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

Year 31 Exterior Monitoring Technical Report
(September 2012-August 2013)

THIS PAGE INTENTIONALLY LEFT BLANK

Prepared by:

Environmental Assessment

And Standards Program

Maryland Department of the Environment

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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.
Effects Range Low (ERL)	Concentration below which effects are rarely observed or predicted among sensitive life stages and (or) species of biota for Sediment Effect Concentrations used to evaluate sediment concentrations of trace elements and sediment concentrations of trace elements and synthetic organic compounds.
Effects Range Median (ERM)	Concentration above which effects are frequently or always observed among most species of biota for Sediment Effect Concentrations used to evaluate sediment concentrations of trace elements and synthetic organic compounds.
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 in*material*	Sediments consisting of particles less than or equal to 0.062 mm 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 31

(September 2012– August 2013)

Prepared by
The Environmental Assessment and Standards Program

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

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

November 2014

ACKNOWLEDGMENTS

The Hart-Miller Island Dredged Material Containment Facility (HMI DMCF) is a large and complex operation and its success goes to the credit of many individuals within numerous organizations.

Within the Science Services Administration of the Maryland Department of the Environment (MDE) a special thanks is offered to Matthew Rowe, John Backus, Shareda Holifield, Angel Valdez, and Project III Principle Investigators (PIs) Jeff Carter, Patricia Brady, Nicholas Kaltenbach. John Backus was responsible for making sure that the project work was done efficiently in a coordinated manner and met all the technical goals set by the Technical Review Committee for Year 31. Shareda Holifield was responsible for reviewing the three individual technical reports of Projects II, III and IV, compiling all four into the Year 31 Exterior Monitoring Report (including the Project I Summary), and compiling/managing the data for all projects. Angel Valdez created the GIS maps for the Project I Summary. The PIs were responsible for all the benthic laboratory work to include identifying organisms, assembling the data and performing the necessary calculations, and writing the Project III Technical and Data reports. For their technical support to the PIs a special thanks is given to Charles Poukish, biologist and manager of the Field Evaluation Division, and Chris Luckett, biologist and taxonomist. Last but not least a special thanks to the Towson University interns and research assistants Jan Anderson, Kasey Bolyard, and Cheyenne Owens for their most essential work of patiently sorting the benthic samples and assisting with identifications. It must be noted that all the calculations that assumptions and conclusions are drawn from are based on the work of the individuals sorting the organisms. Their work is the foundation for all subsequent work.

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

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

INTRODUCTION

The HMIDMCF was designed to receive dredged material from navigation channel maintenance and improvement activities in the Baltimore Harbor and its approaches. Construction of the HMI DMCF, 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.

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

The first sampling cruises for monitoring Year 28 took place in September 2009, while HMI was still receiving dredged material. The April 2010 sampling cruises marked the first sampling after closure. Thus, only the April 2010 monitoring results can be considered post-closure baseline data. Year 31 marks the 3rd full year of post-closure monitoring. It is important that monitoring continues for at least 5 years post-closure during this crucial period of dewatering and crust management, and habitat development of the North Cell to establish a robust post-closure data set. These 5 years of data can then be compared to the thirty years of data collected during dredged material placement. This comparison of pre- and post-closure data will allow the scientists to determine differences, if any, in the exterior environment, and whether the differences were a result of HMI operations. The information learned can be applied to future dredged material containment facilities.

Throughout this Year 31 Exterior Monitoring Technical report, the companion *Year 31 Data Report* is referenced. This report contains the detailed information in regards to sampling locations, field description of samples which includes and is not limited to the number of specimens collected and the detailed results of findings.

HMI EXTERIOR MONITORING DESIGN

The HMIDMCF 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: Year 31 HMI post-closure monitoring locations. For Year 31, MGS analyzed sediment for physical and chemical properties from all 43 sites, MDE sampled the benthic organisms at 22 sites, and CBL collected the brackish water clam *Rangia cuneata* from 13 sites in the fall and 12 sites in the spring for tissue and sediment analysis of metals and metalloids

HMI PROJECT SUMMARIES

PROJECT II: Sedimentary Environment and Groundwater Monitoring

The Coastal and Environmental Geosciences Program of the MGS has been involved in monitoring the physical and chemical behavior of near-surface sediments around the \HMI DMCF from the initial planning stages of construction of the facility to the present. The facility stopped receiving dredged material in December, 2009. As part of the 31st year exterior monitoring program, MGS collected bottom sediment samples from 43 sites on both September 10, 2012 and April 2, 2013. The sediment samples were analyzed for various physical and chemical properties: (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).

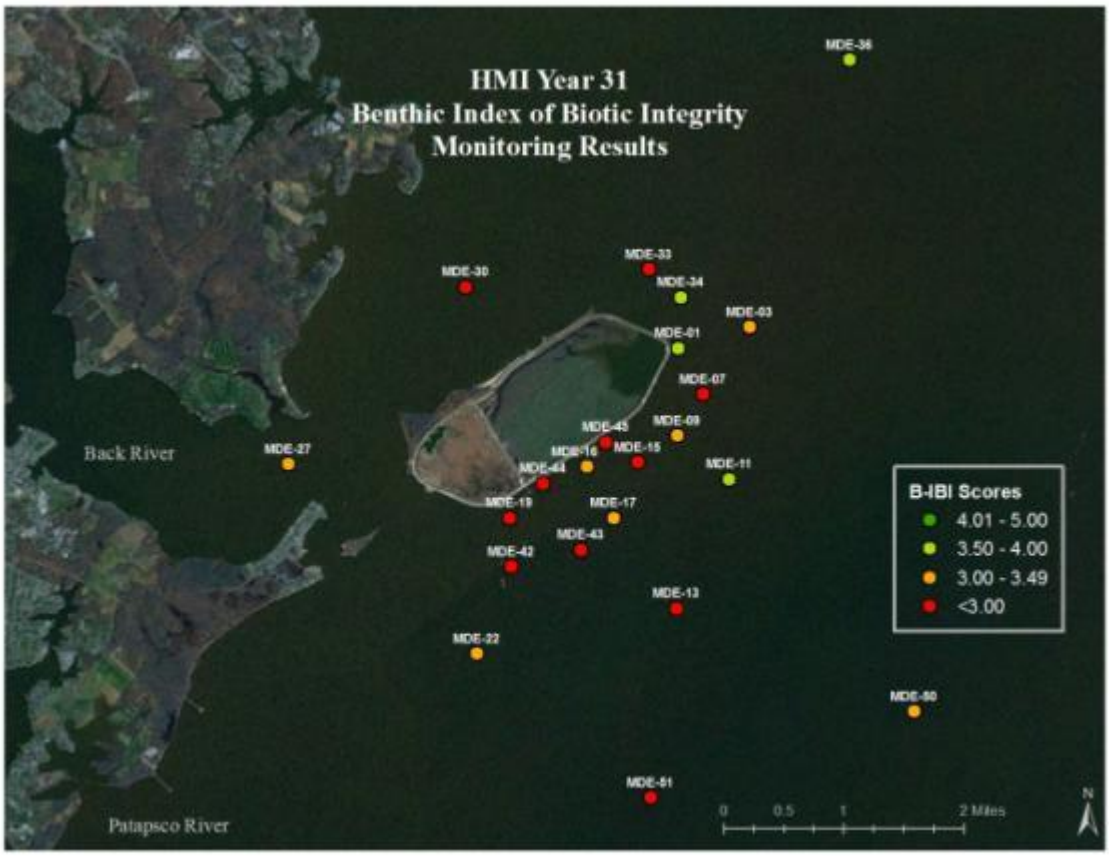
An analysis of the grain distribution of Year 31 displays no trends in the sedimentation patterns from cruise to cruise. The utilization and findings of the sedimentological procedures described in Kerhin et al. (1988) shows a depositional environment that is similar to the last five monitoring years. No significant changes occurred during Year 31. The sediment distribution pattern displays a pattern that is consistent with the findings of previous monitoring years dating back to 1988.

