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

Year 28 Exterior Monitoring Technical Report

(September 2009-August 2010)

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DEFINITION OF TERMS

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

Bioturbation — Mixing of sediments by the burrowing and feeding activities of sediment-dwelling organisms. This disturbs the normal, layered patterns of sediment accumulation.

Box and Whisker Diagram — A graphical summary of the presence of outliers in data for one or two variables. This plot, which is particularly useful for comparing parallel batches of data, divides the data into four equal areas of frequency. A box encloses the middle 50 percent, where the median is represented as a vertical line inside the box. The mean may be plotted as a point.

Horizontal lines, called whiskers, extend from each end of the box. The lower (left) whisker is drawn from the lower quartile to the smallest point within 1.5 interquartile ranges from the lower quartile. The other whisker is drawn from the upper quartile to the largest point within 1.5 interquartile ranges from the upper quartile.

Values that fall beyond the whiskers, but within 3 interquartile ranges (suspect outliers), are plotted as individual points. Far outside points (outliers) are distinguished by a special character (a point with a + through it). Outliers are points more than 3 interquartile ranges below the lower quartile or above the upper quartile.

Brackish — Salty, though less saline than sea water. Characteristic of estuarine water.

Bryozoa — Phylum of colonial animals that often share one coelomic cavity. Encrusting and branching forms secrete a protective housing (zooecium) of calcium carbonate or chitinous material. Possess lophophore feeding structure.

Bulk sediment chemistry — Results of chemical analyses of whole sediments (in terms of wet or dry weight), without normalization (e.g., to organic carbon, grain-size, acid volatile sulfide).

Cation — A positively charged ion, (e.g., Na^+ and Mg^{2+}).

Congener — A term in chemistry that refers to one of many variants or configurations of a common chemical structure (e.g., polychlorinated biphenyls [PCBs] occur in 209 different forms with each congener having two or more chlorine atoms located at specific sites on the PCB molecule).

Contaminant — A chemical or biological substance in a form that can be incorporated into, onto or be ingested by and that harms aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment, and includes but is not limited to the substances on the 307(a)(1) list of toxic pollutants of the Clean Water Act promulgated on January 31, 1978 (43 FR 4109).

Contaminated material	Material dredged from Baltimore Harbor, originating to the northwest of a line from North Point to Rock Point. Material shows high concentrations of metals, PCBs, organics, etc.
Dendrogram	A branching, diagrammatic representation of the interrelations of a group of items sharing some common factors (as of natural groups connected by ancestral forms).
Depurate	To cleanse or purify something, especially by removing toxins.
Desiccation	The process of drying thoroughly; exhausting or depriving of moisture.
Diversity index	A statistical measure that incorporates information on the number of species present in a habitat with the abundance of each species. A low diversity index suggests that the habitat has been stressed or disturbed.
Dominant (species)	An organism or a group of organisms that by their size and/or numbers constitute the majority of the community.
Dredge	Any of various machines equipped with scooping or suction devices used in deepening harbors and waterways and in underwater mining.
Dredged material containment	A disposal method that isolates the dredged material from the environment. Dredged material containment is placement of dredged material within diked confined disposal facilities via pipeline or other means.
Dredged Material Containment Facility (DMCF)	A diked area, either in-water or upland, used to contain dredged material. The terms confined disposal facility (CDF), dredged material containment area, diked disposal facility, and confined disposal area are used interchangeably.
Effluent	Something that flows out or forth; an outflow or discharge of waste, as from a sewer.
Enrichment factor	A method of normalizing geochemical data to a reference material, which partially corrects for variation due to grain size.
Epifauna	Benthic animals living on the surface of the bottom.
Fine-grained material	Sediments consisting of particles less than or equal to 0.062 mm in diameter.

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

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

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

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

PROJECT I : SUMMARY REPORT FOR THE HART-MILLER ISLAND DREDGED MATERIAL CONTAINMENT FACILITY YEAR 28

(September 2009 – August 2010)

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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.

Exterior monitoring each year begins with a fall sampling typically conducted in September. HMI Year 28 began in September 2009 prior to the December 31, 2009 closure, thus monitoring results will be part of the baseline study material to be compared to monitoring results post closure.

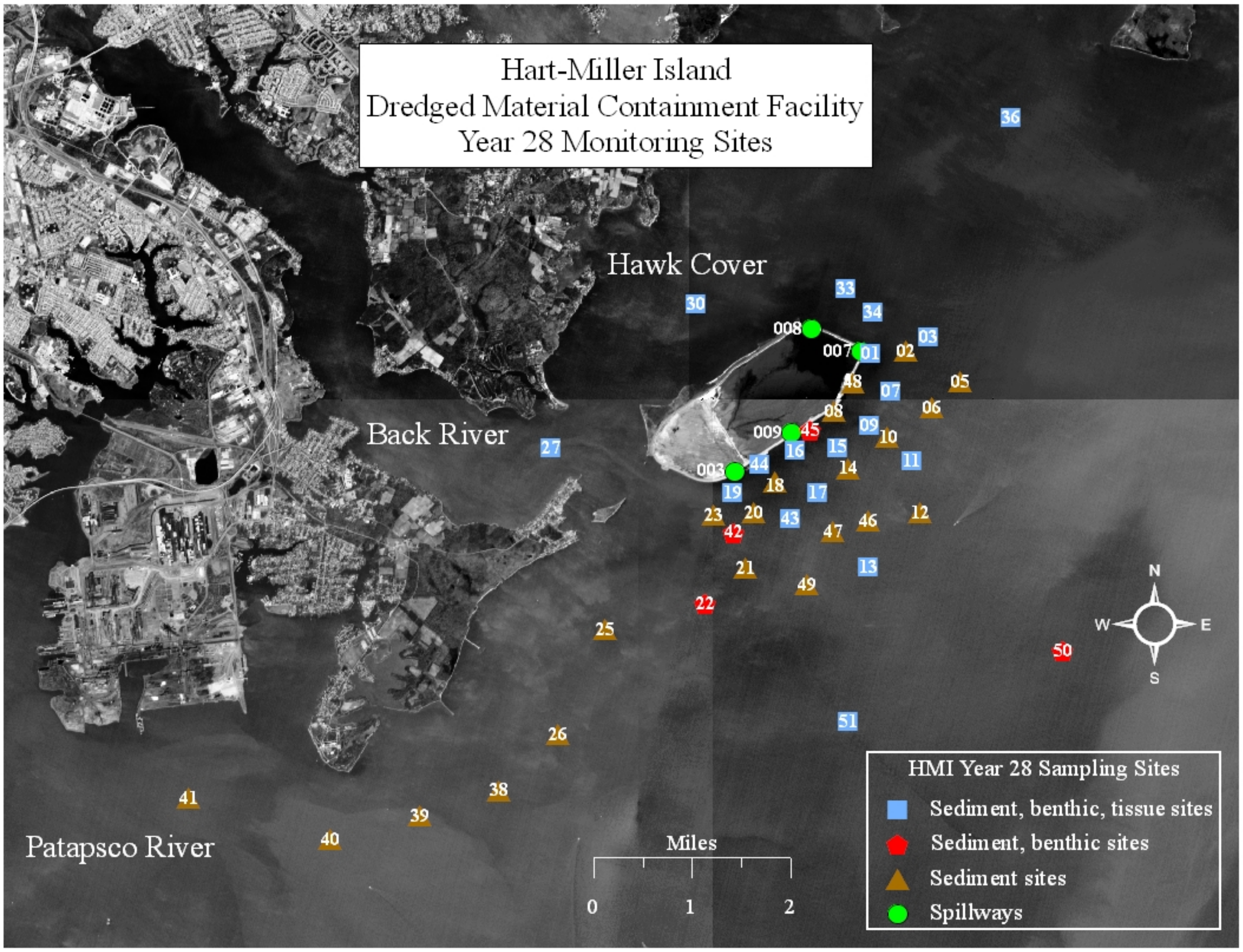
HMI EXTERIOR MONITORING DESIGN

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 28, 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 28 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 3, 2009, and on April 7, 2010. 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 27 and Year 28. 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 has the highest sand content typically around 90 percent. Between September 2008 and April 2009 (Year 27) there was a slight decrease in sand content. By September 2009 (Year 28) sand content in the northeast region returned to greater than 90 percent. MDE-50, a new site located 3.5 miles southeast of HMI was 96 percent sand. Otherwise, there were no significant changes in sand content around HMI in Year 28.

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.

In Year 28 station MDE-41, at the mouth of Baltimore Harbor, continued to be clay-rich (clay:mud ratio > 0.50) which is consistent with previous years. Of those sites in proximity to HMI a clay-rich area southeast of HMI was present both September 2008 and September 2009 but then diminished slightly in size in the April sampling of both years. This pattern is 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. However, in the spring 2010 of the sites adjacent to the south-east wall only MDE-08 was found to be silt-rich. The change in sediment composition is likely a result of natural dynamics.

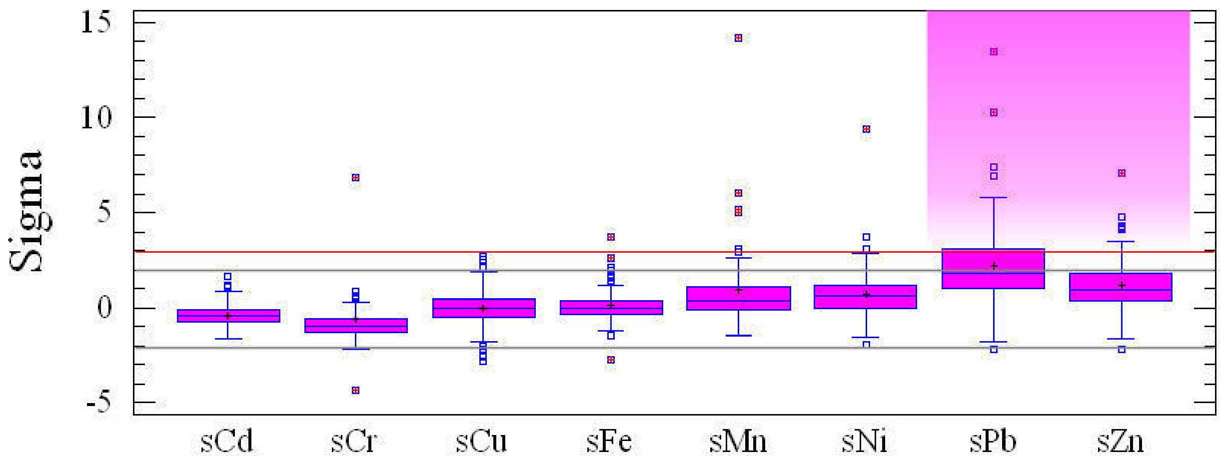
In general, the grain size distribution (i.e., sand, silt and clay) of Year 28 samples was found to be consistent with the findings of previous monitoring years.

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 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 impacts to 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 ERL while at other sites concentrations for Zn and Ni were high enough to exceed the ERM. 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 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].



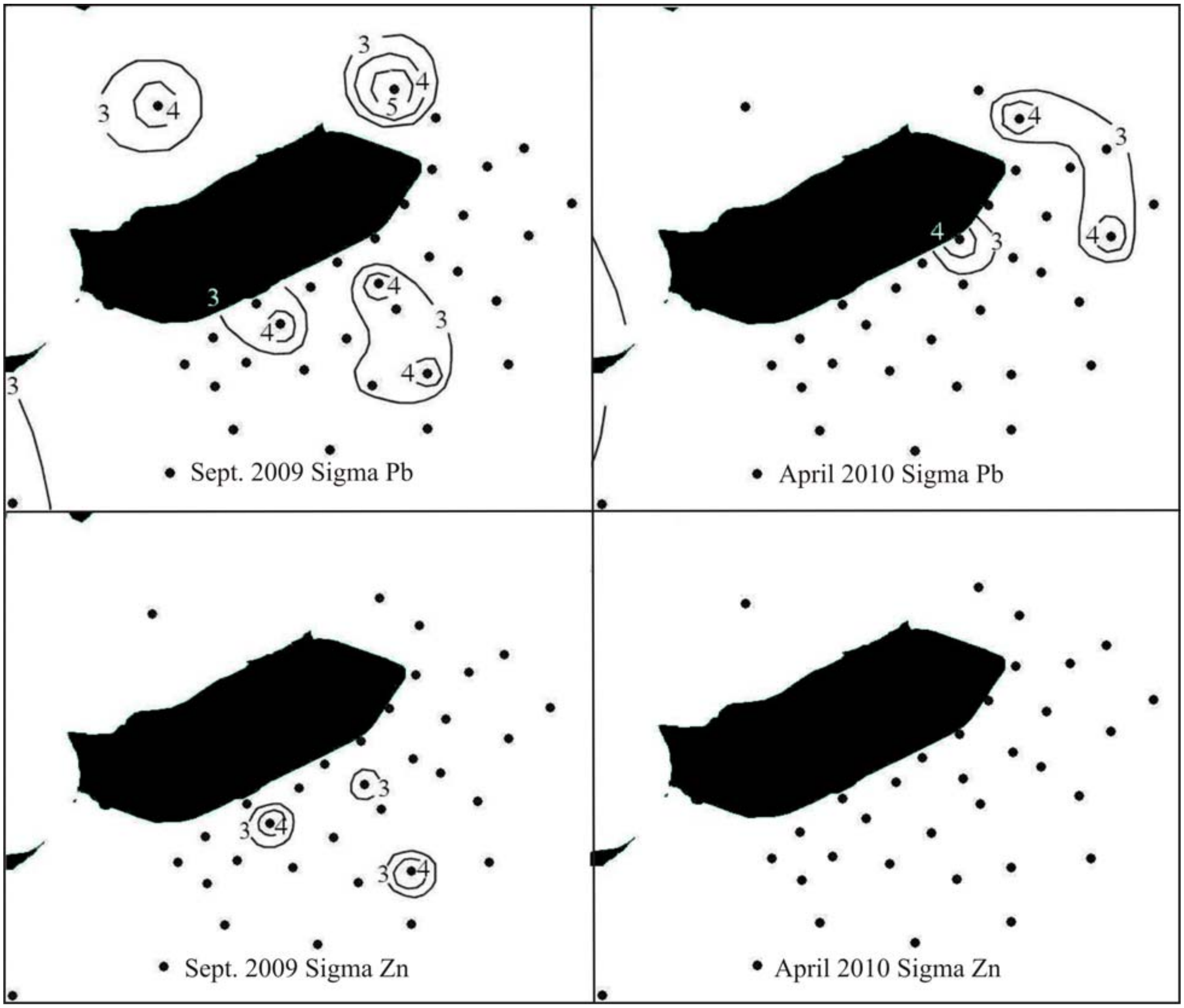
Summary Figure 1-2. Year 28 concentration of metals at HMI relative to baseline values. Metal concentrations greater than 2 standard deviations (horizontal grey lines) are considered elevated above baseline.

The results for Year 28 were similar to Year 27 where all of the metals except Pb and Zn, and to a lesser extent Mn, were found to be within the range expected for normal baseline behavior in the area (Summary Figure 1-2). In Year 28 approximately 28 percent of the samples contain Pb exceeding 3 sigma compared to approximately 25 percent in Year 27. There was a slight reduction in Zn from 11 percent in Year 27 exceeding 3 sigma to 8 percent in Year 28. For Mn approximately seven percent of the samples exceeded 3 sigma. It should be noted that most of the samples with elevated metal levels are in the Baltimore Harbor zone of influence, not resulting from HMI discharge.

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 1-3 shows the sigma levels for Pb and Zn for Year 28 fall and spring monitoring periods 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 1-3 identify those areas that are significantly elevated above baseline levels.



Summary Figure 1-3. September 2009 and April 2010 distribution of Pb and Zn around HMI. Values are expressed in multiples of Sigma.

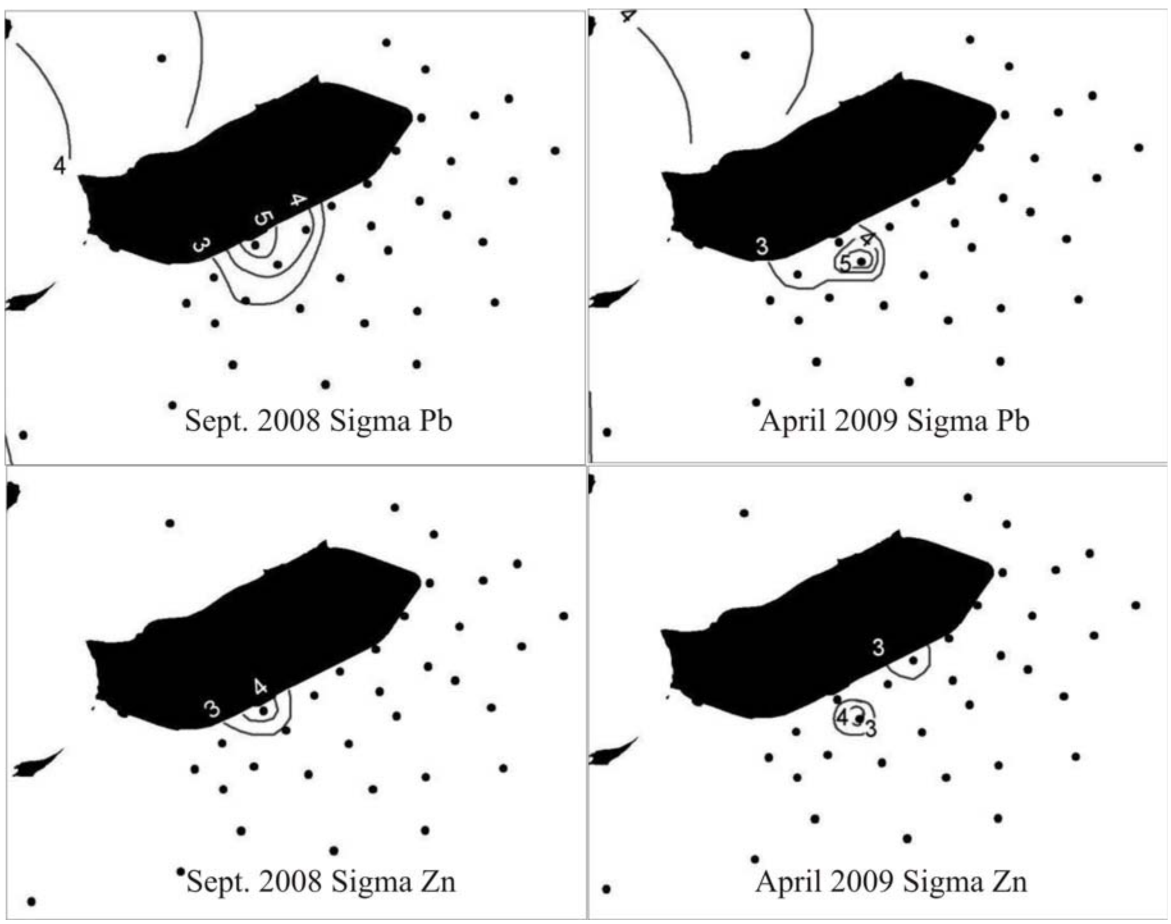
The spatial distribution of both Pb and Zn enriched areas in the fall suggests that the South Cell discharge was the source. This is especially true for Pb where the enrichment is more broad and contiguous to the dike (top left quadrant, Summary Figure 1-3). Based on discharge records supplied by MES there was a period of steady discharge, starting in July and continuing through August, leading up to the September sampling (a graph of the discharge data is given in Appendix I). During this same time period there was very little discharge from the North Cell and as can be seen there was no enrichment for Zn and only an isolated area for Pb.

Based on the spring sampling, the area of Pb enrichment was off the northeast side of HMI suggesting the source was from the North Cell discharge. All three North Cell spillways were used during February and March preceding the April sampling. Discharges from Spillways 007 and 008 were small, and as previous studies have shown (Year 12 Interpretive Report) when discharge is less than 10 MGD excess metals are more likely to be released. Thus, effluent may have contained above background levels of Pb. For both cruises

Zn was found to be below 3 sigma indicating Zn concentration in the effluent was at least at back ground levels.

When comparing Year 28 to Year 27, Pb showed slightly higher enriched levels both in terms of the number of sites and the extent of spatial distribution (Summary Figure 1-3 and Summary Figure 1-4). In Year 27, Pb distribution was localized around the South Cell Spillway 003 with no other enrichment that could possibly be contributed to HMI operations. However, for Year 28 the North Cell operations appear to have had some effect in both the fall and spring as can be seen with the enrichment of Pb off the north and northeast side of HMI. In Year 27 this same area showed no enrichment for Pb. It should be noted that there were no discharge events that occurred in the month preceding both the September and April Year 27 sampling cruise.

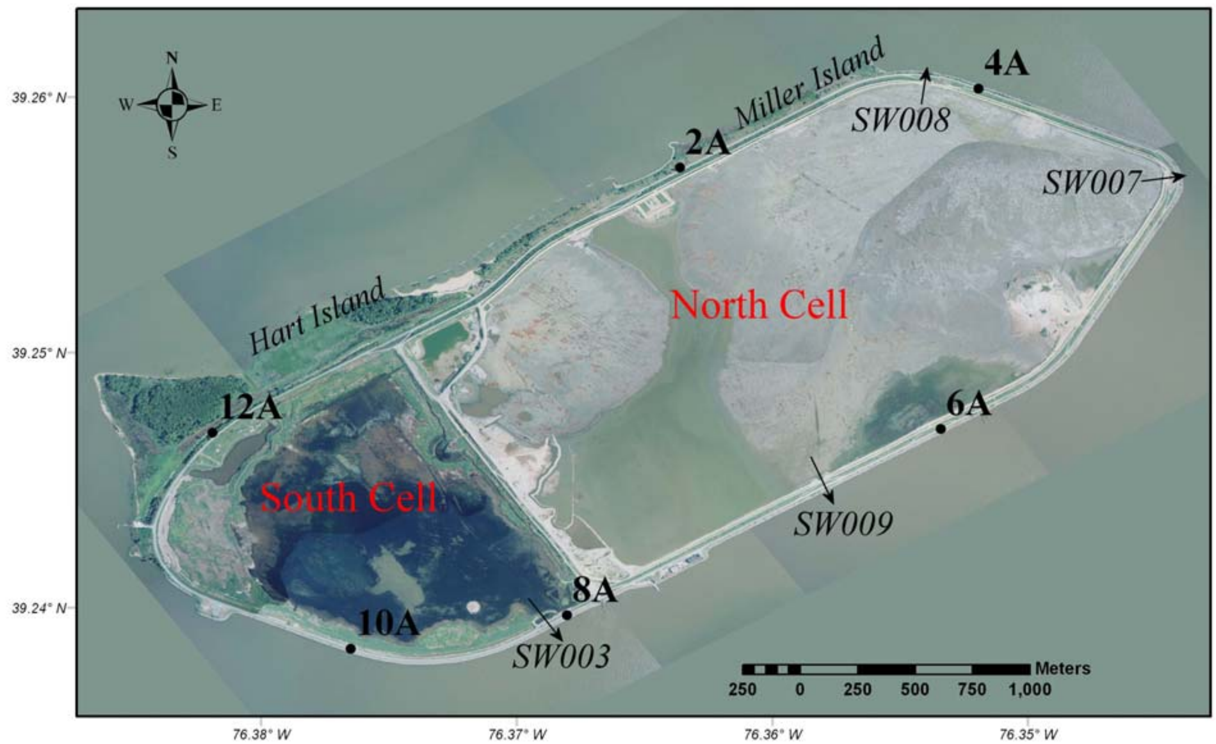
Zinc also had a greater extent of spatial distribution in the fall of Year 28 compared to Year 27, and like Pb in Year 27 was localized around the South Cell spillway. The spring of Year 28 showed no enrichment for Zn, which is an improvement from Year 27.



Summary Figure 1-4. September 2008 and April 2009 distribution of Pb and Zn around HMI. Values are expressed in multiples of Sigma.

Groundwater Monitoring Wells

Groundwater samples from six wells were collected on June 12, 2009, December 11, 2009, and June 22, 2010, 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 1-5).



Summary Figure 1-5. Groundwater sampling wells locations.

All wells were found to be anoxic or hypoxic with dissolved oxygen (DO) levels less than 1.57 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

In Wells 2A and 6A, the groundwater shows a reducing environment based on the depletion in sulfate in comparison to predicted concentrations. However, for the June 2010 sampling showed a positive excess of sulfate in Well 6A 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 for all samplings showed a positive excess of sulfate which indicates it is similar to the oxidizing environment seen in the South Cell. The one sampling of Well 6A that resulted in a positive excess of sulfate suggests a shift toward an oxidizing environment.

Alkalinity concentrations and pH in Well 6A were found to be higher than Wells 2A and 4A with the exception of the December 2009 sampling when there was a rather sharp reduction of alkalinity in 6A and a sharp increase in Well 2A. Alkalinity in Well 6A is higher than all South Cell wells while 2A and 4A are similar to South Cell Well 8A and higher than 10A and 12A. The higher concentrations suggest that the alkalinity in the North Cell wells, and especially in 6A, had not been neutralized by acid production.

Most metal concentrations except Fe are lower in the Well 2A and 6A. 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 are higher because it has more of an oxidizing environment much like the South Cell wells.

Total dissolved nitrogen (as ammonium) decreased by approximately half in Well 6A over the last two samplings. The reduction suggests that the reducing process is less dominant in Well 6A in comparison to past samplings. Ammonium is produced as a byproduct of anaerobic respiration; since the water in this well has not undergone an oxidative stage, ammonium is higher. Wells 2A and 4A were similar in concentration to South Cell Wells 8A and 10A.

The groundwater from the North Cell Wells 2A and 6A 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, Well 6A is 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. Well 6A is near Spillway 009 where most of the effluent water of the North Cell is channeled for discharge.

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 for the June, 2010 sampling was 6.5 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 28 was the second 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 4, 2009 and on April 15, 2010 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 concentrations, salinity, temperature, pH, conductivity, and secchi depth were measured *in situ.*

Water Quality

The water quality parameters measured during the September 2009 and the April 2010 sampling cruises showed minimal variations between surface and bottom conditions indicating that the water column was well mixed and not stratified. Some stratification did occur in the spring 2010 at stations MDE-50 and MDE-51. However, this is not an unfavorable condition and is often typical where brackish and fresh water converge and temperatures differ.

Dissolved oxygen (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 2009 and April 2010 sampling events, bottom-water DO concentrations exceeded the water quality standard of 5.0 ppm at all stations with the exception of MDE-50 and MDE-51. In September 2009 both stations were below the threshold, and in April 2010 only MDE-51. These stations are well outside the zone of HMI influence, and it is suspected that intrusion of bottom water from the nearby shipping channel is the probable source of low oxygenated bottom water.

Like DO, measures of bottom-water temperature and salinity are important and relevant to benthic macroinvertebrate health. In Year 28, bottom-water temperature did not vary much between stations during both the September 2009 and April 2010 sampling events. In September 2009 the average temperature was only 0.38°C lower than the 24-year fall average of 24.44°C. In April 2010 the average bottom-water temperature was 2.28°C higher than the 13-year spring average of 12.01°C. Salinity regimes changed between September and April. Salinity during the fall mainly fell within the low mesohaline regime (>5 ppt – 18 ppt) with a range of 3.33 ppt to 11.27 ppt, and an average of 5.06 ppt. Salinity in the spring fell within the oligohaline regime (0.5 ppt - 5 ppt) with a range of 0.41 ppt – 6.03 ppt, and an average of 1.56 ppt. The minimum salinity found during both the September and April sampling events was below the low range for their respective regime; however, 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 40 taxa were found over the two seasons of sampling during Year 28. This is comparable to the 12-year average of 39.6 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 taxa of Arthropoda were found in Year 28. The most common types of arthropods were the amphipods and the isopods. Seven taxa of annelid worms in the Class Polychaeta were found, and six species of bivalve mollusks were found.

Of the 40 taxa found in Year 28, twenty were considered infaunal, fifteen were considered epifaunal, and the remaining five were too general to classify as either infaunal or epifaunal (see Ranasinghe et al. 1994). The most common infaunal species found during Year 28 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 2009 average taxa richness was highest at the Nearfield stations (15 taxa) followed by the Reference stations (13.6 taxa). Both the Back River/Hawk Cove and South Cell Exterior Monitoring stations had an average of 13 taxa found.

In April 2010 the average taxa richness did not vary greatly between station types. The average taxa richness was highest at Nearfield stations (16.08 taxa) while Reference stations and Back River/Hawk Cove stations averaged 15.02 and 15.00 respectively, and South Cell Exterior Monitoring stations averaged 14.67.

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 2009 cruise.

The B-IBI is calculated using different metrics, and the metrics used are dependent upon the salinity. In the fall of 2009 the average salinity was 5.06 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 0 to 4. 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 2009 ranged from a high of 3.36 at the Nearfield station MDE-07 located on the northeast side of HMI to 2.03 at the Nearfield station MDE-33 located a half a mile off the north most extent of HMI. The low diversity at MDE-33 was primarily due to the large percentage of the amphipod *A. lacustre*, which accounted for 50 percent of total infaunal abundance at this station. Station MDE-30, a Back River/Hawk Cove station, more likely influenced by Back River, had the second lowest score of 2.37. The highest average SWDI (2.87) was found at both Nearfield sites (n=12) and Reference sites (n=5). The SWDI average for the three South Cell Exterior Monitoring stations was 2.74. Back River/Hawk Cove stations had the lowest average at 2.48.

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 2009, total infaunal abundance ranged from 422.4 individuals/m^2 found at the Nearfield station MDE-17 to 6,380.6 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*, and *L. plumulosus*. Overall, Back River stations had the highest average total infaunal abundance at 3,424 individuals/ m^2 with South Cell Exterior Monitoring stations having the second highest average at 1,602 individuals/m^2. The average total infaunal abundance for Reference stations was 1,188 individuals/m^2 and Nearfield stations had the lowest average at 1,279 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 28 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 2009 stations MDE-30 and MDE-50 had the lowest percent of pollution-indicative taxa abundance (PITA) at 2.74 percent. MDE-27 at the mouth of Back River had the highest PITA at 56.57 percent while MDE-09 a Nearfield station located near Spillway 009 had the second highest PITA at 44.75 percent. In terms of station type, the lowest average PITA was 7.65 percent for the Reference stations, followed by 28.22 percent for the Nearfield stations, and 29.37 percent for South Cell Exterior Monitoring stations. The Back River/Hawk Cove stations (MDE-27 and 30) had the highest average PITA of 29.65 percent; however, MDE-30 as stated earlier had the lowest PITA and therefore, the high average is simply due to the high PITA found at MDE-27.

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 the fall of 2009 the average salinity for all stations was 5.06 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 2009 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.*

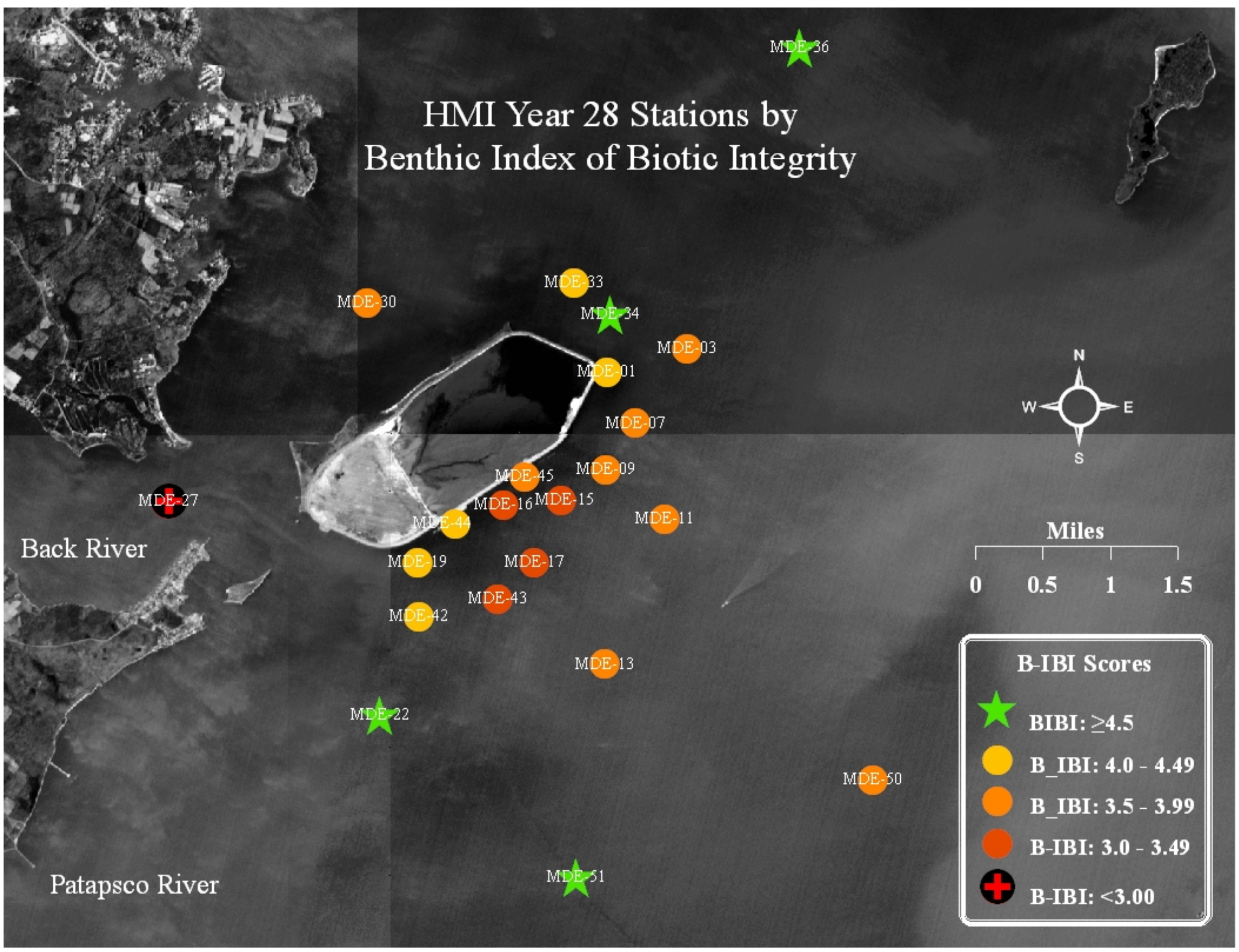
For the September 2009 sampling, the PSTA ranged from 14.84 percent at MDE-27, a Back River Hawk Cove station located at the mouth of Back River to 60.52 percent at MDE-36 a Reference station located approximately 4 miles north of HMI. The average for all stations was 32.90 percent.

In terms of station types the Back River Hawk Cove stations had the lowest average PSTA at 27.25 percent; Nearfield stations averaged 28.58; South Cell Exterior Monitoring stations averaged 34.36 percent, and the references stations had the highest average of 44.64 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 28 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 27 over previous monitoring, and in Year 28 there was a slight improvement over Year 27. Like Year 27, with the exception of the Back River station MDE-27 all stations met or exceeded the benchmark criteria of 3.0, (Summary Figure 1-6). When compared to Year 27, ten sites resulted in higher scores, seven sites remained the same, and only five sites resulted in lower scores, but still meeting the benchmark. Regarding those sites in proximity to the South Cell spillway, the B-IBI scores improved at sites MDE-19 and 43, remained the same at MDE-17 and 42, and decreased from 4.5 to 4.0 at MDE-44. Three of the four sites with a B-IBI score equal to or greater than 4.5 were Reference sites.



Summary Figure 1-6. HMI stations by B-IBI scores.

In summary, Year 28 was similar to Year 27 with just a slight increase in overall B-IBI scores. Starting with Year 25 through Year 28, Summary Table 1-2 shows those sites that have failed in any one year. The Back River site MDE-27 failed each year. MDE-30, north of Back River, but still potentially influenced by Back River, showed slight improvement in Year 27 and again in Year 28. MDE-19, which historically often had a low B-IBI score again showed improvement. 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 27 with one improving, one remaining the same, and one with a slight decrease in B-IBI. Summary Table 1-2 is simply a snapshot of stations that have failed at one time or another starting with Year 25; a more detailed comparison of present to historical results is given in Appendix III.

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

Stations	Year 25	Year 26	Year 27	Year 28
BR/HC MDE-27	2.67	2.33	2.50	2.50
BR/HC MDE-30	2.33	2.33	3.00	3.50
Nf. MDE-17	2.67	3.00	3.00	3.00
Nf. MDE-19	2.67	2.33	3.00	4.00
Nf. MDE-35	2.67	3.00	N/A	N/A
Ref. MDE-13	2.67	3.00	3.50	3.50
SC MDE-42	4.33	2.33	3.00	4.00
SC MDE-43	3.67	2.33	3.00	3.00
SC MDE-44	2.67	3.00	4.50	4.00

PROJECT IV: Analytical Services

For Year 28 exterior monitoring at HMI, CBL collected the clam *Rangia cuneata* both in September 2009 and April 2010. A total of 18 sites were sampled during the September and April sampling events. Ten sites, MDE-07, 09, 11, 16, 19, 30, 34, 36, 44, and 51 were sampled during both cruises. In the addition to these ten, in September sites MDE-01, 15, 17, and 27 were sampled and in April sites MDE-03, 13, 33, and 43 were sampled (Summary Figure 1-1). In addition to clams, sediment samples were concurrently collected and analyzed for trace metals. In Year 27, analysis was not conducted for polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). In Year 28 both sediment and clam samples collected by CBL were analyzed for PCBs and PAHs.

As part of the annual sediment survey, CBL conducted analysis for concentrations of target trace elements in surface sediments collected in September 2009 around HMI by MGS. Metal analysis focuses 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).

Metals in Sediment

The following is a summary of the sediment samples collected in September 2009 by MGS and analyzed for As, Se, Ag, T-Hg, and MeHg by CBL.

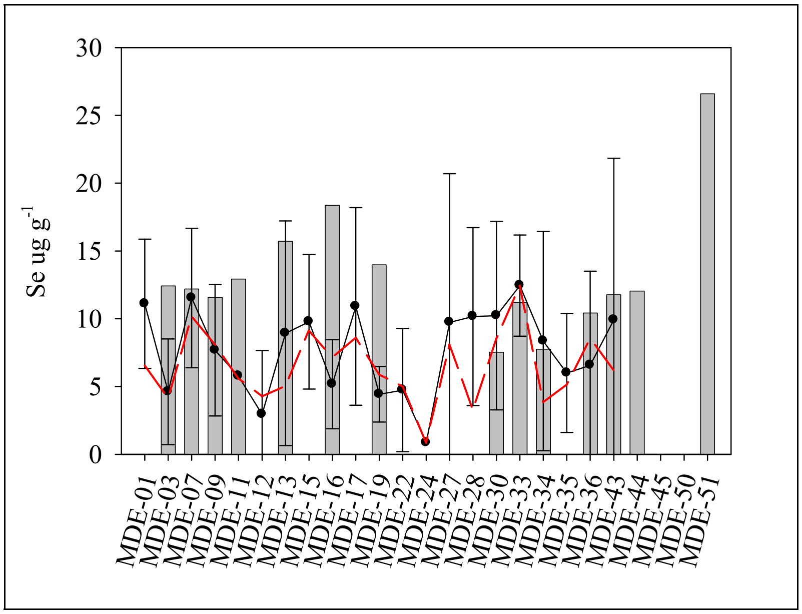
Concentrations of As in the sediment were generally found to be similar to concentrations seen in previous years with the exception of sites MDE-38 and MDE-18. Concentrations of samples collected in September 2009 when compared to data collected between 1998 and 2008 exceeded the mean by more than 5 ug g^{-1}. However, concentrations of As were similar to concentrations found at these same two sites between 1999 and 2001. The concentrations of Se were generally high but fell within the standard deviation of the average of previous years. Higher concentrations of Se were also seen between 1999 and 2001 and again in the fall of 2008 and 2009. Ag was found to have concentrations lower than the mean and median concentrations of previous years.

Unlike Ag, concentrations of T-Hg in sediment were generally greater than the running mean of previous years but fell within the standard deviation of measurements made between 1998 and 2008. Concentrations of T-Hg at stations MDE-18, 38, 39, and 44 were much higher than in previous years. However, sediment samples were also collected from site MDE-44 (a South Cell station) during the MDE biota cruise in September 2009 and April 2010 and concentrations of T-Hg in these samples were less that 100 ng g^{-1}. This is compared to a concentration of slightly less than 800 ng g^{-1} in the sample collected during the MGS cruise. This variation in sediment concentration points to either a large spatial or high temporal variability, and is indicative of the need for repeated sampling at the wide range of sites, thus better characterizing the sediments. Concentrations of MeHg were typical and comparable to other areas of the Chesapeake Bay (Heyes et al. 2006).

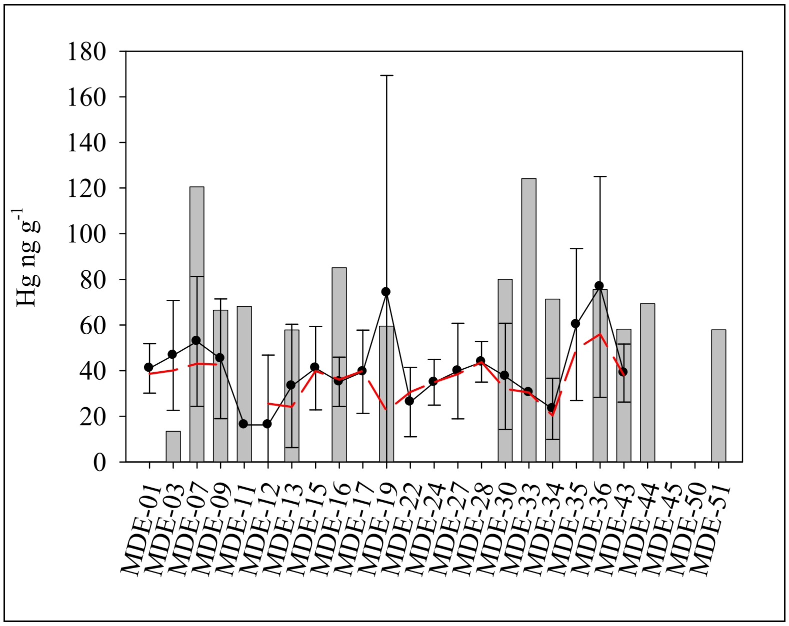
Metals in Clam Tissue

The clam *Rangia cuneata* was collected from 14 sites in September 2009 and 14 sites in April 2010. Tissue was analyzed for As, Se, Ag, Cd, Pb, Hg and MeHg. Tissue samples were also analyzed for PCBs and PAHs.

In clam samples collected in September 2009 concentrations of As, Se, Cd and Hg were close to the running mean at each station, and were lower than the running mean for MeHg, Ag, and Pb. For those samples collected in April 2010 concentrations of As and MeHg were close to the historical concentrations while Pb, Ag and Cd were equal to, or lower than the running mean based on previous years. Concentrations of Se, which were found to be generally high in sediments when compared to previous years, and Hg, were higher than the standard deviation around the historical mean in clam concentrations at some sites (Summary Figure 1-7 and Summary Figure 1-8). Clam tissue collected from Stations MDE-16 and MDE-19, which are near the dike wall and possibly influenced by effluent from Spillways 009 and 003 respectively, had elevated levels of Se. However, station MDE-51 which is a new Reference site located beyond the zone of HMI influence had higher levels of Se than all other stations. The high levels seen at MDE-51 would indicate there are other sources of Se; however, given the high levels seen at MDE-16 and 19 close monitoring of the effluent from HMI is imperative.



Summary Figure 1-7. Concentrations of Se in clams collected in April 2010. Concentrations (bars) are dry weight based, and the 1998-2008 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2008 median (dashed line).



Summary Figure 1-8. Concentrations of Hg in clams collected April 2010. Concentrations (bars) are dry weight based, and the 1998-2008 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2008 median (dashed line).

Total PCB concentrations in sediments and clams

As a cost savings, analysis of PCBs were not done every year during the dredge filling stage. In Year 27, PCBs were not analyzed, thus in Year 28 clams collected during the September 2009 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.

With the exception of MDE-17, total PCB concentrations in sediment samples were similar at all sites when compared to historical data. The total PCB concentration in sediment at site MDE-17 was 2 times higher than the historical average and outside the standard deviation. MDE-17 is located approximately 1 mile southeast of the dike wall and within the zone of HMI influence. However, stations MDE-16, and 19 are located closer to the dike and yet had concentrations below their historical average. Sediment was also collected at MDE-44 which is close to South Cell Spillway 003 but there is no historical data with which to compare; however, concentrations were similar to other sites. Given that these three sites had comparatively low PCB concentrations it is not likely the high concentration seen at MDE-17 is due to HMI operations.

Unlike total PCBs in sediment, concentrations in clams collected in September of 2009 were on average 2 times higher than the historical running mean for most of the sites. Clams collected from the reference site, MDE-36, also showed the same elevated concentrations when compared to the historical mean concentration. Rangia are primarily non-select filter feeders gaining nutrition by using a siphon to filter large quantities of plant detritus and phytoplankton from the water (Verween et. al. 2006). Given the high total PCB concentration found in tissue collected from the reference station MDE-36, located three miles north of HMI, it is likely that the overall elevated concentrations seen in Year 28 at all the sites are due to a source or sources other than operations at HMI.

Total PAH concentrations in sediments and clams

With the exception of MDE-17, total PAH concentrations in sediment samples at all sites were similar to historical data. Total PAH concentration at site MDE-17 was greater than twice the historical mean and outside the standard deviation of the means. The total PCB concentration was also higher at site MDE-17 then previously observed. Concentrations of total PAHs in clams remained near historical levels with the exception being clams from site MDE-17, which appear slightly elevated. The clam concentrations mirror the sediment changes, suggesting a possible local influence. A local influence could not be differentiated from the PCB data, thus the association is weak.

As with PCBs, total PAH concentrations at MDE-16, 19 and 44 (close proximity to South Cell Spillway 003) were comparatively low. MDE-16 was considerably below the historical average, MDE-19 was consistent with the historical average and MDE-44 has no historical data but compared to all stations had the third lowest concentration. Total PAHs concentration at MDE-17, also in proximity to the South Cell but farther away then the former mentioned sites was over twice the historical average. Again, it is unlikely the enrichment of total PAHs at MDE-17 is due to HMI operations. PAH concentrations in both sediments and clams sampled over the entire region were generally similar to previous years studied, thus it seems unlikely that any activities within the HMI complex have influenced PAH concentrations in sediments and biota.

PROJECT I SUMMARY AND RECOMMENDATIONS

Based on samples collected by MGS in September 2009 there were 3 areas within the zone of HMI influence that showed enrichment of Pb two of which also showed enrichment of Zn. One area was contiguous to the South Cell by Spillway 003; a second area was along the southeast wall of the North Cell but not contiguous; and the third was a small area on the north side of HMI between Spillway 007 and 008.

The first area of enrichment included stations MDE-18 and 44 which are in close proximity to the South Cell Spillway 003. In samples collected September 2009, MGS reported enrichment of Pb at MDE-44, and enrichment of both Pb and Zn at MDE-18. At these same sites, metals in clam tissue analyzed by CBL were found to be near the running mean and for some metals slightly below. Bioaccumulation factors for metals, especially Pb, were also low. MDE did not collect benthic samples at MDE-18; however, the B-IBI score for MDE-44 was 4.0. All other benthic sites in proximity to the South Cell met or exceeded the benchmark of 3.0. Based on the triad approach for interpreting results (i.e., comparing results of Projects II, III, and IV), in the vicinity of the South Cell, the fall 2009 data suggest that although metals (Pb and Zn) were enriched in sediment, the biota appear not to have been adversely affected.

In the second area near North Cell Spillway 009, Pb and Zn were enriched at stations MDE-15 and 46, and only Pb was enriched at stations MDE-14 and 47 (Summary Figure 1-3). Of the four sites CBL and MDE only sampled MDE-15. In the composite of clams collected by CBL, concentrations of all metals, with the exception of Hg, were at or below the running mean. Mercury was nearly twice the running mean; however, the bioaccumulation factor was favorably below 1. The B-IBI score reported by MDE was 3.0 just meeting the benchmark. As with the sites proximal to the South Cell, the data suggest again that although metals (Pb and Zn) were enriched in sediment, the biota appear not to have been adversely affected.

The third and final area, on the north side of HMI, included only station MDE-33 and had a rather high enrichment of Pb (Summary Figure 1-3). In September 2009 CBL did not sample MDE-33 but did sample MDE-34 approximately a half mile southeast. Concentrations of metals in the composite of clams collected at MDE-34, with the exception of total Hg (37.82 ng g^{-1}), were below the running average. The concentration of total Hg in the sediment collected by CBL concurrently with the clams was 163.28 ng g^{-1}, which is well below the Potential Effects Level (PEL) of 700 ng g^{-1}. MDE did collect replicate benthic samples at MDE-33 and although it was a very sandy site the B-IBI was a good score of 4.0 (Summary Figure 1-6). MDE-34, which was on the fringe of the area of Pb enrichment, had an excellent B-IBI score of 4.5. As with the previous two areas with enrichment of Pb and Zn, overall when comparing the results of the three Projects (hence the Sediment Quality Triad) the data suggest that although some contaminants are elevated in the sediment there appear to be no adverse effects within the biota.

The Year 28 April 2010 results showed no enrichment of Zn which is an improvement compared to Year 27 and previous years. Enrichment of Pb was not seen in the area of the South Cell in Year 28 which is an improvement over Year 27. However, there was an area of enrichment along the dike of the North Cell slightly north of Spillway 009, and a rather large area northeast of HMI. In Year 27 neither of these locations had enrichment of Pb or Zn.

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 addition, results for the sites within, and proximal to, the two areas of enrichment of Pb are within range of those sites distanced from the areas 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 28 April sampling of clams, CBL found that concentrations of As and MeHg were close to the historical concentrations, and concentrations of Pb, Ag and Cd were equal to, or lower than, the running mean based on previous years samplings. CBL did find that Se and Hg were elevated beyond the standard deviation around the historical mean clam concentrations at some sites.

Enrichments of Pb and Zn are still rather persistent around the South and North Cells. Results of Project III show that benthic communities have been rather healthy over the past two years. B-IBI scores for all stations, with the exception of MDE-27 (influenced by Back River), have met or exceeded the benchmark of 3.00. Clam studies conducted by CBL have shown that concentrations of metals are generally consistent with previous years although in Year 28 higher concentrations of Se were seen. Selenium was also found slightly elevated at some sites in sediment.

With the closure of the North Cell and the new phase of dewatering and crust management, the opportunity for sediment to be exposed to the atmosphere resulting in the oxidation of sulfides is augmented. Salts dissolved by subsequent rainfall can create acidic condition, which in turn can liberate available metals. Hence, even though exterior monitoring shows favorable results, it is crucial that monitoring continue so that any possible changes are captured early and before adverse effects are realized.

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APPENDIX 1: SEDIMENTARY ENVIRONMENT (PROJECT II)

(September 2009 - August 2010)

Technical Report

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EXECUTIVE SUMMARY

The Coastal and Environmental Geosciences Program of the MGS has been involved in monitoring the physical and chemical behavior of near-surface sediments around the Hart-Miller Island Dredged Material Containment Facility (HMI 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 3, 2009 and April 7, 2010. The sediment samples were analyzed for various physical and chemical properties of the samples: (1) grain size composition (relative proportions of sand, silt, and clay) and (2) total elemental concentrations of iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), cadmium (Cd), lead (Pb), phosphorous (P), carbon (C), nitrogen (N), and sulfur (S)

For exterior bottom sediments sampled during Year 28, 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.

Results of the elemental analyses are statistically similar to the previous year's data. With regard to the National Oceanic and Atmospheric Administration (NOAA) Effects Range Low (ERL) and Effects Range Medium (ERM) values, this year's 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. Ni and Zn exceed the ERM values at some sites.

ERL and ERM 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. Because this 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 used a grain size normalization technique to assess changes in the sediments that may be attributed to 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, the data show that certain sediment samples are significantly enriched with Pb and Zn compared to the baseline levels.

Pb levels adjacent to the HMI were higher, in terms of the number of samples exceeding 3 sigma levels, compared to the previous year. The spatial extent of Pb enrichment was broader. In September, Pb enrichment was seen at three areas: one adjacent to Spillway 003 (MDE-44 and 18); a second, more dispersed area, southeast of HMI; and an isolated site north of the facility (MDE-34). By spring, Pb enrichment along the eastern side was isolated to one station (MDE-8) next to the facility. However, the Pb enrichment was seen at three sites northeast of the facility.

In September, Zn enrichment was between 3 and 4 sigma at three isolated sites (MDE-15, 18 and 46). In April, Zn enrichment was below 3 sigma at all sites within the HMI zone of influence.

Spatial distribution of both Pb and Zn enriched areas in September suggests that the South Cell discharge was the source. There was a period of steady discharge from the South Cell just prior to the sampling cruise as opposed to very little discharge from the North Cell during the same period. Based on the spring sampling, the spatial distribution of Pb enriched areas shifted north, suggesting that the source of the Pb may be from the North Cell even though there was continued discharge from the South Cell. During the month prior to the spring sampling, there were discharges from all three North Cell spillways. Although the volume of discharges from Spillway 007 and 008 were small (6 and 3.5 million gallons, respectively, over a 2 month period), effluent may have contained above background levels of Pb. North Cell discharge appeared to have had a minimal effect for both cruises, with regard to Zn enrichment.

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.

These persistent enriched levels 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 (Spring 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, in the vicinity of the facility higher than expected levels of Zn and Pb have persisted. Figure 1-1, in addition to showing the sampling sites for Year 28, 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 22 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).

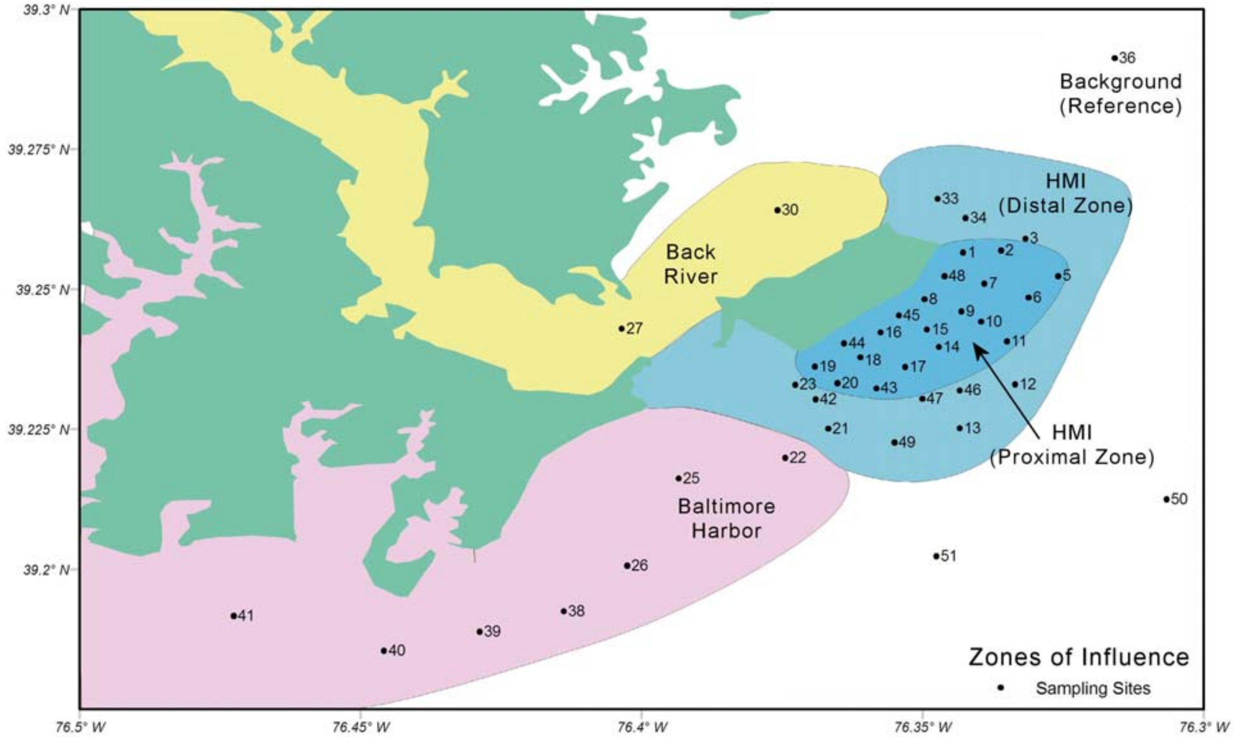


Figure 1-1. Sampling locations for Year 28. Color areas show zones of influence found in previous studies. Stations 38 – 41 were added in Year 18 to measure the influence of Baltimore Harbor. Starting the previous monitoring year (Year 27), four stations in the Back River zone were dropped and additional 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 28 cruises are summarized below. Information, which was provided by Carolyn Blakeney, Casandra Carr and Amanda Peñafiel of MES, covered the period from April 1, 2009 to April 30, 2010.

