off. Between May, 2010 and February, 2011, all discharges from the North Cell were from Spillway 007 and Spillway 008, through which 9.76 million gallons and 14.09 million gallons, respectively, of effluent were discharged. Discharges from the two spillways were sporadic and almost always less than 2 mgal per day (mgd). The two spillways were closed in mid-February due to elevated Zn concentrations and failure to pass annual toxicity testing (MES, 2011a). There were no discharges from the North Cell after February 14, 2011. All North Cell water was being diverted to the South Cell for discharge (MES, 2011b).

Total discharge from the South Cell was 418 million gallons, approximately 40 million gallons less than the volume discharged during the previous year. Discharge was sporadic during the monitoring year with daily rates 6 mgd or less (Figure 1-4). Water from the South Cell was discharged as needed for dewatering and to regulate the water levels in the South Cell habitat area. Water was discharged from mid-July to September to lower the water level 2 feet in the South Cell for mudflat exposure for migrating birds. During September, Bay water was pumped in from the holding pond to raise the level of the habitat pond. There were no discharges during this period. Beginning October, the pond level was maintained through the winter until the next drawdown (following July). During the hold period, water was discharged to maintain the pond level which was affected by a number of factors including rainfall amounts.





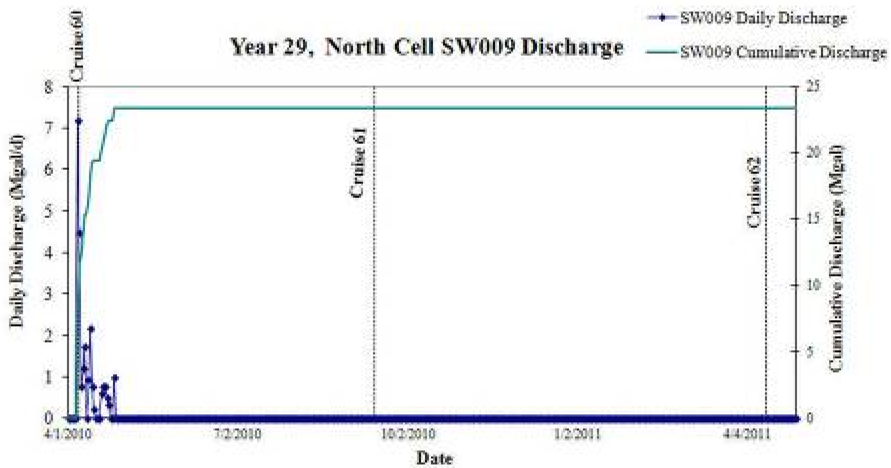


Figure 1-3. Daily and cumulative discharge from the three North Cell spillways (SW), 007, 008 and 009. The exterior sediment sampling events are marked by the vertical lines. Cumulative discharge total covers a 13 month period: April 1, 2010 to April 30, 2011).

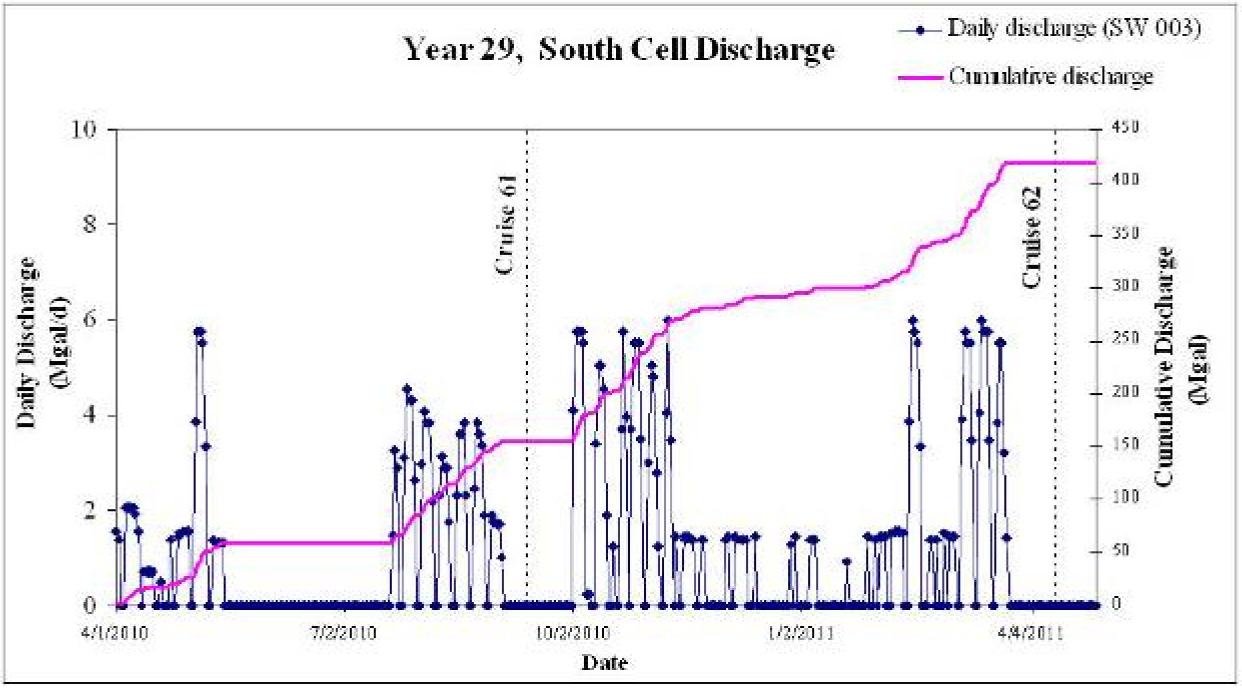


Figure 1-4. Daily and cumulative discharge from the South Cell. The discharge from the South Cell is from SW003, which is the only discharge point for the Cell. The exterior sediment sampling events are marked by the vertical lines.

OBJECTIVES

As in the past, the main objectives of the Year 29 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.

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 14, 2010 (Cruise 61), and the second, on April 14, 2011 (Cruise 62).

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 29 sample locations are reported in the companion *Year 29 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 29 cruises. The stations were identical to those sampled during monitoring years 27 and 28.

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 P, C, S and N. 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 29 Data Report*.

Using plastic scoops cleaned with deionized water, the crew took sediment sub-samples from below the flocculent 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^{o}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 1-5).

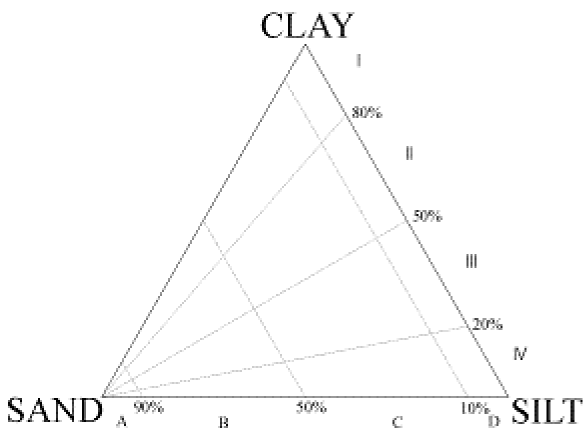


Figure 1-5. Pejrup's Diagram (1988) classification of sediment type.

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*. (ActLab). The quality assurance and quality control of ActLab 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 ActLab 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 ActLab, 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 ActLab are presented in the *Year 29 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 29 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 29 results are discussed with respect to the preceding Year 28 results, and where appropriate, with references to earlier monitoring year results.

All sampling sites visited during Year 29 yielded results that can be compared to those measured during Year 28. The grain size composition (proportions of sand, silt, and clay) of the samples is depicted as a series of Pejrup's diagrams in Figure 1-6. 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 28 and 29, for 43 sediment samples common to all four cruises.

Variable	Sept 2009 Cruise 59	Apr 2010 Cruise 60	Sept 2010 Cruise 61	Apr 2011 Cruise 62
Sand (%)				
Mean	23.65	21.49	22.98	21.67
Median	4.53	3.94	5.30	3.70
Minimum	0.72	0.55	0.84	0.72
Maximum	98.68	98.40	98.89	97.14
Range	97.95	97.86	98.05	96.42
Count	43	43	43	43
Clay:Mud				
Mean	0.55	0.54	0.58	0.54
Median	0.55	0.55	0.57	0.55
Minimum	0.45	0.30	0.42	0.36
Maximum	0.69	0.65	0.99	0.82
Range	0.24	0.35	0.57	0.46
Count	43	43	43	43

The ternary diagrams show similar distributions of sediment type. 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 the September 2010 sampling (Cruise 61), points lie above the 50% line, indicating that the fine (muddy) fraction of the sediments contains more clay than silt. For the April 2011 (Cruise 62), points shift slightly closer to the 50% line, indicating the fine fraction contains even amounts of clay and silt.

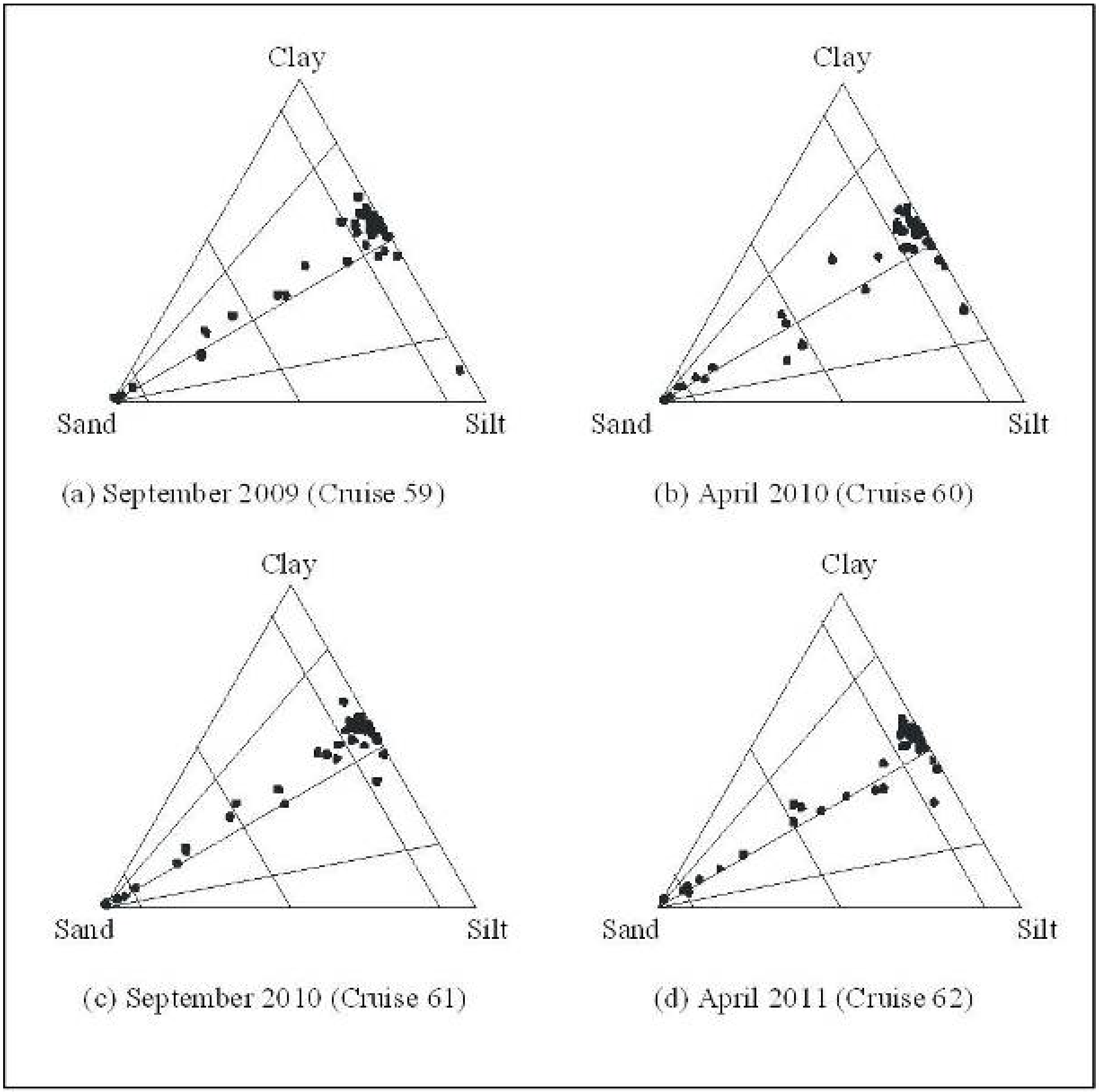


Figure 1-6. Pejrup diagrams showing the grain size composition of sediment samples collected in Years 28 and 29 from the 43 sampling sites common to all four cruises: (a) September, 2009, (b) April, 2010, (c) September, 2010, and (d) April, 2011.

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 less than 2 % for the four samplings. The mean clay:mud ratio was 0.58 for sampling Cruise 61 and decreased to 0.54 for Cruise 62, the same average ratio as the previous April 2010 (Cruise 60).

Sandy sediments are associated with the shallower areas around the diked facility. (Figure 1-7). 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 Figure 1-8 and Figure 1-9, three contour levels represent 10%, 50%, and 90% sand, coinciding with the parallel lines in Pejrup's diagram (Figure 1-5). 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.

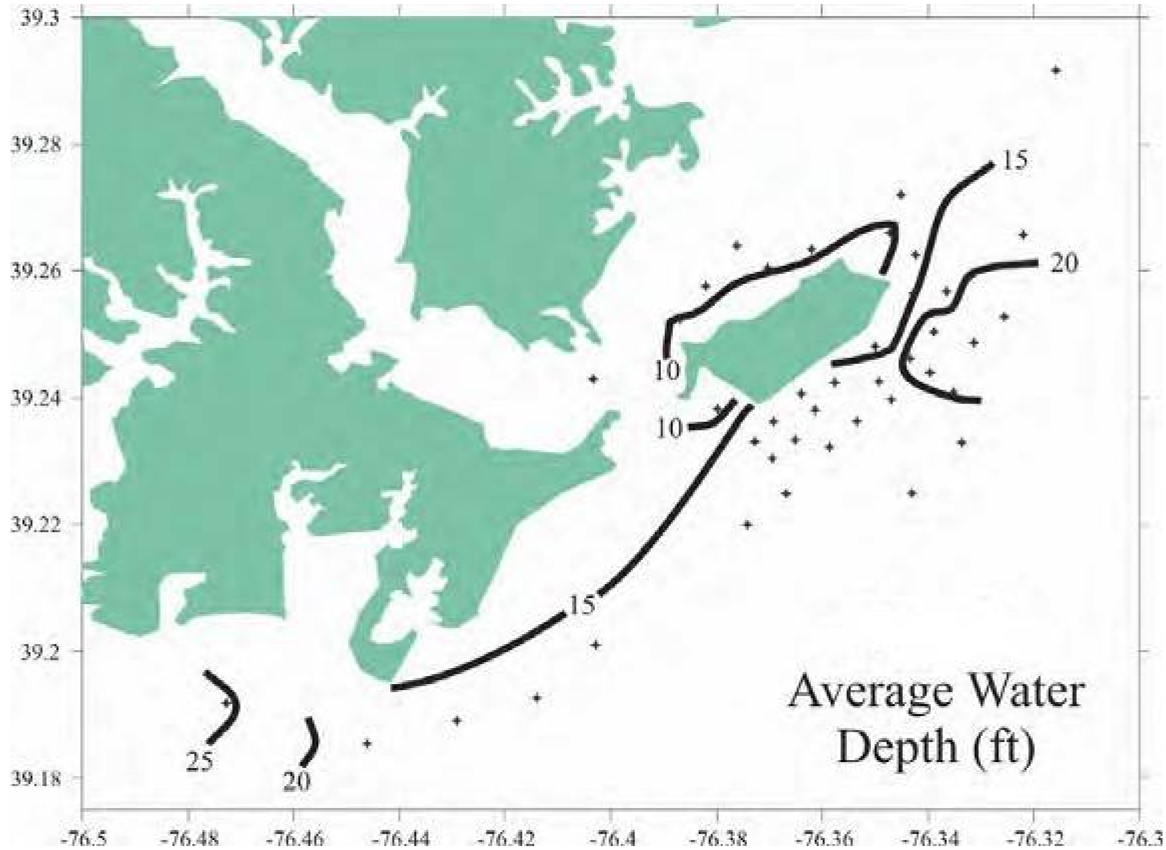


Figure 1-7. Average water depths around HMI and vicinity. Contour interval = 5 ft.

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 28 and 29 are very similar in appearance (Figure 1-8 and Figure 1-9). 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 (Figure 1-9). 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. It should be noted that one of the newly added stations southeast of the facility (MDE-50) contained more than 90% sand. This site corresponds to a historical oyster bar, the substrate of which consists of sand and shell.

Compared to the distribution of sand, the distribution of clay:mud ratios has tended to be slightly more variable over time (Figure 1-10 and Figure 1-11). 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 1-6. 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 (Figure 1-10 and Figure 1-11). MDE-41, at the mouth of Baltimore Harbor, 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, confined to one station by the following April sampling. In the previous monitoring year, this area was dominated with less silt (clay:mud ratio <0.55). A clay-rich area south of HMI (in proximal zone) was present in both September 2009 and September 2010, but diminished in size in the April sampling of both years. These patterns of change are most likely due to seasonal changes. 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.

Silt-rich sediments (clay:mud ratio < 0.50) are generally found immediately adjacent to the walls of the dike, commonly in the vicinity of spillways. Generally the silt-rich areas were consistent during the previous monitoring years with regards to the area adjacent to the walls of the dike to the south remaining silt-rich. In April and September 2010, the silt-rich area was confined to a single station (MDE-8 in April and MDE-16 in September). By April 2011, the silt-rich area expanding to three stations south and adjacent to the dike wall (Figure 1-11).

Understanding the specific reasons for these variations in grain size is difficult. They involve the amount, quality, and timing of discharge from particular spillways and the interaction of the effluent with tides and currents in the receiving waters. Those, in turn, are influenced by flow from the Susquehanna River. Based on the overall similarities between the fine fraction results from the past three years, one may conclude that the depositional environment in the vicinity of HMI has not changed over this period. The depositional environment appears to be very stable.

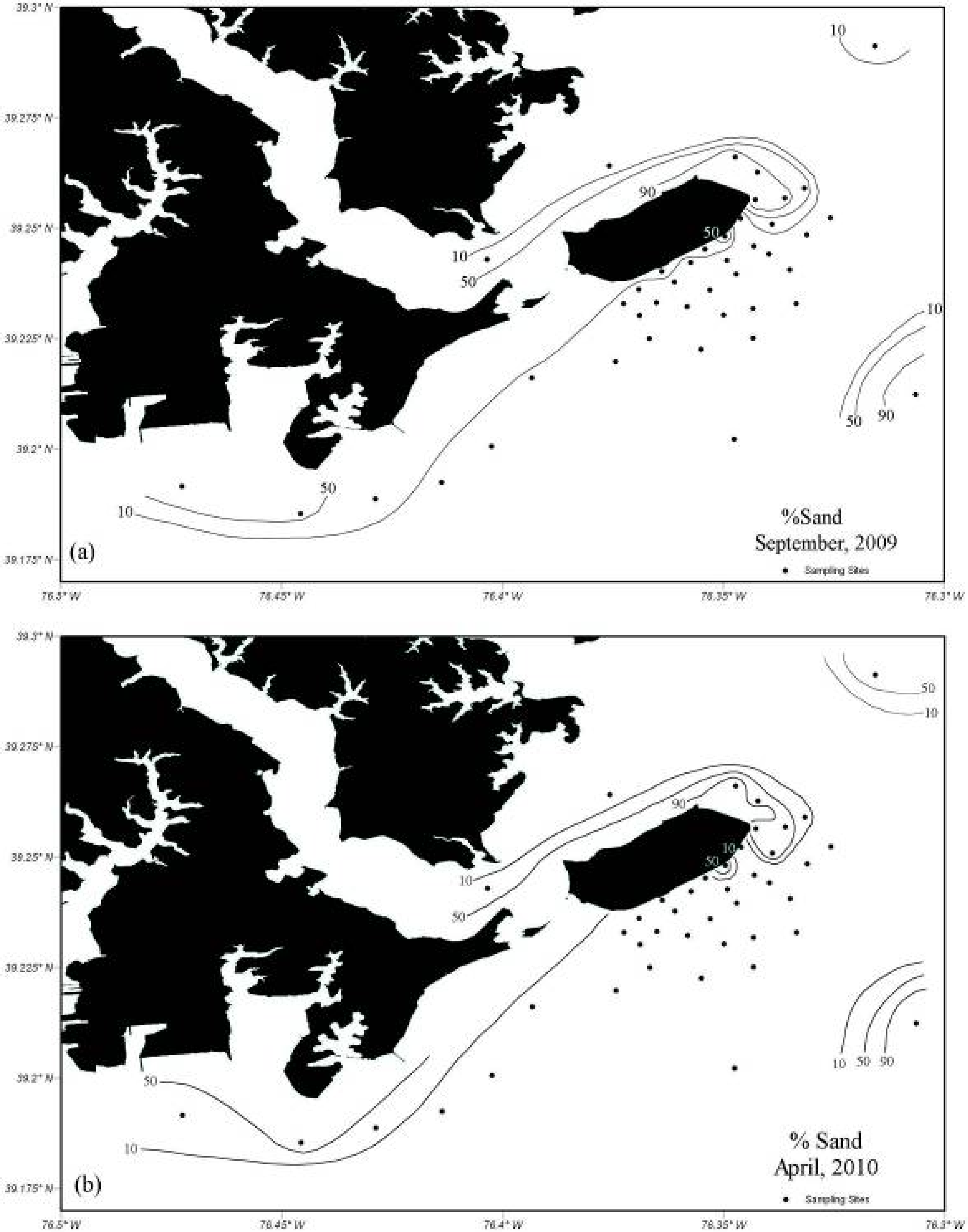


Figure 1-8. Sand distribution for Monitoring Year 28: (a) September, 2009 (Cruise 59), (b) April, 2010 (Cruise 60). Contour intervals are 10%, 50%, and 90% sand.

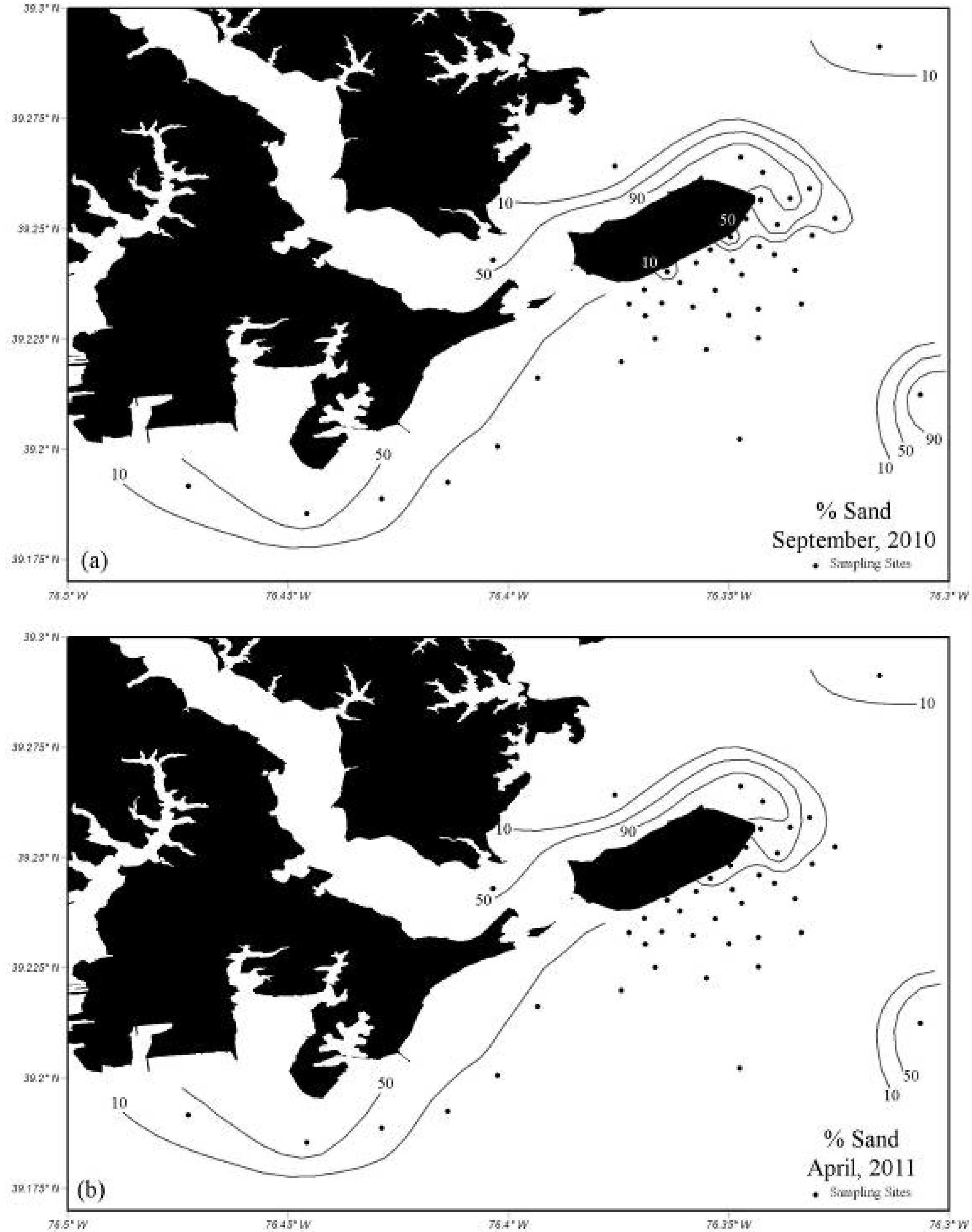


Figure 1-9. Sand distribution for Monitoring Year 29: (a) September, 2010 (Cruise 61), (b) April, 2011 (Cruise 62). Contour intervals are 10%, 50%, and 90% sand.

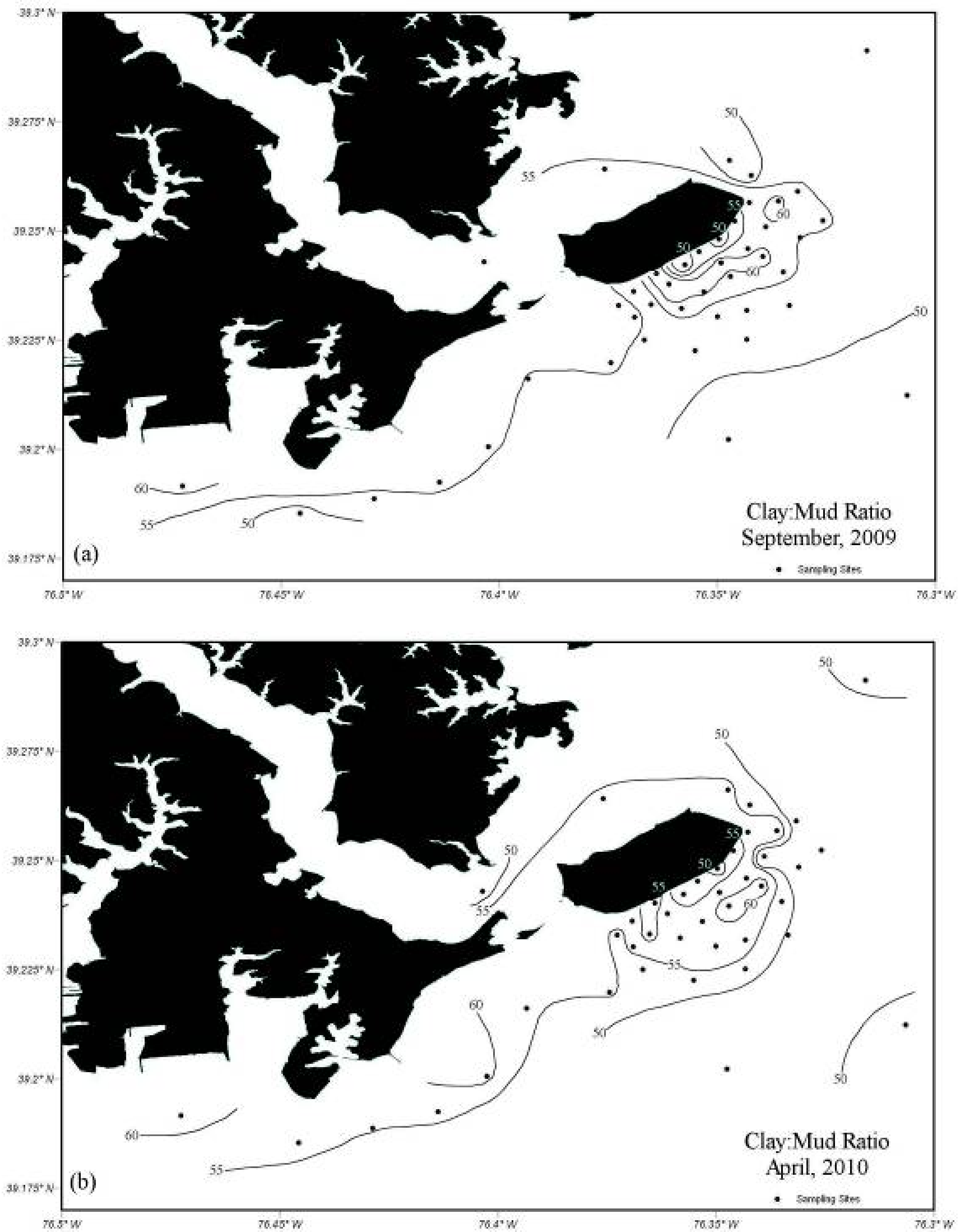


Figure 1-10. Clay:Mud ratios for Monitoring Year 28: (a) September, 2009 (Cruise 59), (b) April, 2010 (Cruise 60). Contour intervals are.50%, 55%, and 60% (clay:mud ratio expressed as %).

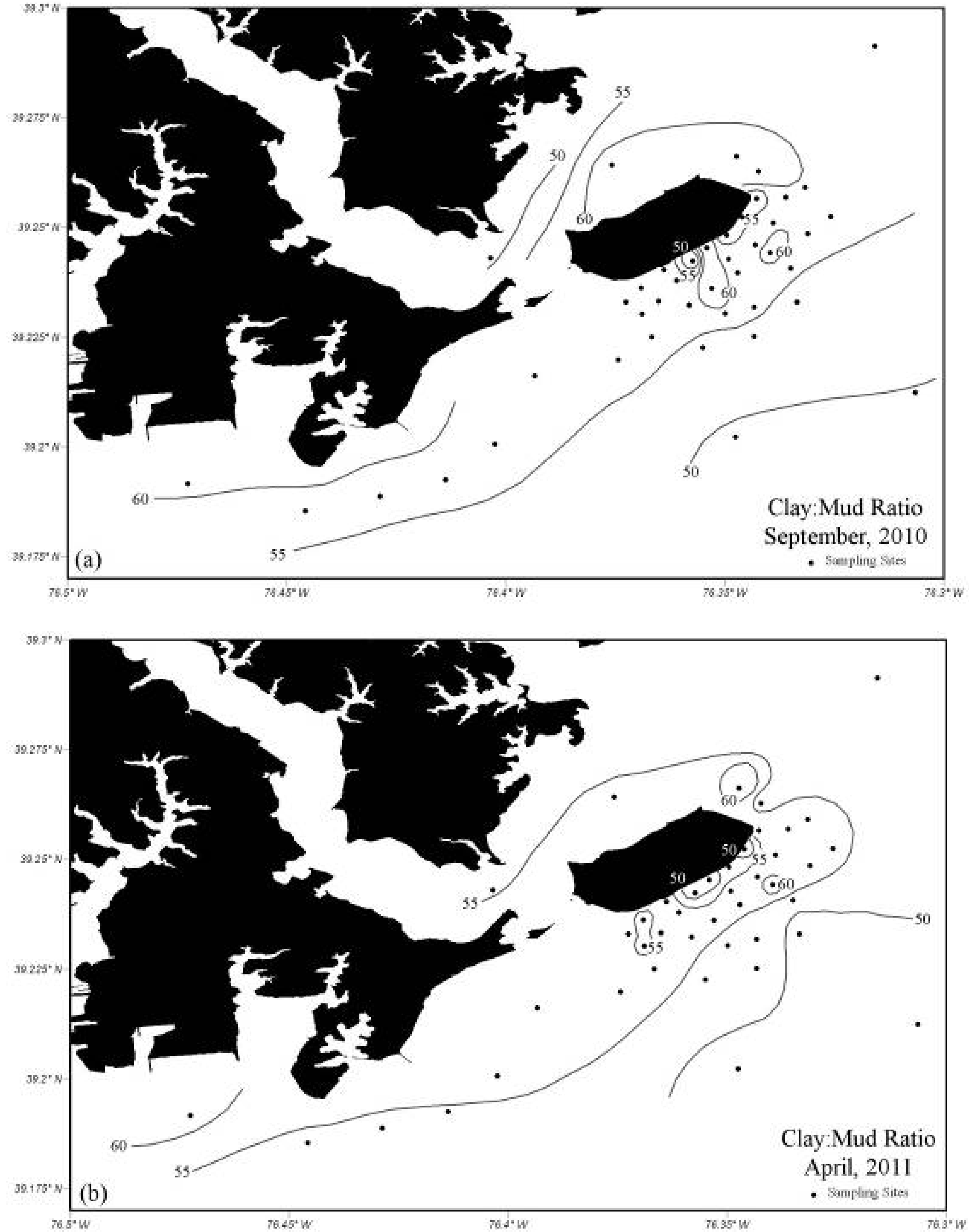


Figure 1-11. Clay;Mud ratios for Monitoring Year 29: (a) September, 2010 (Cruise 61), (b) April, 2011 (Cruise 62). Contour intervals are 50%, 55%, and 60% (clay:mud ratio expressed as %)

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	12.37	0.55	668.00	15.03	6.81	44.43
b	0.19	71.92	18.74	1.17	217.70	0.00	4.09	0.00
c	1.37	160.80	70.80	7.57	4157.00	136.00	76.49	472.50
R2	0.12	0.73	0.61	0.92	0.36	0.82	0.88	0.78
Sigma Level (%)	61	23	27	22	43	29	21	30

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.

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

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

A listing of the summary statistics for the elements analyzed is given in Table 1-3. Generally, the statistics are very similar to the previous two years, including an anomalously high Cr value of 455 ppm which was measured from MDE-41 sampled during the September 2010 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. Similar to last year, samples collected at this site during both sampling cruises contained significant gravel (>5%), a portion of which may have been 'slag ' which would explain the high metal contents.

With regard to Effects Range Low (ERL) and Effects Range Medium (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 limit.

	%P	**Cd**	**Cr**	**Cu**	**%Fe**	**Mn**	**Ni**	**Pb**	**Zn**
Ave	0.072	0.75	111	42	4.26	2833	82	49	293
Std	0.028	0.30	60	18	1.59	1601	35	24	151
Min	0.001	0.30	8	2	0.24	239	4	4	13
Max	0.120	1.80	455	80	6.59	10300	172	121	789
n	86	74	86	86	86	86	86	86	86
ERL	n/a	1.3	81	34	n/a	n/a	21	47	150
#>ERL	n/a	4	69	63	n/a	n/a	81	51	70
ERM	n/a	9.5	370	270	n/a	n/a	52	218	410
#>ERM	n/a	0	1	0	n/a	n/a	70	0	12

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 difference. 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, compared to the baseline (Figure 1-12).

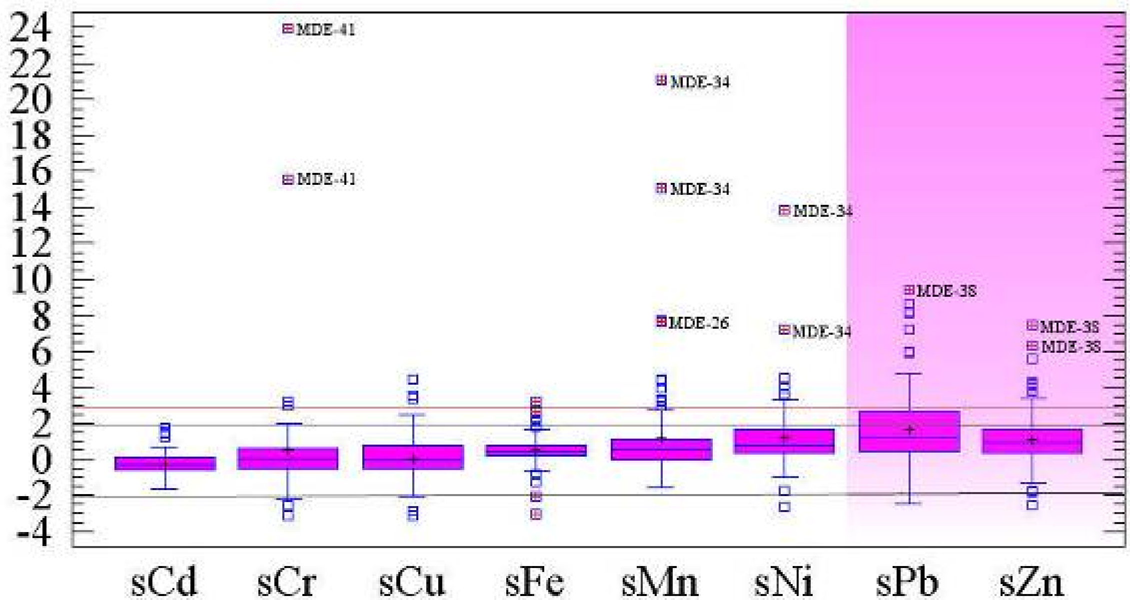


Figure 1-12. A box and whisker diagram showing the range of the sigma levels for both the September and April cruises for Year 29. The box encloses the middle 50% of the sigma level values for each metal (interquartile range, IQR); the median is indicated by the blue line within each box. The blue vertical 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)

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 1-12 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 1-12) are considered to be within the natural variability of the baseline values. With the exception of Mn, Pb and Zn, metals at most sites for both sampling cruises are within the range expected for normal baseline behavior in the area. Approximately 20% of the samples contain Pb significantly exceeding the baseline levels (*i.e.*, >3 sigma levels, indicated by red line), 12% of the samples contain Mn levels exceeding the baseline and 10% of the samples contain Zn levels exceeding the baseline. Overall levels for Pb and Zn are very similar to previous monitoring years. Most of the samples with elevated metal levels are in the Baltimore Harbor Zone of influence (Stations MDE-26, MDE-38, and MDE-41). However, both fall and spring samples for MDE-34 yielded outside outlier values for Mn and Ni.

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 2010 and April 2011 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 ERLs or ERMs and sigma levels greater than two. 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-9, MDE-14, MDE-18, MDE-19, and MDE-46 from the September 2010 cruise, and sites MDE-11, MDE-14, MDE-34, MDE-45, and MDE-50 from the April 2011 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. 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 1-13 shows distribution of the sigma levels for Pb for Year 29 monitoring periods in the study area adjacent to HMI; sigma levels for Zn are shown in Figure 1-14. 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.

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, 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 both metals are clearly isolated from the HMI zone of influence adjacent to the island. Both metals showed similar enrichment values as compared to Year 28. There was a seasonal shift in level of enrichment with slightly higher values in the fall.

HMI – Pb levels adjacent to the HMI were lower, in terms of the number of samples exceeding 3σ, compared to the previous year. The spatial extent of Pb enrichment was spotty, limited to three sites, but in the general area as the previous fall. Pb enrichment was confined to MDE-18, adjacent to Spillway 003; a second site (MDE-46) southeast of HMI; and a third site north of the facility (MDE-34). By April 2011, no Pb enrichment was documented on southeastern side of the facility. Although enrichment was still persistent at the northeast site, the level dropped dramatically. In the fall, Zn enrichment was 4 sigma at two isolated sites (MDE-18 and MDE-46). In April, no Zn enrichment (> 3 sigma) was documented within the HMI Zone of influence.

Spatial distribution of both Pb and Zn enriched areas in the fall suggests that the South Cell discharge may be the source of the eastern enrichment area. There was a period of steady discharge from South Cell Spillway 003 a week prior to the September 2010 sampling cruise (Figure 1-4) as opposed to no discharge from North Cell Spillway 009 during the same period. Based on the April 2011 sampling, Pb enrichment was confined to the northeast tip of the facility and at a reduced level. The Pb may have persisted through the winter since there were no discharges from the North Cell in the two months prior to the April 2011 sampling. In addition, North Cell discharge appeared to have had a minimal effect for both cruises, with regard to Zn enrichment. The lower enrichment levels and reduced spatial extent of the enrichment were attributed to the steps that the HMI facility took to minimize the loadings of these metals.

The spatial extent and the levels found in the Baltimore Harbor and Back River zones vary according to seasonal weather changes, which influence the hydrodynamic conditions and sediment loading, and activity within those sources. 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.

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 Year 28 monitoring, rainfall was above average but the Baltimore Harbor and Back River zones remained separate from the HMI zone. Although precipitation amounts during Year 29 were lower than the previous year, the total amount was above the long term average. However, Baltimore Harbor and Back River zones continue to remain separate from the HMI zone.

To illustrate the long-term trend of the data, the highest levels of Zn enrichment (% excess Zn) in the HMI zone of influence for all monitoring sampling events (cruises) are plotted in Figure 1-15. The data from this monitoring year, shown as the solid points, show a pronounced fluctuation over the past two monitoring years, but the overall trend is a drop in enrichment that began in Year 26.

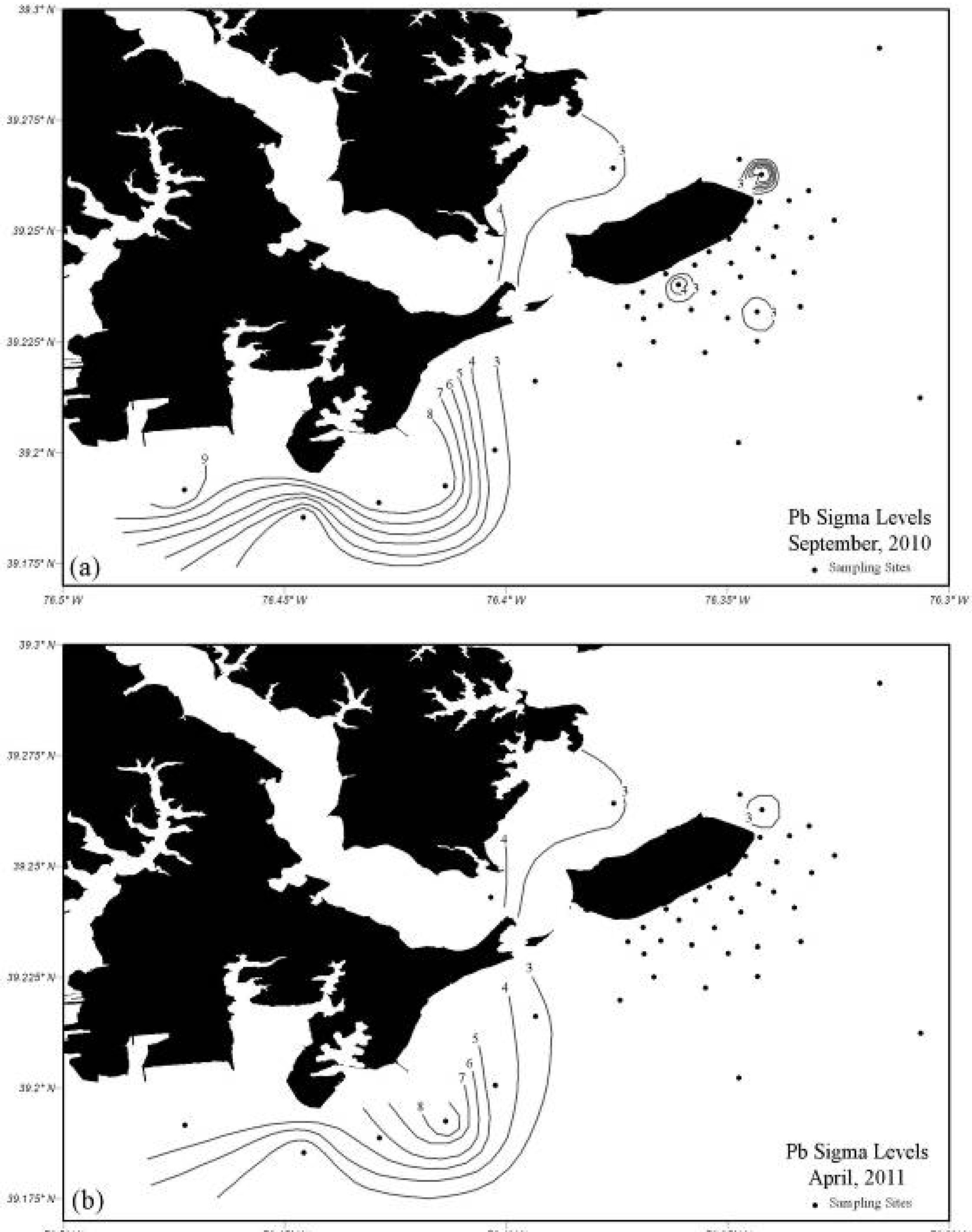


Figure 1-13. Distribution of Pb in the study area for the September and April sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3=transitional (values less than 3 not shown),>3=significantly enriched.

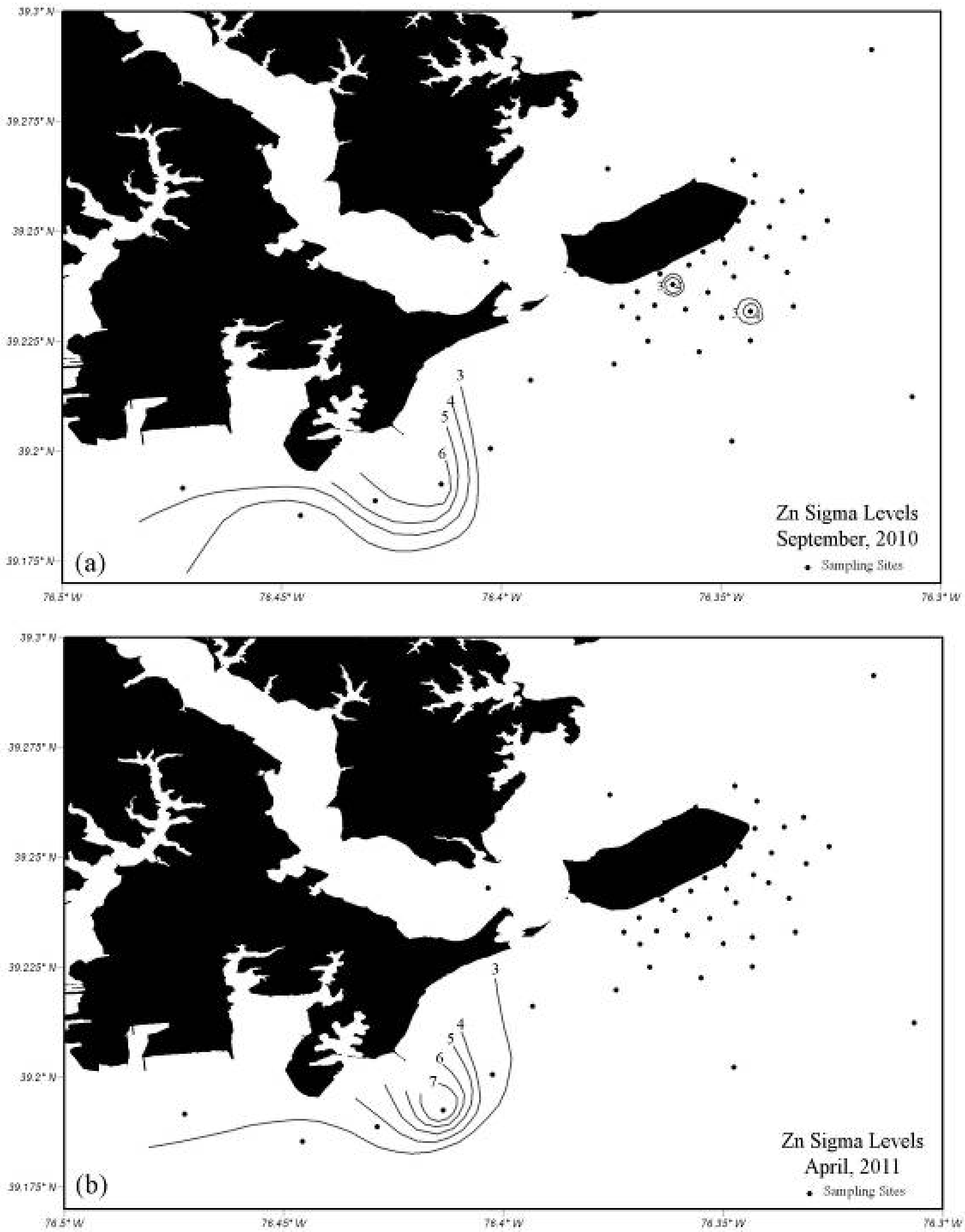


Figure 1-14. Distribution of Zn in the study area for the September and April sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (values less than 3 not shown), >3 = significantly enriched.

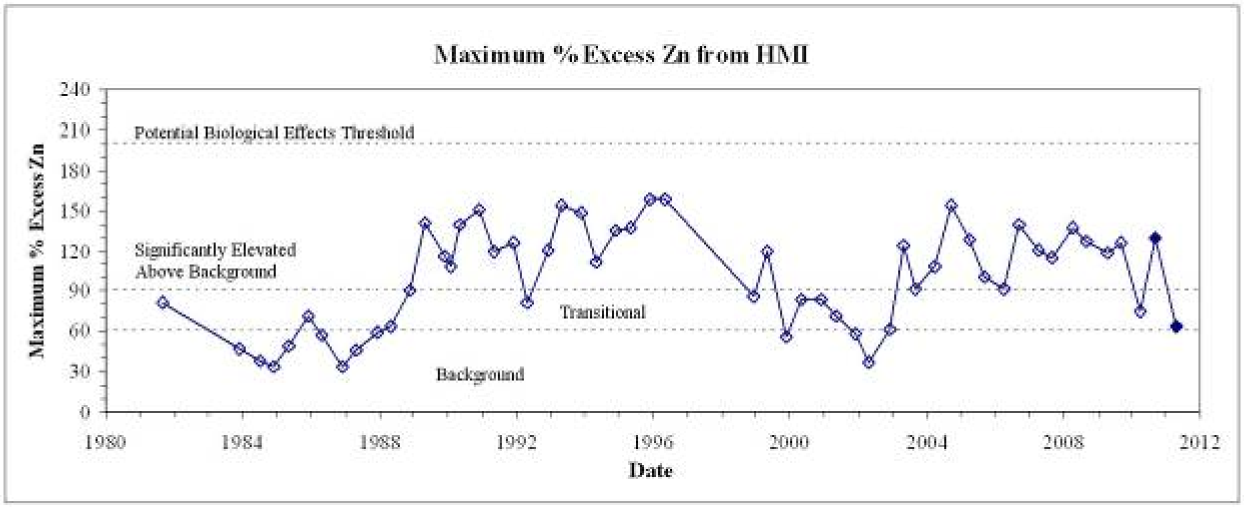


Figure 1-15. Record of the maximum % excess Zn for all of the cruises for which MGS analyzed the sediments. The filled points are the data from this year's study (Cruises 61 and 62).

CONCLUSIONS AND RECOMMENDATIONS

The grain size distribution of the Year 29 sediment samples does not show any clear trends in sedimentation patterns from cruise to cruise, other than that attributed to seasonal effects. The clay:mud ratios show that the depositional environment was similar during 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 29.

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, 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 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, 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. Most of the samples with potential benthic effects due to high concentrations of Ni are in the Back River and Baltimore Harbor Zones of Influence. 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 HMI. The two sampling sites in Back River showed no enrichment for Zn. Material from the Harbor did not influence the sediments in the HMI zone.

Within the area affected by facility operations, Pb, showed slightly lower enriched levels, both in terms of the number of sites and extended spatial distribution, compared to the previous year. Sediments were slightly enriched (3-4 sigma levels) with Zn at two sites during the fall, no sites were enriched with Zn in the spring. The enrichment levels and spatial extent of the enrichment were attributed to the HMI facility operational activities. Total discharge from the South Cell was 418 million gallons, approximately 40 million gallons less than the volume discharged during the previous year. Discharge was over two discrete periods: August-September, 2010 and October 2010-April, 2011. However, daily discharge rates were low (< 6 MGD). The extended period of low discharge prior to the September 2010 sampling (Cruise 61) corresponded to lowering of pond level to expose extensive mud flats. Precipitation during this time was above average, adding to the discharged amount, and contributing to conditions that may have been less conducive to oxidizing the sediments within the facility. As a result, there may have been lower mobilization of certain metals. This was reflected in lower enrichment in the exterior sediments. Enrichment of both Pb and Zn was seen in the sediments adjacent to the spillway during the fall, but at reduced extent and lower levels compared to previous years. The constant discharges through the winter of 2010-11 and prior to the April 2011 sampling were done to maintain the South Cell pond at a target level. Input into the South Cell during this time was from precipitation and water transferred from the North Cell. During high pond levels, sediment exposure is minimal and thus, lower leaching of specific metals would be expected. This would explain the even lower levels of Pb and Zn seen outside the spillway in the spring.