Metal data was interpreted by taking 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. Findings from the samples collected during Year 31 showed no aberrant behavior in metal levels, revealing statistics that are very similar to the previous two years. At most sampling sites, concentrations of Cr, Cu, and Pb in the sediment exceed the ERL (Effects Range Low) values, while concentrations of Ni exceed the ERM values at most sites. Additionally, concentrations of Zn exceed the ERM (Effects Range Median) values at some sites. However, these guidelines that are based on national data do not allow for unique Chesapeake Bay watershed conditions nor take into account grain size induced variability in metal concentrations in the sediment. Therefore, through the grain size normalization procedure that corrects the deficiencies and normalizes the data, findings reveal that Pb, and Zn are significantly enriched greater than two standard deviations (95%) in some samples compared to the previous year in terms of the number of sites and spatial distribution.

PROJECT III: Benthic Community Studies

Benthic communities in the vicinity of HMI were compared to communities located at some distance from the facility. Twenty-two stations were sampled on September 11, 2012 and on April 9, 2013. The water quality parameters measured *in situ* included dissolved oxygen concentrations, salinity, temperature, pH, conductivity, and Secchi depth. The salinity regime returned to its historical average after heavy freshwater inflows during Year 30.

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI), a multi-metric index of biotic condition that evaluates summer populations of benthic macro-invertebrates, was calculated for all stations sampled in September 2012.



Summary Figure 1-2: Year 31 B-IBI Monitoring Results

Findings in Year 31 showed that the health of the benthic macroinvertebrate community was less than historical averages. Out of 22 stations, nineteen performed below their historical averages. No stations met their historic highs. Year 31 marks the third consecutive year where B-IBI's have trended downward. This three year decline in B-IBI's can be attributed to fluctuations

in the invertebrate community, which includes a greater than 50 percent decrease in the abundance of the polychaete worm *M. virdis* and a decline in the bivalves *R. cuneata and M. balthica.* Since the organisms are sensitive to pollution, the decrease in these normally abundant organisms serves to results in an increase the proportion of pollution indicative organisms.

Multivariate analysis of September 2012 benthic invertebrate communities indicated that four distinct station groups out of thirteen total stations distributed broadly on the southern and northeast tip of the island, revealing stressed benthic invertebrate communities. The four stations were identified as outliers, representing benthic invertebrate communities with low similarity in comparison with the other stations.

PROJECT IV: Analytical Services

As part of the HMI annual exterior sediment survey for year 31, the University of Maryland for Environmental Science Chesapeake Biological Laboratory measured and evaluated the levels of sediment contaminants in the vicinity of HMI. On each occasion, a minimum of 10 sites were selected from the larger pool, where sediments and clams were collected and analyzed for total mercury (t-Hg), methylmercury (MeHg), silver (Ag), selenium (Se), arsenic (As), lead (Pb), and cadmium(Cd). The concentrations of target trace elements in surface sediments in a number of stations were also determined, including polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). The results of quality assurance (QA/QC) were acceptable. No sites investigated in 2012 had an enrichment of more than one trace element. In general, concentrations were similar to the sites' running median for 1998-2011. Additionally, the clam *Rangia* was collected from 11 stations, and similarly, concentrations in these clams were similar to the running mean determined from previous years with some exceptions. Concentrations of PCBs in sediment and clams were generally similar to or below the historical averages. The total concentrations of PAHs in sediment collected in 2012 from sites around the HMI complex were similar to or above historical levels with some exceptions. Concentrations of PAHs in clams were also at or above historical levels at all sites. All deviations from historical averages were within xxx standard deviations and are not considered as being "significant".

PROJECT I SUMMARY AND RECOMMENDATIONS

Due to this being only the third full year of post-closure exterior monitoring for HMI, monitoring needs to continue for a number of years to further evaluate changes, trends and impacts in the environment surrounding HMI. MGS collected bottom sediments from 43 sites on September 10, 2012 and April 2, 2013. These sediment samples were analyzed for various physical and chemical properties, which included grain size composition. The grain size distribution did not show any clear trends in sediment patterns from cruise to cruise. The effects from Hurricane Sandy, which occurred in October 2012, appeared to be minimal around the exterior HMI DMCF. The clay:mud ratios show that the depositional environment was similar during the years dating back to 1988, and no significant changes occurred in Year 31. Both Pb and Zn showed lower enrichment levels, both in terms of the number of sites and extended spatial distribution, compared to the previous year. During the fall, sediments were slightly enriched (3 sigma levels -99%) with Zn at one site. However, no sites were enriched with Zn in the spring. In the fall, 6 sites were enriched with Pb, and the number of sites and spatial distribution was similar to the findings of the previous spring. This lower enrichment of Pb and Zn in the spring can be explained by the dissipating effects from Hurricane Sandy, which occurred after samples taken in the fall. In general, elemental analyses showed the following at most sampling sites: Cr, Cu, and Pb exceeded ERL values and concentrations of Ni exceed the ERM values. At some sites, Zn exceeds the ERM values.

During Year 31, the HMI DMCF experienced interior water quality issues related to crust management operations in preparation for environmental restoration efforts and to unusual weather events, producing higher than normal rainfall. Low pH levels and high metals in the North Cell were reported both this past monitoring year and this monitoring year. No water was discharged directly from the North Cell spillways, nor was water transferred to the South Cell as it was done this previous year. Therefore, over 500 million gallons of water remain in the North cell at the end of the monitoring year. Additionally, if there are any future discharges from the facility, especially in the North Cell, continued monitoring should continue at the current level would be necessary in order to document the effect that operations haveon the exterior environment and to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of pool or crust management inside the facility. Close operation with MES is important in this endeavor. Also, in regards to water management, all discharged water meets the State Permit Regulations and is discharged within permit limits. The decline in B-IBI's continues to worsen in macroinvertebrate community with nineteen of the 22 stations demonstrating lower than their historic averages. While two stations tied their historic lows and four stations set new historic lows. None of the 22 stations met their historic highs. In Year 30, MDE reported that there was a cluster of contiguous stations close to the dike of the island and South Cell outfall/barge offloading dock that performed poorly. Combined with three nearby

passing stations, the group consists of eight stations at the southwest corner of HMI. While six of these eight failed to meet the benchmark criteria of 3.00 in Year 31, poorly performing stations were widespread throughout the HMI region and in every station type. Therefore, there is not convincing long-term historical evidence that this cluster is consistently or significantly poor. This area will receive more attention in Year 32. In the future, benthic monitoring will be maintained, but at a reduced level until stabilization of the island is complete, and this will involve sampling fifteen select sites.