Between April 1, 2009 and December 31, 2009, 3.54 million cubic yards of dredged material were place in the North Cell. Placement was not uniform but sporadic with no material placed between May 20, 2009 and September 22, 2009 (Figure 1-2). 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 additional water input in the North Cell and South Cell. The South Cell also received water that flows into the holding pond used for controlling the interior waterfowl pond and spray irrigation. Figure 1-3 compares the monthly rainfall for HMI and Baltimore Washington International Airport (BWI) for the period between January 2009 and April 2010. While the trend in monthly total precipitation recorded at HMI tracked that of BWI, monthly totals at HMI were generally lower. However, total amount of precipitation for both HMI and BWI were about 10 inches higher than recorded for the previous 12-month period (i.e., 27th monitoring year). Total precipitation at HMI during this monitoring year (April, 2009 to April, 2010) was the highest since the 25th monitoring year.

Also shown in Figure 1-3 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 early fall (dry). The flow rate generally was not influenced by local precipitation. During this monitoring period, high seasonal average was 50,628 cubic feet per second (cfs) and low seasonal average was 26,413 cfs. The seasonal averages were high 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, 1993).

Total discharge from the North Cell for the monitoring year was 1,804 million gallons, which was twice that of the previous year but only a quarter of the volume discharge during 26th year monitoring (2007-08). Discharge from the North Cell was sporadic throughout the monitoring year (Figure 1-4). Highest discharges (>10 mgd) corresponded to the two periods of material placement, one at the beginning of the monitoring and the second during the fall of 2009. However, the higher discharges also corresponded to periods of higher rainfall. Discharges were intermittent and less than 10 mgd between July 2009 and October, 2009, and after the facility stopped accepting new dredged material. Spillways 007, 008 and 009 were used for discharge with 99% of the total discharge coming from Spillway 009.

Total discharge from the South Cell was 465 million gallons, approximately four times the volume discharged during the previous year. Discharge was sporadic during the monitoring year with daily rates less than 10 mgd (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 July to August to lower the water level 2 feet in the South Cell for mudflat exposure for migrating birds. Between September and mid-October, Bay water was pumped in from the holding pond to raise the level of the habitat pond. There were no discharges during this period. 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.

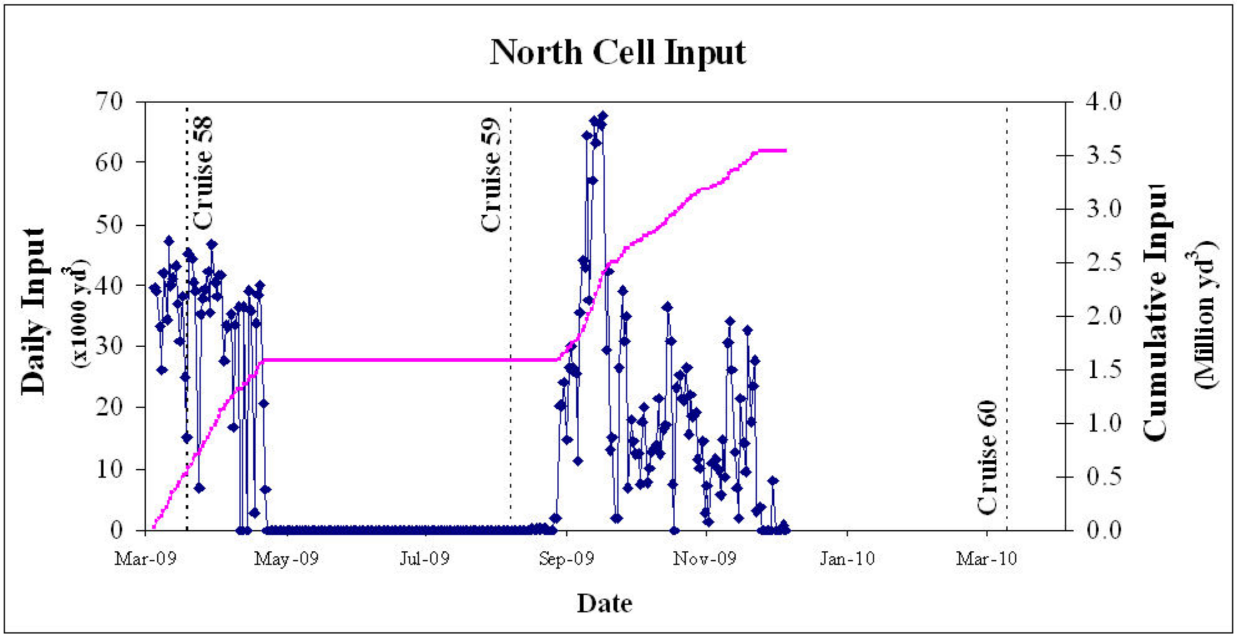


Figure 1-2. Dredged material inputs into HMI between April, 2009 and May, 2010. Blue line with diamond points indicates daily input, and pink line indicates cumulative input.

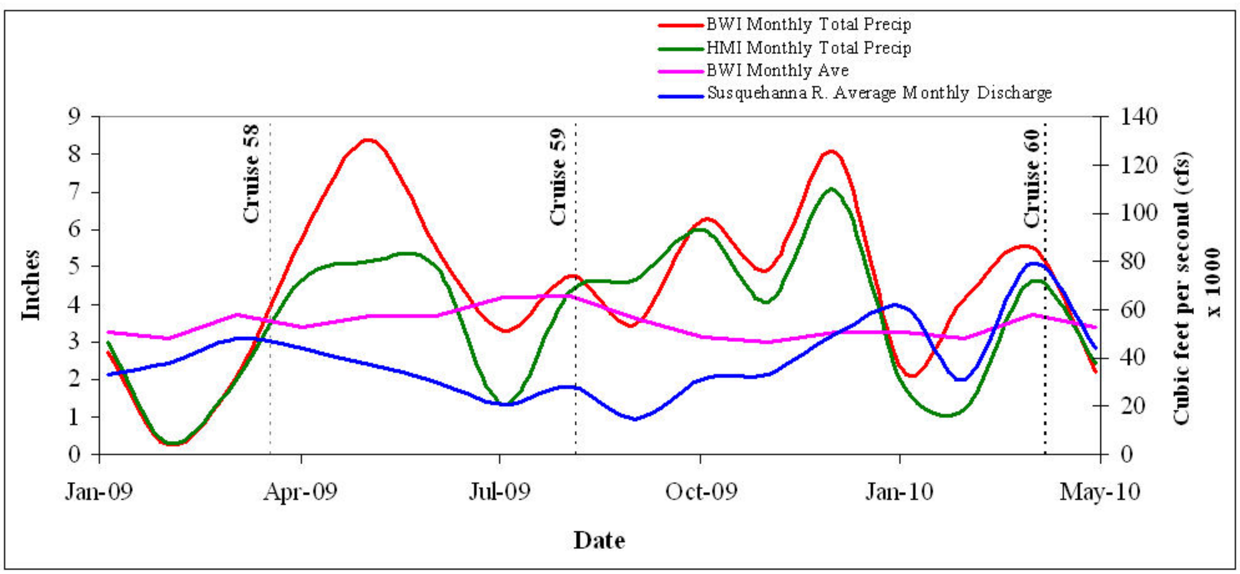
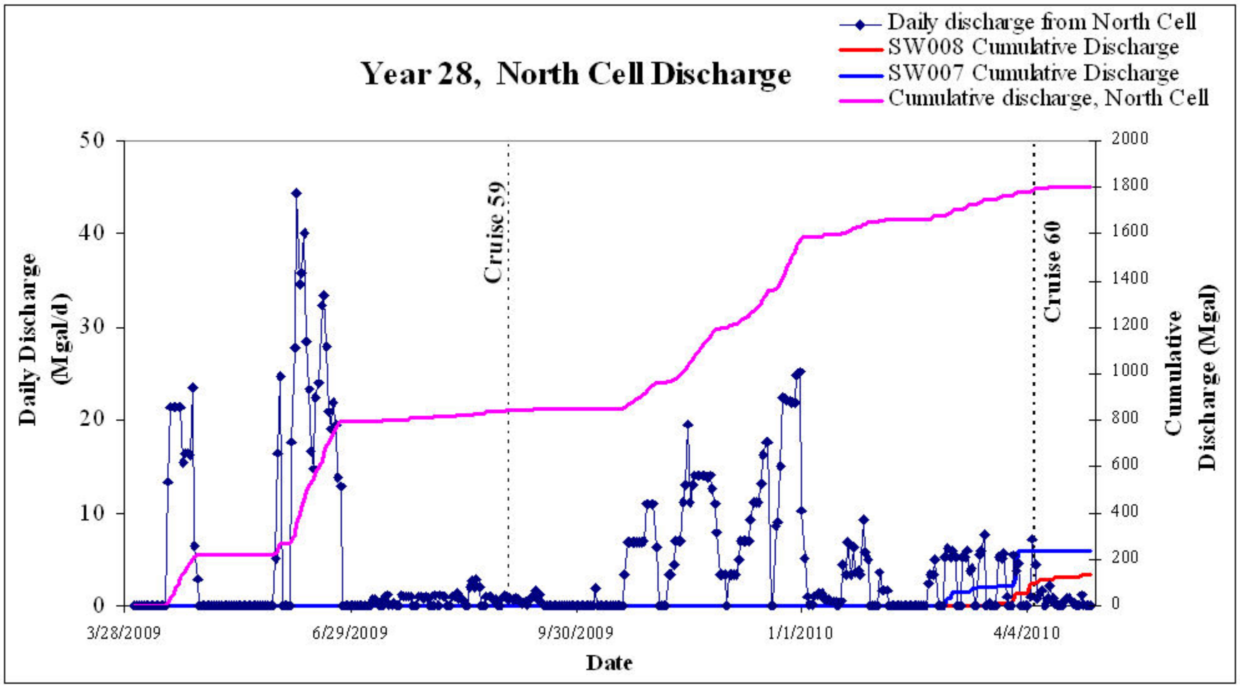


Figure 1-3. Comparison of monthly precipitation data collected at HMI Facility and at the National Weather Service (NWS) Station at BWI with the average monthly discharge of the Susquehanna River. BWI monthly averages were based on monthly precipitation data from 1871 to 2010. Susquehanna River data were obtained from the USGS website.



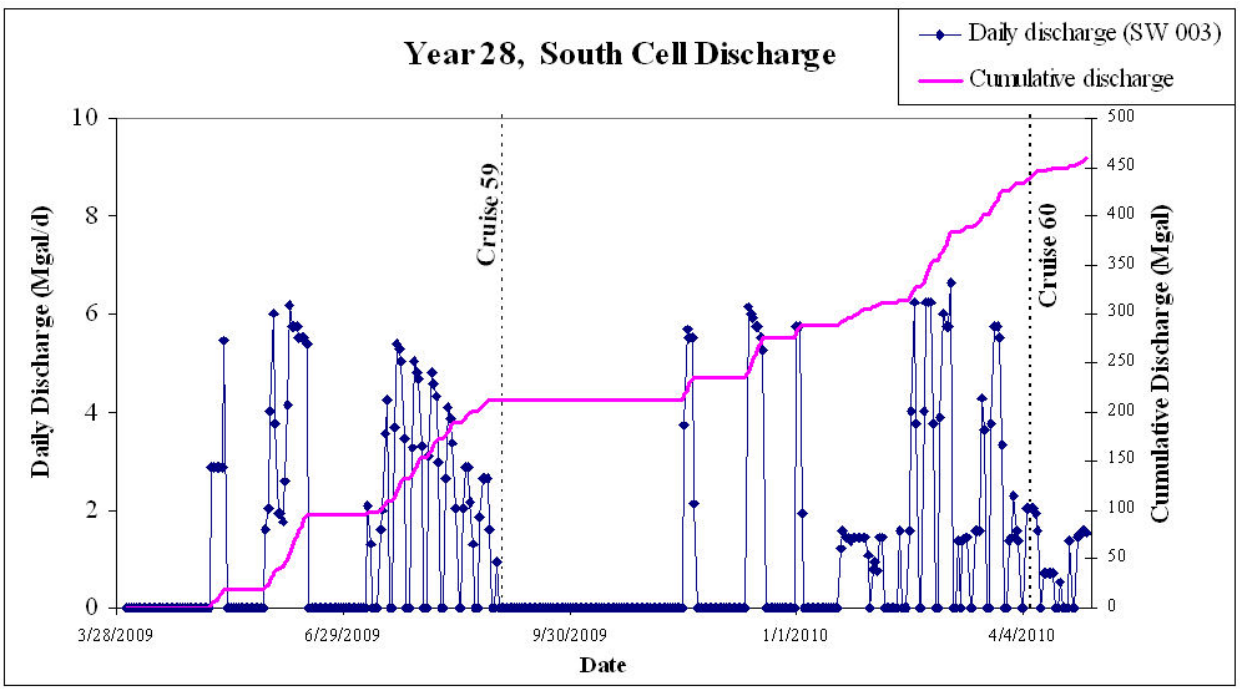


Figure 1-4. Daily and cumulative discharge from the North and South Cells. The daily discharge amounts from the North Cell are the sum of the respective discharge from Spillways (SW) 007, 008 and 009. The exterior sediment sampling events are marked by the vertical lines.

OBJECTIVES

As in the past, the main objectives of the Year 28 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 3, 2009, and the second, on April 7, 2010.

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 most sites. Target and actual coordinates (latitude and longitude - North American Datum of 1983) of Year 28 sample locations are reported in the companion *Year 28 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 28 cruises. The stations were identical to those sampled during Year 27.

At 39 stations for both the September and April cruises, a single grab sample was collected, described lithologically, and split. Triplicate grab samples were collected at the remaining four stations (MDE-2, MDE-7, MDE-9 and MDE-31) and, likewise, described and split. MGS analyzed one split for grain size composition, a suite of metals, and phosphorus, carbon, sulfur and nitrogen. The CBL analyzed the second split collected for a different suite of metals. Field descriptions of samples are included as appendices in the *Year 28 Data Report*.

Using plastic scoops rinsed 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^{o}C until they could be processed in the laboratory. CBL's splits were handled in much the same way, except that they included the floc layer and were frozen instead of refrigerated. CBL's samples are only collected for the fall sampling of each monitoring year. Therefore, the spring sampling procedure does not include a split.

Laboratory Procedures

Textural Analyses

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

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

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

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

The relative proportions of sand, silt, and clay were determined using the sedimentological procedures described in Kerhin et al. (1988). The sediment samples were pre-treated with hydrochloric acid and hydrogen peroxide to remove carbonate and organic matter, respectively. Then the samples were wet sieved through a 62-µm mesh to separate the sand from the mud (silt plus clay) fraction. The finer fraction was analyzed using the pipette method to determine the silt and clay components. Each fraction was weighed; percent sand, silt, and clay were determined; and the sediments were categorized according to Pejrup's (1988) classification (Figure 1-5).

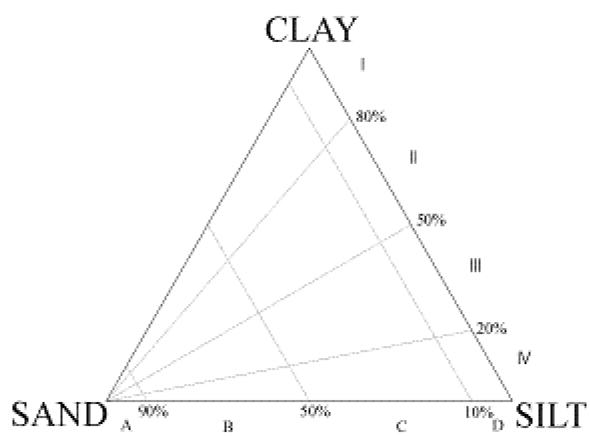


Figure 1-5. Pejrup's Diagram (1988) classification of sediment type.

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 28 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 28 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 28 results are discussed with respect to the preceding Year 27 results, and where appropriate, with references to earlier monitoring year results.

All sampling sites visited during Year 28 yielded results that can be compared to those measured during Year 27. 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 27 - 28, for 43 sediment samples common to all four cruises.

Variable	Sept 2008 Cruise 57	Apr 2009 Cruise 58	Sept 2009 Cruise 59	Apr 2010 Cruise 60
Sand (%)				
Mean	23.07	21.50	23.65	21.49
Median	4.19	5.02	4.53	3.94
Minimum	0.61	0.52	0.72	0.55
Maximum	97.99	98.13	98.68	98.40
Range	97.38	97.60	97.95	97.86
Count	**43**	**43**	**43**	**43**
Clay:Mud				
Mean	0.55	0.56	0.55	0.54
Median	0.56	0.56	0.55	0.55
Minimum	0.44	0.40	0.45	0.30
Maximum	0.63	0.61	0.69	0.65
Range	0.19	0.22	0.24	0.35
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%). In general, points lie above the 50% line, indicating that the fine (muddy) fraction of the sediments contains more clay than silt.

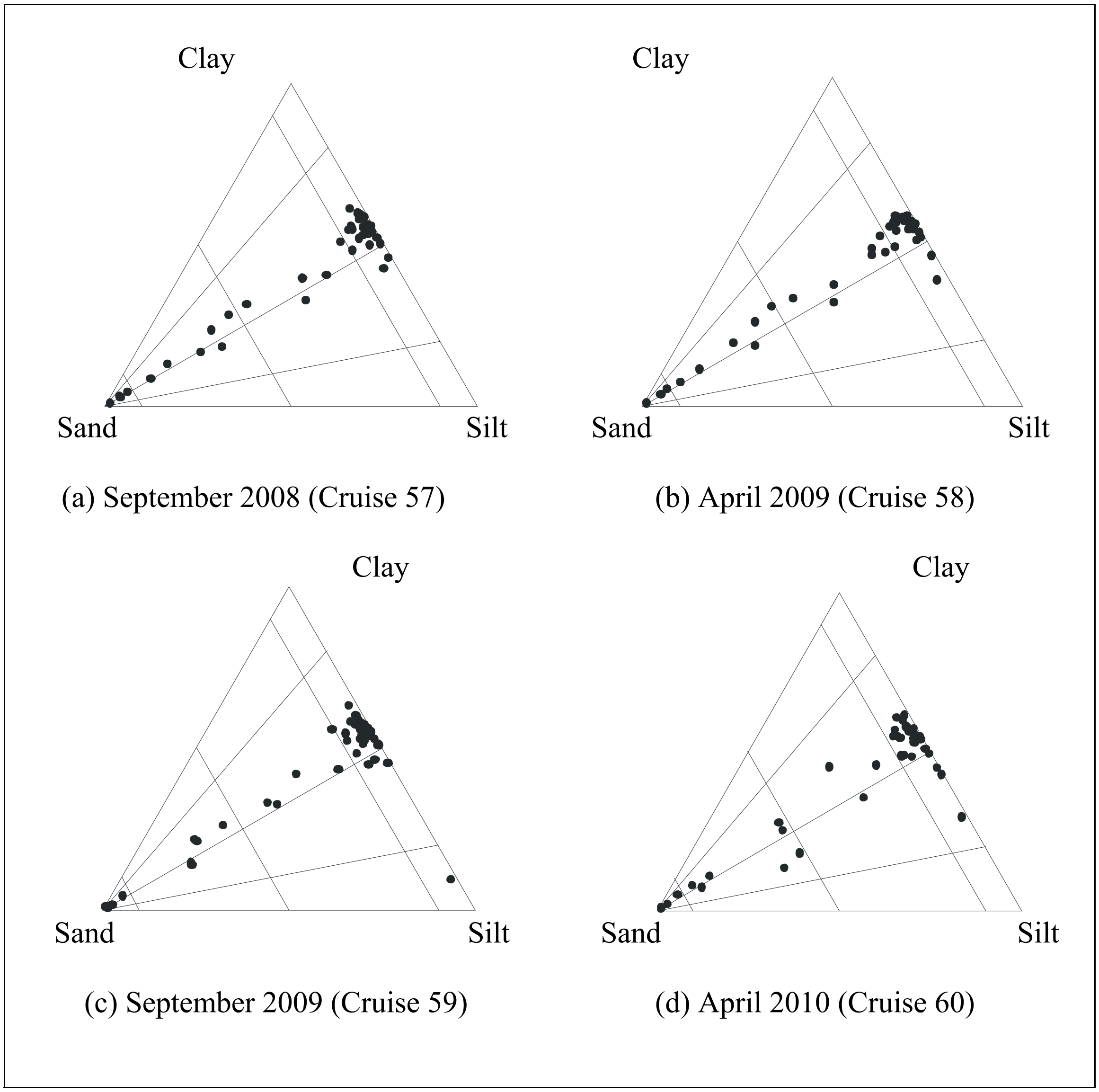


Figure 1-6. Pejrup diagrams showing the grain size composition of sediment samples collected in Years 27 and 28 from the 43 sampling sites common to all four cruises: (a) September 2008, (b) April 2009, (c) September 2009, and (d) April 2010.

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 0.55 for sampling Cruise 57 and increased slightly to 0.56 for Cruise 58 and dropped to 0.55 and 0.54, respectively for Cruise 59 and 60 of this monitoring year.

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.

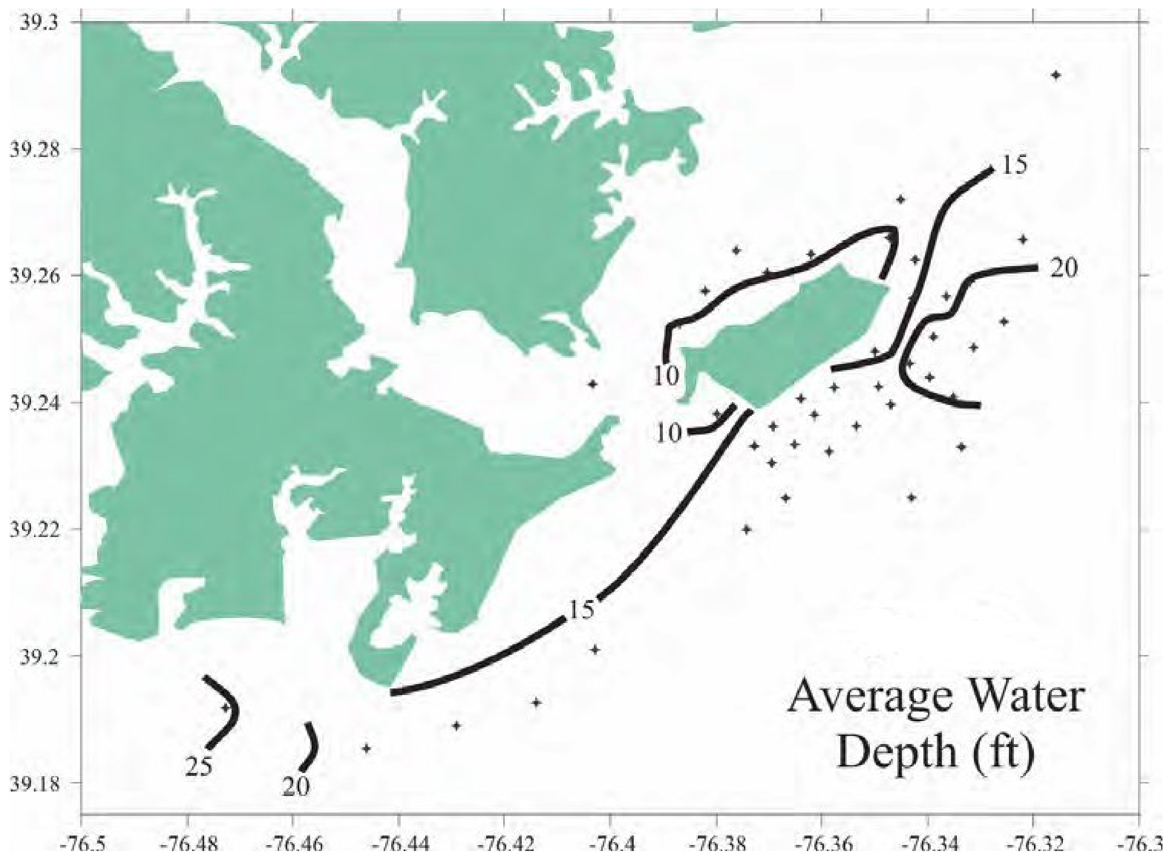


Figure 1-7. Average water depths around HMI and vicinity. Contour interval = 5 ft.

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 27 and 28 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 changed slightly based on September 2008 sampling. By April 2009, sand content in the area dropped below 90%, indicating a slight increase in silt/clay. By September 2009 (Year 28), sand content returned to greater than 90% (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 clay-rich area south of HMI was present in both September 2008 and September 2009, but diminished in size in the April sampling of both years. This pattern of change is 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. The silt-rich areas were consistent during the previous two years of monitoring with regards to the area adjacent to the walls of the dike to the south remaining silt-rich. However, based on the most recent cruise (April 2010) the silt-rich area was confined to one station (MDE-8) (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 similarities between the fine fraction results from Year 27 and Year 28, one may conclude that the depositional environment in the vicinity of HMI has not changed over this period. While there were a larger number of clay-rich sites in September sampling, there was a subsequent decrease in April sampling for the previous and this year monitoring. The grain size distribution of Year 28 samples is largely consistent with the findings of past monitoring years.

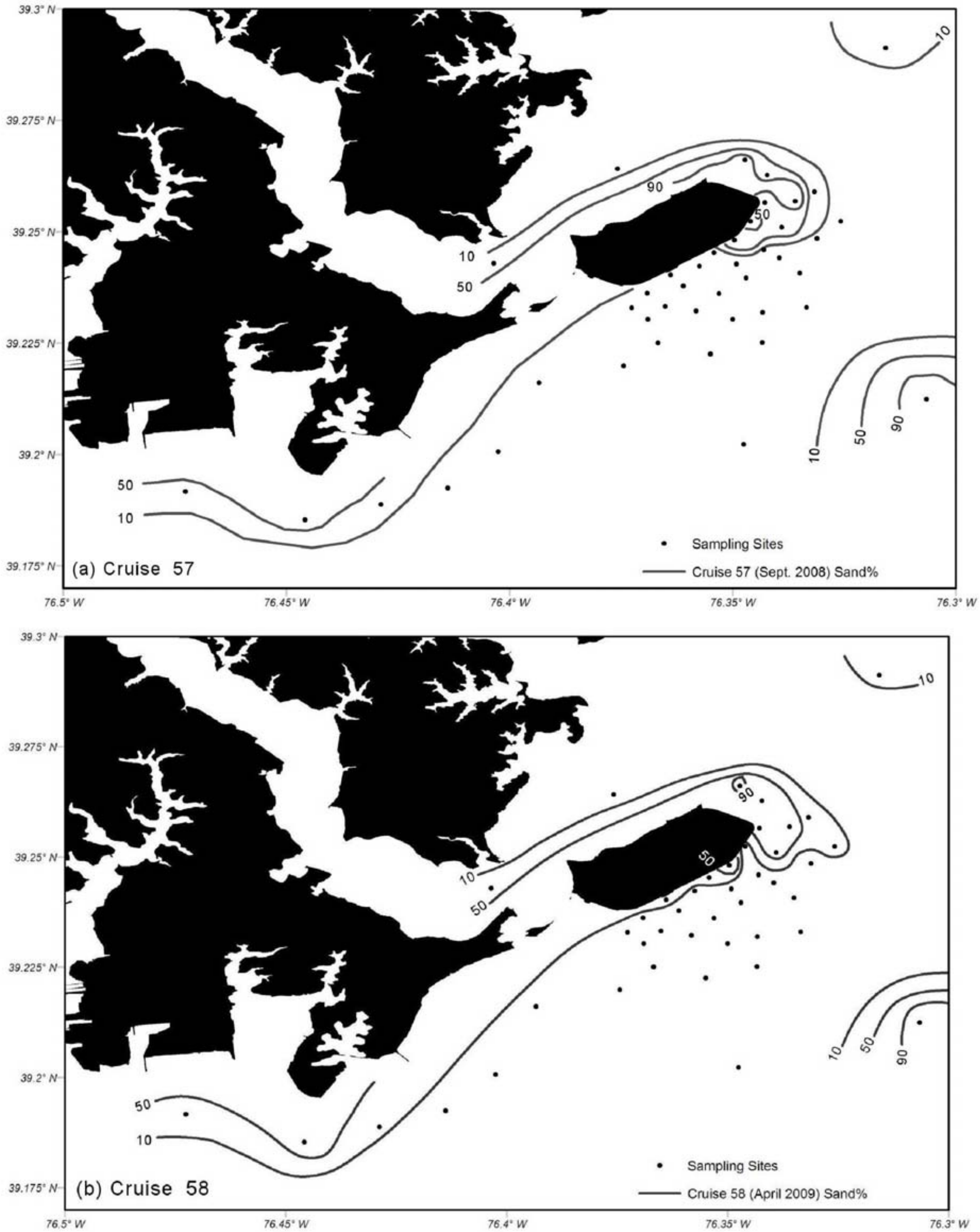


Figure 1-8. Sand distribution for Monitoring Year 27: (a) September 2008 (Cruise 57), (b) April 2009 (Cruise 58). Contour intervals are 10%, 50%, and 90% sand.

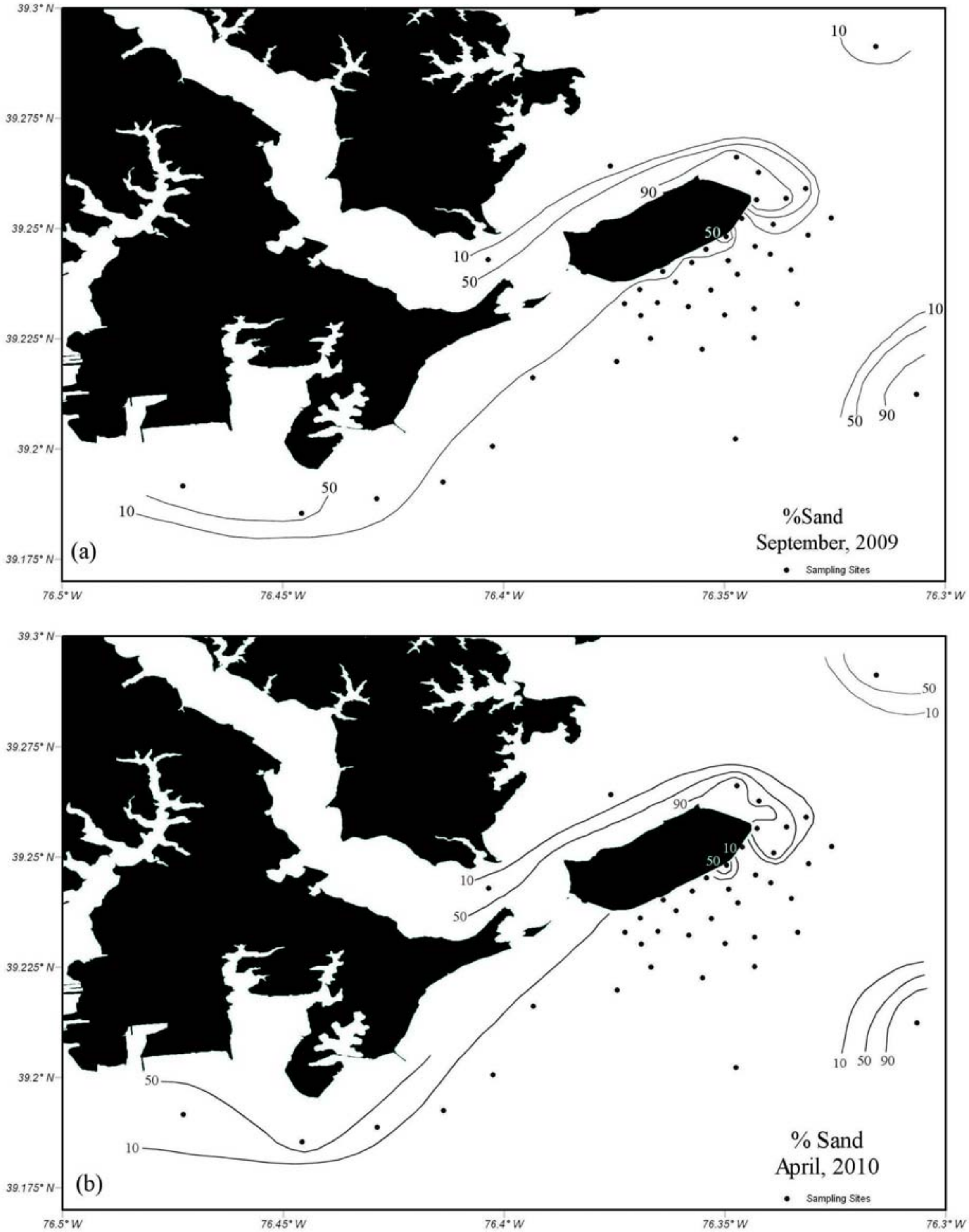


Figure 1-9. Sand distribution for Monitoring Year 28: (a) September 2009 (Cruise 59), (b) April 2010 (Cruise 60). Contour intervals are 10%, 50%, and 90% sand.

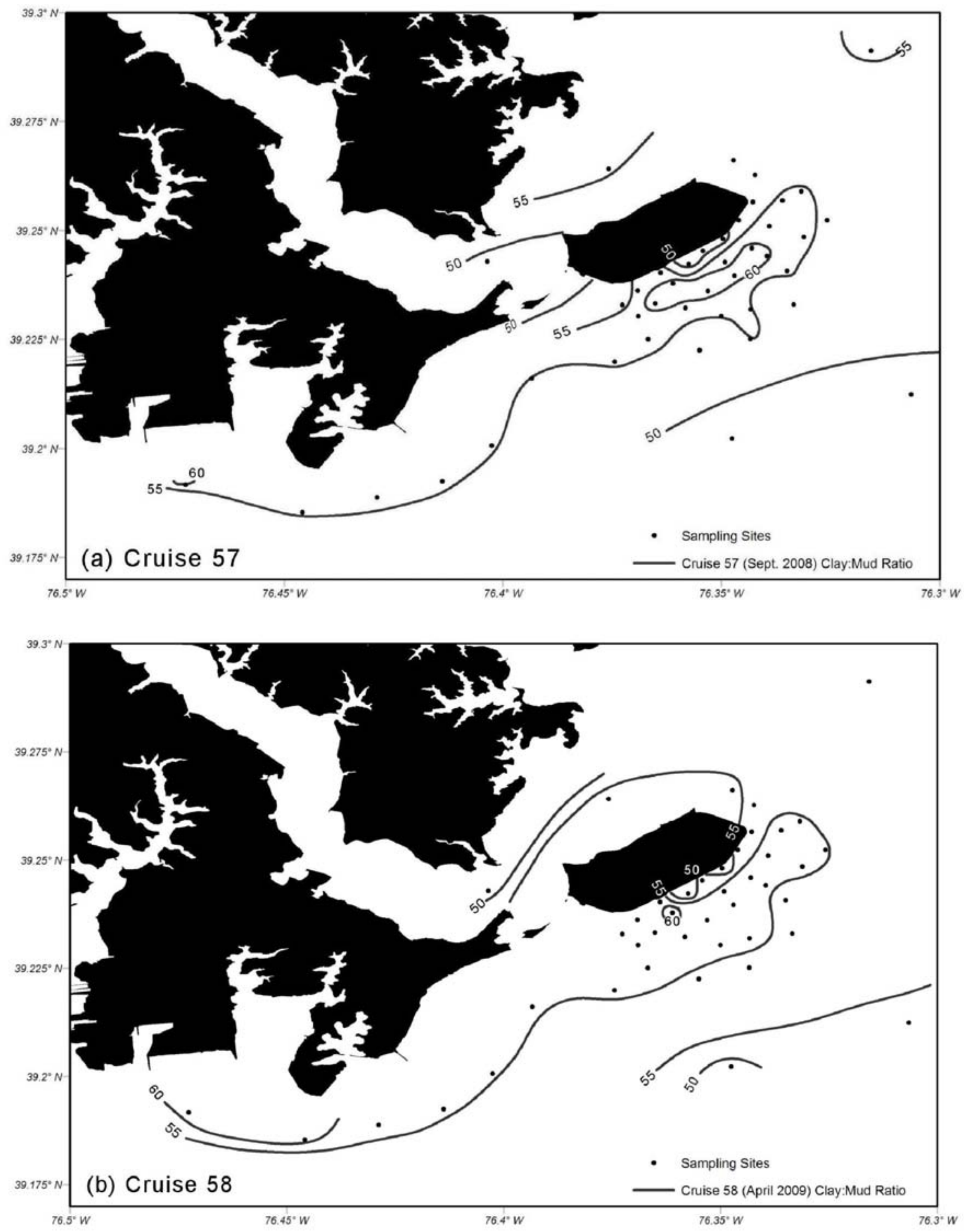


Figure 1-10. Clay;Mud ratios for Monitoring Year 27: (a) September 2008 (Cruise 57), (b) April 2009 (Cruise 58). Contour intervals are 50%, 55%, and 60% (clay:mud ratio expressed as %)

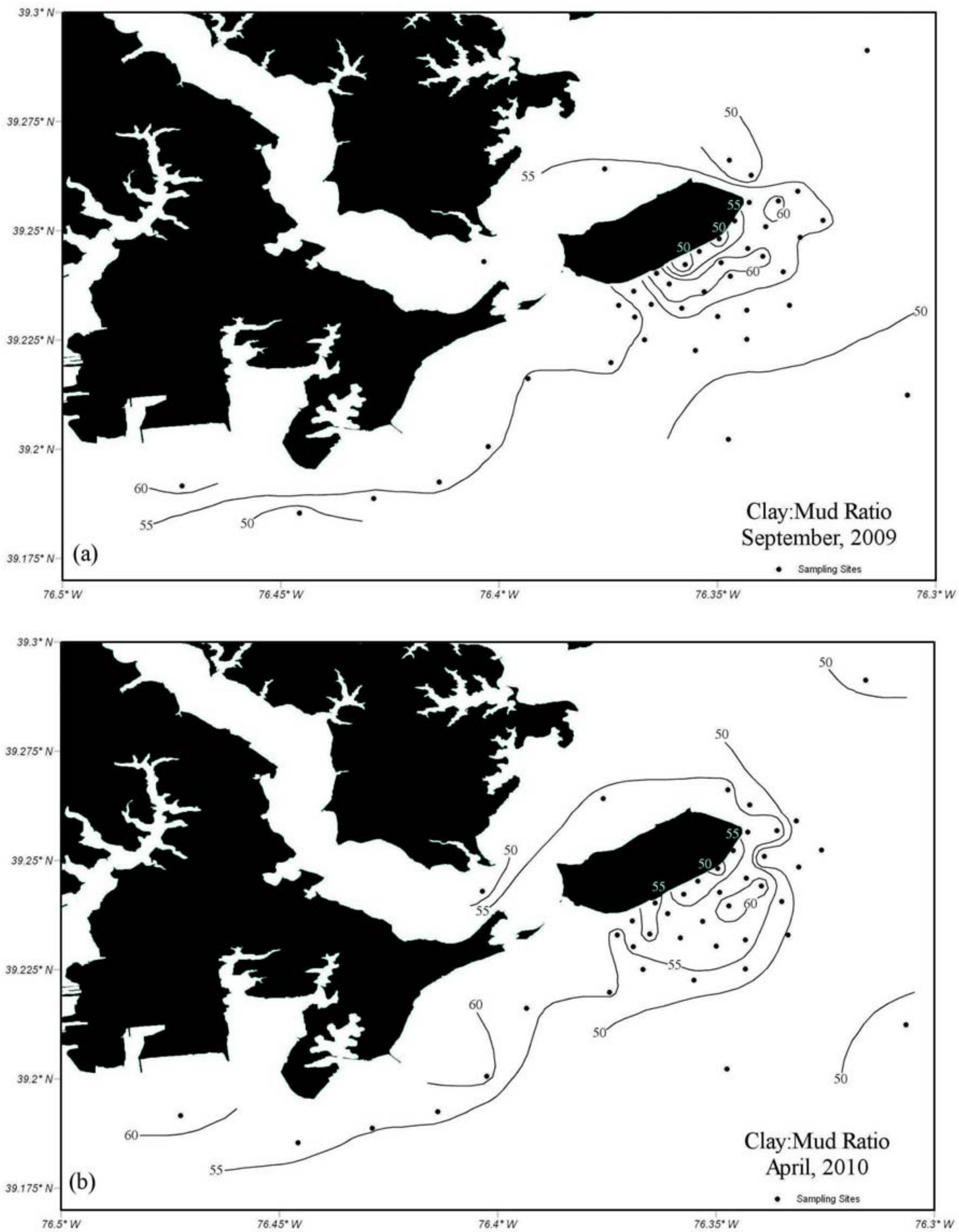


Figure 1-11. Clay:Mud ratios for Monitoring Year 28: (a) September 2009 (Cruise 59), (b) April 2010 (Cruise 60). Contour intervals are.50%, 55%, and 60% (clay:mud ratio expressed as %).

Elemental Analyses

Interpretive Technique for Metals

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

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

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

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

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

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

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

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

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

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

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

General Results

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 424 ppm which was measured from MDE-41 sampled during the September 2009 cruise. The sample also contained the maximum 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. Ni and Zn exceed the ERM values at some sites.

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). 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:

3. When the sigma level exceeds +2 [indicating enriched metals concentrations over baseline] and;
4. 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].

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	0.070	0.69	88	41	3.83	2610	74	52	291
Std	0.028	0.30	48	17	1.39	1424	32	24	143
Min	0.003	0.30	16	3	0.24	360	7	4	16
Max	0.120	1.60	424	76	5.55	9020	152	133	779
n	86	72	82	86	86	86	86	86	86
ERL	n/a	1.3	81	34	n/a	n/a	21	47	150
#>ERL	n/a	5	55	62	n/a	n/a	79	56	71
ERM	n/a	9.5	370	270	n/a	n/a	52	218	410
#>ERM	n/a	0	1	0	n/a	n/a	67	0	17

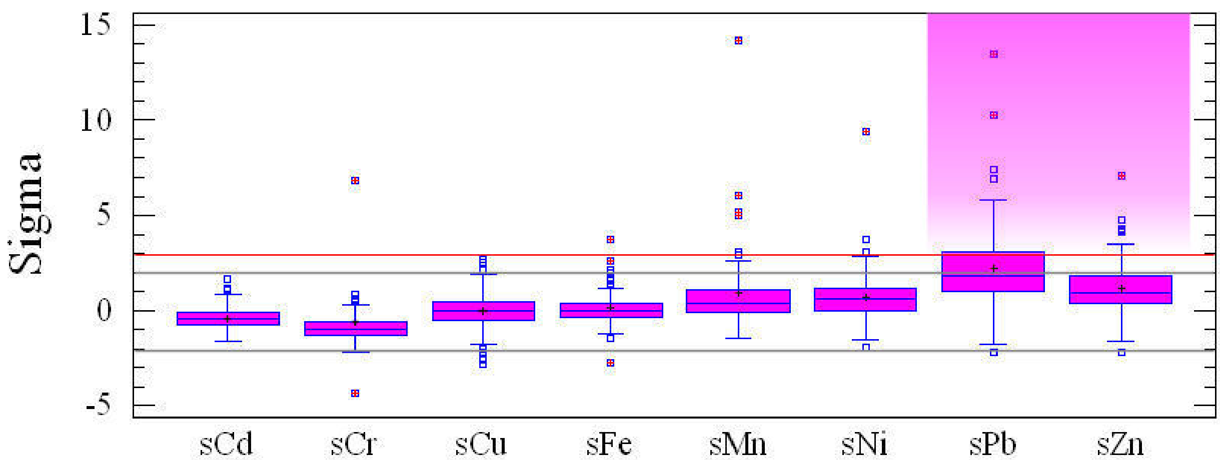


Figure 1-12. A box and whisker diagram showing the range of the sigma levels for both the September and April cruises for Year 28. An extreme outlier (+28) is not shown for Cr. The outlier corresponds to MDE-41 which is in the Baltimore Harbor zone of influence.

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 28% of the samples contain Pb significantly exceeding the baseline levels (*i.e.*, >3 sigma levels, indicated by red line), 7% of the samples contain Mn levels exceeding the baseline and 8% 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 (shown as outliers in Figure 1-12) are in the Baltimore Harbor zone of influence.

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 the sigma levels for Pb for Year 28 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. With the exception of higher Pb at MDE-41, both metals showed similar enrichment values as compared to Year 27. There was a seasonal shift in level of enrichment with slightly higher values in the fall.

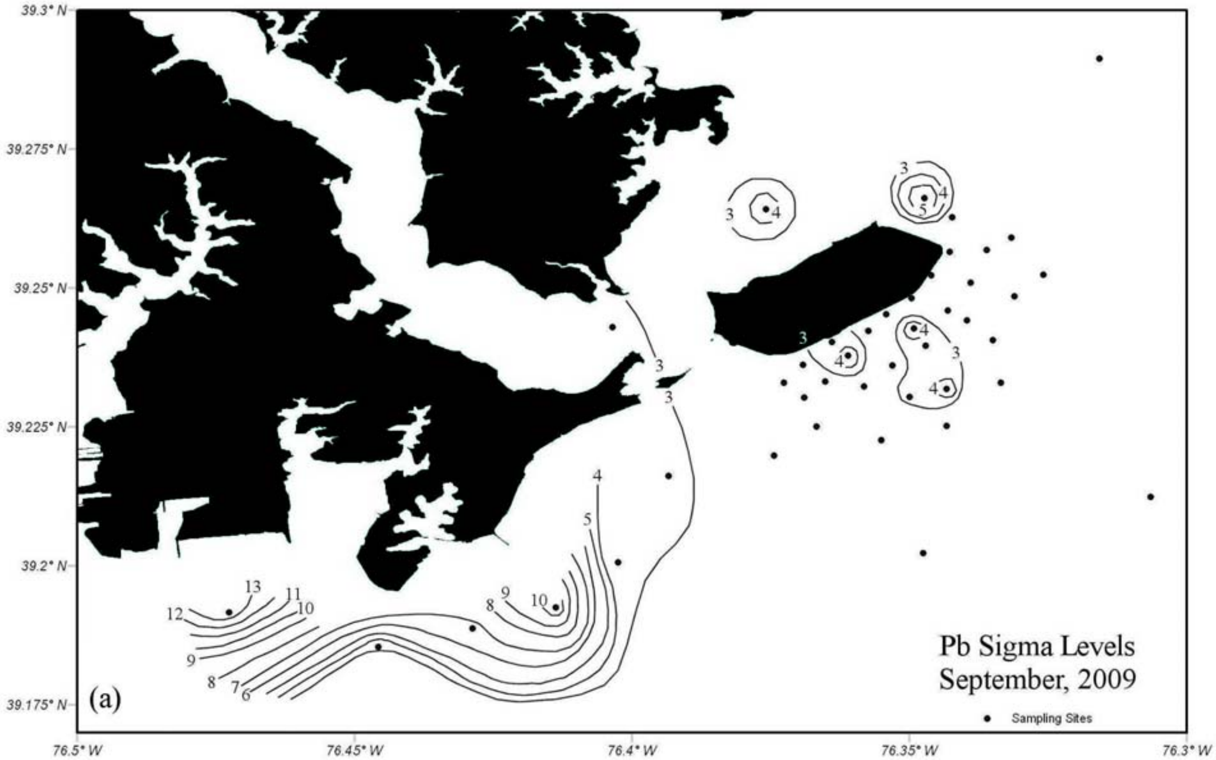
HMI – Pb levels adjacent to the HMI were higher, in terms of the number of samples exceeding 3σ, compared to the previous year. The spatial extent of Pb enrichment was also broader. In the fall, Pb enrichment was seen at three areas: one adjacent to Spillway 003 (MDE-44 and 18); a second, more dispersed area, southeast of HMI; and an isolated site north of the facility (MDE-34). By spring, Pb enrichment along the eastern side was isolated to one station (MDE-8) next to the facility. However, the Pb enrichment was seen at three sites northeast of the facility. In the fall, Zn enrichment was between 3 and 5 sigma at three isolated sites (MDE-15, 18 and 46). In April, Zn enrichment was below 3 sigma at all sites within the HMI zone of influence.

Spatial distribution of both Pb and Zn enriched areas in the fall suggests that the South Cell discharge was the source. There was a period of steady discharge from the South Cell just prior to the sampling cruise (Figure 1-4) as opposed to very little discharge from the North Cell during the same period. Based on the spring sampling, the spatial distribution of Pb enriched areas shifted north, suggesting that the source of the Pb may be from the North Cell even though there was continued discharge from the South Cell. During the month prior to the spring sampling, there were discharges from all three North Cell spillways. Although the volume of discharges from Spillway 007 and 008 were small (6 and 3.5 million gallons, respectively, over a 2 month period), effluent may have contained above background levels of Pb. North Cell discharge appeared to have had a minimal effect for both cruises, with regard to Zn enrichment.

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 continued to be 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, suggest a continued downward trend that began in Year 26.



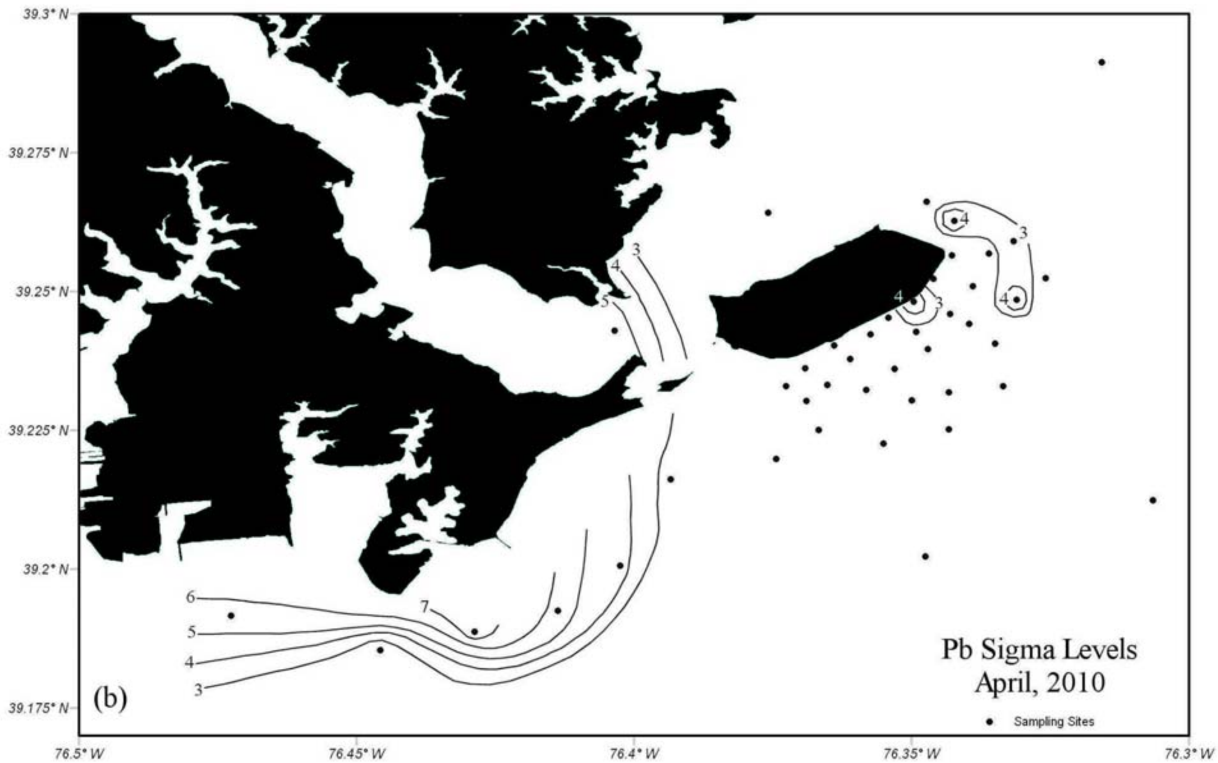


Figure 1-13. Distribution of Pb in the study area for the September and April sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (values less than 3 not shown), >3 = significantly enriched.

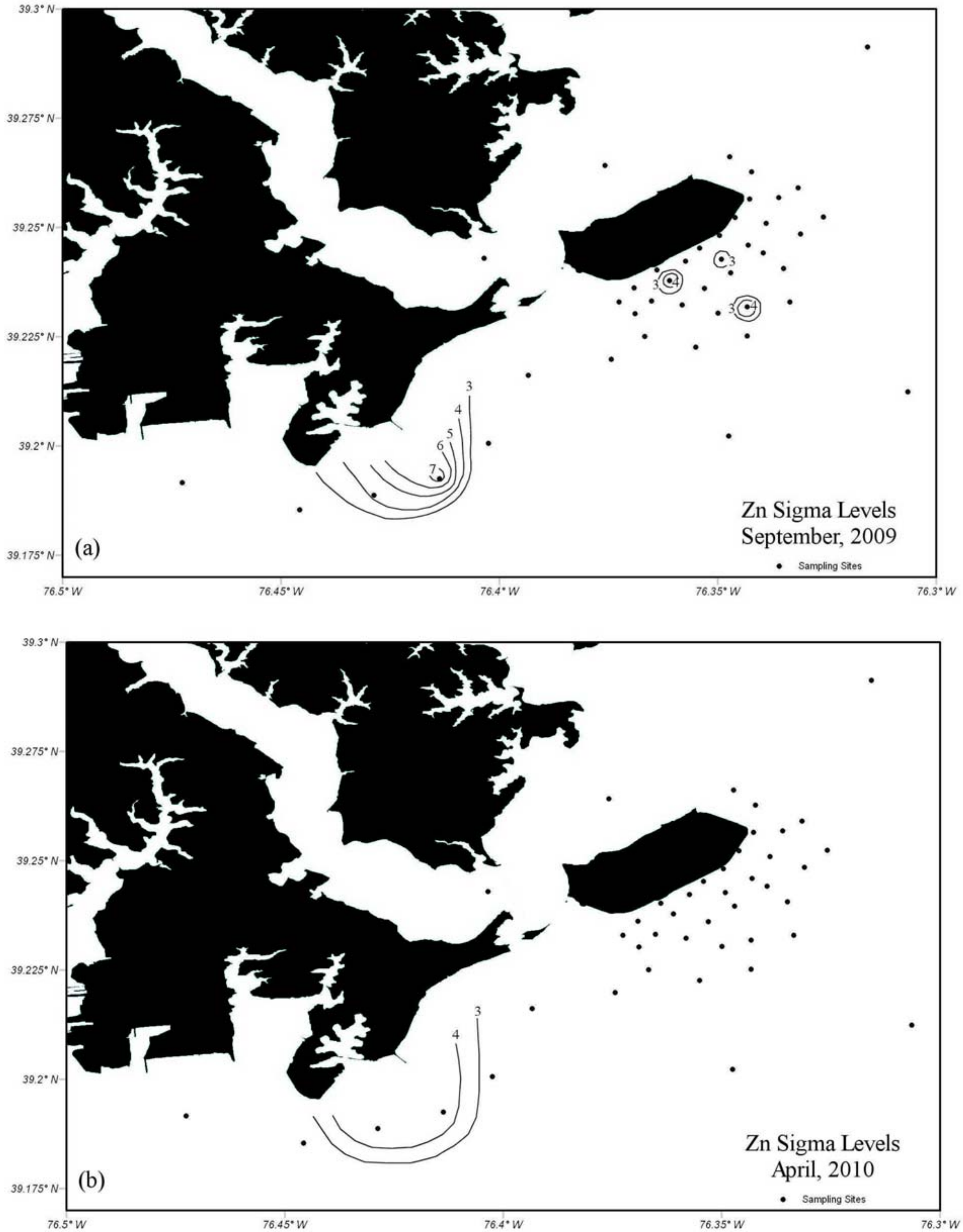


Figure 1-14. Distribution of Zn in the study area for the September and April sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (values less than 3 not shown), >3 = significantly enriched.

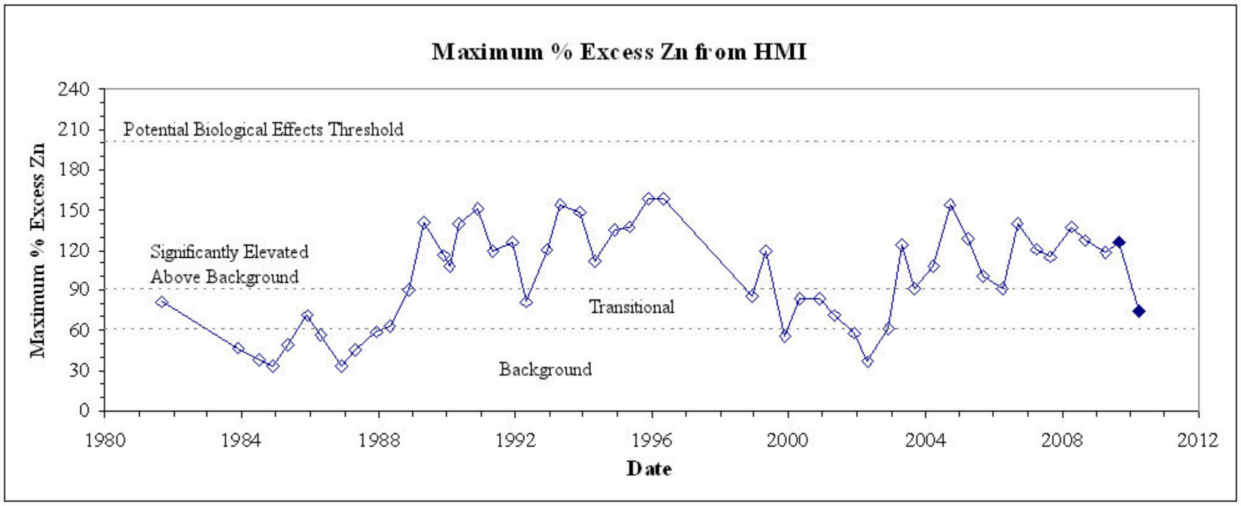


Figure 1-15. Record of the maximum % excess Zn for all of the cruises for which MGS analyzed the sediments. The filled points are the data from this year's study (Cruises 59 and 60).