Total discharge from the North Cell for the monitoring year was 47 million gallons, which was a fraction of the total (1,804 mgal) for the previous year. Approximately half of the discharge was from Spillway 009 which occurred before May, 2010 (Figure 1-3). During the remainder of the monitoring period, all discharges were from Spillway 007 and Spillway 008, which contributed 9.76 million gallons and 14.09 million gallons, respectively. Discharges from the two spillways were sporadic and almost always less than 2 mgal per day. All discharge from the North Cell ceased after February 14, 2011 when effluent began to exceed permit limits for Zn. Based on increased Zn concentration, it is assumed that sediments were exposed at times to an oxidizing environment, thus mobilizing Zn as well as other metals (although effluent test result did not document higher concentration in other metals tested). However, release of Pb and Zn from the North Cell appeared to be limited based on lower enrichment levels seen adjacent to the active spillways, especially in the spring. The lower enrichment levels and reduced spatial extent of the enrichment were attributed to the steps that the HMI facility took to minimize the loadings of these metals.

Although this year's monitoring documents a drop in enrichment of Zn around the HMI facility, enrichment for Pb remained above background levels. This persistent enriched level indicates a need for continued monitoring, particularly since the facility is no longer accepting material and operations in the North Cell will focus on long-term crust management in preparation for environmental restoration efforts. As expected, the volume of effluent from the North Cell has decline during dewatering and crust management operations, resulting in higher metal levels in the effluent. MES documented high Zn levels in the North Cell on several occasions during this monitoring year. As a result, North Cell water has been diverted to the South Cell for discharge. Monitoring should continue in order 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 MES to counteract the effects of exposing contained dredged material to the atmosphere. Close cooperation with MES is important in this endeavor.

In order to assess the potential influence of Baltimore Harbor on the HMI exterior sediments better, the additional sampling sites should be maintained, at least temporarily. Further, since the South Cell has been converted to upland wetlands, the additional sample locations near the discharge point should be maintained to assess this aspect of the facility operation as part of the on-going monitoring program.

REFERENCES

Baker, J., Mason, R., Cornwell, J., Ashley, J., Halka, J., and Hill, J. 1997, Spatial mapping of sedimentary contaminants in the Baltimore Harbor/Patapsco river/Back river system: ,Solomons, MD., University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, UMCES CBL Reference Series ,97-142, 112 p.

Berner, R.A., 1981, A new geochemical classification of sedimentary environments, Journal Sed. Pet., v. 51, pp.359 - 365

Blankenship, K., 1993, Freshet provides chance to study role of Bay algae, Bay Journal, v. 3, no. 4, p. 1.

Buchman, M.F., 2008, NOAA Screening Quick Reference Tables, NOAA OR&R Report 08-1, Seattle WA, Office of Response and Restoration Division, National Oceanic and Atmospheric Administration, 34 p.

Cantillo, A.Y., 1982, Trace elements deposition histories in the Chesapeake Bay, Unpubl. Ph.D. dissertation, Chemistry Dept., Univ. of Maryland, College Park, MD, 298 p.

Cornwell, J.C., P.A. Sampou, D.J. Conley, and M. Owens, 1994, Changes in sediment biogeochemical composition across an estuarine salinity gradient.

Hennessee, E.L., P.J. Blakeslee, and J.M. Hill, 1986, The distribution of organic carbon and sulfur in surficial sediments of the Maryland portion of the Chesapeake Bay, J. Sed. Pet. , v. 56, p. 674-683.

Hennessee, E.L., Cuthbertson, R., and Hill, J.M., 1989, Sedimentary environment, in Assessment of the Environmental Impacts of the Hart/Miller Island Containment Facility: 6th Annual Interpretive Report Aug. 86 - Aug. 87: Annapolis, MD, Maryland Dept. of Natural Resources, Tidewater Admin., p. 9-96.

Hennessee, E.L., Cuthbertson, R., and Hill, J.M., 1990a, Sedimentary environment, in Assessment of the Environmental Impacts of the Hart and Miller Islands Containment Facility: 7th Annual Interpretive Report Aug. 87 - Aug. 88: Annapolis, MD, Maryland Dept. of Natural Resources, Tidewater Admin., p. 29-143.

Hennessee, E.L., Cuthbertson, R., and Hill, J.M., 1990b, Sedimentary environment, in Assessment of the Environmental Impacts of the Hart and Miller Islands Containment Facility: 8th Annual Interpretive Report Aug. 88 - Aug. 89: Annapolis, MD, Maryland Dept. of Natural Resources, Tidewater Admin., p. 20-144.

Hennessee, E.L., and Hill, J.M., 1992, Sedimentary environment, in Assessment of the Environmental Impacts of the Hart and Miller Island Containment Facility: 9th Annual Interpretive Report Aug. 89 - Aug. 90: Annapolis, MD, Maryland Dept. of Natural Resources, Tidewater Admin., p. 13-45.

Hennessee, E.L., and Hill, J.M., 1993, Sedimentary environment, *in* Assessment of the Environmental Impacts of the Hart and Miller Island Containment Facility: 10th Annual Interpretive Report Aug. 90 - Aug. 91: Annapolis, MD, Maryland Dept. of Natural Resources, Tidewater Admin., p. 12-42.

Hennessee, E.L., Hill, J.M., Park, J., Kerhin, R.T., and Cuthbertson, R., 1994 The Continuing State Assessment of the Environmental Impacts of Construction and Operation of the Hart-Miller Island Containment Facility Project II Sedimentary Environment Eleventh Year Interpretive Report (November 1991 - October 1992, Maryland Geological Survey File Report 94-7.

Hill, J.M., Hennessee, E.L., Park, J., and Kerhin, R.T., 1994 The Continuing State Assessment of the Environmental Impacts of Construction and Operation of the Hart-Miller Island Containment Facility Project II Sedimentary Environment Twelfth Year Interpretive Report (November 1992 - October 1994, Maryland Geological Survey File Report 94-11.

Hill, J.M., Hennessee, E.L., Park, J., and Kerhin, R.T., 1998 The Continuing State Assessment of the Environmental Impacts of Construction and Operation of the Hart-Miller Island Containment Facility Project II Sedimentary Environment Thirteenth Year Interpretive Report (November 1993 - October 1995), Maryland Geological Survey File Report 98-5.

Hill, J.M., Hennessee, E.L., and Park, J. 1998 The Continuing State Assessment of the Environmental Impacts of Construction and Operation of the Hart-Miller Island Containment Facility Project II Sedimentary Environment Fourteenth Year Interpretive Report (November 1994 - October 1996), Maryland Geological Survey File Report 98-7.

Johnson, B.H., Heath, R.E. and Kim, K., 1989, Development of a three-dimensional hydrodynamic model of the upper Chesapeake Bay: Final Report to the Maryland Dept. of Natural Resources, Tidewater Admin.

Kerhin, R.T., Hill, J., Wells, D.V., Reinharz, E., and Otto, S., 1982a, Sedimentary environment of Hart and Miller Islands, in Assessment of the Environmental Impacts of Construction and Operation of the Hart and Miller Islands Containment Facility: First Interpretive Report August 1981 - August 1982: Shady Side, MD, Chesapeake Research Consortium, p.64-99.

Kerhin, R.T., Reinharz, E., and Hill, J., 1982b, Sedimentary environment, in Historical Summary of Environmental Data for the Area of the Hart and Miller Islands in Maryland: Hart and Miller Islands Special Report No. 1: Shady Side, MD, Chesapeake Research Consortium, p. 10-30.

Kerhin, R.T., Halka, J.P., Wells, D.V., Hennessee, E.L., Blakeslee, P.J., Zoltan, N., and Cuthbertson, R.H., 1988, The Surficial Sediments of Chesapeake Bay, Maryland: Physical Characteristics and Sediment Budget: Baltimore, MD, Maryland Geol. Survey Report of Investigations No. 48, 82 p.

Marquardt, D.W., 1963, An algorithm for least squares estimation of nonlinear parameters: Jour. Soc. Industrial and Applied Mathematics, v. 11, p. 431-441.

MES, 2011a, February 2011 Monthly Update: metals and pH treatment at HMI and Cox Creek, March 4, 2011, Update 194_030411.

MES, 2011b, March 2011 Monthly Update: metals and pH treatment at HMI and Cox Creek, April 1, 2011, Update 195_040111.

Pejrup, M., 1988, The triangular diagram used for classification of estuarine sediments: a new approach, in de Boer, P.L., van Gelder, A., and Nio, S.D., eds., Tide-Influenced Sedimentary Environments and Facies: Dordrecht, Holland, D. Reidel Publishing Co., p. 289-300.

Redfield, A.C., B.H. Ketchum, and F.A. Richards, 1966, The Influence of Organisms on the Composition of Seawater, (in) The Sea: Vol. II (ed. Hill) Wiley- Interscience, New York.

Rowe, M.C. and Hill, J.L., 2008, Scientific Rationale for Relocating Hart-Miller Island Exterior Monitoring Stations in Advance of Facility Closure, report submitted to Hart-Miller Island Citizens Oversight Committee, Maryland Dept. of the Environment, Ecological Assessment Division, Dec. 1, 2008, 14 p.

Sinex, S.A., Cantillo, A.Y., and Helz, G.R., 1980, Accuracy of acid extraction methods for trace metals in sediments, Anal. Chem., v. 52, p. 2342-2346.

Sinex, S.A., and Helz, G.R., 1981, Regional geochemistry of trace metals in Chesapeake Bay sediments, Environ. Geology, v. 3, p. 315-323.

Suhr, N.H., and Ingamells, C.O., 1966, Solution techniques for analysis of silicates, Anal. Chem., v. 38, p. 730-734.

Van Loon, J.C., 1980, Analytical Atomic Absorption Spectroscopy Selected Methods: New York, Academic Press, 337 p.

Wang, H., 1993, Addendum: Numerical model investigation of circulation and effluent dispersion around Hart-Miller Island in the upper Chesapeake Bay, *in* Assessment of the Environmental Impacts of the Hart and Miller Island Containment Facility: 10th Annual Interpretive Report Aug. 90 - Aug. 91: Annapolis, MD, Maryland Dept. of Natural Resources, Tidewater Admin.

Wells, D.V., and Kerhin, R.T., 1983, Areal extent of recently introduced sediments to the Hart-Miller Islands area: Unpubl. special report submitted to Chesapeake Research Consortium: Baltimore, MD, Maryland Geol. Survey, 30 p.

Wells, D.V., and Kerhin, R.T., 1985, Modification of the sedimentary environment during construction of the Hart-Miller Island Diked Disposal Facility, in Magoon, O.T., Converse, H., Miner, D., Clark, D., and Tobin, L.T., eds., Coastal Zone '85: Volume 2: New York, Amer. Soc. of Civil Engineers, p. 1462-1480.

Wells, D.V., Kerhin, R.T., Reinharz, E., Hill, J., and Cuthbertson, R., 1984, Sedimentary environment of Hart and Miller Islands, in Assessment of the Environmental Impacts of Construction and Operation of the Hart and Miller Islands Containment Facility: Second Interpretive Report August 1982 - August 1983: Shady Side, MD, Chesapeake Research Consortium, p. 64-150.

Wells, D.V., Kerhin, R.T., Hill, J., Cuthbertson, R., and Reinharz, E., 1985, Sedimentary environment, in Assessment of the Environmental Impacts of Construction and Operation of the Hart and Miller Islands Containment Facility: 3rd Annual Interpretive Report Aug. '83 - Aug. '84: Annapolis, MD, Maryland Dept. of Natural Resources, Tidewater Admin., p. 93-247.

Wells, D.V., Conkwright, R.D., Hill, J.M., and Cuthbertson, R.H., 1986, Sedimentary environment, in Assessment of the Environmental Impacts of the Hart and Miller Islands Containment Facility: 4th Annual Interpretive Report Aug. '84 - Aug. '85: Annapolis, MD, Maryland Dept. of Natural Resources, Tidewater Admin., p. 19-103.

Wells, D.V., Cuthbertson, R., and Hill, J., 1987, Sedimentary environment, in Assessment of the Environmental Impacts of the Hart and Miller Islands Containment Facility: 5th Annual Interpretive Report Aug. '85 - Aug. '86: Annapolis, MD, Maryland Dept. of Natural Resources, Tidewater Admin., p. 9-87.

APPENDIX 1A: HMI GROUNDWATER MONITORING WELLS 2010-2011 (PROJECT II)

INTRODUCTION

Groundwater samples from six wells were collected by MES on December 17, 2010, and June 21, 2011. The water samples were analyzed for the following parameters: pH, temperature, conductivity, dissolved oxygen (DO), oxygen-reduction potential (ORP), salinity, alkalinity, chloride (Cl^-), sulfate (SO_4^{-2}), 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 1-16: 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 1-4).

Table 1-4. 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 has not received any dredged material since 1990 and has been converted to upland wetlands. Activities within the South Cell are specific to the management of the different habitats. The North Cell, on the other hand, continued to receive dredged material until December, 2009, after which the facility was closed to new material. Since then, activities within the North Cell consisted primarily of crust management (dewatering of sediments) as part of habitat development. Presented in this Appendix is a summary of the well data collected from two samplings: December 2010 and June 2011. 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).

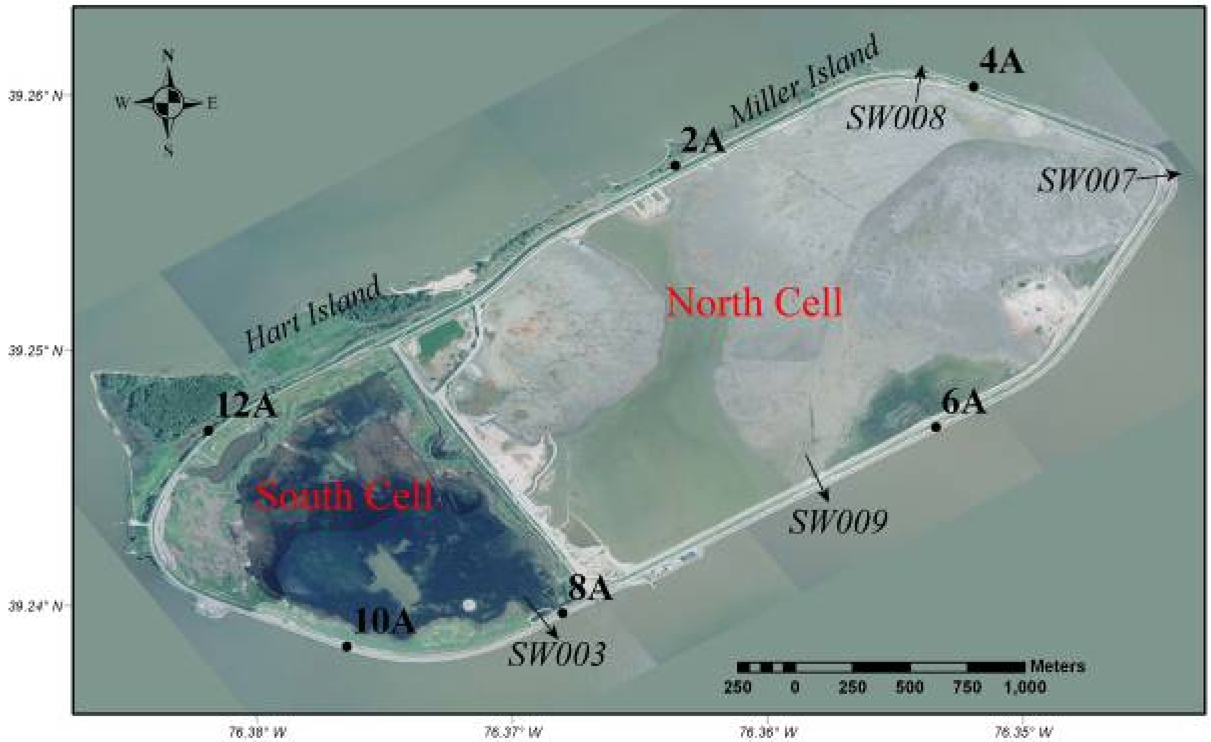


Figure 1-16. Aerial photograph of the HMI DMCF, taken on Sept. 15, 2009, showing the locations of the groundwater monitoring wells (black dots) and the spillways (*SW; black arrows*).

SUMMARY OF WELL DATA

All of the wells continue to be anoxic or hypoxic with DO levels less than 1.0 mg/L. Some of the levels may be the result of sulfide interference with the DO probe. DO levels have been consistently below 2 mg/L since 2006 (Figures 1-17 and 1-18).

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. Dissolved sulfide binds with many metals and restricts their mobility, and is preferentially used as a metal ligand releasing mineralized phosphate into the water.

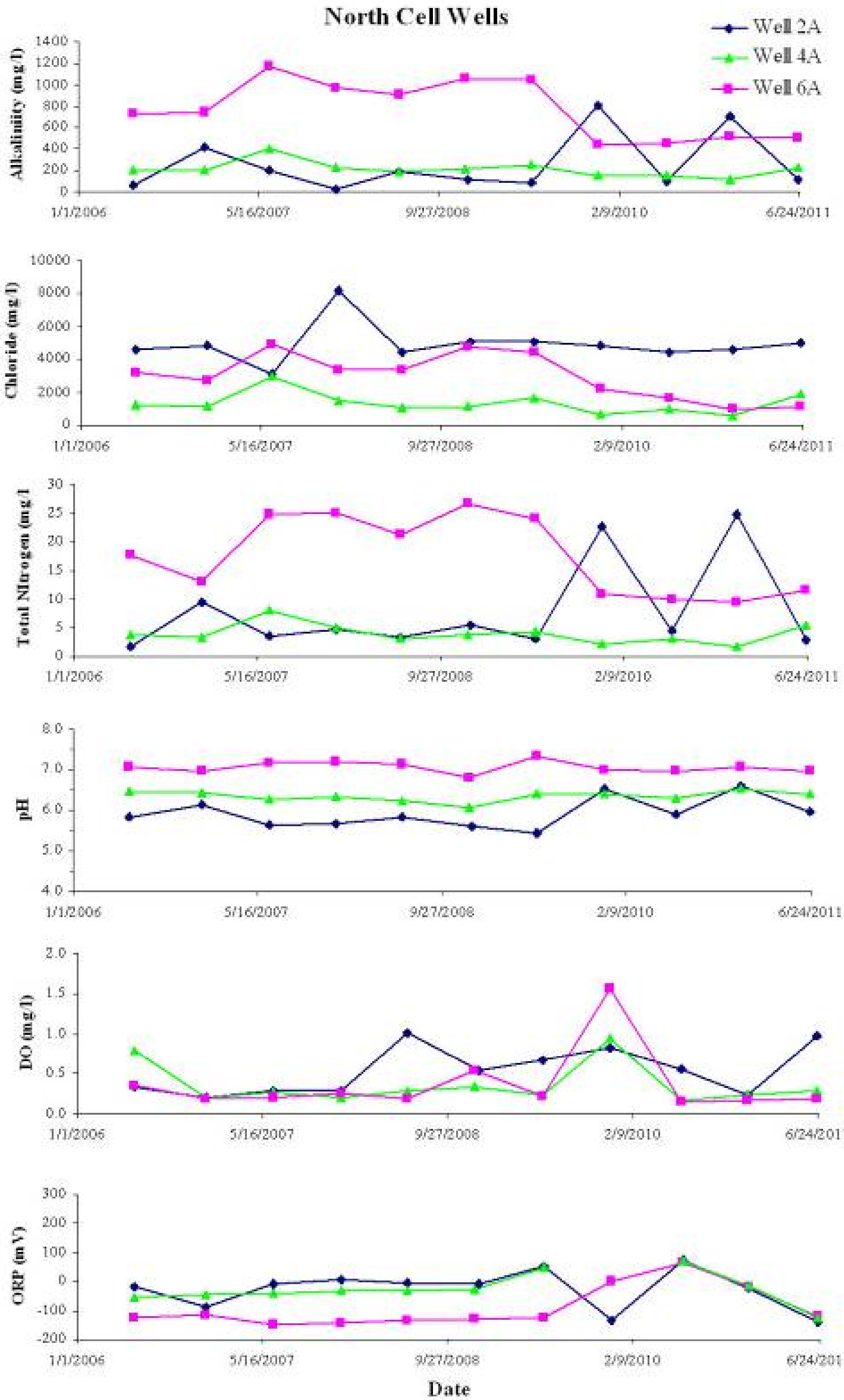


Figure 1-17. Trend plots for specific parameters measured in groundwater samples collected since 2006 from North Cell wells. The Oxidation-Reduction Potential (ORP) value reported for December 2009, for Well 4A was -1533 mV, which was considered an anomaly and not plotted.

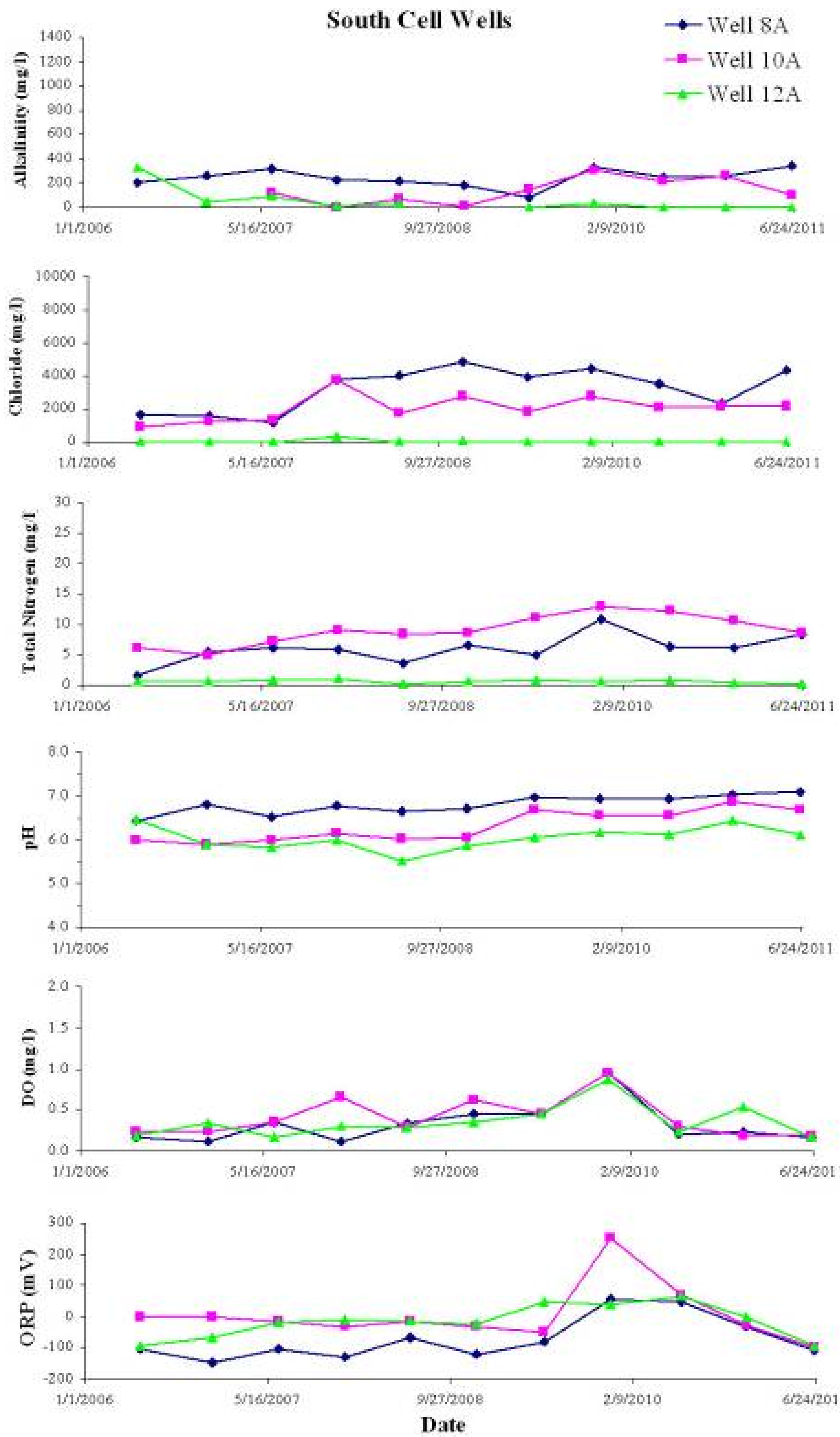


Figure 1-18. Trend plots for specific parameters measured in groundwater samples collected since 2006 from South Cell wells.

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

Based on the depletion in sulfate in comparison to predicted concentrations, North Cell Well 2A is the only well still showing a reducing environment. Groundwater in Well 6A yielded excess sulfate based on both December 2010 and June 2011 samplings, representing a shift from what was observed in the previous samplings (June 2009, December 2009 and June 2010). The predicted sulfate levels are calculated from the chloride concentration based on conservative mixing between rainwater and seawater. Figure 1-19 shows the chloride (Cl^-) concentration 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 excess sulfate concentrations indicate that Wells 4A and 6A are more similar to the oxidizing environment seen in the South Cell wells. The decreasing excess sulfate in Well 6A indicates a shift toward an oxidizing environment. In addition, chloride concentrations in Well 6A have dropped indicating higher rainwater mixing.

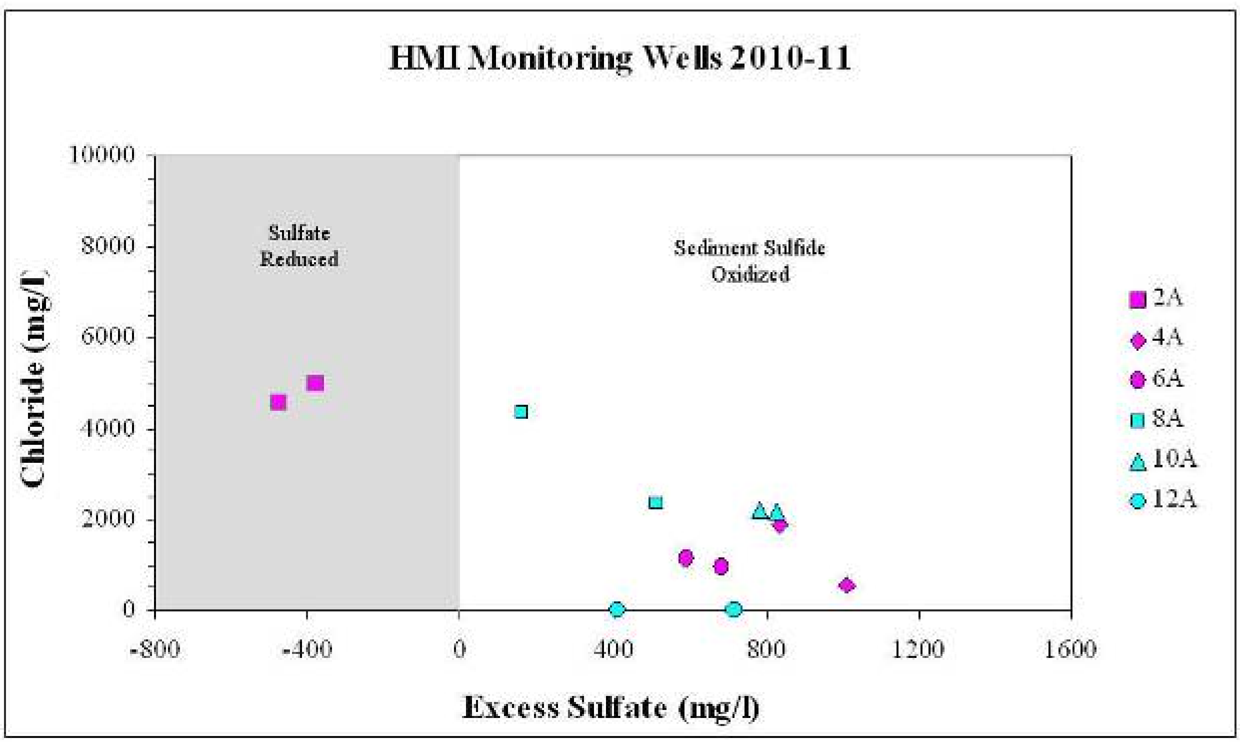


Figure 1-19. Groundwater chloride concentrations as a function of excess sulfate (the difference of the measured sulfate concentrations minus the predicted concentrations). Monitoring wells are grouped by general location; North Cell (pink) or South Cell (light blue).

Alkalinity concentrations in Well 6A have leveled off during the last two sampling events but are higher than the other two wells in the North Cell (except for December 2009 and 2010 samplings for Well 2A) and the wells in the South Cell (Figures 1-17 and 1-18). 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 further supported by the pH values for Well 6A, which have been consistently higher than the other wells (both North and South Cell wells).

Except for Fe, metal concentrations tend to be low in North Cell Well 2A since they are not leeched from the sediment by acid or change in oxidation state (Figure 1-20). Acid produced by sediment oxidation can dissolve mineral species and the change in oxidation state that produced the acid can destabilize minerals and make them more soluble. Metal concentrations in Well 4A are higher as that well resembles the oxidizing environment similar to that of the wells in the South Cell. However, overall concentrations of metals have dropped in most wells. Except for As and Zn, most of the trace metals measured were near or below the detection limits in all of the wells (Table 1-5).

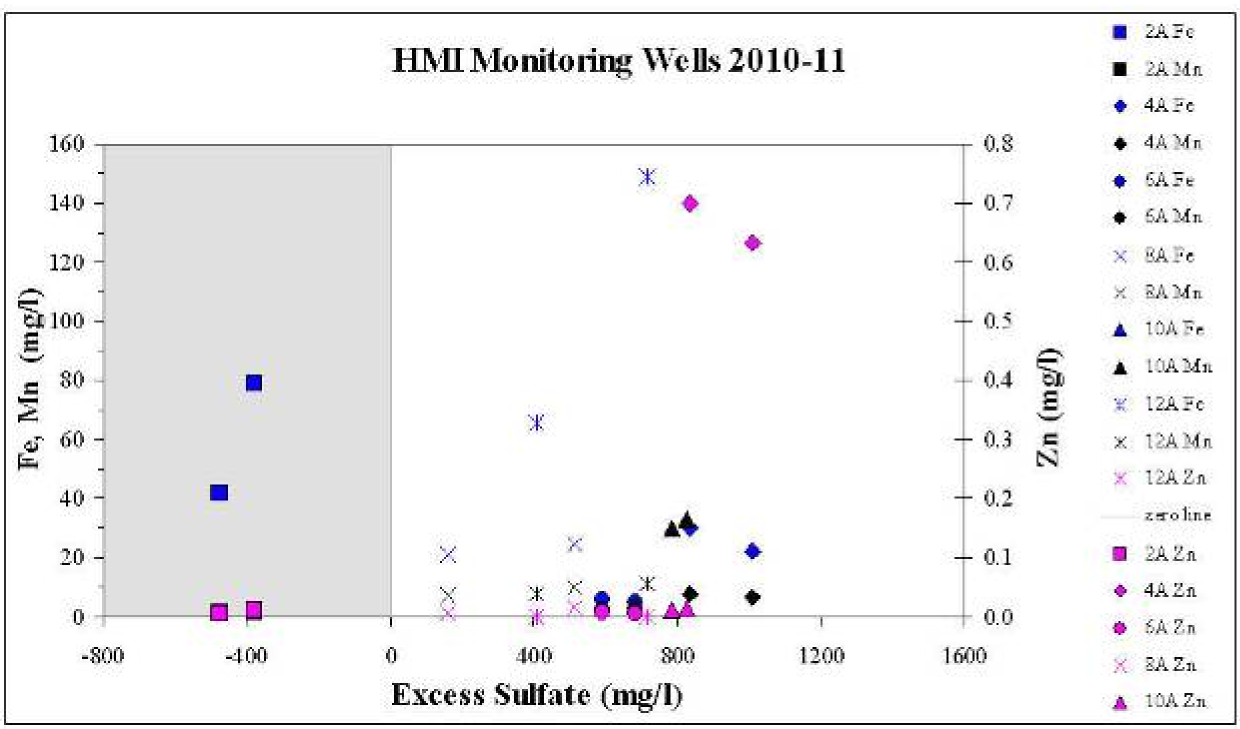


Figure 1-20. Fe, Mn and Zn concentrations as a function of excess sulfate. The different shaped symbols denote individual wells; symbol color (blue, black, and pink) correspond to Fe, Mn and Zn, respectively. Data shown are from the last two well samplings (December 2010 and June 2011).

The major cations are near the predicted conservative mixing concentrations. Since acid generally is not being generated, there is minimum mineral dissolution (specifically calcium carbonate) or ion exchange. 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 (Figure 1-21).

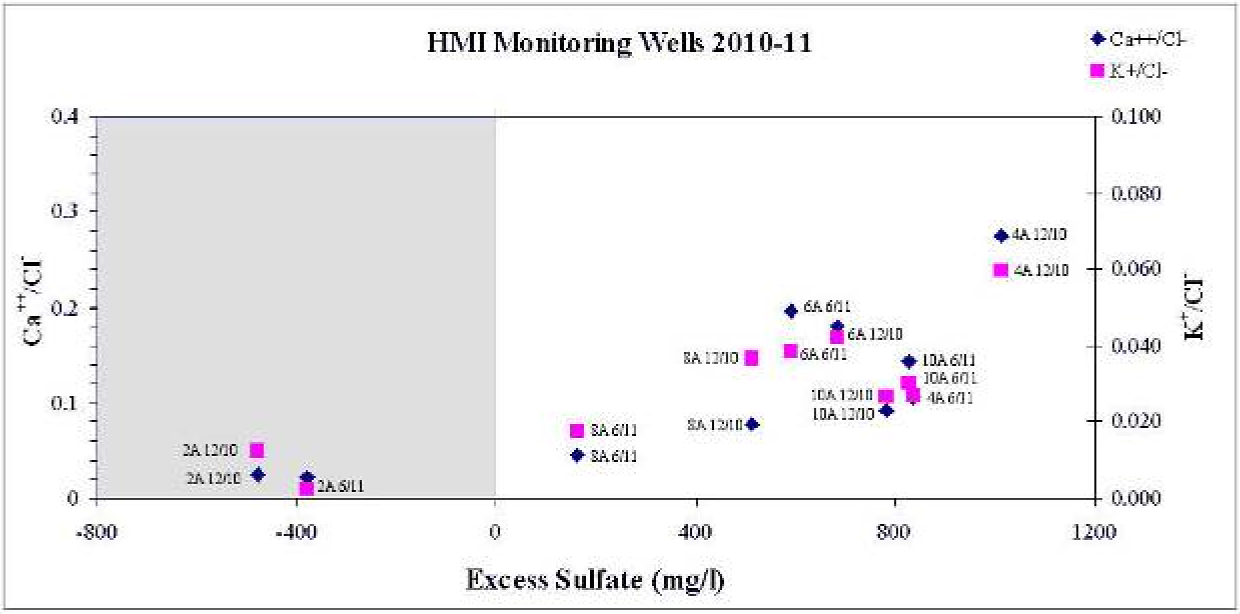


Figure 1-21. The ratios of K^+/Cl^- and Ca^{++}/Cl^- as a function of excess sulfate. For reference, the ratio for both of these cations in seawater is ~0.02. The ratios for Well 12A plotted in the + excess sulfate side of the graph, but way off the chart; the ratios were very high due the extremely low chloride concentrations (Ca^{++}/Cl^- = 6.6, and 9.0; K^+/Cl^- = 1.7 and 1.5 for December 2010 and June 2011 sampling, respectively).

The groundwater from the North Cell Well 2A continues to exhibit behavior typical of anoxic pore waters that have minimum exposure to oxidized sediment. The groundwater is replenished with water from dredged material input which maintains the anaerobic state of the sediments in these areas of the North Cell. Wells 4A and 6A show characteristics similar to the South Cell wells. Excess sulfate has increased, while alkalinity and chloride show a subtle decrease.

South Cell Wells 8A, 10A & 12A

The waters in these wells have been exposed to oxidized sediments, thus the higher levels of excess sulfate (Figures 1-19, 20 and 21). 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 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 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.

PROCESSES OPERATING IN HMI GROUNDWATER

Figure 1-22 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, 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 and acid soluble nutrients and trace organic compounds. This acidified water is either entrained in surface water run off 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 groundwaters sampled

at this point reflect 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.

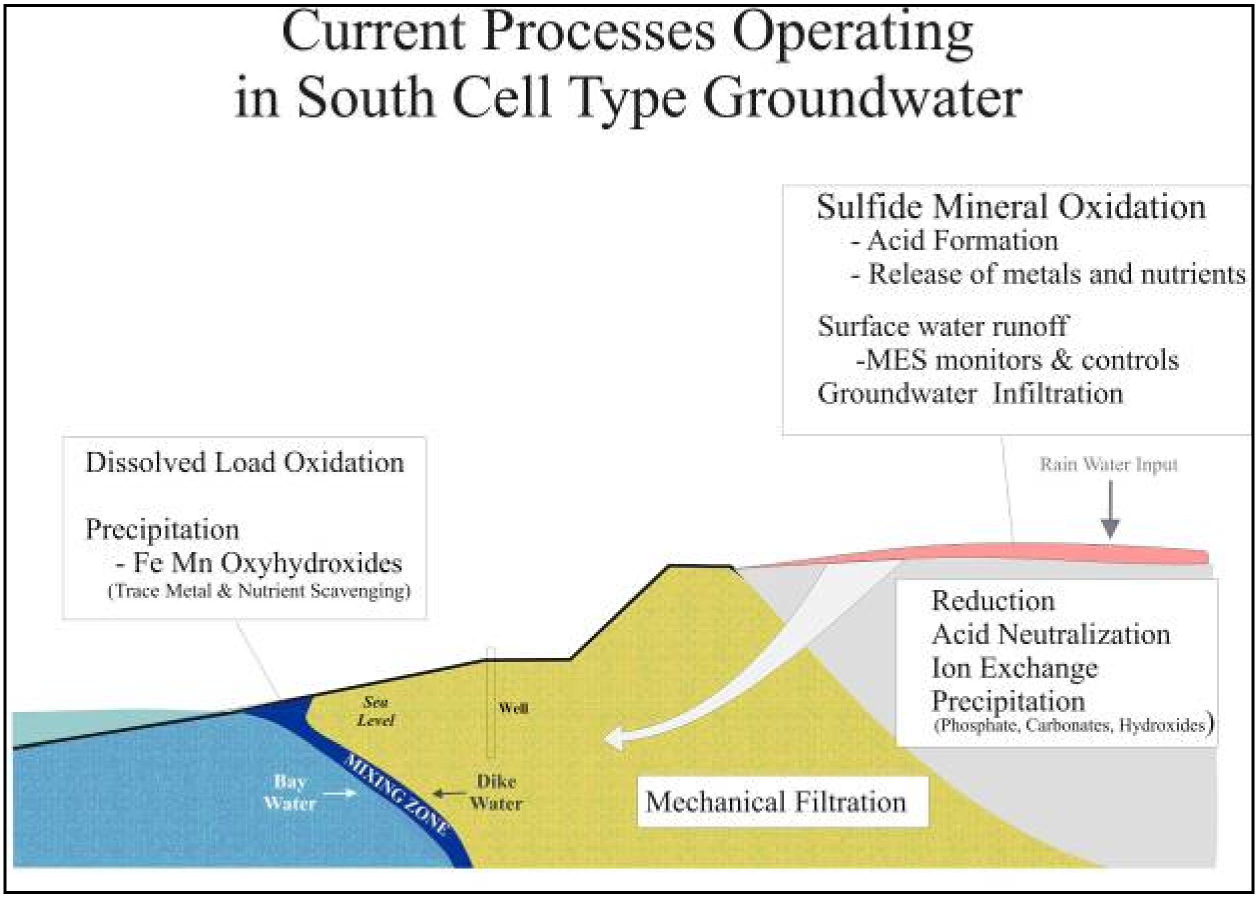


Figure 1-22. Schematic presentation of the processes which produce the groundwater similar to those found in the South Cell wells.

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 slightly different reflecting the heterogeneous material contained in the dike wall and source material that effected transport rates and chemistry of the groundwater.

Table 1-5 is a summary of the trace metal data for the groundwater sampled in December 2010 and June 2011; 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.

Table 1-5. Monitoring wells trace metal analyses for 2010 and 2011 (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	0.053	<dl	0.07	0.05 - 0.2*
As	6	2	0.001	0.008	0.002	0.017	0.01
Cd	6	0	0.002	<dl	<dl	<dl	0.005
Cr (total)	6	0	0.005	<dl	<dl	<dl	0.1
Cu	6	1	0.005	<dl	<dl	0.006	1.3
Fe	6			30.7	5.2	78.9	0.3*
Pb	6	1	0.01	<dl	<dl	0.011	0
Mn	6			3.7	1.3	7.5	0.05*
Zn	6	4	0.005	0.227	<dl	0.700	5*
Ag	6	0	0.001	<dl	<dl	<dl	0.1*
South Cell Type							
	n	***n>dl***	***dl***	***Mean***	***Min***	***Max***	***MCL***
Al	6	0	0.05	<dl	<dl	<dl	0.05 - 0.2*
As	6	1	0.001	0.006	0.002	0.014	0.01
Cd	6	0	0.002	<dl	<dl	<dl	0.005
Cr (total)	6	1	0.005	0.006	<dl	0.009	0.1
Cu	6	0	0.005	<dl	<dl	<dl	1.3
Fe	6			54.0	21.3	149.0	0.3*
Pb	6	5	0.01	<dl	<dl	0.02	0
Mn	6			16.5	7.2	32.9	0.05*
Zn	6	5	0.005	0.012	<dl	0.017	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 effect 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.

REFERENCES

Hill, J., 2005, Hart - Miller Island Well Monitoring: Anaerobic Sampling Study - Groundwater Quality Assessment. Report prepared for Maryland Environmental Service.

Maryland Environmental Service, 2010, Hart –Miller Island Dredged Material Containment Facility Environmental Monitoring: Standard Operating Procedures Manual, updated November, 2010.

URS, 2003, Draft Groundwater Investigation Report December 2001 - June 2003 Hart-Miller Island Dredged Material Containment Facility Baltimore County, MD. Report prepared by the URS Corporation for MD Environmental Service.

U.S. EPA, 2002, National Primary Drinking Water Regulations, EPA 816-F-02-013 (July 2002), Table of contaminants and MCLs downloaded from U.S. EPA website: http://permanent.access.gpo.gov/lps21800/www.epa.gov/safewater/mcl.html

APPENDIX 2: BENTHIC COMMUNITY STUDIES (PROJECT III)

(September 2010 – August 2011)

Technical Report

Prepared by:
Jeff Carter, Principal Investigator
Patricia Brady, Co-principal Investigator
Nicholas Kaltenbach, Co-principal Investigator
Chris Luckett, Taxonomist
Kelsea Croteau, Research Assistant
Chris Marshall, Research Assistant
Charles Poukish, Program Manager

Maryland Department of the Environment
Science Services Administration
Environmental Assessment and Standards Division
and Field Evaluation Division

Prepared for:
Maryland Port Administration
Maryland Department of Transportation
World Trade Center
401 East Pratt Street
Baltimore, Maryland 21202

January 2012

EXECUTIVE SUMMARY

The benthic macroinvertebrate community in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI-DMCF) was studied for the twenty-ninth 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 17, 2010 and on April 19, 2011. This was the third consecutive year with the new station realignment. In Year 27 two established Nearfield stations were dropped (MDE-24 and MDE-35), but three new Nearfield stations were added (MDE-11, MDE-15, and MDE-45). In addition two new Reference stations were added (MDE-50 and MDE-51) and one established Back River Station was dropped (MDE-28).

A total of 44 benthic macroinvertebrate taxa were identified during Year 29. Several taxa were clearly dominant. The worms *Marenzelleria viridis,* and Naididae sp.[1], the clam *Macoma balthica,* and the arthropods *Leptocheirus plumulosus, Melita nitida, Cyathura polita, Gammarus* sp.*, Edotea triloba*, and *Apocorophium lacustre* were among the dominant taxa on both sampling dates. Taxa abundance varied greatly for certain taxa between the two seasons in Year 29. As in past years, abundances for many species were much higher in the spring than in the fall, due to 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*, *Macoma balthica*, and Naididae. In contrast, the species *Streblospio benedicti*, *Polydora cornuta*, and *Heteromastus filiformis* were much more abundant in September 2010, likely indicating summer recruitment for these species, particularly the first two. One taxa, the oligochaete worm of the family Naididae, had unusually high (2.5 times the average abundance for the previous ten years) fall abundances, contributing to depressing the B-IBIs at many stations. This taxon is a strong indicator of enrichment, and has routinely dominated samples from the Back River/Hawk Cove stations.

Several historical biological trends were upheld in Year 29. Species diversity was examined using the Shannon-Wiener diversity index (SWDI). Diversity was higher in September 2010 than in April 2011 at all but three stations. The proportion of pollution sensitive taxa (PSTA) was calculated for the fall cruise only. The proportion of pollution indicative taxa (PITA) was calculated for both cruises. The PITA percentages were lower in April than in September for all stations. This relative difference was due to the recruitment of the pollution sensitive species *Marenzelleria viridis*.

[1] Tubificidae sp. is now described as Naididae sp. due to a reclassification brought about by the International Commission on Zoological Nomenclature. (Case 3305)

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI, Weisberg et al. 1997, Llanso, 2002), a multi-metric index of biotic condition that evaluates summer populations (July 15th to September 30th timeframe) of benthic macroinvertebrates, was calculated for all stations sampled in September 2010. Overall, B-IBI scores were lower than Year 28 and the historical average (mean B-IBI Year 29 = 3.07, mean B-IBI Year 28 = 3.66, historic mean = 3.45). B-IBI scores increased at four stations, decreased at 14 stations, and remained the same at four stations when compared to Year 28. Sixteen of the twenty-two stations met or exceeded the benchmark criteria of 3.0, and six stations (Nearfield stations MDE-01, MDE-19, MDE-34, MDE-45, and Back River stations MDE-27 and MDE-30) failed to meet the benchmark. Four stations set or tied historic lows (Nearfield stations MDE-01, MDE-34, and MDE-45, and Back River/Hawk Cove station MDE-27). The depressed B-IBI scores in Year 29 were likely related to ambient bay segment conditions during the sample period. However, one Nearfield station, MDE-01, was remarkably poor. Because of its proximity to North Cell Spillway 007, MDE-01 will be targeted to receive additional analyses during future monitoring.

The Friedman's nonparametric ANOVA test was significant for September 2010 data but not for April 2010 data. A new station category, the North Cell stations (MDE-01, MDE-07, MDE-03 and MDE-34) was included in the Friedman's procedure to test for adverse impacts from North Cell discharges. However, the significant result for September 2010 was between Reference and Nearfield stations, but the multivariate analyses suggested that these differences were not due to localized impacts from HMI discharges.

INTRODUCTION

Annual dredging of the shipping channels leading to the Port of Baltimore is necessary to maintain safe navigation. An 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 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 29 represents the first full year of post closure data.

The goals of the Year 29 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 29. 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 cruises (Table 2-1; Figure 2-1). Environmental parameters recorded at the time of sample collection are included in Tables 2-2 through 2-5.

Table 2-1. Sampling stations (latitudes and longitudes in degrees, decimal minutes), 7-digit codes of stations used for Year 29 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	Silt/clay	Silt/clay	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	Sand	Sand	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

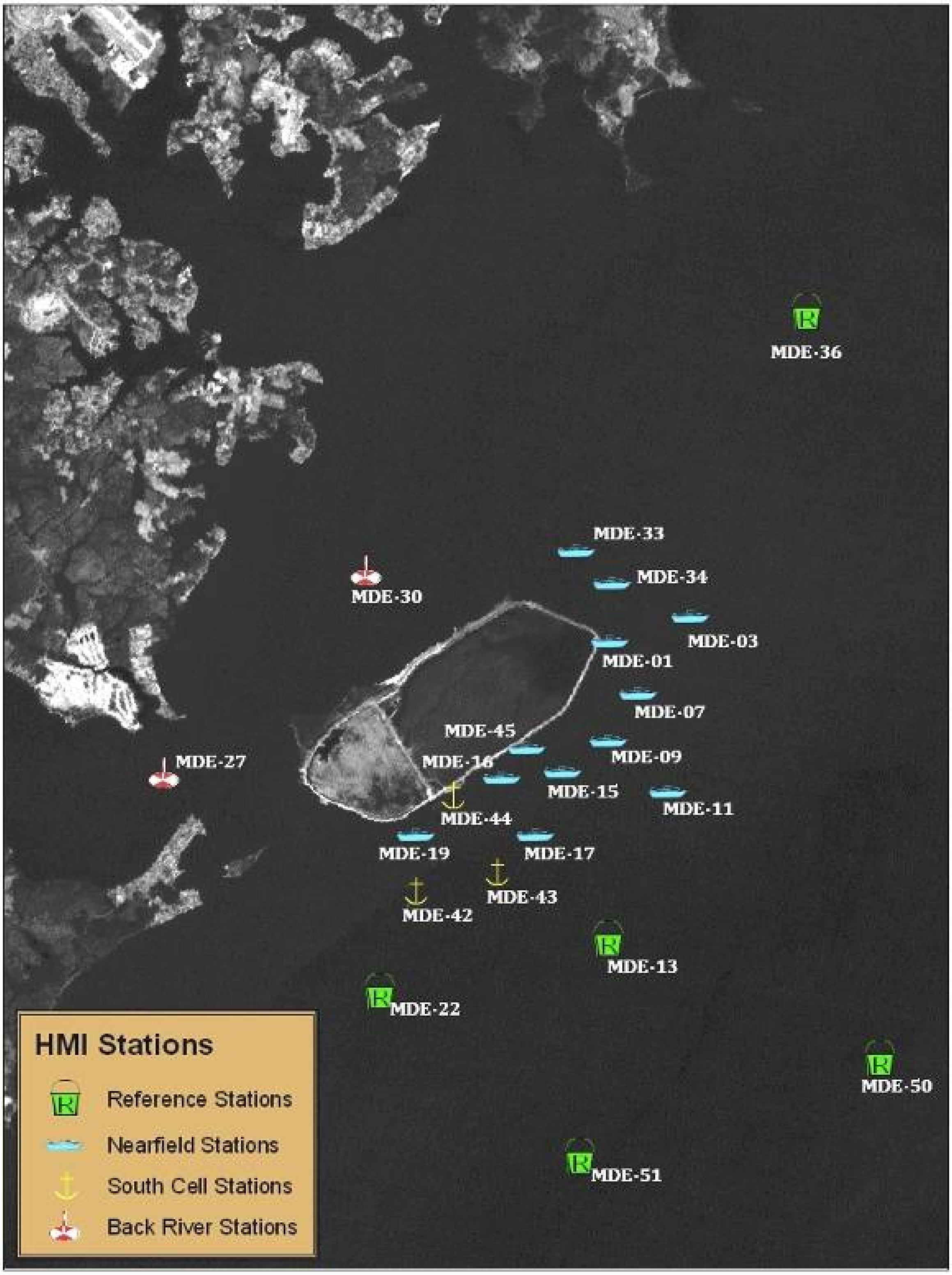


Figure 2-1. Year 29 benthic sampling stations for the HMI exterior monitoring program.

All stations sampled during Year 28 were again sampled for Year 29. In Year 27 two Nearfield stations (MDE-24 and MDE-35) were removed and three new ones (MDE-11, MDE-15, and MDE-45) were added. Also in Year 27, one Back River/Hawk Cove station (MDE-28) was removed and three Reference Stations (MDE-45, MDE-50, and MDE-51) were added[2]. Stations were classified by location and dominant sediment type (Table 2-1). 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. All stations were located using a differential global positioning system (GPS) navigation unit.

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 2010 and April 2011. 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 (Table 2-2 and Table 2-4) and the dominant sediment type for each station was derived from these percentages. 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.

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 29 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.

---

[2] 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"

Six 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, and total abundance of all taxa (excluding Nematoda, Copepoda, and Bryozoa). Four of these measures (total infaunal abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance of pollution-sensitive infaunal taxa and SWDI) were used to calculate the B-IBI for September 2010. 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) thus, was not used with the April 2011 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 29 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 2010 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 2010 and April 2011. 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 2010 and April 2011 cruises (Table 2-3 and Table 2-5 respectively) indicated that water column stratification was not prevalent.

Secchi depths were greater in September 2010 (Table 2-3, range=0.40 m-1.70 m, average = 0.79 m ± 0.25 m) than those in April 2011 (Table 2-5, range=0.20 m-0.60 m, average=0.28 m ± 0.11 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.