For the analytical services, the objectives were to collect clams and associated sediments for analyses of trace elements. Other objectives were to determine the concentrations of target trace elements in surface sediments at a larger number of stations around HMI. PCB and PAH concentrations were determined. No sites investigated in 2012 had an enrichment of more than one trace element. Some trace element concentrations have been trending upward in recent years, but this may simply be part of an oscillation as we have seen in previous years. Some deviations in the relationships between trace elements in sediment suggest changes in source or are the result of differences in diagenetic behavior. Concentrations of trace elements in clams were similar to or below concentrations observed in previous years. Bioaccumulation of some trace elements such as MeHg occurred as expected. While concentrations of PCBs in sediment and clams were generally similar to or below the historical averages, some sites were enriched in other PCB congeners but the reason is unclear. The distribution of PAHs in clams was similar to the sediment but concentrations in clams are orders of magnitude lower than in sediment. Metabolism of PAHs by clams could be partially responsible for the difference in patterns, but also the type of particle the clam ingests.

Based on the data collected for this Year 31 report, the sediment triad approach to determining pollution-induced degradation (Summary Table 1 above) suggests that the aquatic habitat near HMI during Year 31 was impacted by pollution (Scenario 1 - Strong evidence for Pollution.) Nearly all stations have elevated levels of at least one of the metals analyzed. The Threshold Effects Level (TEL), ERM (Effects Range Median), and ERL (Effects Range Low), for certain contaminants are exceeded at a number of sites. In addition, low BIBI scores coincided with elevated contaminant levels at several sites. However, the validity of selecting Scenario – 1 as it relates to whether the cause is strictly a result of the activities at HMI, is questionable. Healthy benthic populations were also found in close proximity to HMI. The presence of both healthy and unhealthy benthic communities in the vicinity of HMI raises some doubt. However, the persistent enriched levels of some metals, the variability in benthic scores, and the inconclusive results of trace element analyses indicate a need for continued monitoring.

REFERENCES

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

APPENDIX 1: SEDIMENTARY ENVIRONMENT (PROJECT II)

(September 2012 - August 2013)

Technical Report

Prepared by
Darlene Wells, Elizabeth Sylvia, and Stephen Van Ryswick

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

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

March 2014

ACKNOWLEDGMENTS

For their assistance during the two Year 31 sampling cruises, we would like to thank the Maryland Department of Natural Resources for providing the research vessel *R/V Kerhin*, Captain Rick Younger for piloting the vessel and First Mate Keith Lindemann for assisting with the collection of samples. We would also like to thank Richard Ortt, Jr., for his assistance in the field. Finally, we extend our thanks to Carolyn Blakeney, Cassandra Carr, Rachel O'Shea, and Amanda Peñafiel at Maryland Environmental Service (MES), who provided us with much of the information related to site operations.

EXECUTIVE SUMMARY

The Coastal and Environmental Geosciences Program of the Maryland Geological Survey (MGS) has been involved in monitoring the physical and chemical behavior of near-surface sediments around the Hart-Miller Island Dredged Material Containment Facility (HMI DMCF) from the initial planning stages of construction of the facility to the present. The facility stopped receiving dredged material in December, 2009. As part of the 31st year exterior monitoring program, MGS collected bottom sediment samples from 43 sites on both September 10, 2012 and April 2, 2013. 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).

The grain size distribution of the Year 31 sediment samples does not show any clear trends in sedimentation patterns from cruise to cruise. Effects from Hurricane Sandy, which occurred at the end of October 2012, appear minimal around the exterior of the HMI DMCF. The clay:mud ratios show that the depositional environment was similar during the last five 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 31.

Elemental analyses data indicate that the sediments are similar to the previous year including the anomalously high Cr value measured at a sampling site in the Baltimore Harbor Zone of influence; this Zone has consistently been high in metals in previous years.

Based on summary statistics, the elemental data show that:

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

ERL and ERM threshold values are proposed criteria put forward by NOAA (Buchman, 2008) to gauge the potential for deleterious biological effects of specific metals. 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. MGS also utilized a grain size normalization procedure 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 the data are normalized, Pb and Zn are significantly enriched in some samples compared to the baseline.

In regard to potential adverse benthic effects, the overlap of enrichment and concentration can be used as an indicator of potential biological impacts: based on the intensity of the effect (enrichment based on sigma level, and concentrations exceeding ERL or ERM), Zn>Pb>Ni; in regard to the number of samples, Pb>Zn>Ni. From the preliminary toxicology work done in Year 25, enrichments of Zn and Pb are probably the most significant in influencing benthic communities as a result of HMI operations. Pb enriched samples are associated with the three local sources HMI, Baltimore Harbor and Back River. Zn on the other hand shows enrichment from Baltimore Harbor and a decreasing enrichment from HMI. The two sampling sites in Back River showed no enrichment for Zn. Prior to Year 28 monitoring, most of the samples with potential benthic effects due to high concentrations of Ni were in the Back River and Baltimore Harbor Zones of Influence. Between Monitoring Years 28 and 30, sigma levels of Ni steadily increased in the HMI Zone. This year, sigma levels of Ni were within normal ranges in the HMI Zone except at MDE-34 in the fall. However, in terms of absolute concentration, Ni exceeds ERL at most sites and ERMs and some sites.

Both Pb and Zn showed lower enriched levels, both in terms of the number of sites and extended spatial distribution, compared to the previous year. Sediments were slightly enriched (at 3 sigma levels – 99%) with Zn at one site in the HMI Zone during the fall; no sites were enriched with Zn in the spring. Six sites in the HMI Zone yielded sediments enriched in Pb in the fall, the number of sites and spatial distribution was very similar to the previous spring (2012). By spring 2013, the number of sites enriched with Pb dropped to two sites in the HMI Zone. The lower enrichment of Pb and Zn in the HMI Zone during the spring is attributed to dissipating effects from Hurricane Sandy which occurred just after the fall sampling (Cruise 65) and that there were no discharges from the facility between the fall and spring samplings.

During Year 31, the HMI DMCF continued to experienceinterior water quality issues related to crust management operations in preparation for environmental restoration efforts and to unusual weather events producing higher than normal rainfall. Similar to the previous year, MES documented very low pH as well as high metals in the North Cell on several occasions during this monitoring year. Therefore, no water was discharged directly from the North Cell spillways, nor was water transferred to the South Cell as it was done during the previous year. Consequently, over 500 million gallons of water still remain in the North Cell at the end of the monitoring year. Due to fragile pond conditions and efforts to control pH in the South Cell,

minimal water was discharged from the South Cell. If there are any future discharges from the facility, especially from the North Cell, continued monitoring at the current level would be necessary in order to document the effect that operations have on the exterior environment and to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of crust and water management inside the facility. Close cooperation with MES is important in this endeavor.