CONCLUSIONS AND RECOMMENDATIONS

The grain size distribution of the Year 28 sediment samples does not show any clear trends in sedimentation patterns from cruise to cruise. This is due to the complexity of the environmental conditions and source of material to the area. The clay:mud ratios show that the depositional environment was similar during last three 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 28.

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. Ni and Zn exceed the ERM values at some sites.

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 have significantly enriched 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 higher enriched levels, both in terms of the number of sites and extended spatial distribution, compared to the previous year. Sediments were slightly enriched (3-5 sigma levels) with Zn at three 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 465 million gallons, approximately four times the volume discharged during the previous year. Discharge was over two discrete periods: July-August, 2009 and January-April, 2010. However, daily discharge rates were low (< 10 MGD). The extended period of low discharge prior to the fall sampling (Cruise 59) corresponded to lowering of pond level to expose extensive mud flats. Under certain circumstances, this period may be conducive to oxidizing the sediments within the facility, mobilizing certain metals, which are reflected in enrichment in the exterior sediments. Enrichment of both Pb and Zn was seen in the sediments adjacent to the spillway during the fall. The sporadic discharges prior to the spring sampling were done to maintain the South Cell pond at a target level. During high pond levels, sediment exposure is minimal and thus, lower leaching of specific metals would be expected. This would explain the lower levels of Pb and Zn seen outside the spillway in the spring.

Approximately 3.54 mcy of material was placed in the North Cell during the first nine months of the monitoring year. This amount was 30% more than the volume placed during the previous year. The facility stopped accepting new dredged material at the end of 2009.

Total discharge from the North Cell was 1,804 million gallons, approximately four times the volume from the previous monitoring year, and most of the discharge was through Spillway 009. Discharges greater than 10 mgd were done in two distinct periods, corresponding to material placement. The first period was two months before the September 2009 sampling, and the second during the end of 2009, well before the April cruise. The sporadic, low-flow (<10 mgd) discharge occurred at all three spillways after the end of 2009. Given the amount and timing of the discharges, it is not surprising to see minimum enrichment in the sediments adjacent to the spillway for the North Cell in the fall and higher enrichment (of Pb) in the spring.

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. Consequently, the volume of effluent the North Cell is expected to decline while dewatering and crust management operations will lead to higher metal levels in the effluent, which can result in higher enrichment in sediment outside the facility, similar to what was documented for the South Cell after its closure to new material. 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.

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APPENDIX 1A: HMI GROUNDWATER MONITORING WELLS 2009 (PROJECT II)

INTRODUCTION

Groundwater samples from six wells were collected on June 12, 2009, December 11, 2009, and June 22, 2010, 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 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 three samplings: June 2009, December 2009 and June 2010. 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).

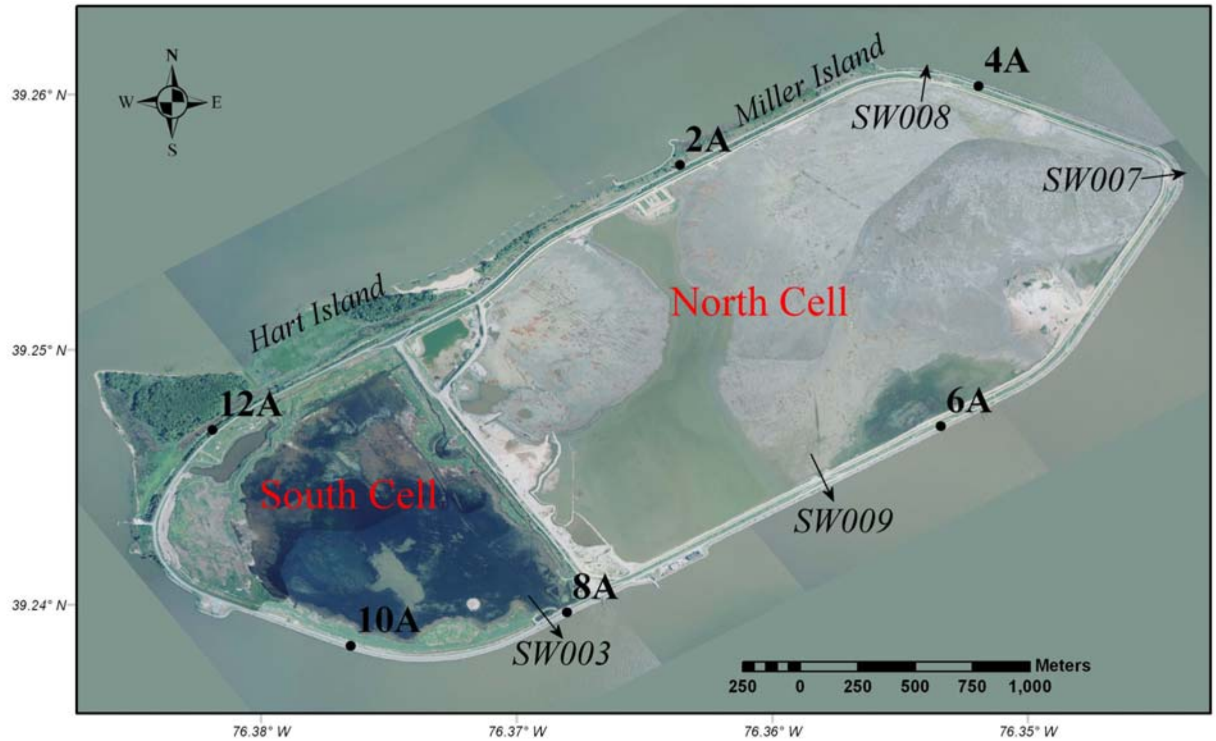

Figure 1-16. Aerial photograph of the HMI DMCF, taken on Sept. 15, 2009, showing the locations of the groundwater monitoring wells (black dots) and the spillways (*SW; black arrows*)..

SUMMARY OF WELL DATA

All of the wells continue to be anoxic or hypoxic with dissolved oxygen (DO) levels less than 1.57 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.

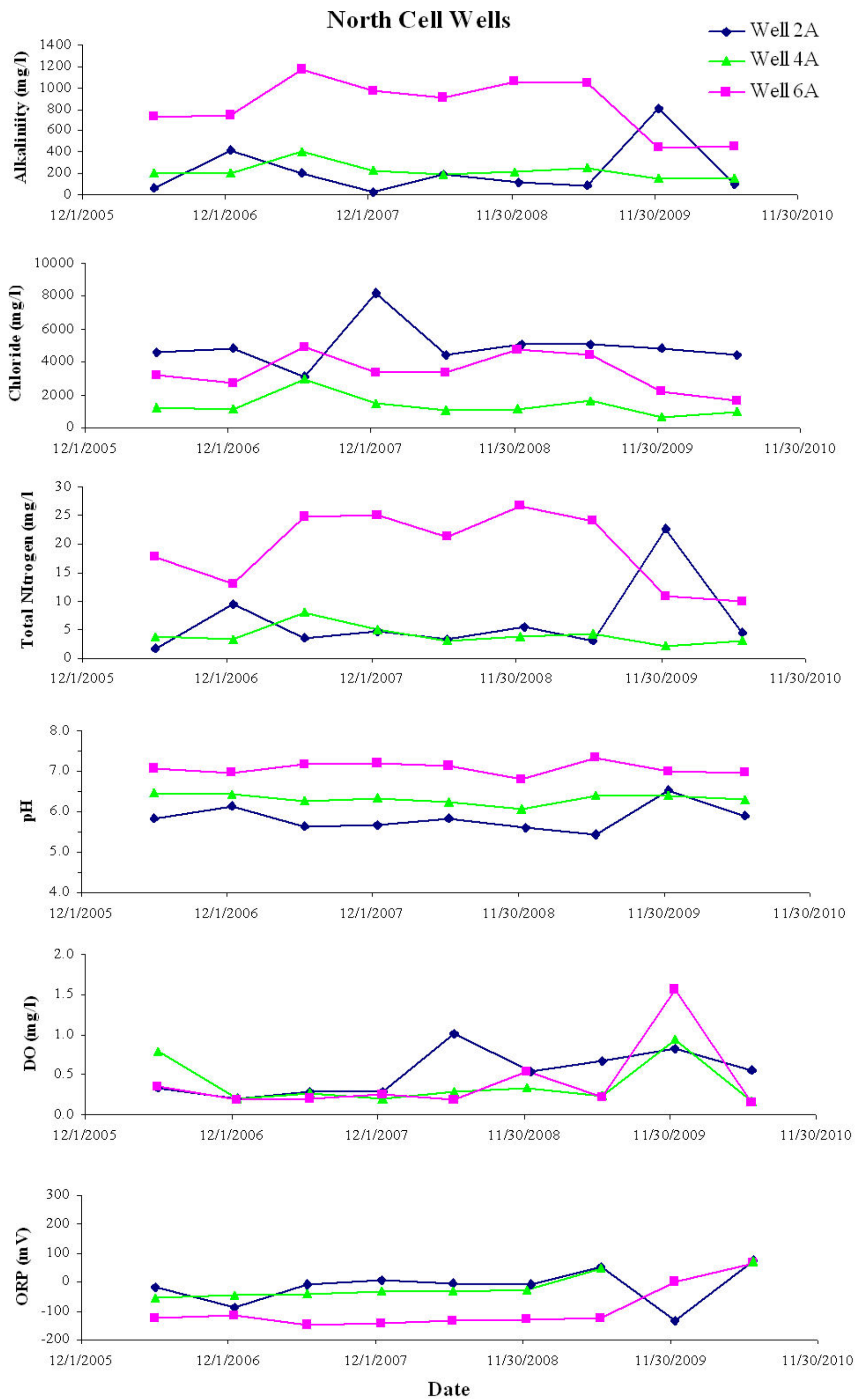

Figure 1-17. Trend plots for specific parameters measured in groundwater samples collected since 2006 from North Cell wells. The Oxidation-Reduction Potential (ORP) value reported for Dec., 2009, for Well 4A was -1533 mV, which was considered an anomaly and not plotted.

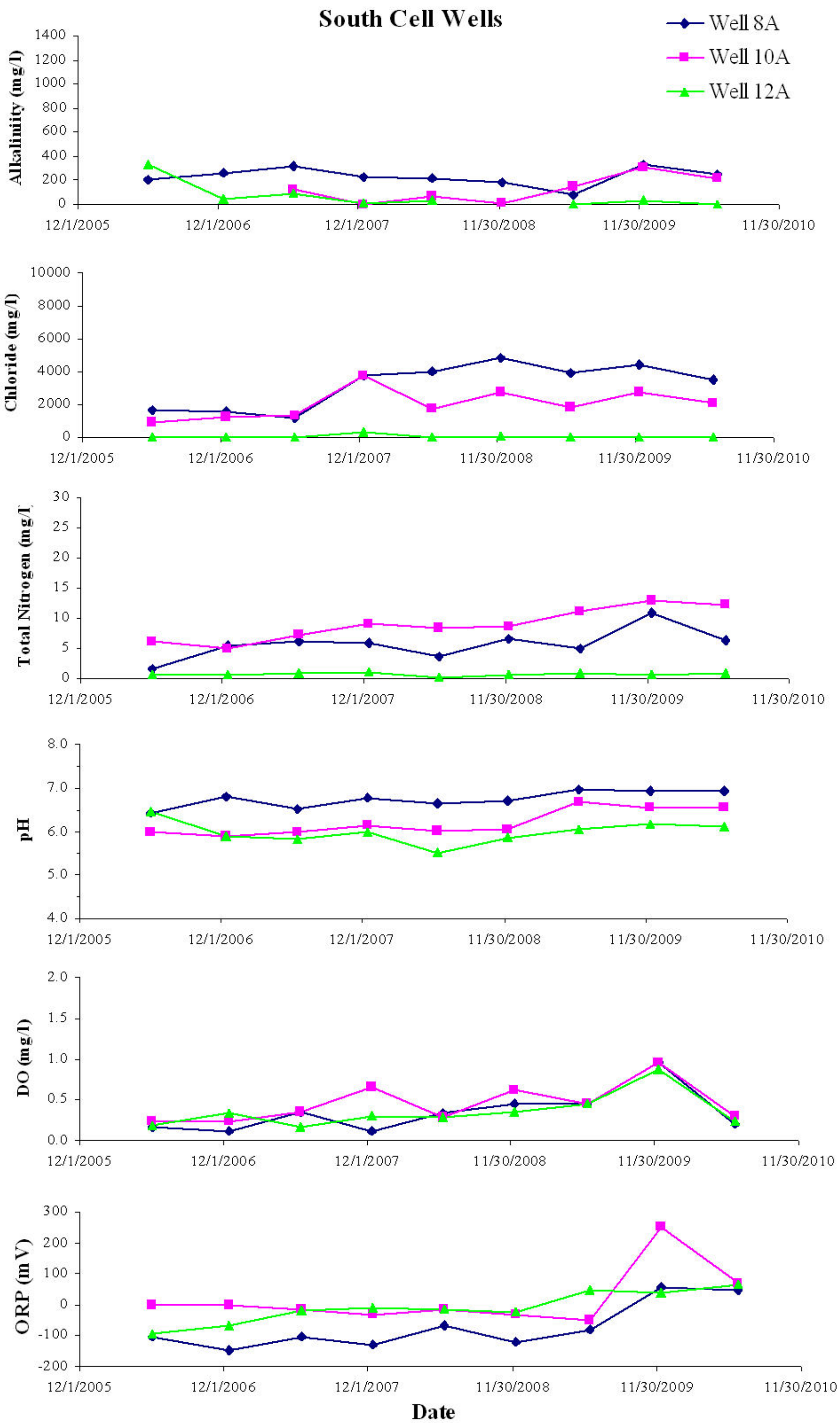

Figure 1-18. Trend plots for specific parameters measured in groundwater samples collected since 2006 from South Cell wells.

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, the groundwater shows a reducing environment in the North Cell Wells 2A and 6A for all sampling events except for June 2010 (Well 6A). Well 4A yielded positive excess sulfate values for all sampling events, while chloride levels changed very little. 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 Well 4A is more similar to the oxidizing environment seen in the South Cell wells. The decreasing excess sulfate in Well 6A suggests a shift toward an oxidizing environment. In addition, chloride concentrations in Well 6A have dropped indicating higher rainwater mixing.

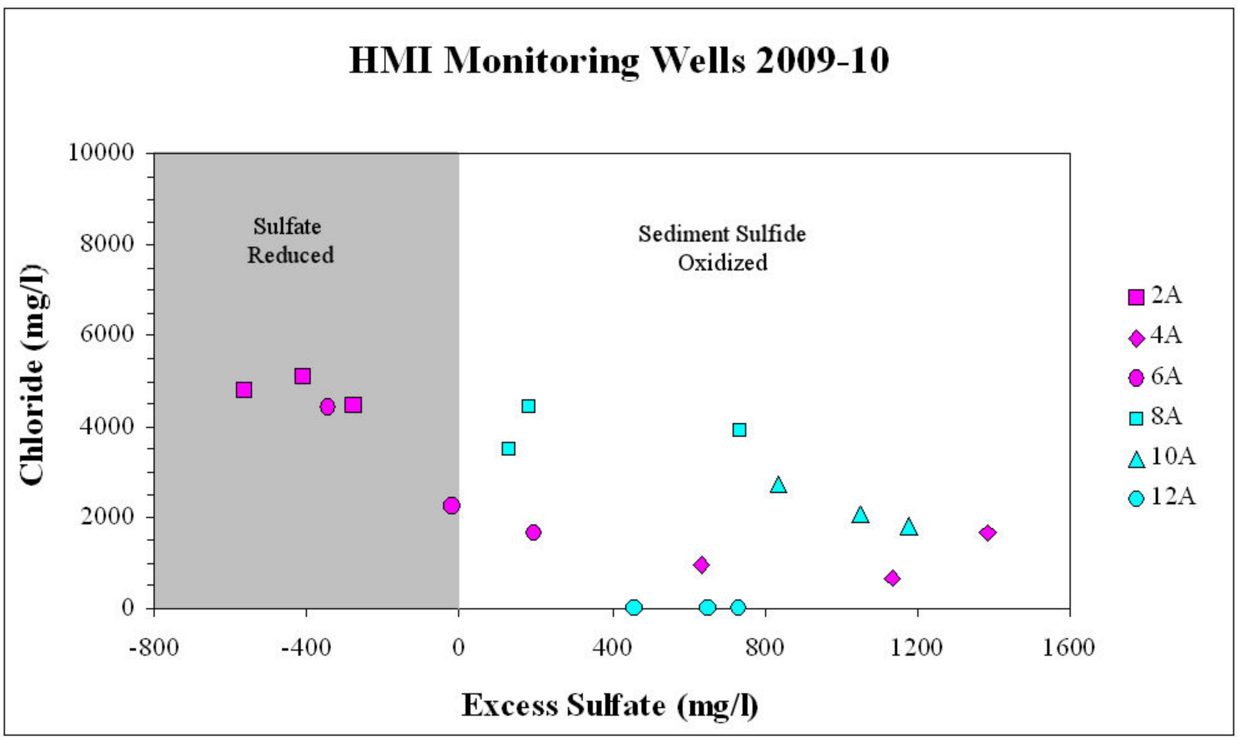

Figure 1-19. Groundwater chloride concentrations as a function of excess sulfate (the difference of the measured sulfate concentrations minus the predicted concentrations). Monitoring wells are grouped by general location; North Cell (pink) or South Cell (light blue).

Although alkalinity concentrations dropped during the last two sampling events, alkalinity in Well 6A continued to be higher than the other two wells in the North Cell (except for Dec. 2009 sampling 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 had not been neutralized by acid production. 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).

Most metal concentrations except Fe are generally lower in the reducing wells (North Cell Well 2A and 6A) 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. Most of the trace metals measured [except As] were near or below the detection limits. Conversely, metal concentrations in Well 4A are higher as that well resembles the oxidizing environment similar to that of the wells in the South Cell.

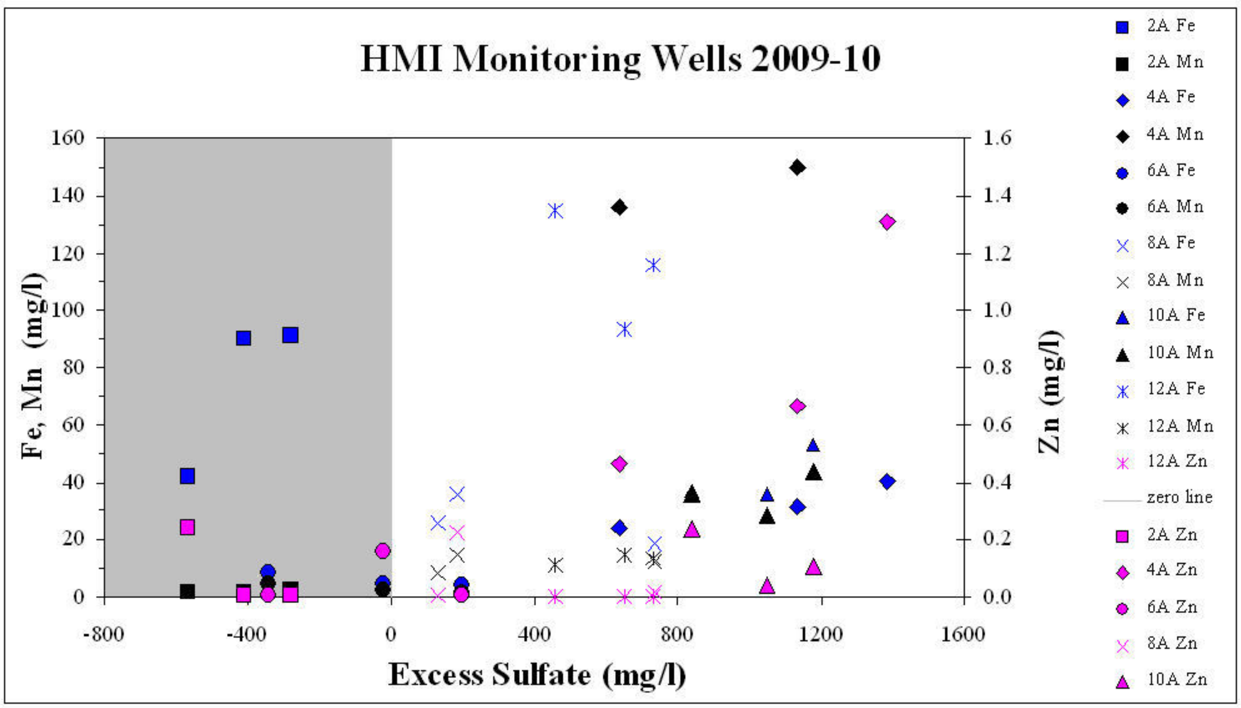

Figure 1-20. Fe, Mn and Zn concentrations as a function of excess sulfate. The different shaped symbols denote individual wells; symbol color (blue, black, and pink) correspond to Fe, Mn and Zn, respectively.

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+). 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).

Total dissolved nitrogen (as ammonium), on average, had been about three times higher in Well 6A compared to the other wells, both in North and South Cells. However, the total nitrogen decreased by half for the last two sampling events, suggesting that the reducing process is less dominant in the groundwater. Ammonium is produced as a by-product of anaerobic respiration. Since a portion of the water in this well may have undergone an oxidative stage, ammonium is lower.

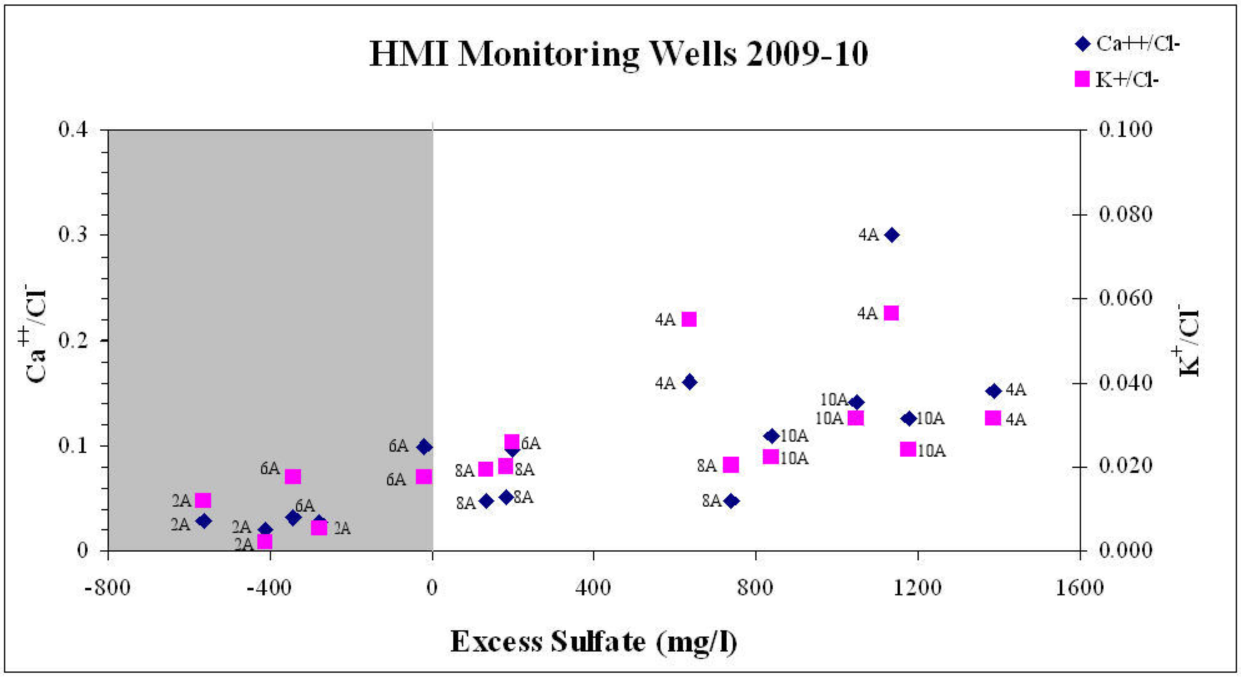

Figure 1-21. The ratios of K^+/Cl^- and Ca^{++}/Cl^- as a function of excess sulfate. For reference, the ratio for both of these cations in seawater is ~0.02. The ratios for Well 12A plotted in the + excess sulfate side of the graph, but way off the chart; the ratios were very high due the extremely low chloride concentrations (Ca^{++}/Cl = 5.6, 6.3 and 10.1; K^+/Cl^- = 1.2, 1.3 and 2.3 for June 2009, Dec. 2009 and June 2010 sampling, respectively).

The groundwater from the North Cell Wells 2A and 6A 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. Well 6A, however, is beginning to show characteristics similar to the South Cell wells. Excess sulfate showed a subtle increase, while alkalinity, chloride and total nitrogen decreased. ORP also showed an overall increase from June 2009 to June 2010. This well is near Spillway 009 where most of the effluent water from the North Cell is channeled for discharge.

South Cell Wells 8A, 10A & 12A

The waters in these wells have been exposed to oxidized sediments, thus the higher levels of excess sulfate (Figure 1-19). 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 lower, while metals and cations are higher than in 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 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 increase 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 water 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.

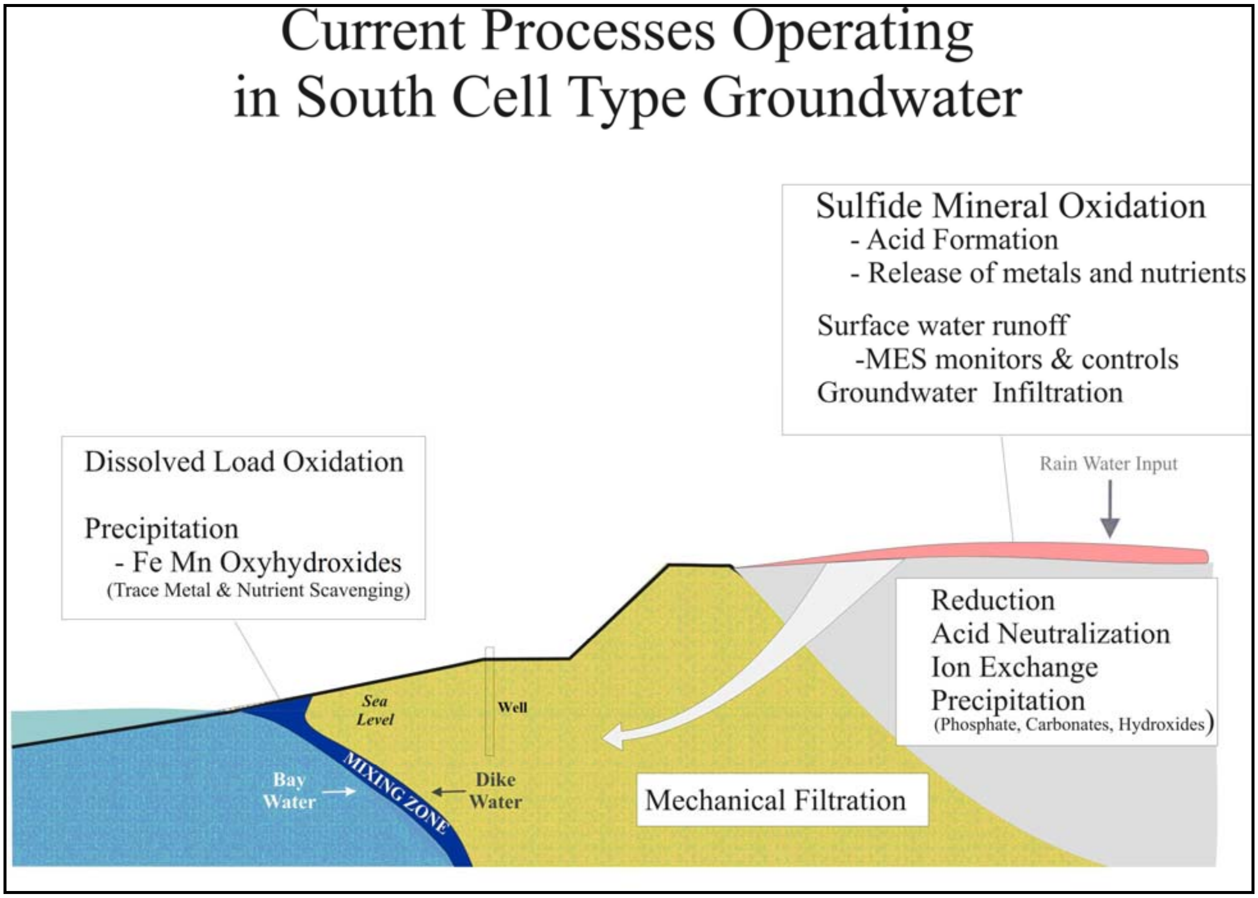

Figure 1-22. Schematic presentation of the processes which produce the groundwater similar to those found in the South Cell wells.

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 beginning to undergo the initial oxidation. 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 groundwaters sampled in 2009 and 2010; listing the number of samples, the number below detection, the 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 are low.

Table 1-5. Monitoring wells trace metal analyses for 2009 and 2010 (three 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***	***Min***	***Max***	***MCL***
Al	9	0	0.05	<dl	<dl	0.05 - 0.2*
As	9	5	0.01	<dl	0.03	0.01
Cd	9	3	0.002	<dl	0.05	0.005
Cr (total)	9	3	0.005	<dl	0.129	0.1
Cu	9	3	0.005	<dl	0.028	1.3
Fe	9	9		3.7	91.0	0.3*
Pb	9	0	0.01	<dl	<dl	0
Mn	9	9		1.4	12.0	0.05*
Zn	9	9	0.005	0.006	1.31	5*
Ag	9	0	0.001	<dl	<dl	0.1*
South Cell Type						
	n	***n>dl***	***dl***	***Min***	***Max***	***MCL***
Al	9	1	0.05	<dl	<dl	0.05 - 0.2*
As	9	4	0.01	<dl	0.02	0.01
Cd	9	4	0.002	<dl	0.05	0.005
Cr (total)	9	6	0.005	0.01	0.126	0.1
Cu	9	3	0.005	<dl	0.028	1.3
Fe	9	9		18.4	135.0	0.3*
Pb	9	0	0.01	<dl	<dl	0
Mn	9	9		8.2	43.7	0.05*
Zn	9	8	0.005	<dl	0.236	5*
Ag	9	0	0.001	<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

The North Cell samples were overall 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 MCL. 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.

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APPENDIX 2: BENTHIC COMMUNITY STUDIES (PROJECT III)

(September 2009 – August 2010)

Technical Report

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January 2011

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-eighth 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 4, 2009 and on April 15, 2010. This was the second 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 40 benthic macroinvertebrate taxa were identified during Year 28. Several taxa were clearly dominant. The worms *Marenzelleria viridis,* and Naididae sp.[1], the clams *Macoma balthica* and *Mytilopsis leucophaeata,* and the arthropods *Leptocheirus plumulosus, Melita nitida, Cyathura polita,* 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 28. Several species declined sharply from April to September, which indicated possible high predation mortality: Naididae sp., *L. plumulosus*, *M. viridis*, Gammarus sp., Ameroculodes sp. complex, Nemata, and Platyhelminthes. In contrast, the species *Streblospio benedicti*, *Polydora cornuta*, and *Heteromastus filiformis* were much more abundant in September 2009, likely indicating summer recruitment for these species, particularly the first two. Total abundance (excluding Bryozoa and Copepoda) was higher at most stations in April 2010 than September 2009, primarily due to the spring recruitment of the worms Naididae sp. and *M. viridis,* and the amphipod *L. plumulosus*.

Several historical biological trends were upheld in Year 28. Species diversity was examined using the Shannon-Wiener diversity index (SWDI). Diversity was higher in September 2009 than in April 2010 at all stations. The proportion of pollution sensitive taxa (PSTA) and pollution indicative taxa (PITA) was calculated for both cruises. The PSTA percentage was higher in April than in September. The PITA percentages were lower in April than in September. These relative differences were both due to the large recruitment of the pollution sensitive species *Marenzelleria viridis*.

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

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

sampled in September 2010. Overall, B-IBI scores were comparable to Year 27 (mean B-IBI Year 28 = 3.66; mean B-IBI Year 27 = 3.43). B-IBI scores increased at ten stations, decreased at five stations, and remained the same at seven stations. Twenty-one stations met or exceeded the benchmark criteria of 3.0, and only one station (Back River station MDE-27) failed to meet the benchmark.

The Friedman's nonparametric Analysis of Variance (ANOVA) test was non-significant for both the September 2009 and April 2010 data. There were no significant differences in the benthic macroinvertebrate communities among the four station types. The cluster analysis for the September 2009 data identified two clearly defined multi-station groups with similar benthic macroinvertebrate assemblages, but neither group was associated with any adverse impacts from HMI operations. Cluster analysis was not conducted on April 2010 data because active reproduction/recruitment during the spring was not conducive for identifying stable macroinvertebrate population patterns among the stations.

INTRODUCTION

Annual dredging of the shipping channels leading to the Port of Baltimore is necessary to maintain safe navigation. An average of 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 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. The results of the post-construction monitoring are compared to the baseline monitoring data, as well as to inter-seasonal and inter-annual data.

Since December 31, 2009, HMI no longer receives dredged material; however, monitoring continues under authority of the original *Wetlands License* (*No.72-127*). Year 28 represents the culmination of monitoring data collected during 28 years of dredged disposal operations, beginning with the pre-operational phase in 1981. Since Year 17, the Maryland Department of the Environment (MDE) has been responsible for all aspects of benthic community monitoring. Post closure monitoring began in Year 28 and will continue through at least Year 30.

The goals of the Year 28 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 a transect leading away from the 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 28. 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 September and April 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 28 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	Silt/clay	XIF5505
MDE-03	39° 15.5436	-76° 19.9026	Silt/clay	Silt/clay	XIG5699
MDE-07	39° 15.0618	-76° 20.3406	Sand	Silt/clay	XIF5302
MDE-09	39° 14.7618	-76° 20.5842	Silt/clay	Silt/clay	XIF4806
MDE-11	39° 24.072	-76° 33.504	Silt/clay	Silt/clay	XIG4501
MDE_15	39° 24.281	-76° 34.921	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	Sand	XIG7589
MDE-50	39° 25.237	-76° 34.611	Sand	Sand	N/A
MDE-51	39° 22.263	-76° 35.507	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

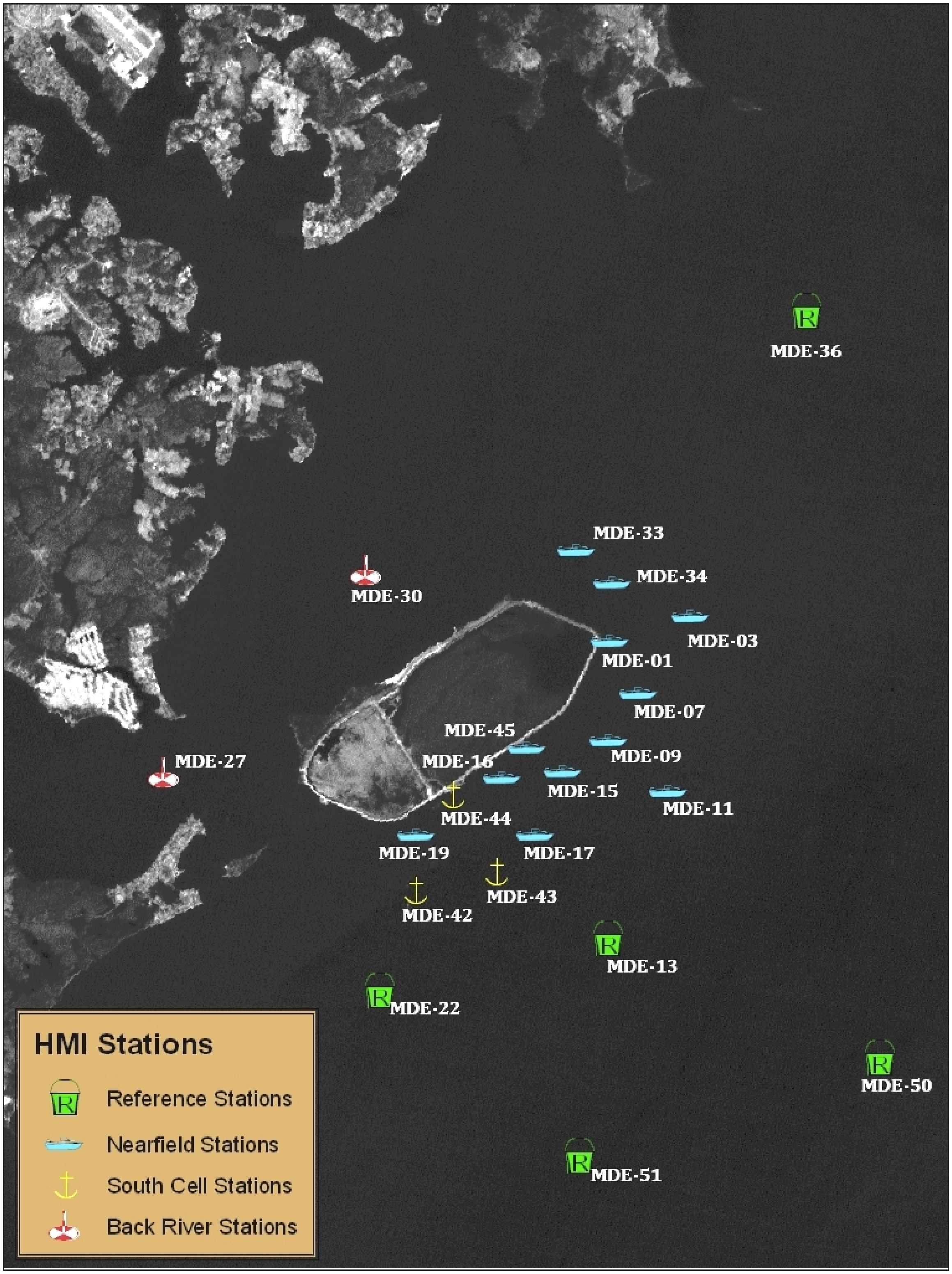

Figure 2-1. Year 28 benthic sampling stations for the HMI exterior monitoring program.

All stations sampled during Year 27 were again sampled for Year 28. 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 to the sampled stations. 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 to the sampled stations[2]. Stations were classified by location and dominant sediment type. Stations were divided into four location groups (Nearfield stations, Reference stations, Back River/Hawk Cove stations, and South Cell Exterior Monitoring stations) and five sediment types (silt/clay, shell, detritus, gravel, and sand). All benthic community stations coincided with stations sampled by the Maryland Geological Survey (MGS) for sediment analysis. 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 2009 and April 2010. 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 28 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 2009. The B-IBI is a multi-metric index of biotic integrity used to determine if benthic populations in different areas of the Chesapeake Bay are stressed (Llanso 2002). The B-IBI has not been calibrated for periods outside the summer index period (July 15 through September 30) and, thus, was not used with the April 2010 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 28 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 2009 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 2009 and April 2010. 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 2009 and April 2010 cruises indicated that water column stratification was not prevalent. The exceptions to this generalization were at Reference Stations MDE-50 and MDE-51 where there was typically a one degree difference in water temperature, a 0.5 unit difference in pH, a 5 ppt difference in salinity, and a 5 mg/L difference in DO. This sort of stratification is not unusual in parts of the Chesapeake Bay. Perhaps proximity to deeper shipping channel water may influence water quality at these stations in ways not found at other HMI stations (Table 2-5).

Secchi depths were greater in September 2009 (Table 2-3, range=0.50 m-1.40 m, average = 0.89 m ± 0.29 m) than those in April 2010 (Table 2-5, range=0.40 m-0.60 m, average=0.50 m ± 0.06 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 28, bottom water temperatures did not vary much between stations during both sampling seasons. The September 2009 mean bottom water temperature (Table 2-3, mean=24.06°C ± 0.43°C, range= 23.66°C – 25.28°C) was 0.38ºC lower than the 24-year fall average of 24.44ºC. Bottom water temperatures were seasonably lower in April 2010 (Table 2-5) with a range of 12.19°C –15.67°C and an average of 14.29°C ± 0.72°C. April 2010 mean temperature was 2.28°C higher than the 13-year spring average of 12.01ºC.

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 2009 mean bottom DO (Table 2-3, mean=6.74 ppm ± 1.65 ppm, range=1.41 – 8.47 ppm) was 0.50 ppm lower than the 13-year fall average of 7.28 ppm. The April 2010 mean bottom DO (Table 2-5, mean=8.45 ppm ± 1.24 ppm, range=4.37 ppm - 9.69 ppm) was 1.49 ppm lower than the 13-year spring average of 9.94 ppm. Historically fall DO is 2.66 ppm lower than spring DO due to reduced oxygen solubility with elevated seasonal temperatures. This year there was only a 1.71 ppm difference in spring vs. fall mean bottom DO concentration. The lowest bottom DO values during the fall (1.41 ppm and 2.77 ppm) occurred at Reference Stations MDE-51 and MDE-50 respectively. The lowest bottom DO value during the spring (4.37 ppm) also occurred at Reference Station MDE-51. These readings were below the State standard of 5 ppm. In Year 27, there was also a DO impairment at Reference Station MDE-51 in the April 2009 sampling cruise (4.18 ppm). At the time the impairment was characterized as atypical. Stations MDE-50 and MDE-51 were newly established and first sampled in Year 27. Despite this impairment, the B-IBI continued to meet or exceed the benchmark of 3.0. The breach of DO standards at these stations is not indicative of “best obtainable reference conditions”. Because these stations reside well outside the zone of HMI influence it is suspected that intrusion of bottom water from the nearby shipping channel is the probable source of low oxygenated bottom water. As a result, these stations serve as reference stations for conditions that are encountered in the upper Chesapeake Bay but not in close proximity to HMI. Over the coming years, 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 24-year mean bottom salinity is 6.12 ppt. Low mesohaline conditions (≥5-12 ppt.) were found during the fall 2009 sampling season and Oligohaline conditions (0.5 ppt – 5 ppt) were found during the spring 2010 sampling season.

In Year 28 mean salinity values varied considerably between September (Table 2-3, mean=5.06 ppt ± 1.91 ppt, range = 3.33 ppt – 11.27 ppt) and April (Table 2-5, mean=1.56 ppt ± 1.25 ppt, range 0.41 ppt – 6.03 ppt). The mean fall salinity was comparable to the historical average (mean =6.12 ppt, ± 2.76 ppt). However, mean spring salinity was lower than the historical mean (3.03 ppt ± 2.32 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 28 physical parameters measured *in situ* at all HMI stations on September 4, 2009.

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	12:32	Ebb	3.70	0.2	NE	5	10	23	30	0	1	0	90	10	0	0
MDE-03	12:23	Ebb	5.34	0.2	NE	5	10	23	30	0	1	75	0	20	0	5
MDE-07	12:05	Ebb	5.73	0.1	NE	5	10	23	30	0	1	40	50	10	0	0
MDE-09	11:54	Ebb	4.18	0.2	NE	5	10	23	30	0	1	85	0	10	0	5
MDE-11	11:37	Ebb	5.45	0.2	NE	5	10	23	30	0	1	80	0	15	0	5
MDE-13	10:44	Ebb	4.86	0.0	NE	5	10	23	30	0	1	88	0	10	0	2
MDE-15	10:28	Ebb	5.06	0.0	NE	5	10	22	30	0	1	70	0	25	0	5
MDE-16	9:52	Ebb	4.38	0.0	NE	5	10	21	30	0	1	85	0	10	0	5
MDE-17	9:10	Ebb	5.04	0.2	NE	10	15	21	30	0	1	50	0	45	0	5
MDE-19	9:30	Ebb	4.66	0.2	NE	10	15	21	30	0	1	95	0	5	0	0
MDE-22	8:36	Ebb	5.32	0.2	NE	10	12	21	30	0	1	85	0	10	0	5
MDE-27	13:55	Ebb	3.65	0.0	NE	2	5	24	30	0	1	65	0	5	0	30
MDE-30	13.36	Ebb	2.82	0.0	NE	2	5	23	30	0	1	70	0	20	0	10
MDE-33	13.03	Ebb	2.16	0.1	NE	2	5	23	30	0	1	0	95	5	0	0
MDE-34	12:48	Ebb	3.14	0.2	NE	5	10	23	30	0	1	0	80	15	0	5
MDE-36	13:20	Ebb	3.12	0.2	NE	5	10	23	30	0	1	80	0	15	0	5
MDE-42	8:49	Ebb	4.73	0.2	NE	10	15	21	30	0	1	90	0	7	0	3
MDE-43	9:00	Ebb	5.18	0.2	NE	10	15	21	30	0	1	60	0	25	0	15
MDE-44	9:41	Ebb	5.61	0.2	NE	10	15	21	30	0	1	93	0	5	0	2
MDE-45	10:17	Ebb	4.51	0.0	NE	5	10	22	30	0	1	85	0	13	0	2
MDE-50	11:15	Ebb	4.09	0.0	NE	5	10	23	30	0	1	0	95	5	0	0
MDE-51	10:56	Ebb	5.00	0.0	NE	5	10	23	30	0	1	80	0	15	0	5

Note: The weather code 1 stands for "Partly Cloudy", code 0 stands for "Clear".

Table 2-3. Year 28 water quality parameters measured *in situ* at all HMI stations on September 4, 2009.

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	3.25	23.72	8.34	7.85	0.6	5,902
		Bottom	3.70	3.39	23.71	8.05	7.81		6,100
MDE-03	XIG5699	Surface	0.50	4.25	24.17	7.21	7.60	0.9	7,609
		Bottom	5.34	4.27	23.93	7.21	7.60		7,651
MDE-07	XIF5302	Surface	0.50	4.18	24.03	7.48	7.67	0.8	7,488
		Bottom	5.73	4.31	23.93	7.17	7.70		7,728
MDE-09	XIF4806	Surface	0.50	3.77	23.86	7.78	7.73	0.8	6,807
		Bottom	4.18	4.54	23.95	6.93	7.59		8,108
MDE-11	XIG4501	Surface	0.50	4.33	24.03	7.74	7.77	0.9	7,750
		Bottom	5.45	4.86	23.90	7.14	7.73		8,657
MDE-15	XIF4609	Surface	0.50	4.33	24.05	7.72	7.81	0.7	7,743
		Bottom	5.06	4.98	24.02	7.16	7.71		8,839
MDE-16	XIF4615	Surface	0.50	4.38	23.95	7.53	7.77	0.6	7,837
		Bottom	4.38	4.78	24.00	6.90	7.65		8,507
MDE-17	XIF4285	Surface	0.50	4.80	23.88	7.42	7.77	1.3	8,551
		Bottom	5.04	5.07	24.08	7.09	7.66		8,993.
MDE-19	XIF4221	Surface	0.50	4.36	23.82	7.78	7.87	1.2	7,789
		Bottom	4.66	4.67	23.93	7.03	7.72		8.332
MDE-33	XIF6008	Surface	0.50	3.30	23.86	8.60	7.92	0.9	5,980
		Bottom	2.16	3.33	23.70	8.32	7.87		6,022
MDE-34	XIF5805	Surface	0.50	3.50	23.83	8.33	7.84	0.7	6,327
		Bottom	3.14	3.54	23.83	8.24	7.83		6,686
MDE-45	N/A	Surface	0.50	4.31	23.97	7.29	7.69	0.6	7,720
		Bottom	4.51	4.79	24.06	6.69	7.62		8,530
Reference Stations									
MDE-13	XIG3506	Surface	0.50	5.09	24.19	7.35	7.72	1.3	9,037
		Bottom	4.86	5.16	24.09	6.51	7.56		9,164
MDE-22	XIF3224	Surface	0.50	5.19	23.99	7.36	7.77	1.0	9,205
		Bottom	5.32	6.66	24.58	5.48	7.61		11,652
MDE-36	XIG7589	Surface	0.50	2.80	23.53	8.26	7.78	0.9	5,097
		Bottom	3.12	3.43	23.66	7.42	7.62		6,248
MDE-50	N/A	Surface	0.50	5.35	24.38	7.38	7.73	1.3	9,489
		Bottom	4.09	9.57	25.19	2.77	7.22		16,318
MDE-51	N/A	Surface	0.50	5.26	24.07	7.41	7.80	1.4	9,334
		Bottom	5.00	11.27	25.28	1.41	7.22		19,022
Back River/Hawk Cove Stations									
MDE-27	XIF4642	Surface	0.50	3.95	24.30	8.89	8.32	0.6	7,097
		Bottom	3.65	4.35	23.76	7.36	7.94		7,811
MDE-30	XIF5925	Surface	0.50	3.42	23.90	9.15	8.21	0.7	6,172
		Bottom	2.82	3.74	23.72	8.47	8.00		6,674
South Cell Exterior Monitoring Stations									
MDE-42	XIF3879	Surface	0.50	4.80	23.92	7.24	7.73	0.5	8,552
		Bottom	4.73	4.81	23.92	7.01	7.77		8,560
MDE-43	XIF3985	Surface	0.50	4.89	23.95	7.44	7.77	1.3	8,714
		Bottom	5.18	5.32	24.19	6.69	7.63		9,430
MDE-44	XIF4482	Surface	0.50	4.43	23.88	7.47	7.78	0.6	7,924
		Bottom	2.83	4.58	23.82	7.24	7.76		8,187

Table 2-4. Year 28 physical parameters measured *in situ* at all HMI stations on April 15, 2010.

MDE Station	Time	Tide	Water Depth (m)	Wave Height (m)	Wind Direction	Wind Speed (knots) Min.	Wind Speed (knots) Max.	Air Temp (ºC)	Cloud Cover (%)	Weather Past 24 hrs.	Weather Today	Observed Bottom Sediment (%) silt/clay	sand	shell	gravel	detritus
MDE-01	12:10	Ebb	4.46	0.2	W	2	5	19	0	0	0	50	0	50	0	0
MDE-03	12:00	Ebb	5.65	0.2	W	2	2	18	0	0	0	50	10	40	0	0
MDE-07	11:50	Ebb	5.99	0.1	W	1	2	18	0	0	0	70	5	20	0	5
MDE-09	11:40	Ebb	5.71	0.2	W	1	2	18	0	0	0	50	15	35	0	0
MDE-11	11:30	Flood	5.27	0.1	W	1	2	17	0	0	0	80	0	20	0	0
MDE-13	10:35	Flood	4.88	0.1	W	1	2	14	0	0	0	75	5	15	0	5
MDE-15	10:21	Flood	5.14	0.1	W	1	2	14	0	0	0	60	0	10	0	30
MDE-16	10:00	Flood	4.49	0.1	W	1	2	14	0	0	0	90	0	10	0	0
MDE-17	9:07	Flood	5.09	0.2	SW	2	5	10	0	0	0	75	0	25	0	0
MDE-19	9:15	Flood	4.81	0.2	SW	2	5	12	0	0	0	90	0	10	0	0
MDE-22	8:29	Flood	7.07	0.2	W	2	5	8	0	0	0	90	0	10	0	0
MDE-27	13:13	Ebb	3.57	0.2	W	2	5	20	0	0	0	75	0	5	0	20
MDE-30	12:58	Ebb	2.95	0.1	W	1	3	20	0	0	0	70	0	30	0	0
MDE-33	12:28	Ebb	2.33	0.2	W	2	5	20	0	0	0	0	85	15	0	0
MDE-34	12:20	Ebb	2.57	0.2	W	2	5	19	0	0	0	15	60	25	0	0
MDE-36	12:41	Ebb	3.20	0.3	W	5	7	20	0	0	0	10	70	20	0	0
MDE-42	8:42	Flood	6.61	0.2	SW	2	5	9	0	0	0	90	0	10	0	0
MDE-43	8:50	Flood	4.28	0.2	SW	2	5	9	0	0	0	90	0	10	0	0
MDE-44	9:30	Flood	5.52	0.2	SW	2	5	13	0	0	0	90	2	8	0	0
MDE-45	10:18	Flood	7.55	0.1	W	1	2	14	0	0	0	60	0	10	0	30
MDE-50	11:10	Flood	4.10	0.2	W	2	4	17	0	0	0	0	5	90	5	0
MDE-51	10:49	Flood	4.85	0.1	W	1	2	16	0	0	0	90	0	10	0	0

Note: The weather codes 0 stands for "Clear".

Table 2-5. Water quality parameters measured *in situ* at all HMI stations on April 15, 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	0.69	15.21	9.79	7.83	0.5	1,322
		Bottom	3.44	0.65	14.92	9.69	7.60		1,237
MDE-03	XIG5699	Surface	0.50	0.61	15.30	9.56	7.75	0.5	1,165
		Bottom	5.65	0.64	14.64	9.28	7.69		1,210
MDE-07	XIF5302	Surface	0.50	0.65	15.09	9.35	7.70	0.5	1,291
		Bottom	5.99	0.67	14.89	9.31	7.76		1,296
MDE-09	XIF4806	Surface	0.50	0.69	15.24	9.33	7.69	0.6	1,303
		Bottom	5.71	1.28	14.45	8.56	7.66		2,371
MDE-11	XIG4501	Surface	0.50	0.95	15.13	8.99	7.61	0.5	1,783
		Bottom	5.27	2.39	13.69	7.06	7.26		4,392
MDE-15	XIF4609	Surface	0.50	0.95	14.99	8.97	7.62	0.4	1,775
		Bottom	5.14	1.58	14.38	8.39	7.50		2,923
MDE-16	XIF4615	Surface	0.50	0.93	15.19	9.11	7.61	0.5	1,746
		Bottom	4.49	1.28	14.52	8.82	7.51		2,379
MDE-17	XIF4285	Surface	0.50	1.56	14.73	8.76	7.44	0.5	2,902
		Bottom	5.09	2.10	14.12	7.62	7.29		3,880
MDE-19	XIF4221	Surface	0.50	1.02	14.94	9.12	7.52	0.5	1,907
		Bottom	4.31	1.17	14.40	8.98	7.58		2,188
MDE-33	XIF6008	Surface	0.50	0.51	14.65	9.50	7.65	0.6	965
		Bottom	2.33	0.53	14.27	9.33	7.73		1013
MDE-34	XIF5805	Surface	0.50	0.53	14.58	9.51	7.69	0.6	1,013
		Bottom	2.57	0.52	14.34	9.50	7.77		995
MDE-45	N/A	Surface	0.50	0.85	15.23	9.17	7.64	0.5	1,585
		Bottom	7.55	0.91	14.88	8.81	7.79		1,709
Reference Stations									
MDE-13	XIG3506	Surface	0.50	1.85	14.48	8.39	7.45	0.5	3,385
		Bottom	4.88	3.39	13.24	6.21	7.14		6,171
MDE-22	XIF3224	Surface	0.50	1.79	13.71	8.74	7.32	0.5	3,320
		Bottom	6.2	2.05	13.71	8.78	7.20		3,801
MDE-36	XIG7589	Surface	0.50	0.41	15.33	9.63	7.74	0.4	784
		Bottom	3.20	0.41	15.01	9.28	7.74		789
MDE-50	N/A	Surface	0.50	3.73	14.03	8.59	7.40	0.6	3,733
		Bottom	4.10	2.23	13.62	8.18	7.38		4,041
MDE-51	N/A	Surface	0.50	2.12	14.32	8.36	7.35	0.5	4,031
		Bottom	4.94	6.03	12.19	4.37	7.07		10,612
Back River/Hawk Cove Stations									
MDE-27	XIF4642	Surface	0.50	0.91	15.98	9.08	7.77	0.9	1,701
		Bottom	3.57	1.03	14.85	8.23	7.62		1,945
MDE-30	XIF5925	Surface	0.50	0.80	15.91	9.84	7.95	0.5	1,501
		Bottom	2.95	0.76	15.67	9.48	7.87		1,430
South Cell Exterior Monitoring Stations									
MDE-42	XIF3879	Surface	0.50	1.23	14.03	9.04	7.38	0.5	2,246
		Bottom	5.11	1.40	13.96	8.97	7.29		2,600
MDE-43	XIF3985	Surface	0.50	1.58	14.65	8.90	7.35	0.5	2,921
		Bottom	4.28	2.11	14.10	8.30	7.24		3,952
MDE-44	XIF4482	Surface	0.50	0.95	14.97	9.03	7.58	0.4	1,784
		Bottom	5.21	1.22	14.52	8.79	7.66		2,280

BENTHIC MACROINVERTEBRATE COMMUNITY

Taxa Richness and Dominance

A total of 40 taxa were found over the two seasons of sampling during Year 28. This is comparable to the 12-year average of 39.58 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 taxa of Arthropoda were found in Year 28. This is similar to the 12-year mean of 17.91 taxa (range= 12-23 taxa). The most common types of arthropods were the amphipods (including *Leptocheirus plumulosus*) and the isopods (including *Cyathura polita*). Seven taxa of annelid worms in the Class Polychaeta were found. This is comparable to the 15-year mean of 7.58 taxa (range= 6-10 taxa). Six species of bivalve mollusks were found. This is similar to the 12-year mean of 5.75 taxa (range= 4-7 taxa). Overall, bivalve mollusk average abundance was lower in September 2009 than in April 2010 (Table 2-6 and Table 2-7).