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 29, bottom water temperatures did not vary much between stations during both sampling seasons. The September 2010 mean bottom water temperature (Table 2-3, mean=22.52°C ± 0.32°C, range= 21.29°C – 22.85°C) was 1.84ºC lower than the 25-year fall average of 24.36ºC. Bottom water temperatures were seasonably lower in April 2011 (Table 2-5) with a range of 12.20°C –14.20°C and an average of 12.96°C ± 0.43°C. April 2011 mean temperature was 0.86°C higher than the 14-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 2010 mean bottom DO (Table 2-3, mean=7.34 ppm ± 0.50 ppm, range=6.79 – 8.72 ppm) was 0.05 ppm higher than the 14-year fall average of 7.28 ppm. The April 2011 mean bottom DO (Table 2-5, mean=10.11 ppm ± 0.17 ppm, range=9.73 ppm – 10.35 ppm) was 0.16 ppm higher than the 14-year spring average of 9.95 ppm. Historically fall DO is 2.67 ppm lower than spring DO due to reduced oxygen solubility with elevated seasonal temperatures. This year there was a 2.77 ppm difference in spring vs. fall mean bottom DO concentration. Reference Stations MDE-50 and MDE-51 both had DO concentrations that also exceeded the water quality standard (5.0 ppm) to protect aquatic life during both seasons. In Years 27 and 28 there were times when these relatively new stations did not meet the 5.0 ppm standard. For this reason, MDE will continue to evaluate data from these stations and consider their viability as reference stations.

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 25-year mean bottom salinity is 6.28 ppt. Low mesohaline conditions (≥5-12 ppt.) were found during the fall 2010 sampling season and tidal fresh conditions (0.0 ppt – 0.5 ppt) were found during the spring 2011 sampling season.

In Year 29 mean salinity values varied considerably between September (Table 2-3, mean=10.07 ppt ± 0.98 ppt, range = 8.15 ppt – 11.30 ppt) and April (Table 2-5, mean=0.38 ppt ± 0.26 ppt, range 0.12 ppt – 1.24 ppt). The mean fall salinity was 3.83 ppt higher than the historical average (mean =6.28 ppt, ± 2.80 ppt). However, mean spring salinity was 2.46 ppt lower than the historical mean (2.84 ppt ± 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.

Table 2-2. Year 29 physical parameters measured *in situ* at all HMI stations on September 17, 2010.

MDE Station	Time	Tide	Water Depth (m)	Wave Height (m)	Wind Direction	Wind Speed (knots) Min.	Max	Air Temp. (°C)	Cloud Cover (%)	Weather Past 24 hrs.	Today	Observed Bottom Sediment (%) silt/clay	sand	shell	gravel	detritus
MDE-01	12:41	Ebb	3.29	0.1	SW	1	3	24	30	5	0	0	90	10	0	0
MDE-03	12:30	Ebb	5.52	0.1	SW	1	3	24	30	5	0	75	0	25	0	0
MDE-07	12:20	Ebb	5.24	0.1	SW	1	3	24	30	5	0	75	5	20	0	0
MDE-09	12:06	Ebb	5.40	0.2	SW	3	5	24	30	5	0	80	5	15	0	0
MDE-11	11:57	Ebb	5.33	0.3	SW	3	5	24	30	5	0	80	10	10	0	0
MDE-13	10:55	Ebb	4.72	0.1	SW	1	3	22	30	5	0	65	5	30	0	0
MDE-15	10:36	Ebb	3.11	0.1	SW	1	3	22	30	5	0	80	5	15	0	0
MDE-16	10:15	Ebb	4.21	0.1	SE	1	3	22	35	5	0	80	5	15	0	0
MDE-17	9:25	Ebb	4.69	0.5	SW	8	10	20	35	5	0	80	0	20	0	0
MDE-19	9:40	Ebb	4.45	0.3	SW	3	5	21	30	5	0	90	7	3	0	0
MDE-22	8:40	Ebb	4.90	0.5	SW	8	10	20	30	5	0	90	1	9	0	0
MDE-27	14:04	Ebb	3.41	0.1	SE	1	3	25	30	5	0	75	0	15	0	10
MDE-30	13.38	Ebb	2.53	0.1	SW	1	3	24	30	5	0	80	10	10	0	0
MDE-33	13.23	Ebb	1.83	0.1	SW	1	3	24	30	5	0	0	90	10	0	0
MDE-34	13:05	Ebb	2.19	0.1	SW	1	3	24	30	5	0	0	95	5	0	5
MDE-36	14:39	Flood	2.96	0.1	SW	1	3	24	30	5	0	80	0	20	0	0
MDE-42	8:57	Ebb	4.61	0.5	SW	8	10	20	30	5	0	90	1	9	0	0
MDE-43	9:06	Ebb	4.78	0.5	SW	8	10	20	30	5	0	80	0	20	0	0
MDE-44	9:58	Ebb	5.43	0.3	SW	3	5	21	30	5	0	90	0	10	0	0
MDE-45	10:30	Ebb	4.69	0.1	SW	1	3	22	30	5	0	85	5	10	0	0
MDE-50	11:36	Ebb	3.87	0.1	SW	3	5	24	30	5	0	5	85	5	0	0
MDE-51	1110	Ebb	4.78	0.1	SW	1	3	22	30	5	0	91	2	7	0	0

Note: The weather code 5 stands for “Light Rain”, code 0 stands for “Clear”.

Table 2-3. Year 29 water quality parameters measured *in situ* at all HMI stations on September 17, 2010.

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	8.71	22.46	7.84	7.86	0.7	14,900
		Bottom	3.29	9.30	22.42	7.52	7.85		15,880
MDE-03	XIG5699	Surface	0.50	9.35	22.69	8.12	7.87	0.7	15,990
		Bottom	5.52	9.96	22.48	7.15	7.84		16,910
MDE-07	XIF5302	Surface	0.50	8.69	22.48	8.18	7.88	0.7	14,930
		Bottom	5.24	9.85	22.53	7.49	7.88		16,740
MDE-09	XIF4806	Surface	0.50	9.01	22.51	7.75	7.86	0.8	15,370
		Bottom	5.40	9.92	22.54	7.50	7.89		16,870
MDE-11	XIG4501	Surface	0.50	9.80	22.68	7.52	7.83	0.8	16,670
		Bottom	5.33	9.94	22.52	7.31	7.85		16,890
MDE-15	XIF4609	Surface	0.50	9.22	22.41	7.59	7.83	0.7	15,860
		Bottom	3.11	9.88	22.48	7.56	7.90		16,400
MDE-16	XIF4615	Surface	0.50	9.66	22.54	7.02	7.80	0.7	16,360
		Bottom	4.21	10.61	22.67	6.81	7.79		17,930
MDE-17	XIF4285	Surface	0.50	9.07	22.25	7.76	7.66	0.8	15,539
		Bottom	4.69	10.53	22.59	7.05	7.65		17,904
MDE-19	XIF4221	Surface	0.50	10.64	22.74	7.09	7.74	0.6	18,000
		Bottom	4.45	10.90	21.29	8.26	7.93		18,400
MDE-33	XIF6008	Surface	0.50	8.23	22.69	8.75	8.01	0.7	14,190
		Bottom	1.83	8.26	22.71	8.72	8.07		14,250
MDE-34	XIF5805	Surface	0.50	8.23	22.71	8.49	7.97	0.7	14,200
		Bottom	2.19	9.47	22.53	7.58	7.92		16,090
MDE-45	N/A	Surface	0.50	9.37	22.46	7.20	7.82	0.6	15,990
		Bottom	4.69	10.58	22.69	6.82	7.81		17,880
Reference Stations									
MDE-13	XIG3506	Surface	0.50	10.23	22.59	7.39	7.80	0.9	17,330
		Bottom	4.72	10.68	22.60	7.11	7.83		18,050
MDE-22	XIF3224	Surface	0.50	10.45	22.52	7.32	7.67	1.7	17,724
		Bottom	4.90	11.30	22.72	6.79	7.62		19,171
MDE-36	XIG7589	Surface	0.50	7.87	22.81	8.31	7.81	0.7	13,670
		Bottom	2.96	8.63	22.20	7.21	7.80		14,810
MDE-50	N/A	Surface	0.50	10.70	22.89	7.47	7.82	1.0	18,090
		Bottom	3.87	11.23	22.85	7.21	7.88		18,920
MDE-51	N/A	Surface	0.50	10.97	22.78	7.37	7.84	0.7	18,490
		Bottom	4.78	11.23	22.79	7.12	7.84		18,920
Back River/Hawk Cove Stations									
MDE-27	XIF4642	Surface	0.50	8.12	23.06	9.18	8.35	0.4	14,020
		Bottom	3.41	8.63	22.36	7.62	8.11		15,030
MDE-30	XIF5925	Surface	0.50	7.97	22.64	8.42	7.96	0.7	13,770
		Bottom	2.53	8.15	22.39	8.10	7.98		14,050
South Cell Exterior Monitoring Stations									
MDE-42	XIF3879	Surface	0.50	10.39	22.53	7.31	7.63	1.1	17,664
		Bottom	4.61	11.02	22.70	6.86	7.58		18,568
MDE-43	XIF3985	Surface	0.50	9.53	22.32	7.54	7.64	0.8	16,352
		Bottom	4.78	10.87	22.63	6.91	7.59		18,413
MDE-44	XIF4482	Surface	0.50	10.34	22.74	7.07	7.76	0.9	17,530
		Bottom	5.43	10.67	22.74	6.86	7.82		18,070

Table 2-4. Year 29 physical parameters measured *in situ* at all HMI stations on April 19, 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	1:13	Flood	3.33	0.1	N	0	2	19	100	1	2	0	85	15	0	0
MDE-03	12:50	Flood	2.59	0.3	N	2	4	18	100	0	0	70	0	30	0	0
MDE-07	12:27	Flood	3.80	0.3	N	2	4	18	100	0	0	70	5	25	0	0
MDE-09	12:05	Flood	5.56	0.1	N	0	2	17	100	0	0	80	5	15	0	0
MDE-11	11:57	Flood	4.61	0.3	N	2	4	16	100	0	0	80	10	10	0	0
MDE-13	10:39	Flood	5.14	0.1	W	0	2	17	100	0	0	60	5	35	0	0
MDE-15	10:28	Flood	4.82	0.1	W	0	2	17	100	0	0	80	10	10	0	0
MDE-16	10:06	Flood	4.74	0.1	W	0	2	16	100	0	0	75	10	15	0	0
MDE-17	9:18	Flood	5.39	0.1	N/A	0	0	15	100	0	0	75	0	25	0	0
MDE-19	9:44	Flood	5.16	0.1	W	0	2	16	100	0	0	90	5	5	0	0
MDE-22	8:32	Flood	5.38	0.1	N/A	0	0	15	100	0	0	95	1	4	0	0
MDE-27	15:01	Flood	3.55	0.3	N	2	4	16	100	0	0	70	0	15	0	15
MDE-30	14:51	Flood	2.47	0.2	N	2	4	15	100	0	0	80	10	10	0	0
MDE-33	13:56	Flood	1.83	0.1	N	0	2	19	100	0	0	0	85	15	0	0
MDE-34	13:45	Flood	3.16	0.2	N	0	2	19	100	0	0	0	95	5	0	0
MDE-36	14:26	Flood	3.20	0.1	N	0	2	16	100	0	0	75	0	25	0	0
MDE-42	8:48	Flood	5.02	0.1	N/A	0	0	15	100	0	0	95	2	3	0	0
MDE-43	9:02	Flood	5.27	0.1	N/A	0	0	16	100	0	0	85	0	15	0	0
MDE-44	9:53	Flood	4.20	0.1	W	0	2	16	100	0	0	90	0	10	0	0
MDE-45	10:21	Flood	5.20	0.1	W	0	2	17	100	0	0	80	10	10	0	0
MDE-50	11:24	Flood	4.60	0.1	N	2	4	17	100	0	0	5	85	10	0	0
MDE-51	10:58	Flood	3.45	0.1	NE	2	4	17	100	0	0	90	3	7	0	0

Note: The weather codes 1 stands for "Partly Cloudy", weather code 2 stands for "Continuous Cloud Cover".

Table 2-5. Year 29 water quality parameters measured *in situ* at all HMI stations on April 19, 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	0.43	13.42	9.92	7.62	0.3	878
		Bottom	3.33	0.42	13.27	9.92	7.62		862
MDE-03	XIG5699	Surface	0.50	0.13	12.82	10.27	7.84	0.25	263
		Bottom	2.59	0.12	12.81	10.33	7.90		270
MDE-07	XIF5302	Surface	0.50	0.28	13.04	10.09	7.68	0.25	571
		Bottom	3.80	0.28	13.00	10.09	7.68		570
MDE-09	XIF4806	Surface	0.50	0.29	12.92	10.09	7.65	0.3	593
		Bottom	5.56	0.29	12.91	10.11	7.64		599
MDE-11	XIG4501	Surface	0.50	0.14	12.84	10.17	7.79	0.3	295
		Bottom	4.61	0.15	12.81	10.06	7.77		346
MDE-15	XIF4609	Surface	0.50	0.25	13.23	10.31	7.75	0.2	512
		Bottom	4.82	0.31	12.86	10.20	7.68		633
MDE-16	XIF4615	Surface	0.50	0.33	12.81	10.28	7.68	0.3	672
		Bottom	4.74	0.35	12.72	10.22	7.66		714
MDE-17	XIF4285	Surface	0.50	0.25	12.77	10.26	7.73	0.3	507
		Bottom	5.39	0.25	12.72	10.24	7.74		507
MDE-19	XIF4221	Surface	0.50	0.41	12.70	10.27	7.72	0.3	816
		Bottom	5.16	0.55	12.87	10.15	7.56		1,108
MDE-33	XIF6008	Surface	0.50	0.37	13.41	9.92	7.66	0.6	747
		Bottom	1.83	0.39	13.37	9.90	7.64		788
MDE-34	XIF5805	Surface	0.50	0.35	13.32	9.93	7.66	0.2	710
		Bottom	3.16	0.35	13.32	10.03	7.65		719
MDE-45	N/A	Surface	0.50	0.34	12.85	10.20	7.67	0.2	696
		Bottom	5.20	0.34	12.83	10.15	7.66		678
Reference Stations									
MDE-13	XIG3506	Surface	0.50	0.14	12.73	10.33	7.80	0.3	282
		Bottom	5.14	0.14	12.57	10.32	7.87		285
MDE-22	XIF3224	Surface	0.50	0.27	12.39	10.24	8.23	0.6	556
		Bottom	5.38	0.76	13.17	9.84	7.93		1,530
MDE-36	XIG7589	Surface	0.50	0.24	13.41	10.06	7.70	0.2	503
		Bottom	3.20	0.24	13.37	10.04	7.73		495
MDE-50	N/A	Surface	0.50	0.17	12.31	10.34	7.77	0.25	344
		Bottom	4.60	0.19	12.20	10.32	7.77		386
MDE-51	N/A	Surface	0.50	0.12	12.57	10.40	7.79	0.2	246
		Bottom	3.45	0.12	12.42	10.35	7.84		244
Back River/Hawk Cove Stations									
MDE-27	XIF4642	Surface	0.50	1.24	14.25	9.76	7.63	0.3	2,395
		Bottom	3.55	1.24	14.20	9.73	7.52		2,386
MDE-30	XIF5925	Surface	0.50	0.58	13.76	10.18	7.63	0.3	1,151
		Bottom	2.47	0.68	13.54	9.95	7.52		1,356
South Cell Exterior Monitoring Stations									
MDE-42	XIF3879	Surface	0.50	0.30	12.51	10.22	7.91	0.2	618
		Bottom	5.02	0.54	12.83	10.10	7.67		1,078
MDE-43	XIF3985	Surface	0.50	0.26	12.63	10.26	7.75	0.2	529
		Bottom	5.27	0.26	12.63	10.24	7.76		527
MDE-44	XIF4482	Surface	0.50	0.38	12.75	10.24	7.68	0.2	778
		Bottom	4.20	0.42	12.72	10.21	7.65		847

BENTHIC MACROINVERTEBRATE COMMUNITY

Taxa Richness and Dominance

A total of 44 taxa were found over the two seasons of sampling during Year 29. This is higher than the 13-year average of 39.93 taxa.

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). Twenty-two taxa of Arthropoda were found in Year 29. This is higher than the 13-year mean of 18.23 taxa (range= 12-23 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 16-year mean of 7.46 taxa (range= 6-10 taxa). Six species of bivalve mollusks were found. This is similar to the 13-year mean of 5.77 taxa (range= 4-7 taxa). Overall, bivalve average abundance was lower in April 2011 than in September 2010 (Table 2-7 and Table 2-6 respectively).

During the spring, Ostracoda, *Mya arenaria*, *Cricotopus* sp., *Orthocladius* sp., *Dictotendipes* sp., *Parachironomus* sp., Hydrozoa, Odonata, *Callinectes sapidus*, *Boccardiella ligerica*, and Copepoda were exclusively found, while *Polydora cornuta*, *Streblospio benedicti*, *Eteone heteropoda*, *Mytilopsis leucophaeta*, *Gobiosoma bosci*, *Similium* sp., *Palaemontes* sp., and Hydrobiidae were only found in fall samples. Year 29 is the third year in a row since Year 21 that *Mya arenaria* was observed. *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 2010 sampling by substrate and station type. Because the mean bottom salinity regime was low mesohaline, 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	52.07	1145.60	55.47	N/A	36.80	18.67	28.16	380.80	6.40
Carinoma tremaphoros	15.42	339.20	18.49	N/A	1.60	6.93	28.16	12.80	29.87
Bivalvia	63.13	1388.80	41.96	N/A	158.40	70.40	44.80	86.40	49.07
Macoma sp.	23.85	524.80	12.44	N/A	75.20	24.53	34.56	22.40	4.27
Macoma balthica	**36.36**	**800.00**	**42.67**	**N/A**	**8.00**	**23.47**	**34.56**	**38.40**	**89.60**
Macoma mitchelli	58.18	1280.00	61.51	N/A	43.20	43.73	35.84	147.20	93.87
Rangia cuneata	**26.18**	**576.00**	**28.09**	**N/A**	**17.60**	**28.27**	**30.72**	**22.40**	**12.80**
Ischadium recurvum	0.58	12.80	0.00	N/A	3.20	1.07	0.00	0.00	0.00
Mytilopsis leucophaeata	2.62	57.60	1.07	N/A	9.60	4.27	0.00	0.00	2.13
Amphicteis floridus	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Capitellidae	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Heteromastus filiformis	60.80	1337.60	69.69	N/A	20.80	49.60	81.92	51.20	76.80
Spionidae	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Marenzelleria viridis	**79.71**	**1753.60**	**93.51**	**N/A**	**17.60**	**80.00**	**75.52**	**32.00**	**117.33**
Streblospio benedicti	173.38	3814.40	129.42	N/A	371.20	225.60	72.96	316.80	36.27
Polydora cornuta	54.69	1203.20	14.22	N/A	236.80	99.20	2.56	0.00	0.00
Boccardiella ligerica	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Nereididae	174.55	3840.00	56.18	N/A	707.20	298.67	40.96	19.20	4.27
Neanthes succinea	96.00	2112.00	72.53	N/A	201.60	150.40	38.40	19.20	25.60

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	19.78	435.20	18.13	N/A	27.20	20.80	7.68	67.20	4.27
Naididae sp.	966.11	21254.40	1148.09	N/A	147.20	608.53	339.20	5113.60	676.27
Amphipoda	23.27	512.00	27.02	N/A	6.40	27.20	15.36	3.20	34.13
Gammaridea	6.11	134.40	7.47	N/A	0.00	4.27	7.68	9.60	8.53
Ameroculodes spp complex	1.16	25.60	0.36	N/A	4.80	2.13	0.00	0.00	0.00
Leptocheirus plumulosus	221.67	4876.80	258.13	N/A	57.60	204.80	149.76	182.40	435.20
Gammarus sp.	1.75	38.40	0.36	N/A	8.00	3.20	0.00	0.00	0.00
Melitidae	4.65	102.40	0.71	N/A	22.40	8.53	0.00	0.00	0.00
Melita nitida	62.25	1369.60	35.56	N/A	182.40	90.13	17.92	25.60	49.07
Corophiidae	4.36	96.00	2.84	N/A	11.20	7.47	0.00	3.20	0.00
Apocorophium lacustre	96.29	2118.40	64.71	N/A	238.40	174.93	3.84	0.00	0.00
Cyathura polita	**128.58**	**2828.80**	**153.96**	**N/A**	**14.40**	**123.20**	**124.16**	**60.80**	**202.67**
Edotea triloba	1.16	25.60	1.42	N/A	0.00	0.53	2.56	3.20	0.00
Chiridotea almyra	0.87	19.20	0.36	N/A	3.20	1.60	0.00	0.00	0.00
Cirripedia	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Balanus improvisus	10.18	224.00	3.91	N/A	38.40	14.93	8.96	0.00	0.00
Balanus subalbidus	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Rhithropanopeus harrisii	17.16	377.60	8.18	N/A	57.60	29.33	5.12	0.00	0.00
Membranipora sp	+	+	+	N/A	+	+	+	0	+
Chironomidae	0.00	0.00	0.00	N/A	0.00	0.00	0.00	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.	1.75	38.40	2.13	N/A	0.00	2.13	0.00	6.40	0.00
Chironomus sp.	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Hydrobiidae	1.45	32.00	0.00	N/A	8.00	2.67	0.00	0.00	0.00
Gammaridae	5.82	128.00	2.13	N/A	22.40	10.67	0.00	0.00	0.00
Copepoda	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Gobiosoma bosci	1.75	38.40	0.71	N/A	6.40	2.67	1.28	0.00	0.00
Mysidacea	0.29	6.40	0.36	N/A	0.00	0.53	0.00	0.00	0.00
Cassidinidea ovalis	13.38	294.40	0.00	N/A	73.60	24.53	0.00	0.00	0.00
Argulus sp.	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Palaemonetes sp.	0.29	6.40	0.36	N/A	0.00	0.53	0.00	0.00	0.00
Simulium sp.	0.29	6.40	0.36	N/A	0.00	0.00	1.28	0.00	0.00
Apocorophium sp.	2.04	44.80	2.49	N/A	0.00	3.73	0.00	0.00	0.00
Platyhelminthes	0.29	6.40	0.36	N/A	0.00	0.53	0.00	0.00	0.00
Tanytarsini sp.	0.29	6.40	0.00	N/A	1.60	0.53	0.00	0.00	0.00

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 the April 2011 sampling by substrate and station type. Because the mean bottom salinity regime was tidal fresh, 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	16.32	326.40	17.78	N/A	1.60	12.22	2.13	49.07	12.80
Carinoma tremaphoros	7.68	153.60	8.89	N/A	1.60	5.24	8.53	14.93	8.53
Bivalvia	16.32	326.40	18.13	N/A	0.00	1.16	49.07	6.40	49.07
Macoma sp.	32.00	640.00	35.56	N/A	0.00	4.65	53.33	78.93	64.00
Macoma balthica	35.52	710.40	46.22	N/A	0.00	12.80	23.47	102.40	64.00
Macoma mitchelli	35.84	716.80	39.82	N/A	1.60	18.04	17.07	100.27	55.47
Rangia cuneata	14.72	294.40	15.29	N/A	4.80	18.62	6.40	4.27	19.20
Ischadium recurvum	0.32	6.40	0.36	N/A	0.00	0.58	0.00	0.00	0.00
Mytilopsis leucophaeata	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Capitellidae	6.40	128.00	9.24	N/A	0.00	5.24	6.40	17.07	0.00
Heteromastus filiformis	41.28	825.60	54.76	N/A	8.00	19.20	46.93	98.13	59.73
Spionidae	0.32	6.40	0.36	N/A	0.00	0.58	0.00	0.00	0.00
Marenzelleria viridis	3504.32	70086.40	2593.07	N/A	7076.80	4896.00	2156.80	1427.20	1826.13
Streblospio benedicti	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Polydora cornuta	0.32	6.40	0.36	N/A	0.00	0.58	0.00	0.00	0.00
Boccardiella ligerica	0.32	6.40	0.36	N/A	0.00	0.58	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
Nereididae	16.64	332.80	16.36	N/A	9.60	29.09	4.27	0.00	0.00
Neanthes succinea	59.20	1184.00	49.78	N/A	80.00	80.87	34.13	32.00	32.00
Naididae sp.	644.16	12883.20	709.69	N/A	310.40	364.22	328.53	2054.40	576.00
Amphipoda	41.60	832.00	48.00	N/A	3.20	33.16	40.53	46.93	68.27
Gammaridea	0.96	19.20	0.00	N/A	4.80	1.75	0.00	0.00	0.00
Ameroculodes spp complex	0.32	6.40	0.00	N/A	1.60	0.58	0.00	0.00	0.00
Leptocheirus plumulosus	731.20	14624.00	800.00	N/A	355.20	660.36	663.47	774.40	1015.47
Gammaridae	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Gammarus sp	3.52	70.40	3.20	N/A	3.20	4.65	0.00	6.40	0.00
Melitidae	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Melita nitida	17.92	358.40	18.13	N/A	9.60	13.38	25.60	25.60	19.20
Corophiidae	3.84	76.80	3.20	N/A	4.80	6.40	0.00	2.13	0.00
Apocorophium sp.	126.08	2521.60	66.13	N/A	332.80	229.24	0.00	0.00	0.00
Apocorophium lacustre	286.08	5721.60	251.73	N/A	308.80	471.85	74.67	32.00	70.40
Cyathura polita	92.80	1856.00	105.60	N/A	33.60	88.44	119.47	74.67	100.27
Edotea triloba	1.92	38.40	1.42	N/A	4.80	2.91	2.13	0.00	0.00
Chiridotea almyra	1.92	38.40	2.13	N/A	0.00	3.49	0.00	0.00	0.00
Balanus improvisus	0.64	12.80	0.71	N/A	0.00	1.16	0.00	0.00	0.00
Rhithropanopeus harrisii	6.08	121.60	2.49	N/A	19.20	11.05	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
Membranipora sp	+	+	+	N/A	+	+	+	+	+
Chironomidae	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Coelotanypus sp.	0.64	12.80	0.71	N/A	0.00	0.58	0.00	2.13	0.00
Orthocladiinae	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Cricotopus sp.	0.96	19.20	0.36	N/A	3.20	1.16	0.00	2.13	0.00
Cryptochironomus sp.	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Tanytarsini	0.32	6.40	0.00	N/A	1.60	0.58	0.00	0.00	0.00
Copepoda	+	+	+	N/A	+	+	+	0.00	0.00
Ostracoda	6.08	121.60	6.76	N/A	0.00	0.58	0.00	29.87	8.53
Mysidacea	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Platyhelminthes sp.	30.40	608.00	35.20	N/A	1.60	30.25	29.87	14.93	46.93
Mya arenaria	0.32	6.40	0.36	N/A	3.20	0.58	0.00	0.00	0.00
Eteone heteropoda	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Cassidinidea ovalis	0.96	19.20	0.36	N/A	3.20	1.75	0.00	0.00	0.00
Hydrozoa	6.40	128.00	7.11	N/A	0.00	11.64	0.00	0.00	0.00
Odonata	0.32	6.40	0.71	N/A	0.00	0.58	0.00	0.00	0.00
Callinectes sapidus	0.64	12.80	0.36	N/A	1.60	1.16	0.00	0.00	0.00
Piscicola sp.	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Gobiosoma bosci	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Orthocladius	0.32	6.40	0.36	N/A	0.00	0.58	0.00	0.00	0.00
Isopoda	0.32	6.40	0.00	N/A	1.60	0.58	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
Chironomini	0.32	6.40	0.36	N/A	0.00	0.58	0.00	0.00	0.00
Dicrotendipes sp.	0.32	6.40	0.36	N/A	0.00	0.58	0.00	0.00	0.00
Chaoborus sp.	0.32	6.40	0.36	N/A	0.00	0.58	0.00	0.00	0.00
Parachironomus	0.32	6.40	0.36	N/A	0.00	0.58	0.00	0.00	0.00
Chironomidae pupa	0.64	12.80	0.71	N/A	0.00	1.16	0.00	0.00	0.00

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

Of the 44 taxa found in Year 29, eighteen were considered truly infaunal, eighteen were considered epifaunal, and the remaining eight were considered too general to classify as either infaunal or epifaunal (see Ranasinghe et al. 1994). The most common infaunal species found during Year 29 were worms from the family Naididae, the amphipods *L. plumulosus* and *Gammarus* sp., the polychaete worm *M. viridis*, the bivalve *M. balthica*, and the isopod *C. polita*. The most common epifaunal species were the amphipods *A. lacustre* and *M. nitida,* and the isopod *E. triloba.*

Nearfield station MDE-01 had the highest number of taxa in September 2010 (21 taxa, Table 2-8). The station with the fewest number of taxa (11 taxa) in September was South Cell Exterior Monitoring station MDE-42 (Table 2-8). Overall, average taxa richness was highest at the Nearfield stations but did not vary greatly between station types (average taxa richness: Nearfield=16.17 taxa, Reference=14.20 taxa, Back River/Hawk Cove=14 taxa, South Cell Exterior Monitoring=13 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, 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 29 September 2010 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 (%)	B-IBI
Nearfield Stations								
MDE-01	7564.80	8928.00	21	14	2.68	0.34	22.84	2.00
MDE-03	2374.40	2451.20	18	12	2.83	12.13	30.19	3.50
MDE-07	1644.80	1779.20	17	13	3.12	28.40	40.47	4.00
MDE-09	2809.60	2924.80	19	14	2.76	10.48	60.59	3.00
MDE-11	2086.40	2246.40	18	14	3.36	25.46	35.28	4.00
MDE-15	1465.60	1619.20	16	12	2.65	16.16	19.65	3.50
MDE-16	1094.40	1190.40	15	11	2.74	21.64	23.39	3.00
MDE-17	1478.40	1568.00	17	14	3.40	9.52	27.71	3.00
MDE-19	2681.60	2841.60	14	11	1.91	16.23	62.77	2.50
MDE-33	582.40	1017.60	12	10	2.75	12.09	43.96	3.00
MDE-34	441.60	787.20	14	11	3.08	11.59	31.88	2.50
MDE-45	2304.00	2361.60	13	10	1.56	12.22	73.89	2.50
MEANS	**2210.67**	**2476.27**	**16.17**	**12.17**	**2.74**	**14.69**	**39.38**	**3.04**
HISTORIC MEAN, n=29 years								**3.52**
Reference Stations								
MDE-13	1766.40	1958.40	17	13	2.88	18.84	44.93	3.50
MDE-22	633.60	691.20	12	11	3.06	36.36	12.12	4.00
MDE-36	1126.40	1145.60	15	12	3.01	28.41	46.02	3.50
MDE-50	268.80	480.00	12	12	3.23	30.95	21.43	3.00
MDE-51	1651.20	1753.60	15	12	2.92	21.71	39.53	3.50
MEANS	**1089.28**	**1205.76**	**14.20**	**12.00**	**3.02**	**27.25**	**32.81**	**3.50**
HISTORIC MEAN, n=29 years								**3.78**
Back River/Hawk Cove Stations								
MDE-27	11763.2	12025.6	15	12	0.97	1.96	91.57	1.00
MDE-30	435.2	460.8	13	10	2.62	17.65	54.41	2.50
MEANS	**6099.2**	**6243.2**	**14.00**	**11.00**	**1.80**	**9.80**	**72.99**	**1.75**
HISTORIC MEAN, n=29 years								**2.98**
South Cell Exterior Monitoring Stations								
MDE-42	2412.80	2496.00	11	10	2.58	24.14	41.11	3.50
MDE-43	1728.00	1913.60	13	12	2.77	24.07	27.04	3.50
MDE-44	1401.60	1446.40	15	12	2.68	19.18	49.32	3.00
MEANS	**1847.47**	**1952.00**	**13.00**	**11.33**	**2.68**	**22.46**	**39.16**	**3.33**
HISTORIC MEAN, n=7 years								**3.76**

In April 2011, the greatest taxa richness (20 taxa) occurred at Nearfield station MDE-07 (Table 2-9). The lowest taxa richness (5 taxa) from spring 2011 sampling was recorded at Nearfield station MDE-33. Overall, average taxa richness did not vary greatly between station types. The average taxa richness was highest at Nearfield stations (13.58 taxa), followed by Back River/Hawk Cove Stations (13.50 taxa), Reference stations (11.80 taxa), and South Cell Exterior Monitoring stations (11.67 taxa).

Table 2-9. Summary of metrics for each HMI benthic station surveyed during the Year 29 April 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 (%)
Nearfield Stations							
MDE-01	9830.4	9977.6	15	8	1.09	N/A	5.60
MDE-03	11155.2	11264	15	10	1.92	N/A	2.75
MDE-07	4832	5216	20	11	1.31	N/A	5.30
MDE-09	7520	7571.2	15	11	1.56	N/A	9.53
MDE-11	2784	2796.8	12	11	1.55	N/A	7.36
MDE-15	4921.6	4953.6	13	11	1.67	N/A	6.50
MDE-16	3769.6	3788.8	12	10	1.75	N/A	8.66
MDE-17	3936	3968	12	10	1.64	N/A	8.29
MDE-19	3558.4	3718.4	15	11	2.10	N/A	8.81
MDE-33	11289.6	11289.6	5	5	0.26	N/A	0.00
MDE-34	9510.4	9536	14	10	1.55	N/A	7.13
MDE-45	4505.6	4947.2	15	11	1.86	N/A	12.22
MEANS	**6467.7**	**6585.6**	**13.58**	**9.92**	**1.52**	**N/A**	**6.85**
Reference Stations							
MDE-13	3936.00	3993.60	11	10	1.32	N/A	6.83
MDE-22	4083.20	4364.80	12	10	2.24	N/A	10.19
MDE-36	6048.00	6124.80	16	9	1.95	N/A	4.44
MDE-50	3545.60	3558.40	10	8	0.85	N/A	0.36
MDE-51	4326.40	4403.20	10	8	2.10	N/A	25.89
MEANS	**4387.84**	**4488.96**	**11.80**	**9.00**	**1.69**	**N/A**	**9.54**
Back River/Hawk Cove Stations							
MDE-27	7993.60	8192.00	17	10	1.46	N/A	70.22
MDE-30	2233.60	2284.80	10	12	1.64	N/A	6.02
MEANS	**5113.60**	**5238.40**	**13.5**	**11**	**1.55**	**N/A**	**38.12**
South Cell Exterior Monitoring Stations							
MDE-42	3852.80	4307.20	13	10	2.11	N/A	11.79
MDE-43	4473.60	4505.60	11	9	1.97	N/A	14.74
MDE-44	2707.20	2796.80	11	10	2.31	N/A	19.15
MEANS	**3677.87**	**3869.87**	**11.67**	**9.67**	**2.13**	**N/A**	**15.23**

Since the first benthic survey studies of the Hart-Miller Island area in 1981, a small number of taxa have been dominant. Year 29 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 *M. mitchelli*, the isopod *C. polita*, and the polychaete worms *M. viridis*, *H. filiformis* and *N. succinea.*

Several other taxa were among the most dominant in only one season. In September 2010, the polychaete *S. benedicti* and the amphipod *M. nitida* were within the top ten most dominant taxa, but not in April 2011. Likewise, the bivalve *M. balthica* was among the most dominant in April 2011, but not in September 2010. 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 Table 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 29 late summer sampling, September 2010, stations MDE-1 to MDE-22. Because the mean bottom salinity regime was low mesohaline, 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	6.4	0	6.4	0	19.2	12.8	0	19.2	0
Carinoma tremaphoros	0	0	0	6.4	12.8	12.8	12.8	12.8	6.4	25.6	25.6
Bivalvia	0	0	102.4	19.2	38.4	12.8	19.2	38.4	57.6	51.2	19.2
Macoma sp.	0	12.8	0	0	44.8	51.2	6.4	6.4	0	0	19.2
Macoma balthica	0	0	19.2	12.8	19.2	6.4	12.8	19.2	12.8	128	38.4
Macoma mitchelli	0	12.8	44.8	32	38.4	12.8	70.4	64	6.4	64	25.6
Rangia cuneata	12.8	32	38.4	108.8	32	19.2	32	12.8	12.8	0	19.2
Ischadium recurvum	12.8	0	0	0	0	0	0	0	0	0	0
Mytilopsis leucophaeata	38.4	6.4	0	0	6.4	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	51.2	44.8	89.6	102.4	134.4	166.4	44.8	25.6	44.8	38.4	38.4
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	6.4	96	275.2	12.8	192	51.2	64	96	19.2	70.4	76.8
Streblospio benedicti	1171.2	339.2	179.2	422.4	108.8	108.8	51.2	19.2	108.8	12.8	0
Polydora cornuta	947.2	57.6	19.2	25.6	51.2	12.8	0	0	89.6	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereididae	2752	44.8	19.2	249.6	262.4	140.8	6.4	0	179.2	0	6.4
Neanthes succinea	742.4	294.4	70.4	224	108.8	160	6.4	6.4	294.4	0	0
Eteone heteropoda	25.6	25.6	6.4	38.4	51.2	0	12.8	0	12.8	0	0
Naididae sp.	531.2	352	480	1241.6	576	684.8	217.6	230.4	288	1657.6	76.8
Amphipoda	0	0	6.4	0	51.2	25.6	134.4	32	38.4	19.2	0
Gammaridea	0	0	0	0	0	0	0	44.8	6.4	0	38.4

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	6.4	0	0	0	0	0	0	0	0	6.4	0
Leptocheirus plumulosus	6.4	19.2	211.2	64	76.8	96	672	422.4	166.4	416	185.6
Gammarus sp.	32	0	0	0	0	0	0	0	0	6.4	0
Melitidae	89.6	0	0	0	0	0	0	12.8	0	0	0
Melita nitida	716.8	19.2	12.8	19.2	51.2	51.2	115.2	25.6	19.2	57.6	19.2
Corophiidae	44.8	25.6	6.4	12.8	0	0	0	0	0	0	0
Apocorophium lacustre	934.4	870.4	44.8	96	83.2	12.8	0	0	51.2	0	6.4
Cyathura polita	6.4	160	134.4	160	288	256	128	108.8	96	236.8	96
Edotia triloba	0	0	0	6.4	0	0	0	0	0	0	0
Chiridotea almyra	0	0	0	6.4	0	0	0	0	0	0	0
Cirripedia	0	0	0	0	0	0	0	0	0	0	0
Balanus improvisus	153.6	0	6.4	12.8	0	44.8	0	0	6.4	0	0
Balanus subalbidus	0	0	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	230.4	25.6	12.8	51.2	19.2	25.6	0	6.4	6.4	0	0
Membranipora sp	+	+	+	+	+	+	+	+	+	+	+
Chironomidae	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	0	0	0	0	6.4	6.4	0	12.8	0
Chironomus sp.	0	0	0	0	0	0	0	0	0	0	0
Victorella pavida	0	0	0	0	0	0	0	0	0	0	0
Gammaridae	89.6	0	0	0	0	0	0	0	0	38.4	0
Copepoda	0	0	0	0	0	0	0	0	0	0	0
Gobiosoma bosc	25.6	6.4	0	0	0	6.4	0	0	0	0	0
Mysidacea	0	0	0	0	0	0	6.4	0	0	0	0
Cassidinidea ovalis	294.4	0	0	0	0	0	0	0	0	0	0
Argulus sp.	0	0	0	0	0	0	0	0	0	0	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
Palaemonetes sp.	0	0	0	0	0	0	0	0	0	0	0
Simulium sp.	0	0	0	0	0	0	0	0	0	0	0
Apocorophium sp.	0	0	0	0	0	0	0	0	44.8	0	0
Platyhelminthes	0	6.4	0	0	0	0	0	0	0	0	0
Tanytarsini sp.	6.4	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 29 late summer sampling, September 2010, stations MDE-27 to MDE-51. Because the mean bottom salinity regime was low mesohaline, 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	550.4	211.2	134.4	12.8	134.4	0	0	19.2	6.4	0	6.4
Carinoma tremaphoros	19.2	6.4	0	0	12.8	25.6	44.8	19.2	6.4	6.4	83.2
Bivalvia	160	12.8	230.4	268.8	6.4	32	96	19.2	19.2	134.4	51.2
Macoma sp.	44.8	0	172.8	51.2	0	6.4	6.4	0	0	76.8	25.6
Macoma balthica	76.8	0	0	6.4	6.4	198.4	51.2	19.2	51.2	25.6	96
Macoma mitchelli	294.4	0	140.8	19.2	25.6	134.4	108.8	38.4	32	12.8	102.4
Rangia cuneata	12.8	32	19.2	19.2	57.6	6.4	25.6	6.4	19.2	19.2	38.4
Ischadium recurvum	0	0	0	0	0	0	0	0	0	0	0
Mytilopsis leucophaeata	0	0	0	0	0	0	0	6.4	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	102.4	0	0	0	12.8	121.6	57.6	51.2	19.2	32	160
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	51.2	12.8	19.2	12.8	192	128	166.4	57.6	96	32	25.6
Streblospio benedicti	460.8	172.8	198.4	70.4	160	19.2	32	57.6	25.6	44.8	51.2
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
Nereididae	32	6.4	64	6.4	51.2	0	0	12.8	0	6.4	0
Neanthes succinea	38.4	0	19.2	38.4	12.8	0	6.4	70.4	0	6.4	12.8
Eteone heteropoda	128	6.4	51.2	25.6	19.2	0	6.4	6.4	0	6.4	12.8
Naididae sp.	10176	51.2	6.4	44.8	339.2	972.8	428.8	627.2	1676.8	6.4	588.8
Amphipoda	6.4	0	0	25.6	25.6	19.2	38.4	44.8	19.2	0	25.6
Gammaridea	0	19.2	0	0	0	25.6	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	12.8	0	0	0	0	0	0	0
Leptocheirus plumulosus	275.2	89.6	12.8	147.2	147.2	512	588.8	204.8	243.2	64	256
Gammarus sp.	0	0	0	0	0	0	0	0	0	0	0
Melitidae	0	0	0	0	0	0	0	0	0	0	0
Melita nitida	51.2	0	0	12.8	0	44.8	83.2	19.2	32	0	19.2
Corophiidae	0	6.4	0	0	0	0	0	0	0	0	0
Apocorophium lacustre	0	0	19.2	0	0	0	0	0	0	0	0
Cyathura polita	89.6	32	32	12.8	64	249.6	172.8	185.6	115.2	6.4	198.4
Edotia triloba	0	6.4	0	0	6.4	0	0	0	0	0	6.4
Chiridotea almyra	0	0	0	12.8	0	0	0	0	0	0	0
Cirripedia	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	0	0	0	0	0	0	0	0
Membranipora sp	0	0	+	0	+	0	+	+	+	0	+
Chironomidae	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	6.4	6.4	0	0	0	0	0	0	0	0	0
Chironomus sp.	0	0	0	0	0	0	0	0	0	0	0
Victorella pavida	0	0	32	0	0	0	0	0	0	0	0
Gammaridae	0	0	0	0	0	0	0	0	0	0	0
Copepoda	0	0	0	0	0	0	0	0	0	0	0
Gobiosoma bosc	0	0	0	0	0	0	0	0	0	0	0
Mysidacea	0	0	0	0	0	0	0	0	0	0	0
Cassidinidea ovalis	0	0	0	0	0	0	0	0	0	0	0
Argulus sp.	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-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Palaemonetes sp.	0	0	0	0	0	0	0	0	6.4	0	0
Simulium sp.	0	0	0	0	6.4	0	0	0	0	0	0
Apocorophium sp.	0	0	0	0	0	0	0	0	0	0	0
Platyhelminthes	0	0	0	0	0	0	0	0	0	0	0
Tanytarsini sp.	0	0	0	0	0	0	0	0	0	0	0

Table 2-12. Average number of individuals collected per square meter at each station during the HMI Year 29 spring sampling, April 2011, stations MDE-1 to MDE-22. Because the mean bottom salinity regime was tidal fresh, 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	0	0	6.4	0	0	0	32	0	0	0
Carinoma tremaphoros	0	0	6.4	6.4	6.4	0	6.4	6.4	0	25.6	38.4
Bivalvia	0	0	12.8	0	6.4	0	0	0	6.4	0	19.2
Macoma sp.	0	0	6.4	6.4	0	0	0	0	0	38.4	185.6
Macoma balthica	0	0	6.4	19.2	12.8	6.4	25.6	6.4	6.4	76.8	243.2
Macoma mitchelli	0	0	0	12.8	12.8	0	38.4	70.4	6.4	64	89.6
Rangia cuneata	12.8	19.2	12.8	51.2	6.4	6.4	12.8	0	12.8	6.4	0
Ischadium recurvum	0	6.4	0	0	0	0	0	0	0	0	0
Mytilopsis leucophaeata	0	0	0	0	0	0	0	0	0	0	0
Capitellidae	0	0	6.4	0	0	51.2	0	0	0	0	44.8
Heteromastus filiformis	12.8	12.8	6.4	19.2	32	6.4	51.2	19.2	70.4	76.8	134.4
Spionidae	0	6.4	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	7910.4	6470.4	3808	5465.6	1984	2886.4	3193.6	1856	2668.8	1606.4	2060.8
Streblospio benedicti	0	0	0	0	0	0	0	0	0	0	0
Polydora cornuta	0	0	0	0	0	6.4	0	0	0	0	0
Boccardiella ligerica	0	6.4	0	0	0	0	0	0	0	0	0
Nereididae	38.4	70.4	57.6	153.6	12.8	0	0	0	0	0	0
Neanthes succinea	192	121.6	12.8	281.6	38.4	19.2	57.6	12.8	57.6	25.6	12.8
Naididae sp.	550.4	307.2	256	716.8	204.8	268.8	320	326.4	326.4	313.6	416
Amphipoda	0	140.8	12.8	51.2	12.8	12.8	19.2	25.6	44.8	19.2	12.8
Gammaridea	19.2	0	0	0	0	0	0	0	0	0	0
Ameroculodes spp. complex	0	0	0	0	0	0	0	0	0	0	0
Leptocheirus plumulosus	96	409.6	332.8	531.2	339.2	576	979.2	1350.4	576	1190.4	838.4

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
Gammaridae	0	0	0	0	0	0	0	0	0	0	0
Gammarus sp	0	19.2	0	0	0	0	0	0	0	0	0
Melitidae	0	0	0	0	0	0	0	0	0	0	0
Melita nitida	32	0	6.4	6.4	0	0	0	19.2	19.2	70.4	25.6
Corophiidae	6.4	6.4	0	6.4	0	0	6.4	0	0	0	6.4
Apocorophium sp.	0	1100.8	89.6	0	0	0	0	0	0	0	0
Apocorophium lacustre	966.4	2304	166.4	51.2	6.4	19.2	70.4	25.6	76.8	83.2	57.6
Cyathura polita	25.6	160	57.6	153.6	115.2	128	140.8	70.4	89.6	70.4	172.8
Edotea triloba	6.4	0	0	12.8	0	0	6.4	0	6.4	0	0
Chiridotea almyra	0	0	0	0	0	0	0	0	0	38.4	0
Balanus improvisus	0	6.4	6.4	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	64	0	12.8	25.6	0	0	0	0	0	6.4	0
Membranipora sp	+	+	+	+	+	+	+	+	+	+	0
Chironomidae	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	0	0	0	0	0	0	0	0	0
Orthocladiinae	0	0	0	0	0	0	0	0	0	0	0
Cricotopus sp.	12.8	0	0	0	0	0	0	0	0	0	0
Cryptochironomus sp.	0	0	0	0	0	0	0	0	0	0	0
Rheotanytarsus sp.	6.4	0	0	0	0	0	0	0	0	0	0
Copepoda	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

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
Platyhelminthes sp.	0	76.8	179.2	0	6.4	0	25.6	0	0	6.4	6.4
Mya arenaria	0	0	6.4	0	0	0	0	0	0	0	0
Eteone heteropoda	0	0	0	0	0	0	0	0	0	0	0
Cassidinidea ovalis	12.8	0	6.4	0	0	0	0	0	0	0	0
Hydrozoa	0	0	128	0	0	0	0	0	0	0	0
Odonata	0	6.4	0	0	0	0	0	0	0	0	0
Callinectes sapidus	6.4	0	6.4	0	0	0	0	0	0	0	0
Piscicola sp.	0	0	0	0	0	0	0	0	0	0	0
Gobiosoma bosci	0	0	0	0	0	0	0	0	0	0	0
Orthocladius	0	0	6.4	0	0	0	0	0	0	0	0
Isopoda	6.4	0	0	0	0	0	0	0	0	0	0
Chironomini	0	6.4	0	0	0	0	0	0	0	0	0
Dicrotendipes sp.	0	0	6.4	0	0	0	0	0	0	0	0
Chaoborus sp.	0	0	0	0	0	6.4	0	0	0	0	0
Parachironomus	0	0	0	0	0	0	0	0	0	0	0
Chironomidae pupa	0	6.4	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 29 spring sampling, April 2011, stations MDE-27 to MDE-51. Because the mean bottom salinity regime was tidal fresh, 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	96	51.2	0	6.4	89.6	6.4	6.4	0	32	0	0
Carinoma tremaphoros	6.4	0	0	6.4	0	19.2	0	19.2	6.4	0	12.8
Bivalvia	0	0	0	0	0	134.4	6.4	38.4	102.4	0	0
Macoma sp.	51.2	0	0	0	0	160	0	32	160	0	0
Macoma balthica	64	0	0	0	0	51.2	0	179.2	12.8	0	121.6
Macoma mitchelli	211.2	0	0	0	12.8	32	19.2	64	83.2	6.4	0
Rangia cuneata	12.8	0	0	6.4	76.8	0	25.6	0	32	0	0
Ischadium recurvum	0	0	0	0	0	0	0	0	0	0	0
Mytilopsis leucophaeata	0	0	0	0	0	0	0	0	0	0	0
Capitellidae	6.4	0	0	0	0	19.2	0	0	0	0	38.4
Heteromastus filiformis	160	0	0	6.4	0	38.4	166.4	6.4	6.4	12.8	179.2
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	1452.8	768	10899.2	6592	3168	1817.6	2489.6	409.6	2579.2	2905.6	1990.4
Streblospio benedicti	0	0	0	0	0	0	0	0	0	0	0
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
Nereididae	0	0	0	0	0	0	0	0	0	0	0
Neanthes succinea	83.2	0	6.4	121.6	38.4	6.4	64	12.8	19.2	0	32
Naididae sp.	5612.8	134.4	0	678.4	268.8	454.4	659.2	518.4	550.4	12.8	1120
Amphipoda	12.8	115.2	0	12.8	70.4	64	96	51.2	57.6	0	44.8
Gammaridea	0	0	0	0	0	0	0	0	0	0	0
Ameroculodes spp. complex	0	0	0	6.4	0	0	0	0	0	0	0
Leptocheirus plumulosus	320	1164.8	268.8	512	1017.6	1075.2	800	1267.2	979.2	544	652.8

Table 2-13 – (continued)

Taxon	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
	Station										
Gammaridae	0	0	0	0	0	0	0	0	0	0	0
Gammarus sp	6.4	12.8	12.8	0	19.2	0	0	0	0	0	0
Melitidae	0	0	0	0	0	0	0	0	0	0	0
Melita nitida	44.8	6.4	0	0	12.8	57.6	25.6	19.2	12.8	6.4	0
Corophiidae	0	0	0	12.8	32	0	0	0	0	0	0
Apocorophium sp.	0	0	0	1331.2	0	0	0	0	0	0	0
Apocorophium lacustre	6.4	32	102.4	121.6	1280	140.8	32	96	83.2	44.8	0
Cyathura polita	44.8	6.4	0	102.4	64	153.6	121.6	83.2	96	6.4	172.8
Edotia triloba	0	0	0	6.4	0	0	0	0	0	6.4	0
Chiridotea almyra	0	0	0	0	0	0	0	0	0	0	0
Balanus improvisus	0	0	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	0	0	0	12.8	0	0	0	0	0	0	0
Membranipora sp	0	+	+	+	+	0	+	+	+	0	+
Chironomidae	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	6.4	0	0	6.4	0	0	0	0	0	0
Orthocladiinae	0	0	0	0	0	0	0	0	0	0	0
Cricotopus sp.	6.4	0	0	0	0	0	0	0	0	0	0
Cryptochironomus sp.	0	0	0	0	0	0	0	0	0	0	0
Rheotanytarsus sp.	0	0	0	0	0	0	0	0	0	0	0
Copepoda	0	0	0	0	+	0	0	0	+	+	+
Ostracoda	51.2	38.4	0	0	6.4	0	0	0	25.6	0	0
Mysidacea	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	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
	Station										
Platyhelminthes sp.	38.4	0	0	6.4	38.4	83.2	0	0	140.8	0	32
Mya arenaria	0	0	0	0	0	0	0	0	0	12.8	0
Eteone heteropoda	0	0	0	0	0	0	0	0	0	0	0
Cassidinidea ovalis	0	0	0	0	0	0	0	0	0	0	0
Hydrozoa	0	0	0	0	0	0	0	0	0	0	0
Odonata	0	0	0	0	0	0	0	0	0	0	6.4
Callinectes sapidus	0	0	0	0	0	0	0	0	0	0	0
Piscicola sp.	0	0	0	0	0	0	0	0	0	0	0
Gobiosoma bosc	0	0	0	0	0	0	0	0	0	0	0
Orthocladius	0	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0
Chironomini sp.	0	0	0	0	0	0	0	0	0	0	0
Dicrotendipes sp.	0	0	0	0	0	0	0	0	0	0	0
Chaoborus sp.	0	0	0	0	0	0	0	0	0	0	0
Parachironomus sp.	0	0	0	0	6.4	0	0	0	0	0	0
Chironomidae pupa	0	0	0	0	6.4	0	0	0	0	0	0

Infaunal Taxa Abundance

Average total infaunal abundance was lower in the fall (September 2010) than in the spring (April 2011) (Figure 2-2), which is primarily a result of a greater number of organisms in the spring due to recruitment. This has occurred in each of the past 13 years (excluding Year 23, which had an unusually large winter die-off of *R. cuneata*). In September 2010, total infaunal abundance ranged from 268.8 to 11,763.2 organisms per square meter (individuals/m^2) and averaged 2,259.8 individuals/m^2 (Table 2-8). The highest September 2010 abundance was found at the Back River/Hawk Cove station MDE-27, due primarily to large numbers of Naididae worms, *S. benedicti*, *M. mitchelli* and *L. plumulosus*. The lowest infaunal abundance in September 2010 was found at the Back River/Hawk Cove station MDE-30 (Table 2-8). The average total infaunal abundance was highest at Back River/Hawk Cove stations (6,099.2 individuals/m^2) followed by Nearfield stations (2,210.67 individuals/m^2), South Cell Exterior Monitoring stations (1,847.47 individuals/m^2), and Reference stations (1,089.28 individuals/m^2) in September. No trend of increasing/decreasing abundances associated with distance from HMI could be discerned. The 29-year mean (4,815.66 individuals/m^2) of fall abundance for the Back River stations is much higher than the Reference (1,927.74 individuals/m^2) and Nearfield (2,188.06 individuals/m^2) means. Mean abundance in the South Cell stations has a seven-year average of 1,265.07 individuals/m^2.