INTRODUCTION

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

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

Previous Work

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

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

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

For a number of years after HMI began operating, no major changes were observed in the surrounding sedimentary environment. Then, in April 1989, more than two years after the first release of effluent from the facility, anomalously high Zn values were detected in samples collected near Spillway 007 (Hennessee et al., 1990b). Zn levels rose from the regional average enrichment factor of 3.2 to 5.5; enrichment factors are normalized concentrations, referenced to a standard material. Enrichment factors are the ratios of concentrations, in this case Zn to Fe, which are in turn normalized to the same ratio in a standard reference material; this number is dimensionless. Effluent discharged during normal operation of the facility was thought to be the probable source of the enrichment of Zn accumulating in the sediments. This was confirmed by use of the Upper Bay Model (Wang, 1993), a numerical, hydrodynamic model, which was used to predict the dispersion of discharge from the facility, coupled with discharge records from the spillways. From the discharge records it was noted that there is a significant increase in metal loading to the exterior sediments during periods of low discharge [<10 million gallons per day (MGD)]; periods of higher discharge rates corresponded to lower metal levels in the exterior sediments.

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

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

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

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

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

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

released from the facility; the higher the discharge, the higher the concentration in the plume outside the facility.

The 3-D hydrodynamic model explains the structure of the plume of material found in the exterior sediments, but it does not explain why the level of Zn in the sediments increases at lower discharges. To account for this behavior, the chemistry of the effluent discharged from the facility was examined, as reported in the *Year 11 Technical Report*. As a result of this examination, a model was constructed to predict the general trend in the behavior of Zn as a function of discharge rate from the facility. The model has two components: (1) loading due to material similar to the sediment in place and (2) loading of enriched material as predicted from a regression line based on discharge data supplied by MES. The behavior of this model supports the hypothesis of metal contamination during low flow conditions. Sediments discharged from the facility are one of the sources of metals that enrich the exterior sediments. When exposed to the atmosphere, these sediments oxidize in a process analogous to acid mine drainage (i.e., sulfide minerals oxidize to produce sulfuric acid, which leaches acid-soluble metals, nutrients, and organic compounds that are released with the discharged waters). Since the initial detection of Zn, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, higher than expected levels of Zn and Pb have persisted in the vicinity of the facility. Figure 1-1, in addition to showing the sampling sites for Year 31, 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 31 years of monitoring that this occurred. Surprisingly, the record rainfall from back-to-back storms in Year 30 monitoring (i.e., Hurricane Irene, and Tropical Storm Lee) did not result in the any incursion of Baltimore Harbor material (MDE, 2013).

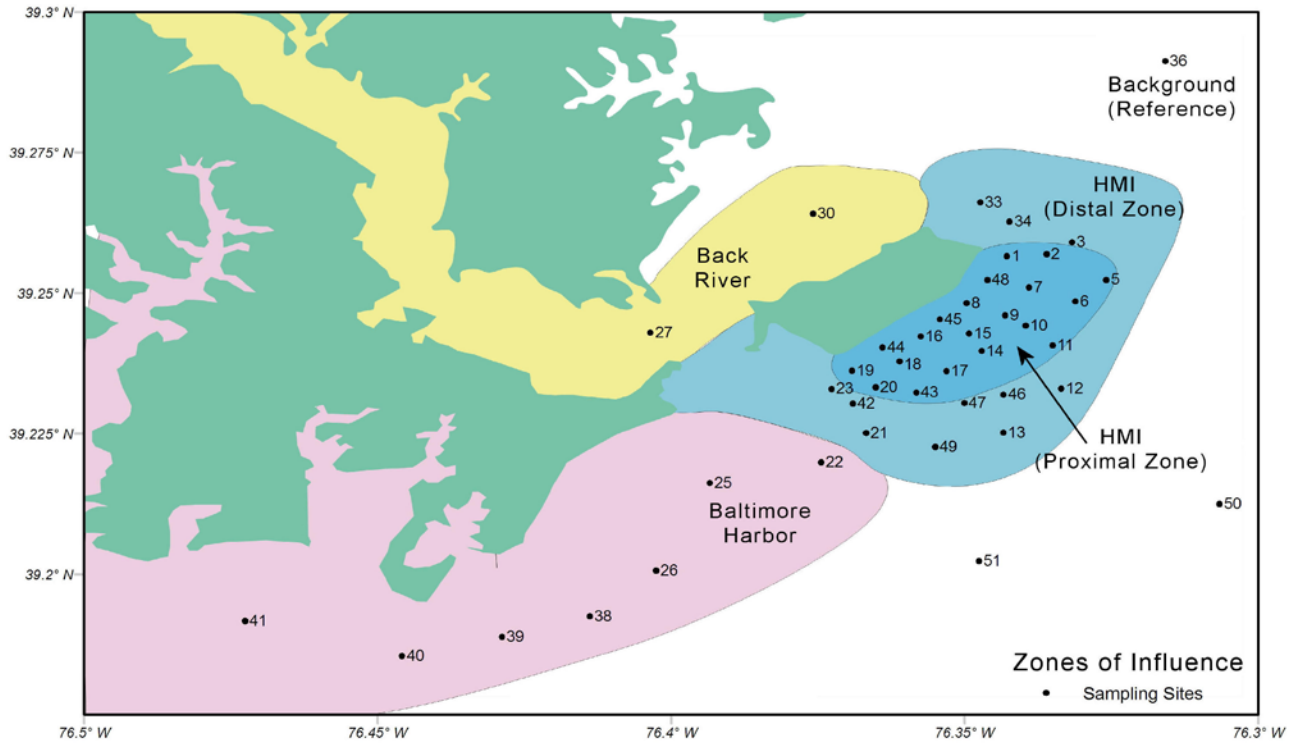


Figure 1- 1: Sampling locations for Year 31. Color areas show zones of influence found in previous studies. Stations 38 – 41 were added in Year 18 to measure the influence of Baltimore Harbor. Starting in Year 27, four stations in the Back River zone were dropped and additional stations added in the proximal zone and southeast of the facility, beyond the HMI zone of influence.

HMI stopped accepting dredged material after December 31, 2009 and facility operations shifted to dewatering and long-term crust management in the North Cell in preparation for environmental restoration activities. Past monitoring studies have shown that, during periods of extended crust management and dewatering when discharge volume is decreasing, metal concentrations in the discharge tend to increase. Therefore, metals

concentrations in the sediments in the region of HMI influence to the east of the facility are expected to increase during the post-closure operation phase. In anticipation of these changes, a modified sediment sampling scheme was implemented during the 27th monitoring year, to provide better coverage in targeted areas south and east of the facility (Rowe and Hill, 2008). The modified sampling scheme was continued during this 31st monitoring year (Figure 1.1).

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 31 cruises are summarized below. Information, which was provided by Carolyn Blakeney, Cassandra Carr, Rachel O'Shea, and Amanda Peñafiel of MES, covered the period from April 1, 2012 to April 30, 2013.

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

Figure 1-2 compares the monthly rainfall for HMI and Baltimore Washington International Airport (BWI) for the period between March 2012 and May 2013. The trend in monthly total precipitation recorded at HMI generally tracked that of BWI. The differences in HMI and BWI monthly amounts illustrate the variations in precipitation on a local scale. Hurricane Sandy, which made landfall near Brigantine, New Jersey on October 29, 2012, contributed significant rainfall to the Maryland-Delaware region, but not in the upper Susquehanna River Basin (Figure 1-3). HMI received 8.5 inches of rain from Hurricane Sandy over a two day period (October 29 and 30), representing a significant influx of water into the facility. Precipitation amounts for BWI were at or below normal for the rest of the monitoring year.