During the spring, Ostracoda, *Platyhelminthes* sp., *Mya arenaria*, *Cricotopus* sp., *Cryptochironomus* sp., *Rheotanytarsus* sp., *Cassidinidea ovalis*, Hydrozoa, Odonata, *Callinectes sapidus*, *Piscicola* sp., and Copepoda were exclusively found, while *Polydora cornuta*, *Boccardiella ligerica*, *Eteone heteropoda*, and Mysidacea were only found in fall samples. Year 28 is the second 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 partly accounts for any recent drop 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 2009 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	0.87	19.20	1.13	N/A	0.00	0.00	0.00	9.60	0.00
Carinoma tremaphoros	7.27	160.00	8.66	N/A	2.56	4.80	11.52	3.20	12.80
Bivalvia	44.22	972.80	11.67	N/A	154.88	70.93	21.76	3.20	2.13
Macoma sp.	4.95	108.80	6.02	N/A	1.28	3.73	5.12	3.20	10.67
Macoma balthica	133.82	2944.00	170.54	N/A	8.96	61.87	220.16	112.00	311.47
Macoma mitchelli	16.58	364.80	18.45	N/A	10.24	14.40	17.92	32.00	12.80
Rangia cuneata	102.11	2246.40	79.44	N/A	179.20	114.67	107.52	83.20	29.87
Ischadium recurvum	12.22	268.80	3.76	N/A	40.96	22.40	0.00	0.00	0.00
Mytilopsis leucophaeata	112.58	2476.80	38.40	N/A	364.80	173.87	75.52	3.20	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	56.15	1235.20	64.75	N/A	26.88	45.87	80.64	35.20	70.40
Spionidae	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Marenzelleria viridis	109.67	2412.80	86.21	N/A	189.44	100.27	122.88	240.00	38.40
Streblospio benedicti	229.82	5056.00	256.00	N/A	140.80	226.67	39.68	723.20	230.40
Polydora cornuta	40.44	889.60	27.86	N/A	83.20	69.87	8.96	3.20	0.00
Boccardiella ligerica	0.29	6.40	0.00	N/A	1.28	0.53	0.00	0.00	0.00
Nereididae	1.16	25.60	1.13	N/A	1.28	1.60	1.28	0.00	0.00
Neanthes succinea	31.71	697.60	29.74	N/A	38.40	35.73	30.72	48.00	6.40

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	2.62	57.60	1.13	N/A	7.68	3.73	1.28	0.00	2.13
Naididae sp.	191.71	4217.60	239.44	N/A	29.44	86.40	53.76	1084.80	247.47
Amphipoda	50.91	1120.00	60.61	N/A	17.92	28.80	87.04	112.00	38.40
Gammaridea	9.02	198.40	11.67	N/A	0.00	0.00	23.04	41.60	0.00
Ameroculodes spp. complex	4.95	108.80	6.40	N/A	0.00	7.47	3.84	0.00	0.00
Leptocheirus plumulosus	287.13	6316.80	291.39	N/A	272.64	208.00	217.60	771.20	396.80
Gammarus sp.	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Melitidae	9.89	217.60	10.16	N/A	8.96	9.07	14.08	6.40	8.53
Melita nitida	83.20	1830.40	100.89	N/A	23.04	45.87	52.48	275.20	155.73
Corophiidae	2.33	51.20	0.75	N/A	7.68	3.20	2.56	0.00	0.00
Apocorophium lacustre	100.95	2220.80	10.92	N/A	407.04	173.87	25.60	0.00	2.13
Cyathura polita	118.11	2598.40	137.79	N/A	51.20	91.20	115.20	131.20	221.87
Edotia triloba	13.38	294.40	12.80	N/A	15.36	5.87	44.80	0.00	0.00
Chiridotea almyra	2.62	57.60	0.38	N/A	10.24	4.27	0.00	3.20	0.00
Cirripedia	3.78	83.20	0.00	N/A	16.64	6.93	0.00	0.00	0.00
Balanus improvisus	29.96	659.20	6.40	N/A	110.08	53.87	2.56	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	7.27	160.00	3.76	N/A	19.20	12.27	2.56	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.	0.87	19.20	1.13	N/A	0.00	0.53	1.28	3.20	0.00
Chironomus sp.	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Victorella pavida	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Gammaridae	0.00	0.00	0.00	N/A	0.00	0.00	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 bosc	0.29	6.40	0.00	N/A	1.28	0.53	0.00	0.00	0.00
Mysidacea	4.65	102.40	4.89	N/A	3.84	5.33	2.56	3.20	6.40
Cassidinidea ovalis	0.00	0.00	0.00	N/A	0.00	0.00	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

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

Table 2-7. Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 28 April 2010 sampling by substrate and station type. Because the mean bottom salinity regime was oligohaline, 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	16.58	364.80	18.49	N/A	8.00	3.20	3.84	153.60	0.00
Carinoma tremaphoros	4.07	89.60	4.98	N/A	0.00	3.20	2.56	9.60	6.40
Bivalvia	87.27	1920.00	102.40	N/A	19.20	85.87	83.20	48.00	125.87
Macoma sp.	87.27	1920.00	105.24	N/A	6.40	14.40	203.52	48.00	211.20
Macoma balthica	197.24	4339.20	231.47	N/A	43.20	197.87	247.04	204.80	106.67
Macoma mitchelli	21.82	480.00	26.67	N/A	0.00	12.27	14.08	92.80	25.60
Rangia cuneata	32.00	704.00	24.18	N/A	67.20	38.93	26.88	25.60	17.07
Ischadium recurvum	8.73	192.00	9.96	N/A	3.20	14.93	2.56	0.00	0.00
Mytilopsis leucophaeata	39.27	864.00	21.69	N/A	118.40	64.53	17.92	0.00	0.00
Capitellidae	1.16	25.60	1.42	N/A	0.00	0.53	0.00	9.60	0.00
Heteromastus filiformis	30.25	665.60	36.62	N/A	1.60	8.53	87.04	12.80	34.13
Spionidae	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Marenzelleria viridis	797.38	17542.40	397.87	N/A	2595.20	971.20	944.64	220.80	241.07
Streblospio benedicti	2.33	51.20	2.84	N/A	0.00	0.00	2.56	16.00	2.13
Polydora cornuta	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Boccardiella ligerica	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00

Table 2-7 – (continued)

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Nereididae	15.42	339.20	17.78	N/A	4.80	23.47	11.52	0.00	0.00
Neanthes succinea	39.56	870.40	46.58	N/A	8.00	50.67	32.00	22.40	19.20
Naididae sp.	1437.67	31628.80	1681.78	N/A	339.20	1466.67	1056.00	2540.80	1222.40
Amphipoda	163.78	3603.20	162.49	N/A	169.60	144.53	130.56	342.40	177.07
Gammaridea	52.36	1152.00	50.49	N/A	60.80	38.93	49.92	144.00	49.07
Ameroculodes spp. complex	33.45	736.00	19.56	N/A	96.00	30.93	48.64	9.60	34.13
Leptocheirus plumulosus	1152.00	25344.00	1203.20	N/A	921.60	810.67	1025.28	3065.60	1452.80
Gammaridae	15.71	345.60	19.20	N/A	0.00	0.00	0.00	172.80	0.00
Gammarus sp.	180.07	3961.60	183.11	N/A	166.40	182.93	83.20	336.00	226.13
Melitidae	4.95	108.80	5.69	N/A	1.60	2.67	5.12	0.00	17.07
Melita nitida	186.76	4108.80	218.31	N/A	44.80	130.67	85.76	659.20	264.53
Corophiidae	15.42	339.20	6.40	N/A	56.00	27.73	1.28	0.00	0.00
Apocorophium sp.	0.29	6.40	0.36	N/A	0.00	0.00	1.28	0.00	0.00
Apocorophium lacustre	205.96	4531.20	82.13	N/A	763.20	345.60	39.68	16.00	51.20
Cyathura polita	123.35	2713.60	140.80	N/A	44.80	92.27	177.92	92.80	177.07
Edotia triloba	23.27	512.00	12.80	N/A	70.40	25.07	37.12	3.20	6.40
Chiridotea almyra	2.91	64.00	0.71	N/A	12.80	5.33	0.00	0.00	0.00
Balanus improvisus	24.44	537.60	29.87	N/A	0.00	44.80	0.00	0.00	0.00
Rhithropanopeus harrisii	4.07	89.60	4.62	N/A	1.60	6.40	1.28	0.00	2.13

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	+	+	+	0.00	+
Chironomidae	0.29	6.40	0.00	N/A	1.60	0.53	0.00	0.00	0.00
Coelotanypus sp.	1.75	38.40	2.13	N/A	0.00	1.07	1.28	6.40	2.13
Orthocladiinae	1.16	25.60	1.07	N/A	1.60	1.60	1.28	0.00	0.00
Cricotopus sp.	1.16	25.60	0.71	N/A	3.20	2.13	0.00	0.00	0.00
Cryptochironomus sp.	0.58	12.80	0.71	N/A	0.00	0.53	1.28	0.00	0.00
Rheotanytarsus sp.	0.58	12.80	0.71	N/A	0.00	1.07	0.00	0.00	0.00
Copepoda	+	+	+	N/A	+	0.00	+	0.00	0.00
Ostracoda	2.62	57.60	2.49	N/A	3.20	1.07	1.28	19.20	0.00
Mysidacea	0.00	0.00	0.00	N/A	0.00	0.00	0.00	0.00	0.00
Platyhelminthes sp.	13.96	307.20	6.40	N/A	48.00	16.00	1.28	54.40	0.00
Mya arenaria	9.89	217.60	3.56	N/A	38.40	3.73	34.56	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	0.87	19.20	1.07	N/A	0.00	1.60	0.00	0.00	0.00
Hydrozoa	0.29	6.40	0.36	N/A	0.00	0.53	0.00	0.00	0.00
Odonata	0.29	6.40	0.36	N/A	0.00	0.53	0.00	0.00	0.00
Callinectes sapidus	0.29	6.40	0.36	N/A	0.00	0.53	0.00	0.00	0.00
Piscicola sp.	0.87	19.20	0.71	N/A	1.60	1.60	0.00	0.00	0.00
Gobiosoma bosc	0.29	6.40	0.00	N/A	1.60	0.53	0.00	0.00	0.00

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

Of the 40 taxa found in Year 28, twenty were considered truly infaunal, fifteen were considered epifaunal, and the remaining five were considered too general to classify as either infaunal or epifaunal (see Ranasinghe et al. 1994). The most common infaunal species found during Year 28 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-07 had the highest number of taxa in September 2009 (20 taxa, Table 2-8). Nearfield stations MDE-01 and MDE-34 had 19 taxa. The station with the fewest number of taxa (8 taxa) in September was Back River/Hawk Cove station MDE-30 (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=15 taxa, Reference=13.6 taxa, Back River/Hawk Cove=13 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. Thus, 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 28 September 2009 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	1107.2	2048.0	19	10	3.11	46.82	10.40	4.0
MDE-03	1273.6	1465.6	17	12	2.96	29.65	36.68	3.5
MDE-07	1164.8	1465.6	20	14	3.36	19.23	17.58	3.5
MDE-09	1158.4	1376	14	9	2.79	25.41	44.75	3.5
MDE-11	691.2	812.8	15	11	3.11	33.33	38.89	3.5
MDE-15	844.8	972.8	11	10	2.84	17.42	32.58	3.0
MDE-16	665.6	768.0	14	9	2.67	22.12	37.50	3.0
MDE-17	422.4	473.6	11	8	2.60	30.30	37.88	3.0
MDE-19	2131.2	2355.2	13	11	3.06	29.73	30.03	4.0
MDE-33	2380.8	4089.6	12	8	2.03	15.86	6.45	4.0
MDE-34	2259.2	3084.8	19	12	3.02	41.93	17.85	4.5
MDE-45	1254.4	1420.8	14	13	2.88	31.12	28.06	3.5
MEANS	**1279.5**	**1694.4**	**15**	**11**	**2.87**	**28.58**	**28.22**	**3.6**
HISTORIC MEAN, n=28 years								**3.4**
Reference Stations								
MDE-13	569.6	608.0	14	11	3.19	49.44	14.61	3.5
MDE-22	2022.4	2265.6	11	10	2.90	44.30	13.29	4.5
MDE-36	1734.4	2342.4	16	13	2.90	60.52	4.80	4.5
MDE-50	467.2	544.0	12	10	2.46	16.44	2.74	3.5
MDE-51	1145.6	1286.4	15	13	2.92	52.51	2.79	4.5
MEANS	**1187.8**	**1409.3**	**14**	**11**	**2.87**	**44.64**	**7.65**	**4.10**
HISTORIC MEAN, n=28 years								**3.6**
Back River/Hawk Cove Stations								
MDE-27	6380.8	6969.6	18	13	2.59	14.84	56.57	2.5
MDE-30	467.2	473.6	8	7	2.37	39.73	2.74	3.5
MEANS	**3424.0**	**3721.6**	**13**	**10**	**2.48**	**27.29**	**29.65**	**3.0**
HISTORIC MEAN, n=28 years								**2.98**
South Cell Exterior Monitoring Stations								
MDE-42	2496.0	2841.6	12	10	2.76	36.92	35.90	4.0
MDE-43	915.2	998.4	14	13	2.92	20.28	38.46	3.0
MDE-44	1395.2	1523.2	13	10	2.55	45.87	13.76	4.0
MEANS	**1602.1**	**1787.7**	**13**	**11**	**2.74**	**34.36**	**29.37**	**3.67**
HISTORIC MEAN, n=6 years								**3.57**

In April 2010, the greatest taxa richness (19 taxa) occurred at Nearfield stations MDE-09 and MDE-34. The second greatest taxa richness (18 taxa) occurred at Nearfield station MDE-07 and Back River/Hawk Cove station MDE-27. The lowest taxa richness (12 taxa) from April 2010 sampling was recorded at Nearfield station MDE-16 and Back River/Hawk Cove station MDE-30. Overall, average taxa richness did not vary greatly between station types. The average taxa richness was highest at Nearfield stations (16.08 taxa), while Reference stations and Back River/Hawk Cove stations averaged 15.02 and 15.00 respectively, and South Cell Exterior Monitoring stations averaged 14.67.

Table 2-9. Summary of metrics for each HMI benthic station surveyed during the Year 28 April 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 (%)
Nearfield Stations							
MDE-01	4268.8	5715.2	16	7	2.37	34.18	31.48
MDE-03	1356.8	1401.6	16	12	2.82	21.23	51.89
MDE-07	3532.8	3846.4	18	13	2.45	20.83	57.79
MDE-09	3360.0	3590.4	19	13	2.72	18.48	56.95
MDE-11	1939.2	2112	17	12	2.96	25.74	51.49
MDE-15	2713.6	3020.8	14	13	2.74	22.64	50.47
MDE-16	1491.2	1638.4	12	10	2.62	11.59	65.24
MDE-17	2310.4	2540.8	14	11	2.59	17.17	64.27
MDE-19	5849.6	6726.4	16	13	2.43	4.16	68.27
MDE-33	6630.4	7206.4	16	11	2.05	57.53	11.20
MDE-34	6380.8	6732.8	19	11	2.30	46.03	21.06
MDE-45	13574.5	13964.8	16	12	1.47	0.94	82.08
MEANS	**4450.7**	**4874.7**	**16**	**11**	**2.46**	**23.38**	**51.02**
Reference Stations							
MDE-13	1804.8	2060.8	14	12	2.88	10.99	64.89
MDE-22	6009.6	7078.4	17	12	2.34	5.22	75.83
MDE-36	3513.6	6840.0	17	10	2.76	22.40	50.27
MDE-50	4985.6	5081.6	14	11	1.68	61.87	24.65
MDE-51	3769.6	4236.8	14	12	2.56	9.00	60.95
MEANS	**4016.6**	**5059.5**	**15**	**11**	**2.4**	**21.90**	**55.32**
Back River/Hawk Cove Stations							
MDE-27	12000.0	13516.8	18	15	2.07	1.33	82.40
MDE-30	2649.6	2828.8	12	8	2.52	10.63	54.35
MEANS	**7324.8**	**8172.8**	**15**	**11**	**2.30**	**5.98**	**68.38**

South Cell Exterior Monitoring Stations							
MDE-42	5459.2	6508.8	16	13	2.13	3.40	81.71
MDE-43	2444.8	2912.0	14	12	2.50	14.92	63.87
MDE-44	3622.4	3993.6	14	11	2.46	4.77	60.07
MEANS	**3842.1**	**4471.5**	**15**	**12**	**2.40**	**7.70**	**68.55**

Since the first benthic survey studies of the HMI area in 1981, a small number of taxa have been dominant. Year 28 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*, *M. nitida*, and *A. lacustre*, the bivalves *M. balthica* and *M. leucophaeata*, the isopod *C. polita*, and the polychaete worm *M. viridis*.

Several other taxa were among the most dominant in only one season. In September 2009, the polychaete *S. benedicti* and the bivalve *R. cuneata* were within the top ten most dominant taxa, but not in April 2010. Likewise, amphipods of the genus *Gammarus* and the polychaete *N. succinea* were among the most dominant in April 2010, but not in September 2009. 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 28 late summer sampling, September 2009, 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	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carinoma tremaphoros	0.0	6.4	6.4	0.0	0.0	0.0	6.4	6.4	0.0	19.2	19.2
Bivalvia	12.8	12.8	6.4	6.4	44.8	0.0	0.0	6.4	12.8	19.2	25.6
Macoma sp.	6.4	0.0	0.0	0.0	0.0	6.4	25.6	0.0	0.0	12.8	0.0
Macoma balthica	0.0	25.6	32	25.6	64	89.6	44.8	0.0	57.6	288	659.2
Macoma mitchelli	0.0	0.0	44.8	0.0	19.2	6.4	44.8	0.0	6.4	32	32
Rangia cuneata	160	89.6	108.8	211.2	57.6	83.2	19.2	44.8	19.2	19.2	12.8
Ischadium recurvum	172.8	6.4	32	12.8	44.8	0.0	0.0	0.0	0.0	0.0	0.0
Mytilopsis leucophaeata	275.2	108.8	153.6	153.6	6.4	6.4	0.0	6.4	12.8	0.0	0.0
Amphicteis floridus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Capitellidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heteromastus filiformis	32	44.8	57.6	0.0	70.4	57.6	76.8	0.0	70.4	147.2	249.6
Spionidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marenzelleria viridis	262.4	179.2	12.8	25.6	25.6	38.4	6.4	12.8	6.4	19.2	25.6
Streblospio benedicti	89.6	377.6	179.2	339.2	217.6	32	230.4	224	160	217.6	83.2
Polydora cornuta	57.6	236.8	121.6	185.6	0.0	12.8	0.0	0.0	0.0	0.0	0.0
Boccardiella ligerica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nereididae	0.0	0.0	0.0	6.4	0.0	6.4	0.0	6.4	0.0	0.0	0.0
Neanthes succinea	102.4	25.6	51.2	115.2	32	108.8	0.0	70.4	0.0	0.0	0.0
Eteone heteropoda	0.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0
Naididae sp.	25.6	89.6	25.6	179.2	44.8	51.2	44.8	25.6	0.0	422.4	185.6
Amphipoda	6.4	0.0	12.8	12.8	19.2	12.8	64	12.8	19.2	115.2	179.2
Gammaridea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	64.0

Table 2-10 – (continued)

	Station										
Taxon	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Ameroculodes spp complex	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	89.6	0.0
Leptocheirus plumulosus	96	12.8	243.2	25.6	51.2	0.0	230.4	166.4	38.4	454.4	313.6
Gammarus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melitidae	38.4	6.4	0.0	0.0	0.0	0.0	6.4	6.4	0.0	19.2	44.8
Melita nitida	32	6.4	64	0.0	19.2	0.0	96	44.8	6.4	160	172.8
Corophiidae	0.0	0.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Apocorophium lacustre	179.2	102.4	185.6	0.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0
Cyathura polita	96	83.2	70.4	32	83.2	70.4	76.8	89.6	44.8	307.2	198.4
Edotia triloba	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chiridotea almyra	19.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cirripedia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Balanus improvisus	281.6	19.2	32	32	0.0	12.8	0.0	25.6	19.2	0.0	0.0
Balanus subalbidus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhithropanopeus harrisii	76.8	32	6.4	6.4	6.4	12.8	0.0	6.4	0.0	0.0	0.0
Membranipora sp	+	+	+	+	+	+	+	+	+	+	0.0
Chironomidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coelotanypus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chironomus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Victorella pavida	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gammaridae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copepoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gobiosoma bosc	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mysidacea	6.4	0.0	6.4	6.4	0.0	0.0	0.0	6.4	0.0	12.8	0.0
Cassidinidea ovalis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Argulus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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

Table 2-11. Average number of individuals collected per square meter at each station during the HMI Year 28 September 2009 sampling, 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	19.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carinoma tremaphoros	6.4	0.0	0.0	6.4	0.0	32	6.4	0.0	6.4	0.0	38.4
Bivalvia	6.4	0.0	684.8	25.6	25.6	0.0	0.0	6.4	19.2	44.8	12.8
Macoma sp.	6.4	0.0	0.0	0.0	0.0	0.0	0.0	32	0.0	0.0	19.2
Macoma balthica	217.6	6.4	0.0	0.0	0.0	486.4	57.6	332.8	204.8	12.8	339.2
Macoma mitchelli	64	0.0	0.0	0.0	6.4	19.2	12.8	6.4	25.6	6.4	38.4
Rangia cuneata	134.4	32	275.2	332.8	467.2	12.8	51.2	25.6	38.4	19.2	32
Ischadium recurvum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mytilopsis leucophaeata	6.4	0.0	985.6	384	345.6	0.0	0.0	6.4	0.0	25.6	0.0
Amphicteis floridus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Capitellidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heteromastus filiformis	64	6.4	0.0	25.6	6.4	115.2	70.4	25.6	25.6	19.2	70.4
Spionidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marenzelleria viridis	441.6	38.4	64	569.6	480.0	12.8	12.8	89.6	19.2	38.4	32
Streblospio benedicti	1446.4	0.0	153.6	268.8	51.2	256	275.2	160.0	262.4	12.8	19.2
Polydora cornuta	6.4	0.0	19.2	217.6	32	0.0	0.0	0.0	0.0	0.0	0.0
Boccardiella ligerica	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nereididae	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Neanthes succinea	96	0.0	0.0	25.6	12.8	0.0	12.8	6.4	6.4	12.8	19.2
Eteone heteropoda	0.0	0.0	0.0	38.4	0.0	0.0	6.4	0.0	0.0	0.0	6.4
Naididae sp.	2156.8	12.8	0.0	96	25.6	640.0	70.4	32.0	83.2	0.0	6.4
Amphipoda	64.0	160.0	12.8	12.8	140.8	64.0	32.0	19.2	57.6	44.8	57.6
Gammaridea	83.2	0.0	0.0	0.0	51.2	0.0	0.0	0.0	0.0	0.0	0.0

Table 2-11 – (continued)

Taxon	Station										
	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Ameroculodes spp. complex	0.0	0.0	0.0	0.0	19.2	0.0	0.0	0.0	0.0	0.0	0.0
Leptocheirus plumulosus	1440.0	102.4	576	211.2	256.0	448	236.8	505.6	390.4	236.8	281.6
Gammarus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melitidae	12.8	0.0	6.4	0.0	12.8	25.6	0.0	0.0	25.6	0.0	12.8
Melita nitida	544.0	6.4	6.4	12.8	6.4	307.2	83.2	76.8	102.4	0.0	83.2
Corophiidae	0.0	0.0	25.6	0.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0
Apocorophium lacustre	0.0	0.0	1209.6	403.2	64.0	0.0	6.4	0.0	0.0	57.6	6.4
Cyathura polita	153.6	108.8	38.4	44.8	102.4	409.6	64.0	192.0	128.0	6.4	198.4
Edotia triloba	0.0	0.0	19.2	38.4	217.6	0.0	0.0	0.0	0.0	6.4	0.0
Chiridotea almyra	6.4	0.0	6.4	25.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cirripedia	0.0	0.0	0.0	83.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Balanus improvisus	0.0	0.0	0.0	236.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Balanus subalbidus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhithropanopeus harrisii	0.0	0.0	0.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Membranipora sp	0.0	0.0	0.0	+	+	+	+	0.0	+	0.0	+
Chironomidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coelotanypus sp.	6.4	0.0	0.0	0.0	6.4	0.0	0.0	0.0	6.4	0.0	0.0
Chironomus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Victorella pavida	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gammaridae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copepoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gobiosoma bosc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mysidacea	6.4	0.0	0.0	6.4	0.0	12.8	0.0	6.4	19.2	0.0	12.8
Cassidinidea ovalis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Argulus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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

Table 2-12. Average number of individuals collected per square meter at each station during the HMI Year 28 April, 2010 sampling stations MDE-1 to MDE-22. Because the mean bottom salinity regime was oligohaline, taxa in bold are pollution sensitive while taxa highlighted in gray are pollution indicative.

	Station										
Taxon	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	0.0	0.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0
Carinoma tremaphoros	0.0	6.4	6.4	6.4	0.0	0.0	6.4	0.0	0.0	12.8	0.0
Bivalvia	0.0	6.4	115.2	108.8	57.6	70.4	224	70.4	89.6	115.2	211.2
Macoma sp.	0.0	0.0	6.4	0.0	0.0	128.0	25.6	0.0	64.0	6.4	556.8
Macoma balthica	0.0	6.4	25.6	134.4	51.2	12.8	243.2	44.8	102.4	723.2	505.6
Macoma mitchelli	0.0	6.4	19.2	25.6	12.8	6.4	25.6	0.0	0.0	32.0	25.6
Rangia cuneata	0.0	64	38.4	12.8	44.8	0.0	19.2	12.8	32.0	25.6	6.4
Ischadium recurvum	160.0	6.4	0.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mytilopsis leucophaeata	364.8	12.8	0.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Capitellidae	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heteromastus filiformis	0.0	0.0	6.4	0.0	25.6	12.8	12.8	0.0	6.4	38.4	243.2
Spionidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marenzelleria viridis	1459.2	288.0	736.0	620.8	499.2	198.4	614.4	172.8	384.0	243.2	313.6
Streblospio benedicti	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.8
Polydora cornuta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Boccardiella ligerica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nereididae	153.6	19.2	0.0	6.4	51.2	38.4	0.0	25.6	12.8	6.4	6.4
Neanthes succinea	134.4	128.0	0.0	44.8	102.4	115.2	6.4	83.2	44.8	12.8	12.8
Naididae sp.	1190.4	147.2	524.8	985.6	473.6	518.4	883.2	166.4	851.2	1740.8	2400.0
Amphipoda	224	153.6	224	268.8	51.2	102.4	102.4	51.2	76.8	307.2	96
Gammaridea	0.0	0.0	0.0	0.0	64	0.0	76.8	25.6	83.2	0.0	0.0
Ameroculodes spp. complex	0.0	6.4	32.0	38.4	19.2	32.0	32.0	6.4	12.8	12.8	0.0
Leptocheirus plumulosus	19.2	428.8	1510.4	883.2	396.8	524.8	467.2	723.2	582.4	2195.2	1881.6

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	0.0	0.0	0.0	0.0	0.0	0.0
Gammarus sp	83.2	6.4	211.2	96.0	51.2	64.0	64.0	51.2	38.4	300.8	102.4
Melitadae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32	0.0
Melita nitida	313.6	12.8	96.0	38.4	57.6	51.2	32.0	64.0	44.8	710.4	268.8
Corophiidae	108.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4
Apocorophium sp.	0.0	0.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0
Apocorophium lacustre	883.2	19.2	64.0	166.4	6.4	32.0	12.8	64.0	12.8	12.8	19.2
Cyathura polita	12.8	76.8	128.0	64.0	89.6	96.0	147.2	64.0	70.4	185.6	377.6
Edotea triloba	6.4	0.0	70.4	38.4	32.0	0.0	25.6	0.0	0.0	0.0	12.8
Chiridotea almyra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.8	0.0	0.0
Balanus improvisus	492.8	0.0	6.4	12.8	6.4	0.0	0.0	0.0	19.2	0.0	0.0
Rhithropanopeus harrisii	51.2	6.4	0.0	0.0	6.4	0.0	0.0	12.8	0.0	0.0	0.0
Membranipora sp	+	+	+	+	+	+	+	+	+	+	0.0
Chironomidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coelotanypus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	6.4
Orthocladiinae	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4
Cricotopus sp.	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cryptochironomus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4
Rheotanytarsus sp.	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copepoda	0.0	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0
Ostracoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	0.0
Mysidacea	0.0	0.0	0.0	0.0	0.0	0.0	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.	0.0	0.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0
Mya arenaria	0.0	0.0	6.4	6.4	0.0	44.8	0.0	0.0	0.0	0.0	0.0
Eteone heteropoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cassidinidea ovalis	19.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrozoa	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Odonata	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Callinectes sapidus	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Piscicola sp.	0.0	0.0	0.0	0.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0
Gobiosoma bosc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 2-13. Average number of individuals collected per square meter at each station during the HMI Year 28 April 2010 sampling, stations MDE-27 to MDE-51. Because the mean bottom salinity regime was oligohaline, 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	300.8	6.4	19.2	6.4	6.4	0.0	0.0	0.0	6.4	0.0	12.8
Carinoma tremaphoros	19.2	0.0	0.0	0.0	0.0	19.2	0.0	0.0	0.0	0.0	12.8
Bivalvia	89.6	6.4	12.8	12.8	0.0	204.8	140.8	32.0	217.6	51.2	83.2
Macoma sp.	96.0	0.0	0.0	6.4	0.0	371.2	243.2	19.2	64.0	19.2	313.6
Macoma balthica	409.6	0.0	0.0	19.2	6.4	172.8	25.6	121.6	1024.0	147.2	563.2
Macoma mitchelli	185.6	0.0	0.0	0.0	0.0	38.4	38.4	0.0	25.6	0.0	38.4
Rangia cuneata	32.0	19.2	64.0	89.6	115.2	12.8	32.0	6.4	64.0	0.0	12.8
Ischadium recurvum	0.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	6.4	0.0
Mytilopsis leucophaeata	0.0	0.0	326.4	57.6	89.6	0.0	0.0	0.0	0.0	0.0	0.0
Capitellidae	19.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heteromastus filiformis	25.6	0.0	0.0	0.0	0.0	83.2	12.8	6.4	12.8	6.4	172.8
Spionidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marenzelleria viridis	160.0	281.6	3782.4	2726.4	787.2	185.6	364.8	172.8	128.0	3084.8	339.2
Streblospio benedicti	32.0	0.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0
Polydora cornuta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Boccardiella ligerica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nereididae	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	12.8	0.0
Neanthes succinea	44.8	0.0	12.8	6.4	6.4	12.8	6.4	38.4	32.0	6.4	19.2
Naididae sp.	4678.4	403.2	32.0	588.8	723.2	2700.8	620.8	345.6	10016.0	12.8	1625.6
Amphipoda	313.6	371.2	211.2	19.2	179.2	51.2	140.8	339.2	44.8	268.8	6.4
Gammaridea	0.0	288.0	57.6	70.4	108.8	108.8	38.4	0.0	89.6	6.4	134.4
Ameroculodes spp. complex	19.2	0.0	153.6	25.6	147.2	32.0	6.4	64.0	32.0	57.6	6.4
Leptocheirus plumulosus	5107.2	1024.0	697.6	748.8	1036.8	1651.2	921.6	1785.6	10752.0	1203.2	480.0

Table 2-13– (continued)

Taxon	Station										
	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Gammaridae	345.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gammarus sp	524.8	147.2	307.2	140.8	204.8	179.2	32	467.2	844.8	12.8	32.0
Melitidae	0.0	0.0	0.0	0.0	6.4	12.8	6.4	32.0	0.0	0.0	19.2
Melita nitida	1171.2	147.2	38.4	64.0	64.0	448.0	70.4	275.2	96.0	12.8	32.0
Corophiidae	0.0	0.0	96.0	128.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Apocorophium sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Apocorophium lacustre	25.6	6.4	1177.6	1728.0	128.0	0.0	6.4	147.2	0.0	19.2	0.0
Cyathura polita	76.8	108.8	12.8	76.8	70.4	204.8	198.4	128.0	179.2	19.2	326.4
Edotia triloba	0.0	6.4	0.0	128.0	147.2	6.4	6.4	6.4	0.0	6.4	19.2
Chiridotea almyra	0.0	0.0	32.0	19.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Balanus improvisus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhithropanopeus harrisii	0.0	0.0	0.0	0.0	6.4	0.0	0.0	6.4	0.0	0.0	0.0
Membranipora sp	0.0	+	+	+	+	0.0	+	+	+	0.0	+
Chironomidae	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coelotanypus sp.	0.0	12.8	0.0	0.0	0.0	6.4	0.0	0.0	6.4	0.0	0.0
Orthocladiinae	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cricotopus sp.	0.0	0.0	0.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cryptochironomus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	0.0	0.0
Rheotanytarsus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copepoda	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	+	+
Ostracoda	32.0	6.4	0.0	6.4	6.4	0.0	0.0	0.0	0.0	0.0	0.0
Mysidacea	0.0	0.0	0.0	0.0	0.0	0.0	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.	108.8	0.0	160.0	32.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mya arenaria	0.0	0.0	25.6	0.0	0.0	0.0	0.0	0.0	6.4	128.0	0.0
Eteone heteropoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cassidinidea ovalis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrozoa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Odonata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Callinectes sapidus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Piscicola sp.	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gobiosoma bosc	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Infaunal Taxa Abundance

Average total infaunal abundance was lower in September 2009 than in April 2010 (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 12 years (excluding Year 23, which had an unusually large winter die-off of *R. cuneata*). In September 2009, total infaunal abundance ranged from 422.4 to 6,380.8 organisms per square meter (individuals/m^2) and averaged 1,497.6 individuals/m^2 (Table 2-8). The highest September 2009 abundance was found at the Back River/Hawk Cove station MDE-27, due primarily to large numbers of Naididae worms, *S. benedicti*, and *L. plumulosus*. The lowest infaunal abundance in September 2009 was found at the Nearfield station MDE-17 (Table 2-8). The average total infaunal abundance was highest at Back River/Hawk Cove stations (3,424 individuals/m^2) followed by South Cell Exterior Monitoring stations (1,602 individuals/m^2), Nearfield stations (1,279 individuals/m^2), and Reference stations (1,188 individuals/m^2) in September. No trend of increasing/decreasing abundances associated with distance from HMI could be discerned. These abundances are somewhat lower than historical averages except at the South Cell Exterior Monitoring stations where the abundance is a little above average (note that the average for South Cell Exterior Monitoring stations is only a six year average whereas long term averages for other station types is based on 28 years of data). The 28-year mean (4,769 individuals/m^2) of fall abundance for the Back River stations is much higher than the Reference (1,958 individuals/m^2) and Nearfield (2,187 individuals/m^2) means. Mean abundance in the South Cell stations has a six-year average of 1,168 individuals/m^2.

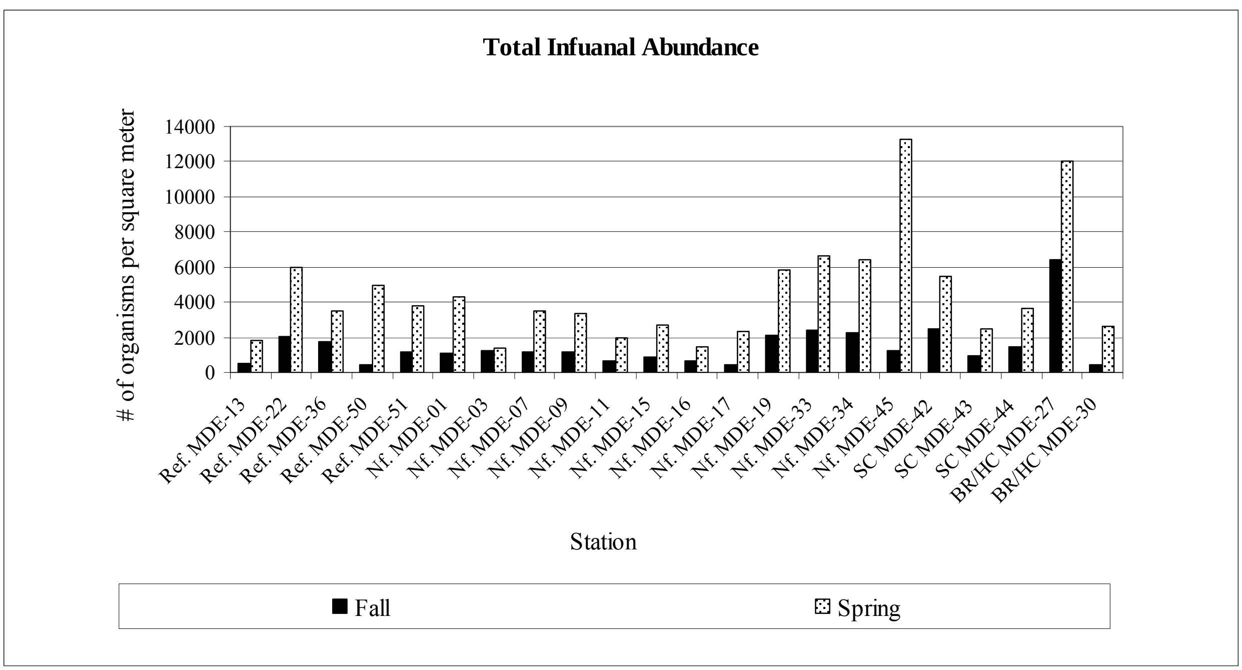

Figure 2-2. Total abundance of infauna taxa collected at each HMI station in Year 28, September 2009 and April 2010 grouped by stations (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

In April 2010, total infaunal abundance ranged from 1,356.8 to 13,574.4 individuals/m^2 and averaged 4,450.7 individuals/m^2. The station with the highest abundance was the Nearfield station MDE-45, due primarily to large numbers of Naididae worms, *M. balthica*, and *L. plumulosus*. The lowest spring abundance occurred at the Nearfield station MDE-03 (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 (3,842.13 individuals/m^2) followed by Reference stations (4,016.64 individuals/m2), Nearfield stations (4,016.64 individuals/m2), and highest at Back River/Hawk Cove stations (7,324.80 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 28, total infaunal abundance was similar to total abundance, accounting for ≥75 percent of all organisms at all stations during both seasons excluding Nearfield station MDE-01 (57.5%) in September 2009. This was primarily due to a high abundance of the epifaunal bivalves *M. leucophaeata* and *I. recurvum,* and the barnacle *B. improvisus*. The high percentage of oyster shell habitat at MDE-01 explains the low percentage of infauna at the station. All three species attach directly to shell or hard surfaces.

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. 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 28 are presented in Table 2-8 and 2-9. In this monitoring year, average diversity was slightly higher in September 2009 than in April 2010.

SWDI values in Year 28 averaged 2.82± 0.30 in September 2009 and 2.4 ± 0.37 in April 2010. The fall average diversity of 2.82 was slightly higher than the 12-year mean fall diversity of 2.35. The lowest diversity value in September 2009 occurred at Nearfield station MDE-33 (2.03, Figure 2-3). This was due to the large percentage of the amphipod *A. lacustre*, which accounted for 50 percent of total infaunal abundance at this station. The highest September 2009 diversity value (3.36) occurred at Nearfield station MDE-07. The lowest diversity value in April 2010 occurred at Nearfield station MDE-45 (1.47); this was due to the large percentage of *M.*

balthica, oligocheates of the Family *Naididae*, and *L. plumulosus*, which accounted for 89 percent of the total infaunal abundance at this station. The highest April 2010 diversity value occurred at Nearfield station MDE-11 (2.96). Comparisons of mean spring diversity values 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.

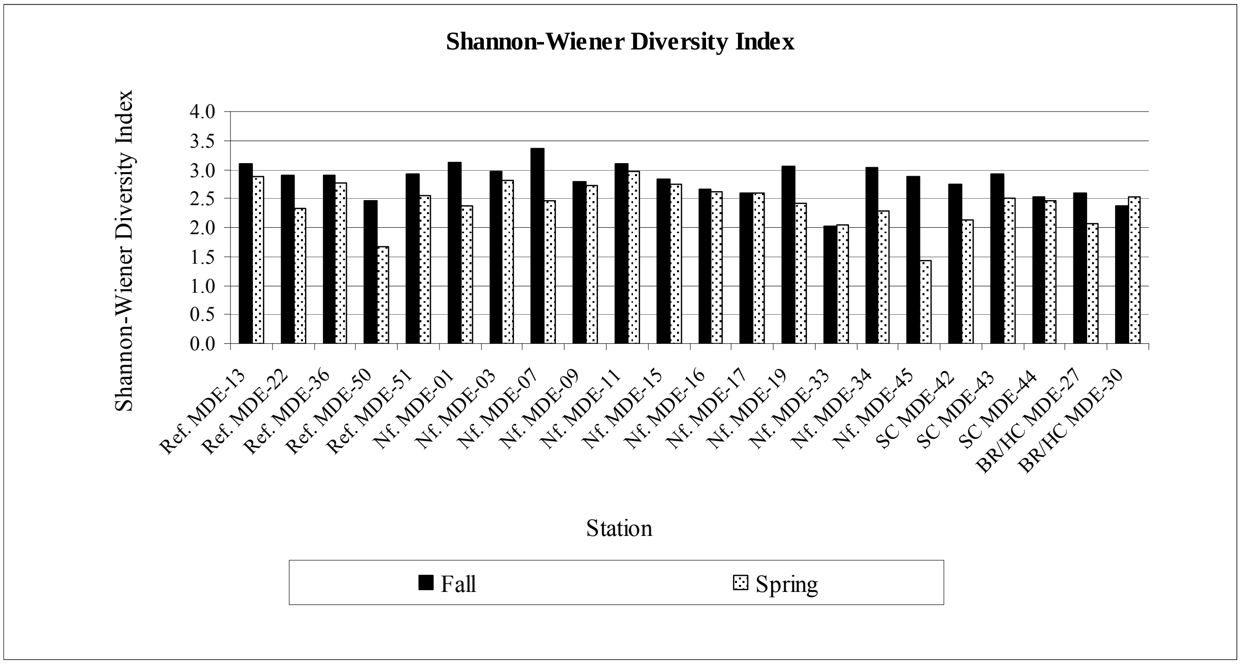

Figure 2-3. Shannon-Wiener Diversity Index (SWDI), HMI Year 28, September 2009 and April 2010 grouped by stations (Ref. = Reference; Nf. = Nearfield; SC = South Cell; BR/HC = Back River Hawk Cove).

On average, Nearfield stations had diversity values similar to Reference stations in September 2009 and April 2010. Comparing station types from the fall only, the lowest average SWDI was 2.48 at the Back River/Hawk Cove stations followed by the South Cell Exterior Monitoring stations at 2.74. Reference and Nearfield station both averaged 2.87 (Table 2-8). Historically, the 22-year mean SWDI values, ranked from lowest to highest, are associated with the following station types: Back River/Hawk Cove (2.15), Nearfield (2.32), Reference (2.37), and South Cell Exterior Monitoring (2.54, n=6 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 2009 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.* Two taxa found during the April 2010 sampling cruise were designated as "pollution-sensitive" according to Alden et al. (2002). These were the polychaete worm *M. viridis,* and the isopod crustacean *C. almyra.* This difference in number of taxa found is due to the seasonal change from low mesohaline to oligohaline 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 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 28, the fall salinity regime was low mesohaline, as it was in Years 27 and 26.

In Year 28, pollution sensitive taxa occurred at all station types. In September, PSTA ranged from 14.84 percent at MDE-27 (Back River/Hawk Cove station) to 60.52 percent at MDE-36 (Reference station -Table 2-8; Figure 2-4). The average PSTA for all stations in September 2009 was 32.90 percent. Comparing station types, the lowest average PSTA was 27.29 percent at the Back River/Hawk Cove stations followed by the Nearfield stations at 28.58 percent followed by the South Cell Exterior Monitoring stations at 34.36 percent. The highest average PSTA was 44.64 percent at Reference stations. Historically, the 28-year mean fall PSTA values, ranked from lowest to highest, are associated with the following station types: Back River/Hawk Cove (31.91 percent), South Cell Exterior Monitoring (32.42 percent, n=6 years), Nearfield (40.16 percent), and Reference (43.50 percent).

In April 2010, the lowest PSTA was 0.94 percent at MDE-45 (Nearfield station) and the highest was 61.87 percent at MDE-50 (Reference station - Table 2-9; Figure 2-4). The average PSTA for all stations in April was 19.18 percent. Back River/Hawk Cove stations had the lowest average PSTA at 5.98 percent, followed by the South Cell Exterior Monitoring stations at 7.70 percent, and the Reference stations at 21.90 percent; the Nearfield stations had the highest average PSTA of 23.38 percent. The abundance of the polychaete worm, *M. viridis*, which reproduces and recruits in the spring, drove this metric in Year 28.

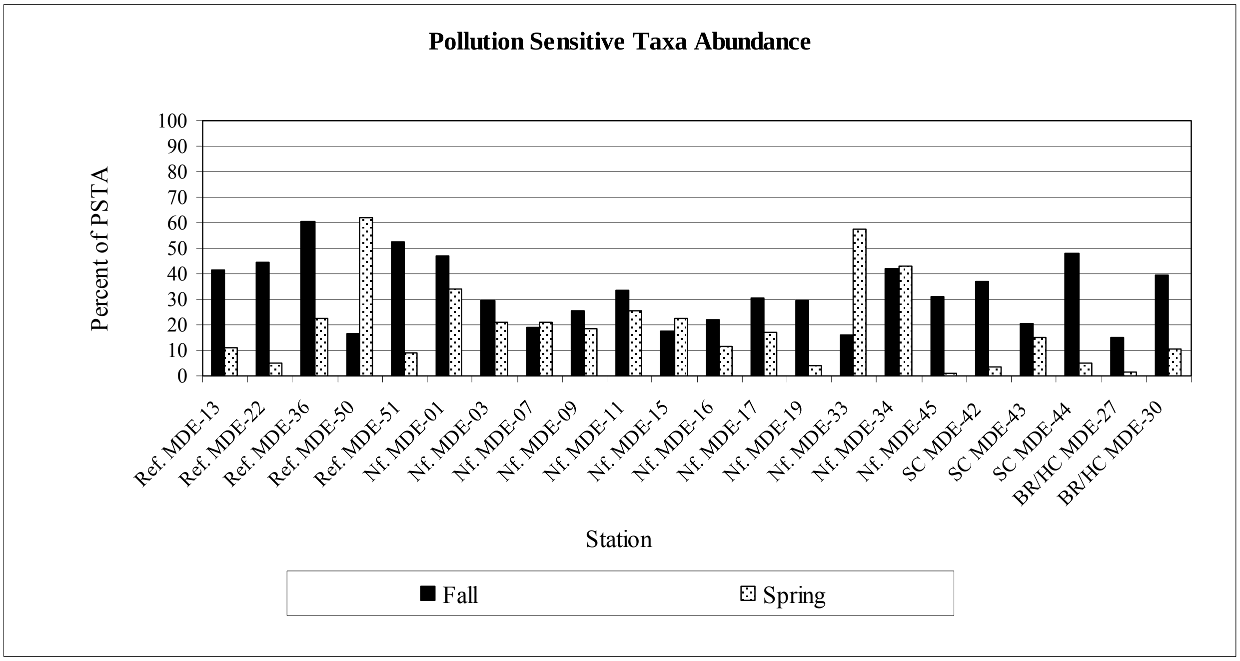

Figure 2-4. Percent abundance comprised of pollution sensitive species (PSTA), HMI Year 28 September 2009 and April 2010 grouped by stations (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

Pollution Indicative Taxa Abundance (PITA)

Four taxa found during the September 2009 sampling of Year 28 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. Seven taxa found during the April 2010 sampling cruise were designated as "pollution-indicative" according to Alden et al. (2002). These were the polychaete worms *S. benedicti, H. filiformis N. succinea,* and *P. cornuta,* the amphipod crustacean *L. plumulosu*s, the Chironomid *Coelotanypus sp.,* and oligochaete worms of the family Naididae. This difference in number of taxa found is due to the seasonal change from low mesohaline to oligohaline 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 28, pollution indicative taxa occurred at all station types. In September, the PITA ranged from 2.74 percent at MDE-30 and MDE-50 (Back River/Hawk Cove and Reference station, respectively) to 56.57 percent at MDE-27 (Back River/Hawk Cove station) (Table 2-8; Figure 2-5). The average PITA for all stations in September 2009 was 23.83 percent. Comparing station types, the lowest average PITA was 7.66 percent at the Reference stations, followed by 28.22 percent at the Nearfield, and 29.37 percent at South Cell Exterior Monitoring stations. The highest average PITA occurred at the Back River/Hawk Cove stations at 29.65 percent. Historically, the 28-year mean fall PITA values, ranked lowest to highest, are associated with the following station types: Reference (20.34 percent), Nearfield (23.38 percent), South Cell Exterior Monitoring (35.45 percent, n = 5 years), and Back River/Hawk Cove (35.47 percent).

In April 2010, the lowest PITA was 11.20 percent at MDE-33 (Nearfield station) and the highest was 82.40 percent at MDE-27 (Back River/Hawk Cove station -Table 2-9; Figure 2-5). The average PITA for all stations in April was 55.96 percent. Nearfield stations had the lowest average PITA at 51.02 percent, followed by the Reference stations at 55.32 percent, and the Back River/Hawk Cove stations at 68.38 percent; the South Cell Exterior had the highest average PITA of 68.55 percent.

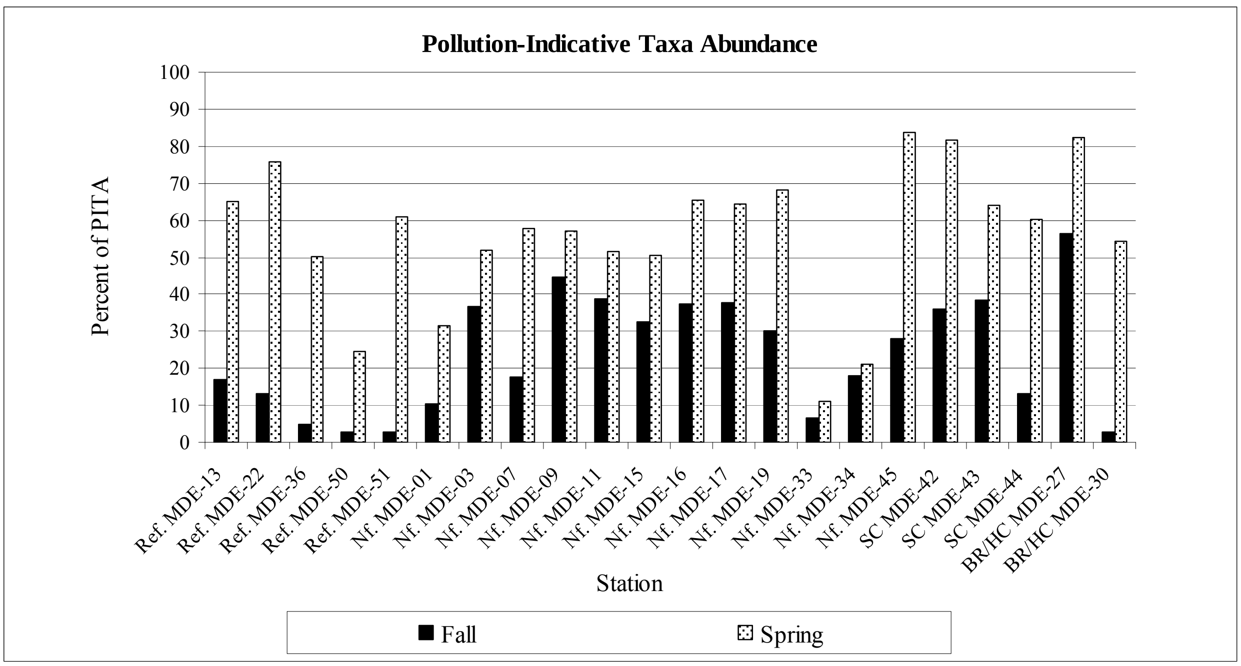

Figure 2-5. Percent abundance comprised of pollution indicative species (PITA), HMI Year 28 September 2009 and April 2010 grouped by stations (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

Benthic Index of Biotic Integrity

The B-IBI was calculated for all stations based on September 2009 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, 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 28 were compared to this benchmark.

Table 2-14. Low mesohaline scoring criteria for measures used in calculating the Chesapeake Bay B-IBI in September 2009 (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	≥80%	40-80%	<40%
Shannon-Wiener Diversity Index	≥2.5	1.7-2.5	<1.7

The vast majority of the individual station B-IBI scores for Year 28 increased or stayed the same when compared to Year 27. Scores increased at 10 stations, remained the same at 7, and decreased at 5 stations. Twenty-one of the 22 stations met or exceeded the benchmark criteria of 3.0 in Year 28. In Year 28, Back River/Hawk Cove station MDE-27 (2.50) was the only station that failed to meet the benchmark criteria of 3.0 (Table 2-8, Figure 2-6). Nine stations were below historic averages and thirteen stations (five Nearfield, two South Cell Exterior Monitoring, four Reference, and two Back River/Hawk Cove) were above.

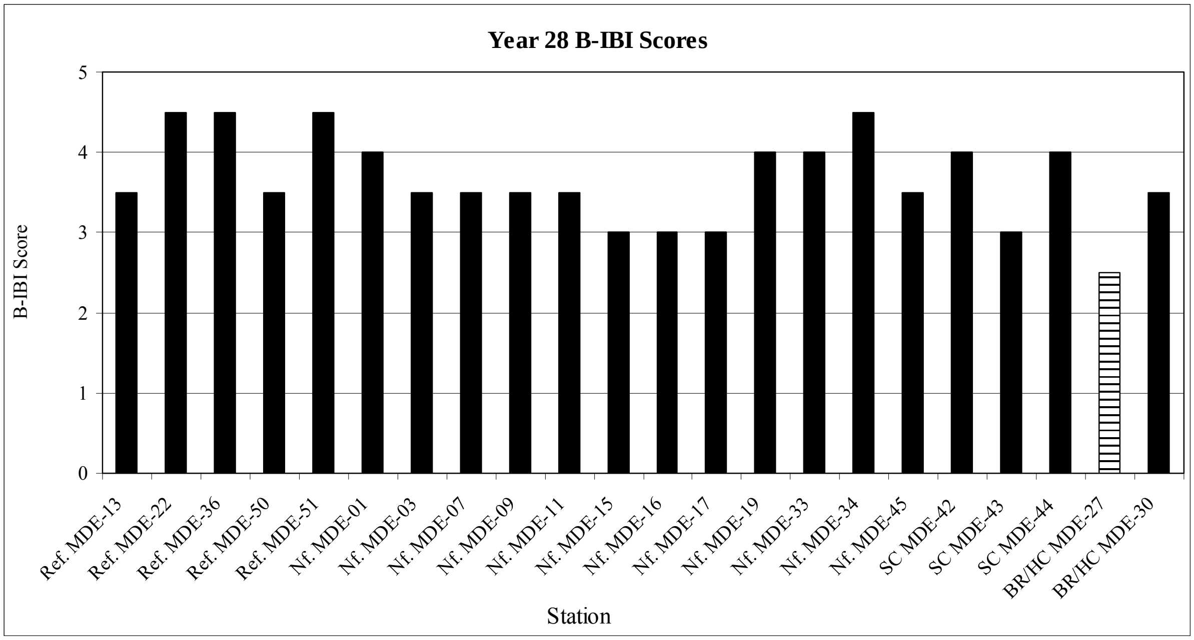

Figure 2-6. B-IBI Scores for all stations in September 2009 grouped by stations (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

The mean B-IBI for Nearfield, Reference, Back River/Hawk Cove, and South Cell Exterior Monitoring stations met or exceeded the benchmark of 3.0. Average B-IBI scores by station type are shown in Figure 2-7. Compared to Year 27, the mean B-IBI increased for all station types. The Year 28 mean B-IBI's for all station types were above the historic average (six year average for South Cell Exterior Monitoring Stations, Table 2-8).