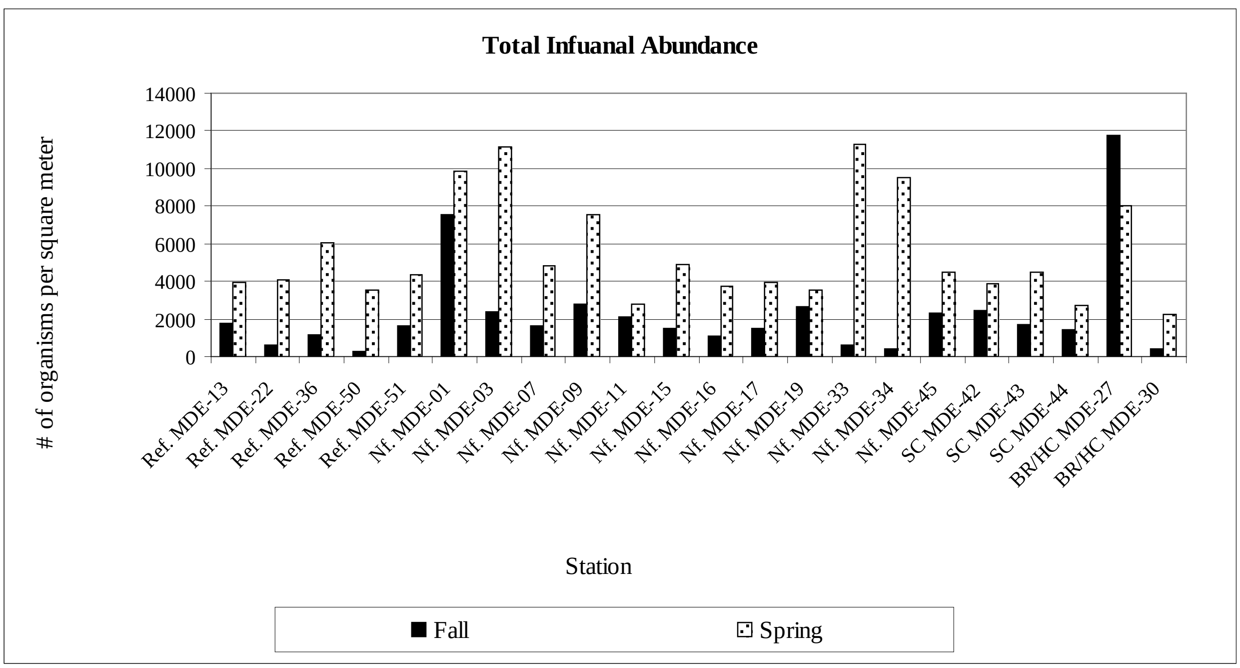


Figure 2-2. Total abundance of infaunal taxa collected at each HMI station in Year 29, September 2010 and April 2011 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

In April 2011, total infaunal abundance ranged from 2,233.60 to11,289.6 individuals/m^2 and averaged 5,491.49 individuals/m^2. The station with the highest abundance was the Nearfield station MDE-33, due primarily to a large number of *M. viridis*. The lowest spring abundance occurred at the Back River/Hawk Cove station MDE-30 (Table 2-9). This was due to depressed abundances of many common species (Table 2-9, 2-12). The average total infaunal abundance was lowest at South Cell Exterior Monitoring stations (3,677.87 individuals/m^2) followed by Reference stations (4,387.84 individuals/m2), Back River/Hawk Cove stations (5,113.60 individuals/m2), and highest at Nearfield stations (6,467.70 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 highly variable and often intense spring recruitment, spring benthic data yields variability that does not lend itself to historic analyses and is an unreliable indicator of community health

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 29, total infaunal abundance was similar to total abundance, 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 29 are presented in Table 2-8 and 2-9. In Year 29, SWDI was calculated for the spring, however, because of the above reasons SWDI is not scored in the spring

SWDI values in Year 29 averaged 2.71± 0.57 in September 2010. The fall average diversity of 2.71 was slightly higher than the 13-year mean fall diversity of 2.29. The lowest diversity value in September 2010 occurred at Back River/Hawk Cove station MDE-27 (0.97, Figure 2-3). This was due to the large percentage of Naididae worms, which accounted for 86.5 percent of total infaunal abundance at this station. The highest September 2010 diversity value (3.40) occurred at Nearfield station MDE-17.

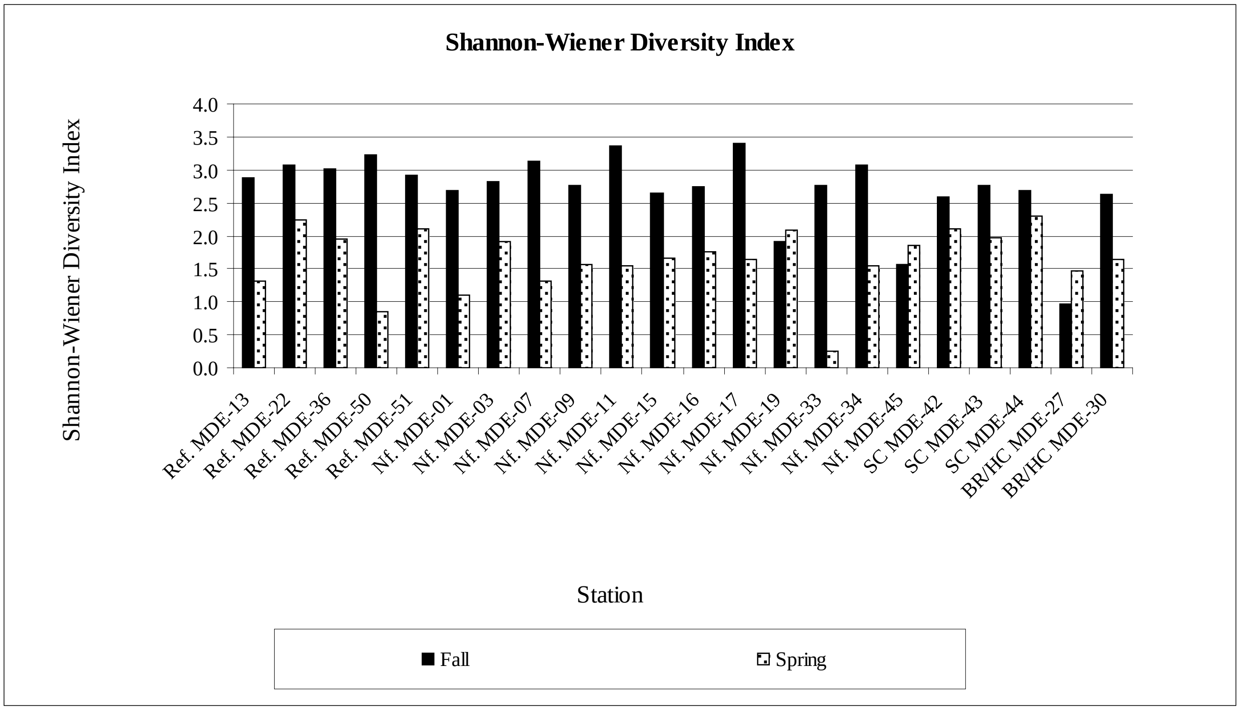


Figure 2-3. Shannon-Wiener Diversity Index (SWDI), HMI Year 29, September 2010 and April 2011 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell; BR/HC = Back River Hawk Cove).

On average, Nearfield stations had diversity values similar to Reference stations in September 2010. Comparing station types from the fall only, the lowest average SWDI was 1.80 at the Back River/Hawk Cove stations followed by the South Cell Exterior Monitoring stations at 2.68, and Nearfield stations at 2.74. The highest average SWDI occurred at the Reference stations at 3.02 (Table 2-8). Historically, the 23-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 (2.56, n=7 yrs). No trend of increasing/decreasing diversity associated with distance from HMI could be discerned.

Pollution Sensitive Taxa Abundance (PSTA)

Four taxa found during the September 2010 sampling cruise were designated as "pollution-sensitive" according to Alden et al. (2002). These were the polychaete worm *M. viridis,* the bivalves *R. cuneata* and *M. balthica,* and the isopod crustacean *C. polita.* In this monitoring year, PSTA values could only be calculated for the fall sampling because PSTA is not a B-IBI metric included for the Tidal Fresh salinity regime according to Alden et al. (2002). When salinity regime is changed the list of candidate species used to calculate this metric also changes. Since PSTA is not a B-IBI metric under tidal fresh conditions, there is no list for pollution sensitive species when these conditions occur. 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 prior to some historical analyses of PSTA fall data. In Year 29, the fall salinity regime was low mesohaline, as it was in Years 28, 27, and 26.

In Year 29, pollution sensitive taxa occurred at all station types. In September, PSTA ranged from 0.34 percent at MDE-01 (Nearfield station) to 36.36 percent at MDE-22 (Reference station -Table 2-8; Figure 2-4). The average PSTA for all stations in September 2010 was 18.16 percent. Comparing station types, the lowest average PSTA was 9.80 percent at the Back River/Hawk Cove stations, followed by the Nearfield stations at 14.69 percent, followed by the South Cell Exterior Monitoring stations at 22.46 percent. The highest average PSTA was 27.25 percent at Reference stations. Historically, the 29-year mean fall PSTA values, ranked from lowest to highest, are associated with the following station types: South Cell Exterior Monitoring (30.76 percent, n=6 years), Back River/Hawk Cove (31.15 percent), Nearfield (39.29 percent), and Reference (42.90 percent).

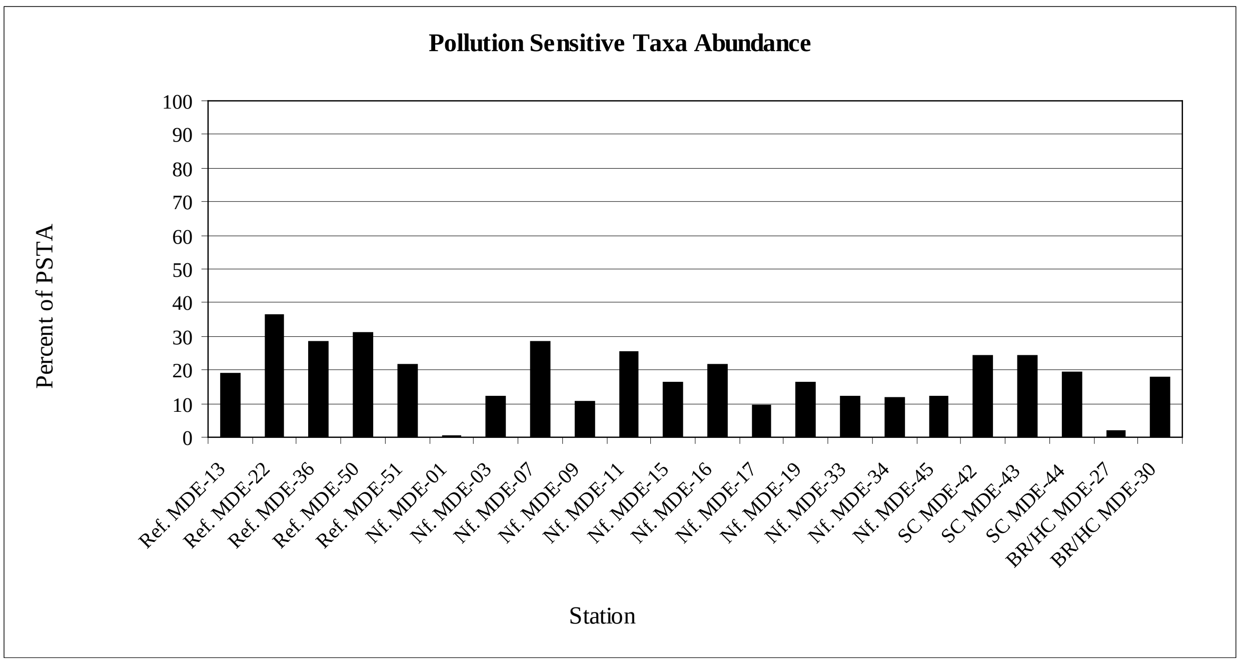


Figure 2-4. Percent abundance comprised of pollution sensitive species (PSTA), HMI Year 29 September 2010 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

Pollution Indicative Taxa Abundance (PITA)

Four taxa found during the September 2010 sampling of Year 29 benthic monitoring were designated as "pollution-indicative" according to Alden et al. (2002): the Chironomid *Coelotanypus sp.*, the polychaete worms *S. benedicti* and *E. heteropoda,* and oligochaete worms of the family Naididae. One taxa found during the April 2011 sampling cruise were designated as "pollution-indicative" according to Alden et al. (2002). This was the oligochaete worm of the family Naididae. This difference in number of taxa found is due to the seasonal change from low mesohaline to tidal fresh salinity regime between the sampling seasons. When regime is changed the list of candidate species used to calculate this metric also changes. Therefore the difference is more of a change in accounting procedures than a change in community structure. The calculation of the PITA is a ratio of the relative PITA abundance to total infaunal abundance.

In Year 29, pollution indicative taxa occurred at all station types, excluding Nearfield station MDE-33 during the April 2011 sampling. In September, the PITA ranged from 12.12 percent at MDE-22 (Reference station) to 91.57 percent at MDE-27 (Back River/Hawk Cove station) (Table 2-8; Figure 2-5). The average PITA for all stations in September 2010 was 40.91 percent. Comparing station types, the lowest average PITA was 32.81 percent at the Reference stations, followed by 39.16 percent at the South Cell Exterior Monitoring stations, and 39.38 percent at Nearfield stations. The highest average PITA occurred at the Back River/Hawk Cove stations at 72.99 percent. Historically, the 29-year mean fall PITA values, ranked lowest to highest, are associated with the following station types: Reference (21.95 percent), Nearfield (23.16 percent), Back River/Hawk Cove (37.00 percent), and South Cell Exterior Monitoring (39.09 percent, n = 7 years).

In April 2011, the lowest PITA was 0.00 percent at MDE-33 (Nearfield station) and the highest was 70.22 percent at MDE-27 (Back River/Hawk Cove station -Table 2-9; Figure 2-5). The average PITA for all stations in April was 11.44 percent. Nearfield stations had the lowest average PITA at 6.85 percent, followed by the Reference stations at 9.54 percent, and the South Cell Exterior Monitoring stations at 15.23; the Back River/Hawk Cove had the highest average PITA of 38.12 percent.

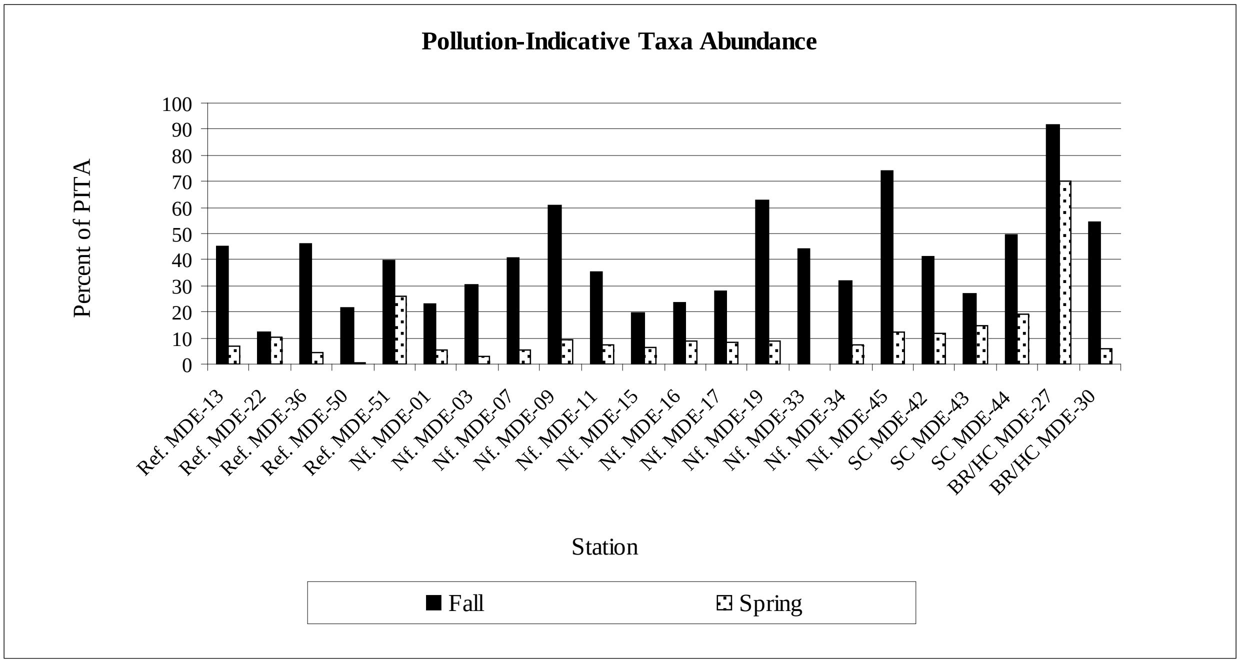


Figure 2-5. Percent abundance comprised of pollution indicative species (PITA), HMI Year 29 September 2010 and April 2011 grouped by station type (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

Benthic Index of Biotic Integrity

The B-IBI was calculated for all stations based on September 2010 data only (see *Methods and Materials*). Four metrics were used to calculate the B-IBI for stations under the low mesohaline classification (5.0 -12 ppt). These metrics were total infaunal abundance, relative abundance of pollution-indicative taxa, relative abundance of pollution-sensitive taxa, and SWDI. The specific scoring criteria for the low mesohaline metrics are presented in Table 2-14. 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 29 were compared to this benchmark.

Table 2-14. Low mesohaline scoring criteria for measures used in calculating the Chesapeake Bay B-IBI in September 2010 (Weisberg et al. 1997).

Measure	Score		
	5	**3**	**1**
Total Abundance (individuals per square meter)	≥ 1500-2500	500-1500 **or >** 2500-6000	< 500 **or** ≥ 6000
% Pollution-indicative Taxa	≤ 10%	10-20%	> 20%
% Pollution-sensitive Taxa	≥25%	5-25%	<5%
Shannon-Wiener Diversity Index	≥2.5	1.7-2.5	<1.7

The vast majority of the individual station B-IBI scores for Year 29 decreased or stayed the same when compared to Year 28. Scores decreased at 14 stations, remained the same at 4, and increased at 4 stations. Sixteen of the twenty-two stations met or exceeded the benchmark criteria of 3.0 in Year 29. In Year 29, Back River/Hawk Cove stations MDE-27 (1.00) and MDE-30 (2.50), Nearfield Stations MDE-01 (2.00), MDE-19 (2.50), MDE-34 (2.50), and MDE-45 (2.50) failed to meet the benchmark criteria of 3.0 (Table 2-8, Figure 2-6). Eighteen stations were below their historic averages and four stations (two Nearfield, one South Cell Exterior Monitoring, and one Reference) were above their historic averages for B-IBI. In addition to eighteen stations being below their historic average three tied historic lows (Nearfield stations MDE-01 and MDE-34, and Back River/Hawk Cove station MDE-27). One station (Nearfield station MDE-45) set a new historic low; however this is only the third year this station has been sampled.

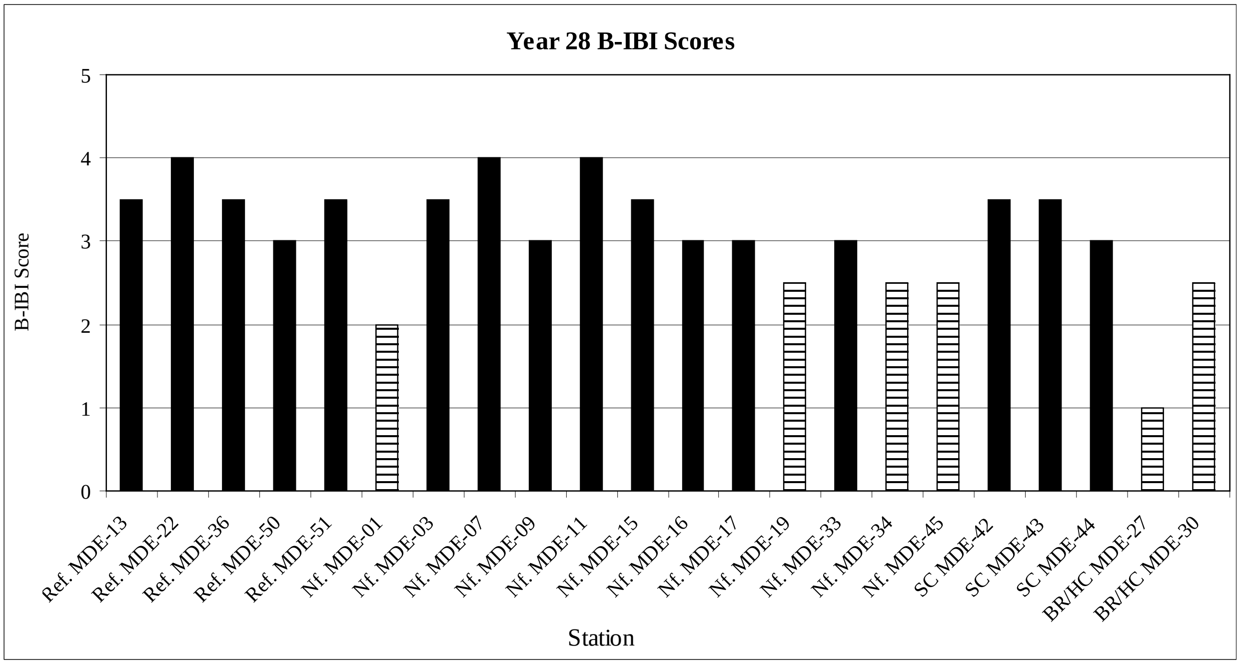


Figure 2-6. B-IBI Scores for all stations in September 2010 grouped by station type (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

The mean B-IBI for Nearfield, Reference, and South Cell Exterior Monitoring stations met or exceeded the benchmark of 3.0. The mean B-IBI for Back River/Hawk Cove stations failed to meet the benchmark of 3.0. Average B-IBI scores by station type are shown in Figure 2-7. Compared to Year 28, the mean B-IBI decreased for all station types. The Year 29 mean B-IBI's for all station types were also below their historic averages (seven year average for South Cell Exterior Monitoring Stations, Table 2-8).

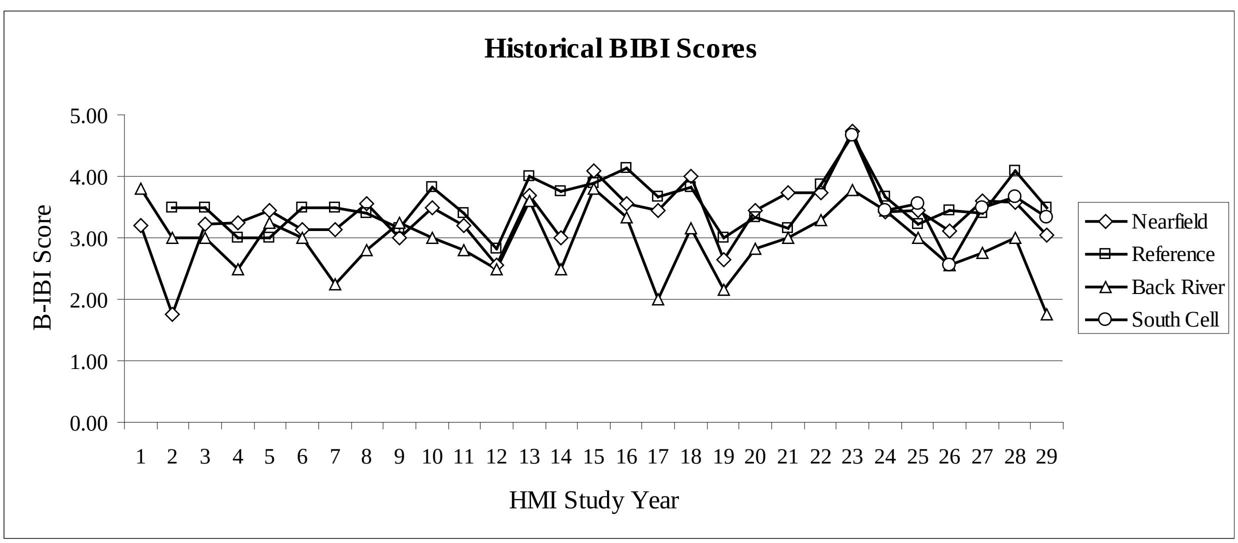


Figure 2-7. Average B-IBI Scores at HMI for Monitoring Years 1-29.

There was no trend of increasing or decreasing B-IBI scores associated with proximity to HMI in Year 29. In some years a slight trend is apparent but there is no consistent association. Back River/Hawk Cove stations have the strongest tendency; they tend to have the lowest average B-IBI. Back River/Hawk Cove stations had the lowest mean in Year 29 and have had the lowest average 24 of 29 years.

Clam Length Frequency Distribution

In September 2010, 90 *R. cuneata* were collected. The greatest average abundance of *R. cuneata* occurred at the Reference stations (4.80 clams/station), followed by the Nearfield stations (4.42 clams/station), the Back River/Hawk Cove stations (3.50 clams/station), and the South Cell Exterior Monitoring stations (2.00 clams/station). The greatest abundance of *R. cuneata* during the fall was found in the 6-10 and 31-35 mm size classes. In April 2010, 46 *R. cuneata* were collected. The greatest average abundance for this species occurred at the Reference stations (2.60 clams/station), followed by the Nearfield and South Cell Exterior Monitoring stations (2.25 and 1.33 clams/station respectively), and the Back River/Hawk Cove stations (1.00 clam/station). The greatest abundance of *R. cuneata* during the spring was found in the 36-40 mm size classes.

Historically, *R. cuneata* tends to be the most abundant bivalve mollusk found in this benthic monitoring project. However, *M. balthica* and *M. mitchelli* outnumbered it in both seasons in Year 29. This change in dominance is associated with an increase in *M. balthica* and *M. mitchelli* abundance and a decrease in *R. cuneata* abundance. It is classified as pollution sensitive during higher salinity years ($\geq$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. In Maryland, *R. cuneata* rarely if ever reaches its reported maximum age (15-20 years) or size (79 mm). Looking at 13 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 2010, 125 *M. balthica* were collected, with 44 coming from Nearfield stations, 42 from South Cell Exterior Monitoring stations, 27 from Reference stations, and 12 coming from Back River/Hawk Cove stations. The greatest abundance of *M. balthica* during the fall was found in the 9-12 and 17-20 mm size classes. In April 2011, 130 *M. balthica* were collected with 58 coming from Reference stations, 36 from South Cell Exterior Monitoring stations, 26 from Nearfield stations, and 10 from Back River/Hawk Cove stations. The greatest abundance of *M. balthica* during the spring was found in the 1-4 mm size class.

M. balthica has been common and found in low to moderate abundance throughout this benthic monitoring project. It is classified as pollution sensitive during higher salinity years ($\geq$ 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. Looking at 13 years of historical HMI frequency distribution data, the strong freshet in Year 23 appears to have caused high mortality in this species; however, it appears to have recovered to previous densities.

In September 2010, 200 *M. mitchelli* were collected, with 82 coming from Nearfield stations, 46 from Back River/Hawk Cove stations, 44 from South Cell Exterior Monitoring stations, and 28 from Reference stations. There was no dominant size class during the fall. In April, 113 *M. mitchelli* were collected with 45 coming from Nearfield stations, 33 from Back River/Hawk Cove stations, 18 from South Cell Exterior Monitoring stations, and 17 from Reference stations. The greatest abundance of *M. mitchelli* during the spring was found in the 9-12 mm size class. Similar to *M. balthica, M. mitchelli* populations declined in the spring of Year 22 and remained depressed for several years. *M. mitchelli* is generally not as dominant as *M. balthica*, however in Year 29, it was the most dominant bivalve. For the last several years, numbers of *M. mitchelli* have been steadily increasing since the die-off in Years 22-23.

MULTIVARIATE AND FRIEDMAN'S ANALYSES

Multivariate Analysis

Multivariate cluster analyses were applied again for Year 29. Multivariate methods are used to make sense of large, complex data sets that consist of numerous variables (the different macroinvertebrate taxa) measured on multiple experimental units (the HMI stations). In general, the purpose of multivariate methods is to simplify the complex data and identify patterns (Johnson, 1998a). The cluster procedure summarizes and classifies the HMI station data by identifying unique groups of stations with similar benthic invertebrate assemblages. The objective is to determine if there are adverse impacts to the surrounding benthic fauna from HMI discharge operations. HMI operations could impact benthic invertebrate assemblages by altering habitat conditions. Habitat conditions are important determinants of faunal community composition.

In this year's report, the clustering method employed was the hierarchical tree figure or dendrogram. In the Year 27 and Year 28 reports three other multivariate methods were utilized to validate the interpretation of the dendrogram – the Hotelling's pseudo T^2 statistic [PST2], the Andrews' plot, and the three-dimensional Principal Components plot. However, for the current year the interpretation of the dendrogram was straightforward and unambiguous to an extent that input from the other procedures was deemed unnecessary.

Clustering analysis was applied to the September 2010 data, but not to the April 2011 data. Cluster analysis of April data has consistently yielded weak results that were difficult to interpret. This was likely due to reproduction/recruitment and the associated unstable benthic macroinvertebrate population dynamics that occur during the spring. Limiting the multivariate analysis to the September data was established with the Year 28 report.

The multivariate clustering procedure has been conducted twenty-four times since Year 12. The formation of identifiable groups has been highly variable, but a number of station pairings have consistently reappeared. The most frequent station pairings that are found in identified cluster groups are: MDE-17 with MDE-30, MDE-19 with MDE-30, MDE-30 with MDE-44, MDE-03 with MDE-09, MDE-13 with MDE-17 and MDE-19 with MDE-22. Three stations have consistently been identified as outliers: MDE-27 (fifteen times since Year 19), MDE-01 (eight times since Year 19) and MDE-51 (three times since Year 27).

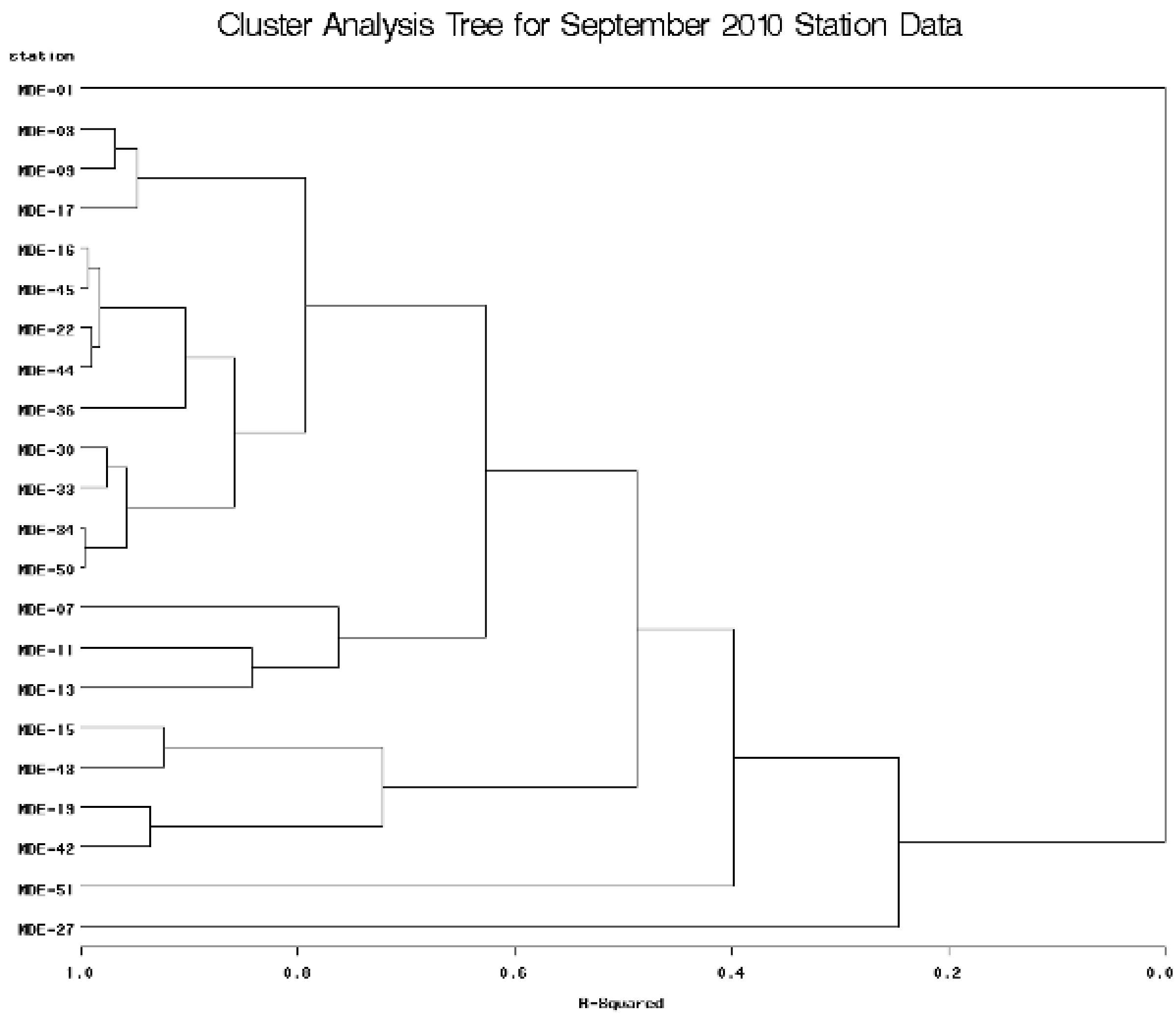


Figure 2-8. September 2010 Cluster Analysis tree.

The cluster tree figure for September 2010 showed a clear articulation of several HMI station groups (Figure 2-8). Using an $R^2 \geq 0.80$ as the threshold for identifying multi-station groups, five multi-station groups (Group 1 to Group 5) and four outlier stations (Outliers 1 to 4) were apparent from examination of the September 2010 tree figure. The stations within a group had similar benthic invertebrate assemblages, while outlier stations were those stations with benthic invertebrate assemblages that were unique enough to exclude them from a multi-station group. Identified station groups were generally poorly correlated to station type except for Group 1, and the four small groups (Group 1, Group 3 – Group 5) demonstrated good spatial proximity effects, with distance between stations in these groups less than the overall average distance between all stations (mean = 3,447 meters).

Group 1, a three station group, was composed of all Nearfield stations: (MDE-03, MDE-09 and MDE-17). Group 1 stations were all located on the eastern side of HMI and exhibited good group spatial proximity. Group 2, the largest identified group, consisted of four Nearfield stations (MDE-16, MDE-33, MDE-34 and MDE-45), three Reference stations (MDE-22, MDE-36 and MDE-50), one Back River station (MDE-30) and one South Cell station (MDE-44). Overall this group did not demonstrate good spatial proximity. Group 2 included three of the four stations that had a predominately sand substrate (MDE-33, MDE-34 and MDE-50)[3]. Reference stations MDE-36 and MDE-50 are the most spatially disparate in Group 2.

Group 3 was the pair of stations MDE-11, a Nearfield station and MDE-13, a Reference station. These stations were located east of HMI and had good group spatial proximity. Group 4 was composed of Nearfield station MDE-15 and South Cell station MDE-43 and this group was also located on the east side of HMI with good group spatial proximity. The final identified multi-station group from the dendrogram, Group 5, was the most spatially compact group identified and was composed of Nearfield station MDE-19 and South Cell station MDE-42.

The identified outlier stations were Nearfield stations MDE-01 and MDE-07, Back River station MDE-27 and Reference station MDE-51. Unlike previous HMI sampling years where MDE-27 was usually identified by the cluster dendrogram figure as being the most unique, in Year 29 it was station MDE-01, followed by MDE-27. In contrast, MDE-07 was the least unique or "weakest" outlier station identified in the figure.

Friedman's Analysis

As in previous HMI annual reports (Years 12 – 15; Years 19 - 28), Friedman's nonparametric ANOVA test was applied to Year 29 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 29 a new fifth station group – the North Cell station group, was added to the four station group types examined in previous reports (Nearfield, Back River, South Cell Exterior Monitoring, and Reference). The North Cell group was created to test for significant impacts from North Cell discharges and included four stations previously identified as Nearfield stations (MDE-01, MDE-03, MDE-07, and MDE-34).

The Year 29 Friedman's nonparametric ANOVA test results (Tables 2-15 and 2-16) indicated that there were significant differences in the ten most abundant infaunal taxa between the five station types in September 2010 ($P < 0.15$) but not in April 2010 ($P < 0.97$). Significant Friedman results in past monitoring years have not occurred often (six times since Year 12) and were usually due to unique macroinvertebrate assemblages at Back River and/or South Cell stations, but high macroinvertebrate abundance variability among stations within station types, usually prevents a significant result.

---

[3] Outlier station MDE-1 was the other station with a predominately sandy substrate, all other stations had a predominately silt/clay substrate.

Table 2-15. Friedman Analysis of Variance for September 2010's 10 most abundant species among: Back River/Hawk Cove, Nearfield, South Cell Exterior Monitoring, North Cell, and Reference stations. ANOVA Chi Sqr. (N = 10, df = 4) = 6.8017 p < 0.14675.

Station Type	Average Rank	Sum of Ranks	Mean	Std. Dev.
Nearfield	3.666667	44.00000	106.2667	185.193
Reference	2.833333	34.00000	63.1467	94.661
Back River	2.458333	29.50000	500.5333	1458.414
South Cell	2.458333	29.50000	101.5111	237.060
North Cell	3.583333	43.00000	186.0000	169.082

Table 2-16. Friedman Analysis of Variance for April 2011's 10 most abundant species among: Back River/Hawk Cove, Nearfield, South Cell Exterior Monitoring Stations, North Cell, and Reference stations. ANOVA Chi Sqr. (N = 10, df = 4) = 0.5688 p < 0.96647.

Station Type	Average rank	Sum of ranks	Mean	Std. Dev
Nearfield	3.000000	36.00000	62.1333	113.2046
Reference	3.125000	37.50000	84.0533	131.6476
Back River	3.166667	38.00000	265.3333	821.8111
South Cell	2.750000	33.00000	61.1556	106.7222
North Cell	2.958333	35.50000	132.4000	270.0957

To pinpoint which type station groups in particular differed from each other for the September 2010 data, a Wilcoxon Signed-Rank post-hoc test was run. Post-hoc analysis with this test requires a Bonferroni correction applied to determine the significance level. This procedure tests the significance between pairs of station groups. The Bonferroni corrected level of significance was $p < 0.025$. Six comparisons were tested for significance: between Reference stations and Nearfield stations, between Reference and South Cell stations, between Reference and North Cell stations, between Nearfield and South Cell stations, between Nearfield and North Cell stations, and between South Cell and North Cell stations. Results indicated a statistically significant difference between Reference and Nearfield stations ($Z = 2.275$, $p = 0.0229$) but not for any of the other comparisons. These results were likely driven by the four Nearfield stations that had impaired benthic communities (as indicated by the B-IBI) in September 2010 (MDE-01, MDE-19, MDE-34 and MDE-45).

CONCLUSIONS

In Year 29, the benthic macroinvertebrate community was examined under slightly unusual conditions for this region of Chesapeake Bay. In September 2010 Bay waters in the vicinity of HMI were low mesohaline (not unusual), while abundant late winter and spring freshwater discharge to the Bay resulted in tidal fresh conditions around HMI in April 2011. The Bay around HMI has been sampled under tidal fresh conditions only two times (Year 23 both seasons). Since the condition occurred in the spring, when B-IBI's are not calculated (and some metrics cannot either be calculated or scored), this occurrence has little impact on conclusions made in this report. For example, the fact that the HMI region was tidal fresh in the spring of Year 29 did not appear to produce unusual abundances in the sampling. Mean overall infaunal abundance, averaged 5,491 individuals/m^2. This metric has ranged from approximately 1,700 to over 20,000 since Year 19

Abundant spring freshwater discharge prevented the early formation of stratified waters at most HMI stations. Unlike Years 27 and 28, water quality measurements at stations MDE-50 and MDE-51 recorded acceptable bottom DO levels. In those years, some readings did not meet the 5.0 ppm standard. However, MDE will continue to evaluate data from these stations and consider their viability as reference stations

The health of the benthic macroinvertebrate community around HMI in Year 29 was generally worse than the previous sampling year and historical averages. The mean B-IBI score for Nearfield stations (3.04) was 0.48 lower than the historic average and the lowest in the last twelve years since stations have been relatively static. The mean B-IBI for all station types decreased in Year 29 to below historic averages. The mean South Cell Exterior Monitoring stations were 0.43 below average. The Reference stations were 0.28 below average and Back River/Hawk Cove stations were 1.23 below average. The mean B-IBI for Back River Hawk Cove stations was also at a historic low. Although there was an overall decline in B-IBI scores in Year 29, Diversity another important metric driving the index did not decrease. SWDI scores have generally been high throughout the study area. After examining the data more closely, the drops in B-IBI seem to be largely due to several factors. PITA was 27% higher than the historic average, due mainly to higher abundances of Naididae (common indicators of enrichment). PSTA was only 50% of its historic average, due mainly to lower abundances of clams and *Marenzelleria viridis*. The overall reductions were largely a regional phenomenon.

Looking at particular stations in Year 29, there are a couple noteworthy observations. Most importantly, station MDE-01 had a B-IBI score of 2.0, failing to meet the benchmark. This ties the historic low for the 13 years the station has been monitored. MDE-01 is approximately 150 meters from the North Cell spillway 007. As with many of the stations which performed below average in Year 29, the SWDI was still high. The PITA and PSTA were elevated and depressed respectively (although not as much as at other stations). Unique to MDE-01, the total infaunal abundance was unusually high, well above the "fair" and "good" range. Often, exceptionally high abundance is a sign of enrichment, especially when found in conjunction with elevated PITA and depressed PSTA. Potential explanations for this poor B-IBI include those for the regional depression in B-IBIs. When the three stations nearest to MDE-01 (MDE-03, MDE-07, and MDE-34) are lumped together to form a four-station composite of "North Cell Exterior Monitoring stations", the mean B-IBI (3.0) is not significantly lower than the means for other relevant (South Cell Exterior Monitoring, Nearfield) station types. Due the proximity to Spillway 007, additional attention will be focused on MDE-01 in future continued monitoring.

Three other stations had or tied historic lows for B-IBI. MDE-45 experienced its historic low (2.5), however this is only this third year the station has been monitored. MDE-27 tied its historic low of 1.0 (the lowest score a station can receive). This Back River/Hawk Cove station routinely fails to meet the B-IBI benchmark; averaging 2.24 over the last 13 years. Compared to the past, the total infaunal abundance was extremely high, nearly twice the historic average. Oligocheate worms in the Family Naididae comprised 86% of the sample. MDE-34 tied its historic low of 2.5 in Year 29. This station has unusually low infaunal abundance depressing the B-IBI. This may be incidental due to laboratory protocols. A very large percentage of bivalves in the station were too small to identify to genus, causing them to not be classified as “infaunal”. Had these clams been larger, most would likely have been classified as infaunal and thereby improved the metric and the B-IBI.

The Friedman’s nonparametric ANOVA test indicated significant differences among the top ten most abundant invertebrate taxa in September 2010 and the Wilcoxon Signed-Rank post-hoc test determined that the significant difference was between Reference stations and Nearfield stations.

Future monitoring plans: MDE is proposing to continue benthic monitoring at the current level until stabilization of the island is complete. The extent of future monitoring has yet to be determined.

REFERENCES

Duguay, L.E. 1990. Project III - Benthic Studies, p. 145-198. *In* Assessment of the Environmental Impacts of the Hart and Miller Island Containment Facility. 8th Annual Interpretive Report, August 1988-August 1989. Maryland Department of Natural Resources, Tidewater Administration, Annapolis, Maryland.

Duguay, L.E. 1992. Project III - Benthic Studies, p. 137-182. *In* Assessment of the Environmental Impacts of the Hart and Miller Islands Containment Facility. 9th Annual Interpretive Report, August 1989-August 1990. Maryland Department of Natural Resources, Tidewater Administration, Annapolis, Maryland.

Duguay, L.E., C.A. Shoemaker and S.G. Smith. 1995a. Project III - Benthic Studies, p. 79-117. *In* Assessment of the Environmental Impacts of the Hart and Miller Islands Containment Facility. 11th Annual Interpretive Report, August 1991-August 1992. Maryland Department of Natural Resources, Tidewater Administration, Annapolis, Maryland.

Duguay, L.E., C.A. Shoemaker and S.G. Smith. 1995b. Project III: Benthic Studies. Pp. 89-127, *In*: Assessment of the Environmental Impacts of the Hart and Miller Islands Containment Facility. 12th Annual Interpretive Report, August 1992-August 1993. Maryland Department of Natural Resources, Tidewater Administration, Annapolis, Maryland.

Duguay, L.E., C.A. Shoemaker and S.G. Smith. 1998. Project III - Benthic Studies, p. 77-115. *In* Assessment of the Environmental Impacts of the Hart-Miller Islands Dredged Material Containment Facility Dredged material containment facility . Year 13 Exterior Monitoring Technical Report, September 1993-August 1994. *Prepared by* Dredging Coordination and Assessment Division of Maryland Department of the Environment *for* Maryland Port Administration.

Duguay, L.E., C.A. Shoemaker and S.G. Smith. 1999. Project III - Benthic Studies, p. 51-87. *In* Assessment of the Environmental Impacts of the Hart-Miller Island Dredged Material Containment Facility Dredged material containment facility , Maryland. Year 14 Exterior Monitoring Technical Report, September 1994-August 1995. *Prepared by* Dredging Coordination and Assessment Division of Maryland Department of the Environment *for* Maryland Port Administration.

Gosner, K. L. 1978. A Field Guide to the Atlantic Seashore from the Bay of Fundy to Cape Hatteras. Houghton Mifflin Company, Boston.

Hopkins, S.H., et al. 1973. The Brackish water clam, Rangia cuneata as indicator of ecological effects of salinity changes in coastal waters. U.S. Army Corps of Engineers Waterways Experiment Station. Vicksburg, MS.

Johnson, Dallas E. 1998. Applied multivariate methods for data analysis. Pacific Grove: Duxbury Press.

Johnson, Dallas E. 1998a. "Chapter 9 Cluster Analysis." Applied multivariate methods for data analysis. Pacific Grove: Duxbury Press. 319-396.

Johnson, Dallas E. 1998b. "Chapter 5 Principal Components Analysis." Applied multivariate methods for data analysis. Pacific Grove: Duxbury Press. 93-146.

Johnson, Dallas E. 1998c. "Chapter 3 Multivariate Data Plots." Applied multivariate methods for data analysis. Pacific Grove: Duxbury Press. 55-76.

Lenat, David R. 1993. A biotic index for the Southeastern United States: derivation and list of tolerance values, with criteria for assigning water-quality ratings. J. N. Am. Benthol. Soc. 12(3): 279-290.

Lippson, A.J. and R.L. Lippson. 1997. Life in the Chesapeake Bay. The Johns Hopkins University Press, Baltimore, Maryland.

Lund, Adam and Mark Lund. Friedman Test in SPSS. February 7, 2012. http://statistics.laerd.com/spss-tutorials/friedman-test-using-spss-statistics.php.

Maryland Department of the Environment, 2009. *In review*. Assessment of the Environmental Impacts of the Hart-Miller Island Dredged Material Containment Facility Dredged material containment facility, Maryland. Year 27 Exterior Monitoring Data Report, September 2007-April 2008. *Prepared by* Dredging Coordination and Assessment Division of Maryland Department of the Environment *for* Maryland Port Administration.

Pfitzenmeyer, H.T., M.J. Johnston and H.S. Millsaps. 1982. *In* Assessment of the Environmental Impacts of Construction and Operation of the Hart and Miller Islands Containment Facility. 1st Annual Interpretative Report, August 1981-August 1982. Maryland Department of Natural Resources, Tidewater Administration 100-132 pp.

Pfitzenmeyer, H. T. 1985. Project II, Benthos. pp. 28-54, *In*: Assessment of the environmental impacts of construction and operation of the Hart and Miller Islands Containment Facility. Third Annual Interpretive Report, Aug.'83-Aug.'84. MD Dept. Nat. Res., Tidewater Admin.

Pfitzenmeyer, H.T. and K.R. Tenore. 1987. Project III - Biota, Part 1 - Benthic Studies, p. 132-171. *In* Assessment of the Environmental Impacts of the Hart and Miller Islands Containment Facility. 5th Annual Interpretive Report, August 185-August 1986. Maryland Department of Natural Resources, Tidewater Administration, Annapolis, Maryland.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. J. Theoret. Biol. 13, 131-144**.**

Ranasinghe, J.A., S.B. Weisberg, D.M. Dauer, L.C. Schaffner, R.J. Diaz and J.B. Frithsen. 1994. Chesapeake Bay Benthic Community Restoration Goals. Report CBP/TRS 107/94. U.S. Environmental Protection Agency, Chesapeake Bay Program. Annapolis, Maryland.

Smith, R.L. 1996. Ecology and Field Biology, Fifth Edition. Harper-Collins CollegePublications.

Weisberg, S.,D. Dauer, L. Schaffner and J. Fithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries* 20(1):149-158.

APPENDIX 3: ANALYTICAL SERVICES (PROJECT IV)

(September 2010 – August 2011)

Technical Report

Prepared by
Andrew Heyes, Principal Investigator

Chesapeake Biological Laboratory
University of Maryland Center for Environmental Science
P.O. Box 38, 1 William St.
Solomons, MD 20688

Prepared for
Maryland Port Administration
Maryland Department of Transportation
World Trade Center
401 East Pratt Street
Baltimore, Maryland 21202

January 2012

EXECUTIVE SUMMARY

Sampling

For Year 29 exterior monitoring at Hart-Miller Island (HMI), Chesapeake Biological Laboratory (CBL) collected the clam *Rangia cuneata* both in September 2010 and April 2011. In addition to clams, sediment samples were concurrently collected and analyzed for trace elements and polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). As part of the annual sediment survey, CBL conducted analysis for concentrations of target trace elements in surface sediments collected in September 2010 around HMI by the Maryland Geological Survey (MGS). Trace element analysis focuses on those not measured by MGS, specifically total mercury (T-Hg), monomethylmercury (MeHg), silver (Ag), and metalloids selenium (Se) and arsenic (As).

Trace elements in Sediment

Concentrations of As and Se in the sediment (fall 2010) were typical of concentrations seen in previous years but sediment at four locations, MDE-6, MDE-9, MDE-12 and MDE-15, exceeded the historic mean and standard deviation. The stations are all located southeast of the island, but at varying distances from the island and among stations that showed no variation from historical concentrations. Concentrations of Ag in sediment were lower than the median and mean concentrations that have been observed in previous years. There is a trend toward lower concentrations of Ag in sediment around the island in recent years.