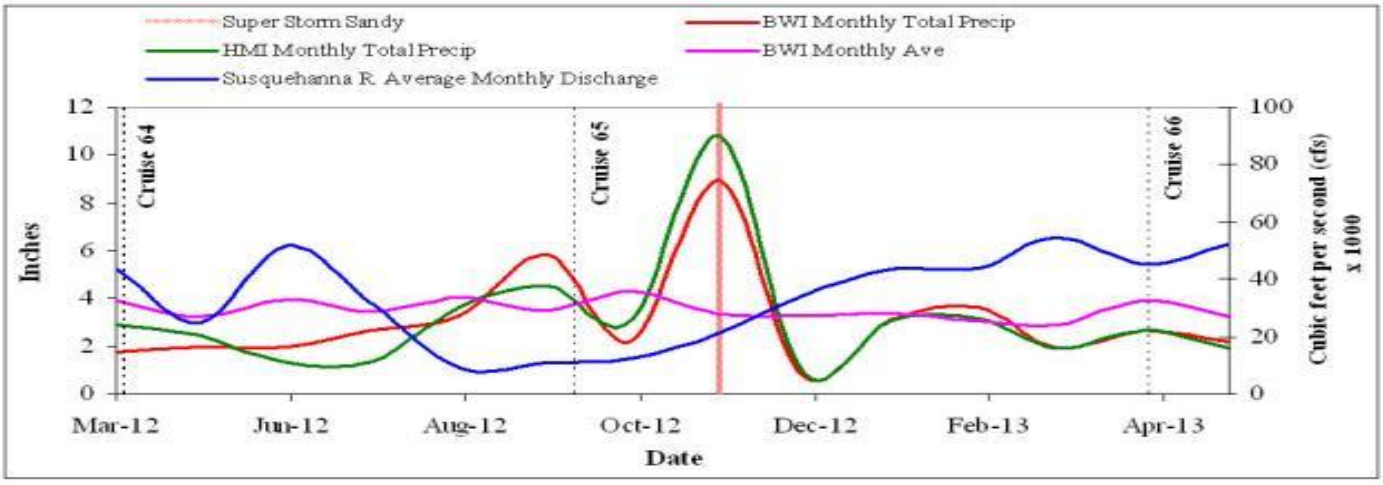


Figure 1- 2: Comparison of monthly precipitation data collected at HMI Facility and at the National Weather Service (NWS) Station at BWI (NOAA, 2013) with the average monthly discharge of the Susquehanna River. BWI monthly averages were based on monthly precipitation data from 1983 to 2012. Susquehanna River data were obtained from the USGS website (U.S.G.S, 2013).

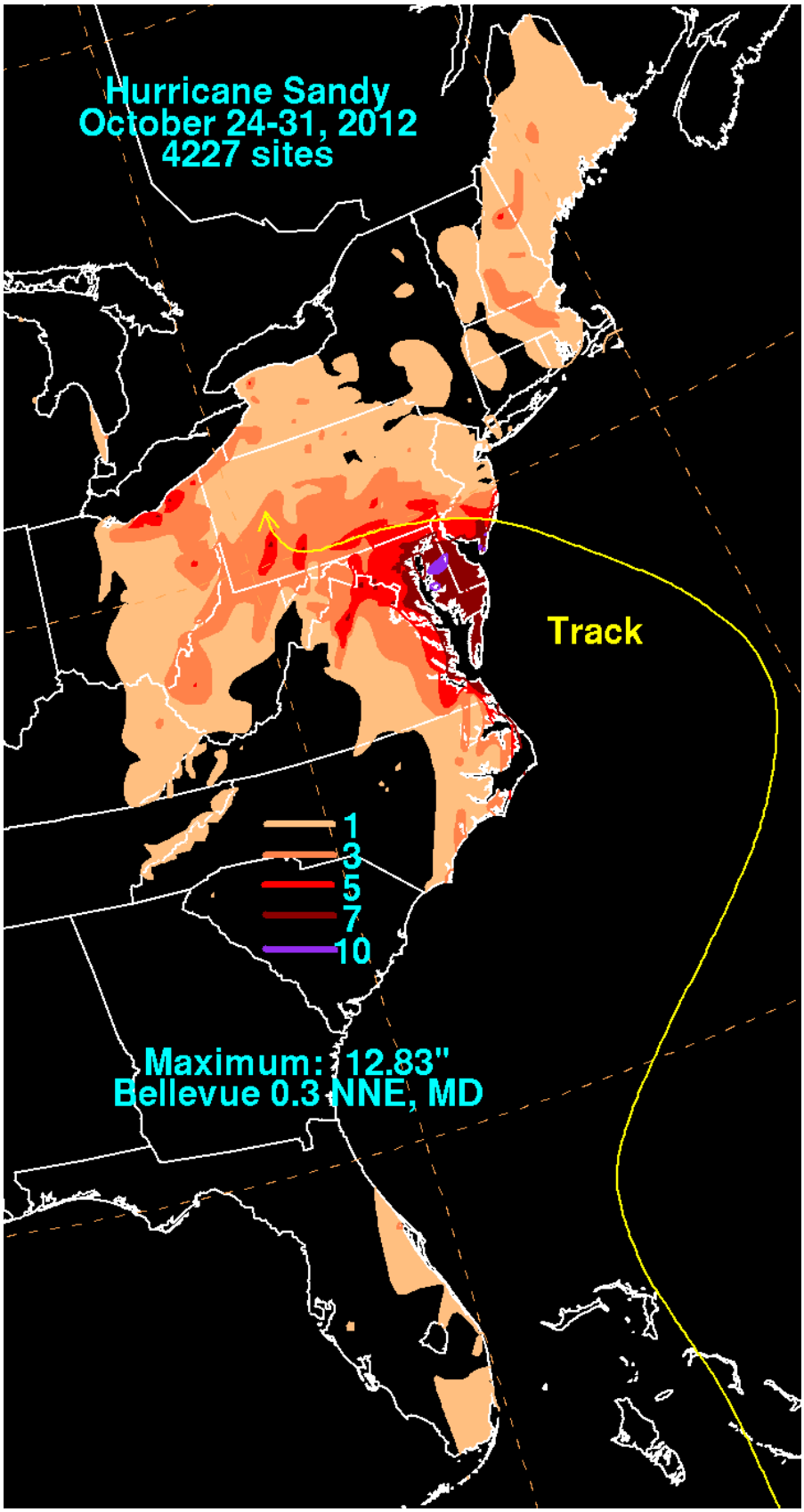


Figure 1- 3: Maps showing areal extent and amounts of rainfall produced by Hurricane Sandy during October 2012. Note that the highest rainfall totals were recorded on Maryland's eastern shore. The map was downloaded from NOAA's Weather Prediction Service web site (Roth, 2012).

Also shown in Figure 1-2 is the average monthly discharge for the Susquehanna River at the Conowingo Dam. As noted earlier, flow from the Susquehanna River influences the dispersion of material around HMI. During this monitoring year, the River flow was largely seasonal, with higher flow during the winter and spring (wet) and low flow during the summer and fall (dry). Unlike the previous year when rainfall from Tropical Storm (TS) Lee contributed to record high flow at Conowingo Dam, the Susquehanna River flow rate this year was not significantly influenced by Hurricane Sandy. For this monitoring period, the May-October average, which represents the low or dry season, was 22,844 cfs, and the November-April average, representing the wet, or high flow season, was 45,587 cfs. These seasonal averages were slightly higher compared to the high and low flow rates (40,878 cfs and 9,376 cfs, respectively) used in the hydrodynamic model to predict the dispersion of discharge from the facility (Wang, 1993).