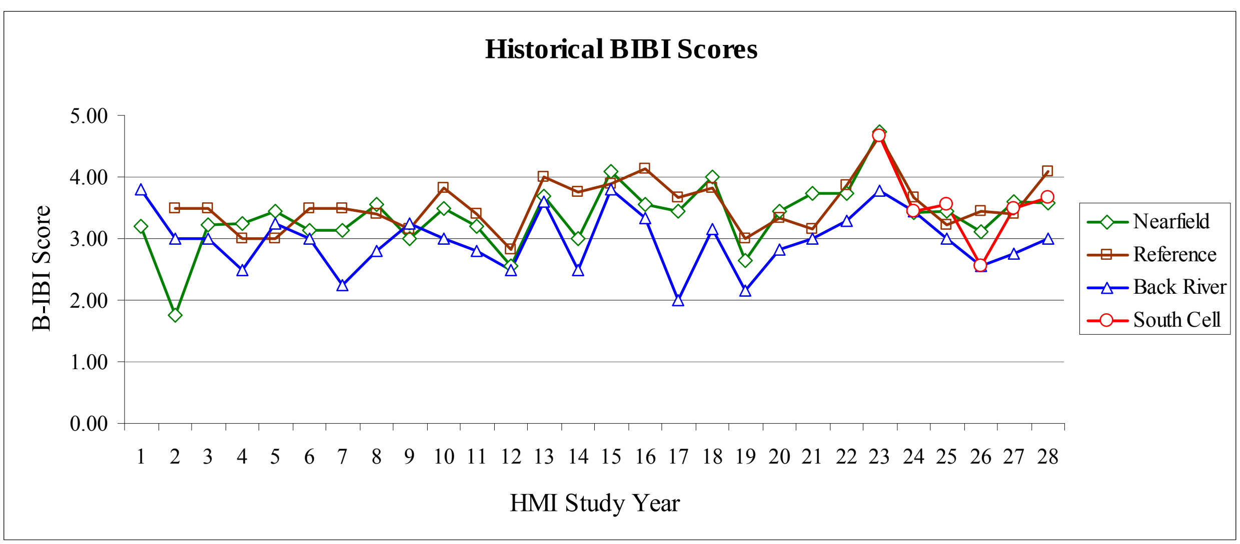

Figure 2-7. Average B-IBI Scores at HMI for Monitoring Years 1-28.

There was no trend of increasing or decreasing B-IBI scores associated with proximity to HMI in Year 28. 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 B-IBI. Back River/Hawk Cove stations had the lowest mean in Year 28 and have had the lowest average 23 of 28 years.

Clam Length Frequency Distribution

In September 2009, 346 *R. cuneata* were collected. The greatest average abundance of *R. cuneata* occurred at the Reference stations (19.20 clams/station), followed by the Nearfield stations (17.50 clams/station), the Back River/Hawk Cove stations (13 clams/station), and the South Cell Exterior Monitoring stations (4.66 clams/station). The greatest abundance of *R. cuneata* during the fall was found in the 1-5 mm size class. In April 2010, 106 *R. cuneata* were collected. The greatest average abundance for this species occurred at the Nearfield stations (5.58 clams/station), followed by the Back River/hawk Cove and Reference stations (4.5 and 4.4 clams/station respectively), and the South Cell Exterior Monitoring stations (2.67 clam/station). There was no dominant size range found during the spring.

Historically, *R. cuneata* tends to be the most abundant bivalve mollusk found in this benthic monitoring project. However, *M. balthica* outnumbered it in both seasons in Year 28. This change in dominance is more associated with an increase in *M. balthica* abundance than a decrease in *R. cuneata* abundance, although both have occurred in the last two years. It is classified as pollution sensitive during higher salinity years (≥5ppt). The population has historically been very dynamic in terms of overall abundance and distribution by size or station type. The main drivers of *R. cuneata* variability appear to be temperature and salinity. In the Chesapeake Bay, this species exists at the northern extent of its range. Because of this, it is subject to high winter mortality during cold winters (Hopkins, et al., 1973). Additionally, ideal salinity conditions for reproduction and recruitment do not occur regularly. In Maryland, *R. cuneata* rarely if ever reach its reported maximum age (15-20 years) or size (79 mm). Looking at 12 years of historical HMI frequency distribution data, it is difficult to identify more than four age classes of clams in any one season. This implies very few clams survive longer than five years.

In September 2009, 456 *M. balthica* were collected, with 169 coming from Reference stations, 137 from South Cell Exterior Monitoring stations, 115 from Nearfield stations, and 35 coming from Back River/Hawk Cove stations. The greatest abundance of *M. balthica* during the fall was found in the 7-12 mm size class. In April 2010, 674 *M. balthica* were collected with 372 coming from Nearfield stations, 188 from Reference stations, 64 from Back River/Hawk Cove stations, and 50 from South Cell Exterior Monitoring stations. Five hundred nine were in the 1-4 mm size class, which is indicative of recruitment.

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 (≥ 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 12 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 2009, 59 *M. mitchelli* were collected, with 27 coming from Nearfield stations, 15 from Reference stations, 10 from Back River/Hawk Cove stations, and 7 from South Cell Exterior Monitoring stations. The greatest abundance of *M. mitchelli* during the fall was found in the 9-12 mm size class. In April, 72 *M. mitchelli* were collected with 29 coming from Back River/Hawk Cove stations, 23 from Nearfield stations, 12 from South Cell Exterior Monitoring stations, and 8 from Reference stations. Forty-eight were in the 1-8 mm size classes, which is indicative of the spring recruitment time period. 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*, even during ideal periods. For this reason, a recruitment of the magnitude exhibited in *M. balthica* is unlikely. Recruitment in Years 27 and 28 are signs of recovery.

STATISTICAL ANALYSIS

Statistical methods applied to HMI Year 28 benthic macroinvertebrate data were Friedman's nonparametric ANOVA test and multivariate clustering procedures. The Friedman's nonparametric test was utilized again in Year 28 to determine if significant differences in the top ten most abundant invertebrate taxa occurred among the four station types (Nearfield, Back River, South Cell Exterior Monitoring, and Reference) for both the September 2009 and April 2010 sampling data. Cluster analysis was employed to identify groups of stations with similar benthic invertebrate assemblages.

In general, cluster techniques are statistical procedures applied to multivariate data sets that initially are unclassified (Johnson, 1998a). The cluster procedure is just one of a number of well-established analytical methods (other methods include Principal Components Analysis, Factor Analysis, and Discriminant Analysis) that can organize a multivariate data set and identify patterns (Johnson, 1998). The objective of cluster analysis was to examine the identified station groups for patterns in their benthic invertebrate assemblages that might indicate impacts from HMI 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 four clustering methods employed were the hierarchical tree figure, Hotelling's pseudo T^2 statistic [PST2], Andrews' plot, and three-dimensional Principal Components plot. All four clustering methods are considered together to identify station groups with similar benthic invertebrate assemblages, because this technique has yielded more reliable results than reliance on the hierarchical tree figure alone (HMI Year 19 – HMI Year 26). Clustering analysis was applied to the September 2009 data, but not to the April 2010 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.

To identify patterns in benthic macroinvertebrate assemblages for the station groups indicated by the cluster procedures, several of the benthic invertebrate metric values (total infaunal abundance, number of infaunal taxa, Shannon-Wiener diversity, PSTA scores, PITA scores, and B-IBI scores) were examined to see how well they correlated to the identified station groups. Good correlations of one or more metric values with identified station groups help to characterize the station groups and outliers, and provide insight into possible effects of HMI operations. This examination of metric values to identified station groups was introduced in the HMI Year 26 annual report.

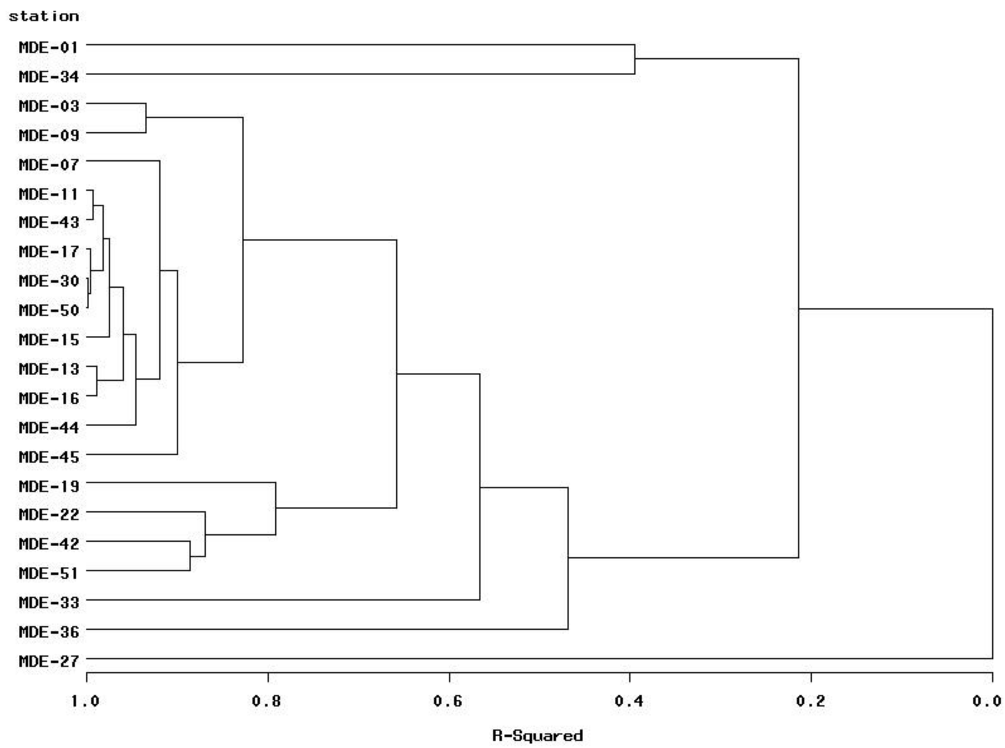

Figure 2-8. September 2009 Cluster Analysis tree.

The cluster tree figure for September 2009 showed a clear articulation of several HMI station groups (Figure 2-8). Using an $R^2 \geq 0.78$ as the threshold for identifying multi-station groups, two multi-station groups (Group 1 and Group 2) and five outlier stations were apparent from examination of the September 2009 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 moderately (Group 1) to weakly (Group 2) correlated to station type, and did demonstrate more spatial proximity than had been observed in cluster analyses from previous HMI monitoring years. Group 1, the largest group, consisted of 13 stations: eight Nearfield stations (MDE-03, MDE-07, MDE-09, MDE-11, MDE-15, MDE-16, MDE-17, and MDE-45), two Reference stations (MDE-13 and MDE-50), two South Cell stations (MDE-43 and MDE-44), and Back River station MDE-30. Nine stations in this group, located within 1,500 meters of the eastern side of HMI (MDE-07, MDE-09, MDE-11, MDE-15, MDE-16, MDE-17, MDE-43, MDE-44, MDE-45) exhibited good spatial proximity, with a median distance between stations of approximately 1,500 meters. Stations MDE-13 and MDE-50 were south and further east, while Back River station MDE-30 was on the western side of the island. The median distance between all stations in this group was 1,652 meters. Group 2 was composed of two Reference stations (MDE-22, and MDE-51), Nearfield station MDE-19, and South Cell station MDE-42. The stations in this group were located to the south of HMI and had good spatial proximity except for Reference station MDE-51. The median distance between stations MDE-19, MDE-22, and MDE-42 was approximately 1,152 meters. The median distance between all stations in the group including MDE-51 was 2,303 meters. The outlier stations were MDE-1, MDE-27, MDE-33, MDE-34, and MDE-36.

The Hotelling pseudo T^2 statistic values provided evidence supporting the identification of two multi-station groups and five outliers (a total of seven distinct "groups"). The PST2 value made a relatively large jump from 2.3 at seven "groups" to 9.6 at six "groups", indicating that seven distinct "groups" (multi-station groups and outliers) was a highly likely interpretation.

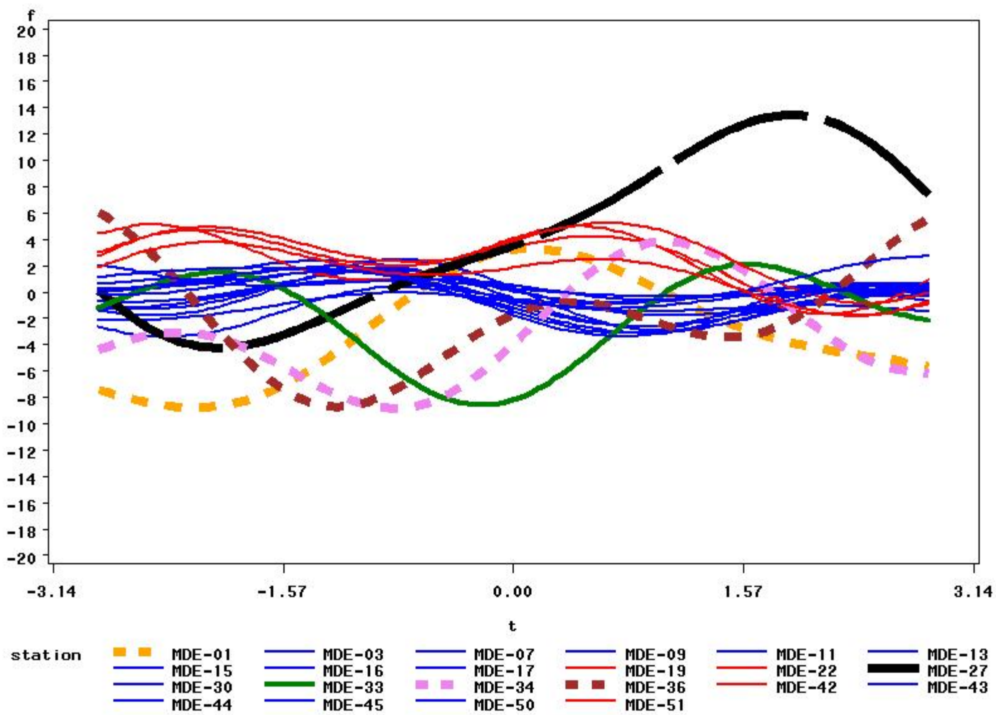

Figure 2-9. Andrews' plot of the September 2009 invertebrate abundance data using the uncorrelated first five principal components in the wave function (accounting for 78.5 percent of the variability of the data). Group 1 stations = continuous blue waves; Group 2 stations = continuous red waves; outlier station MDE-01 = yellow dashed wave; outlier station MDE-27 = black dashed wave; outlier station MDE-33 = green continuous wave; outlier station MDE-34 = light purple dashed wave; and outlier station MDE-36 = brown dashed wave.

The Andrews' plots for the September 2009 yielded fairly strong support for the two multi-station groups and five outlier stations identified by the cluster tree procedure (Figure 2-9). The plot of the wave function constructed from the first five principal components produced excellent coincidence of the stations waves within each group, and good unique wave patterns for the five outlier stations. In the figure, Group 1 stations are the blue unbroken waves and Group 2 stations are the red unbroken waves. Outlier station MDE-01 is the yellow dashed wave, outlier MDE-27 is the black dashed wave, outlier MDE-33 is the green continuous wave, outlier MDE-34 is the light purple dashed wave, and outlier MDE-36 is the brown dashed wave. The first five principal components accounted for 78.5 percent of the variability of the data.

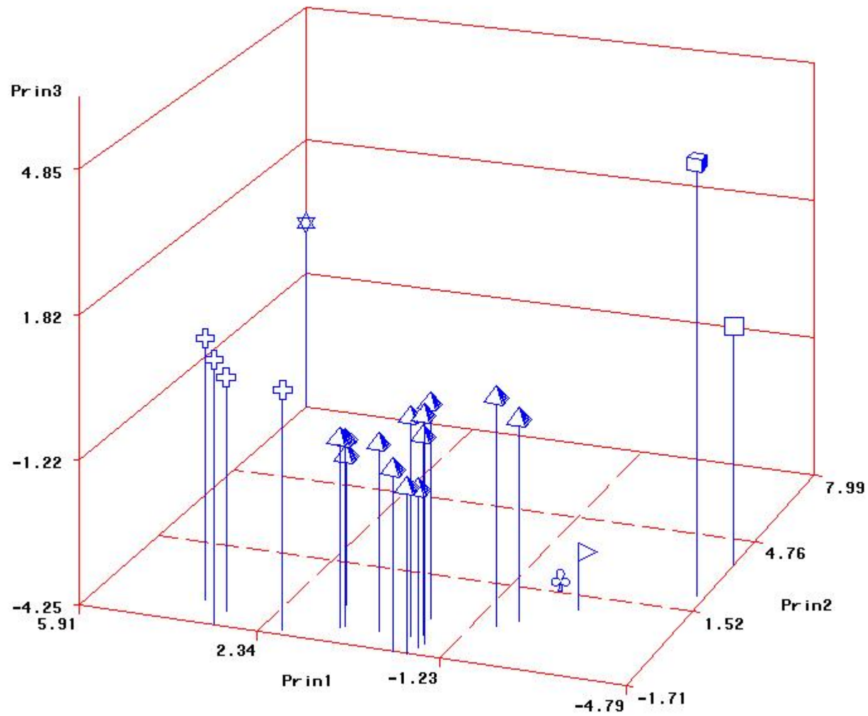

Figure 2-10. Three-dimensional plot of the first three principal components (accounted for 61.7 percent of the variability of the data) for the September 2009 invertebrate abundance data. Group 1 = pyramids; Group 2 = crosses; outlier station MDE-01 = cube; outlier station MDE-27 = star; outlier station MDE-33 = flag; outlier station MDE-34 = square; outlier station MDE-36 = club. Note that Prin1 = principal component 1 axis, Prin2 = principal component 2 axis, and Prin3 = principal component 3 axis.

The three-dimensional plot of the first three principal components for the September 2009 invertebrate abundances also provide moderately fair support for the identified station groups (Figure 2-10). Group 1 (pyramids) and Group 2 (crosses) have fair within group clumping, and fair separation from other station groups and outliers. In the figure it is apparent the stations differed primarily along the first principal component axis. Note that spatial proximity between MDE-33 and MDE-36 and between MDE-01 and MDE-34 might be interpreted as two station groups of two instead of four separate outliers, but this is not supported by the tree figure or the Andrews' plot. The three principal components in the three-dimensional plot account for less of the variability of the data (61.7 percent) than the Andrews' plot or the tree analysis, which explains why it supports but does not entirely coincide with these other two analyses. Also, note in the figure that outlier stations MDE-27 (star) is the most isolated in the three-dimensional space, indicating that the most unique invertebrate assemblage occurred at this Back River station.

Examination of the total infaunal abundance values helped to characterize the identified station groups and check for possible impacts from HMI dredging operations. Group 1 stations strongly correlated to the total infaunal abundance metric, with all 13 stations having less than the overall mean value. In general, Group 1 stations had lower than average abundance of *M. viridis*, Naididae sp., *L. plumulosus*, *M. nitida*, and *C. polita*. Group 1 stations did not correlate well with the other metrics except for B-IBI scores. Twelve of the thirteen stations had slightly less than average B-IBI scores, but all Group 1 station B-IBI scores were passing. For number of infaunal taxa, seven stations were below average, four stations were above average and two stations were average. For diversity, seven stations were above average and six stations were below average. For PSTA scores nine stations were below average and four stations were above average. For the PITA scores, eight stations were above average and five stations were below average. In general Group 1 stations, located to the east of HMI, can be characterized as sites with less than average infaunal abundance, less than average pollution sensitive species and more than average pollution indicative species, but overall had healthy benthic invertebrate communities not adversely impacted by HMI operations. Eleven of the Group 1 stations were silt/clay sites, while the other two stations in the group (MDE-07 and MDE-50) were sandy sites.

Group 2 stations correlated moderately well to total infaunal abundance, Shannon Wiener diversity, PSTA percentage, and B-IBI scores. Group 2 stations had higher than average infaunal abundance (3 of 4 stations), with higher than average abundances of *M. balthica*, *M. mitchelli*, *H. filiformis*, *L. plumulosus*, *M. nitida*, and *C. polita*. Group 2 stations were also characterized as having higher than average Shannon Wiener diversity (three of four stations), PSTA percentages (three of four stations), and B-IBI scores (all four stations). Group 2 stations, located to the south of HMI, could also be characterized as having healthy benthic invertebrate assemblages, but somewhat better overall than Group 1 stations. All four Group 2 stations were silt/clay sites. The five outlier stations included three Nearfield stations (MDE-01, MDE-33, MDE-34), Reference station MDE-36, and Back River station MDE-27. Outlier MDE-01, a sandy site located on the north side of HMI, had lower than average infaunal abundance, number of taxa, and pollution indicative species, but higher than average diversity, pollution sensitive species and B-IBI score. MDE-01 could be characterized as having a very healthy benthic invertebrate assemblage. Nearby outlier station MDE-33, also a sandy site on the north side of HMI, had higher than average infaunal abundance and B-IBI scores, and lower than average total taxa number, diversity, pollution sensitive species, and pollution indicative species. MDE-33 also has a healthy benthic invertebrate assemblage. Outlier MDE-34, another sandy site in the same general area of MDE-01 and MDE-33, and outlier station MDE-36, a silt/clay reference station located approximately 3,500 meters north of HMI, could be characterized as having two of the healthiest benthic invertebrate assemblages sampled in Year 28. Both these stations had higher than average infaunal abundance, number of taxa, diversity, pollution sensitive species and B-IBI scores, with lower than average number of pollution indicative species. The final outlier station, Back River MDE-27, a silt/clay site, is the only Year 28 station that could be characterized as having an impaired benthic invertebrate assemblage. It had higher than average infaunal abundance, number of taxa, and pollution indicative species, but lower than average diversity, pollution sensitive species, and B-IBI score (2.5), which is considered failing. This station is adversely impacted from Back River discharge, not from any effects from HMI operations. It is consistently identified as an outlier by the cluster tree analysis.

The Friedman's nonparametric ANOVA test results indicated that there were no significant differences in the ten most abundant infaunal taxa between the four station types in September 2009 ($P < 0.52$) and in April 2010 ($P < 0.48$). Significant Friedman results in past monitoring years have not occurred often 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.

In September 2009 the Back River stations ranked highest for the top ten most abundant taxa, with a mean of 342 individuals per station, followed by South Cell stations (mean of 164 individuals per stations), Nearfield stations (mean of 128 individuals per station), and Reference stations (mean 103 individuals per station). The high average abundance at Back River stations was driven by the very high numbers of benthic macroinvertebrates at MDE-27. Despite having the highest macroinvertebrate abundance, this station was identified as impaired because of low relative diversity and high abundances of *S. benedicti* and Naididae, two pollution indicative species. In April 2010, Back River stations again ranked highest for the top ten most abundant taxa (mean of 673 individuals per station), followed by South Cell stations (mean of 628 individuals per station), Nearfield stations (mean of 357 individuals per station), and Reference stations (mean of 314 individuals per station). The non-significant differences in the September 2009 and April 2010 Friedman's ANOVA was mirrored by lack of major differences between station types for Shannon-Weiner diversity, PSTA percentage, and PITA percentage.

Table 2-15. Friedman Analysis of Variance for September 2009's 10 most abundant species among: Back River/Hawk Cove, Nearfield, South Cell Exterior Monitoring, and Reference stations. ANOVA Chi Sqr. ($N = 10$, $df = 3$) = 2.28000 $p < 0.51636$.

Station Type	Average Rank	Sum of Ranks	Mean	Std. Dev.
Nearfield	2.20000	22.00000	128.2667	62.7987
Reference	2.30000	23.00000	103.0400	69.2470
Back River	3.00000	30.00000	342.4000	378.9175
South Cell	2.50000	25.00000	163.6267	140.1991

Table 2-16. Friedman Analysis of Variance for April 2010's 10 most abundant species among: Back River/Hawk Cove, Nearfield, Reference stations, and South Cell Exterior Monitoring Stations. ANOVA Chi Sqr. (N = 10, df = 3) = 2.50000 p < 0.47529.

Station Type	Average rank	Sum of ranks	Mean	Std. Dev
Nearfield	2.30000	23.00000	356.6545	370.141
Reference	2.10000	21.00000	313.8133	445.062
Back River	2.90000	29.00000	673.2800	1019.754
South Cell	2.70000	27.00000	628.2667	1127.256

CONCLUSIONS

In Year 28, the benthic macroinvertebrate community was examined under fairly typical conditions for this region of Chesapeake Bay. In September 2009 Bay waters in the vicinity of HMI were low mesohaline, while abundant late winter and spring freshwater discharge to the Bay resulted in oligohaline conditions around HMI in April 2010. Abundant spring freshwater discharge prevented the early formation of stratified waters at most HMI stations. However, water quality measurements at stations MDE-50 and MDE-51, particularly low bottom dissolved oxygen levels, indicated possible pycnocline stratification at these two stations. These stations are likely influenced by nearby deep channel waters.

The health of the benthic macroinvertebrate community around HMI in Year 28 was generally similar to the previous sampling year and historical averages. Macroinvertebrate abundance was much lower in Year 28 compared to Year 27 numbers, which was primarily the result of an unusually high *M. viridis* recruitment in Year 27 (the highest ever recorded). Year 28 macroinvertebrate abundance was somewhat lower than the historic average. Diversity was higher in Year 28, but this was not likely due to an improvement in macroinvertebrate health in Year 28, but more likely due to the lower *M. viridis* recruitment numbers. Large swings in abundance are considered "normal" for this and other macroinvertebrate species found in the vicinity of HMI, and spring recruitment is a poor predictor of late summer abundances.

The proportion of pollution sensitive and pollution indicative species were both higher in Year 28 compared to Year 27, and overall these metrics gave no evidence of an increase in pioneer species that is usually associated with disturbed habitats. The total number of taxa was slightly higher than observed in the previous sampling year. Average infaunal abundance, diversity, PSTA percentages and PITA percentages varied moderately for all stations around the historical means. Nearfield station macroinvertebrate metric scores showed no signs of impairment compared to Reference stations in Year 28. Macroinvertebrate community health as measured by the B-IBI scores, were quite similar to Year 27 B-IBI scores, an encouraging sign after three consecutive years of declining scores prior to Year 27. Compared to Year 27, B-IBI scores stayed the same at seven stations, increased at ten stations, and declined at five stations. B-IBI scores in Year 28 were comparable to historical values. Twenty-one of the twenty-two stations met or exceeded the benchmark criteria of 3.0, and only MDE-27 failed to achieve the benchmark (B-IBI = 2.50). Historically at HMI, B-IBI scores experience regular fluctuation indicating that there is no apparent long-term trend of overall increasing or decreasing benthic invertebrate community health at HMI stations. PITA, PSTA, total taxa, infaunal abundance, and B-IBI were all within range of historic averages, with the exception of PITA and PSTA which were a little below average at Reference and Nearfield stations respectively.

Reference and South Cell stations had the highest mean B-IBI scores among the four station types (Reference B-IBI = 4.1; South Cell B-IBI = 3.7), and Nearfield stations had a comparable score of 3.6. In contrast to the relatively healthy benthic macroinvertebrate communities at these sites, the Back River station mean B-IBI of 3.0 indicated a relatively stressed macroinvertebrate community, particularly at MDE – 27, where impairment from Back

River discharge is consistently measured. MDE-30 is less impacted from the adverse effects of Back River discharge and maintained a healthy macroinvertebrate community in Year 28 (B-IBI = 3.5).

Despite the impairment of the macroinvertebrate community and MDE-27, overall there were no significant differences between the four station types as measured by the Friedman's nonparametric ANOVA test, in either September 2009 or April 2010. The September 2009 cluster analysis clearly identified two distinct multi-station groups, indicating that stations within these groups had some uniqueness in their macroinvertebrate assemblages. The largest group was composed of thirteen stations primarily occurring to the east of HMI (except MDE-30). The second smaller group was composed of four stations located south to southeast of HMI. Of the five identified outlier stations, four (MDE-01, MDE-33, MDE-34, and MDE-36) were located northeast of HMI, while the other outlier, MDE-27 was the impaired Back River station. Neither the two identified station groups nor the four outlier stations northeast of HMI showed any evidence of adverse impacts from HMI operations or from other factors. Only station, MDE-27, had an impaired macroinvertebrate community in Year 28. The measured impairment at this station has shown up consistently during the history of HMI sampling. Lower B-IBI scores apparently occur as a result of unique conditions inherent to the Back River drainage, which include relatively high freshwater influx and historically elevated nutrient and sediment loads.

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APPENDIX 3: ANALYTICAL SERVICES (PROJECT IV)

(September 2009 – August 2010)

Technical Report

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EXECUTIVE SUMMARY

Sampling

For Year 28 exterior monitoring at HMI, CBL collected the clam *Rangia cuneata* both in September 2009 and April 2010. In addition to clams, sediment samples were concurrently collected and analyzed for trace metals 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 2009 around Hart-Miller Island (HMI) by Maryland Geological Survey (MGS). Trace element analysis focuses on those not measured by MGS, specifically total mercury (T-Hg), methylmercury (MeHg), silver (Ag), and metalloids selenium (Se) and arsenic (As).

Trace elements in Sediment

Concentrations of As in the sediment were generally found to be similar to concentration seen in previous years with the exception of sites MDE-38 and MDE-18. Concentrations of samples collected in September 2009 when compared to data collected between 1998 and 2008 exceeded the mean by more than 5 ug g^{-1}. However, concentration of As were similar to concentration found at these same two sites between 1999 and 2001. The concentrations of Se were generally high but fell within the standard deviation of the average of previous years. Higher concentrations of Se were also seen between 1999 and 2001 and again in the fall of 2008 and 2009. Silver was found to have concentrations lower than the mean and median concentrations of previous years.

Concentrations of T-Hg in sediment were generally greater than the running mean of previous years but fell within the standard deviation of measurements made between 1998 and 2008. Concentrations of T-Hg at stations MDE-18, 38, 39, and 44 were much higher than in previous years. However, sediment collected from site MDE-44 (a South Cell station) during the Maryland Department of the Environment (MDE) biota cruises in September 2009 and April 2010 had concentrations of T-Hg less that 100 ng g^{-1} 8 times lower than nearly 800 ng g^{-1} in the sample collected during the MGS cruise. This variation in sediment concentration points to either a large spatial or high temporal variability, and is indicative of the need for repeated sampling at the wide range of sites, thus better characterizing the sediments. Concentrations of MeHg were typical and comparable to other areas of the Chesapeake Bay (Heyes et al. 2006).

Trace Elements in Clam Tissue

In clam samples collected in September 2009 concentrations of As, Se, Cd and Hg were close to the stations respective historic running means, and concentrations of MeHg, Ag and Pb were lower. For those samples collected in April 2010 concentrations of As and MeHg were close to the historical concentrations while Pb, Ag and Cd were equal to, or lower than the historic running means determined from previous years. Clam tissue collected from stations MDE-16 and MDE-19, which are near the dike wall and possibly influenced by effluent from

Spillways 009 and 003 respectively, had elevated levels of Se. However, station MDE-51 which is a new Reference site located beyond the zone of HMI influence had higher levels than all other stations. The high levels seen at MDE-51 would indicate there are other sources of Se; however, given the high levels seen at MDE-16 and 19 close monitoring of the effluent from HMI is imperative.

Total PCB concentrations in sediments and clams

With the exception of MDE-17, total PCB concentrations in sediment samples were similar at all sites when compared to historical data. The total PCB concentration in sediment at site MDE-17 was 2 times higher than the historical average and outside the standard deviation. MDE-17 is located approximately 1 mile southeast of the dike wall and within the zone of HMI influence. However, stations MDE-16, and 19 are located closer to the dike and yet had concentrations below their historical average. Sediment was also collected at MDE-44 which is close to South Cell Spillway 003 but there is no historical data with which to compare; however, concentrations were similar to other sites. Given that these three sites had comparatively low PCB concentrations it is not likely the high concentration seen at MDE-17 is due to HMI operations.

Unlike total PCBs in sediment, concentrations in clams collected in 2009 were on average 2 times higher than the historical running mean for most of the sites. Clams collected from the reference site, MDE-36, also showed the same elevated concentrations when compared to the historical mean concentration. Given the high total PCB concentration found in tissue collected from the reference station MDE-36, located three miles north of HMI, it is likely that the overall elevated concentrations seen in Year 28 at all the sites are due to a source or sources other than operations at HMI.

Total PAH concentrations in sediments and clams

With the exception of MDE-17, total PAH concentrations in sediment samples at all sites were similar to historical data. Total PAH concentration at site MDE-17 was greater than twice the historical mean and outside the standard deviation of the means. The total PCB concentration was also higher at site MDE-17 then previously observed. Concentrations of total PAHs in clams remained near historical levels with the exception being clams from site MDE-17, which appear slightly elevated. The clam concentrations mirror the sediment changes, suggesting a possible local influence. A local influence could not be differentiated from the PCB data, thus the association is weak.

As with PCBs, total PAH concentrations at MDE-16, 19 and 44 (close proximity to South Cell Spillway 003) were comparatively low. MDE-16 was considerably below the historical average, MDE-19 was consistent with the historical average and MDE-44 has no historical data but compared to all stations had the third lowest concentration. Total PAHs concentration at MDE-17, also in proximity to the South Cell but farther away than the former mentioned sites was over twice the historical average. Again, it is unlikely the enrichment of total PAHs at

MDE-17 is due to HMI operations. PAH concentrations in both sediments and clams sampled over the entire region were generally similar to previous years studied, thus it seems unlikely that any activities within the HMI complex have influenced PAH concentrations in sediments and biota.

INTRODUCTION

The goals of the project in 2009-2010 were to continue to measure and evaluate the levels of contaminants in the sediment in the vicinity of Hart-Miller Island (HMI) and to relate these, as far as possible, to historical data. Continued comparison and correlation of this data with historical HMI data, will indicate the extent of contamination, biological exposure and if any trends in concentrations are developing at locations around the island.

Specific objectives for Year 28 were:

In the fall of 2009 and spring of 2010 clams and associated sediment were collected 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 mercury (Hg), monomethylmercury (MeHg), silver (Ag), selenium (Se) and arsenic (As) but also lead (Pb) and cadmium (Cd).

A specific objective for Year 28 was to determine the concentrations of target trace elements in surface sediments around HMI at a larger number of stations collected by the Maryland Geological Survey (MGS) in September 2009 as part of the annual sediment survey. Metal analysis focuses on those metals not measured by MGS, specifically mercury (Hg), monomethylmercury (MeHg), silver (Ag), selenium (Se) and arsenic (As).

Finally, the sediment and clams collected in the fall of 2009 were also analyzed for Polychlorinated Biphenyls (PCB's) and Polycyclic Aromatic Hydrocarbons (PAHs).

The results of the quality assurance (QA/QC) procedures and the description of the analytical and field protocols are contained in the *Year 28 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 28 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 2009. Samples from this survey were collected by MGS personnel for Chesapeake Biological Laboratory (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 2009 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

Methods used for metals analysis are similar to those described in detail in Dalal et al. (1999). A subsample of sediment is placed in acid-cleaned quartz flask for microwave digestion, using Environmental Protection Agency (EPA) Method 3052. The Milestone EOTHO-EZ uses quartz reaction vessels placed inside Teflon flasks, which are sealed during the 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 capped with a loose fitting quartz cap, and placed in the Teflon flask. Five milliliters of 30% Peroxide (H_2O_2) is added to the Teflon sleeve and the sleeve 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 analysis of mercury (1-3 g wet weight) were digested in a solution of 70% sulfuric/30% nitric acid in Teflon vials, heating overnight in an oven at 60^0C (Mason and Lawrence, 1999). The digestate was then diluted to 10 mL with distilled-deionized water. Prior to analysis, the samples were further oxidized for 30 minutes with 2 mL of bromine monochloride solution. The excess oxidant was neutralized with 10% hydroxylamine solution and the concentration of mercury 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 EPA Method 1631 (Mason et al. 1993).

Samples for analysis of MeHg were first distilled by sub-boiling distillation. A 1-2 gram sample of sediment, 1 ml of 50% sulfuric acid solution, 500 ul of 20% potassium chloride solution and 200 ul of a copper sulfate and 20 ml of distilled water were combined in a Teflon reaction vessel that is heated while being purged with nitrogen (Horvat et al. 1993, Bloom 1989). The distillate was captured by condensation. The distillate was then reacted with a sodium tetraethylborate to convert the nonvolatile MeHg to gaseous MeHg. The volatile adduct was purged from solution and recollected on a Tenex column at room temperature. The MeHg was then thermally desorbed from the column and analyzed by cold vapor atomic fluorescence (CVAF). Detection limits for Hg and MeHg were based on three standard deviations of the blank measurement.

A subsample of sediment was used for dry weight determinations. Weighed samples from each site were placed in a VWR Scientific Forced Air Oven at 60^0C overnight. Upon drying, samples were then reweighed and a dry/wet ratio was calculated and applied to the concentrations determined on wet samples.

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 polyaromatic hydrocarbon (PAH) cocktail (d_8-napthalene, d_{10}-fluorene, d_{10}-fluoranthene, d_{12}-perylene) and a noncommercial polychlorinated biphenyl (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

The concentration of As in the sediment collected around HMI in Year 28 (September 2009) are typical of concentrations seen in previous years (Figure 3-1). The concentrations of As are close to the running mean (calculated for the period 1998 to 2008) at the majority of the sampling locations. Sediment at two locations, MDE-38 and MDE-18, exceeded the mean by greater than 5 ug g^{-1}. Station MDE-38, is located at the entrance to Baltimore Harbor, Station MDE-18 is located near the South Cell outflow. Concentrations above the historical trend were observed at both these stations in 2008 but were also at least this high during the 1999-2001 time period.

The concentration of Se in the sediments collected in September of 2009 are generally high when compared to concentrations recorded in previous years. However, the concentrations largely fall within the standard deviation of the average of previous years. In 2008, sediment concentrations were also noted as being high in comparison to the concentrations measured from the more recent collection dates. Se concentrations between the years 1999 and 2001 were high and similar to concentrations observed in the fall of 2008 and 2009. In the years between 2001 and 2008 concentrations of Se were lower creating a bimodal record. In 2009, the concentration of Se in sediment from the reference site (MDE-36) was typical of the previous years, and over time, does not show the same fluctuation as the majority of the other sites. The absolute difference in sediment concentration between samples collected in the fall of 2009 and previous years is small, on the order of 1 to 2 ug g^{-1}; but because Se concentrations in sediment are generally low, the increase represents 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 sediment concentrations and toxicity is not well known. Given the wide spread nature, the fluctuations appear to have little to do with HMI operations. However, the export of Se from HMI through the South Cell outflow has increased and concentrations in water appear high, but without a mass balance calculation, the importance of this source can not be assessed. It is recommended that a mass balance of the Se export needs be conducted in order to assess the potential influence of this source relative to the observed variations in the Se concentrations in sediment.

Concentrations of Ag in the sediment collected in the fall of 2009 were lower than the median and average concentrations collected around HMI in previous years (Figure 3-2). Annual fluctuations in the concentration of Ag in sediment are system wide and appear unrelated to HMI operation.

Concentrations of mercury (T-Hg) in sediment were generally greater than the running mean of previous years but concentrations at most sites fell within the standard deviation of measurements made between 1998 and 2008 (Figure 3-2). 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 (Heyes et al. 2006). Concentrations of T-Hg at the stations; MDE-18, MDE-38, MDE-39 and MDE-44, were much higher than in previous years. MDE-38 and MDE-39 are likely influenced by flow from Baltimore Harbor, but MDE-18 and MDE-44 are close to the South Cell outflow. However, sediment samples were also collected from site MDE-44 on the MDE biota cruises in September 2009 and April 2010. Concentrations in sediments collected on these two dates were less than 100 ng g^{-1}. This variation in sediment concentration points to either a large spatial or high temporal variability. It is far more likely the difference stems from a high spatial variability in sediment concentrations at the site. Such results underscore the importance of repeated sampling at the wide range of sites in order to get the best over understanding of the system.

Concentrations of MeHg in sediment collected in September 2009 ranged from 0.02 to 1.28 ng g^{-1} dry weight (Figure 3-3). These concentrations are comparable to the rest of the Chesapeake Bay (Heyes et al. 2006). The percent of mercury that occurred as MeHg was less than 1%. Despite the sediment having slightly higher than average Hg concentrations, it appears to have not influenced the accumulation of MeHg in the sediment.

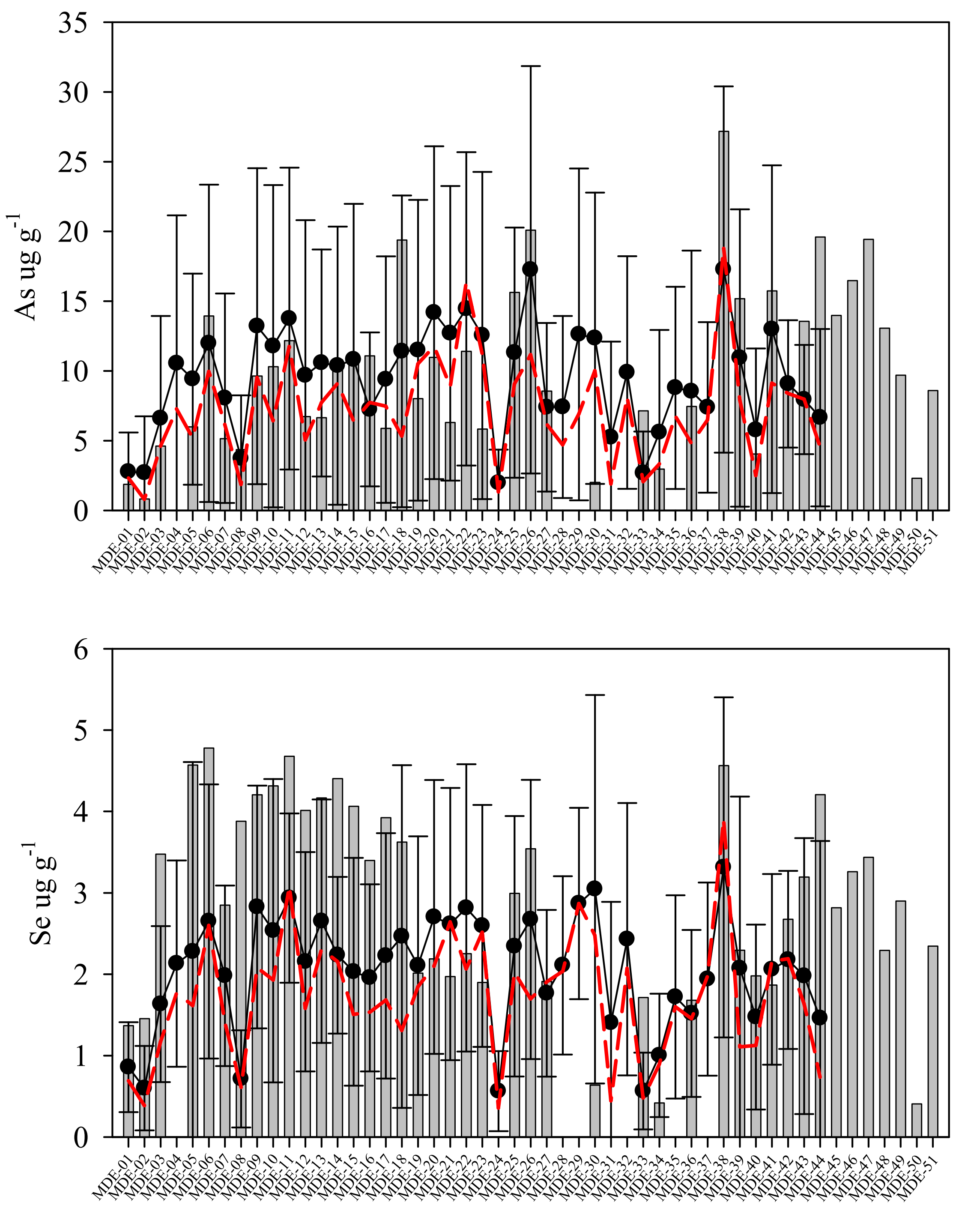
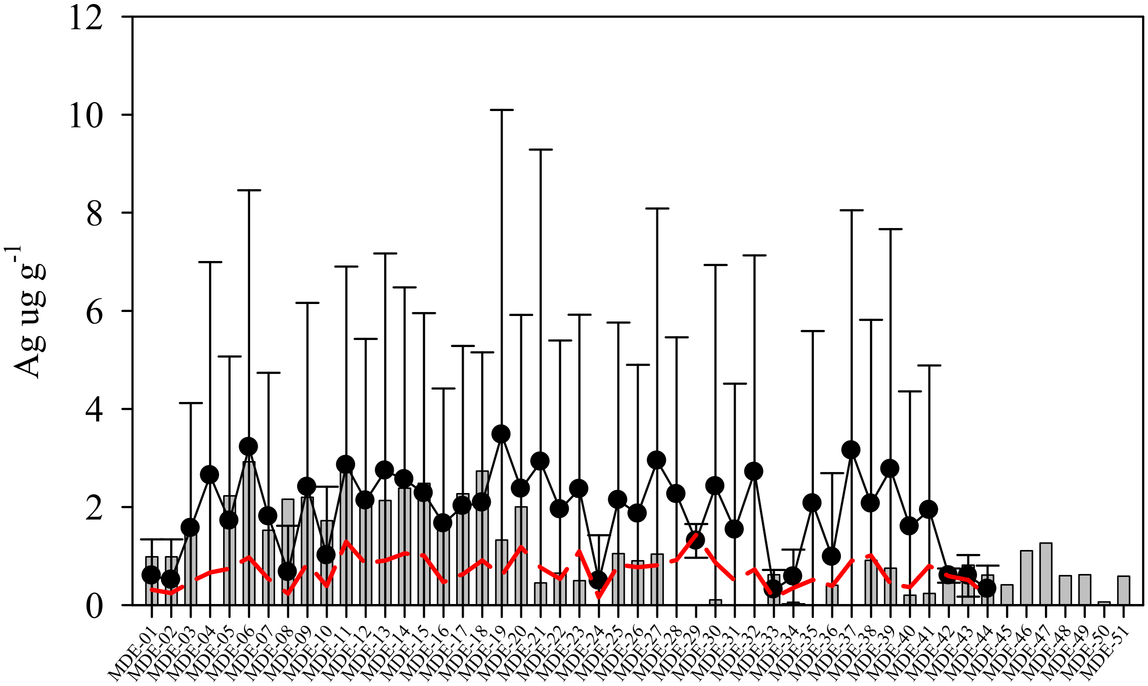


Figure 3-1. As and Se in sediment, expressed as dry weight concentration, collected by MGS in September 2009 (bars) and the 1998-2008 mean (circles) with standard deviation (error bars) and the 1998-2008 median (dashed line).



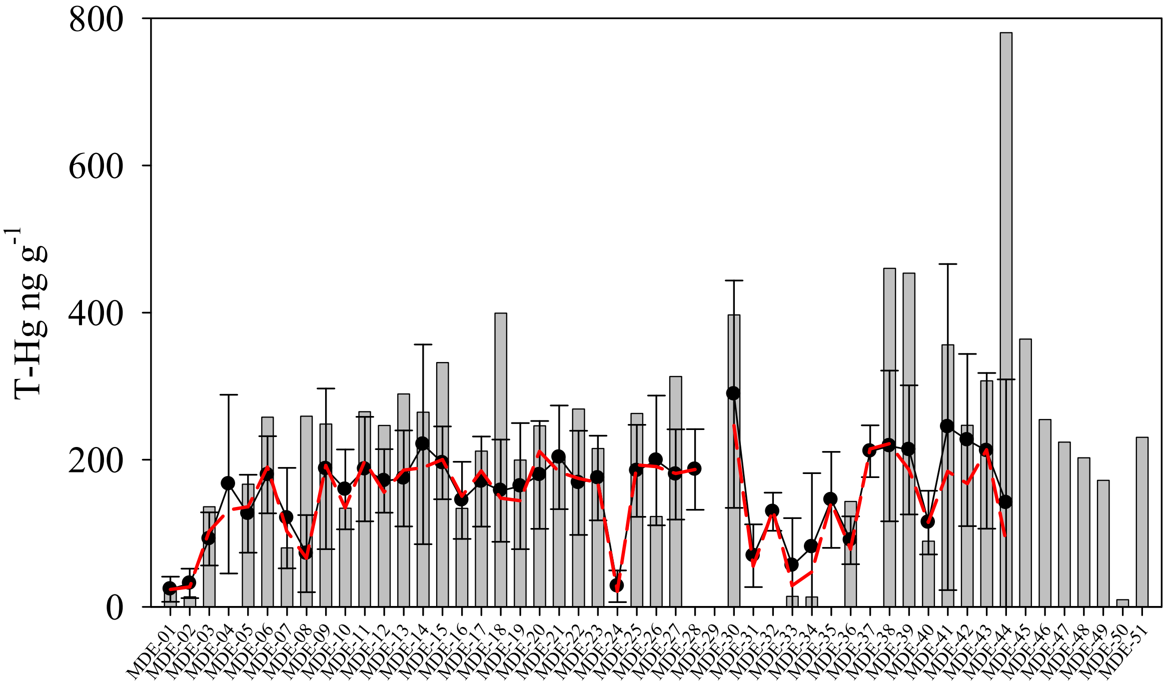


Figure 3-2. Ag and T-Hg concentrations in sediment, expressed as dry weight concentration, collected by MGS in September 2009 (bars) and the 1998-2008 mean (circles) with standard deviation (error bars) and the 1998-2008 median (dashed line).

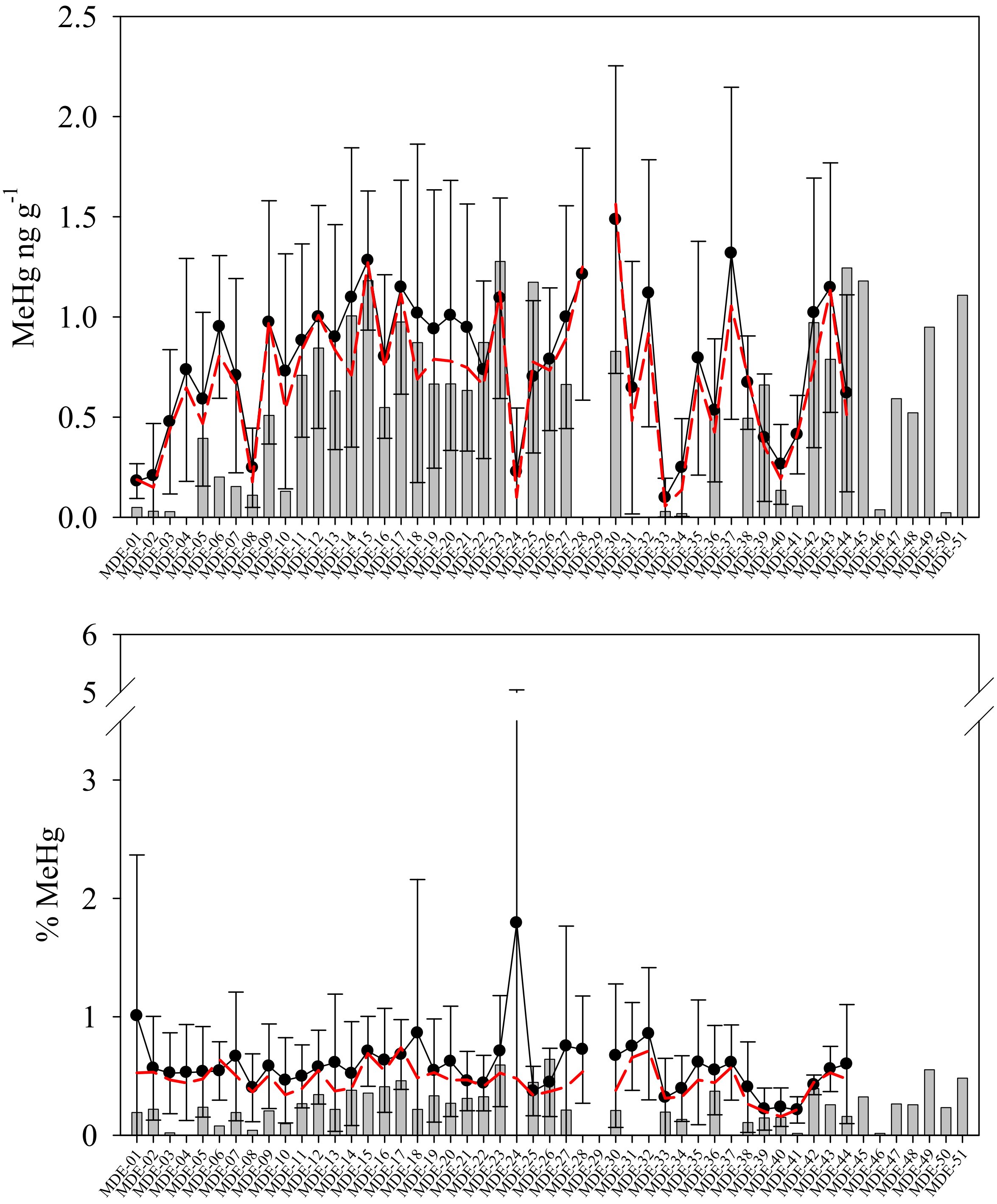


Figure 3-3. MeHg, expressed as dry weight concentrations, and percent of T-Hg as MeHg in sediment collected by MGS in September 2009 (bars), and the 1998-2008 mean (circles), with standard deviation (error bars), and the 1998-2008 median (dashed line).

Trace element Concentrations in Sediments Located Near the South Cell Outflow

Sites MDE-16 through 21, MDE-23, and MDE-42 through 44 are located in the vicinity of the South Cell outflow. These sites are the most likely to be impacted by any contaminants that might be released in discharges from the South Cell. Overall in 2009, concentrations of the measured elements do not appear different at the majority of the sites near the South Cell when compared to other HMI sites (Table 3-1). Two exceptions were sites MDE-18 and MDE-44, where measured concentrations of As and Hg were higher than historical concentrations. The concentrations were also higher than the average of all the South Cell and HMI sites (Table 3-1). Fortuitous sampling of site MDE-44 a few days later as part of the MDE biota cruises suggest these samples might be anomalous and reflect sediment variability. Concentrations of As in the sediment from MDE-44 collected during the September MGS cruise yielded As concentration of 19.6 ug g^{-1} but sediment collected on the MDE cruise yielded a concentration of 1.59 ug g^{-1}. When MDE-44 was sampled again in April 2010, a concentration of 16.92 ug g^{-1} was measured. Concentrations of Hg in sediment collected from the September and April MDE cruises were 56.73 ng g^{-1} and 46.46 ng g^{-1}, respectively, and thus an order of magnitude lower than concentration of 780.48 ng g^{-1} determined for the sediment collected by MGS (Table 3-1). Such variability in trace element concentrations in sediment underscores the need for the dense spatial and temporal sampling of the program. The operation of the South Cell does not appear to have measurably influenced sediment concentrations.

Table 3-1. Sediment concentrations of As, Se, Ag, T-Hg and MeHg on a dry weight basis collected in September 2009. The average of the sites near the South Cell outflow and average of all sites around HMI is given. Reference sites are highlighted in green.

Station	As ug/g	Se ug/g	Ag ug/g	Hg ng/g	MeHg ng/g
MDE-16	11.08	3.40	1.60	133.90	0.55
MDE-17	5.89	3.92	2.27	211.87	0.97
MDE-18	19.39	3.62	2.73	399.25	0.87
MDE-19	8.02	2.01	1.33	199.50	0.66
MDE-20	10.97	2.19	2.00	245.99	0.67
MDE-21	6.30	1.97	0.45	203.73	0.63
MDE-23	5.83	1.90	0.50	215.27	1.28
MDE-42	9.31	2.68	0.58	246.82	0.97
MDE-43	13.55	3.19	0.81	307.09	0.79
MDE-44	19.60	4.21	0.61	780.48	1.24
MDE-36	7.45	1.68	0.40	143.17	0.53
MDE-50	2.31	0.41	0.06	9.68	0.02
MDE-51	8.59	2.35	0.59	230.36	1.11
SC avg	10.99	2.91	1.29	294.39	0.86
HMI avg	10.18	3.02	1.27	223.63	0.51

Metals in Clams

The clam *Rangia* was collected from 14 stations in September 2009 and April 2010. In the September 2009 these sites were MDE-1, 7, 9, 11, 15, 16, 17, 19, 27, 30, 34, 36, 44, 51. Concentrations of As, Se, Ag, Cd, Pb, Hg and MeHg measured in clams collected 2009 displayed some variations from previous years (Figure 3-4 and Figure 3-5). Clam concentrations of As, Se, Cd and Hg were close to the running mean at each station, whereas concentrations of MeHg, Ag and Pb were lower than the running mean. Five new sampling locations were 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. 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 fell in line with concentrations found in clams of the other sites. Concentrations of all trace elements in clams collected from site MDE-51 were similar to clam concentrations from the long term reference site MDE-36.