Concentrations of T-Hg in sediment were generally greater than the running mean of previous years but concentrations at most sites fell within the standard deviation of measurements made between 1998 and 2009. Sites which fell outside the standard deviation were MDE-6, MDE-15, MDE-17, MDE-18, MDE-39 and MDE-51. The time series for MDE-51 is too short to truly assess whether this fluctuation is outside the sites normal variation. While site MDE-39 is near the entrance to Baltimore Harbor, and may fall under its influence, MDE-6, MDE-15, MDE-17 and MDE-18 form a line on the south side of HMI. Of these four sites, MDE-18 had an elevated T-Hg concentration in September of 2009. While the T-Hg concentrations observed at the 4 sites appear unusual for these sites when compared to historic values, they fall within the range observed in main stem of the Chesapeake Bay (0.2 to 250 ng g^{-1} dry weight) (Heyes et al. 2006). Still there is no clear reason for the shift thus further observation is warranted.

Concentrations of MeHg in sediment at most sites fell within the range of what has been typically observed for each site but concentrations at MDE-25 and MDE-38 were higher than what has typically been observed. Being near the entrance to Baltimore Harbor, these stations could have been influenced by exported sediment.

In summary, the stations MDE-6, MDE-9, MDE-12, MDE-15, MDE-17 and MDE-18 deviated outside the standard deviation of the historic mean concentration for more than one trace element and from other sites sampled on the south side of the island in September 2010.

There is no obvious explanation for the results given the apparent patchy distribution of the impacted sites and the limited knowledge of HMI operations at the time this report was written.

Trace Elements in Clam Tissue

The clam *Rangia* was collected from 13 stations in September 2010 and 12 stations in April 2011. Concentrations of As, Se, Ag, Cd, Pb measured in clams collected in the fall of 2010 were almost ubiquitously lower than previous years, whereas concentrations of T-Hg and MeHg were close to the running mean of each station. Concentrations of trace elements in clams collected from the sites more recently added to the sampling grid, MDE-44 and MDE-51, were similar to concentrations found at other sites.

Concentrations of As, Se, T-Hg and MeHg in clams collected in April 2011 were close to the individual sites historical mean concentration, and concentrations of Pb, Ag and Cd were lower than the individual sites running means. Clams were again sampled from sites MDE-44 and MDE-51. Concentrations of trace elements were higher in April than September except in the case of Pb, but concentrations at these sites were comparable to the reference site MDE-36.

Total PCB concentrations in sediments and clams

The total PCB concentrations in sediment collected in September 2010 were similar to or below the historic site averages, being within the standard deviation of the mean with the exception of site MDE-43. Total PCB concentrations in clams were on average 2 times higher than the running mean for all sites including the reference site, MDE-36. The distribution of PCB congeners in sediment and clams of any one site were similar but the magnitudes of the individual congeners differed. The congeners detected in both sediments and clams were weighted toward higher numbers, or masses, which is expected as these congeners are less mobile. The congener patterns in sediment among HMI sites were similar, which suggests no site is subjected to a unique source. While the clams reflect the same distribution of PCB congeners found in the sediment of the site from which they are collected, the clam congener concentrations are higher than the historical mean. This situation would suggest above normal PCB concentrations in the water column with deposition of material of lower than normal PCB concentration. This is an unusual combination.

Total PAH concentrations in sediments and clams

The total concentrations of PAHs in sediment collected in September 2010 from sites around the HMI complex were similar to historical levels. However, concentrations of PAHs in clams where above historical levels, including at the reference site MDE-36. The exception was site MDE-1, where low PAH concentrations in clams where also accompanied by low PAH concentrations in sediment. As the proportions of PAHs and total concentrations of PAHs in clams mirror the sediment, a local influence would be suspected in driving the increased concentrations. However, the wide spread nature of the increase suggests this is not likely. The fact that both PCB and PAH concentrations in clams were elevated above historic levels suggests a wide spread change in the water column particulate load. Such an increase could be achieved through increased resuspension or a regional delivery of fine particles enriched in PCBs and PAHs from elsewhere in the Bay.

Bioaccumulation Factors and Toxicity

Bioaccumulation of trace elements by clams in 2010 and 2011 was typical of past years with Pb showing no accumulation and MeHg showing efficient transfer, with BAFs near 100. According to the toxicological affects criteria (guidelines) established by the National Oceanic and Atmospheric Agency (NOAA) the trace element concentrations of As, Ag and T-Hg in sediment are below the Probable Effects Level (PEL). BAFs calculated on a wet weight basis for PCBs are on the order of 5 for most of the sites studied in 2010. The calculated BAF for site MDE-34 was approximately 20, and has been high for the past two years. Site MDE-1 has a BAF of 60, which is driven by the much lower than normal PCBs levels in the sediment. The lowest indicator of potential toxicity, the Threshold Effects Level (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. This influence even impacts the long term reference site, MDE-36. Although MDE-36 does not exceed the TEL for PAHs or PCBs the concentrations are very close. The PEL was not surpassed by any of the sites sampled for either PCBs or PAHs.

OBJECTIVES

The goals of the project in 2010-2011 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 trends in concentrations are developing at locations around the island.

Specific objectives for Year 29 were:

First, in the fall of 2010 and spring of 2011 collect clams and associated sediment for analyses of trace elements. 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 T-Hg, MeHg, Ag, Se, As, Pb and Cd.

Second, to determine the concentrations of target trace elements in surface sediments at the larger number of stations around HMI visited by the MGS in September 2010. Metal analysis focused on those metals not measured by MGS, specifically T-Hg, MeHg, Ag, Se and As.

Finally, the sediment and clams collected in the fall of 2010 were analyzed 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 29 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 29 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 2010. 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 2010 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 2010, 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 where 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 180^0C 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 mLs with distilled-deionized water. Prior to analysis, the samples were further oxidized for 30 minutes with 2 mLs 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 are heated to approximately 90°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 atomic fluorescence (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°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 with an electron capture detector. Individual PCB congeners are identified and quantified using the method of Mullins 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 29 (September 2010) are typical of concentrations seen in previous years (Figure 3-1). The concentrations of As were close to the running mean (calculated for the period 1998 to 2009) at the majority of the sampling locations. Sediment As concentrations at four locations, MDE-6, MDE-10, MDE-12 and MDE-15, exceeded the historic mean As concentration by greater than 5 ug g^{-1}. The stations are all located SE of the island but do not cluster and at varying distances from the island. Two anomalies were observed in 2009 but at different stations.

In 2008 and 2009 and between the years 1999 and 2001, Se concentrations were high, whereas between 2002 and 2007, Se concentrations were low. This pattern creates a bimodal distribution in the time series and large standard deviations in site data. The concentrations of Se in sediments collected in the fall of 2010 are the same or lower than the mean and median from previous years with four exceptions. MDE-6, MDE-10, MDE-12 and MDE-15 exceeded the stations historic mean Se concentration by greater than 1 ug g^{-1}. Because Se concentrations in sediment are generally low overall, the increase at the four sites is a large percentage change. It has also been observed that Se is known to shift from being an essential element to being toxic over a small range, but 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. The four anomalous sites are the same sites that had anomalous concentrations of As.

Concentrations of Ag in the sediment collected in the fall of 2010 were 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. Annual fluctuations in the concentration of Ag in sediment are system wide and appear unrelated to HMI operation.

Concentrations of T-Hg in sediment were generally greater than the running mean of previous years and concentrations at many sites fell outside the standard deviation of measurements made between 1998 and 2009 (Figure 3-2). Sites which fell well outside the standard deviation were MDE-6, MDE-12, MDE-15, MDE-17, MDE-18, MDE-39 and MDE-51. Site MDE-51 was recently added and we have insufficient data to address whether this fluctuation is outside the sites normal variation. Site MDE-39 is near the entrance to Baltimore Harbor, and may fall under the influence of exported sediment but MDE-6, MDE-15, MDE-17 and MDE-18 form a line on the south side of HMI. Of these four sites, MDE-18 had elevated T-Hg concentrations in September of 2009. Concentrations of T-Hg at a number of other stations also exceeded the standard deviation of measurements from previous years, including MDE-9, MDE-11, MDE-14, MDE-23, MDE-25 and MDE-36. Concentrations of T-Hg in the main stem of the Chesapeake Bay range from 0.2 to 250 ng g^{-1} dry weight. This range in sediment concentrations is comparable to what is present in sediment around HMI, including all the afore mentioned stations but not MDE-39 (Heyes et al. 2006).

Concentrations of MeHg in sediment collected in the fall of 2010 ranged from 0.06 to 2.5 ng g^{-1} dry weight (Figure 3-3). These concentrations are largely comparable to the rest of the Chesapeake Bay (Heyes et al. 2006). Being greater than 2 ng g^{-1}, sediment MeHg concentrations at MDE-25 and MDE-38 are higher than what has typically been observed (Heyes et al. 2006). Sites MDE-25 and MDE-38 are near the entrance to Baltimore Harbor, and these stations are more likely to be influenced by exported sediment and water than the other stations investigated in 2010. The percent of mercury that occurred as MeHg was less than 1% at all sites except for MDE 38 and MDE 50. The high percent MeHg at MDE-50 is driven by the very low T-Hg concentration.

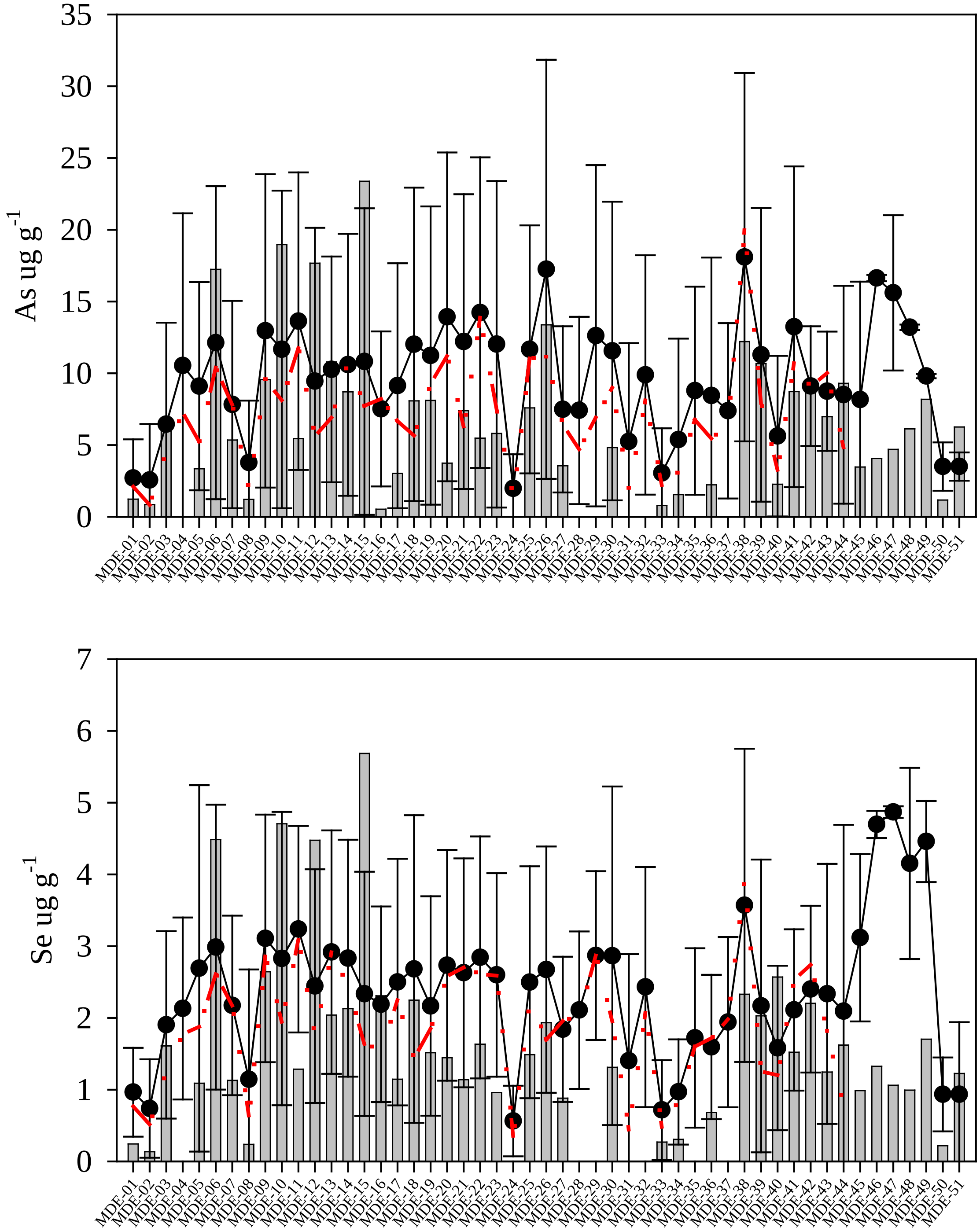


Figure 3-1. As and Se in sediment, expressed as dry weight concentration, collected by MGS in September 2010 (bars) and the 1998-2009 mean (circles) with standard deviation (error bars) and the 1998-2009 median (dashed line).

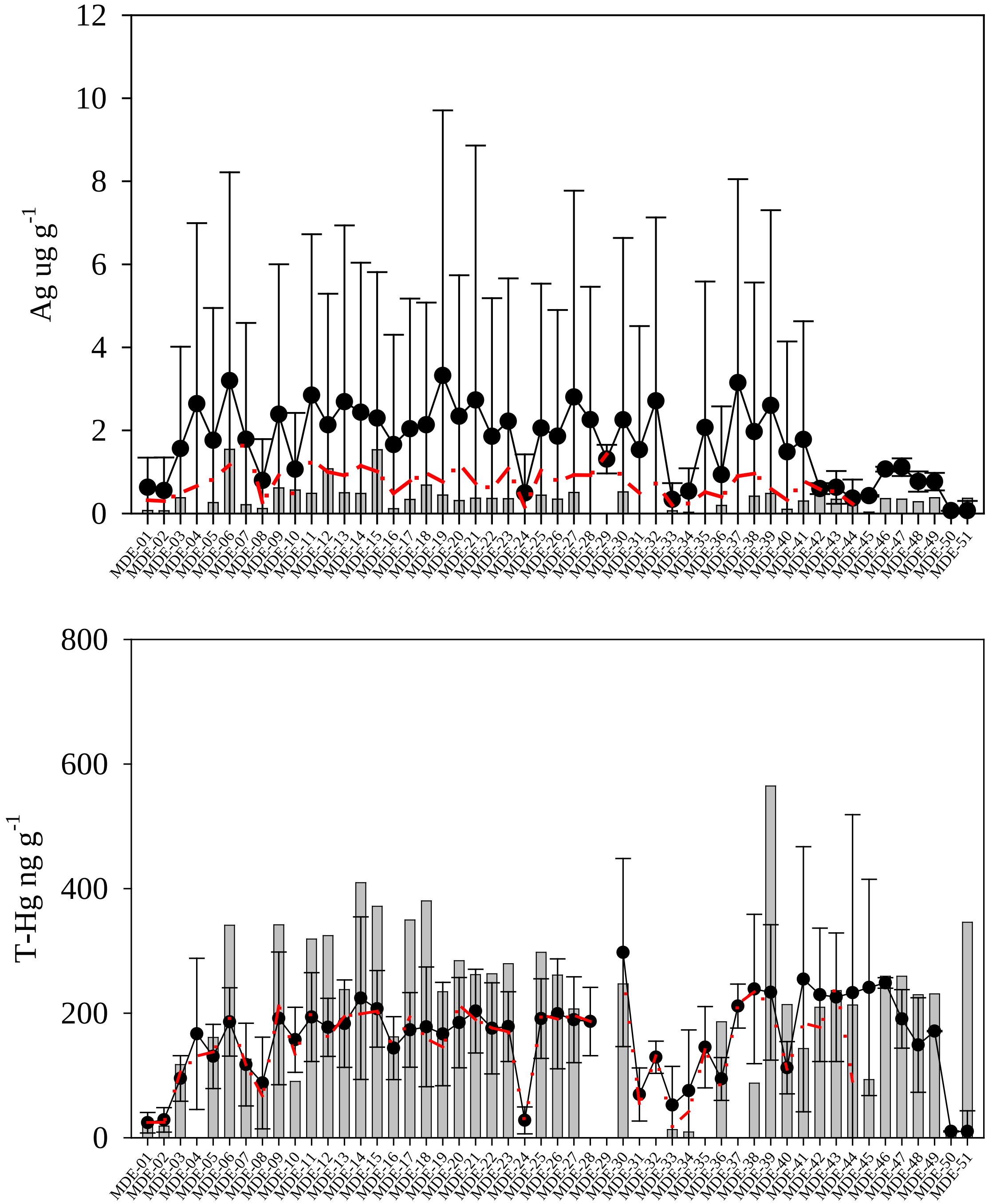


Figure 3-2. Ag and T-Hg concentrations in sediment, expressed as dry weight concentration, collected by MGS in September 2010 (bars) and the 1998-2009 mean (circles) with standard deviation (error bars) and the 1998-2009 median (dashed line).

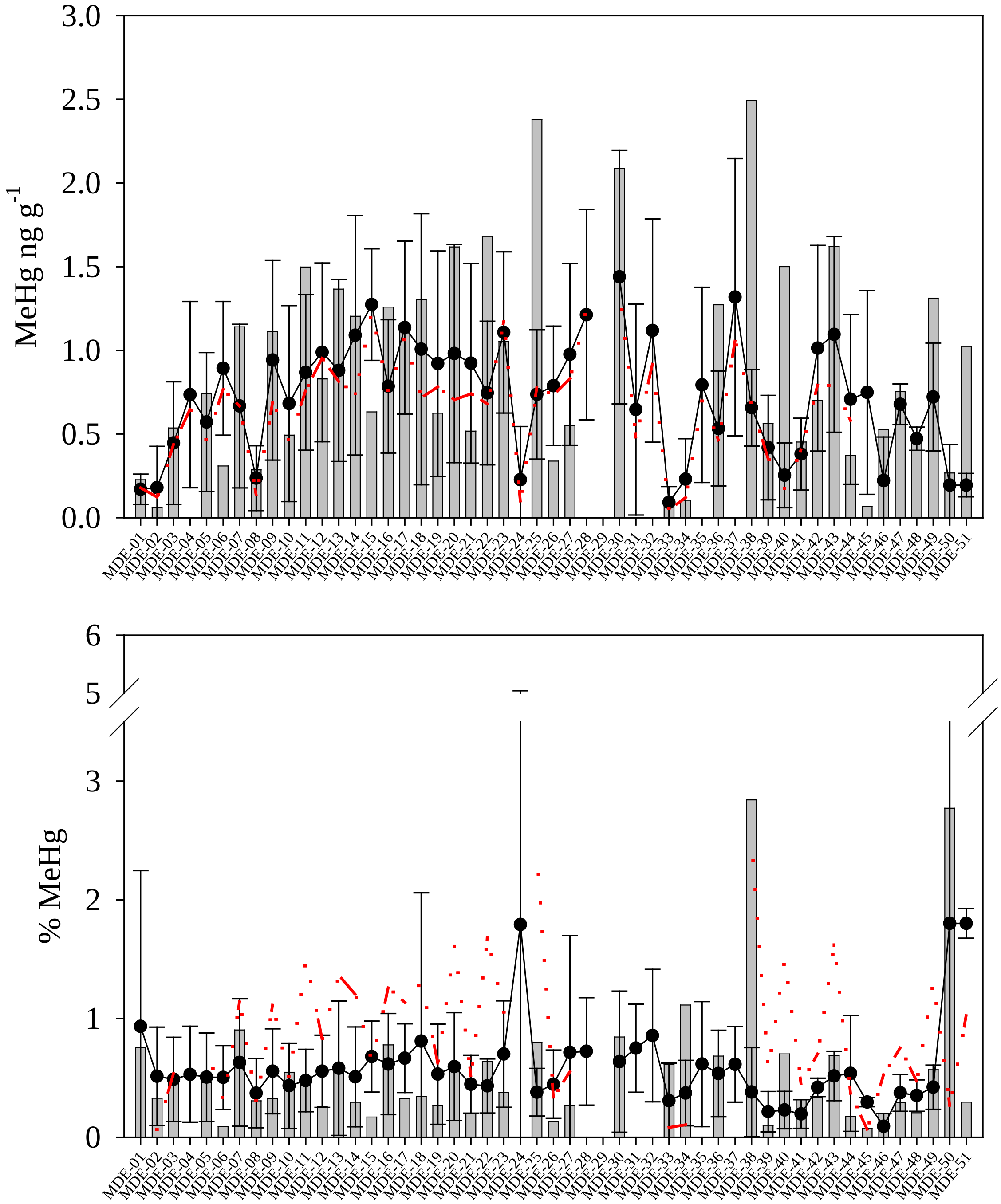


Figure 3-3. MeHg, expressed as dry weight concentrations, and percent of T-Hg as MeHg in sediment collected by MGS in September 2010 (bars), and the 1998-2009 mean (circles), with standard deviation (error bars), and the 1998-2009 median (dashed line).

Trace Elements in Clams

The clam *Rangia* was collected from 13 stations in the September 2010 and 12 stations in April 2011. In September 2010, the sites visited were MDE-1, 9, 15, 16, 19, 22, 27, 30, 34, 36, 43, 44 and 51. Concentrations of As, Se, Ag, Cd, Pb, T-Hg and MeHg measured in clams collected 2010 were almost ubiquitously lower than previous years (Figures 3-4, 3-5). While concentrations of T-Hg and MeHg were close to the running mean of the station from which they were collected, concentrations of As, Se, Ag Cd and Pb were substantially lower than the stations running mean. Five new sampling locations were recently added to the sample pool to increase the spatial sample density around the southern side of the island. Of these newer sites, site MDE-44 and MDE-51 were sampled for clams in September 2010. Site MDE-44 is located adjacent the island on the south side and site MDE-51 is much further south, and was selected to expand the field and number of reference sites. Concentrations of trace elements in clams collected from MDE-44 and MDE-51 fell in line with concentrations found in clams of the other sites including the reference site MDE-36.

Sites from which clams were sampled in April 2011 included MDE-1, 3, 7, 9, 13, 16, 17, 36, 42, 43, 44, and 51. In April 2011, concentrations of As Se, T-Hg, MeHg in clams were close to the historical concentrations of the site from which the clams where collected and concentrations of Pb, Ag and Cd in clams were lower than the sites running mean concentration (Figures 3-6, 3-7). Clams were again sampled from sites MDE-44 and MDE-51. Concentrations of trace elements were higher in April than September except in the case of Pb but the concentrations were comparable to the those obtained on clams collected from the reference site MDE-36.

Sites MDE-6, 12, 15, 17, 18, located on the southeast side of HMI, and MDE-39, located at the mouth of the Potapsco, had one or more trace element concentrations in sediment that were not consistent with sediment concentrations from other sites sampled in 2010 and deviated from the normal historical variability. The concentrations however were not outside the range in concentrations observed at sites around the complex as a whole. MDE-15 was also sampled for sediment in 2010 and MDE-17 in April 2011 as part of the CBL clam survey (Table 3-1). Sediment collected from MDE-15 by CBL had trace element concentrations lower than from the MGS collection and As and Se close to the running mean of 10.8 and 2.3 ug g^{-1}, respectively and T-Hg concentration of 207 ng g^{-1}. Concentrations of trace elements at site MDE-17 remained high in April 2011. Clams collected from these two sites were lower than previous years and did not reflect the elevated sediment concentrations. Thus, while the measured trace element concentrations in surface sediments were higher than historical levels at some sites, these concentrations did not affect clam concentrations.

Table 3-1. Trace elements in sediment from sites MDE-15 and MDE-17 collected by the MGS and the CBL on different surveys.

	Site	As ug/g dry	Se ug/g dry	Ag ug/g dry	t-Hg ug/g dry	MdHg ug/g dry
MGS September	MDE-15	9.44	2.57	0.55	237.41	1.01
CBL September	MDE-15	23.38	5.69	1.53	371.50	0.63
MGS September	MDE-17	7.64	2.09	0.57	393.51	2.91
CBL April	MDE-17	3.03	1.15	0.34	349.56	1.13

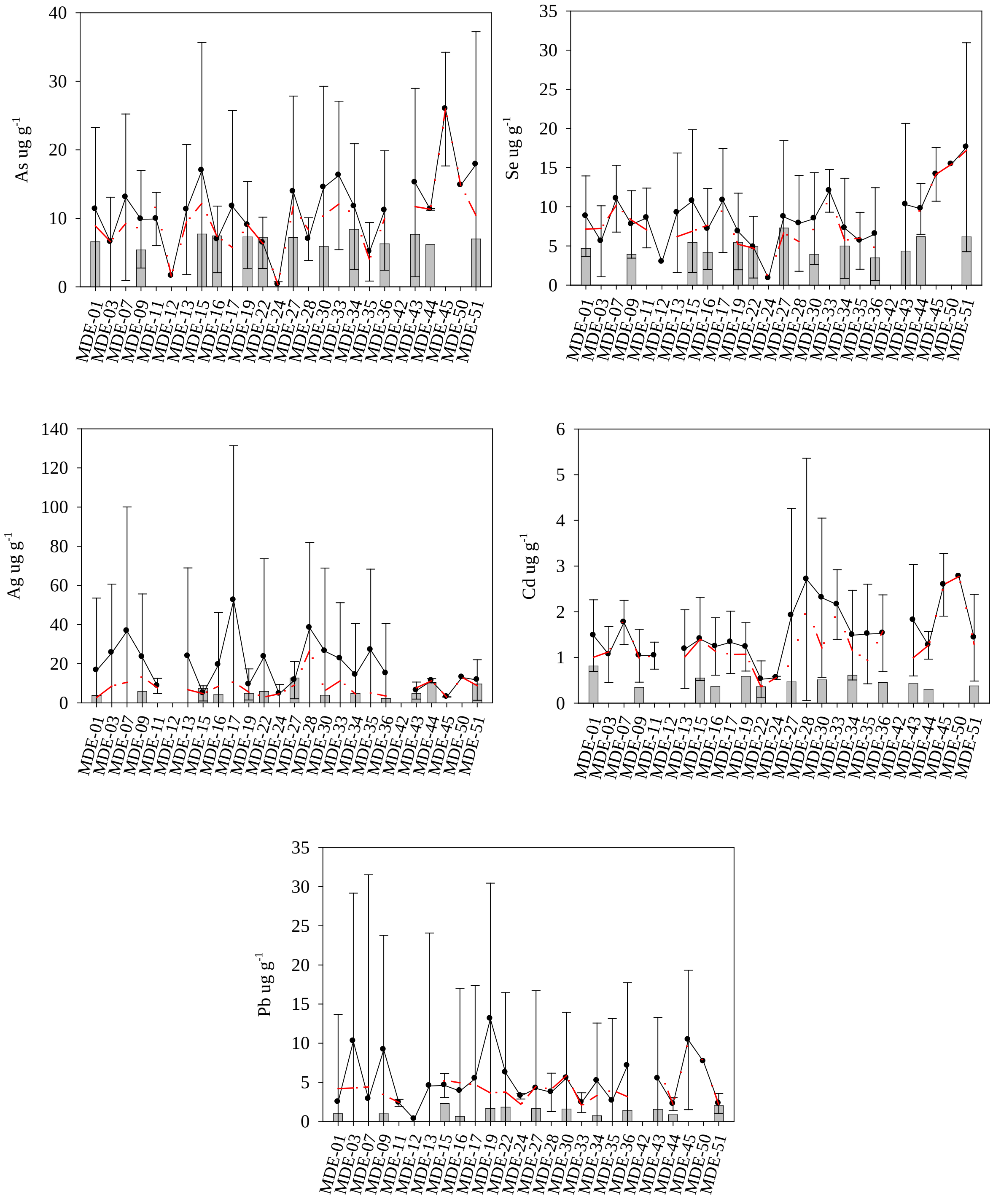


Figure 3-4. Concentrations of Pb, Cd, As, Se, Ag in clams collected in September 2010. Concentrations (bars) are dry weight based, and the 1998-2009 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2009 median (dashed line).

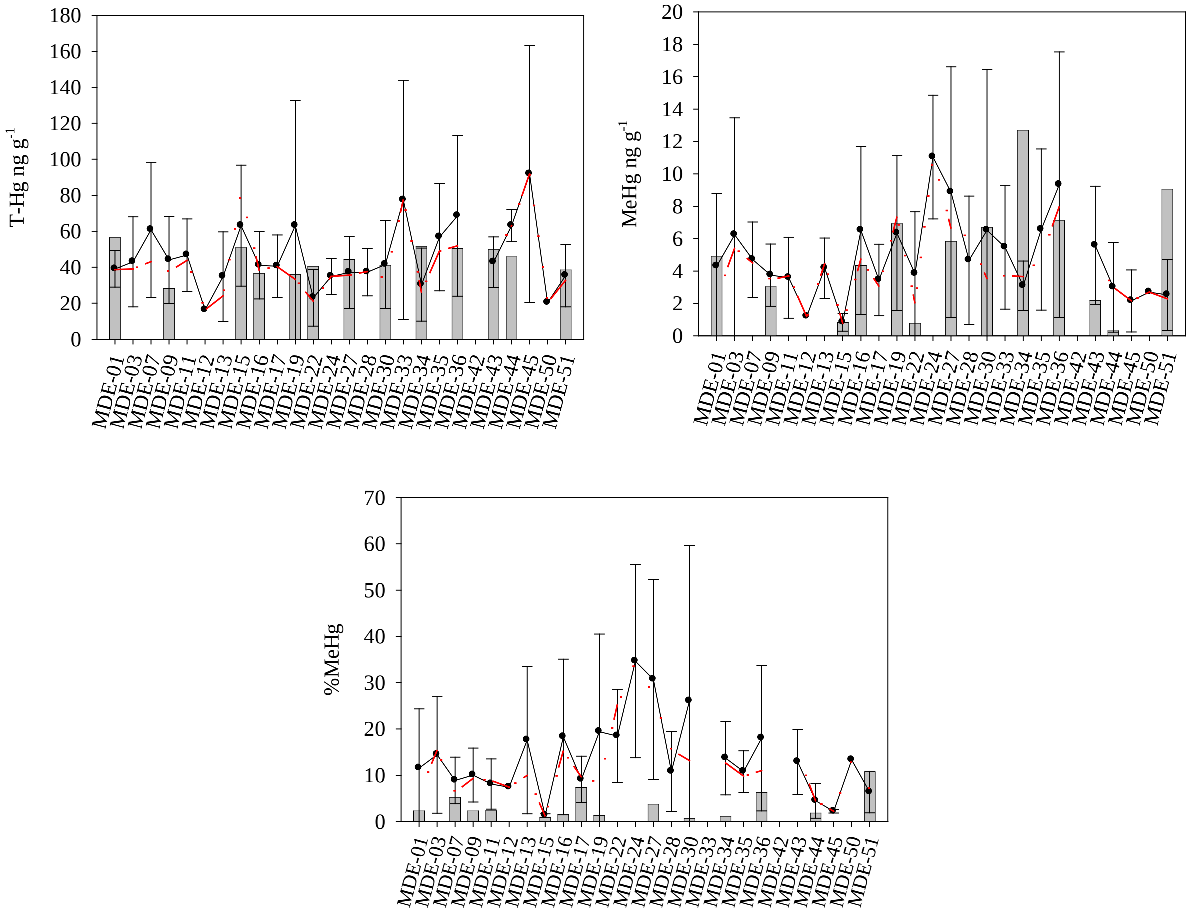


Figure 3-5. T-Hg and MeHg concentrations, expressed on a dry weight basis, and percent of T-Hg that is MeHg in clams, collected in September 2010 (bars) and the 1998-2009 mean (circles) with standard deviation (error bars) and the 1998-2009 median (dashed line).

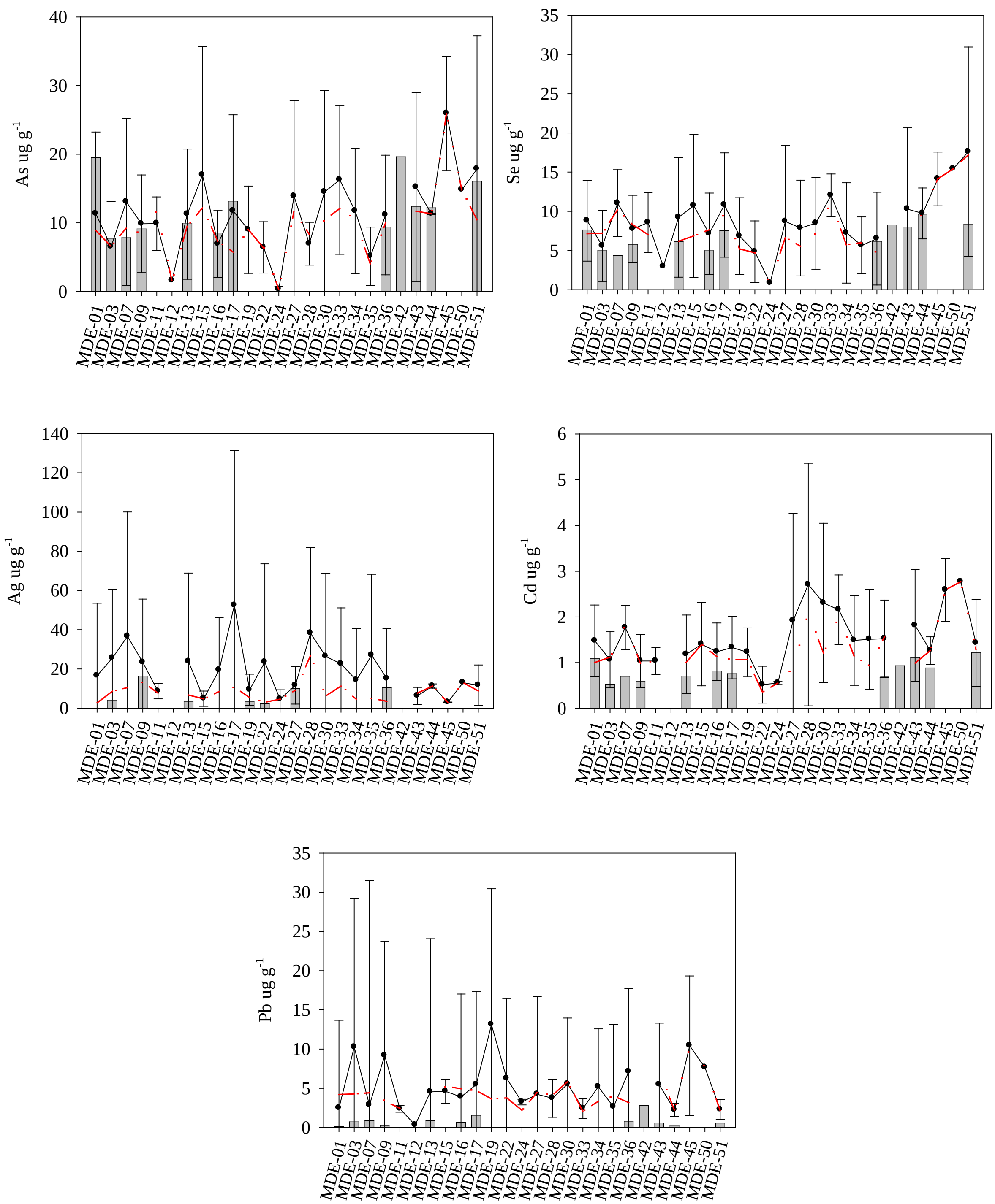


Figure 3-6. Concentrations of As, Se, Ag, Cd, Pb in clams collected in April 2011. Concentrations (bars) are dry weight based, and the 1998-2009 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2009 median (dashed line).

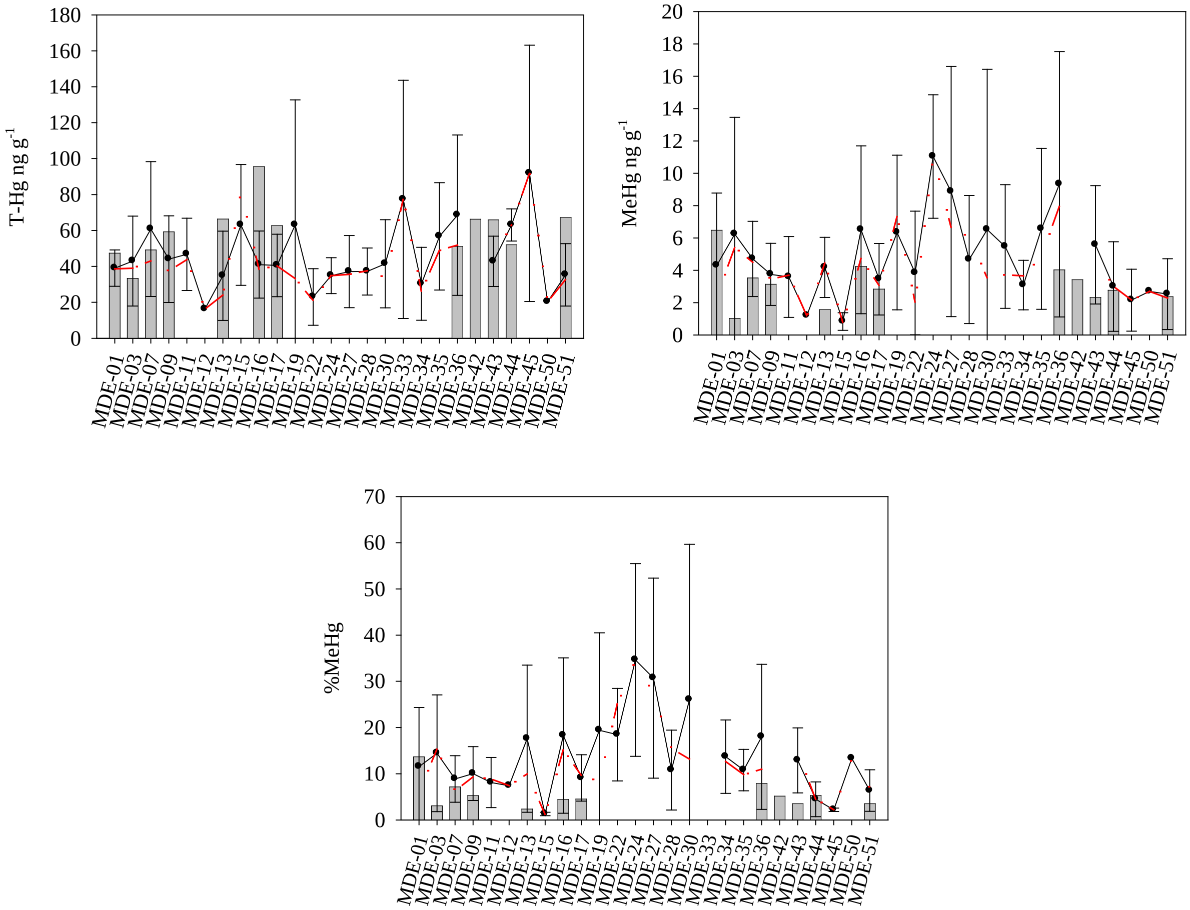


Figure 3-7. T-Hg and MeHg concentrations, expressed on a dry weight basis, and percent of T-Hg that is MeHg in clams, collected in April 2011 (bars) and the 1998-2009 mean (circles) with standard deviation (error bars) and the 1998-2009 median (dashed line).

Bioaccumulation Factors

Clam bioaccumulation factors (BAFs) for the trace elements Cd, Pb, As, Ag, Se, T-Hg and MeHg (Figure 3-8) were calculated using clam concentrations in Figures 3-4 to 3-7) and sediment concentrations presented in Table 3-2. 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 2010 and April 2011, the BAFs for Pb (not shown) 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 both September 2010 and April 2011, little bioaccumulation of As, Cd, T-Hg and Se by the clams was observed (BAFs typically less than 10, Figures 3-8, 3-9). Moderate bioaccumulation of MeHg was generally observed, as BAFs were on the order of 10. High BAFs were calculated for Ag. Most BAFs were between 20 and 50 but BAFs at site MDE-34 in September 2010 and MDE-44 in April 2011 were over 100. These high values are partly the result of very low Ag concentrations in sediment, 0.04 ug g^{-1} and 0.09 ug $g^{-1}$for MDE-34 and MDE-44, respectively. In the fall of 2010, sediment collected from MDE-34 by MGS also had a very low Ag concentration (0.03 ug g^{-1}) but the Ag concentration from MDE- 44 was 0.41 ug g^{-1} which was more typical of sediments collected from around HMI. Concentrations of Ag in clam and sediments were both lower than what has been observed in previous years, thus the net effect is BAFs of between 10 and 100 which are similar to historical values.

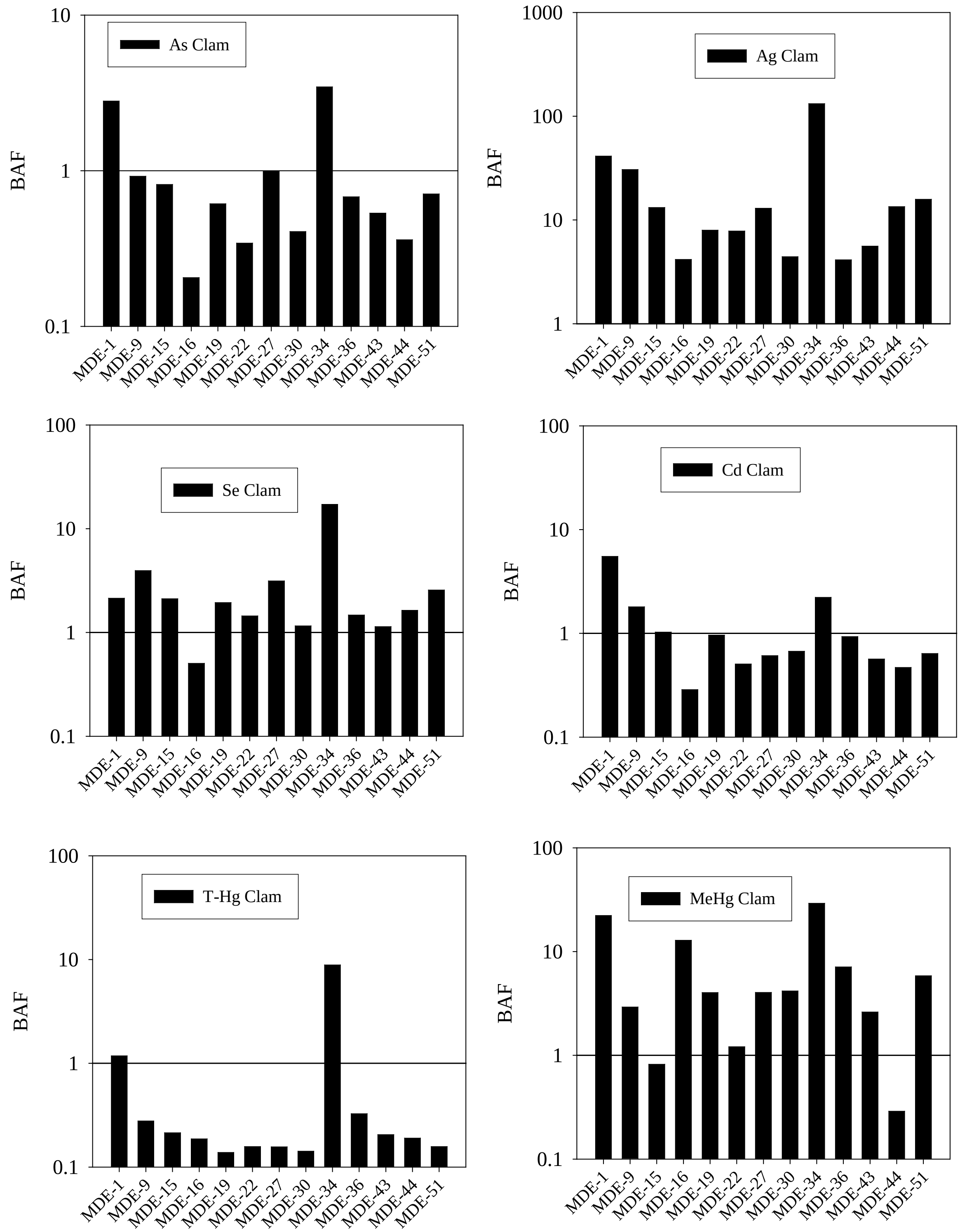


Figure 3-8. Bioaccumulation factors for the metals As, Ag, Se, Cd, T-Hg and MeHg September 2010. Note BAF is presented on a log scale.

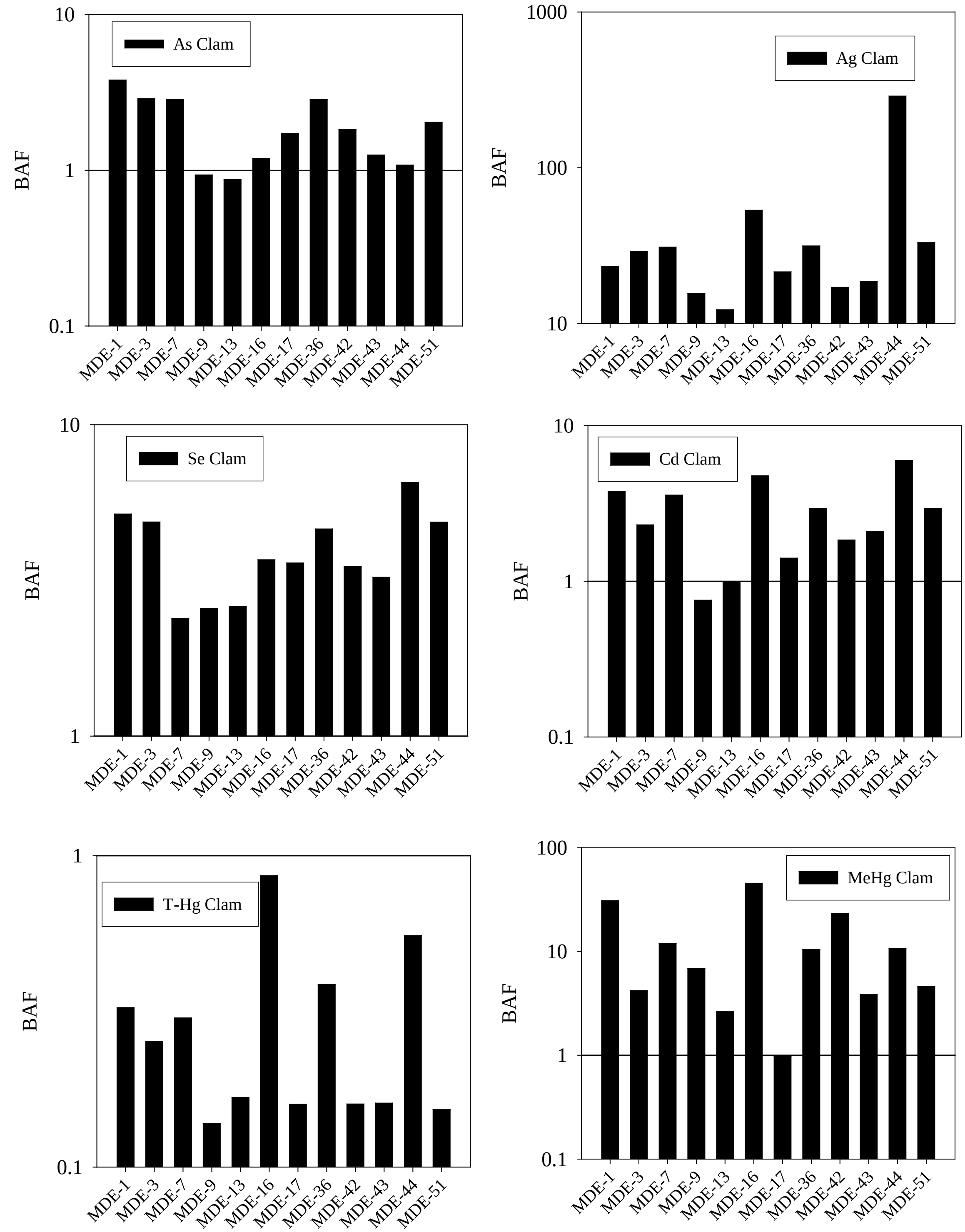


Figure 3-9. Bioaccumulation factors for the metals As, Ag, Se, Cd, T-Hg and MeHg April 2011. Note BAF is presented on a log scale.

Table 3-2. Trace element concentrations in sediment (dry weight) collected along with clams by CBL and MDE in September 2010 and April 2011. The sediment samples were taken from a subset of the same sites as those collected by MGS but on different dates hence the data are 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	2.34	2.19	0.09	0.15	11.57	47.70	0.22
MDE-9	5.82	0.99	0.19	0.19	20.09	101.42	1.03
MDE-15	9.44	2.57	0.55	0.53	53.21	237.41	1.01
MDE-16	36.13	8.29	1.00	1.27	121.62	194.70	0.34
MDE-19	11.84	2.79	0.61	0.61	57.04	259.60	1.72
MDE-22	20.89	3.40	0.75	0.71	83.16	255.32	0.64
MDE-27	7.19	2.32	0.98	0.76	61.41	282.39	1.45
MDE-30	14.46	3.35	0.87	0.76	75.56	288.74	1.60
MDE-34	2.43	0.29	0.04	0.27	11.09	5.82	0.43
MDE-36	9.21	2.36	0.51	0.48	48.60	154.55	1.00
MDE-43	14.33	3.82	0.85	0.75	78.55	241.98	0.83
MDE-44	17.07	3.78	0.77	0.65	79.07	240.59	1.07
MDE-50	2.53	0.41	0.05	0.07	5.35	7.35	0.67
MDE-51	9.82	2.39	0.61	0.59	48.73	244.30	1.55

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-1	5.12	1.48	0.27	0.29	25.63	145.66	0.21
MDE-3	2.68	1.02	0.24	0.23	24.30	131.42	0.24
MDE-7	2.74	1.82	0.19	0.20	17.42	163.04	0.30
MDE-9	9.74	2.25	0.60	0.79	69.10	428.09	0.46
MDE-13	11.35	2.36	0.83	0.71	64.29	395.95	0.59
MDE-16	7.02	1.35	0.11	0.17	20.80	110.62	0.09
MDE-17	7.64	2.09	0.57	0.54	53.95	393.51	2.91
MDE-36	3.28	1.33	0.25	0.23	19.33	132.26	0.38
MDE-42	10.75	2.36	0.60	0.51	62.71	415.18	0.15
MDE-43	9.87	2.47	0.60	0.53	55.93	410.36	0.60
MDE-44	11.27	1.48	0.09	0.15	19.28	93.91	0.26
MDE-51	7.88	1.71	0.51	0.42	43.35	438.72	0.51

Investigating Potential Metal Toxicity

For some trace metals, toxicological affects criteria or guidelines have been established by the National Oceanic and Atmospheric Agency (NOAA). We have used these guidelines 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 3-10 and 3-11). For the metals As, Ag and T-Hg; sediment concentrations are below the PEL.

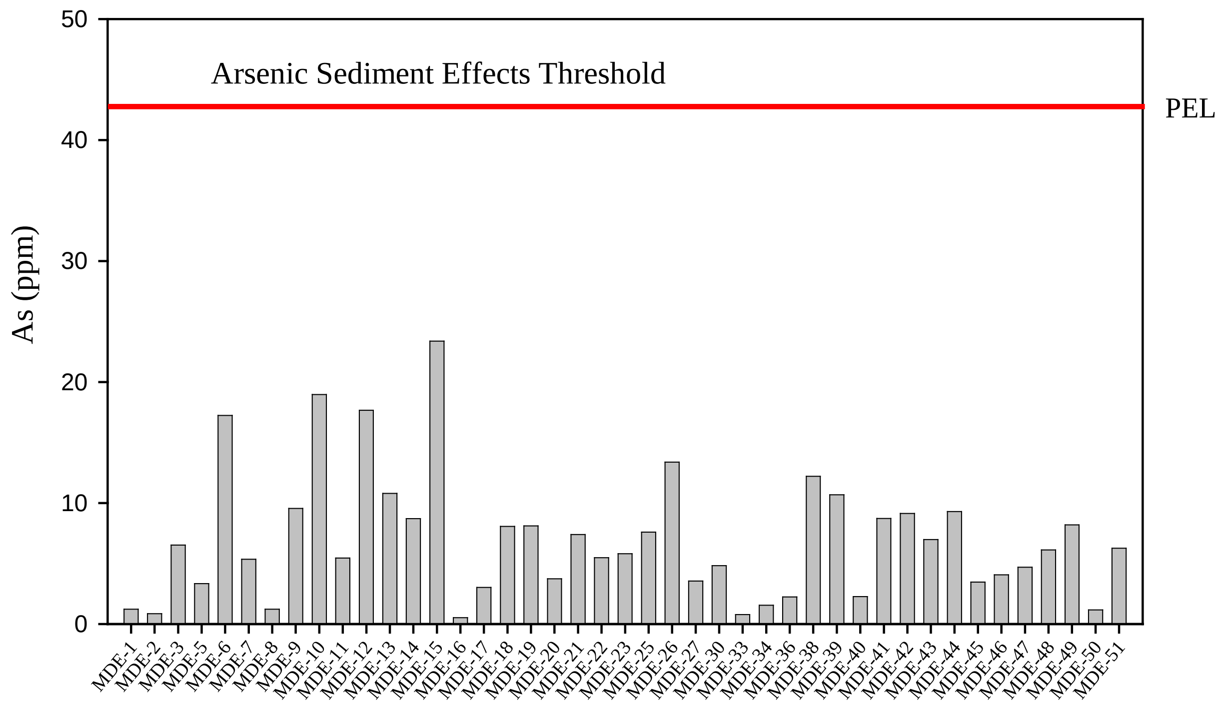


Figure 3-10. As concentrations in sediment along with the PEL as identified by NOAA for marine sediment.