The water in the South Cell continued to be treated for low pH using a lime doser. The treatments began on March 9, 2012, and ran in increments through June 2013 when the pH appeared to have stabilized (MES, 2012a, b, c, and d). The lime treatments in May and June were done to mitigate leakage of low pH water from the North Cell (MES, 2012b). The lime doser was then moved to the East Pit in the North Cell.

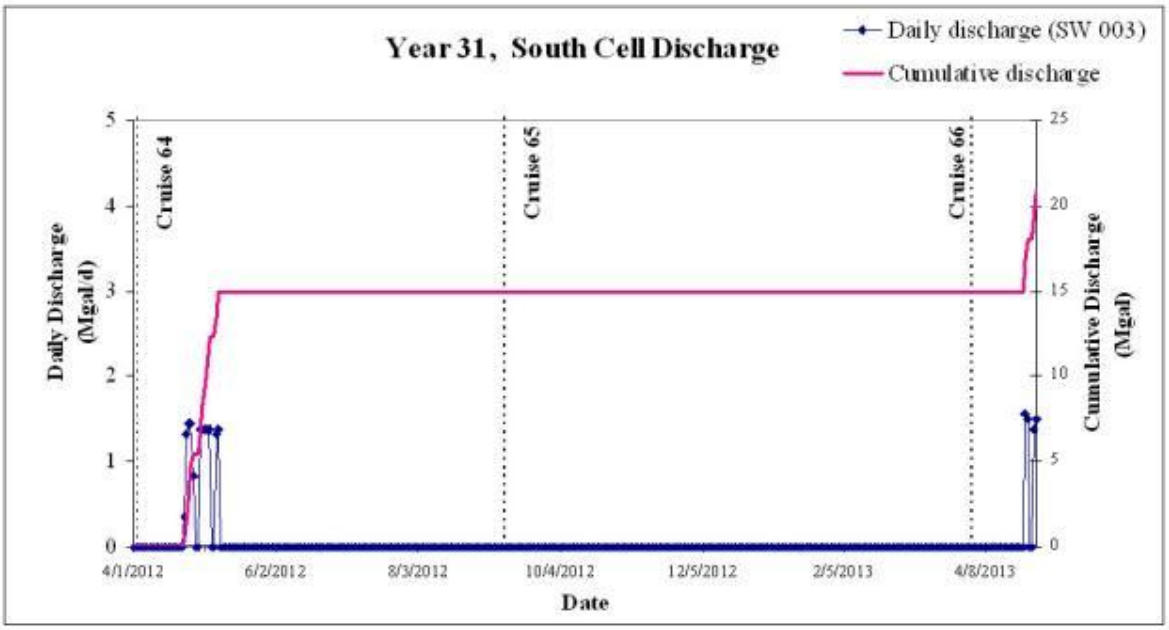


Figure 1- 4: Daily and cumulative discharge from the South Cell for the 13 month period covered in this report. The discharge from the South Cell is from SW003, which is the only discharge point for the Cell. The two discharges from SW003 were done to reduce pond level to the target elevation of 19.2 ft MLW (refer to Figure 1-5). The exterior sediment sampling events are marked by the vertical lines.

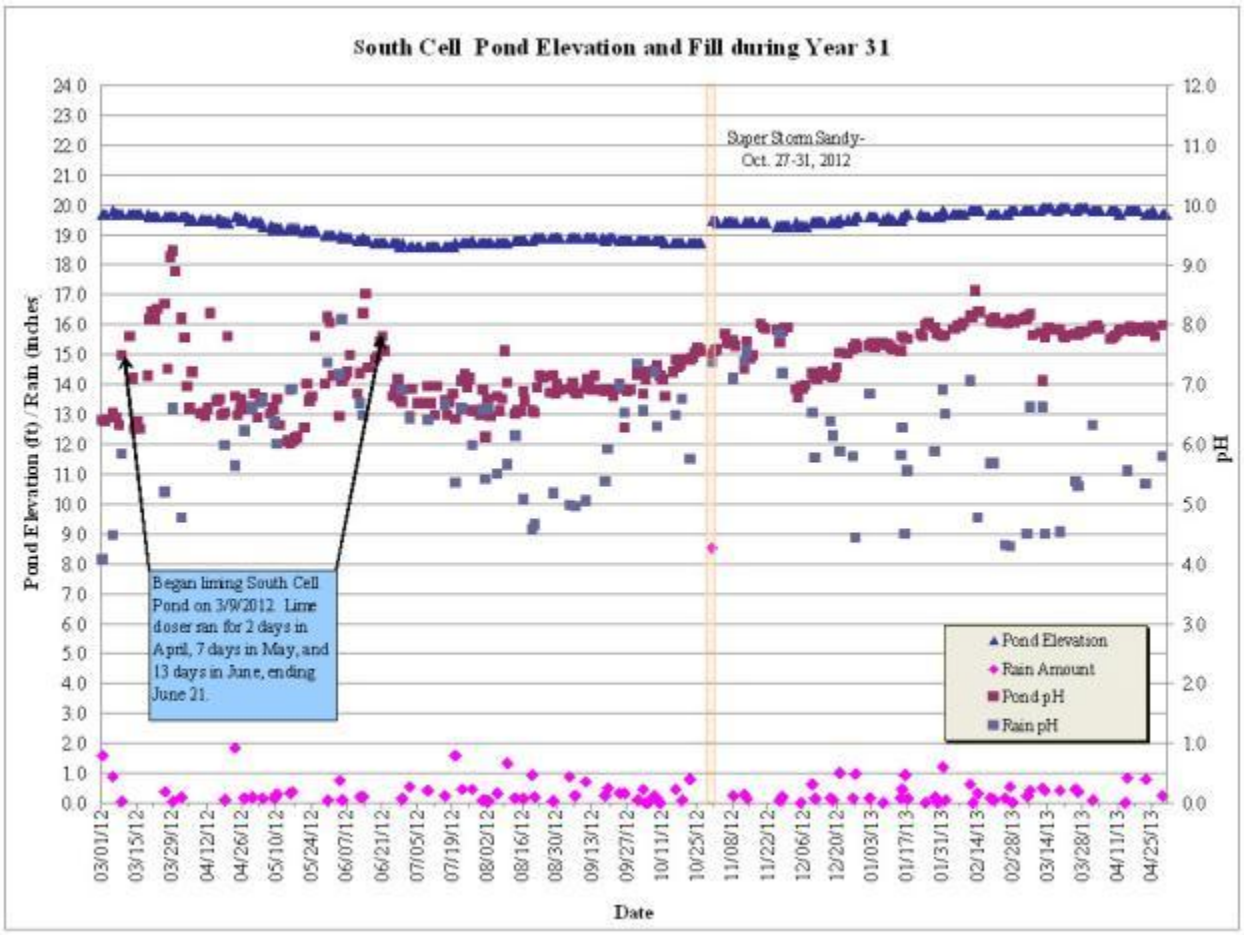


Figure 1- 5: Graph showing the South Cell pond elevation (blue triangles) and pond pH (red squares) for the 31st monitoring year. Also shown are daily precipitation amounts and rain pH collected at the HMIDMCF.