Sites from which clams were sampled in April 2010 were MDE-3, 7, 9, 11, 13, 16, 19, 30, 33, 34, 36, 43, 44, and 51. In April 2010, concentrations of As and MeHg in clams were close to the historical concentrations and concentrations of Pb, Ag and Cd in clams were equal to, or lower than, the running mean based on previous years samplings. However, Se and Hg were elevated beyond the standard deviation around the historical mean clam concentrations at some sites. The elevated concentrations were never more than double the historical mean.

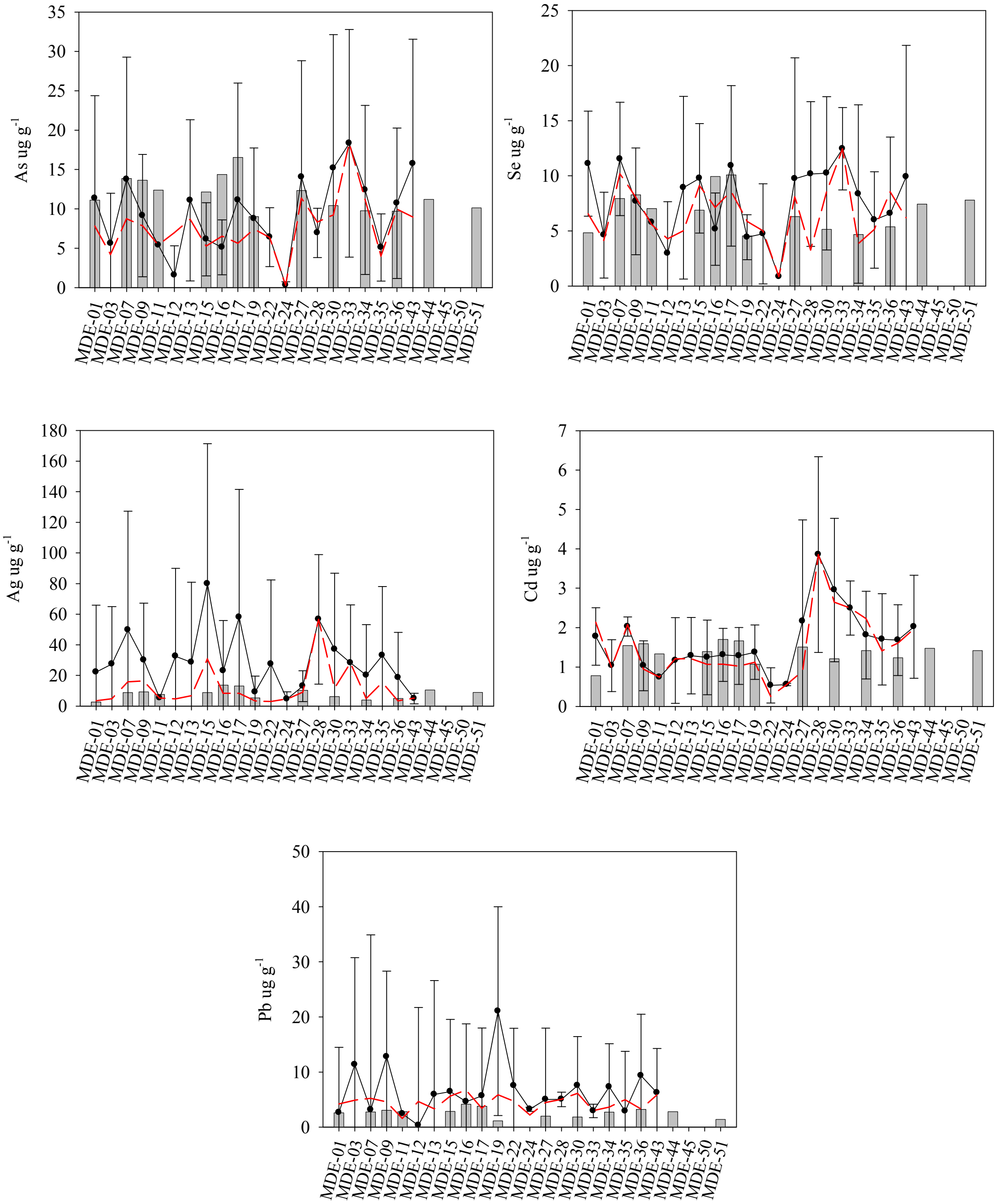


Figure 3-4. Concentrations of Pb, Cd, As, Se, Ag in clams collected in September 2009. Concentrations (bars) are dry weight based and the 1998-2008 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2008 median (dashed line).

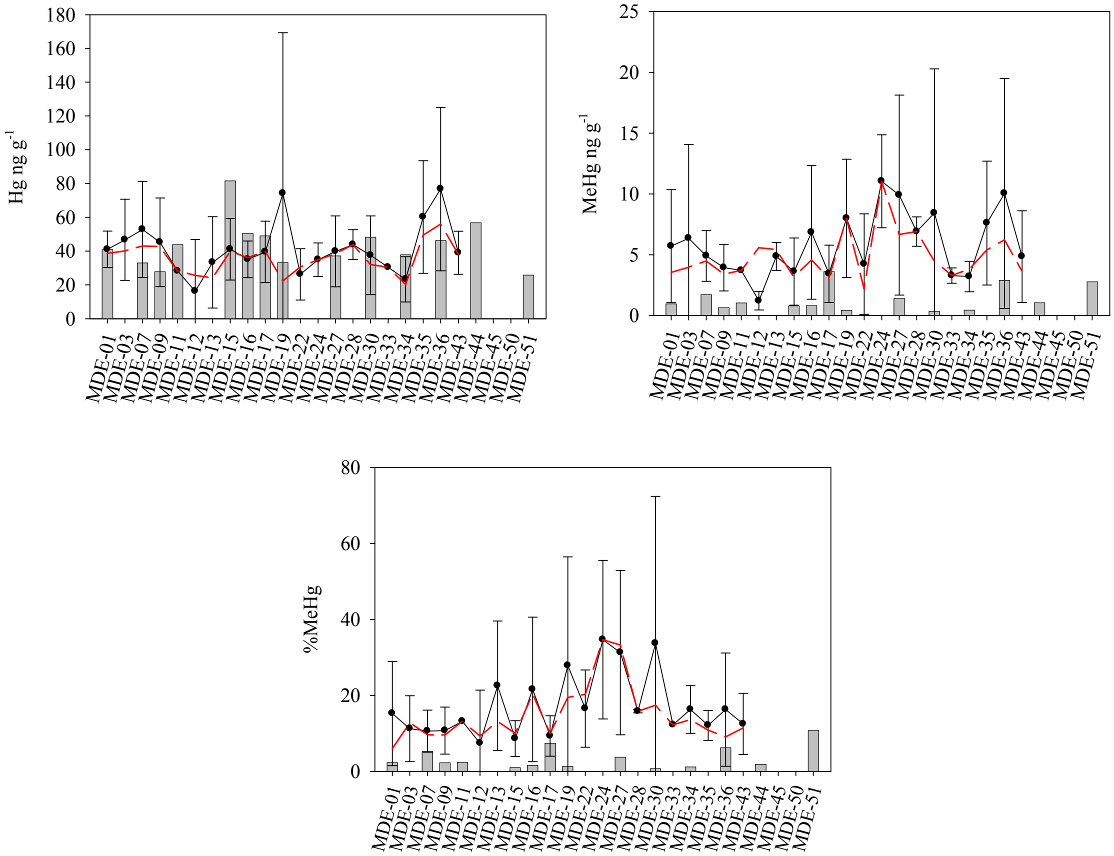


Figure 3-5. Mercury (Hg) and methylmercury (MeHg) concentrations, expressed on a dry weight basis, and percent of Hg that is MeHg in clams, collected in September 2009 (bars) and the 1998-2008 mean (circles) with standard deviation (error bars) and the 1998-2008 median (dashed line).

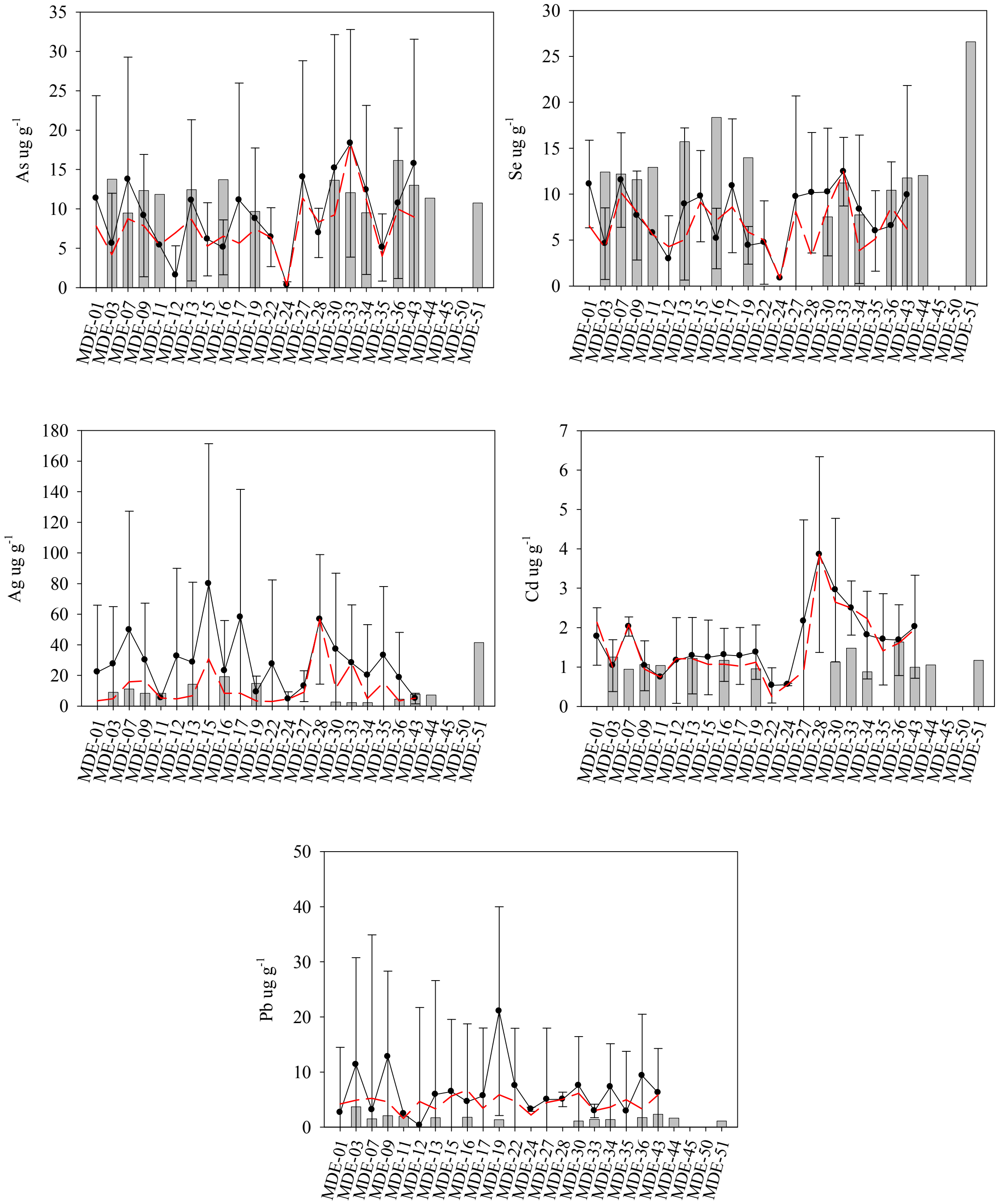


Figure 3-6. Concentrations of Pb, Cd, As, Se, Ag in clams collected in April 2010. Concentrations (bars) are dry weight based, and the 1998-2008 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2008 median (dashed line).

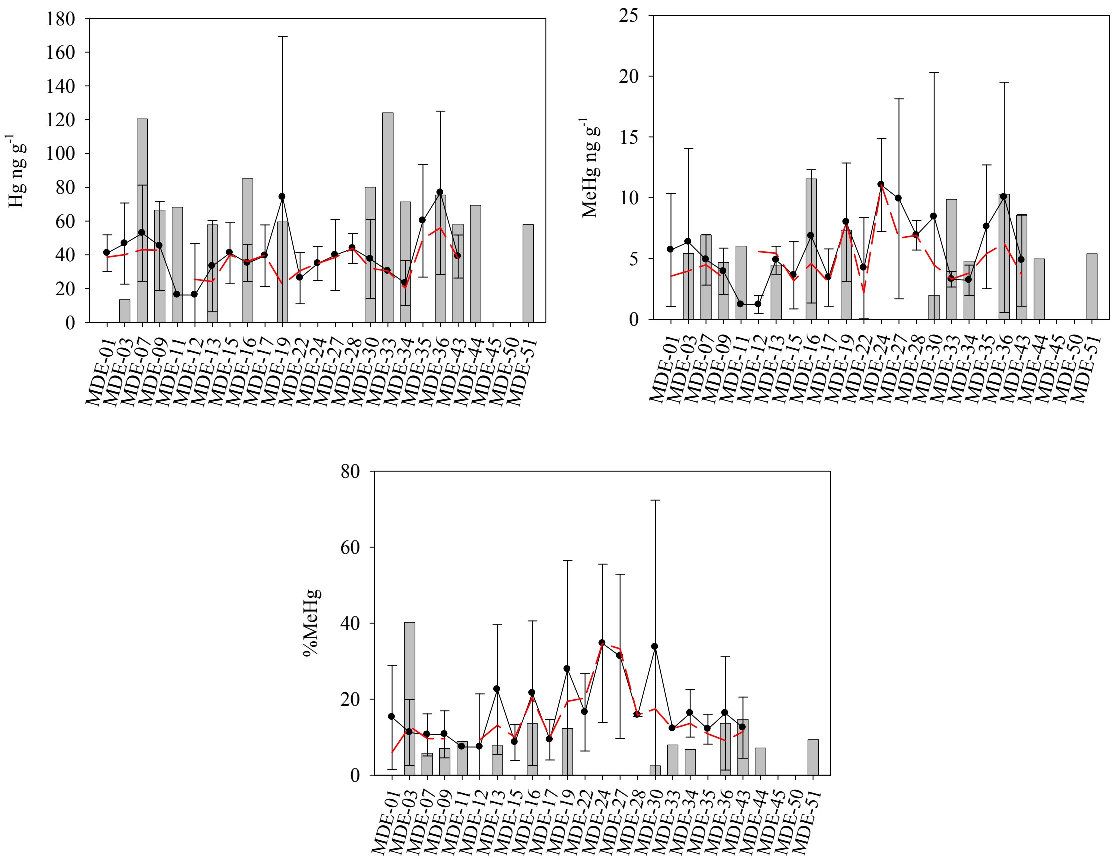


Figure 3-7. Mercury (Hg) and methylmercury (MeHg) concentrations, expressed on a dry weight basis, and percent of Hg that is MeHg in clams, collected in April 2010 (bars) and the 1998-2008 mean (circles) with standard deviation (error bars) and the 1998-2008 median (dashed line).

Clam Collections from Sites Located near the South Cell Outflow

Clams were collected at 4 stations considered within the zone of the potential influence of the South Cell outflow in September 2009 and at 4 stations in April 2010 (Table 3-2). From both these sampling dates, the trace element concentrations in clams were not considered to be different than the average concentrations determined for the other HMI stations (denoted as HMI avg) as the South Cell element concentrations fell within the HMI standard deviation. The exception to this general observation were the higher concentrations of Ag at sites 16 and 17 in September 2009 and at sites 16 and 19, in April 2010. While these concentrations are higher than the HMI average for 2009, the concentrations were below the historical averages of the stations concentrations (Figure 3-4 and Figure 3-6) and thus most likely the result of natural variability at the site.

Table 3-2. Trace metal concentrations in clams collected at stations located near the South Cell outflow in September 2009 and April 2010. The average element concentrations in clams collected from the other HMI stations sampled on the same date are listed as the HMI avg.

a) September 2009

	As ug/g	Se ug/g	Ag ug/g	Cd ug/g	Pb ug/g	T-Hg ng/g	MeHg ng/g
MDE-16	14.38	9.94	13.66	1.70	4.17	50.42	0.81
MDE-17	16.55	10.08	13.08	1.67	3.78	49.00	3.61
MDE-19	9.03	4.55	5.35	1.07	1.15	33.15	0.42
MDE-44	11.21	7.43	10.50	1.48	2.81	56.73	1.04
SC avg	12.79	8.00	10.65	1.48	2.98	47.32	1.47
HMI avg	11.96	6.38	7.19	1.35	2.57	43.75	0.91

b) April 2010

	As ug/g	Se ug/g	Ag ug/g	Cd ug/g	Pb ug/g	T-Hg ng/g	MeHg ng/g
MDE-16	13.71	18.36	19.19	1.17	1.80	85.12	11.54
MDE-19	9.68	13.97	14.80	0.95	1.35	59.57	7.31
MDE-43	13.02	11.77	7.68	0.99	2.33	58.19	8.54
MDE-44	11.37	12.03	7.22	1.05	1.64	69.39	4.95
SC avg	11.94	14.03	12.22	1.04	1.78	68.07	8.09
HMI avg	12.36	11.30	6.98	1.18	1.83	75.28	6.04

Bioaccumulation Factors

The bioaccumulation factors (BAFs) were calculated for the trace elements Cd, Pb, As, Ag, Se, Hg and MeHg (Figure 3-8) using clam concentrations in Figure 3-4 and Figure 3-7) and sediment concentrations presented in Table 3-3. 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 2009 and April 2010, the BAFs for Pb (not shown) were less than one for all sites, indicating there was no bioaccumulation of Pb by the clams. BAFs of less than 1 for Pb have been occurring for the duration of the study.

In both September 2009 and April 2010, little bioaccumulation of As, Cd, Hg and Se by the clams was observed (BAFs typically less than 10, Figure 3-8). Moderate bioaccumulation of Ag and MeHg was generally observed as BAFs were on the order of 10. High MeHg BAFs were calculated for site MDE-27 in September 2009 (Figure 3-8) and MDE-16, 33 and 44 in April 2010 (Figure 3-9). These high values are the result of very low MeHg concentrations in sediment which skew the BAFs, and not the result of high concentrations in clam tissue in the presence of average sediment concentrations. High BAFs were also calculated for Ag at sites MDE-16 and MDE-51 in April 2010. While the high BAF at site MDE-16 can be explained by the very low concentration of Ag in the sediment, this is not the case for site MDE-51, where the elevated BAF is driven by the concentration in clams (Figure 3-6). Site MDE-51 is a highly organic reference site well outside the influence of HMI but could be indicative of depositional environments where contaminants can accumulate. Thus this site is a good barometer of the region. The site MDE-33 seems somewhat anomalous for all trace elements in the spring of 2010. The calculated BAF's are high because the trace element concentrations in sediment are all low, and not because the trace element concentrations in clams are high. The low trace element concentrations in the sediment at this site are likely driven by the site having the lowest percent organic matter (OM) of all the HMI sites (0.5%). Many trace elements are sequestered by organic matter, thus trace element concentrations are often correlated with percent OM.

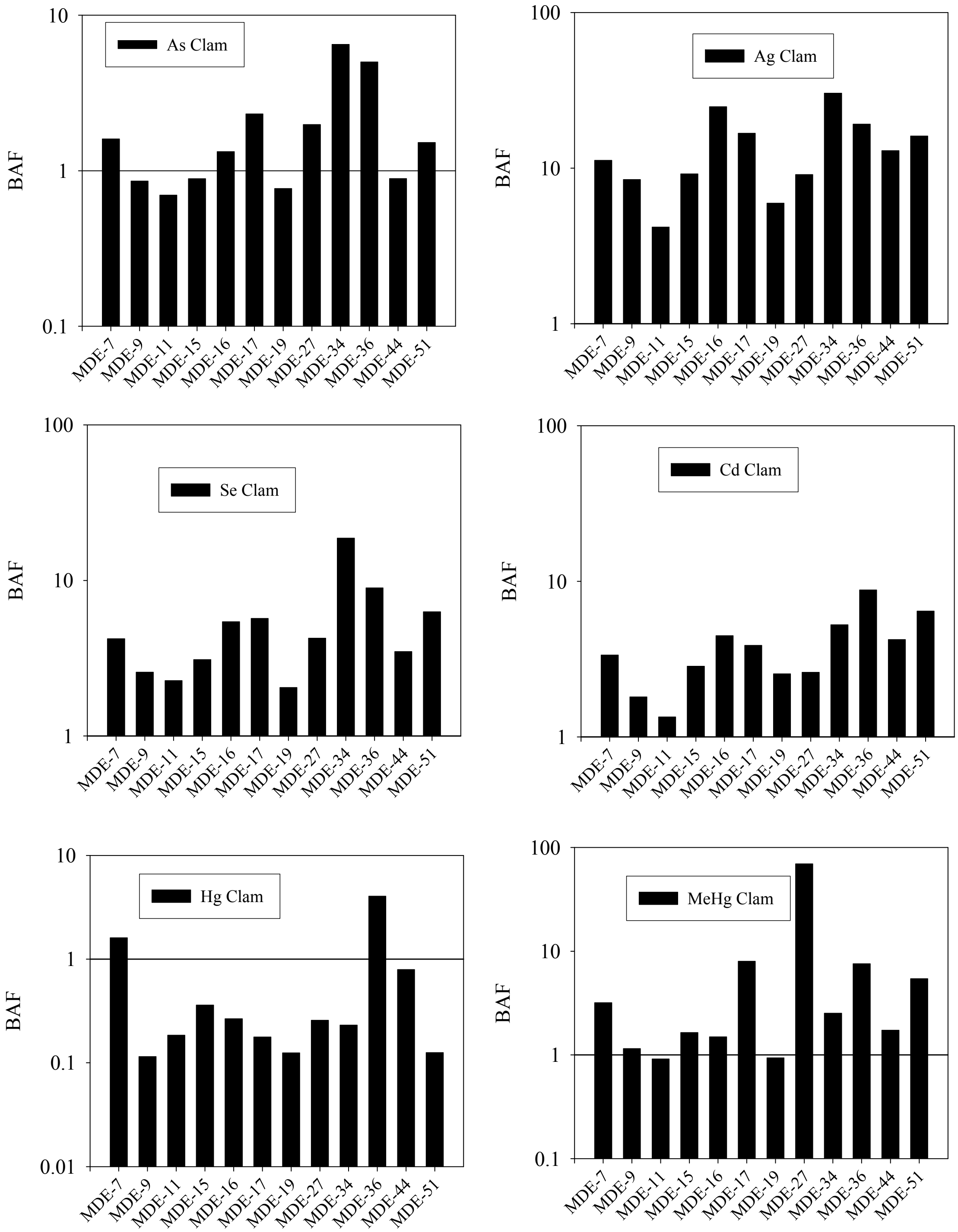


Figure 3-8. Bioaccumulation factors for the metals As, Ag, Se, Cd, Hg and MeHg September 2009.

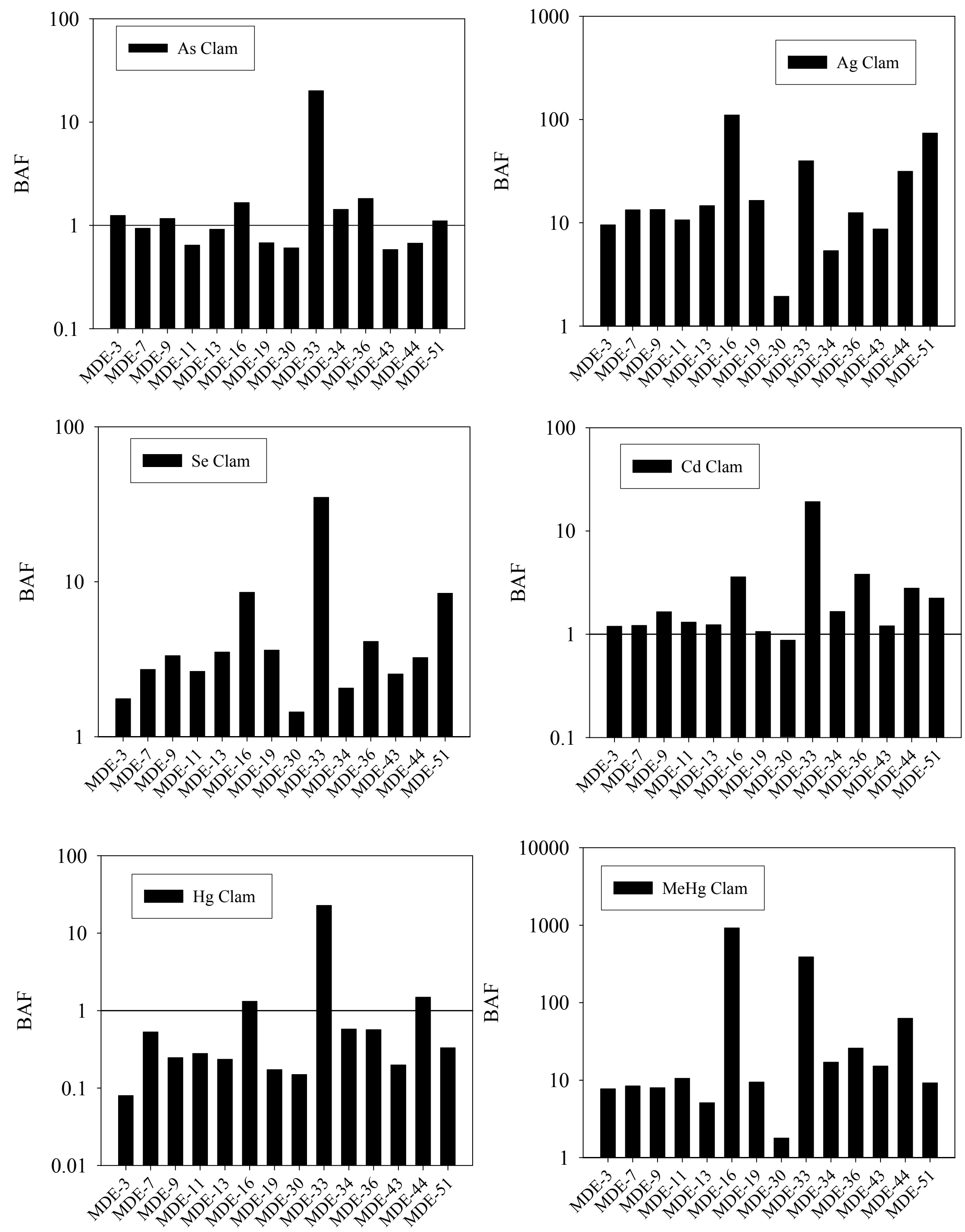


Figure 3-9. Bioaccumulation factors for the metals As, Ag, Se, Cd, Hg and MeHg April 2010.

Table 3-3. Trace element concentrations in sediment (dry weight) collected along with clams by CBL and MDE in September 2009 and April 2010. These samples are not the same as described in the previous sections.

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-7	8.66	1.88	0.78	0.46	45.20	20.47	0.54
MDE-9	15.92	3.22	1.10	0.88	73.41	241.71	0.55
MDE-11	17.80	3.09	1.82	0.99	74.19	236.31	1.12
MDE-15	13.67	2.22	0.96	0.49	56.74	225.66	0.48
MDE-16	10.84	1.83	0.55	0.38	38.67	188.84	0.54
MDE-17	7.14	1.77	0.78	0.43	44.29	275.88	0.45
MDE-19	11.75	2.22	0.90	0.42	53.31	265.34	0.45
MDE-27	6.22	1.48	1.13	0.58	50.95	144.13	0.02
MDE-34	1.51	0.25	0.13	0.27	13.08	163.28	0.17
MDE-36	1.94	0.60	0.26	0.14	14.86	11.41	0.38
MDE-44	12.59	2.13	0.81	0.35	52.53	71.37	0.60
MDE-51	6.68	1.24	0.55	0.22	33.55	205.45	0.51

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-3	11.02	7.06	0.94	1.04	88.99	167.76	0.70
MDE-7	10.10	4.49	0.83	0.78	64.44	227.68	0.82
MDE-9	10.59	3.47	0.62	0.64	62.17	268.98	0.58
MDE-11	18.44	4.90	0.79	0.79	85.87	244.47	0.57
MDE-13	13.57	4.47	0.97	0.98	73.40	245.78	0.87
MDE-16	8.24	2.15	0.17	0.32	30.79	64.63	<0.02
MDE-19	14.26	3.86	0.90	0.90	87.19	344.13	0.77
MDE-30	22.54	5.21	1.39	1.29	134.99	536.28	1.10
MDE-33	<0.6	0.32	0.06	0.08	5.83	5.45	0.03
MDE-34	6.65	3.76	0.43	0.53	44.82	123.50	0.28
MDE-36	8.87	2.53	0.36	0.43	37.89	133.15	0.40
MDE-43	22.31	4.64	0.88	0.82	103.71	293.01	0.56
MDE-44	16.92	3.71	0.23	0.38	38.29	46.46	0.08
MDE-50	2.87	0.62	0.05	0.18	10.57	9.16	0.69
MDE-51	9.73	3.16	0.56	0.52	51.03	174.83	0.59

Investigating Potential Metal Toxicity

For some trace metals, toxicological affects criteria or guidelines have been established by the National Oceanic and Atmospheric Agency (NOAA). These guidelines have been used for available elements as a frame of reference for the overall condition of the sediment around HMI. The Probable Effects Level (PEL) has been plotted along with the concentrations in sediments collected by MGS (Figures 3-10 and 3-11). For the metal As, sediment concentrations were well below the PEL (Figure 3-10). For Hg, sediment concentrations were also below the PEL with the exception of MDE-44 (Figure 3-11). Site MDE-44 is a new site located near the South Cell outflow for which we have gathered little historical data to date. As discussed previously, site MDE-44 was sampled twice in September of 2009 and once in April 2010. The T-Hg concentration determined on sediment collected from the September 2009 MGS survey was 780.48 ng g^{-1} but the concentration was only 71.37 ng g^{-1} for the sediment collected on the 2009 September MDE cruise and 46.46 ng g^{-1} for sediment collected in April 2010. This would indicate either a very transient condition exists at the site, with sediment being deposited and eroded frequently, or there is wide spatial variability in sediment composition within this site leading to the occasional low and high concentration.

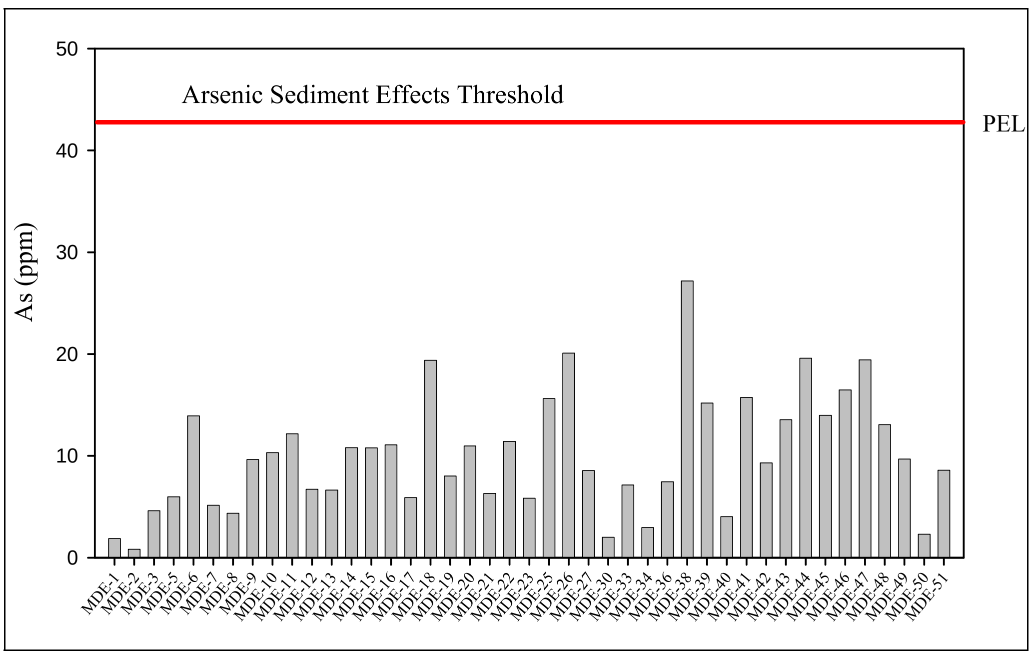


Figure 3-10. Arsenic concentrations in sediment along with the PEL as identified by NOAA for marine sediment.

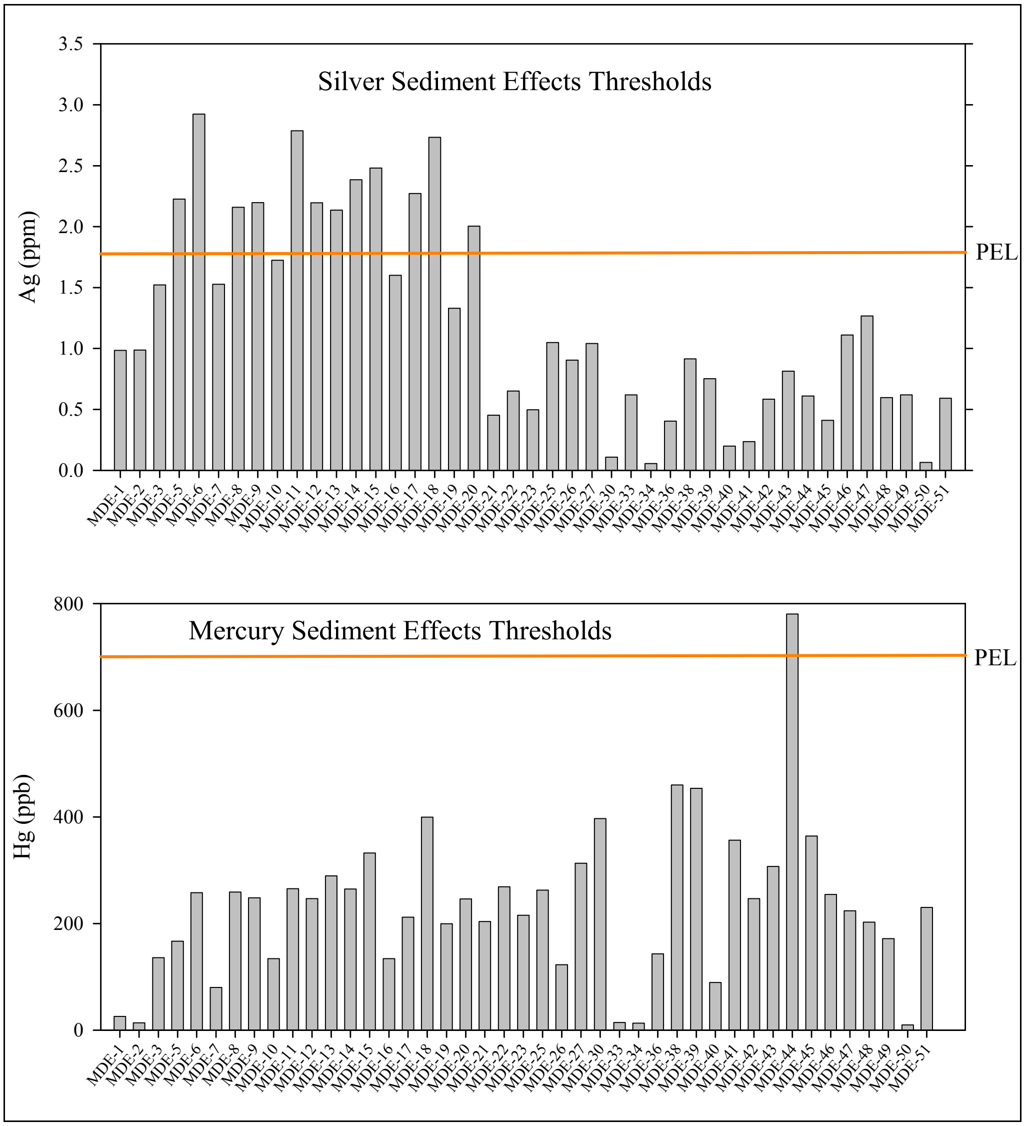


Figure 3-11. Mercury and silver concentrations in sediment along with PEL as identified by NOAA for marine sediment.

In the case of Ag, the PEL of 1.77 ppm was exceeded at a number of sites (Figure 3-11). These sites included MDE-5, 6, 8, 9, 11-15, 17, 18, and 20. These sites cover a wide area on the south side of the island including some that are within the influence of the South Cell outflow. However, such concentrations have regularly been seen around HMI and at almost all the sites under investigation at sometime in the past. Thus, while the concentrations have the potential to influence biota, the concentrations are not anomalous for the area. No PEL has been established for Se as the data used to create this form of screening criteria is very limited for this element.

PCBs in Sediment

The PCBs analyzed for in sediments sampled in September of 2009 are given in Table 3-4, and concentrations are summarized in Figure 3-12 a-n. These figures provide a “signature” from which to investigate trends within and among sites. The sediments collected in 2009 contain high concentrations of the PCB congeners 5, 31+28, 66+95, 132+153+105, 180, 208+195, 206 and 209. High concentrations of these congeners are common and occur in most of the previous years. This can be seen in the plotted running means and medians for each of the sites. In general, concentrations of many PCB congeners were consistent with the mean of previous years. Sites MDE-7 and 17 appear elevated in many congeners compared to the previous years of samples and have similar profiles and congener concentrations as was found at the reference site MDE-51. Site MDE-17 has not been sampled for PCB’s since 2004 so the historical data set is limited. The reference sites, MDE-36 and 50 have few congeners above the detection limits and have very low total PCB concentrations. This is in contrast to MDE-51 which has a congener profile and individual congener concentrations like many of the sites around the HMI complex. Reference sites MDE-50 and 51 are relatively close together but have very different substrates, with MDE 51 being highly organic in nature. In my opinion, having reference sites with different sedimentary substrates is helpful as together they better reflect the different sedimentary environments outside the influence of the HMI facility. 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 3-4. Polychlorinated biphenyl congeners given in the same order as presented in Figure 3-12 a-k (left to right).

Polychlorinated Biphenyl Congeners							
1	cong-1	22	cong-52	43	cong-136	64	cong-177
2	cong-3	23	cong-49	44	cong-77,110	65	cong-202,171,156
3	cong-4,10	24	cong-48,47	45	cong-151	66	cong-157
4	cong-7,9	25	cong-44	46	cong-134,144	67	cong-172,197
5	cong-6	26	cong-37,42	47	cong-107	68	cong-180
6	cong-8,5	27	cong-41,64,71	48	cong-123,149	69	cong-193
7	cong-19	28	cong-40	49	cong-118	70	cong-191
8	cong-12,13	29	cong-100	50	cong-134	71	cong-199
9	cong-18	30	cong-63	51	cong-114	72	cong-170,190
10	cong-17	31	cong-74	52	cong-146	73	cong-198
11	cong-24	32	cong-70,76	53	cong-132,153,105	74	cong-201
12	cong-16,32	33	cong-66,95	54	cong-141	75	cong-203,196
13	cong-29	34	cong-91	55	cong-137,130,176	76	cong-189
14	cong-26	35	cong-56,60	56	cong-163,138	77	cong-208,195
15	cong-25	36	cong-89	57	cong-158	78	cong-207
16	cong-31,28	37	cong-101	58	cong-129,178	79	cong-194
17	cong-33,21,53	38	cong-99	59	cong-187,182	80	cong-205
18	cong-51	39	cong-119	60	cong-183	81	cong-206
19	cong-22	40	cong-83	61	cong-128,167	82	cong-209
20	cong-45	41	cong-97	62	cong-185		
21	cong-46	42	cong-81,87	63	cong-174		

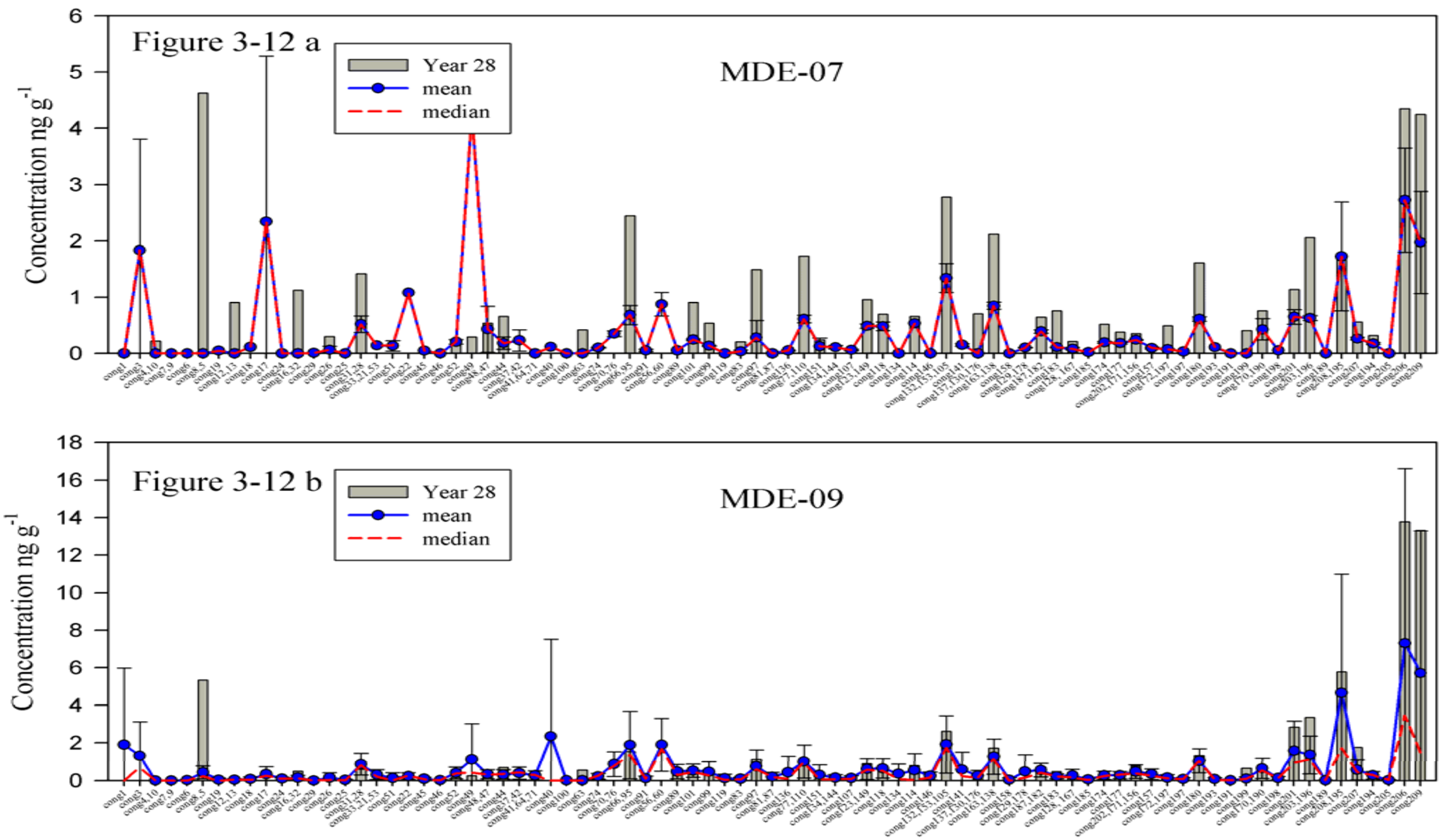


Figure 3-12. Concentrations of PCB congeners in sediments from sites MDE-07 and MDE-09 from September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line) expressed in ng g^{-1} dry weight.

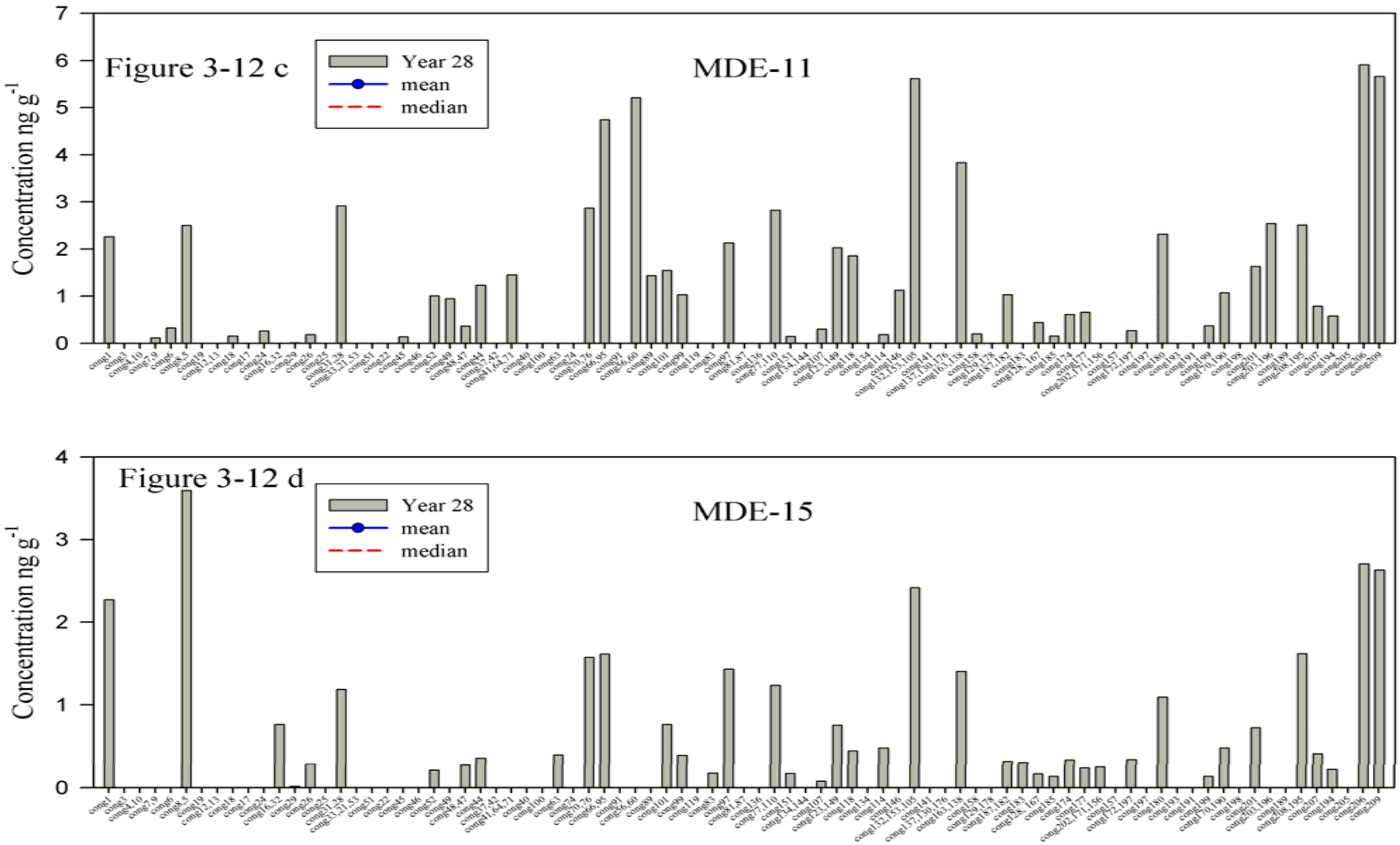
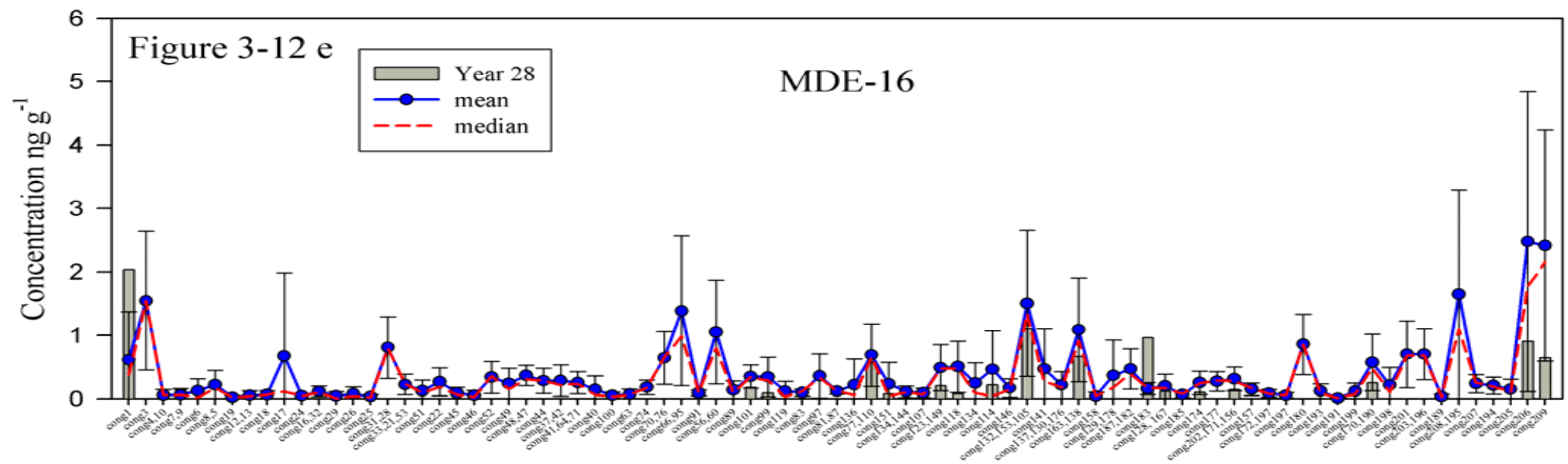


Figure 3-12 continued. Concentrations of PCB congeners in sediments from sites MDE-11 and MDE-15 from September 2009 expressed in ng g^{-1} dry weight. MDE-11 and 15 are newly established sites and thus do not have historical data with which to calculate the mean, median and standard deviation.



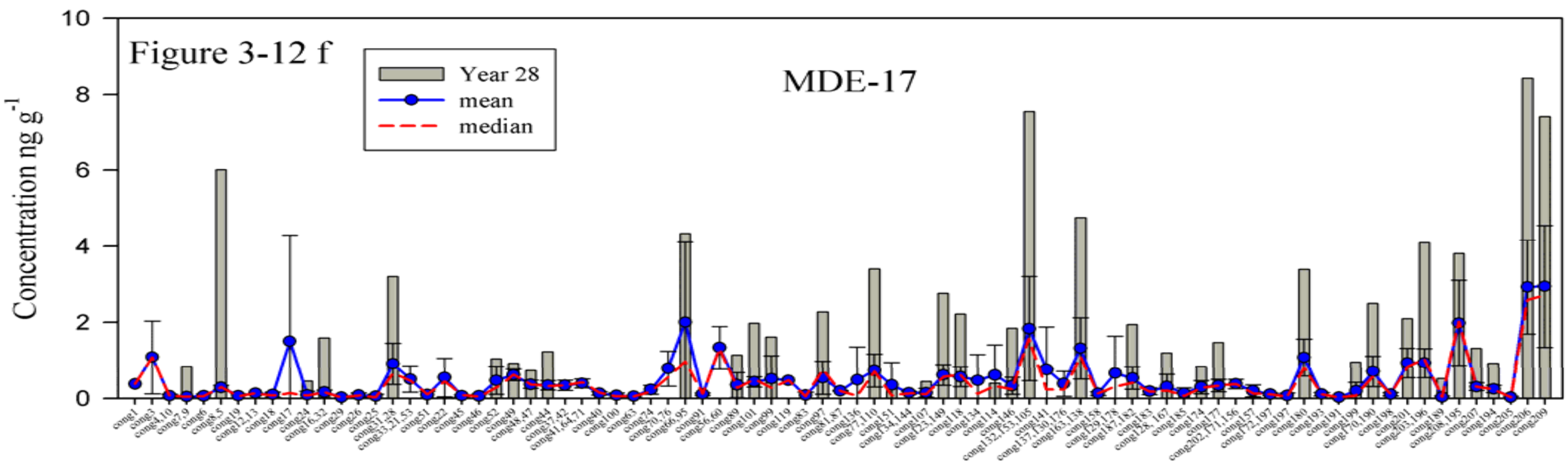
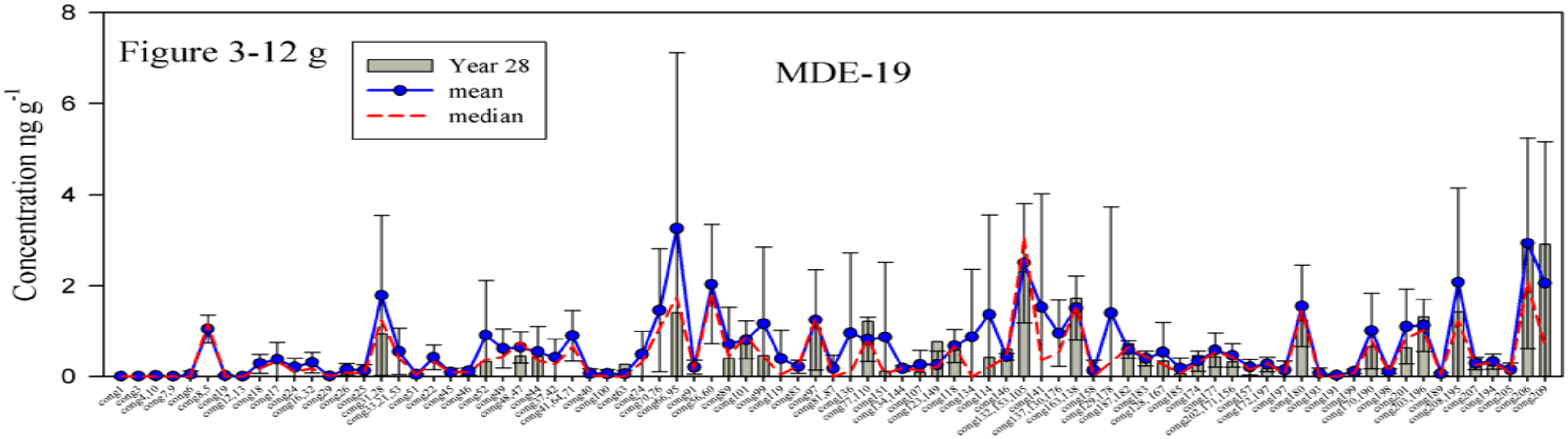


Figure 3-12 continued. Concentrations of PCB congeners in sediments from sites MDE-16 and MDE-17 from September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line) expressed in ng g^{-1} dry weight.



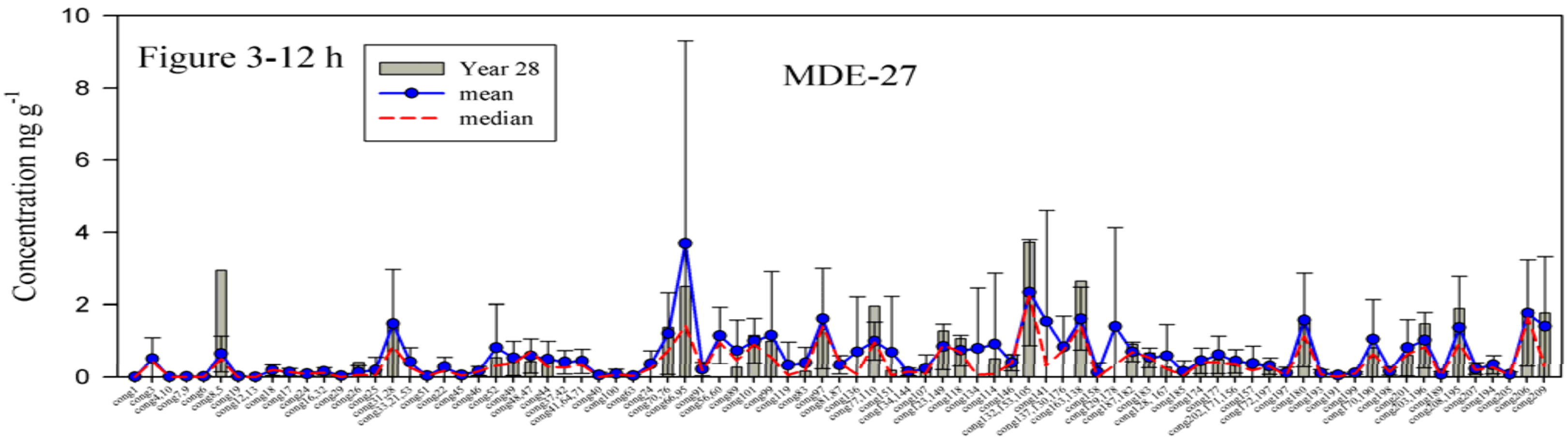


Figure 3-12 continued. Concentrations of PCB congeners in sediments from sites MDE-19 and MDE-27 from September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line) expressed in ng g^{-1} dry weight.