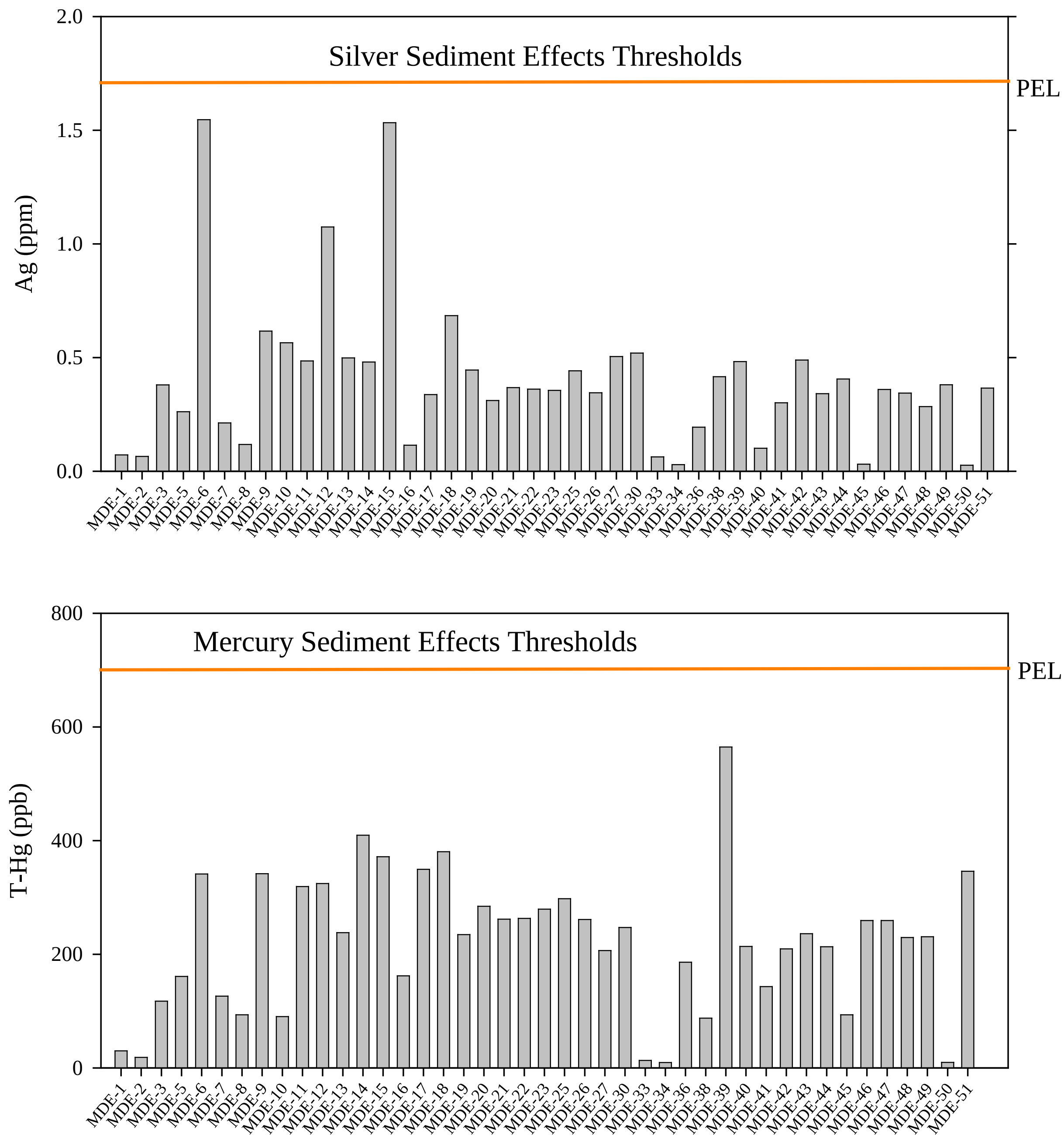
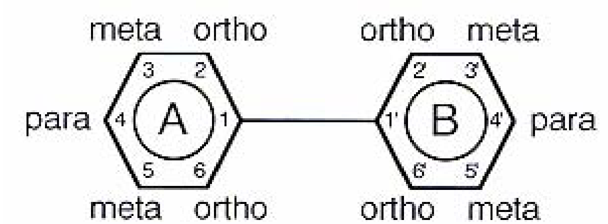


Figure 3-11. T-Hg and Ag concentrations in sediment along with PEL as identified by NOAA for marine sediment.

Polychlorinated Biphenyls (PCBs) in Sediment

The PCB congeners analyzed in the sediments collected in September of 2010 are given in Table 3-3. 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 3-3). 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). The PCB congeners measured around HMI are summarized in Figure 3-12 a-n. These figures provide a "signature" from which to investigate trends within and among sites. Not all congeners can be differentiated by our analysis, and some congeners must be combined. For example congeners 31 and 28 cannot be separated by the GC column and are said to co-elute and we designate the peak 31+28.

The sediments collected in 2010 contain high concentrations of the PCB congeners 31+28, 66+95, 132+153+105, 163+138, 180, 208+195, 206 and 209 which define the sample signatures. 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. In general, concentrations of many PCB congeners were consistent with the mean 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 in water and more likely to stay bound to sediment (Table 3-4). Overall, the congener patterns in sediment from around the island are similar, and no group of congeners indicates the presence of a unique source.

Table 3-3. PCB congeners given in the same order as presented in Figure 3-12 a-n (left to right).

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. PCB 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

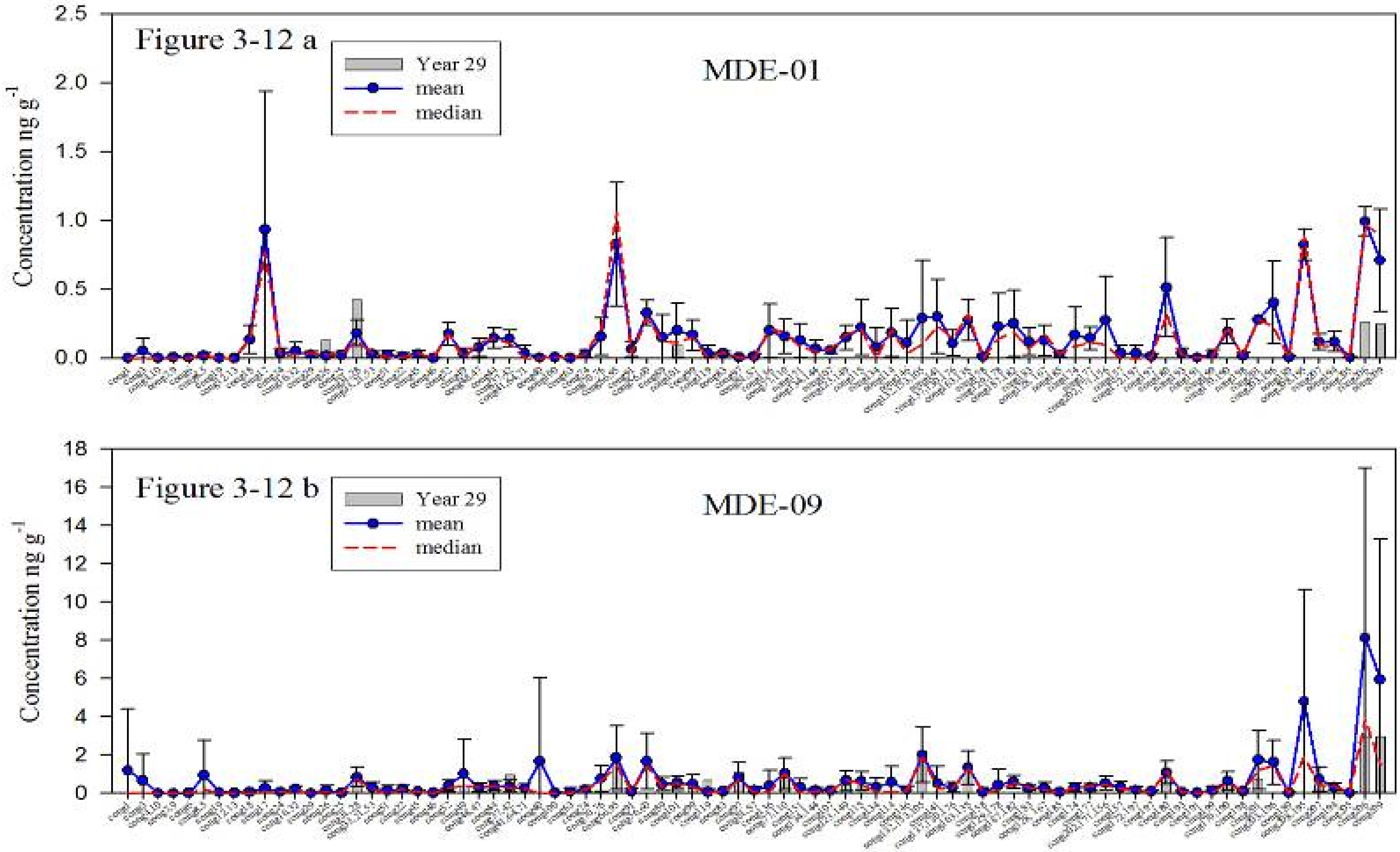
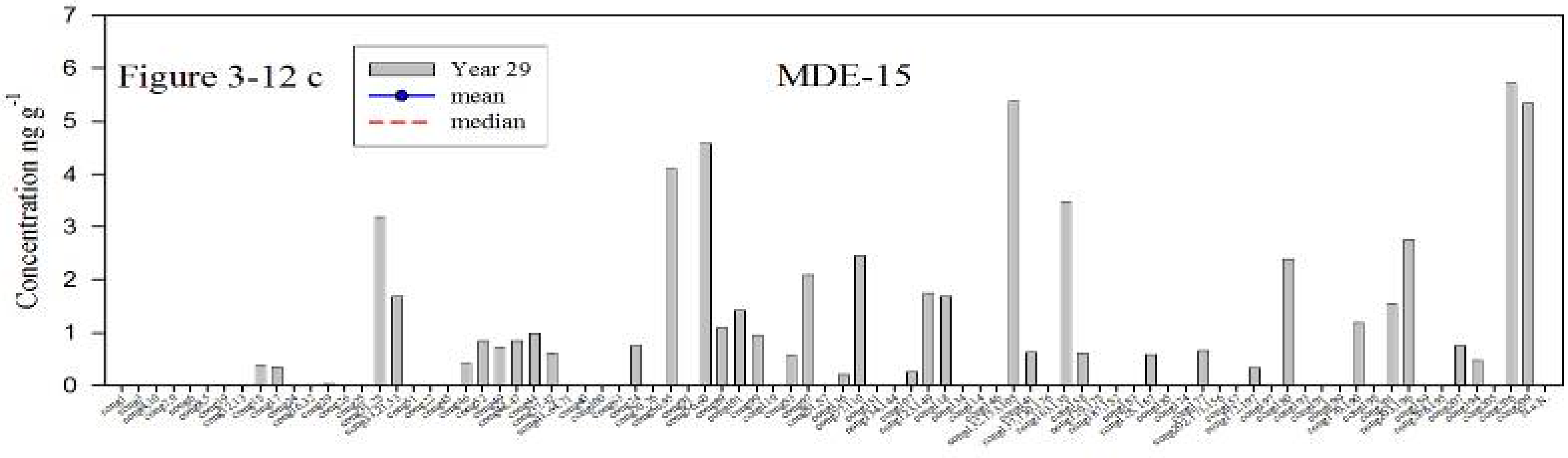


Figure 3-12. Concentrations of PCB congeners in sediments from sites MDE-01 and MDE-09 from September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line) expressed in ng g^{-1} dry weight.



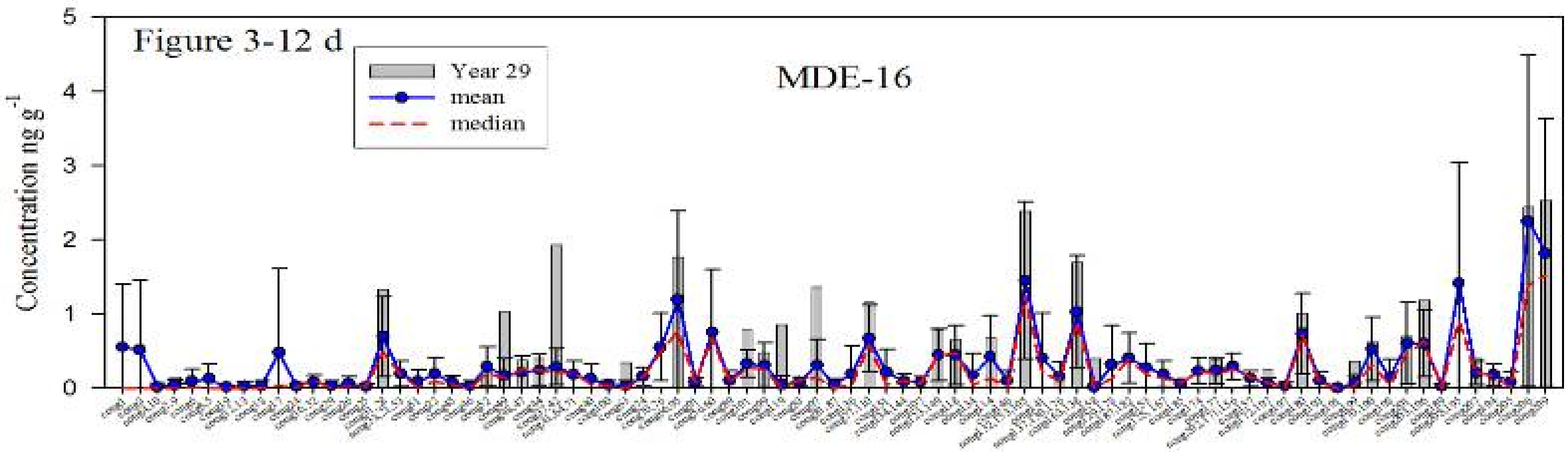


Figure 3-12 continued. Concentrations of PCB congeners in sediments from sites MDE-15 and MDE-16 from September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line) expressed in ng g^{-1} dry weight. MDE-15 is a newly established site and thus does not have historical data with which to calculate the mean, median and standard deviation.

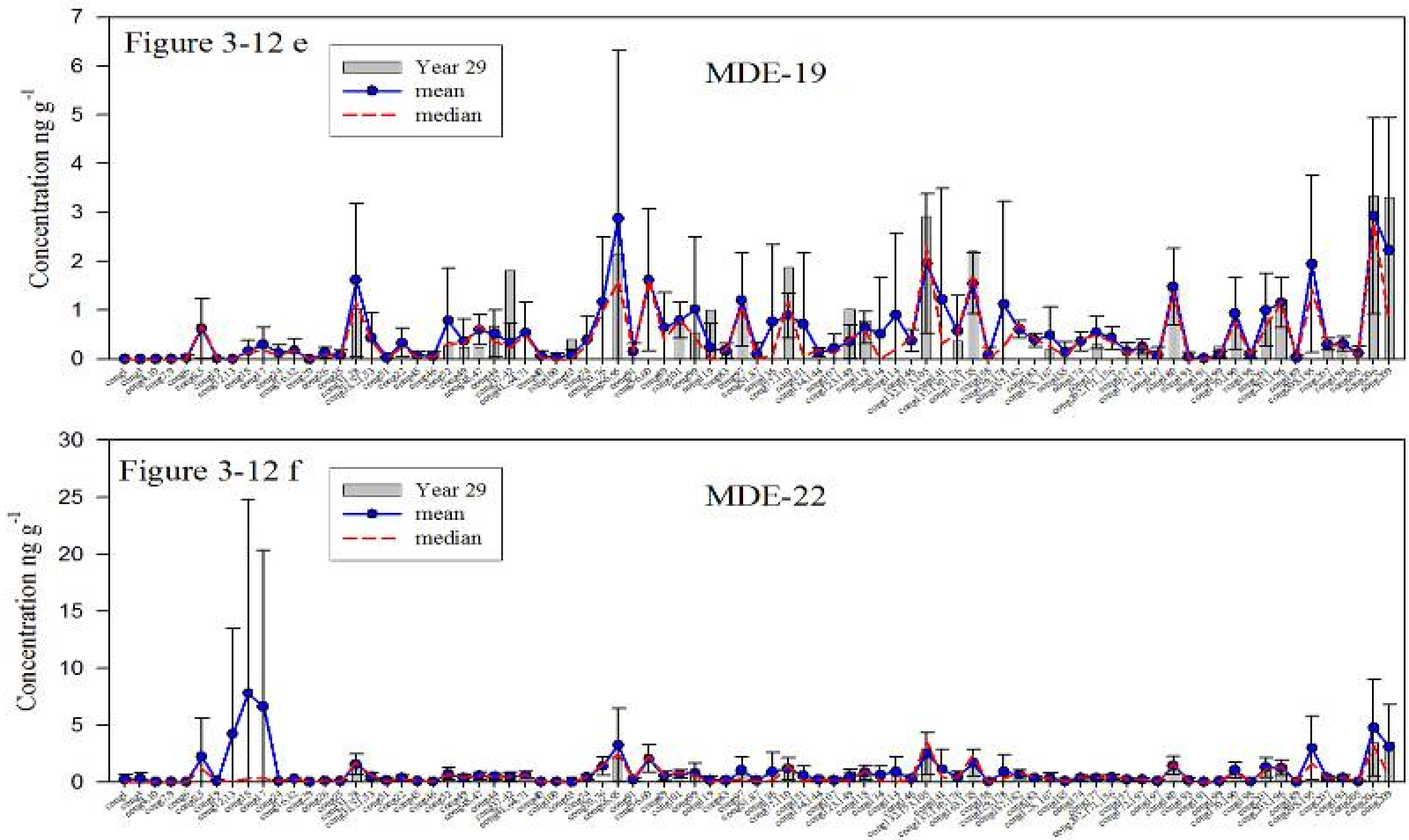
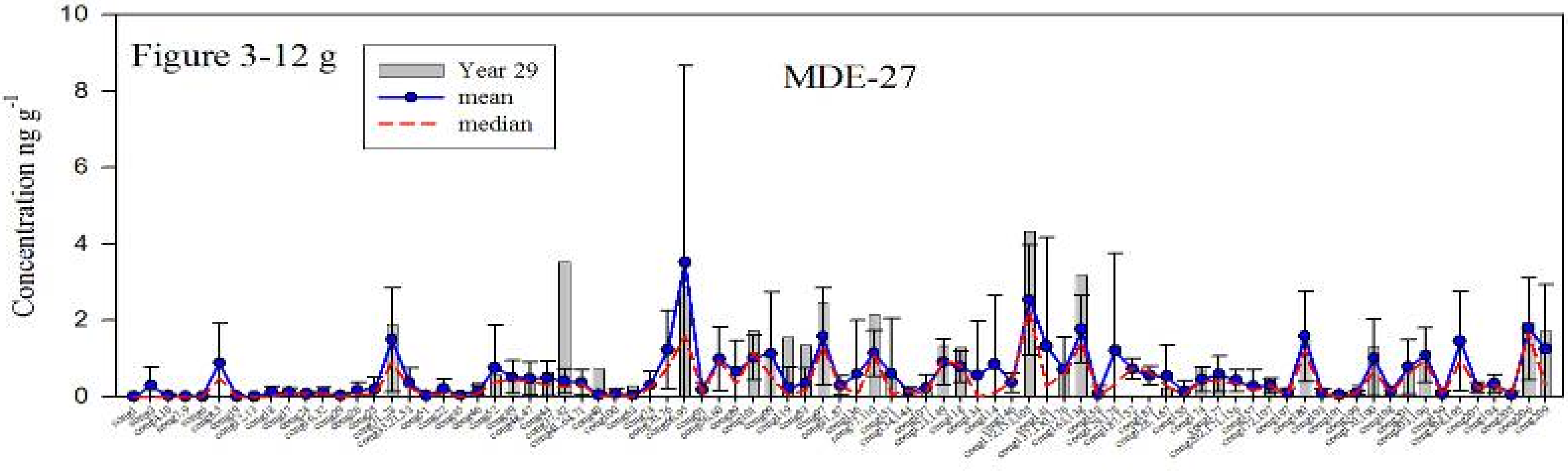


Figure 3-12 continued. Concentrations of PCB congeners in sediments from sites MDE-19 and MDE-22 from September 2010 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line) expressed in ng g^{-1} dry weight.



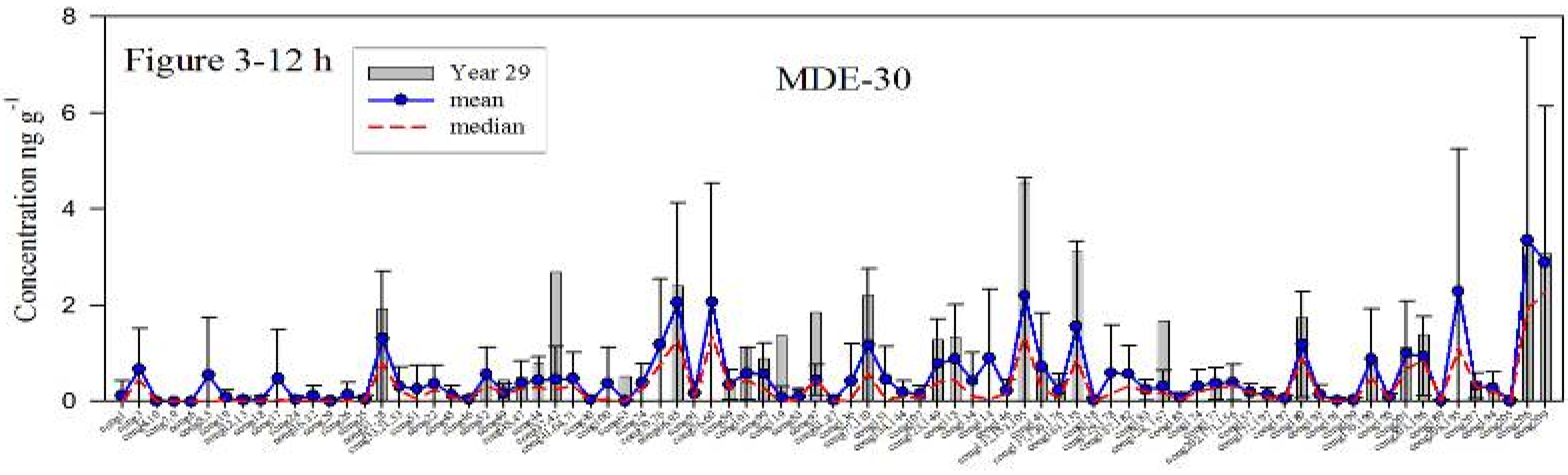


Figure 3-12 continued. Concentrations of PCB congeners in sediments from sites MDE-27 and MDE-30 from September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line) expressed in ng g^{-1} dry weight.

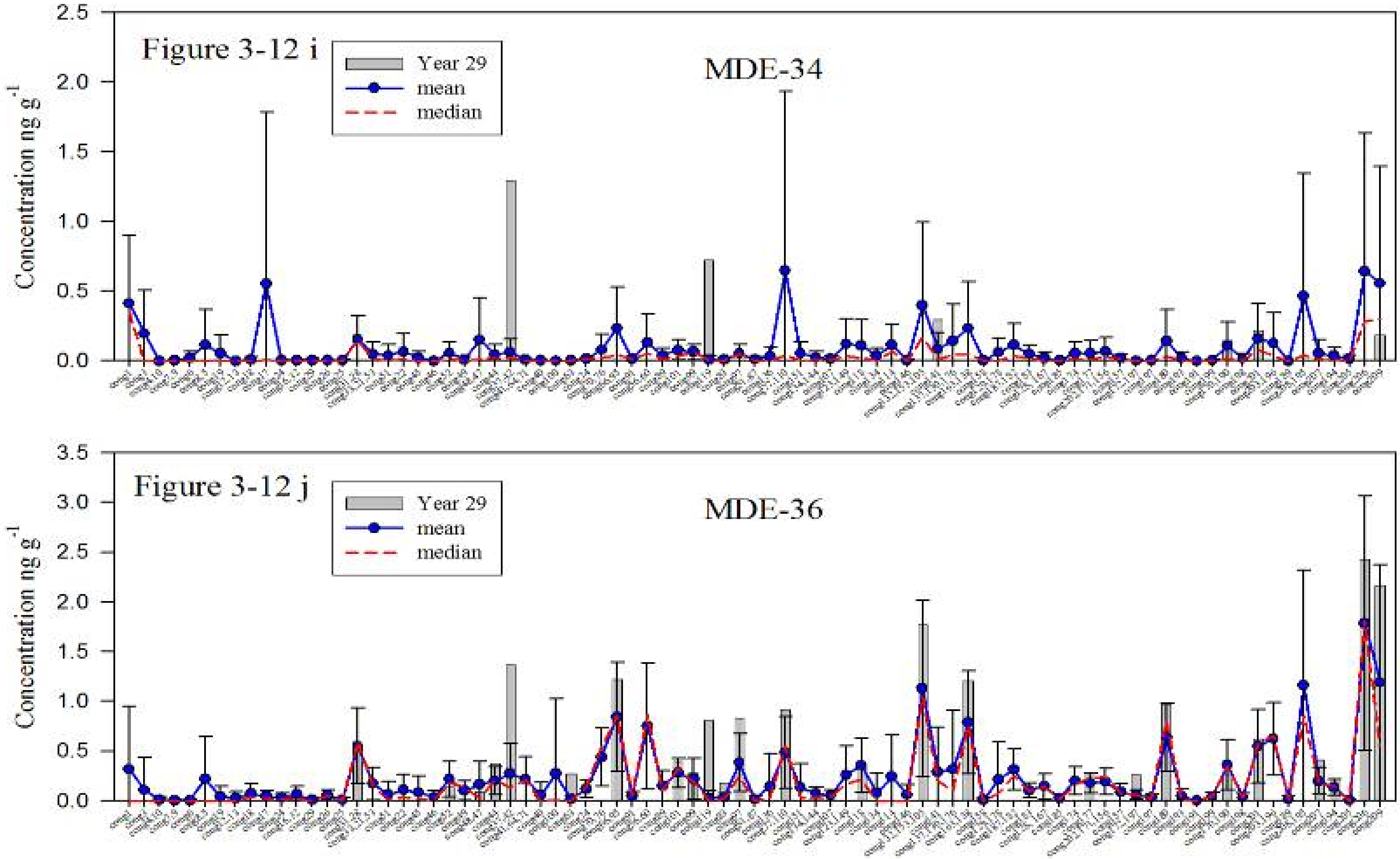
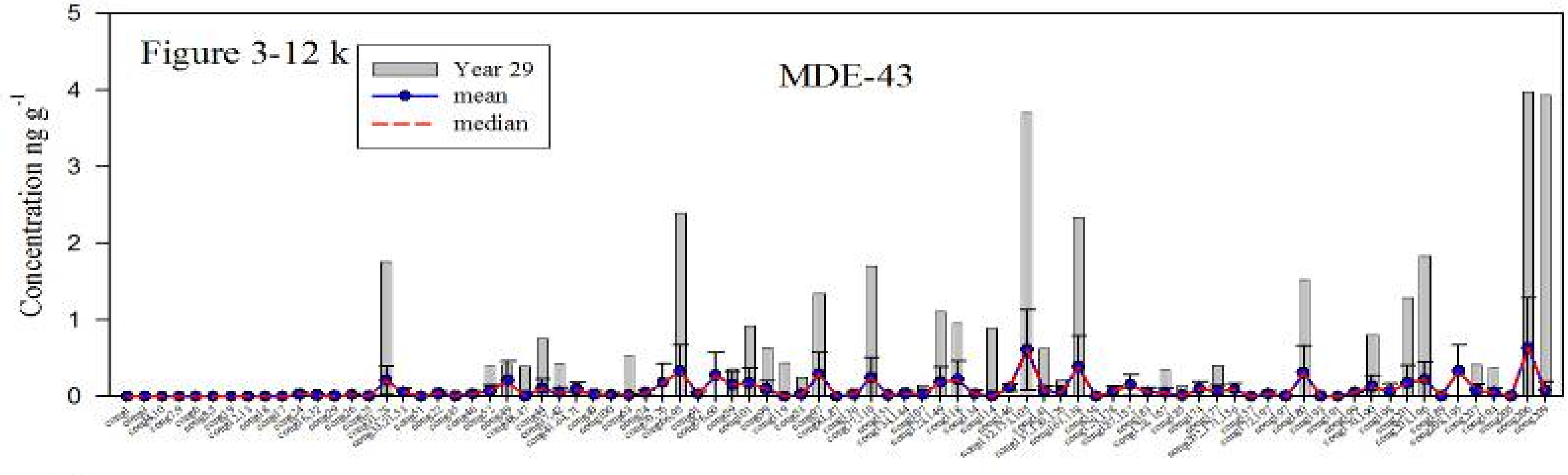


Figure 3-12 continued. Concentrations of PCB congeners in sediments from sites MDE-34 and MDE-36 from September 2010, the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line) expressed in ng g^{-1} dry weight.



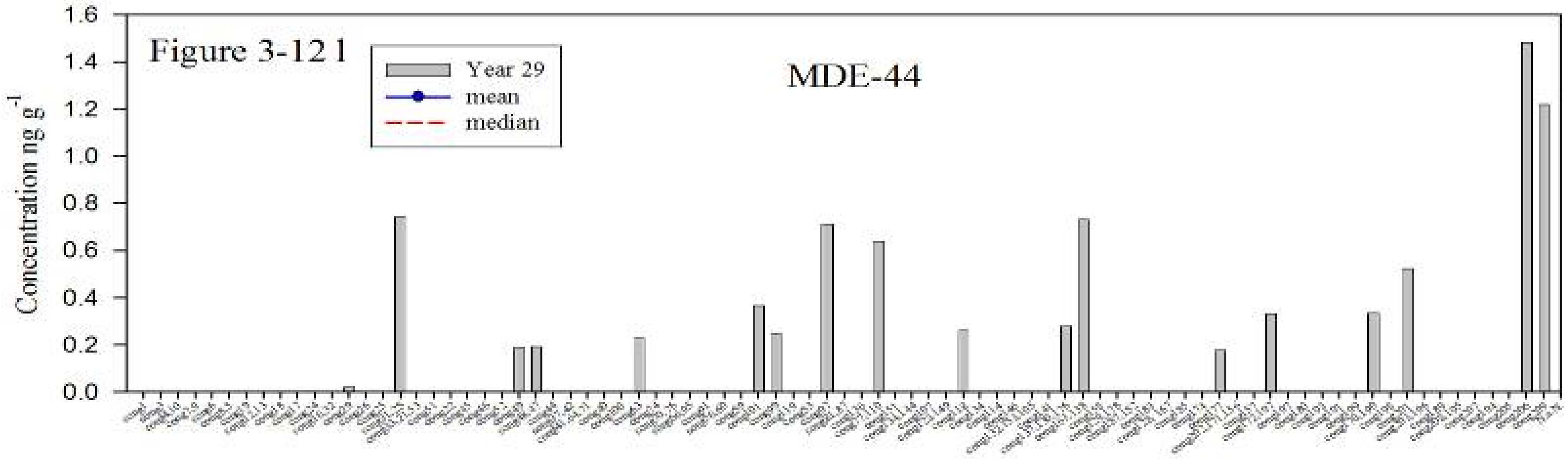
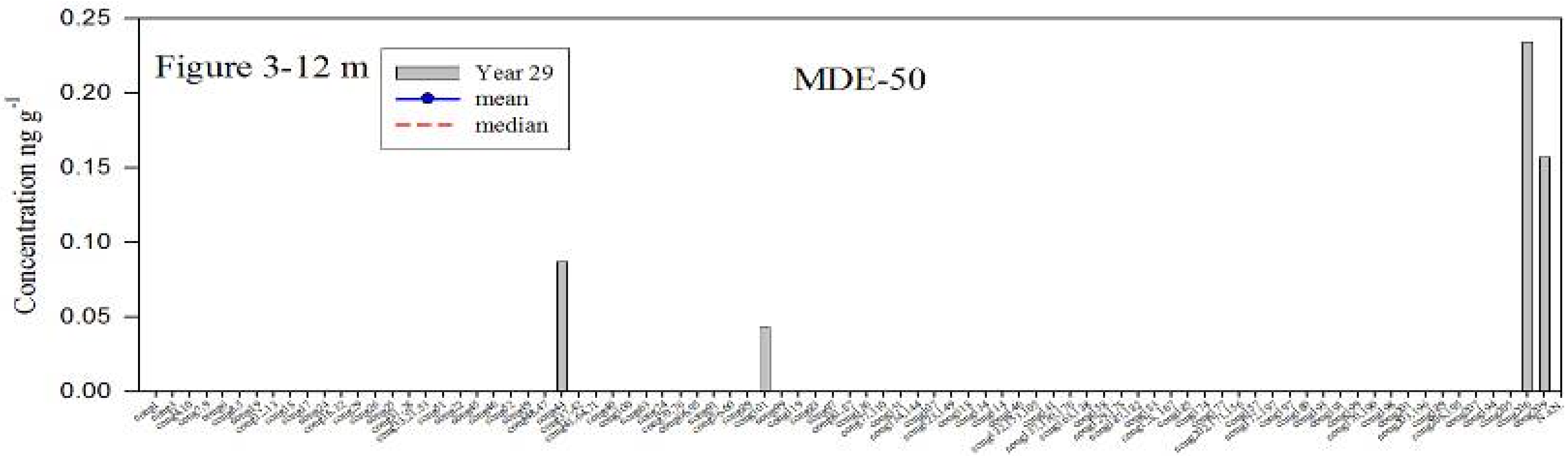


Figure 3-12 continued. Concentrations of PCB congeners in sediments from sites MDE-43 and MDE-44 collected in September 2010. The 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line) expressed in ng g^{-1} dry weight for MDE-43. MDE-44 is a newly established sites, thus we do not have historical data with which to calculate the mean, median and standard deviation.



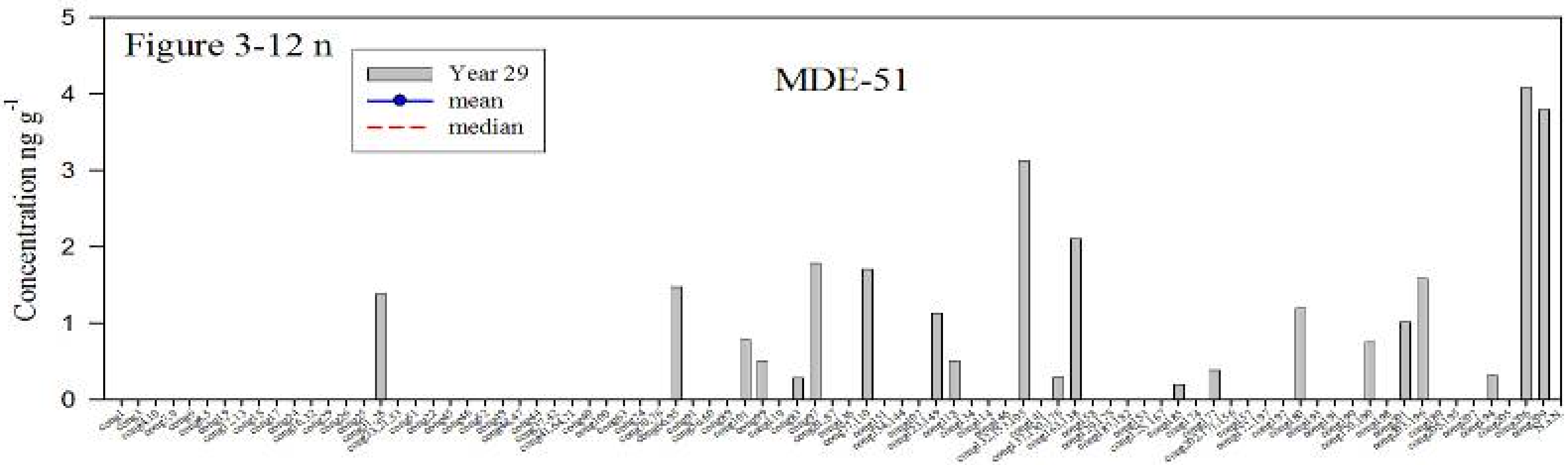


Figure 3-12 continued. Concentrations of PCB congeners in sediments from sites MDE-50 and MDE-51 collected in September 2010. MDE-50 and 51 are newly established sites, thus we do not have historical data with which to calculate the mean, median and standard deviation.

PCB Profiles in Clams

The PCBs congeners determined in the clams collected in September of 2010 are listed in Table 3-3 and concentrations summarized in Figure 3-13 a-m. Some of the sites shown have only been recently added and not all sites have been visited with enough regularity to calculate the mean and median, and thus they are not always shown. 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 groups 66+95, 132+153+105, 163+138, 187+182, 208+195, 206, 209 and the congener 180. 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.

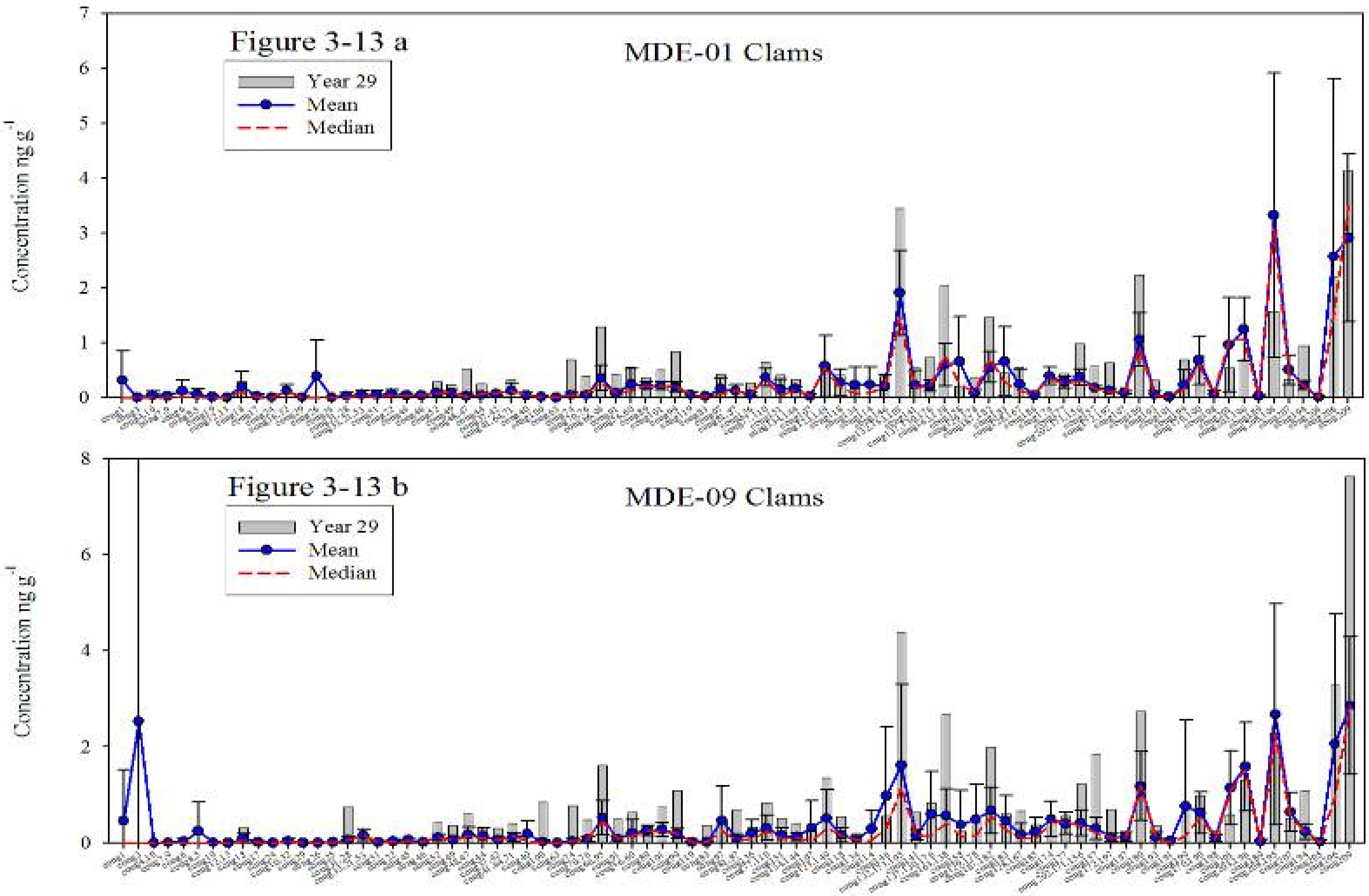


Figure 3-13. Concentrations of PCB congeners in clams from sites MDE-01 and MDE-09 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line) expressed in ng g^{-1} wet weight.

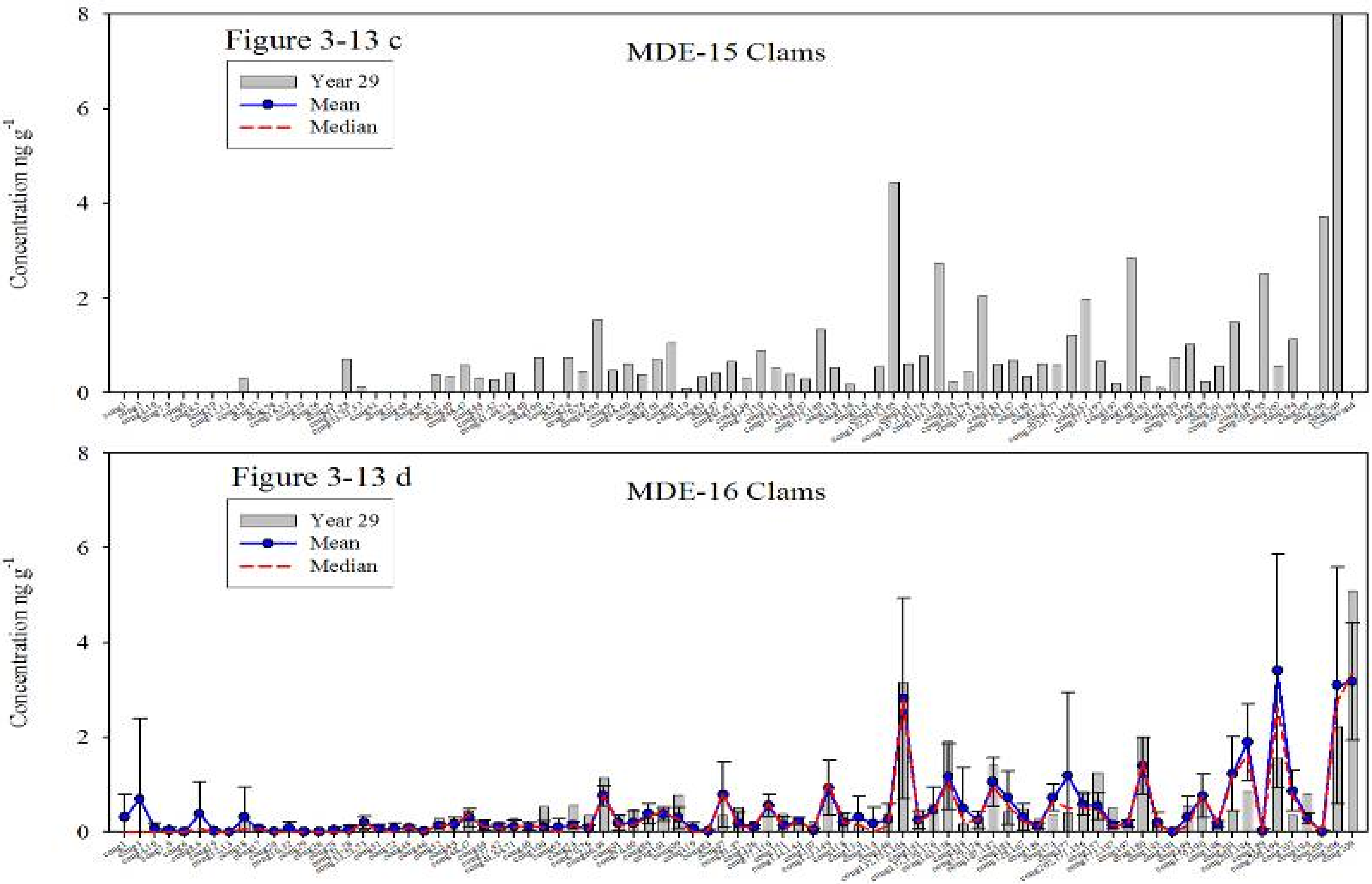
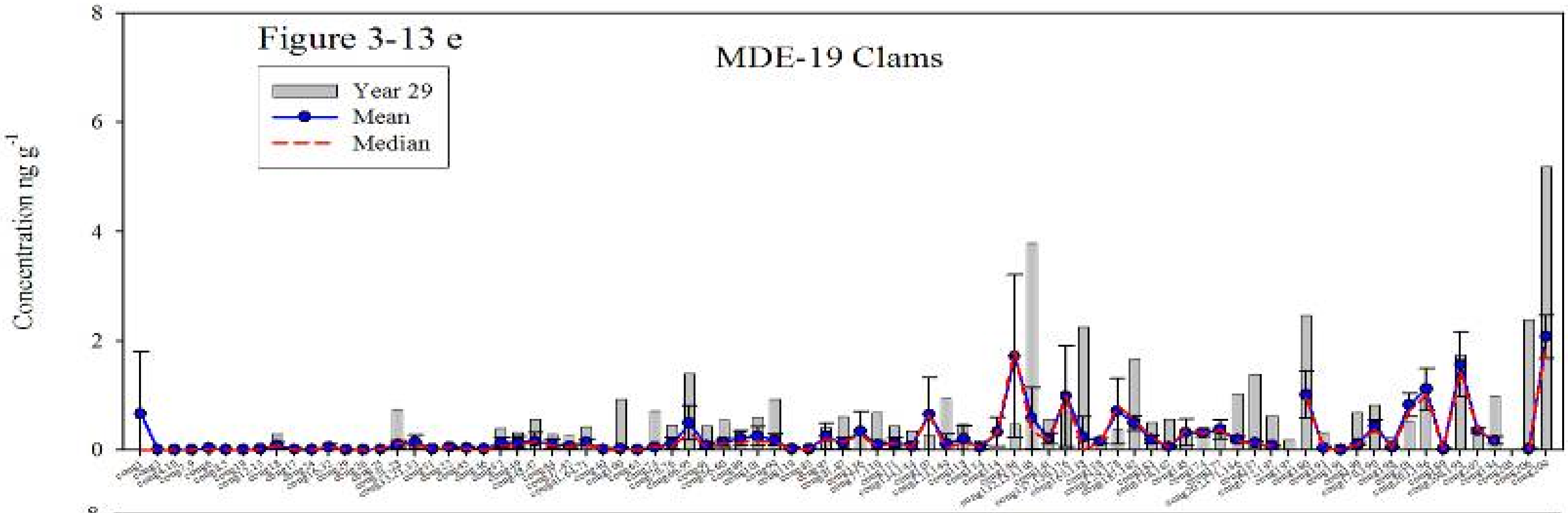


Figure 3-13 continued. Concentrations of PCB congeners in clams from sites MDE-15 and MDE-16 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line) expressed in ng g^{-1} wet weight. MDE-15 is a newly established site, thus we do not have historical data with which to calculate the mean, median and standard deviation.



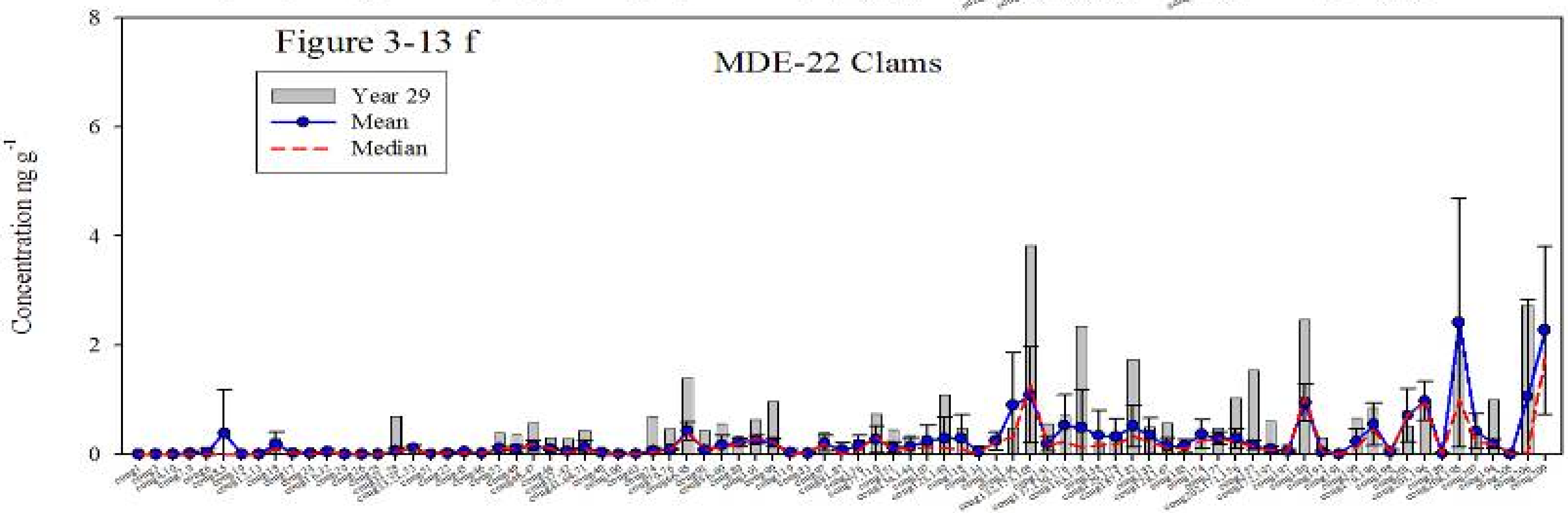


Figure 3-13 continued. Concentrations of PCB congeners in clams from sites MDE-19 and MDE-22 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line) expressed in ng g^{-1} wet weight.