There were two periods of very low flow (*i.e.*, < 2 mgd) discharges from the South Cell (Figure 1.4). Both discharges were done to reduce the pond level to the target elevation of 19.2 ft MLW. Both discharges were within the discharge permit criteria. Between April 1, 2012 and April 30, 2013, total cumulative discharge from the South Cell into the Bay was 20.9 million gallons, the lowest volume since discharge from the South Cell began.

During the 31st year monitoring, there were no discharges from the North Cell into the Bay due to continued water quality issues within the cell (MES, 2012a, b, c, d; 2013a,b). The large influx of water from Hurricane Sandy had resulted pH levels to drop significantly, and metal concentrations to increase in the North Cell (MES, 2012d). To treat the low pH, lime dosers, in the East Pit in the North Cell, were operated from May to November, 2012 when the lime supply ran out. Future water treatment was put on hold until a final design for the North Cell development was chosen (MES, 2012d). MES continued to monitor pH, metal and alkalinity concentrations at the North Cell spillways. Within a month after the storm, metal

concentrations and pH levels at Spillways 007 and 008 recovered to within permit limits. Water quality at Spillway 009 continued to exceed permit limits. Copper and zinc concentrations were approximately 4 times permit limits and pH ranging between 2 and 3 (MES, 2012d).

OBJECTIVES

As with previous monitoring years, the main objectives of the Year 31 monitoring 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 10, 2012 (Cruise 65), and the second, on April 2, 2013 (Cruise 66).

Sampling sites (Figure 1-1) were located in the field by means of a Leica Model MX412B differential global positioning system (GPS) with a built-in beacon receiver. According to the captain, Rick Younger, the repeatability of the navigation system, that is, the ability to return to a location at which a navigation fix has previously been obtained is between 5-10 m (16-33 ft). Where replicates were collected, the captain repositioned the vessel between samples to counteract drifting off the station during sample retrieval. The captain recorded station coordinates and water depth at each site. Target and actual coordinates (latitude and longitude - North American Datum of 1983, or NAD83) of Year 31 sample locations are reported in the companion *Year 31 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 31 cruises. The stations were identical to those sampled during previous three monitoring years.

At 39 stations, a single grab sample was collected, described lithologically, and representative sample taken of the grab. Triplicate grab samples were collected at the remaining four stations (MDE-2, MDE-7, MDE-9 and MDE-30) and, likewise, described and subsampled.

Triplicate samples are identified by 'a, b, or c' after the station number. MGS analyzed each sample for grain size composition, a suite of trace metals, and total nitrogen, carbon and sulfur. During the September cruise, a second subsample was taken from each grab at all stations and analyzed by the Chesapeake Biological Laboratory (CBL) for a different suite of trace metals. Due to abundance of shell material, no sediment was collected from the grab sample at Station MDE-40 during the April 2013 cruise. Field descriptions of samples are included as appendices in the *Year 31 Data Report.*

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

Laboratory Procedures

Textural Analyses

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

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

where: Wc = water content (%)

Ww = weight of water (g)

Wt = weight of wet sediment (g)

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

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

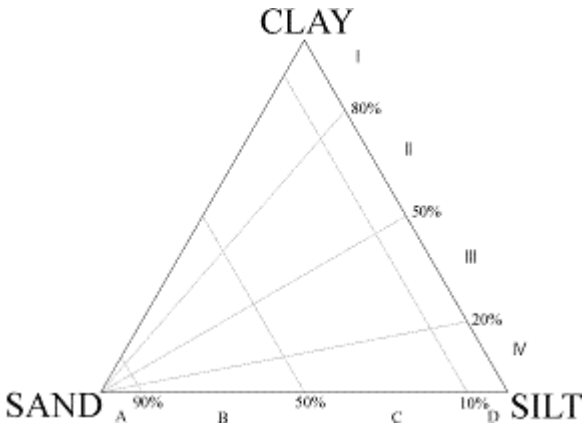


Figure 1- 6: Pejrup's Diagram (1988) classification of sediment type.

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

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

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

Elemental Analysis

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

Results of the analyses of the SRMs reported by ActLabs are presented in the *Year 31 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 31 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 31 results are discussed with respect to the preceding Year 30 results, and where appropriate, with references to earlier monitoring year results.

All sampling sites visited during Year 31 yielded results that can be compared to those measured during Year 30. The grain size composition (proportions of sand, silt, and clay) of the samples is depicted as a series of Pejrup's diagrams in Figure 1-7. Within a diagram, each solid circle represents one sediment sample. Related statistics, by cruise, are presented in Table 1-1.

Table 1-1: Summary statistics for Years 30 and 31, for 43 sediment samples common to all four cruises.

	Year 30		Year 31	
Variable	**Sept 2011 Cruise 63**	**Apr 2012 Cruise 64**	**Sept 2012 Cruise 65**	**Apr 2013 Cruise 66**
Sand (%)				
Mean	21.61	20.93	22.08	19.34
Median	4.21	4.34	4.53	4.22
Minimum	0.88	0.66	0.66	0.82
Maximum	96.83	96.46	96.76	98.26
Range	95.95	95.79	96.09	97.43
Count	43	43	43	42
Clay:Mud				
Mean	0.54	0.54	0.54	0.55
Median	0.54	0.55	0.55	0.56
Minimum	0.44	0.42	0.31	0.45
Maximum	0.64	0.62	0.62	0.62
Range	0.20	0.20	0.31	0.16
Count	43	43	43	42

The ternary diagrams show very similar distributions of sediment type compared to the previous year. The samples range widely in composition, from very sandy (>90% sand) to very muddy (<10% sand). Muddy sediments predominate; at least three-fourths of the samples

contain less than 10% sand. All of the points fall fairly close to the line that extends from the sand apex and bisects the opposite side of the triangle (clay:mud = 0.50 or 50%). For all four samplings (Cruises 63 through 66), most points lie above the 50% line (clay-silt boundary), indicating that the fine (muddy) fraction of the sediments contains more clay than silt.