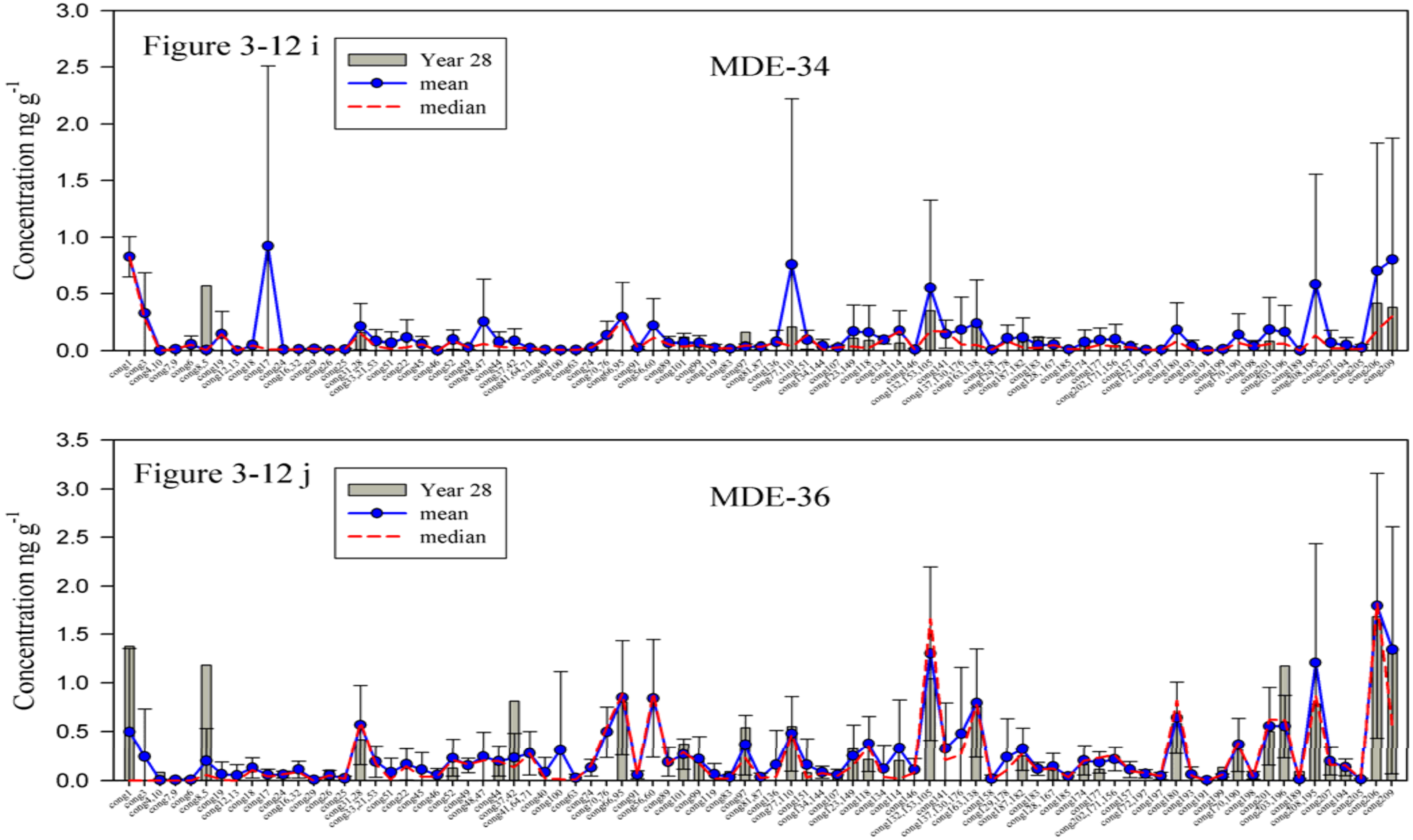


Figure 3-12 continued. Concentrations of PCB congeners in sediments from sites MDE-34 and MDE-36 from September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line) expressed in ng g^{-1} dry weight.

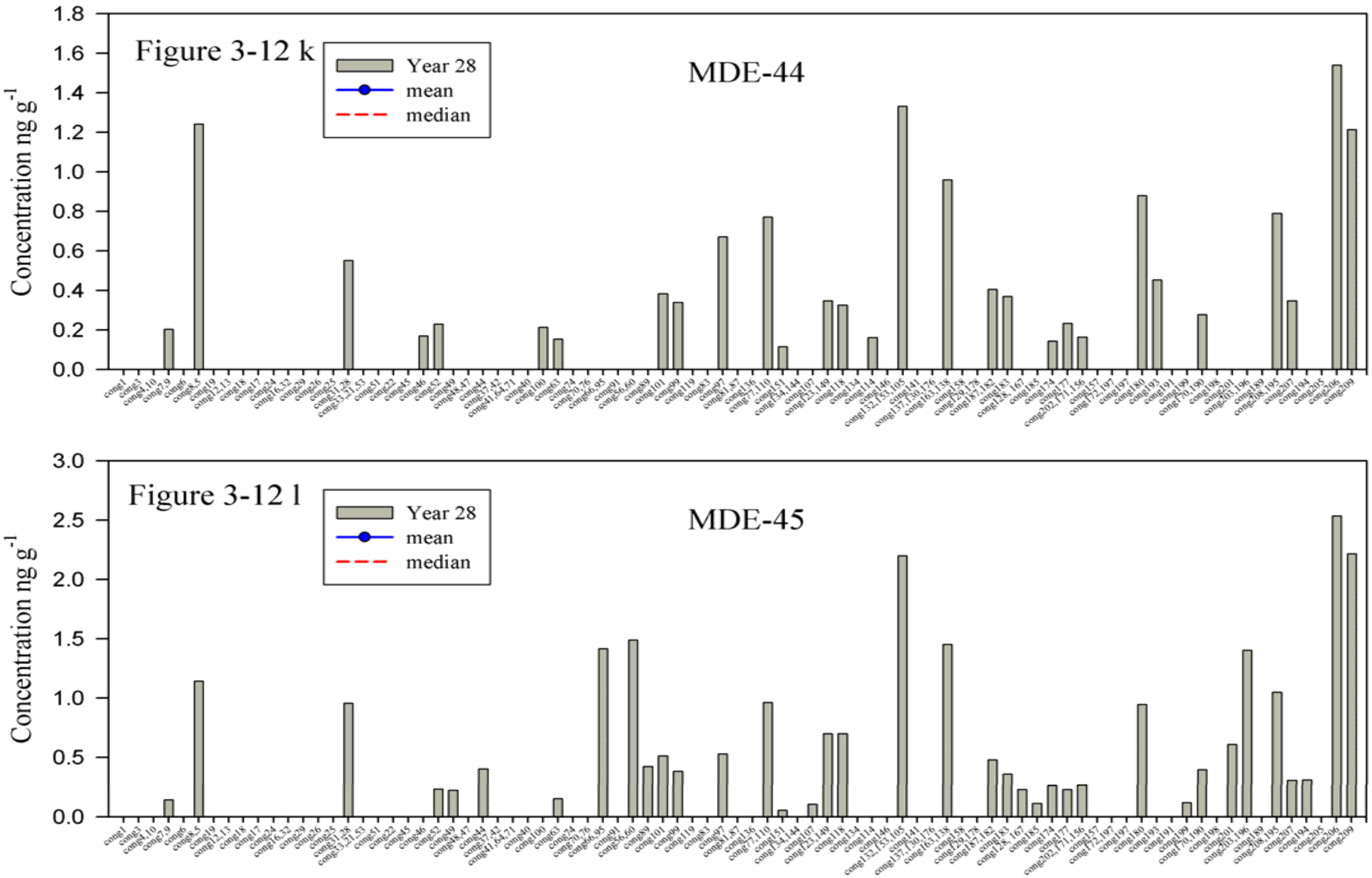


Figure 3-12 continued. Concentrations of PCB congeners in sediments from sites MDE-44 and MDE-45 from September 2009 expressed in ng g^{-1} dry weight. MDE-44 and 45 are newly established sites and thus do not have historical data with which to calculate the mean, median and standard deviation.

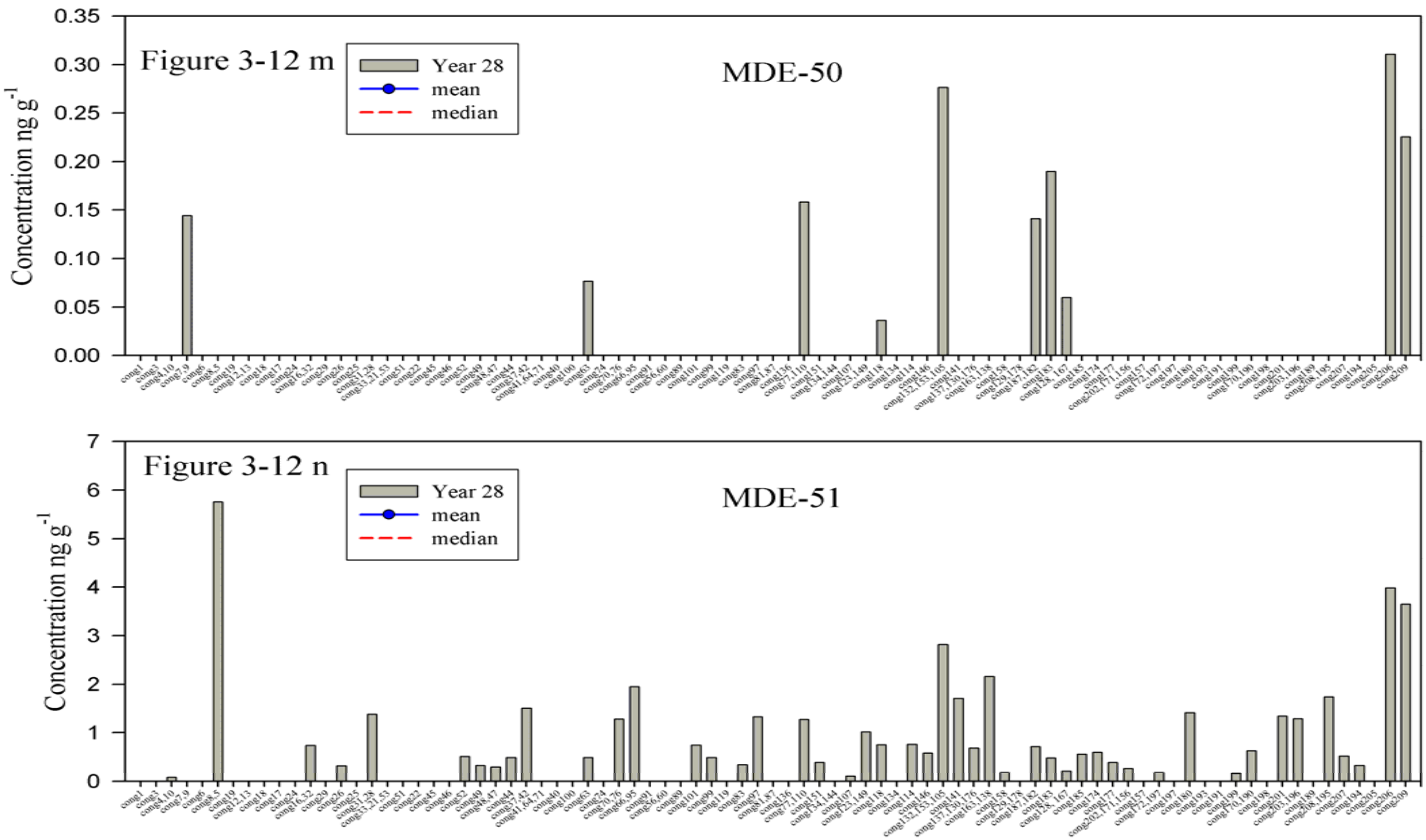


Figure 3-12 continued. Concentrations of PCB congeners in sediments from sites MDE-50 and MDE-51 from September 2009 expressed in ng g^{-1} dry weight. MDE-50 and 51 are newly established sites and thus do not have historical data with which to calculate the mean, median and standard deviation.

PCB Profiles in Clams

The PCBs analyzed for in clams sampled in September of 2009 are given in Table 3-4 and concentrations are summarized in Figure 3-13 a-k. As in the case of the sediment, these figures provide a “signature” from which to investigate trends in the types and amounts of PCBs within and among the sites. The clams traditionally have contained significant amounts of the congener groups 132+153+105, 163+138, 187+182, 208+95, 206+209 and the congener 180. This was also the case in 2009, however congener 22 and the congener pair 37+42 were commonly found in moderate amounts. While the amounts of individual congeners change between the sites, the congener pattern is very similar across all the sites. Not all sites have been visited enough to provide the historical information to calculate the mean and median, and thus they are not always shown. Some of the sites shown have only been recently added.

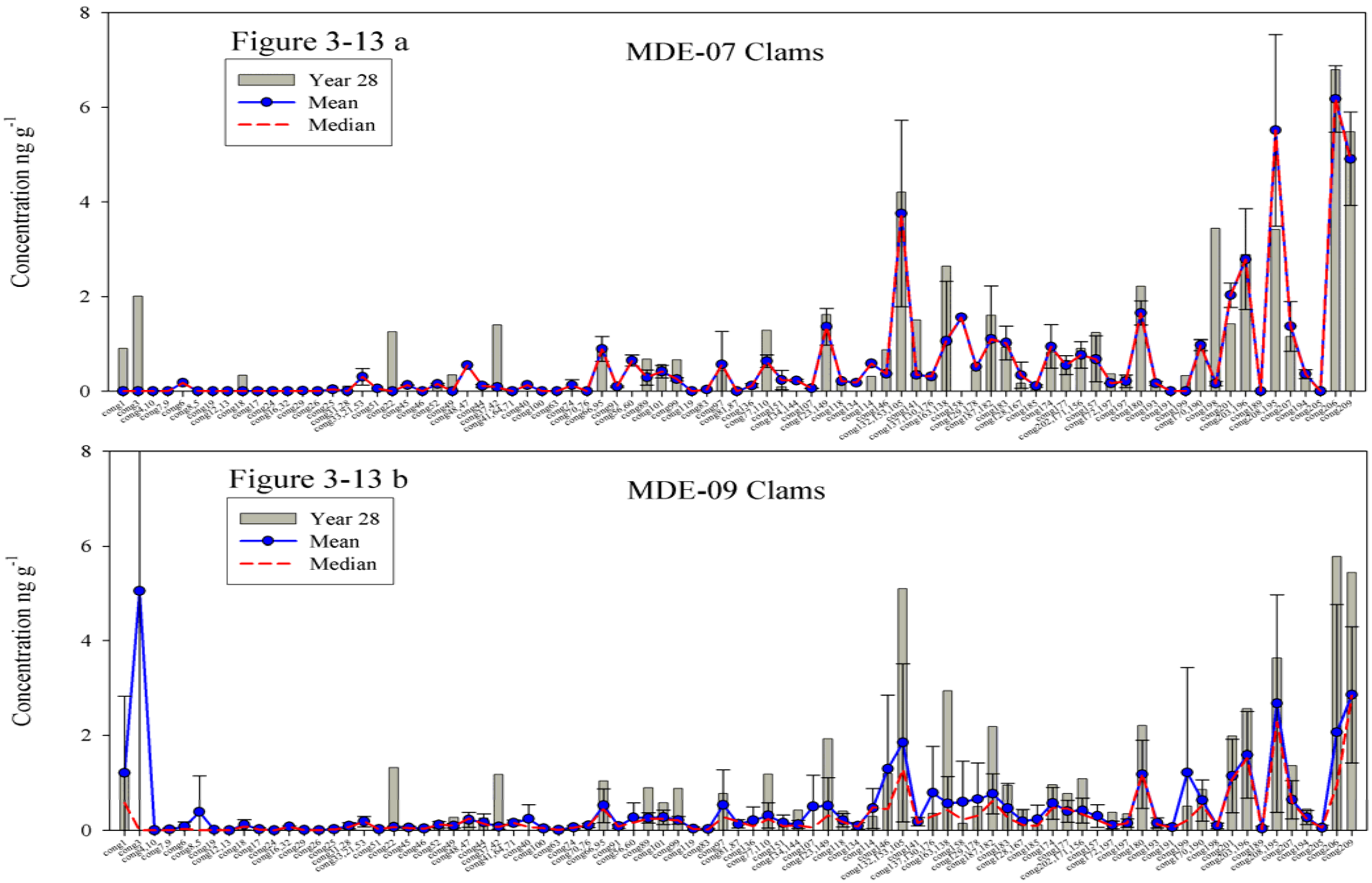


Figure 3-13. Concentrations of PCB congeners in clams from sites MDE-07 and MDE-09 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line) expressed in ng g^{-1} wet weight.

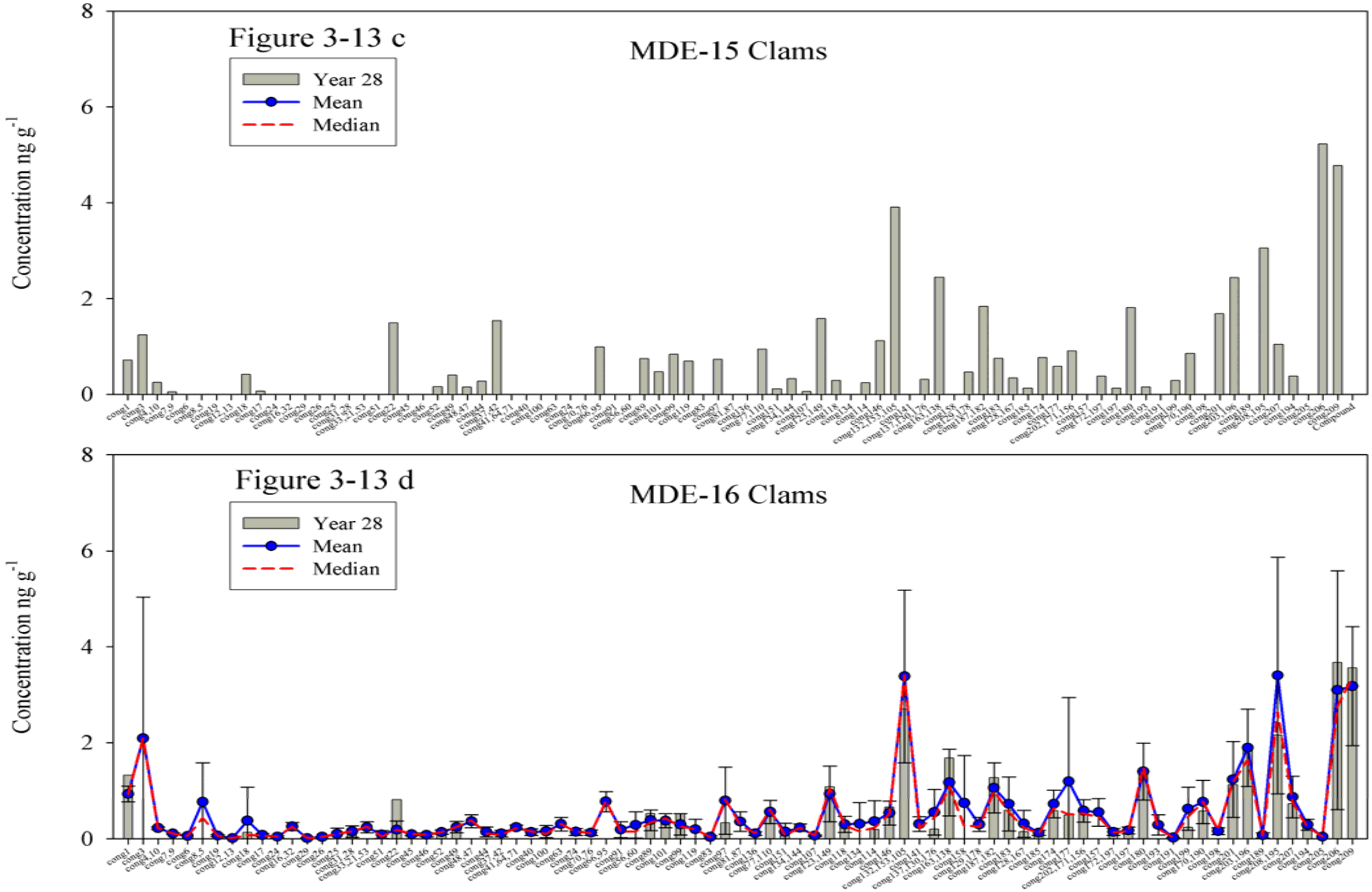


Figure 3-13 continued. Concentrations of PCB congeners in clams from sites MDE-15 and MDE-16 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line) expressed in ng g^{-1} wet weight. MDE-15 is a newly established site and thus does not have historical data with which to calculate the mean, median and standard deviation.

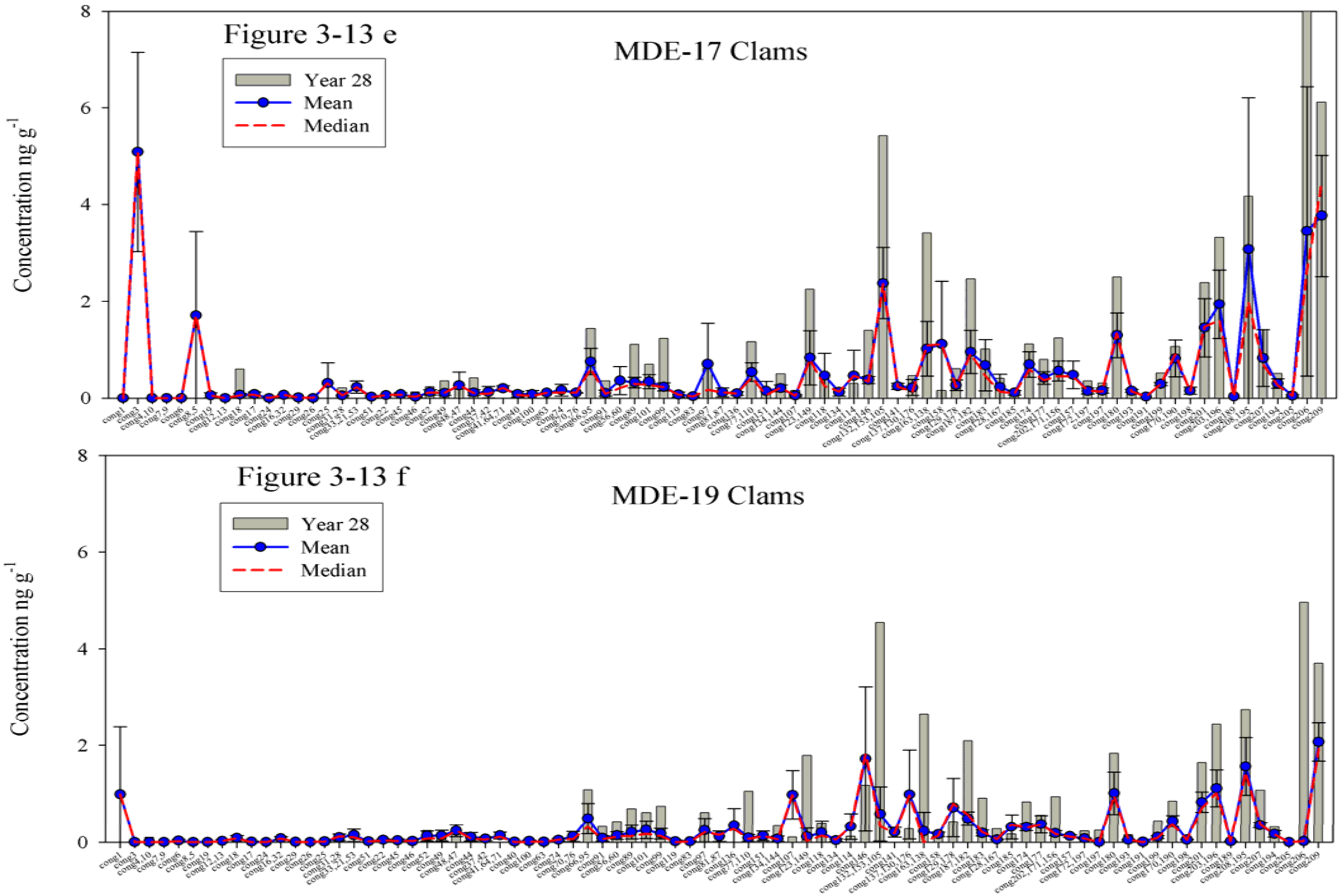
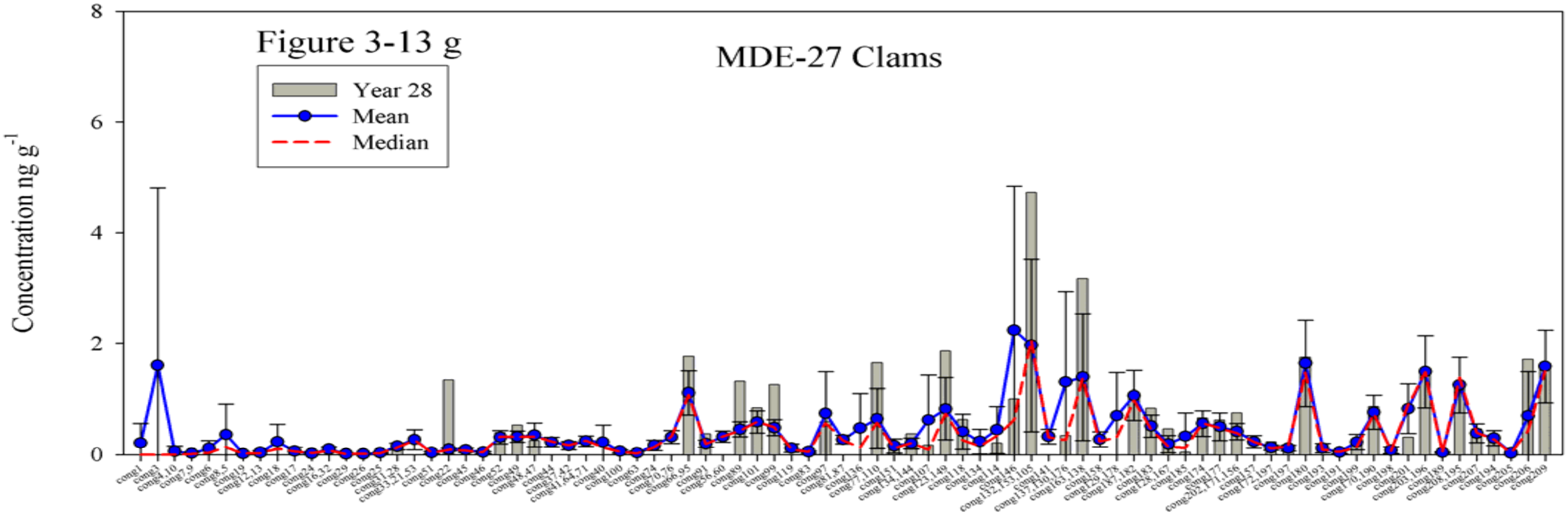


Figure 3-13 continued. Concentrations of PCB congeners in clams from sites MDE-17 and MDE-19 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line) expressed in ng g^{-1} wet weight.



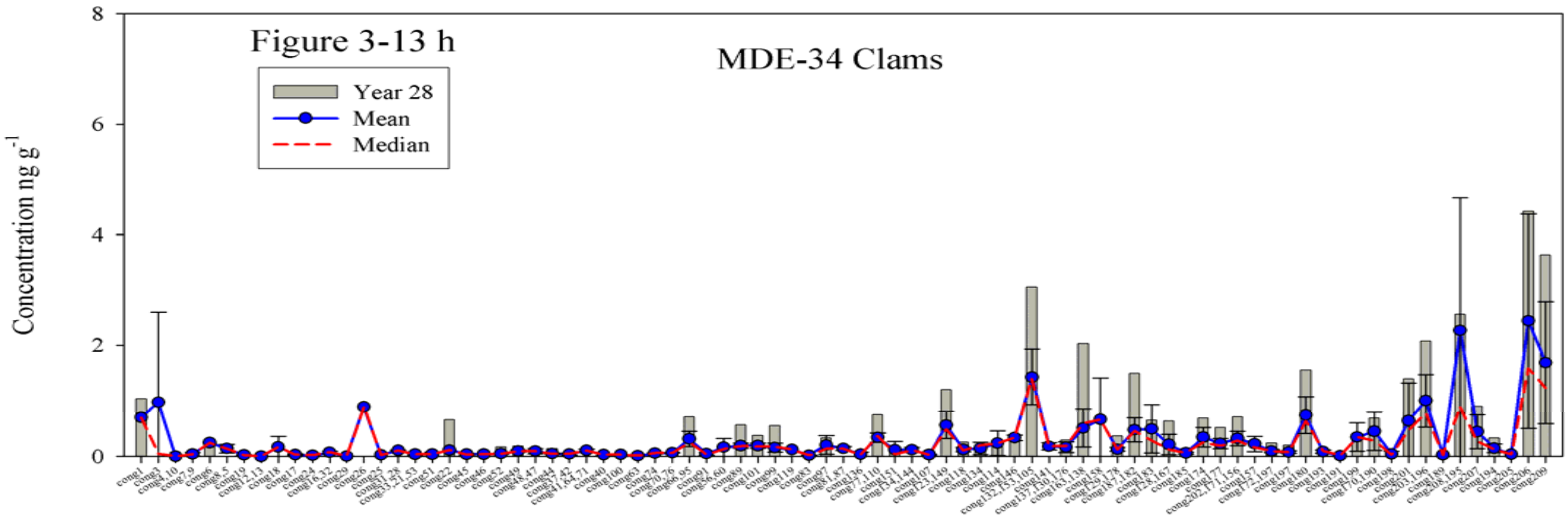
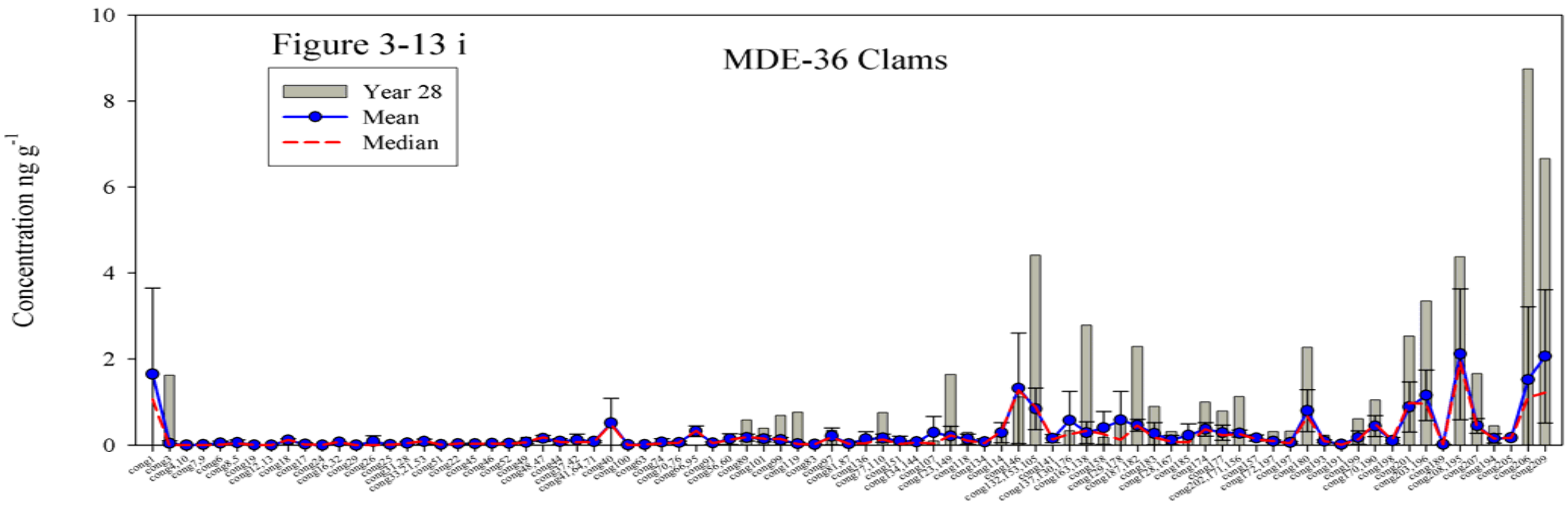


Figure 3-13 continued. Concentrations of PCB congeners in clams from sites MDE-27 and MDE-34 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line) expressed in ng g^{-1} wet weight.



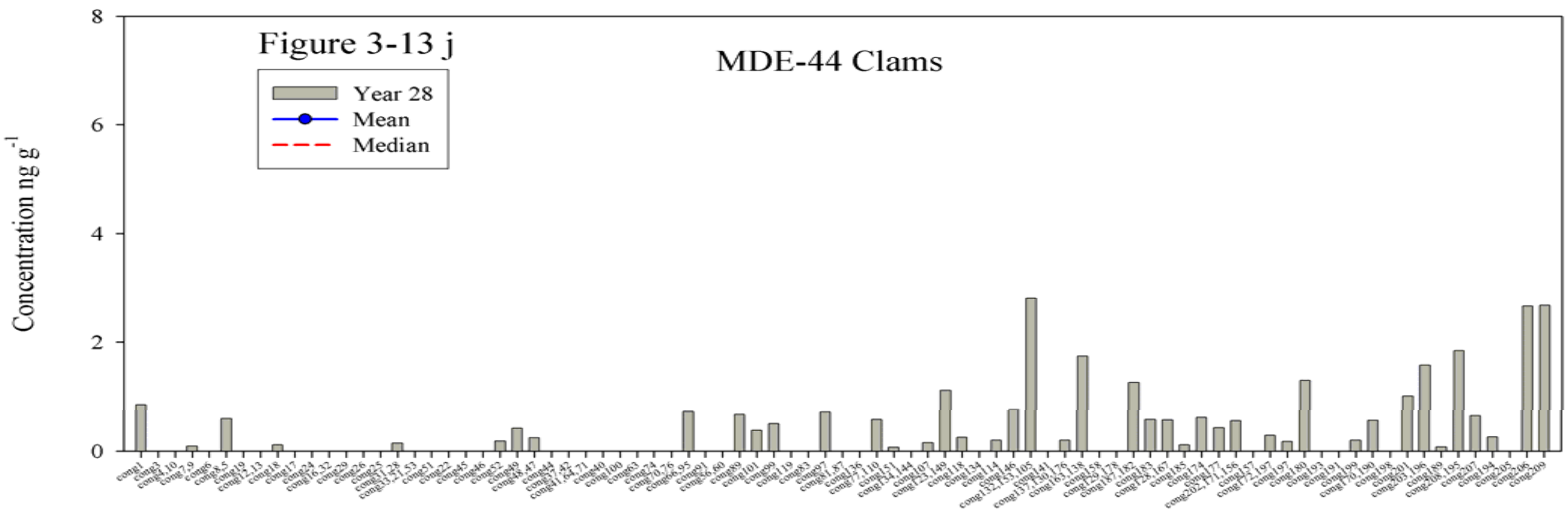


Figure 3-13 continued. Concentrations of PCB congeners in clams from sites MDE-36 and MDE-44 obtained September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line) expressed in ng g^{-1} wet weight. MDE-44 is a newly established site and thus does not have historical data with which to calculate the mean, median and standard deviation.

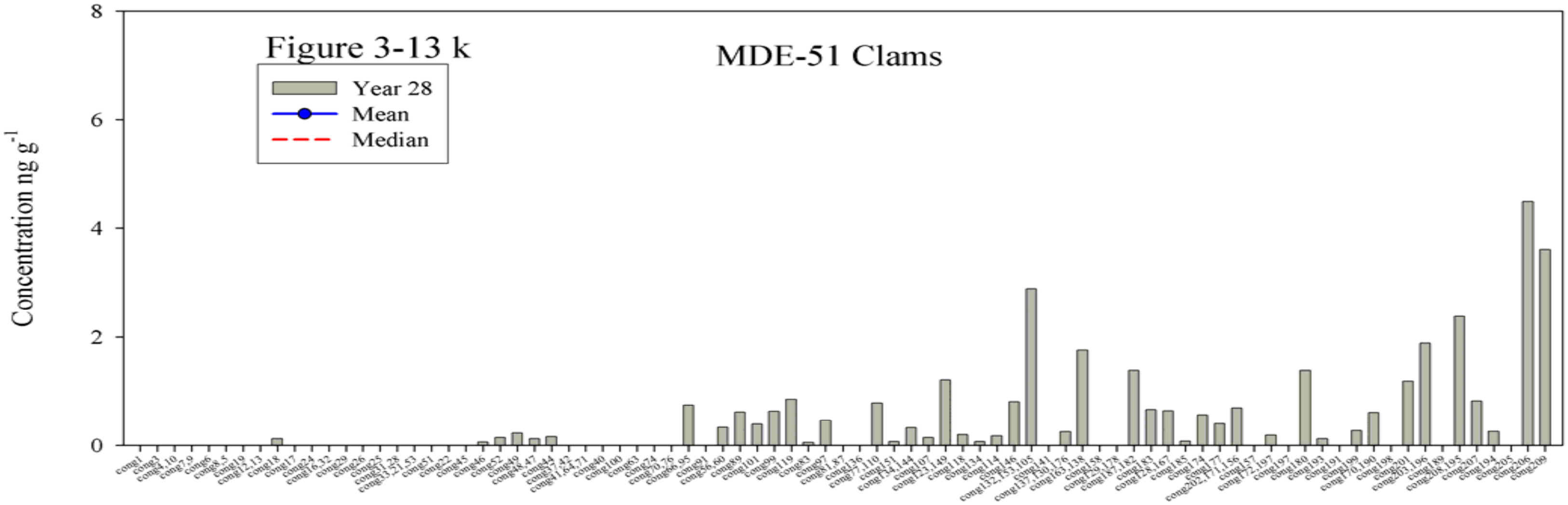


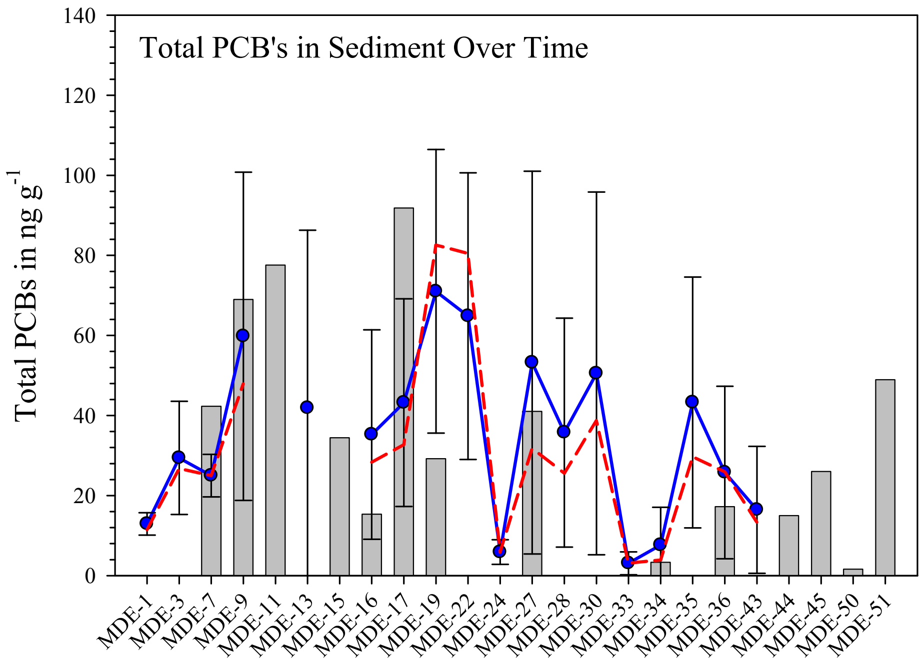
Figure 3-13 continued. Concentrations of PCB congeners in clams from site MDE-51 obtained in September 2009 expressed in ng g^{-1} wet weight. MDE-51 is a newly established site and thus does not have historical data with which to calculate the mean, median and standard deviation.

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 2009 were similar to the historical site averages, being within the standard deviation of the mean with the exception of one site. The total PCB concentration in sediment at site MDE-17 was 2 times higher than the average and outside the standard deviation of what has been previously observed.

Total PCB concentrations in clams collected in September 2009 were on average 2 times higher than the historical running mean for most of the sites. Clams collected from the reference site, MDE-36, also showed the same elevated concentrations when compared to the historical mean concentration. We might have expected the total concentration of PCBs in clams at site MDE-17 to be elevated because, as indicated above, the sediment concentrations of PCBs were elevated relative to other sites. As this was not the case, it suggests either the PCBs were less available for uptake by the clams or the measured elevated PCB concentration was the result of a local anomaly that was not large enough to influence the concentrations in the clams.

Four sites were visited that have been deemed in the influence of the South Cell outflow. These sites were MDE-16, 17, 19 and 44. The concentrations of PCBs in sediments at three of these sites were similar to sediment concentrations elsewhere around the island and to the reference sites. The exception to this observation was of course site MDE-17. Site MDE-17 is located some distance from the island, and given that PCBs are transported largely attached to particulates, it seems odd that this would be the only site showing enrichment. Perhaps this site can act as a depositional trap for fine particulates however, the clams collected from this site showed no unusual enrichment relative to other sites. PCB concentrations in clams collected over the entire region were higher than previous years, thus it seems unlikely that any enrichment was the result of activities within the HMI complex.



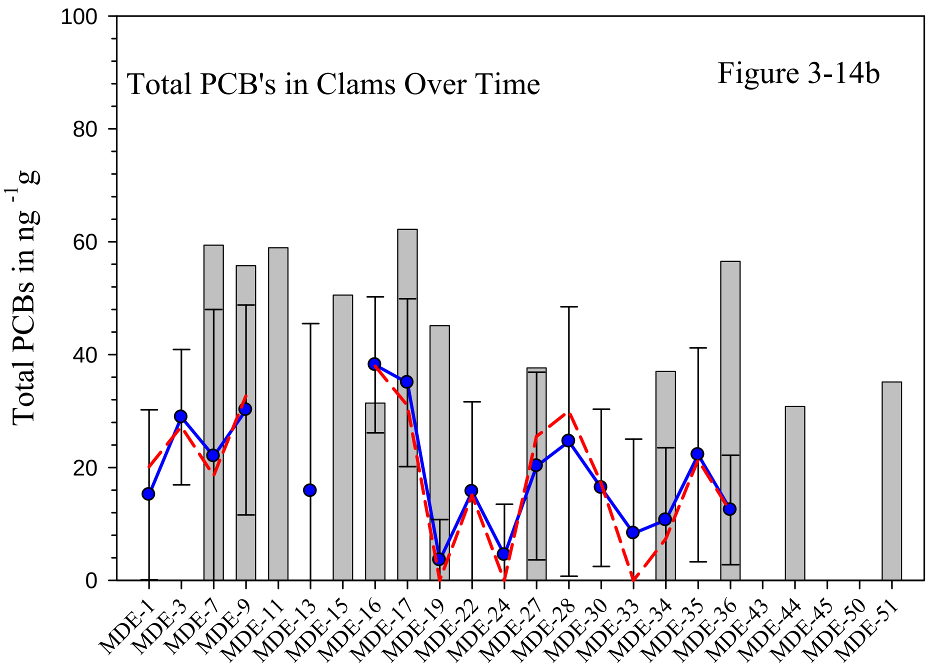


Figure 3-14. Total PCB concentrations in sediments (a) (ng g^{-1} dry weight) and total PCB concentrations in clams (ng g^{-1} wet weight) collected in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line).

Polycyclic Aromatic Hydrocarbons in Sediment

The fingerprints obtained by identifying and measuring the concentrations of a series of PAHs from sites in the vicinity of HMI are shown in Figure 3-15a-n. The specific PAHs analyzed for are given in Table 3-5. 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 site MDE-7 and 17 were elevated above historical levels whereas sediment at site MDE-16 was lower than has historically been observed. Despite the changes in concentrations, the 2009 profiles appeared similar to the historical averages. Being newly established in 2008, MDE-50 and 51 have never had sediment samples analyzed for PAHs. Sediment from site MDE-50 had very low concentrations of PAHs, far lower than at site MDE-36. The low concentrations at MDE-51 resulted in fewer compounds being detected. The low concentrations likely stem from the low organic matter content of the sediment. In the case of site MDE-51, the organic matter content is much higher and as a result, so are many of the PAH compound concentrations. The pattern and concentration of the PAHs measured at MDE-51 were more in line with most of the sites closer to the HMI facility. Together site MDE-36, 50 and 51 reflect a range of depositional environments outside the immediate influence of HMI, as such form a good trio for which to compare sites in closer proximity to the HMI facility.

Table 3-5. Polycyclic aromatic hydrocarbons given in the same order as in Figure 3-15 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		

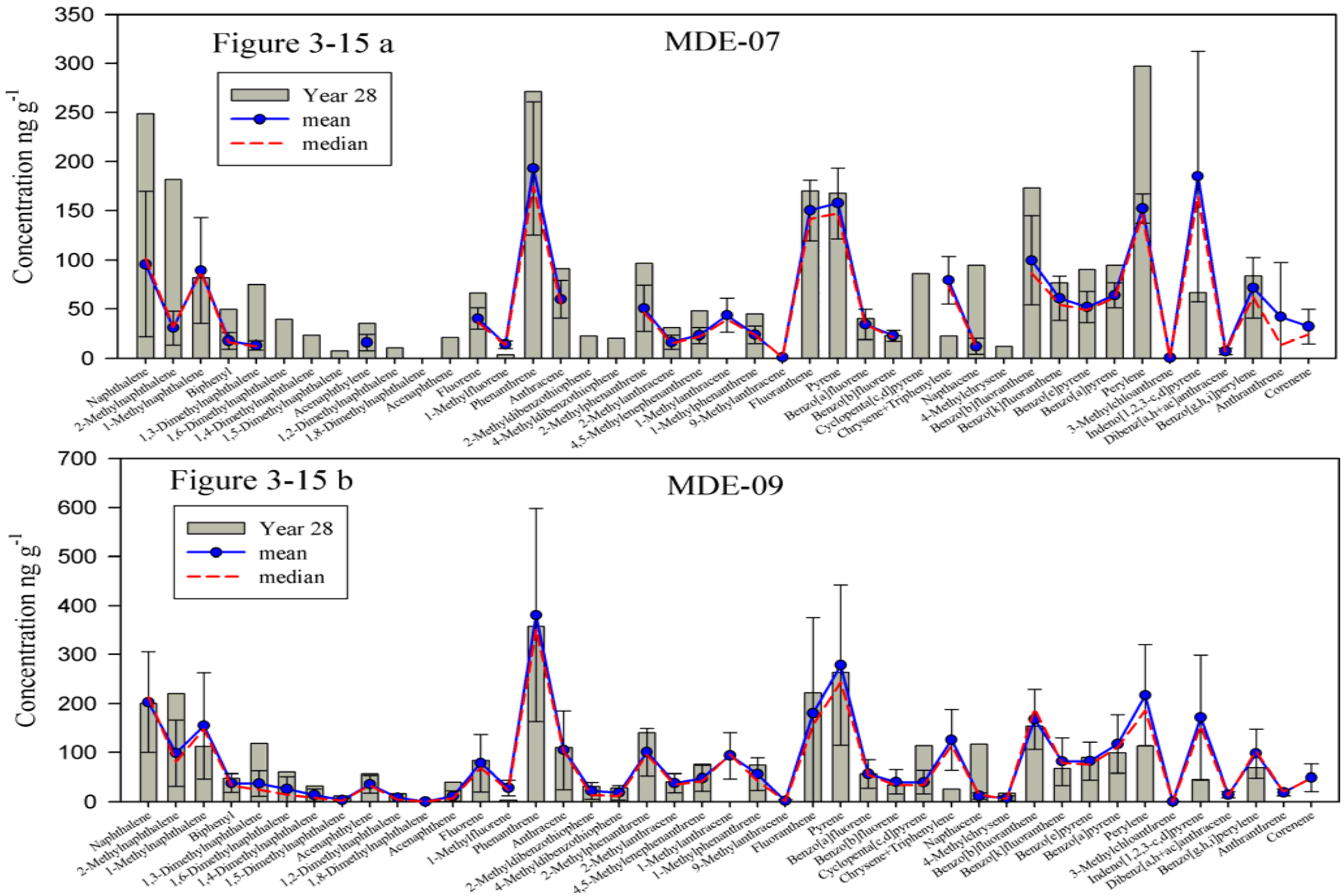
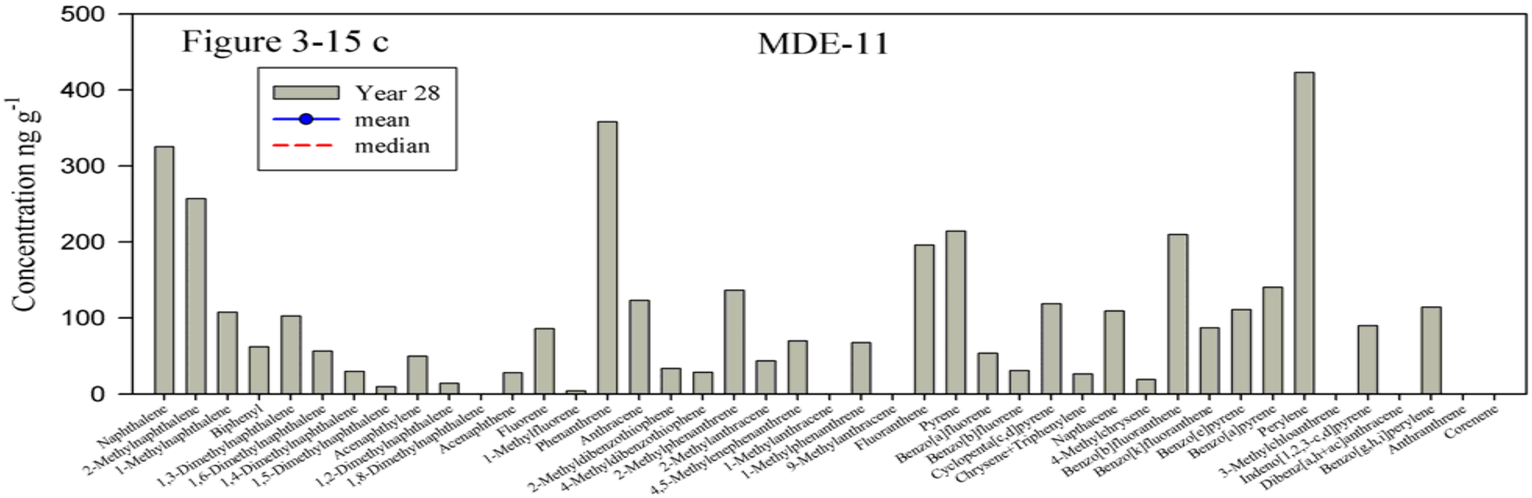


Figure 3-15. Concentrations of PAHs in sediments from site MDE-07 and MDE-09 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line), expressed in ng g^{-1} dry weight.



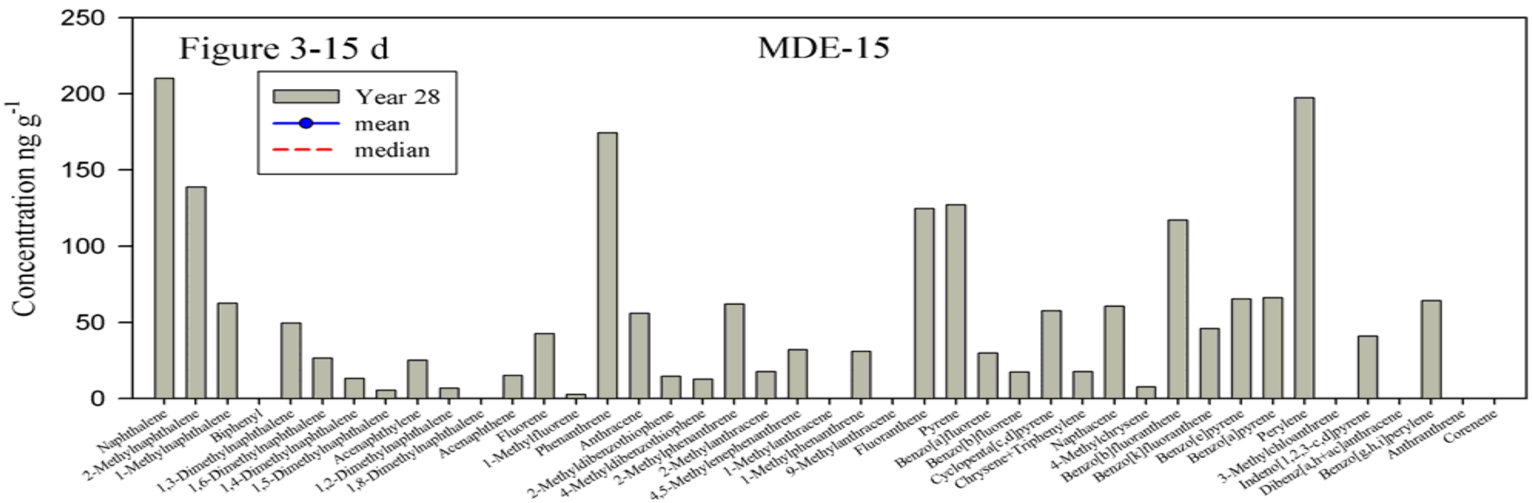
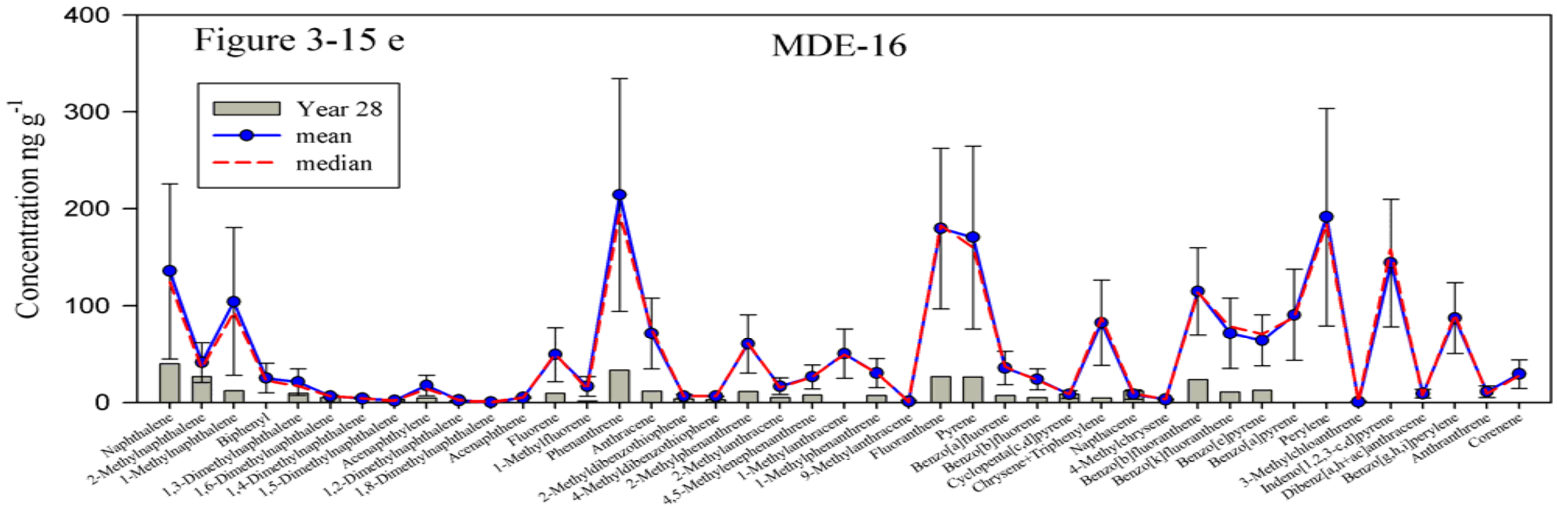


Figure 3-15 continued. Concentrations of PAHs in sediments from site MDE-11 and MDE-15 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line), expressed in ng g^{-1} dry weight.