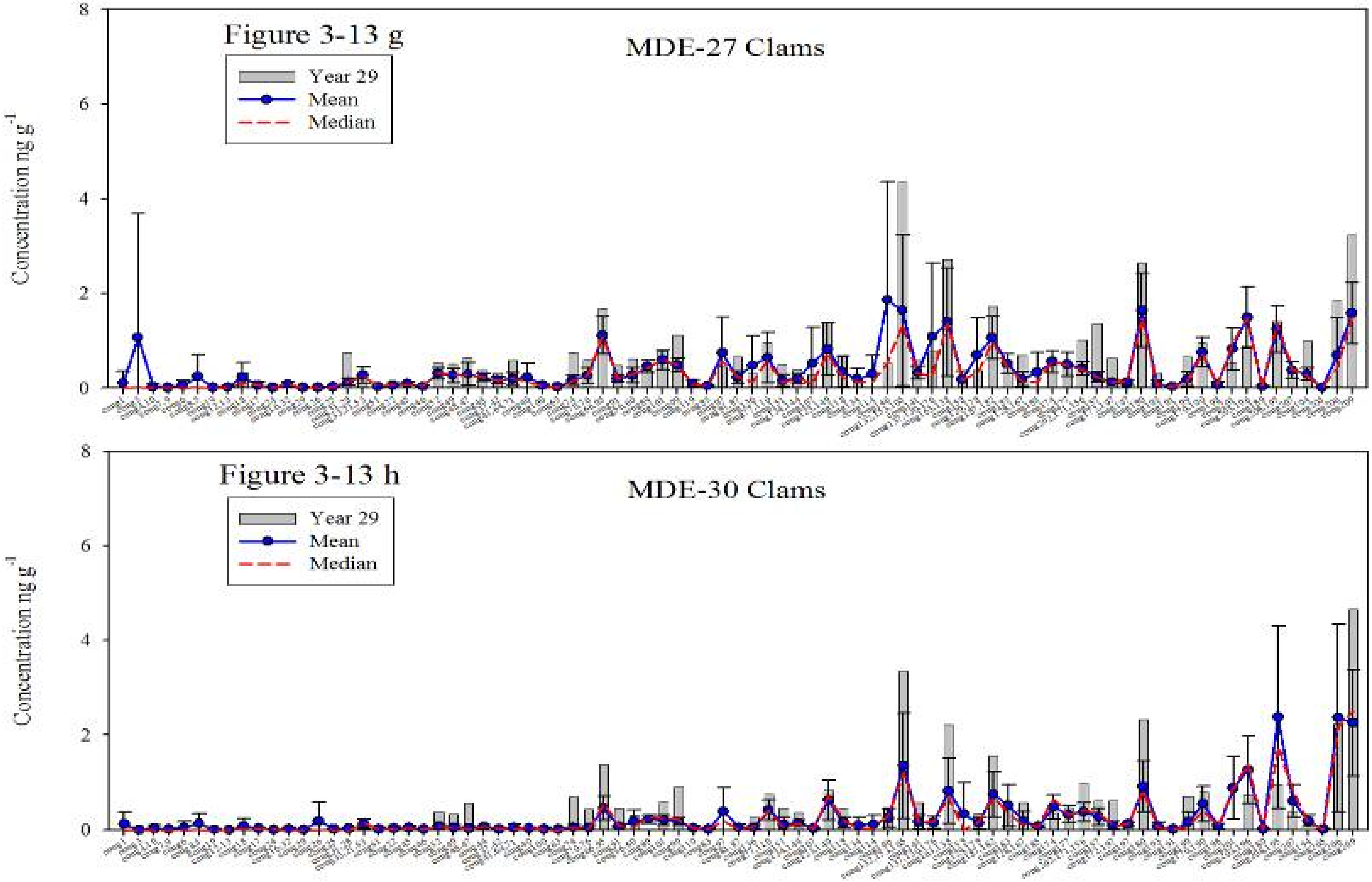
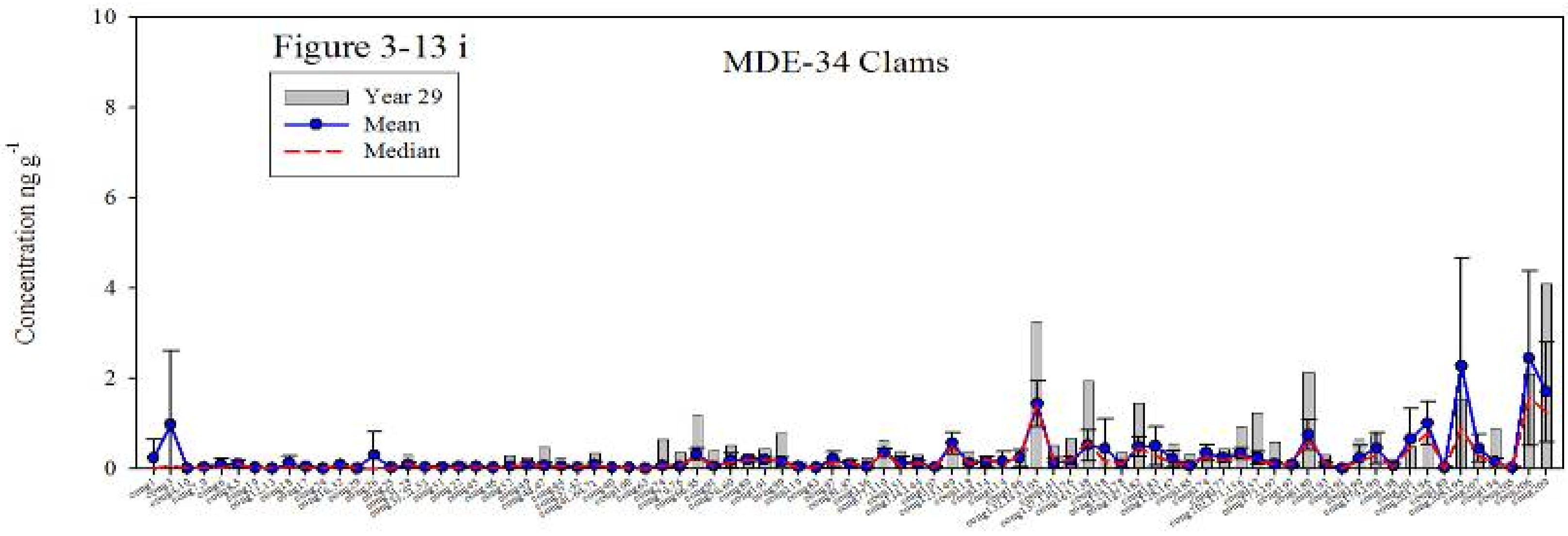


Figure 3-13 continued. Concentrations of PCB congeners in clams from sites MDE-27 and MDE-30 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line) expressed in ng g^{-1} wet weight.



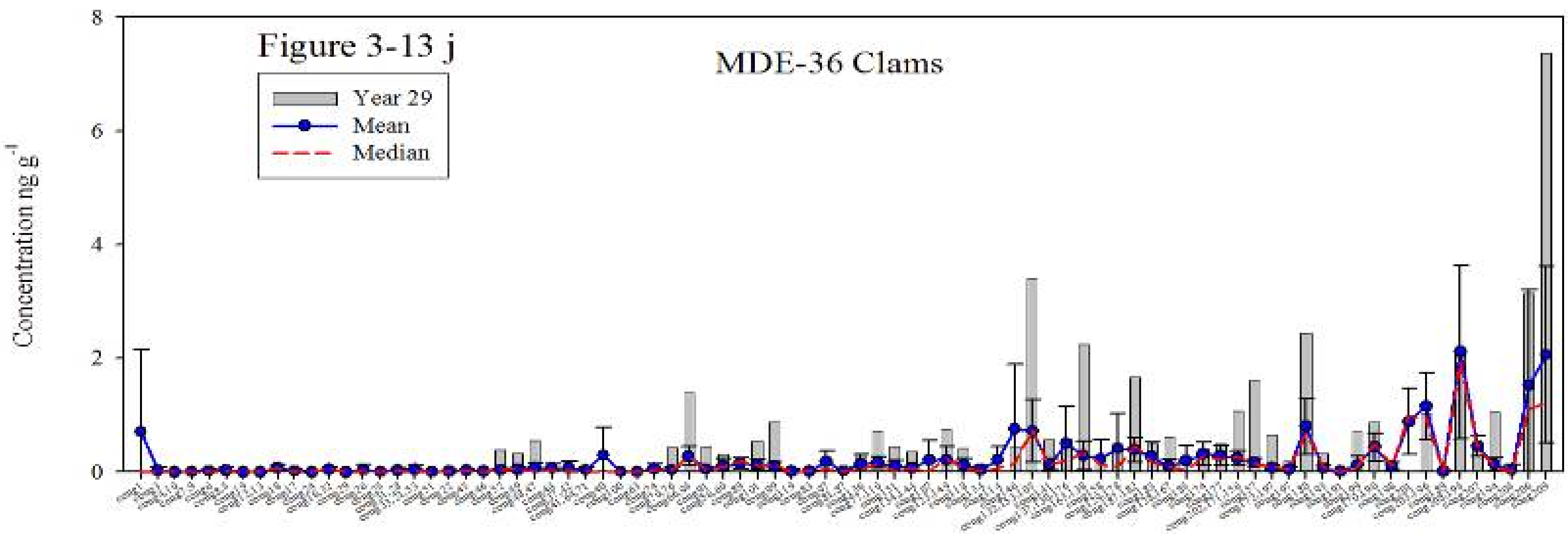
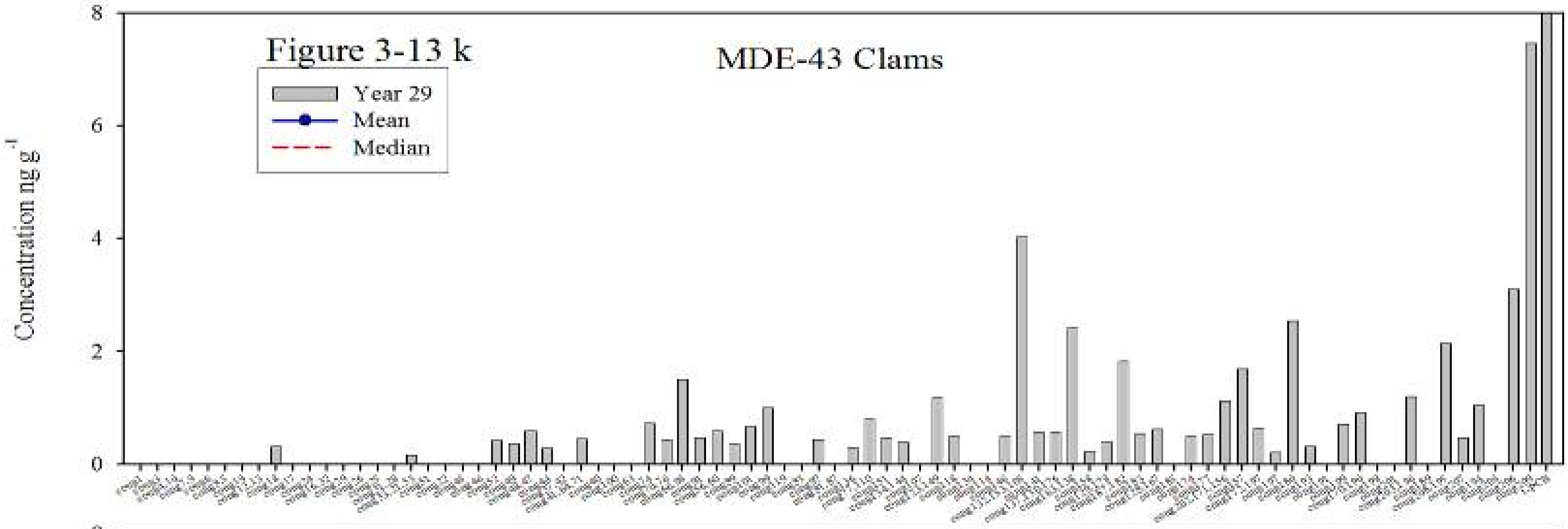


Figure 3-13 continued. Concentrations of PCB congeners in clams from sites MDE-34 and MDE-36 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line) expressed in ng g^{-1} wet weight.



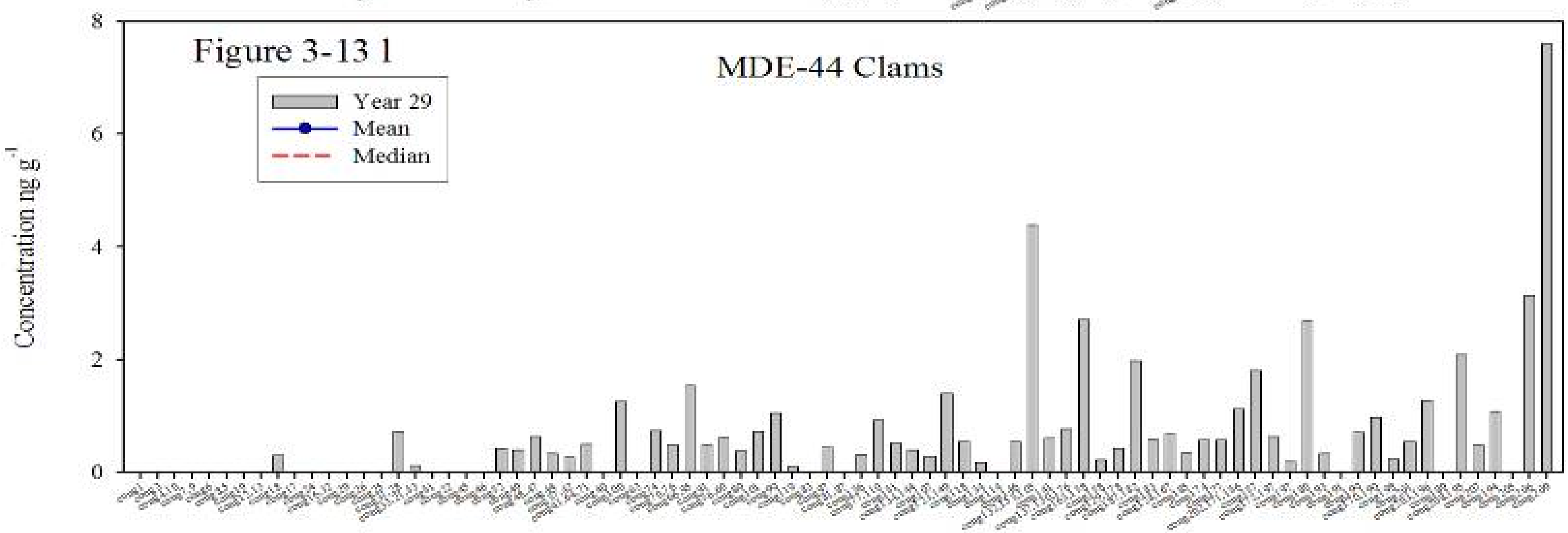


Figure 3-13 continued. Concentrations of PCB congeners in clams from site MDE-43 and MDE-44 obtained in September 2010 expressed in ng g^{-1} wet weight. MDE-43 and MDE-44 are newly established sites, thus we do not have historical data with which to calculate the mean, median and standard deviation.

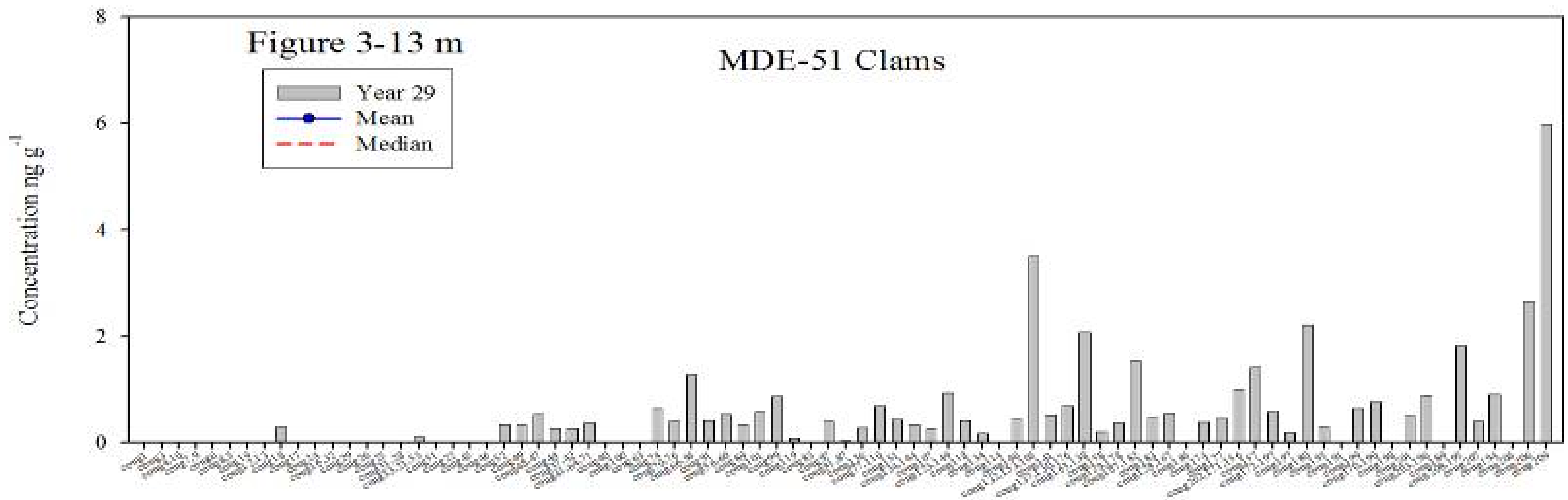
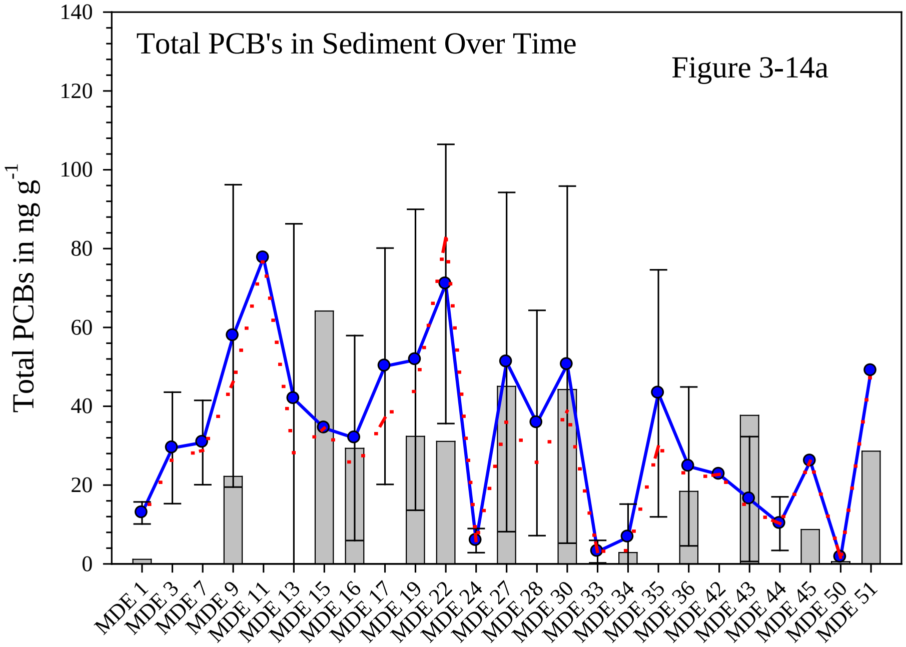


Figure 3-13 continued. Concentrations of PCB congeners in clams from site MDE-51 obtained in September 2010 expressed in ng g^{-1} wet weight. MDE-51 is a newly established site, thus we do not have historical data with which to calculate the mean, median and standard deviation.

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 3-14). The total PCB concentrations in sediment collected in September 2010 were similar to or below the historical site averages, being within the standard deviation of the mean with the exception of MDE-43. Total PCB concentrations in clams were on average 2 times higher than the running mean for all sites including the reference site, MDE-36. This trend can be seen in Figure 3-13a-m, where concentrations of some individual congeners exceed the historical means. The congener distributions in sediment (Figure 3-12a-n) and clams (Figure 3-13a-m) are similar for the same site.

Plots of the PCB homologs were constructed to better examine whether clams are capturing a different set of PCB congeners that might explain why the concentrations in clams appear elevated with respect to historical levels while sediment are lower. The homolog distributions for sediment and clams for each site were plotted as percentage of the total PCB concentration in Figure 3-15a-l. The reference site is plotted with each site as a point of reference. At each site the distribution of homologs (Table 3-4) in sediment and clams are similar with no bias to the lower molecular weight complexes. 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 anomalous unto its self (Figure 3-14a). The clams reflect the same distribution of PCB congeners in the sediment at any one site, but the clam congener concentrations are higher than what has been observed historically. This situation would suggest above normal PCB concentrations in the water column but deposition of material of lower than normal PCB concentrations.



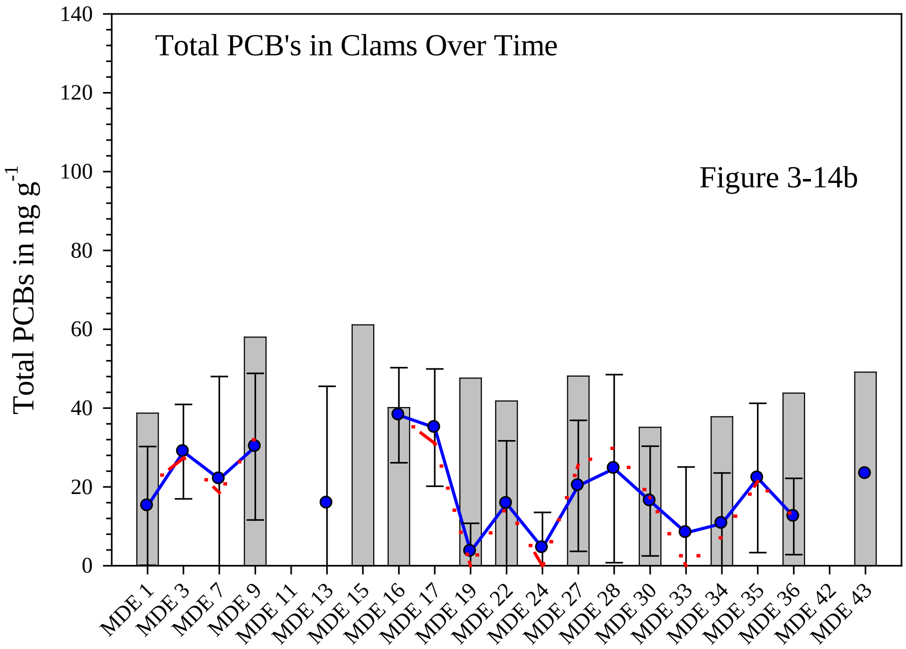


Figure 3-14. Total PCB concentrations in sediments (a) (ng g^{-1} dry weight) and total PCB concentrations in clams (ng g^{-1} wet weight) collected in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line).

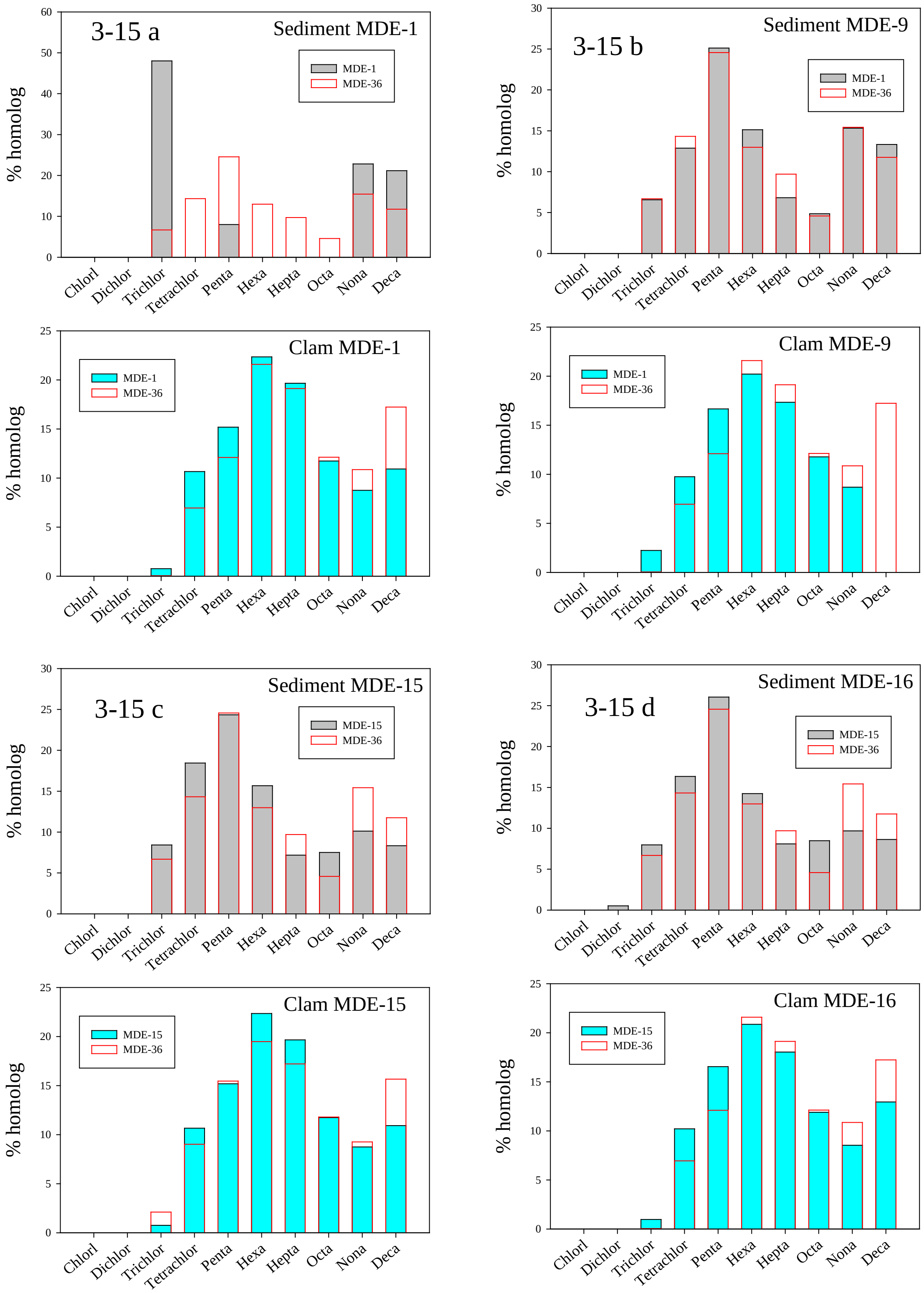


Figure 3-15. Homolog distributions in sediment (grey bars) and clams (blue bars) plotted with reference site MDE-36 (red bars) at sites a) MDE-1, b) MDE-9, c) MDE-15 and d) MDE 16.

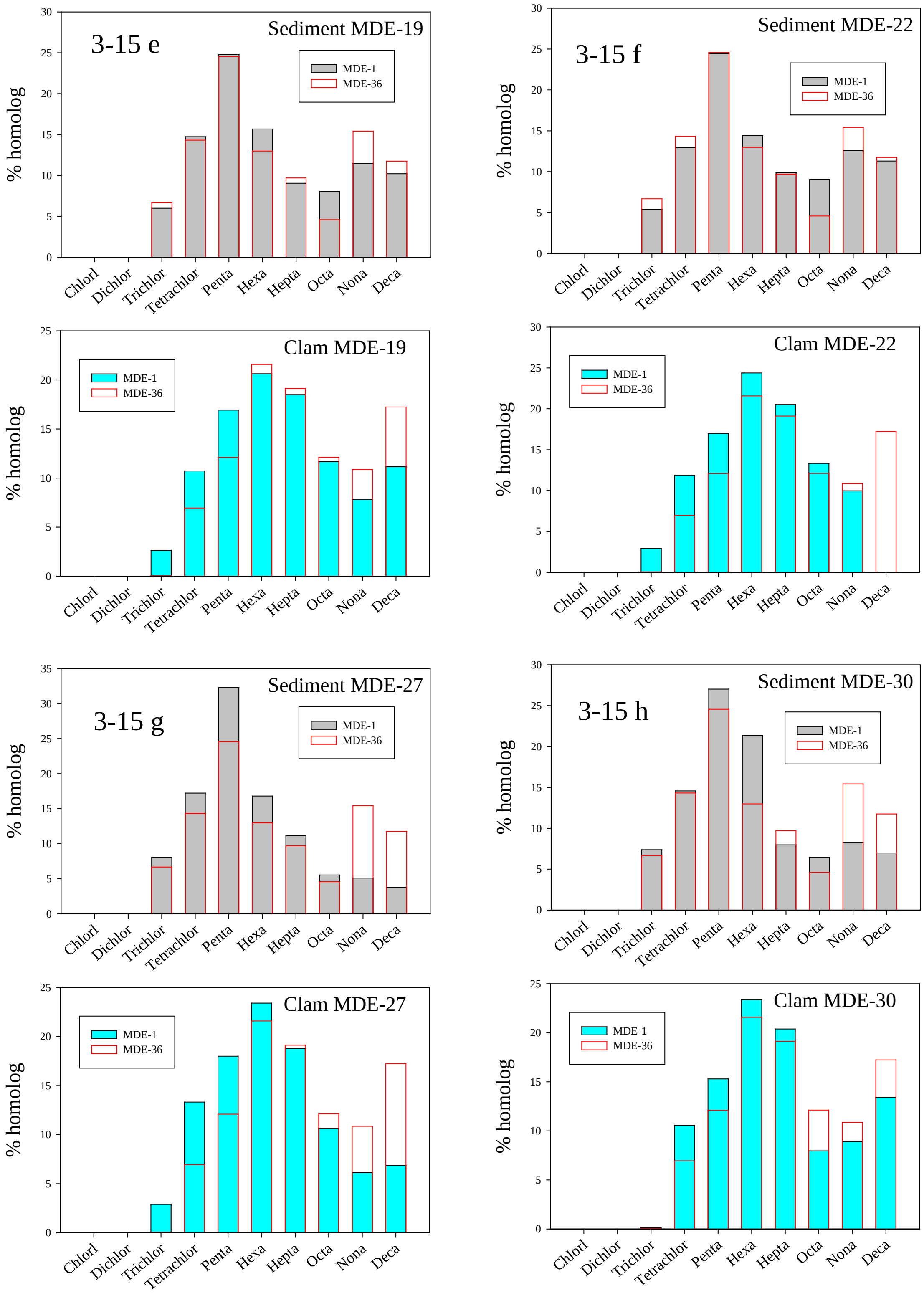


Figure 3-15 continued. Homolog distributions in sediment (grey bars) and clams (blue bars) plotted with reference site MDE-36 (red bars) at sites e) MDE-19, f) MDE-22, g) MDE- 27, h) MDE-30.

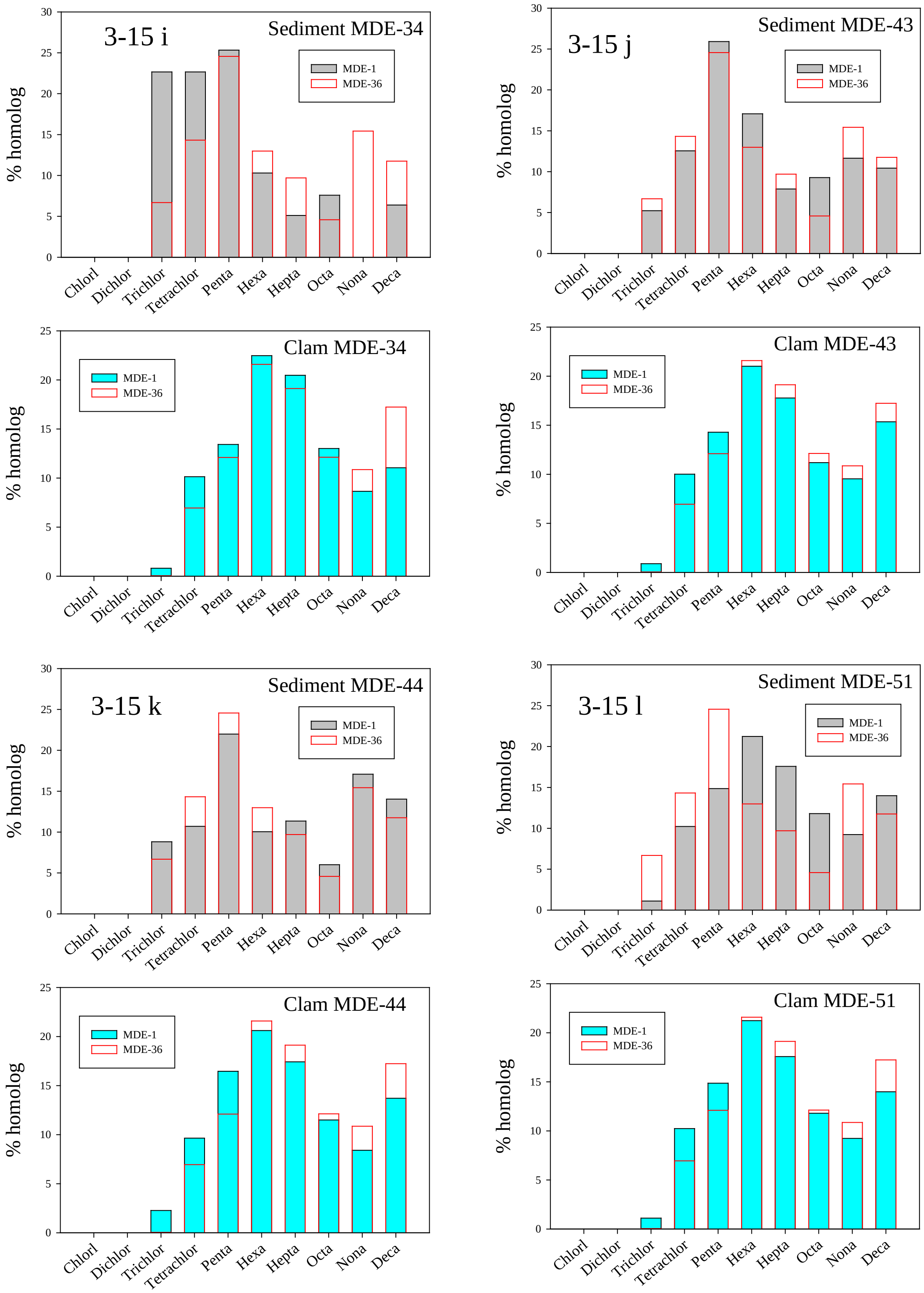


Figure 3-15 continued. Homolog distributions in sediment (grey bars) and clams (blue bars) plotted with reference site MDE-36 (red bars) at sites i) MDE-34, j) MDE 43, k) MDE-44, l) MDE-51.

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 3-16a-n. The most common compounds are: naphthalene, 2-methylnaphthalene, phenanthrene, fluoranthene, pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[e]pyrene, 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 where lower than has been observed in past sampling. Site MDE-27 had higher concentrations and a slightly different pattern in the PAH profile. Cyclopenta[c,d]pyrene and benzo[b]fluouranthene were elevated in concentration well above historical levels and are out of proportion with other congeners. Elevated presence of these compounds relative to the ubiquitous and more stable benzo(e)pyrene suggest less decomposition of PAHs has occurred at this site (Spitzer 2007). Reasons for this could include new sediment being deposited or a slower rate of microbial activity. Despite the high PAH concentrations and unusual profile from MDE-27, as a whole the 2010 profiles are similar to the historical averages. Being newly established in 2008, MDE-43, 44, 50 and 51 have not been visited frequently enough for 2010 PAH concentrations to be compared in a historical context.

Table 3-5. Polycyclic aromatic hydrocarbons given in the same order as in Figure 3-16 a-m (left to right).

Polycyclic Aromatic Hydrocarbons					
1	Napthalene	16	Anthracene	31	Napthacene
2	2-Methylnapthalene	17	2-Methyldibenzothiophene	32	4-Methylchrysene
3	1-Methylnapthalene	18	4-Methyldibenzothiophene	33	Benzo[b]fluoranthene
4	Biphenyl	19	2-Methylphenanthrene	34	Benzo[k]fluoranthene
5	1,3-Dimethylnapthalene	20	2-Methylanthracene	35	Benzo[e]pyrene
6	1,6-Dimethylnapthalene	21	4,5-Methylenephenanthrene	36	Benzo[a]pyrene
7	1,4-Dimethylnapthalene	22	1-Methylanthracene	37	Perylene
8	1,5-Dimethylnapthalene	23	1-Methylphenanthrene	38	3-Methylchloanthrene
9	Acenapthylene	24	9-Methylanthracene	39	Indeno[1,2,3-c,d]pyrene
10	1,2-Dimethylnapthalene	25	Fluoranthene	40	Dibenz[a,h+ac]anthracene
11	1,8-Dimethylnapthalene	26	Pyrene	41	Benzo[g,h,i]perylene
12	Acenapthene	27	Benzo[a]fluorene	42	Anthanthrene
13	Fluorene	28	Benzo[b]fluorene	43	Corenene
14	1-Methylfuorene	29	Cyclopenta[c,d]pyrene		
15	Phenanthrene	30	Chrysene+Triphenylene		

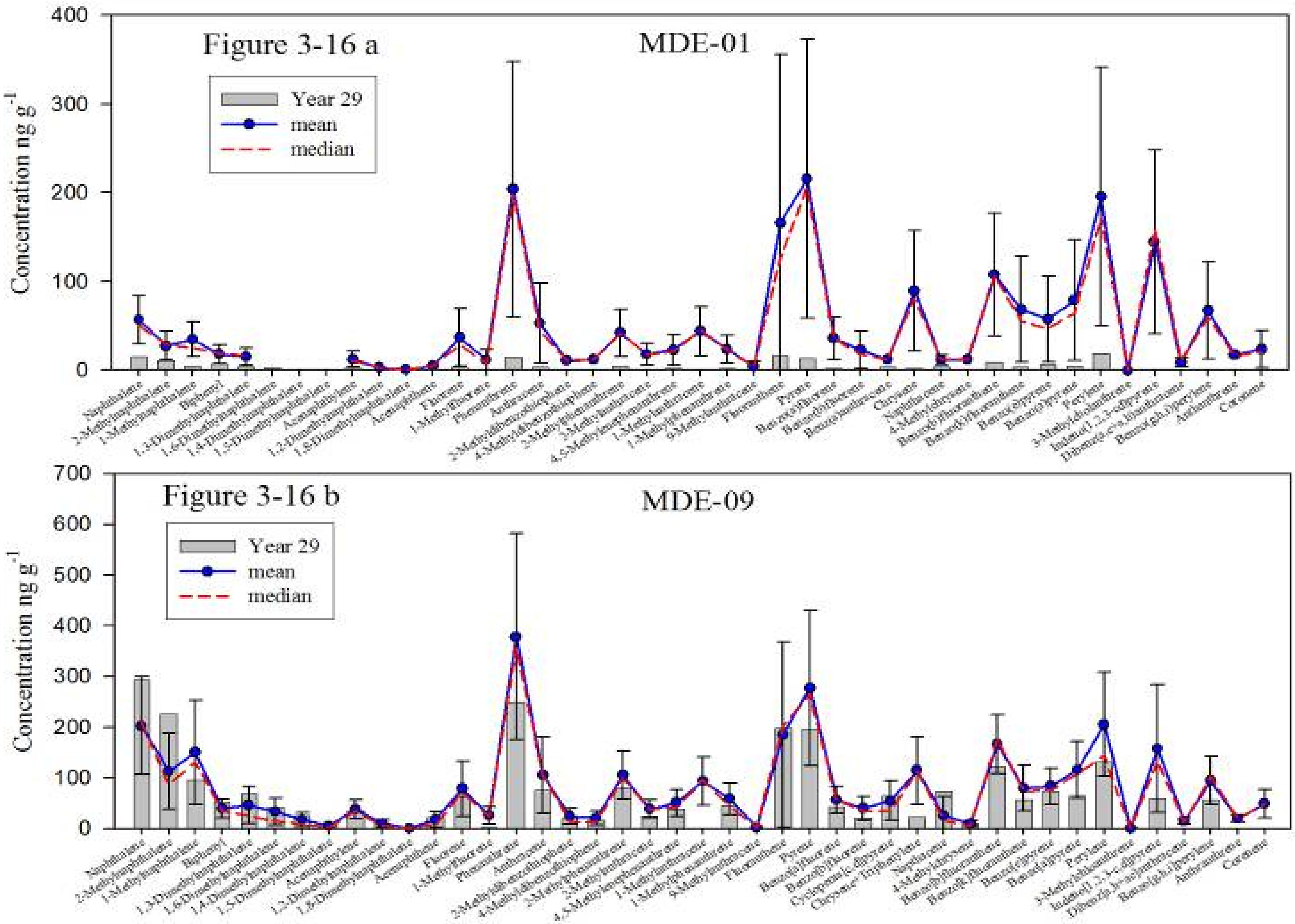


Figure 3-16. Concentrations of PAHs in sediments from site MDE-01 and MDE-09 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line), expressed in ng g^{-1} dry weight.

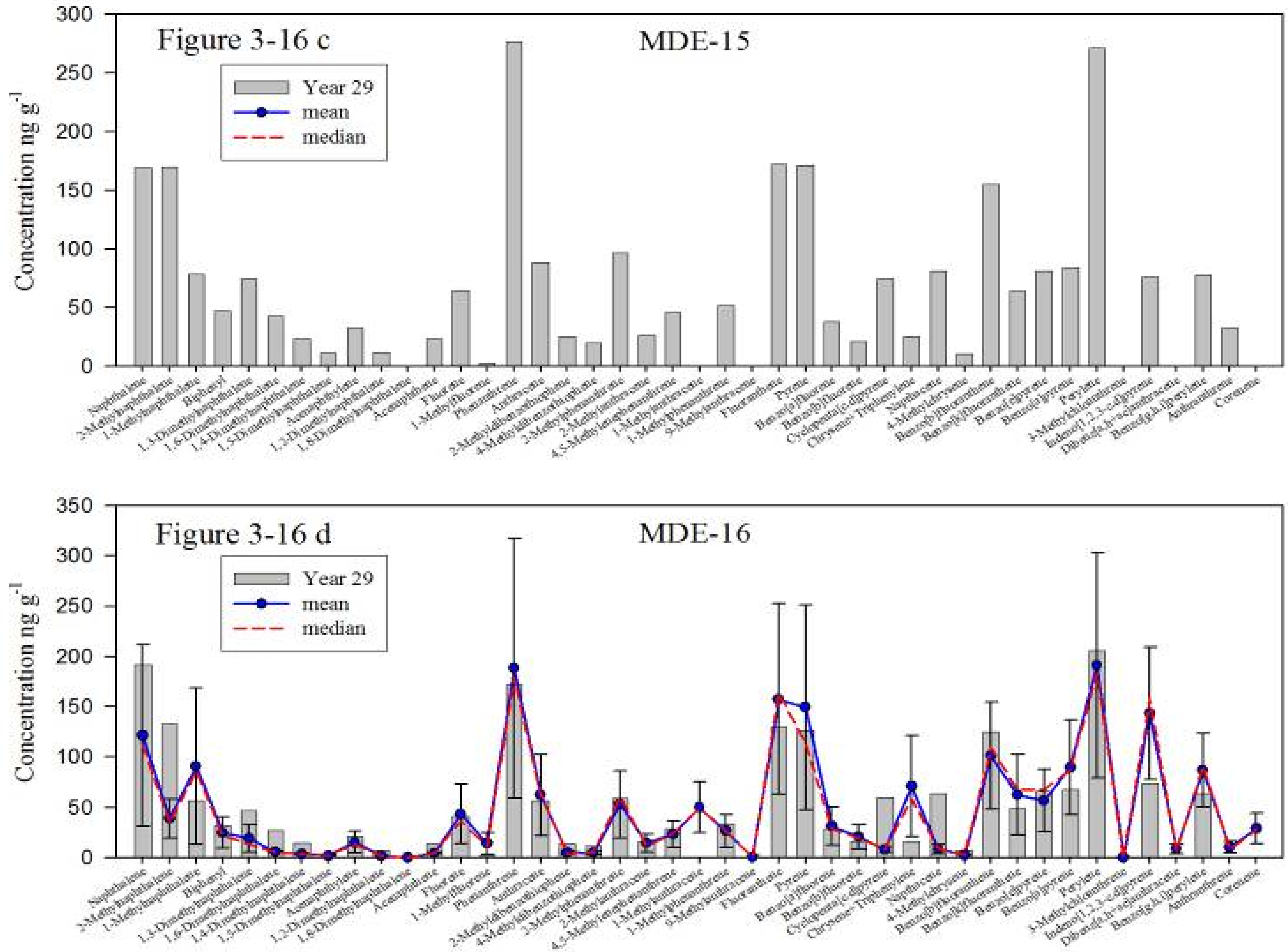
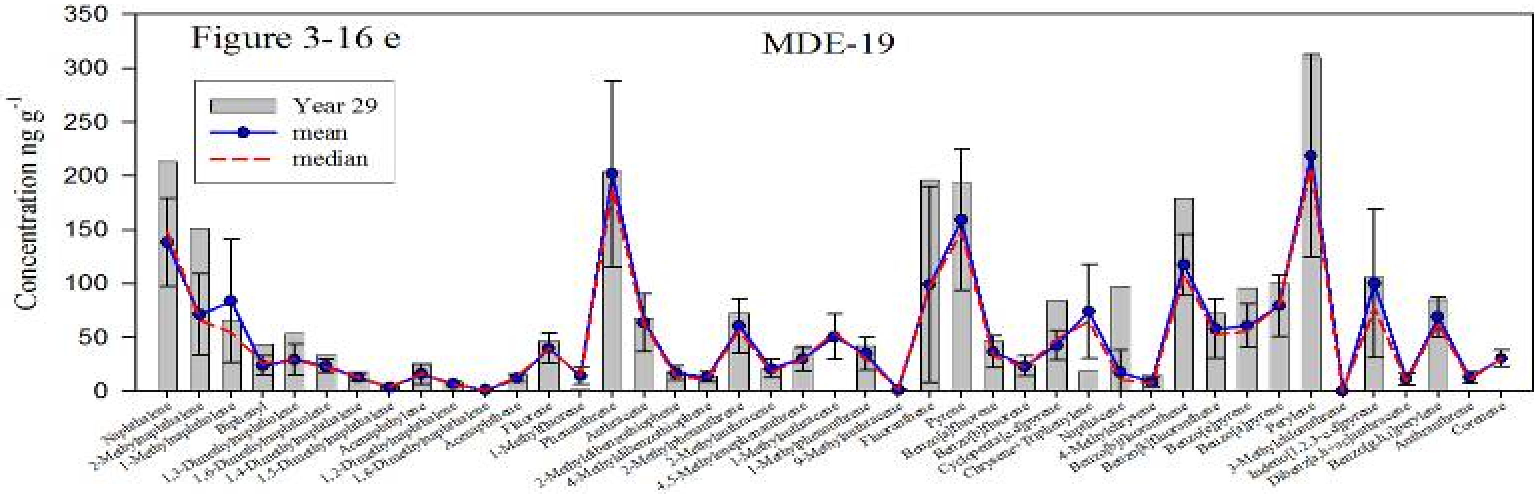


Figure 3-16 continued. Concentrations of PAHs in sediments from site MDE-15 and MDE-16 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line), expressed in ng g^{-1} dry weight.



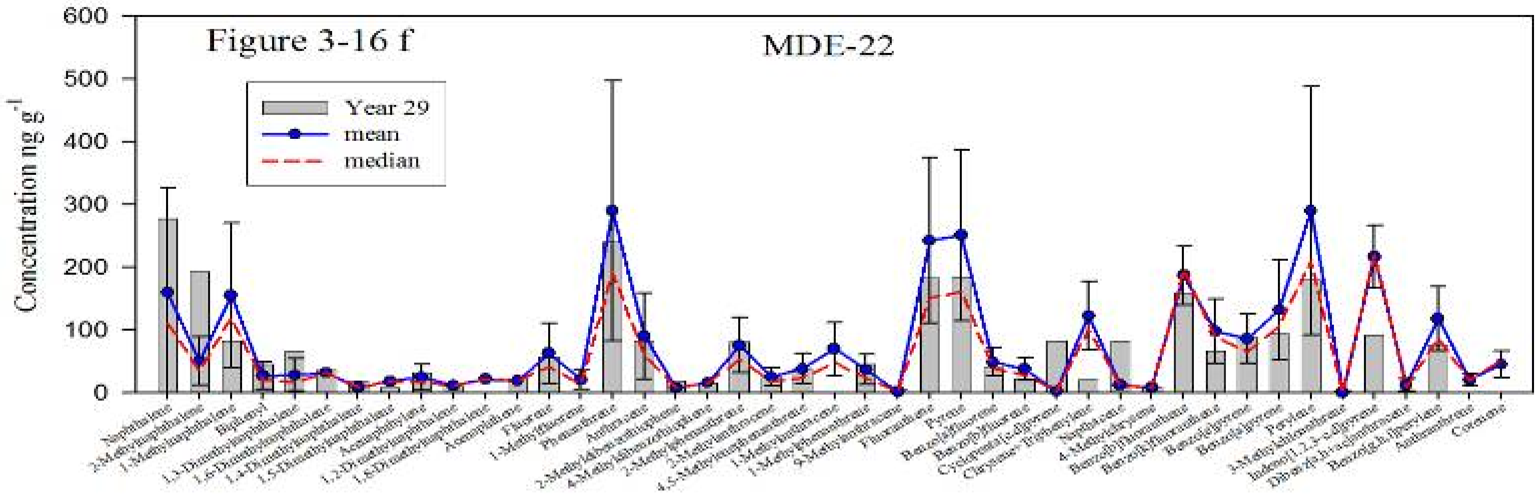


Figure 3-16 continued. Concentrations of PAHs in sediments from site MDE-19 and MDE-22 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line), expressed in ng g^{-1} dry weight.

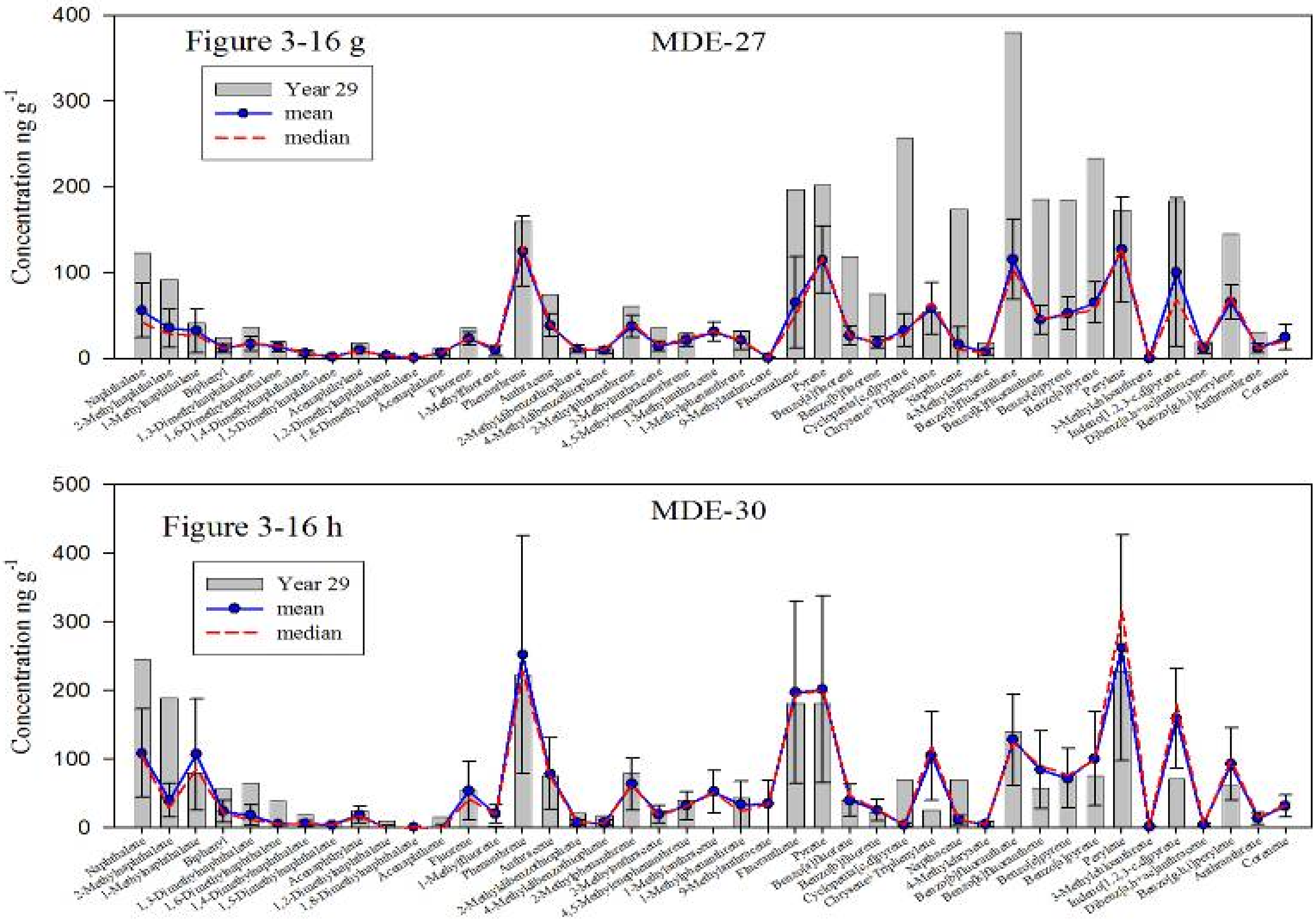


Figure 3-16 continued. Concentrations of PAHs in sediments from site MDE-27 and MDE-30 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line), expressed in ng g^{-1} dry weight.

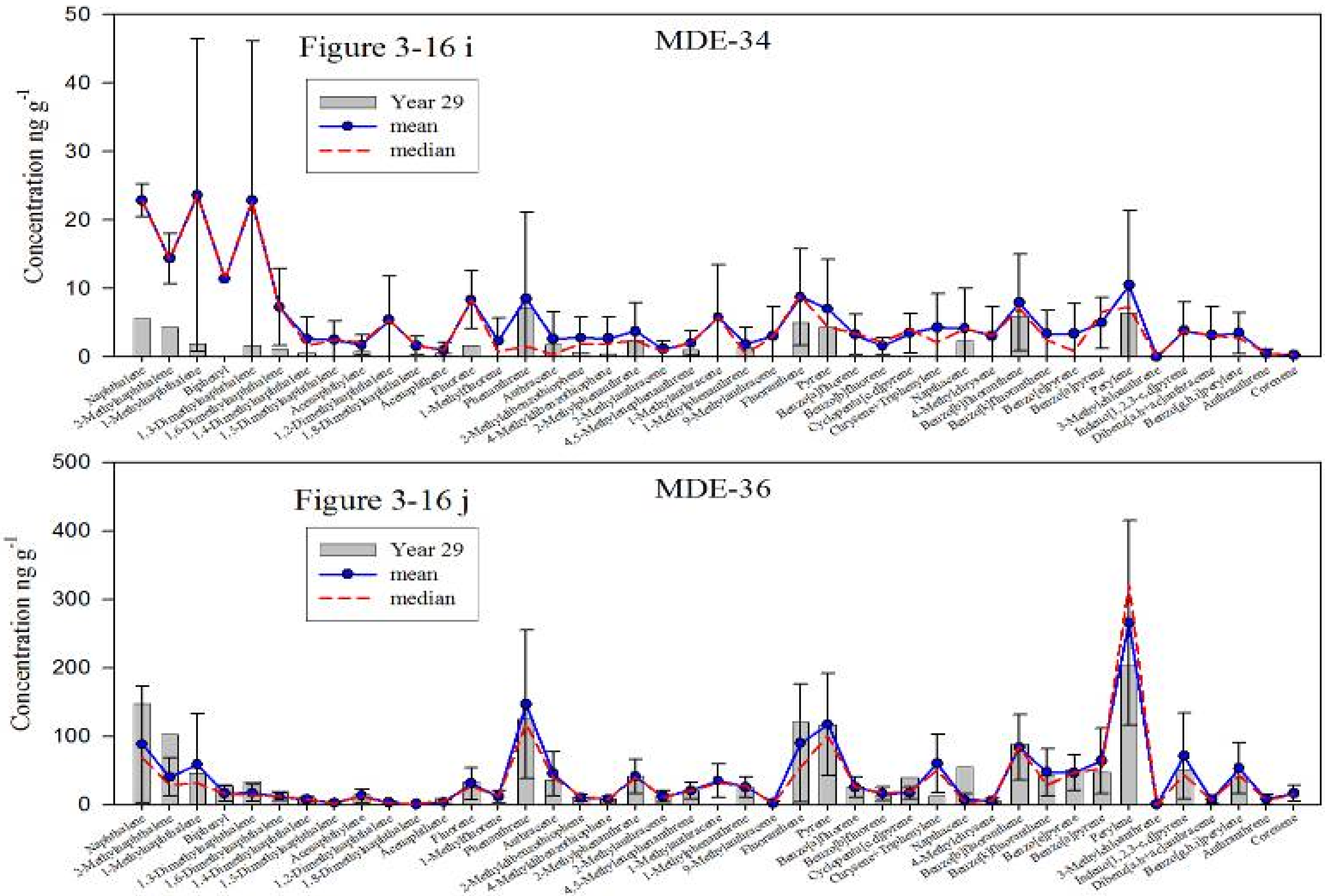


Figure 3-16 continued. Concentrations of PAHs in sediments from site MDE-34 and MDE-36 obtained in September 2010 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line), expressed in ng g^{-1} dry weight.

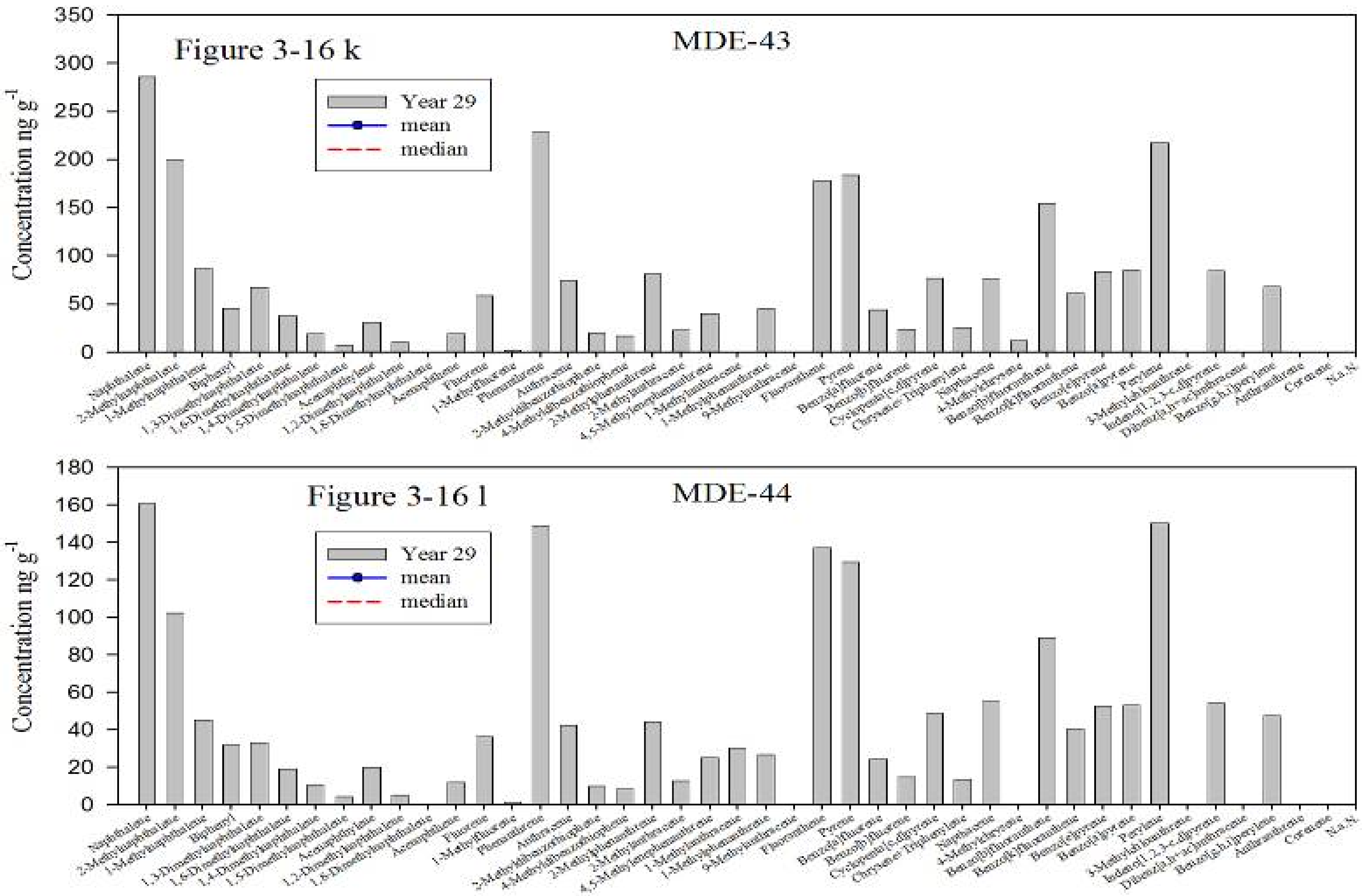
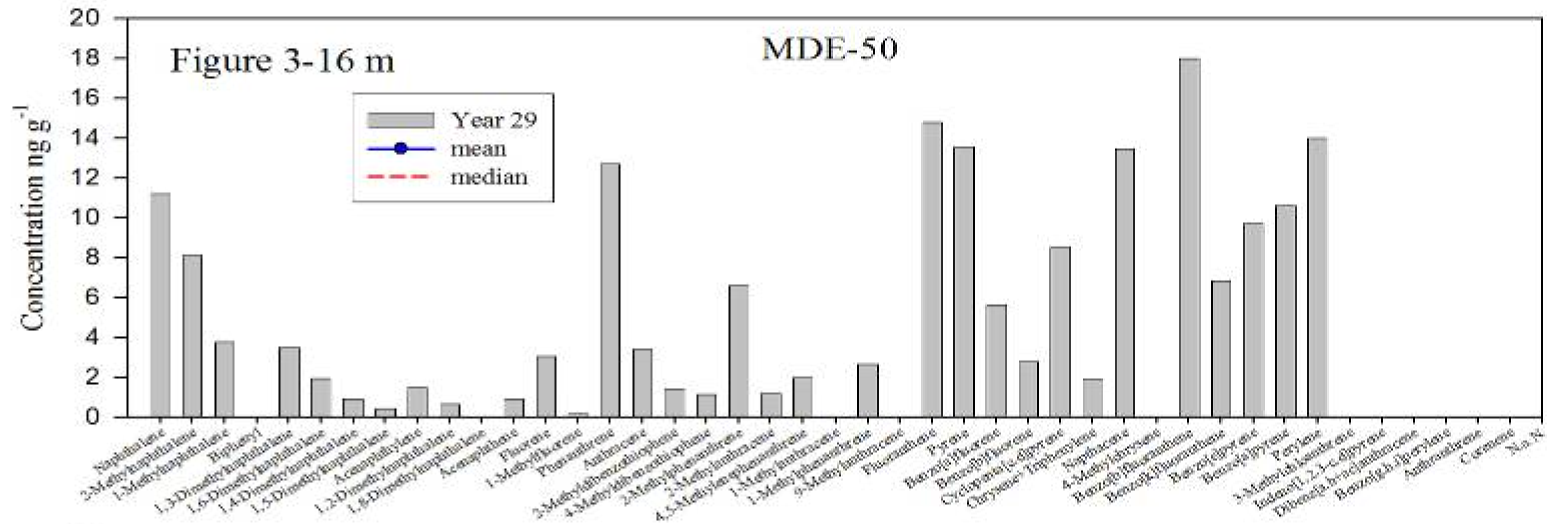


Figure 3-16 continued. Concentrations of PAHs in sediments from site MDE-43 and MDE-44 obtained in September 2010 expressed in ng g^{-1} dry weight. MDE-43 and 44 are newly established sites and thus do not have historical data with which to calculate the mean, median and standard deviation.



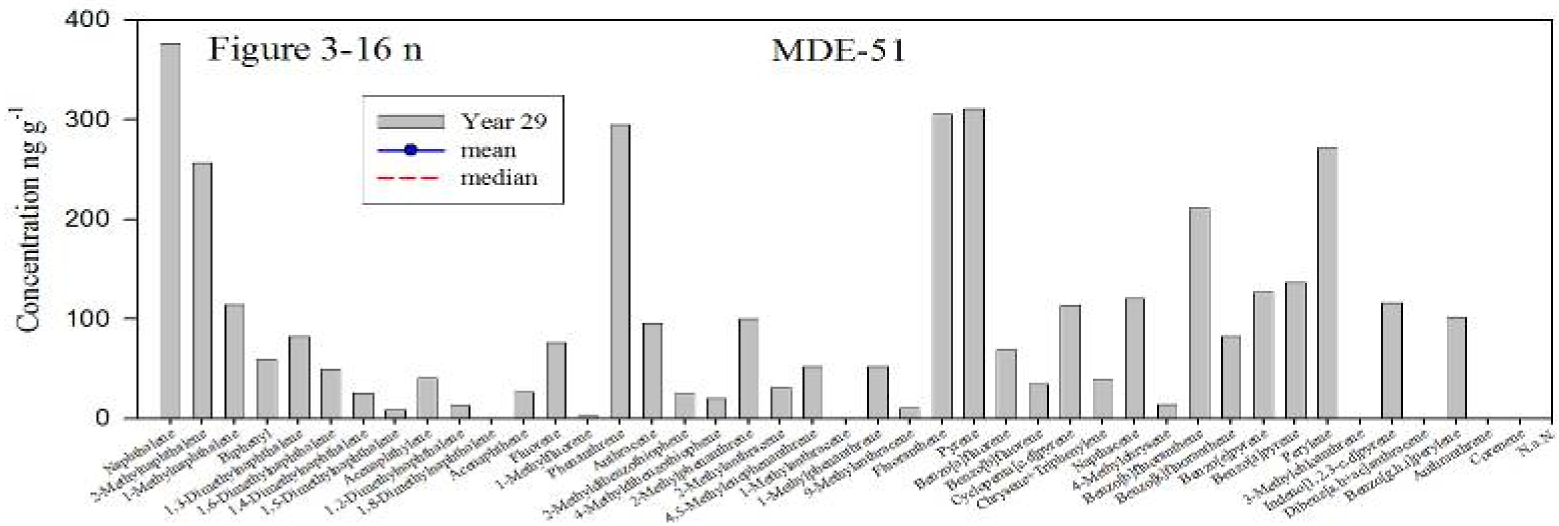


Figure 3-16 continued. Concentrations of PAHs in sediments from sites MDE-50 and MDE-51 obtained in September 2010 expressed in ng g^{-1} dry weight. MDE-50 and 41 are newly established sites and thus does not have historical data with which to calculate the mean, median and standard deviation.

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 3-17 a-l. The compounds most common are the same as those found in the sediments being: phenanthrene, fluoranthene, pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[e]pyrene, and perylene but devoid of naphthalene, 2-methylnaphthalene. Many PAH compounds in the 2010 clam samples were below the methods level of detection. Naphthalene and 2-methylnaphthalene are rapidly metabolized by clams and fish which may explain the non-detects. As in the case of the sediment, the relative proportions of the PAHs together form a distinct pattern that can be found at almost all the sites. The three compounds phenanthrene, fluoranthene and pyrene dominate most samples. Some of the sites sampled in 2010 have not been sampled enough in the past to calculate mean and median values. Overall the concentrations of the various compounds are similar across sites, including the reference sites. When clam and sediment PAH signatures are compared from the same site, clams have fewer low molecular weight PAHs than observed in the sediment at the site, likely because they are metabolized by the clams.

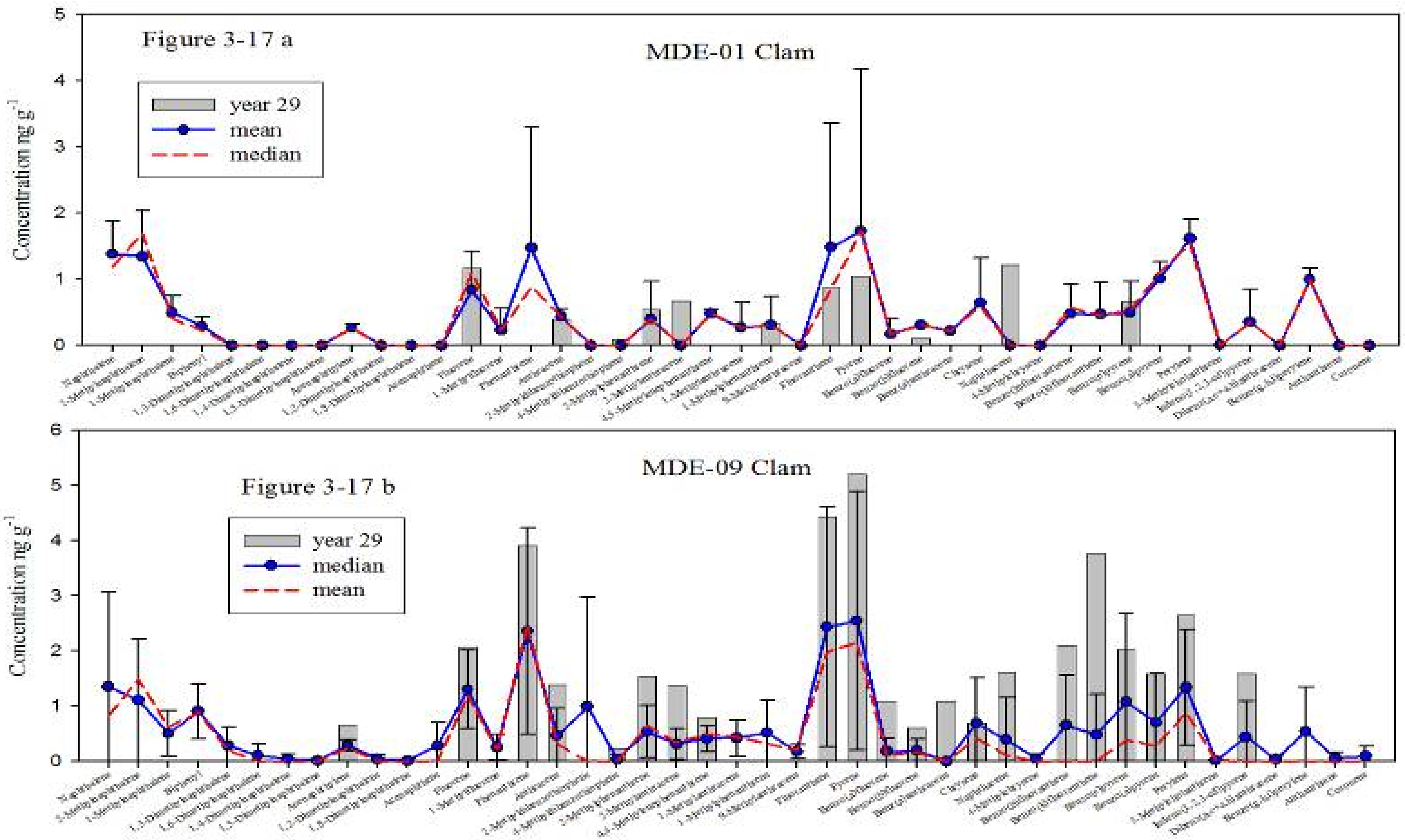


Figure 3-17. Concentrations of PAHs in clams from site MDE-01 and MDE-09 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line), expressed in ng g-1 wet weight.

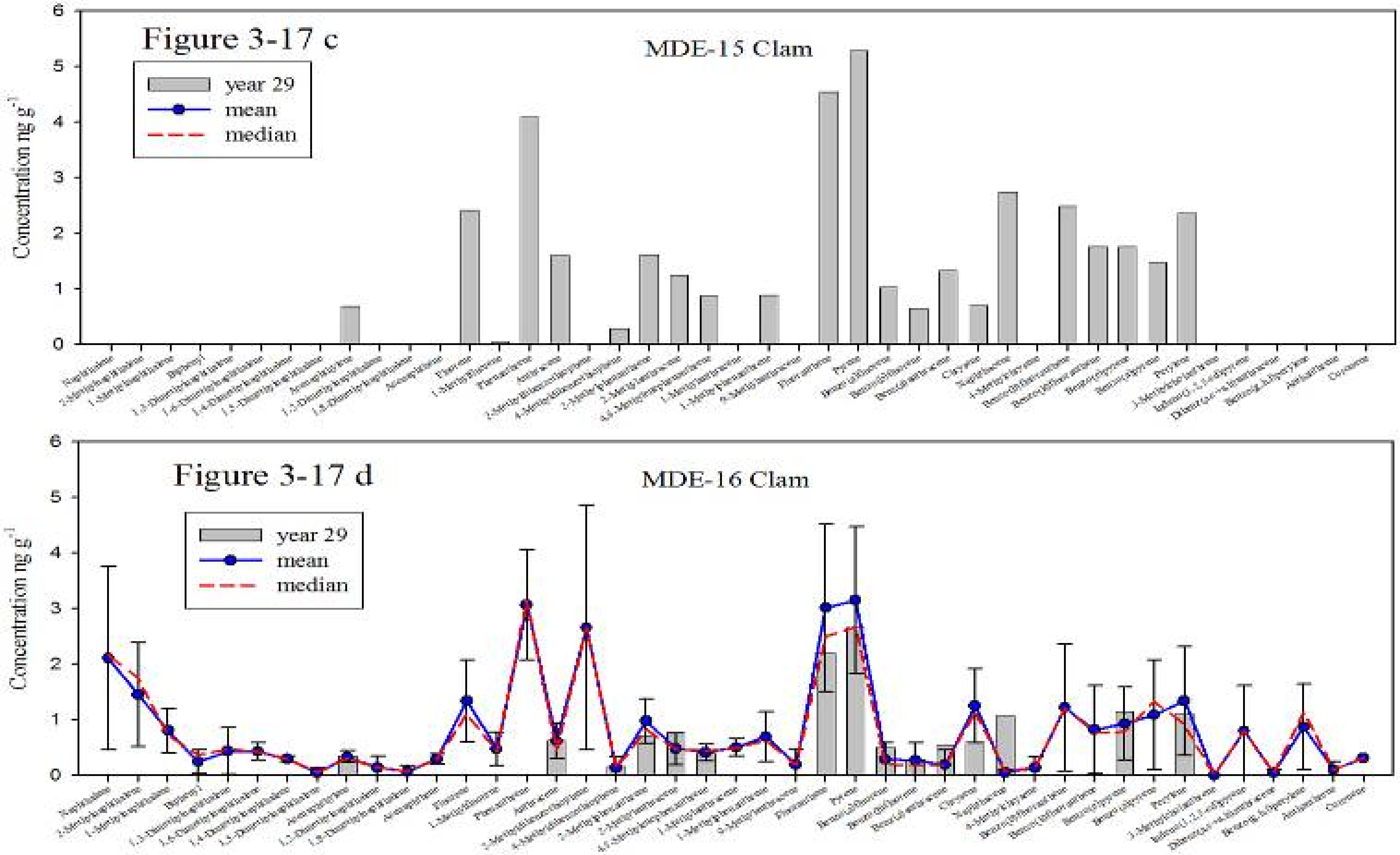


Figure 3-17 continued. Concentrations of PAHs in clams from site MDE-15 and MDE-16 obtained in September 2010 (bars) expressed in ng g^{-1} wet weight. For MDE-16 the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line) are shown. MDE-15 is a newly established site and we do not have historical data with which to calculate the mean, median and standard deviation.

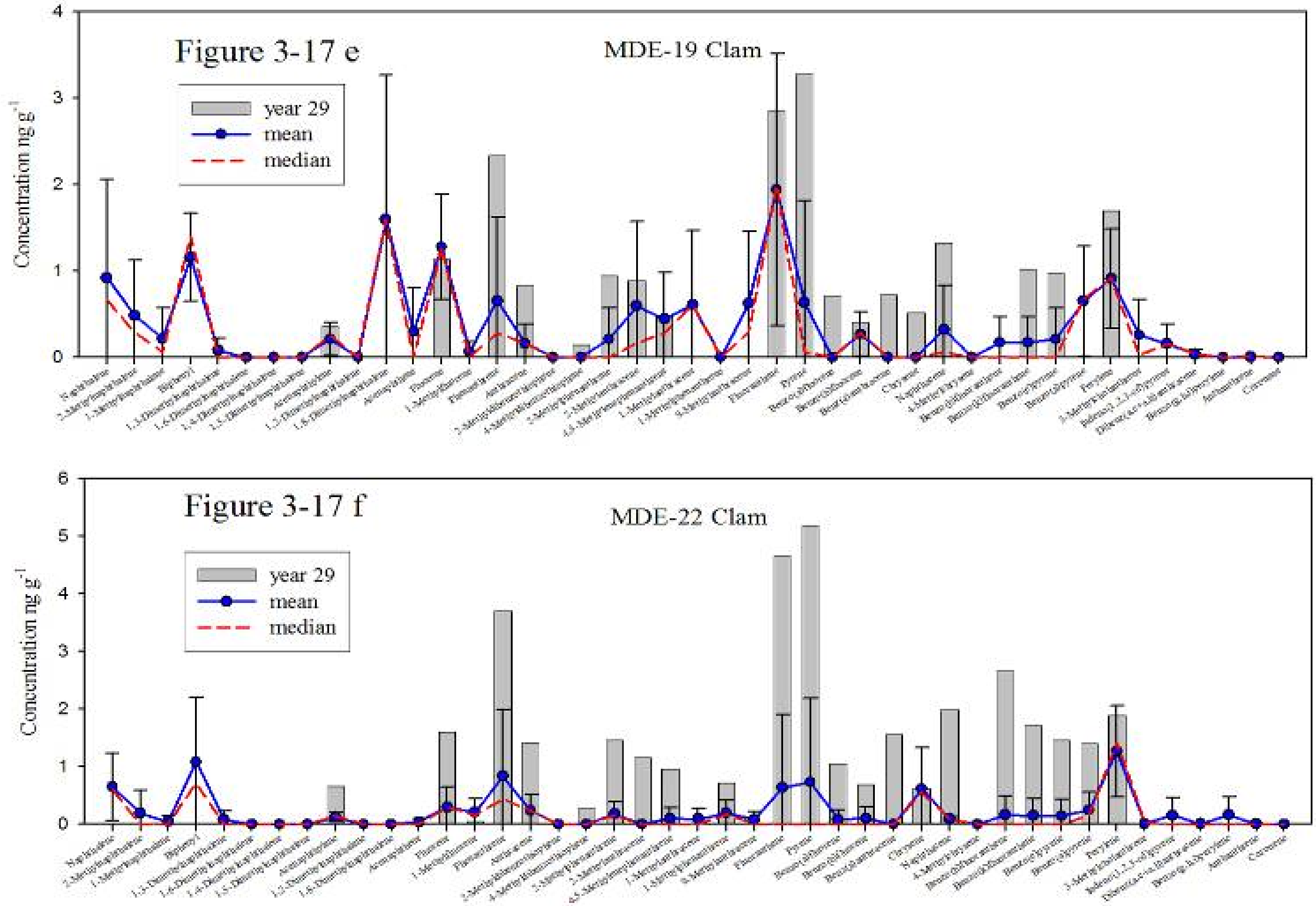
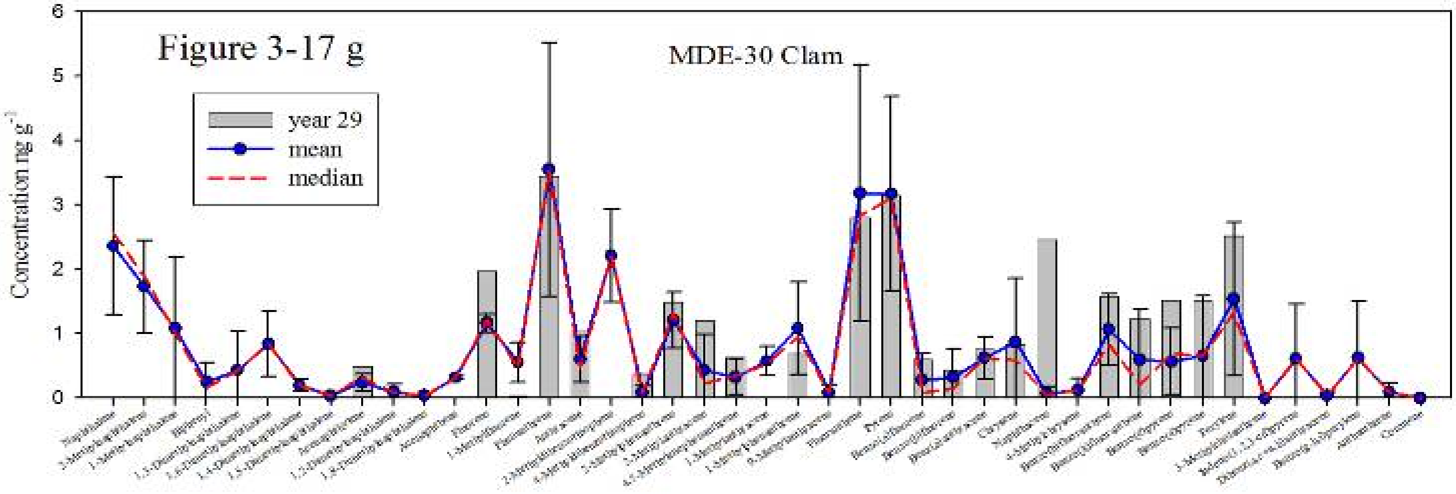


Figure 3-17 continued. Concentrations of PAHs in clams from site MDE-19 and MDE-22 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line), expressed in ng g^{-1} wet weight.



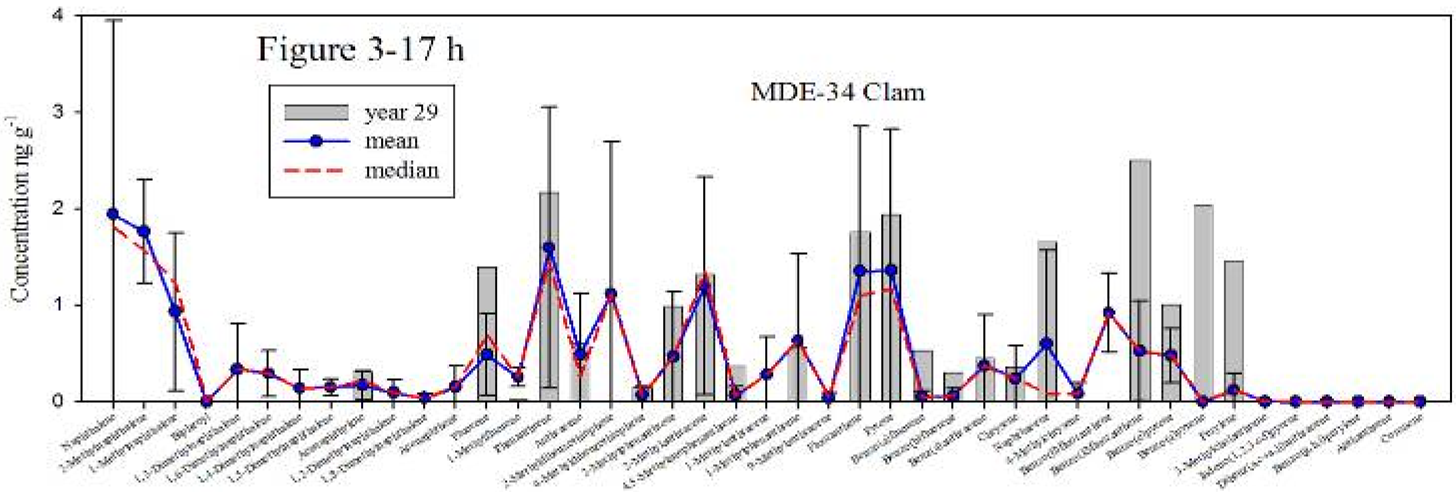
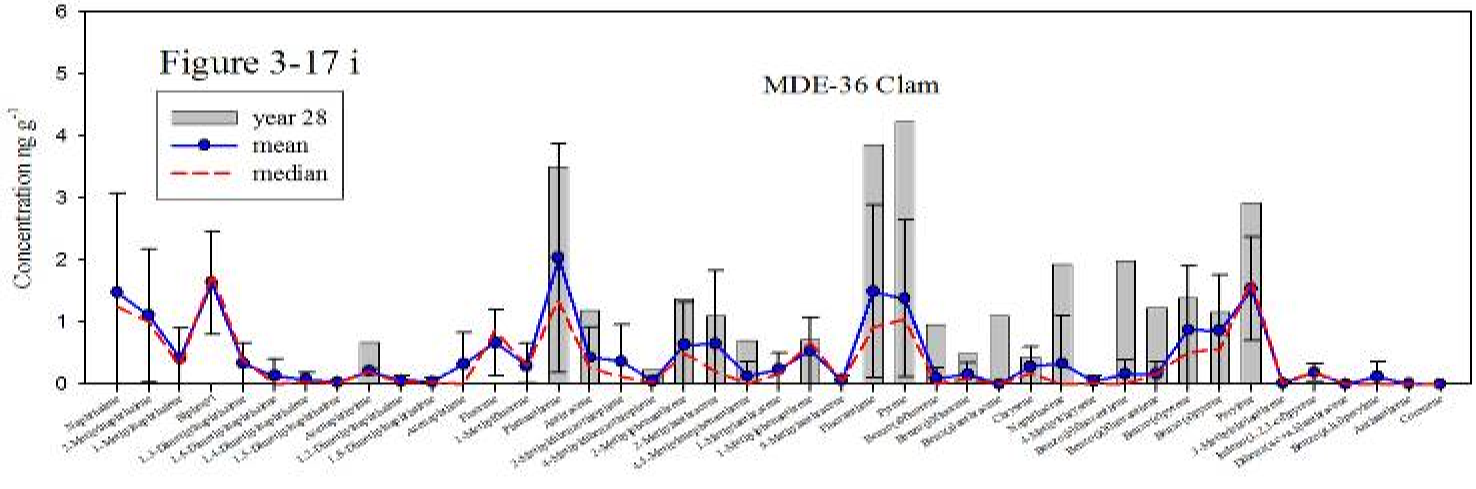


Figure 3-17 continued. Concentrations of PAHs in clams from site MDE-30 and MDE-34 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line), expressed in ng g^{-1} wet weight.



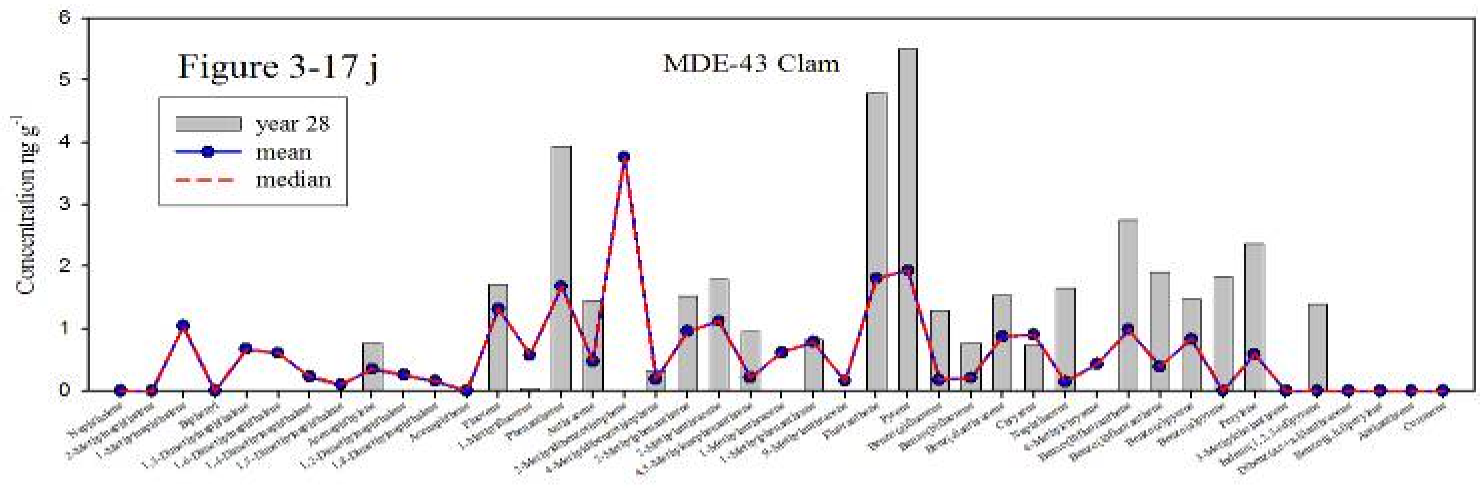
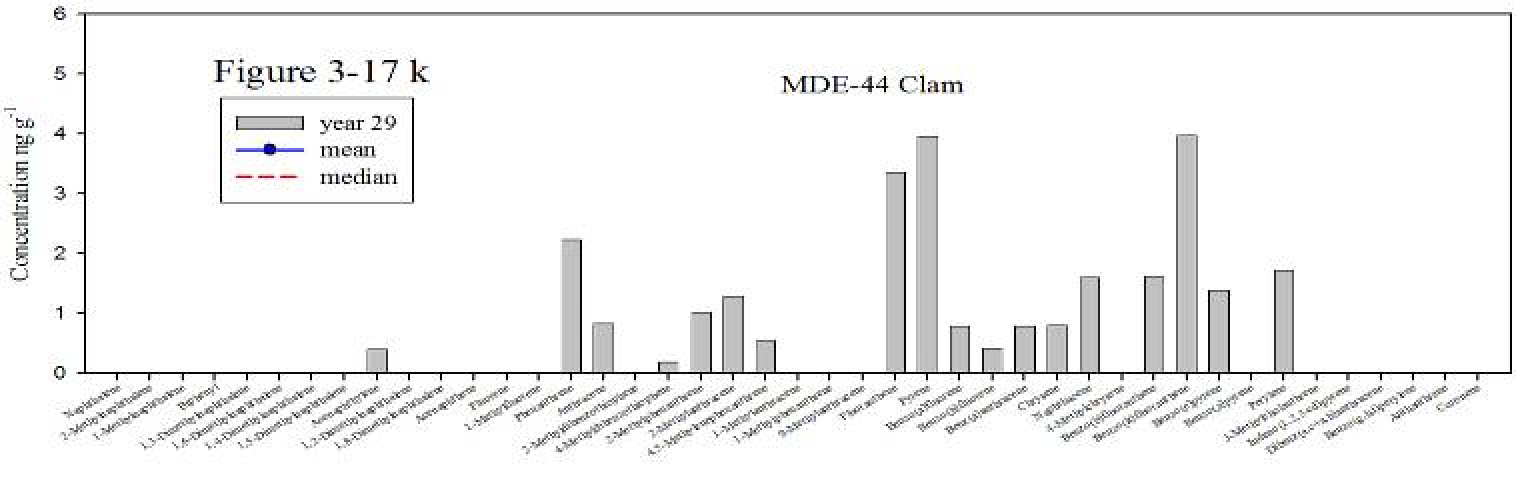


Figure 3-17 continued. Concentrations of PAHs in clams from site MDE-36 and MDE-43 obtained in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line), expressed in ng g^{-1} wet weight.



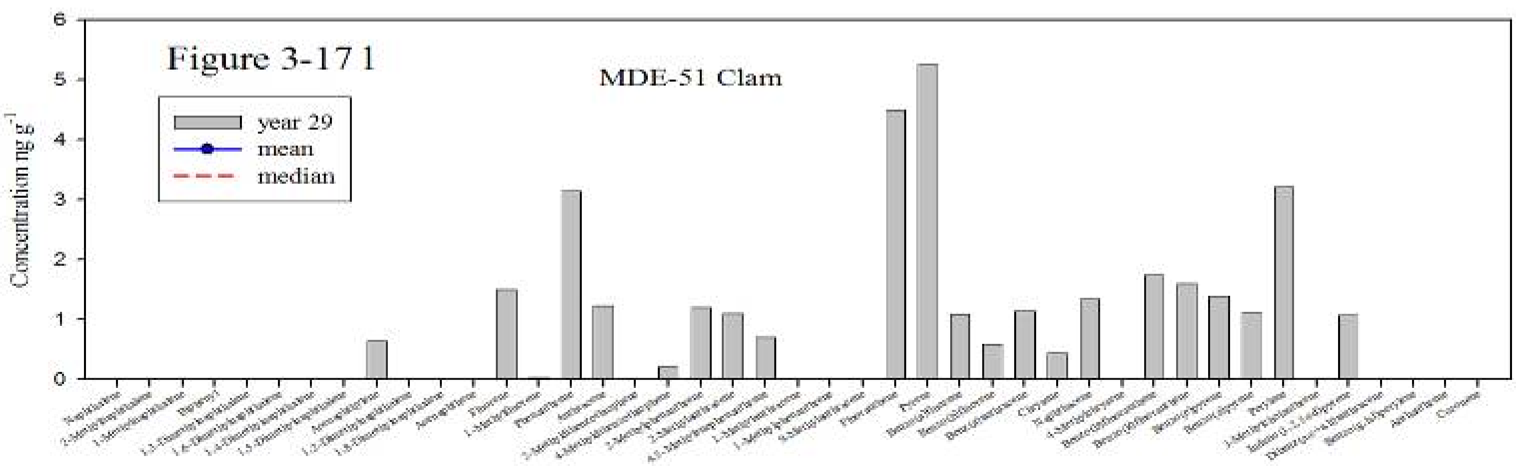


Figure 3-17 continued. Concentrations of PAHs in clams from site MDE-44 and MDE-51 obtained in September 2010 expressed in ng g^{-1} wet weight. MDE-44 and 51 are newly established sites and thus we do not have historical data with which to calculate the mean, median and standard deviation.

Total PAH Concentrations in Sediments and Clams

The total concentrations of PAHs in sediment collected in 2010 from sites around the HMI complex were similar to historical levels (Figure 3-18a). PAH concentrations at site MDE-27 were above the historical levels of the site but within the range observed at other locations in 2010. Site MDE-27 did not have PCB concentrations in sediment above what has historically been observed. Concentrations of PAHs in clams were above historical levels at all but 1 of the sites investigated including at the reference site MDE-36 (Figure 3-18 b). Site MDE-1 was the exception to this trend, where low PAH concentrations in sediment were also observed. The concentrations of PAHs in clams track the sediment concentrations at each site, suggesting a local connection.

The fact that both PCB and PAH concentrations in clams were elevated above historical levels, but sediments were not, might imply a wide spread event that enhanced PAHs and PCBs in the water column particulate load, thus making them more available to uptake by the clams. This could occur by increased sediment resuspension or increased regional delivery of PAH enriched particles from elsewhere in the Bay.

Figure 3-18 a

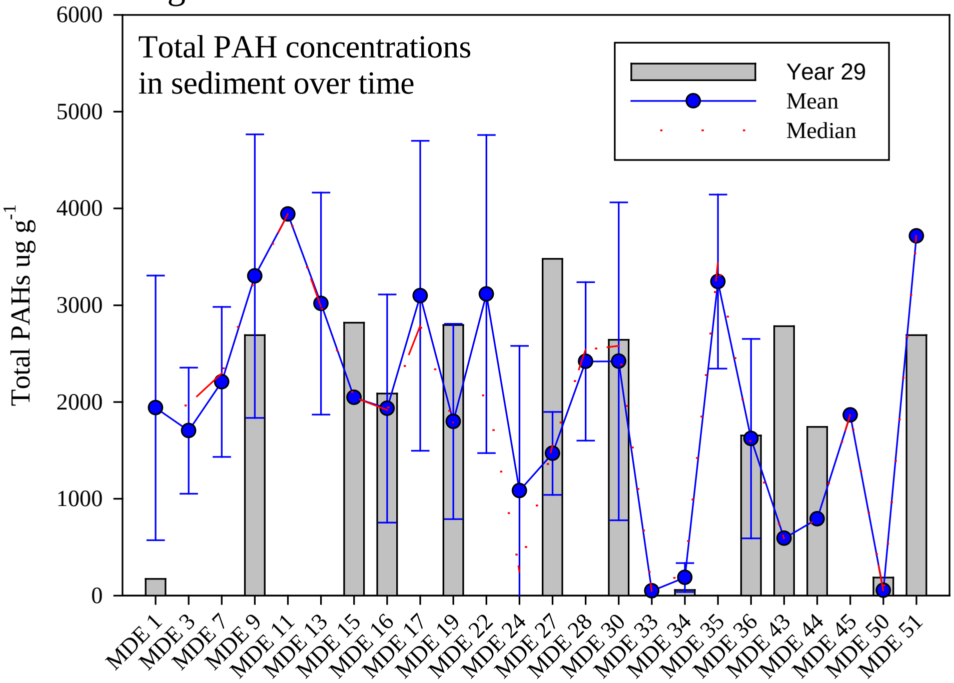


Figure 3-18 b

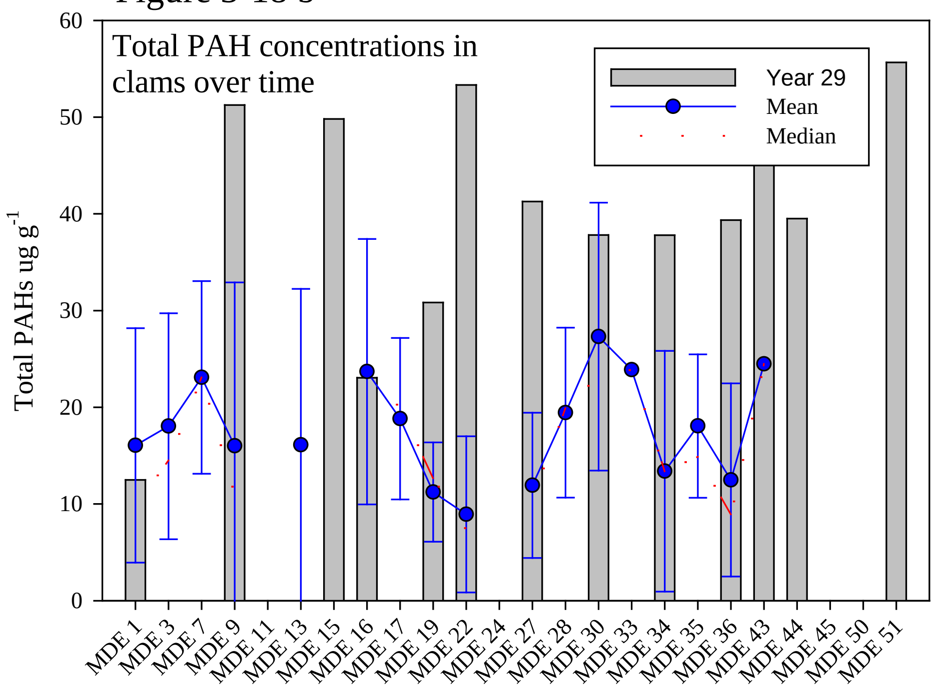


Figure 3-18. Total PAH concentrations in sediments (a) (ug g^{-1} dry weight) and total PAH concentrations in clams (b) (ug g^{-1} wet weight) collected in September 2010 (bars), the 1998-2009 mean with standard deviation (blue circles and error bars) and the 1998-2009 median (dashed line).

Bioaccumulation Factors for PCBs and PAHs

PAHs are typically not accumulated to the extent of PCBs, but rather PAHs are metabolized by organisms at some metabolic cost and it is exposure, rather than accumulated concentration, that 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 from around HMI are orders of magnitude below that of the sediment, hence no bioaccumulation is observed. 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 relative bioavailability. PCB BAFs calculated on a wet weight basis are on the order of 5 for most of the sites studied in 2010 but the BAFs at sites MDE-34 and MDE-44 was 20. This is the second year in a row where MDE-34 has had an anomalous PCB accumulation factor. Site MDE-1 has an accumulation factor of 60, which is driven by the sites much lower than normal level of PCBs in the sediment.

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 TEL and 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 3-19). This influence even has an impact on the long term reference site, MDE-36. MDE-36 does not exceed the TEL for PAHs or PCBs but the concentrations are very close. The PEL was not surpassed by any of the sites for either PCBs or PAHs (Figure 3-19). Concentrations of individual compounds, for which criteria have been established, fall below the established PELs.

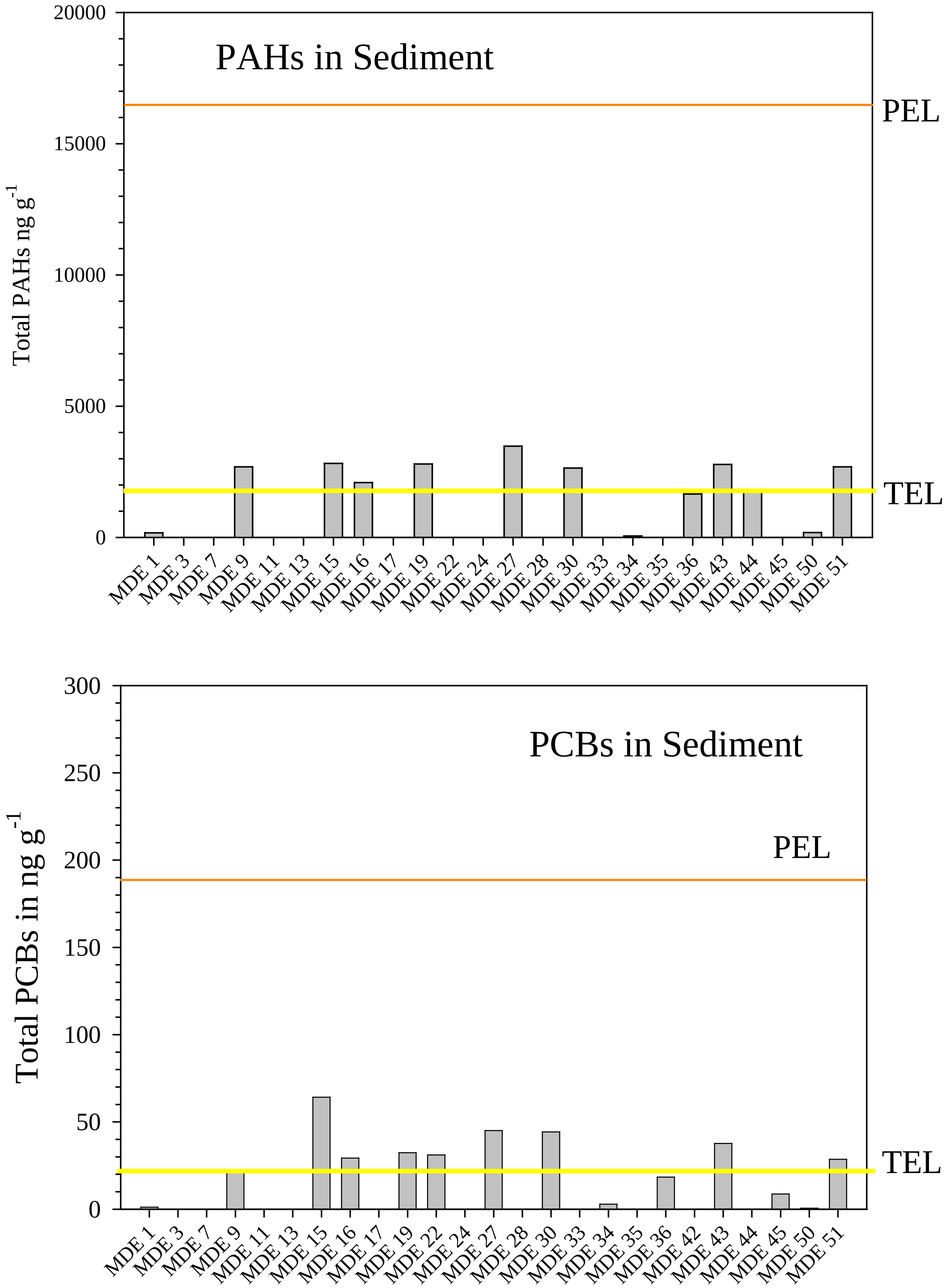


Figure 3-19. Total PAH and Total PCB concentrations in relation to the Threshold Effects Level (TEL) and the Probable Effects Level (PEL) for samples collected in September 2010.

SECTION SUMMARY

The concentrations of trace elements in sediments collected around the HMI facility largely follow what we have observed in previous years, but four sites (MDE-6, MDE-9, MDE-12 and MDE15) stand out having As, Se and Hg concentrations higher than we have typically observed. A number of other sites along the south side of the island had higher than normal Hg concentrations, although not outside the realm of concentrations observed around the Chesapeake Bay as a whole. Two sites had anomalous MeHg concentrations, sites MDE-25 and MDE-38, which are not related to increases in total Hg. Clams did not deviate from historical normal trace element concentrations and reflect the elevated sediment concentrations. In the case of the organic contaminants PAHs and PCBs, the reverse pattern of trace elements was observed, with clams being elevated above historical values and sediment reflecting historical values. Even with the increase in PCB concentrations in clams, the bioaccumulation of PCBs appears typical of past years. No accumulation of PAHs was observed because PAHs in organisms are orders of magnitude below that of the sediment. There was a general shift in the PAH signature of clams with the loss of low molecular weight compounds.

Overall, we 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.

REFERENCES

Bloom, N.S. 1989. Determination of picogram levels of methylmercury by aqueous phase ethylation followed by cryogenic gas chromatography with cold vapor atomic fluorescence detection. Can J Fish Aquat Sci 46:1131-1140.

Dalal, V.P. Baker, J.E. and Mason, R.P. 1999. Environmental Assessment of Poplar Island Dredged material Placement Site, Talbot County, Maryland. Estuaries 22: 770-784.

Heyes, A., Mason, R.P. Kim, E.H. and Sunderland, E.M. 2006. Mercury methylation in Estuaries: incites from measuring rates using mercury stable isotopes. Marine Chemistry 102:134-147.

Horvat, M. Bloom, N.S. and Liang, L. 1993. Comparison of distillation with other current isolation methods for the determination of methyl mercury compounds in environmental samples. Anal Chim Acta 282:153-168.

Kucklick, J.R.; Harvey, H.R.; Ostrom, P.H.; Ostrom, N.E.; Baker, J.E. 1996. Organochlorine Dynamics in the Pelagic Food Web of Lake Baikal. *Environ. Toxicol. and Chem.* 15(8): 1388-1400.

Ko F-C and Baker, J.E. 2004. Seasonal and annual loads of hydrophobic organic contaminants from the Susquehanna River basin to the Chesapeake Bay. Mar. Pollut. Bull. 48:840-851.

Mason, R.P. and Lawrence, A.L. 1999. Concentration, distribution and bioavailability of mercury and methylmercury in sediments of Baltimore Harbor and Chesapeake Bay, Maryland, USA. Environ. Tox. Chem. 18:2438-2447.

Mason, R.M.; W.F. Fitzgerald; J.P. Hurley; A.K. Hanson jr.; P.L. Donaghay and J.M. Sieburth. 1993. Mercury Biogeochemical Cycling in a Stratified Estuary. Limnol. Oceanogr. 38: 1227-1241.

Spitzer T. 2007 Capillary GC of indicator compounds of degradation of polycyclic aromatic hydrocarbons in airborne particulate matter. Chrom. 28 (2) 67-74.