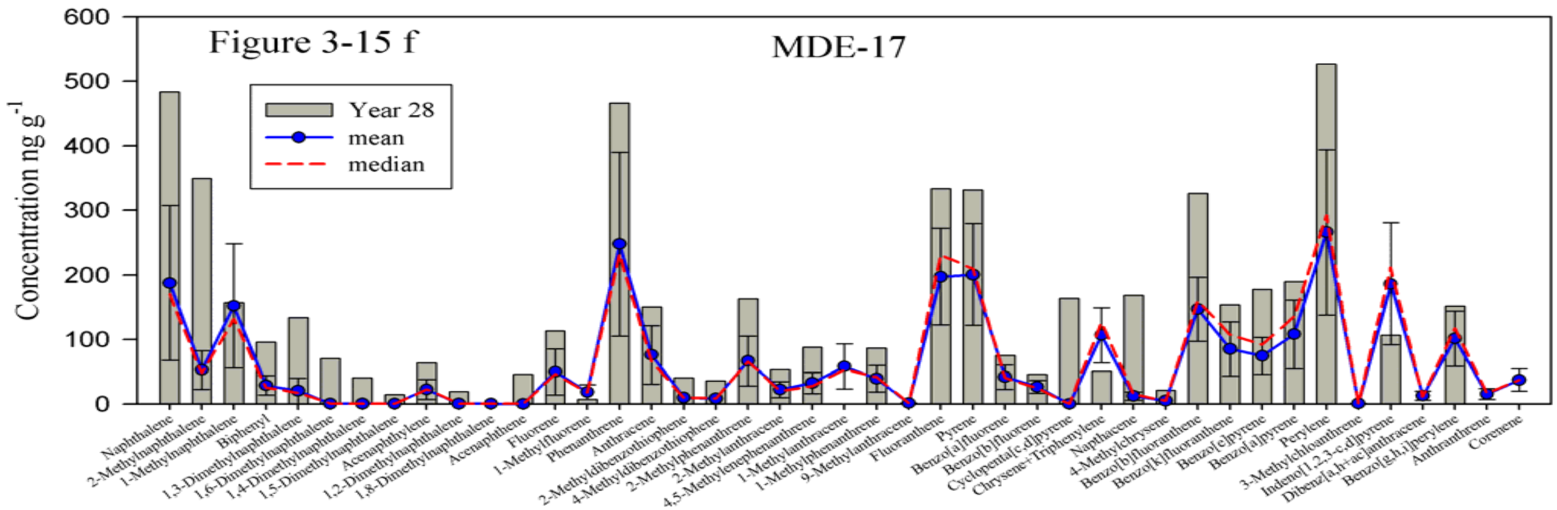
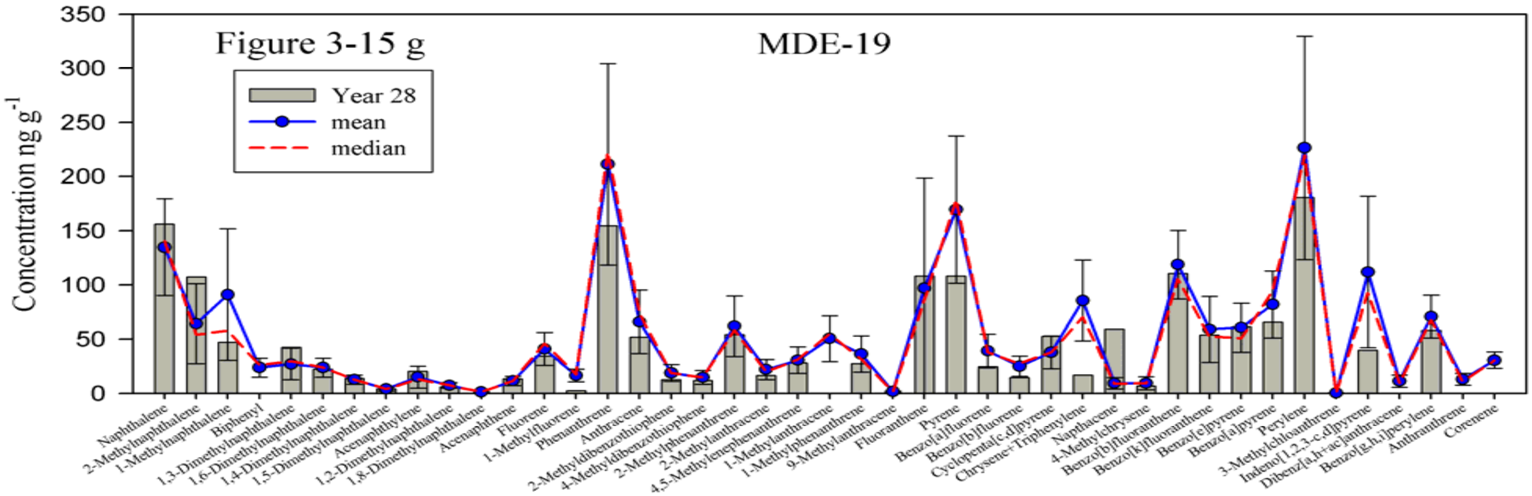


Figure 3-15 continued. Concentrations of PAHs in sediments from site MDE-16 and MDE-17 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line), expressed in ng g^{-1} dry weight.



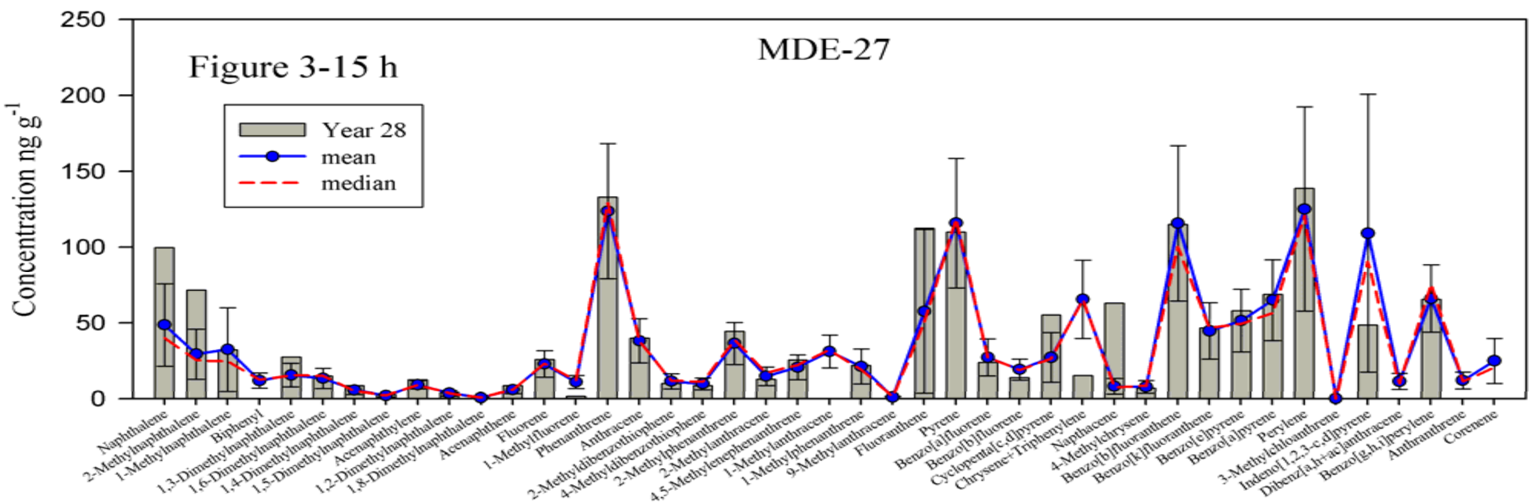


Figure 3-15 continued. Concentrations of PAHs in sediments from site MDE-19 and MDE-27 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line), expressed in ng g^{-1} dry weight.

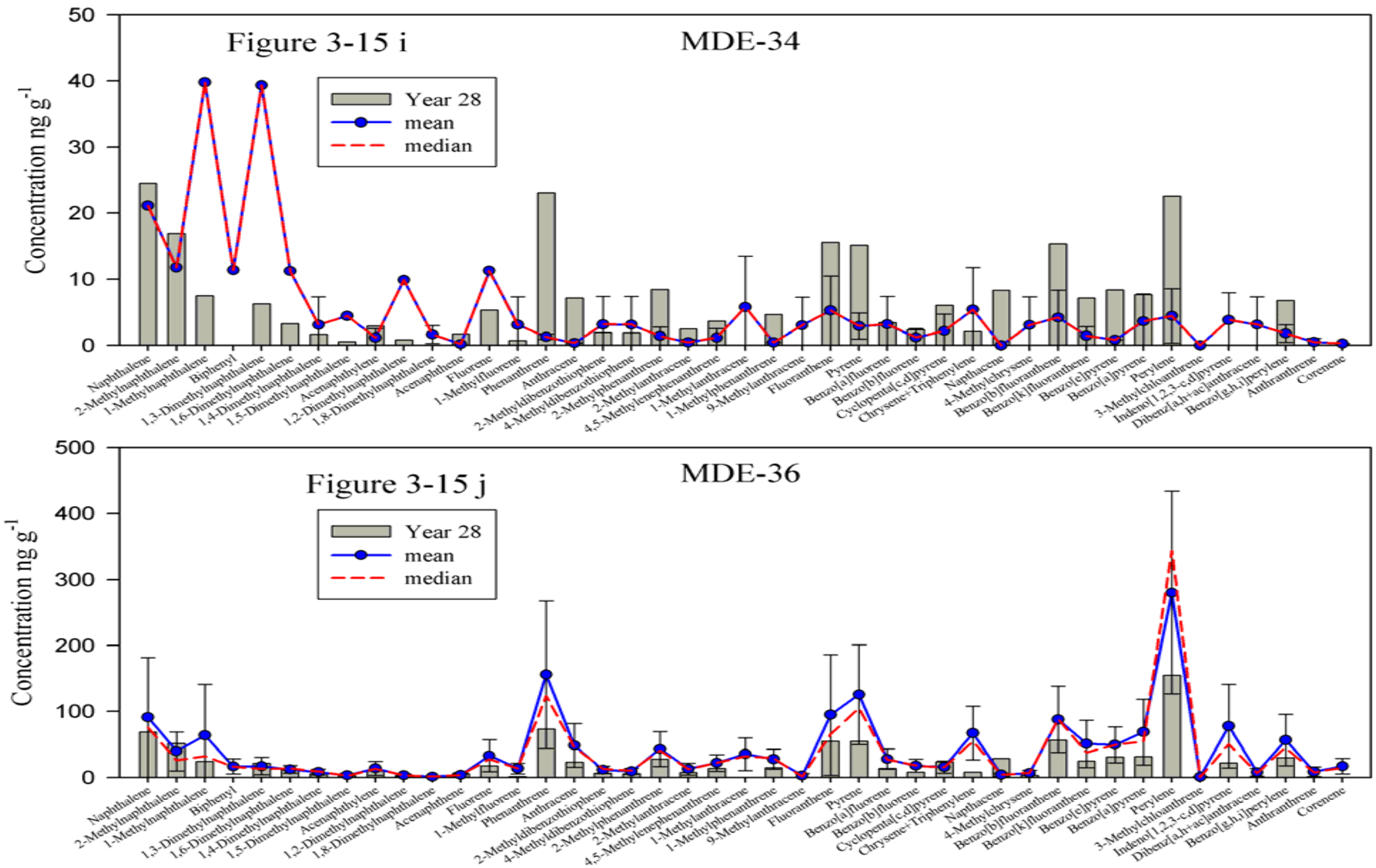


Figure 3-15 continued. Concentrations of PAHs in sediments from site MDE-34 and MDE-36 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line), expressed in ng g^{-1} dry weight.

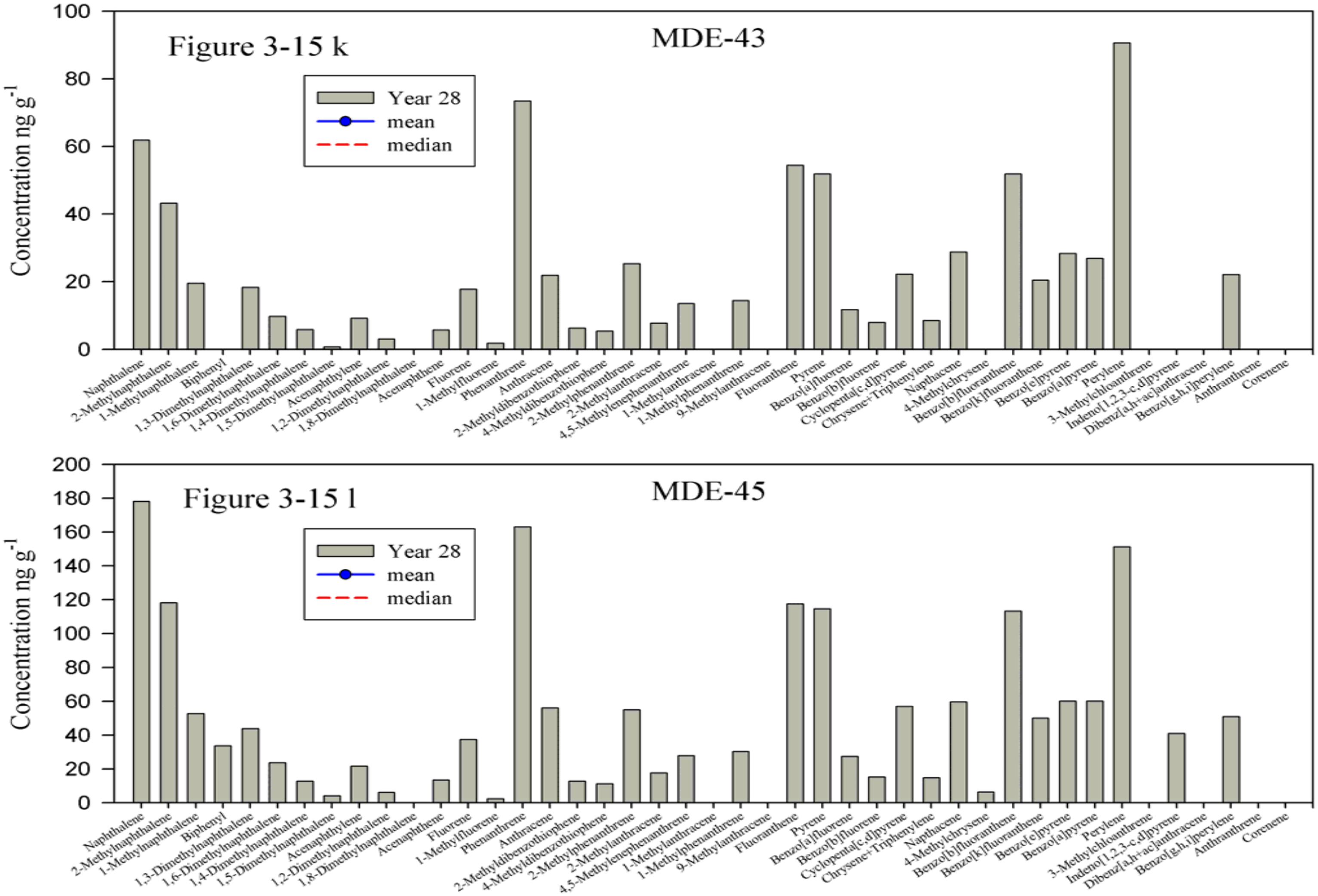


Figure 3-15 continued. Concentrations of PAHs in sediments from site MDE-43 and MDE-45 obtained in September 2009 expressed in ng g^{-1} dry weight. MDE-45 and 50 are newly established sites and thus do not have historical data with which to calculate the mean, median and standard deviation.

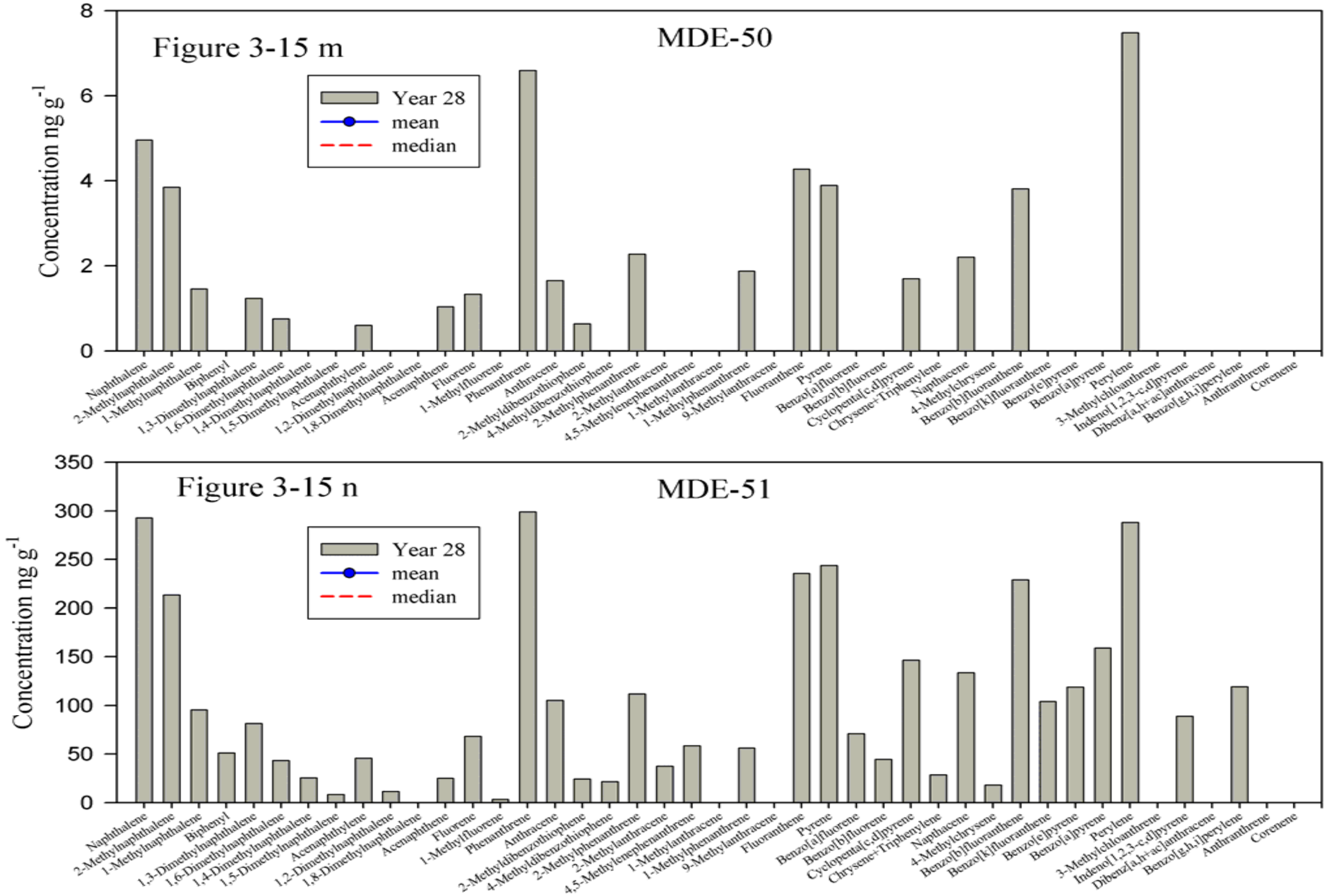


Figure 3-15 continued. Concentrations of PAHs in sediments from sites MDE-50 and MDE-51 obtained in September 2009 expressed in ng g^{-1} dry weight. MDE-50 and 41 are newly established sites and thus does not have historical data with which to calculate the mean, median and standard deviation.

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 3-16 a-l. The specific PAHs analyzed for are given in Table 3-5. The compounds most common are the same as those found in the sediments being: naphthalene, 2-methylnaphthalene, phenanthrene, fluoranthene, pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[e]pyrene, and perylene. Many of the other PAH compounds were below the methods level of detection in the 2009 clam samples. 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. Some of the sites sampled in 2009 have not been sampled in the past, thus no site means and median were available. Overall the concentrations of the various compounds are similar across sites, including the reference sites.

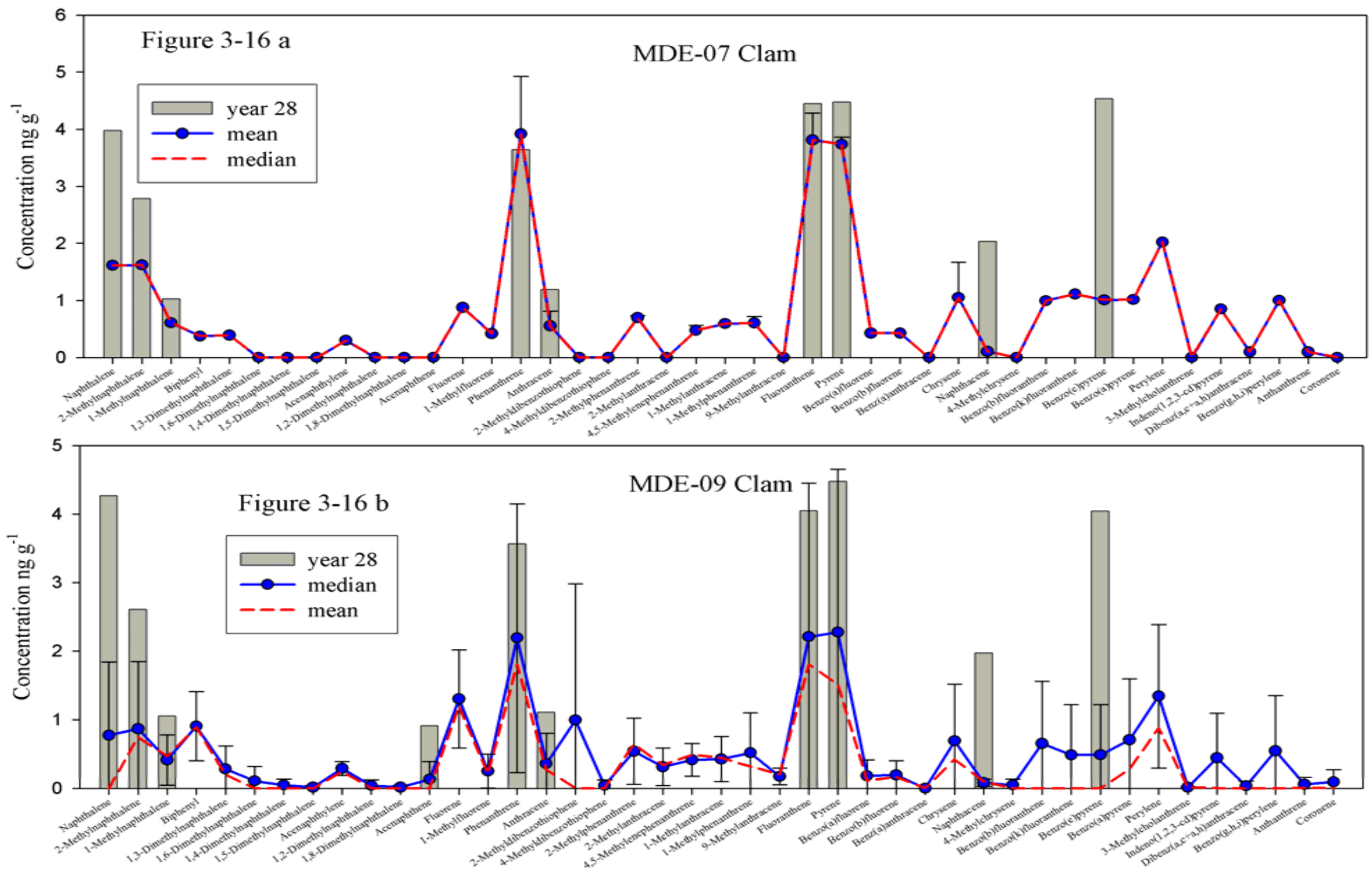


Figure 3-16. Concentrations of PAHs in clams from site MDE-07 and MDE-09 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line), expressed in ng g^{-1} wet weight.

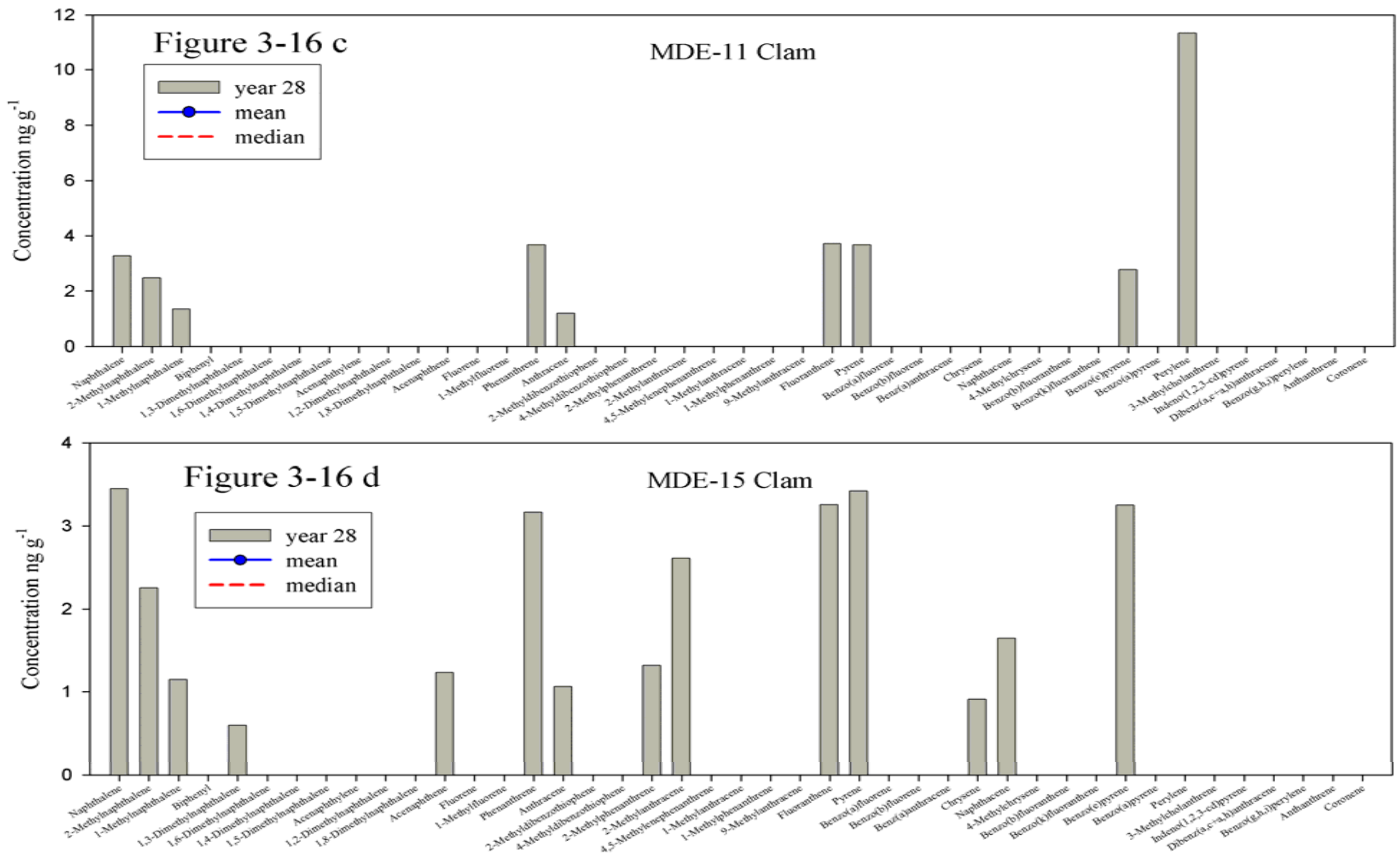


Figure 3-16 continued. Concentrations of PAHs in clams from site MDE-11 and MDE-15 obtained in September 2009 expressed in ng g^{-1} wet weight. MDE-11 and 15 are newly established sites and thus do not have historical data with which to calculate the mean, median and standard deviation.

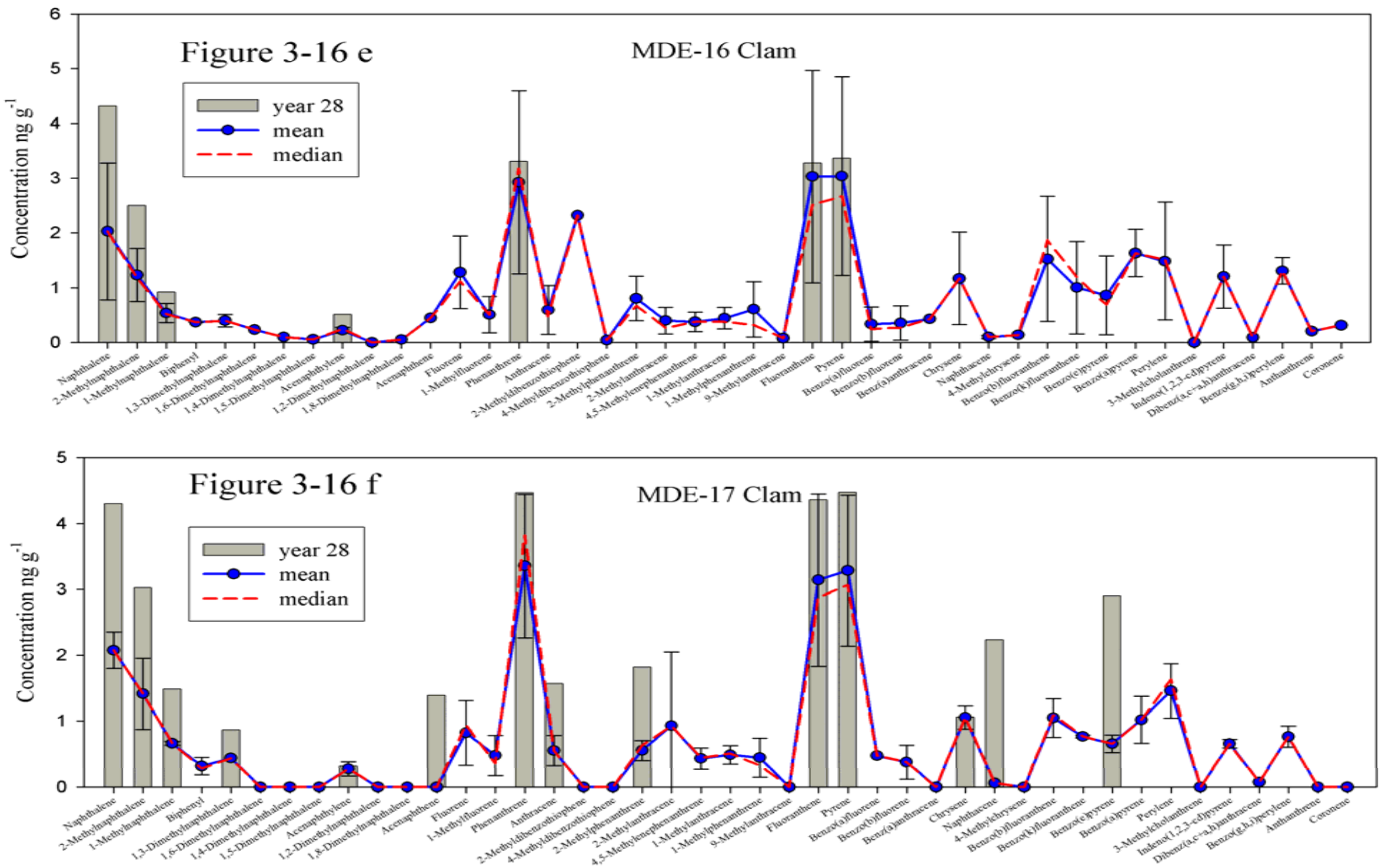
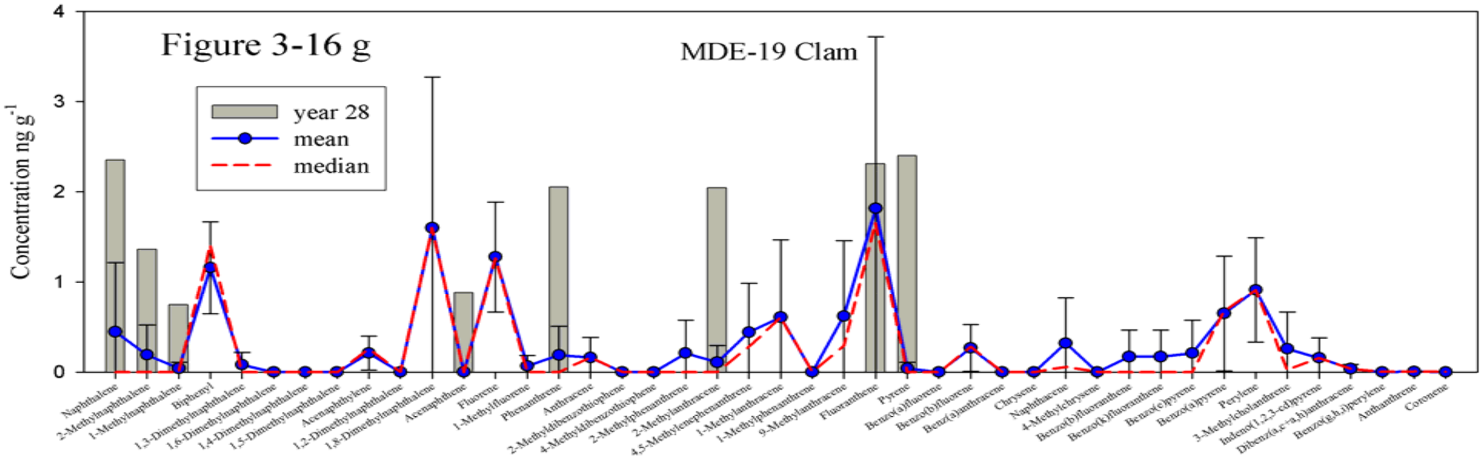


Figure 3-16 continued. Concentrations of PAHs in clams from site MDE-16 and MDE-17 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line), expressed in ng g^{-1} wet weight.



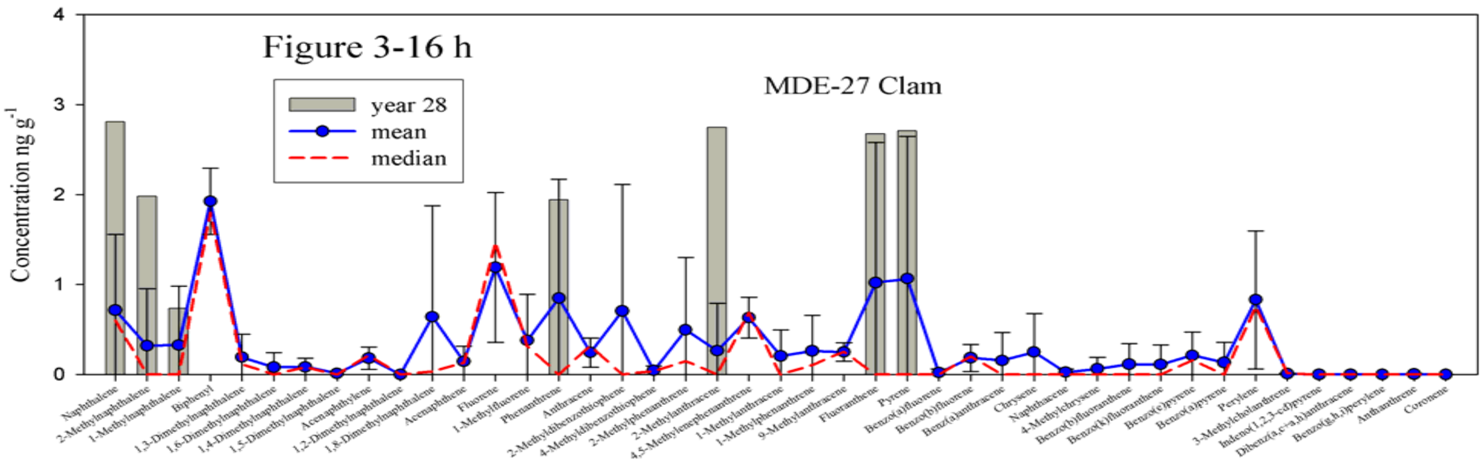
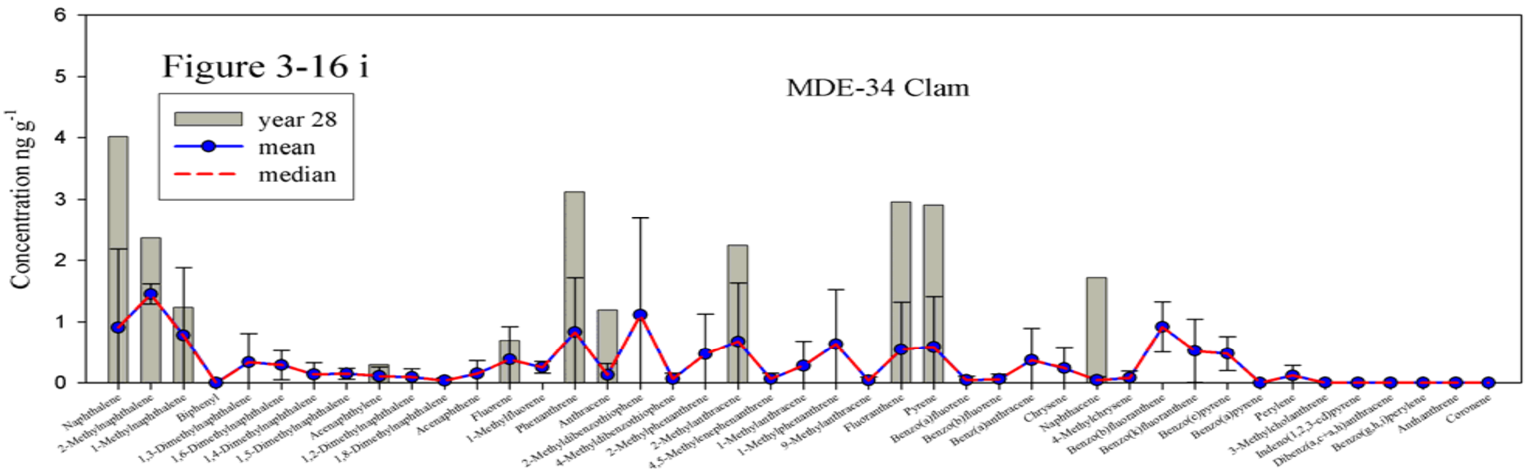


Figure 3-16 continued. Concentrations of PAHs in clams from site MDE-19 and MDE-27 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line), expressed in ng g^{-1} wet weight.



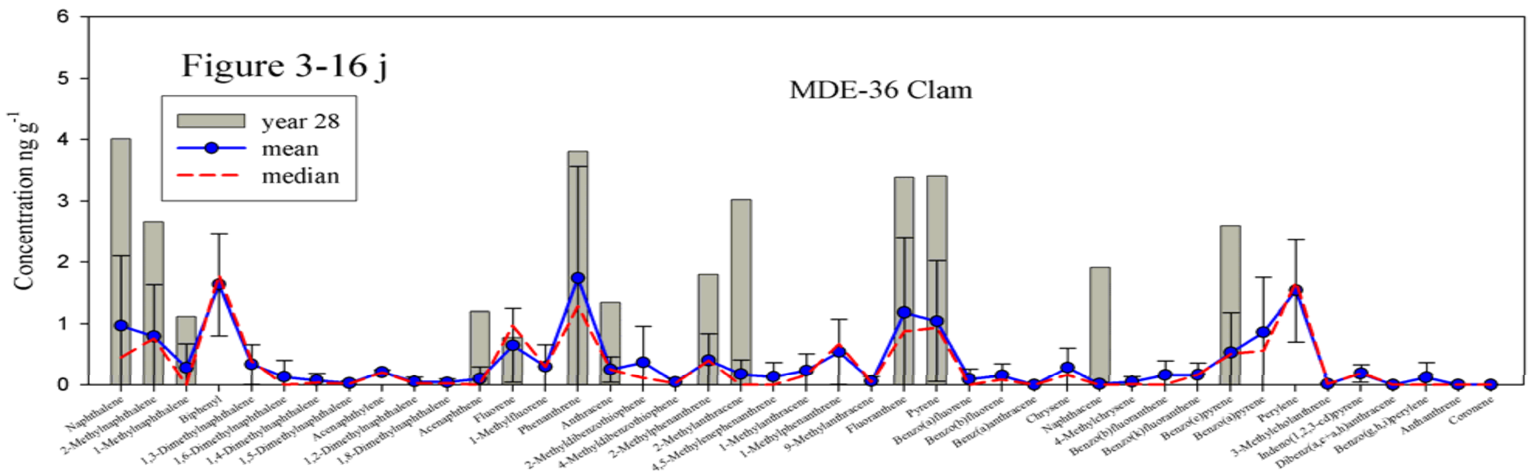


Figure 3-16 continued. Concentrations of PAHs in clams from site MDE-34 and MDE-36 obtained in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line), expressed in ng g^{-1} wet weight.

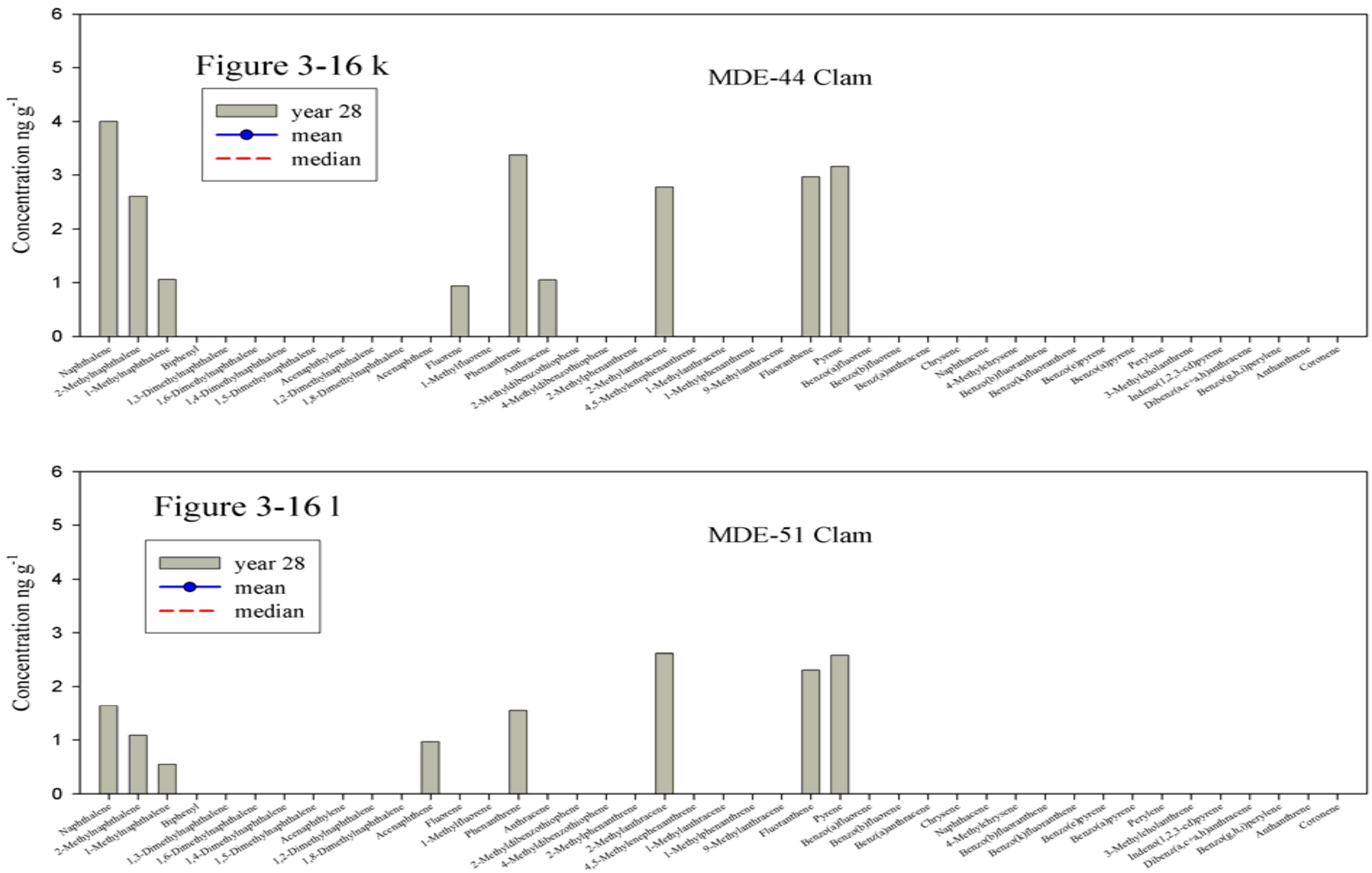
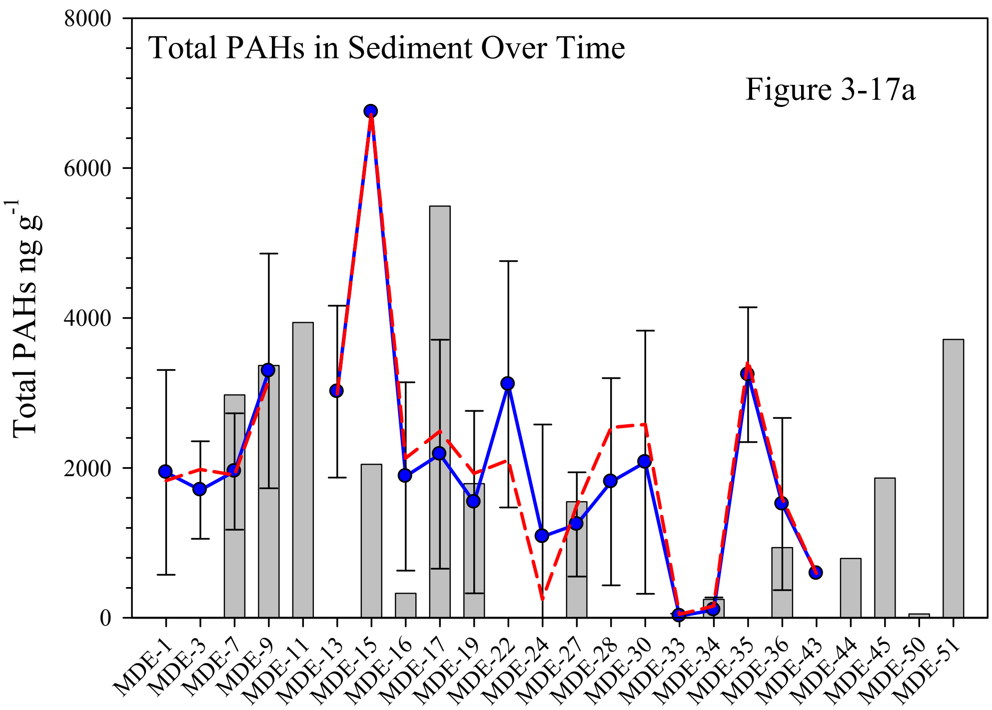


Figure 3-16 continued. Concentrations of PAHs in clams from site MDE-44 and MDE-51 obtained in September 2009 expressed in ng g^{-1} wet weight. MDE-44 and 51 are newly established sites and thus do not have historical data with which to calculate the mean, median and standard deviation.

Total PAH concentrations in sediments and clams

The total concentrations of PAHs in sediments around the island are close to historical levels except for one site (Figure 3-17a). Site MDE-17 has PAH concentrations above historical levels. Site MDE-17 also had higher PCB concentrations in sediments than had previously been observed. Concentrations of PAHs in clams remained near historical levels (Figure 3-17b) with the exception being clams from site MDE-17, which appear slightly elevated in PAH concentrations in 2009. The clam concentrations mirror the sediment changes, suggesting a possible local influence. A local influence could not be differentiated from the PCB data, thus the association is weak.

Four sites were visited that have been deemed in the influence of the South Cell outflow. These sites were MDE-16, 17, 19 and 44. As was the case for PCBs, the concentrations of PAHs in sediments at three of these sites were similar to sediment elsewhere around the island and to the reference sites. The exception is again site MDE-17. This site is located some distance from the island and given that PAHs are transported largely by particulates, as is the case of PCBs, it again seems odd that this would be the only site showing enrichment. Perhaps this site can act as a depositional trap for particulates. PAH concentrations in both sediments and clams sampled over the entire region were generally similar to previous years studied, thus it seems unlikely that any activities within the HMI complex have influenced PAH concentrations in sediments and biota.



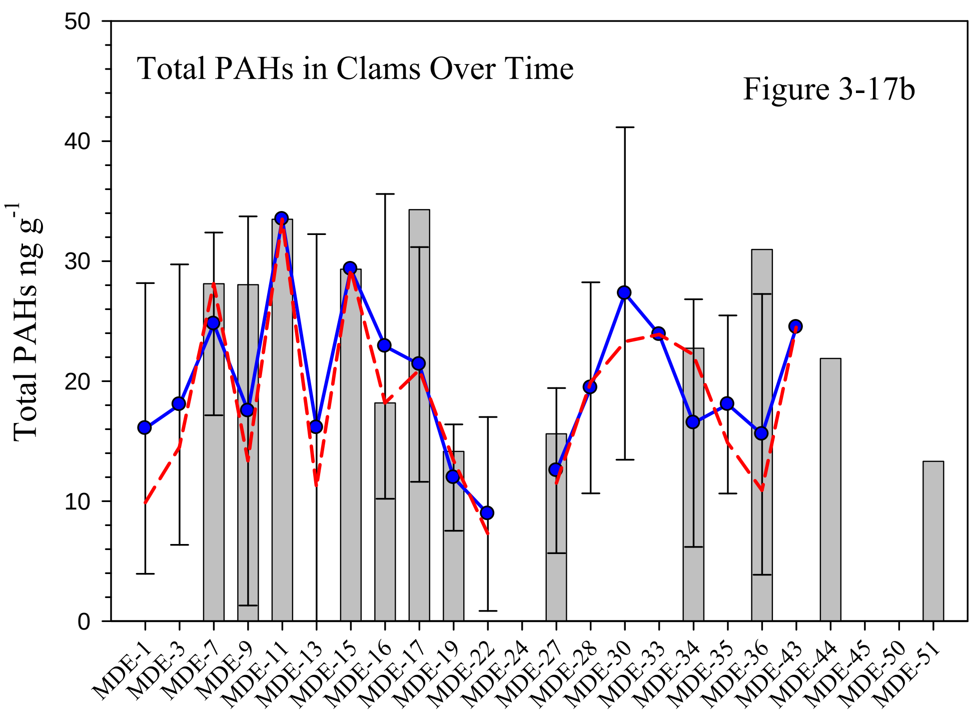


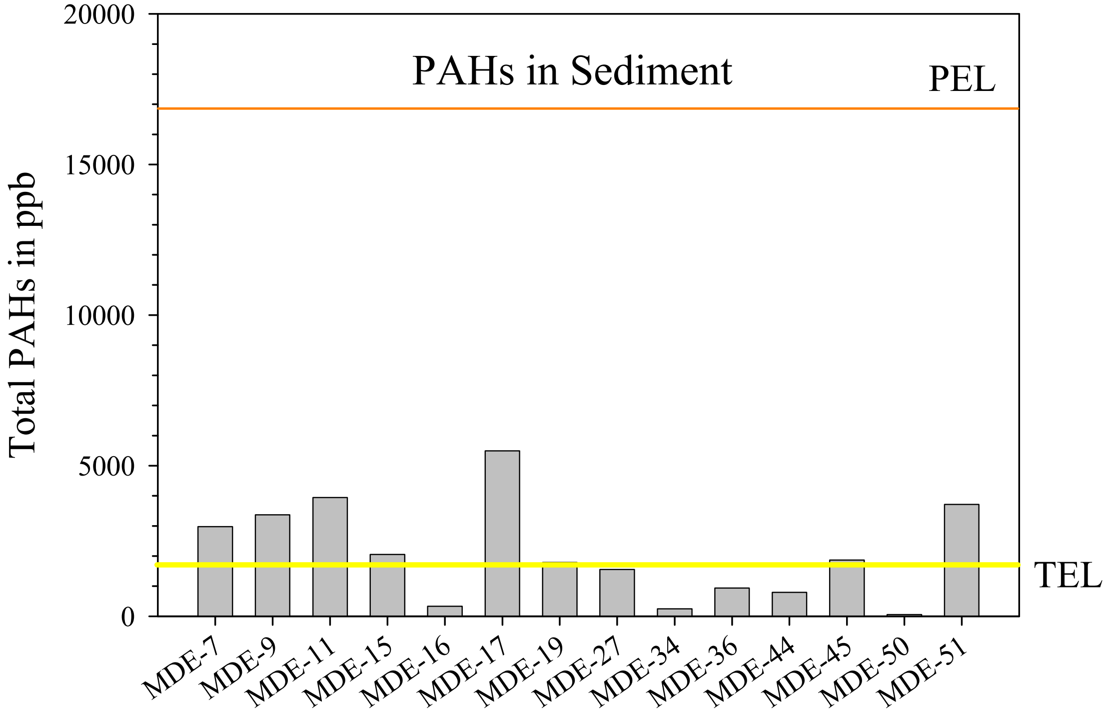
Figure 3-17. Total PAH concentrations in sediments (a) (ng g^{-1} dry weight) and total PAH concentrations in clams (b) (ng g^{-1} wet weight) collected in September 2009 (bars), the 1998-2008 mean with standard deviation (blue circles and error bars) and the 1998-2008 median (dashed line).

Bioaccumulation Factors for PCBs and PAHs

PAHs are typically not bioaccumulated, rather they are metabolized by organisms at some metabolic cost. PCBs however can accumulate in organisms. BAFs calculated on a wet weight basis are on the order of 5 for most sites studied in 2009 but the BAF at site MDE-34 was 20. This site had very low concentrations of PCBs in sediment, the lowest sediment concentration of PCBs of any of the sites examined in 2009. The low sediment PCB concentration then results in a high BAF for the site, despite clam concentrations being typical of the region.

The Potential Sediment Toxicity from Organic Contaminants

The potential toxicity of the PAH and PCB concentrations in sediments around HMI was accessed by comparing the total concentrations to the Threshold Effects Level (TEL) and PEL as developed by NOAA for marine sediments. The TEL is surpassed by a number of the sites, including MDE-51, which is not surprising given the urban influence on sediments near Baltimore. The PEL was not surpassed by any of the sites for either PCBs or PAHs (Figure 3-18). Concentrations of individual compounds, for which criteria have been established, fall below the established PELs.



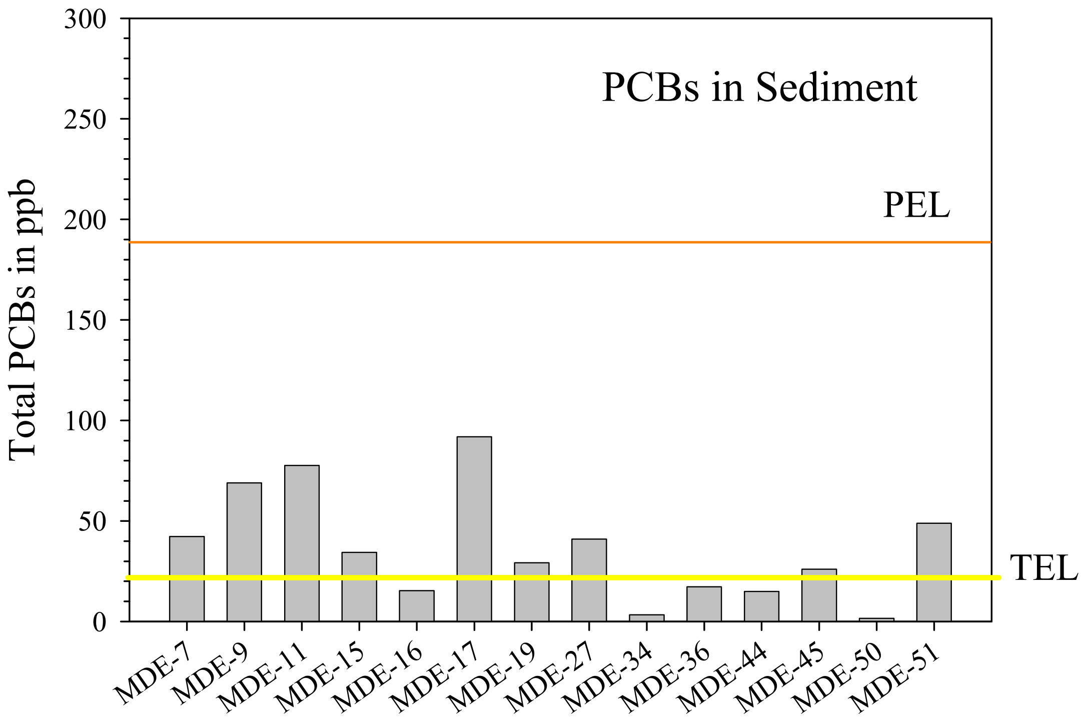


Figure 3-18. Total PAH and Total PCB concentrations in relation to the TEL and the PEL for samples collected in September 2009.

CONCLUSION

The concentrations of trace elements in sediments collected around the HMI facility largely follow previous years, with the exception of Se, which appears to have returned to the higher levels observed prior to 2002. The higher levels of Se need to be followed closely as high concentrations of Se may be present in South Cell outflow water (MES data). It does not appear to be a likely source given the wide spread change in Se concentrations but the magnitude of the flux from the South Cell needs investigating. In light of this observation, I would recommend flow weighted measurement of trace elements during periods of significant discharge from the South Cell. It would also be informative to assess the trace element and organic contaminant concentrations in the water and sediments of the South Cell holding pond in order to determine pool of contaminants present at any given time.

Site MDE- 17 appears to have high levels of both PCBs and PAHs in sediments but the data set for this site is limited.

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