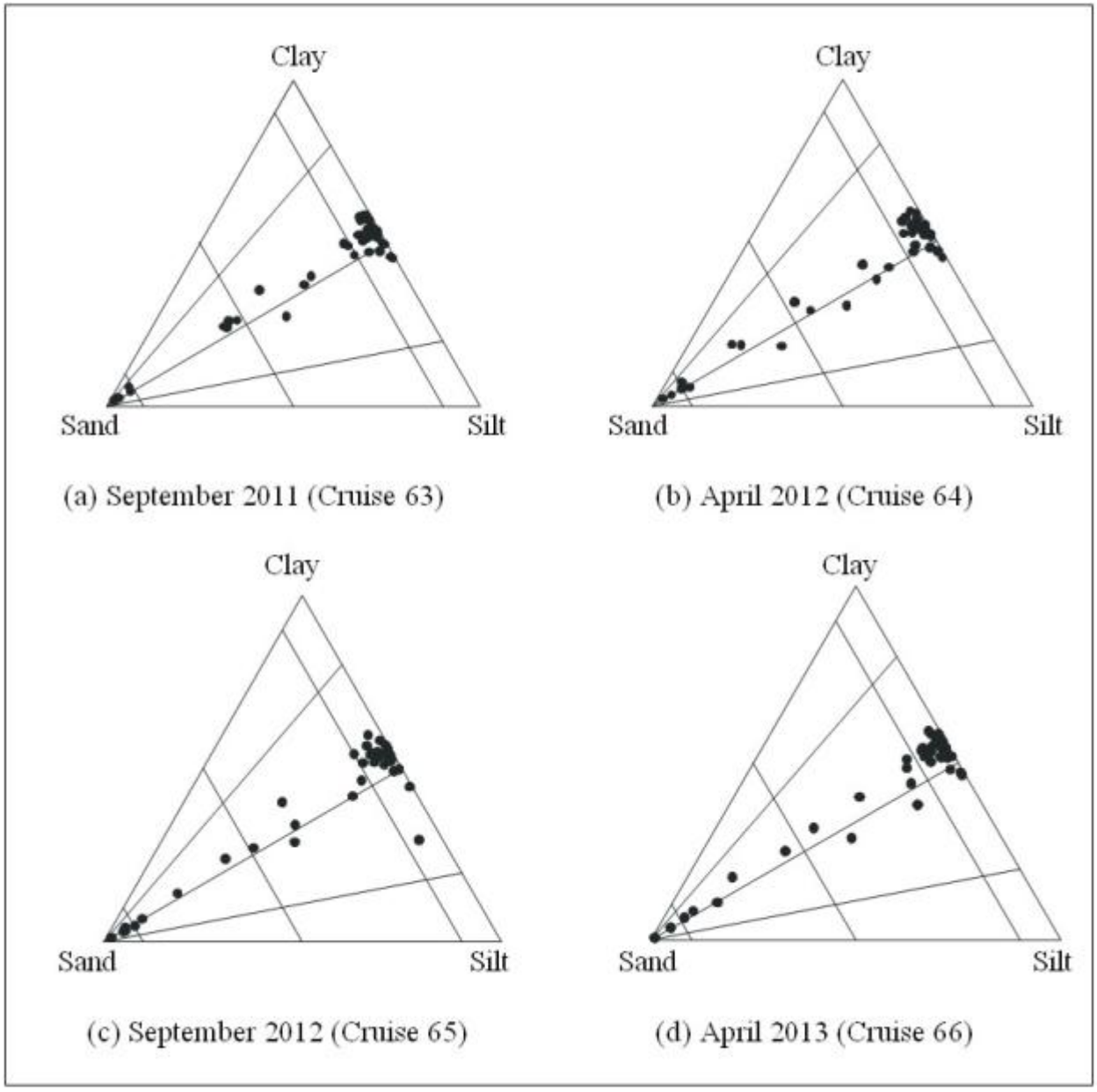


Figure 1- 7: Pejrup diagrams showing the grain size composition of sediment samples collected in Years 30 and 31 from the 43 sampling sites common to all four cruises: (a) September, 2011, (b) April, 2012, (c) September, 2012, and (d) April, 2013.

Based on the summary statistics (Table 1-1), average grain size composition, reported as % sand and as clay:mud ratios, varied little over the four sampling periods. The mean percentage of sand varied approximately 3% for the four samplings. The mean clay:mud ratio was 0.54 for sampling Cruises 63, 64, and 65, and increased slightly to 0.55 for Cruise 66. The

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

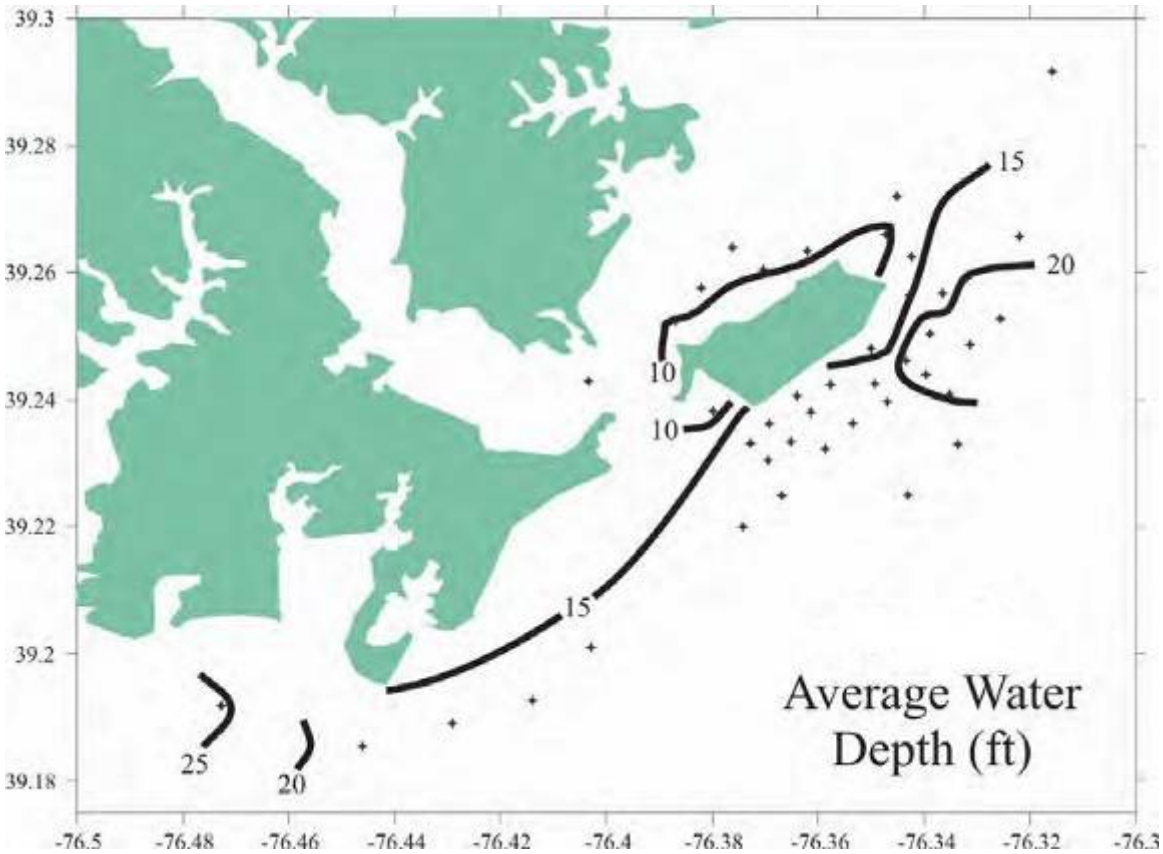


Figure 1- 8: Average water depths around HMI and vicinity. Contour interval = 5 ft.

Broadest north and west of the facility, the shoals are the erosional remnants of a larger neck of land. The once continuous landmass has been reduced to a series of islands, including Hart and Miller, extending from the peninsula that now forms the south shore of Back River. However, not all shallow water samples are sandy. In particular, several of the shallow water samples from Hawk Cove (*e.g.,* MDE-30) contain less than 10% sand. Sand distribution maps

for Years 30 and 31 are strikingly similar in appearance (Figures 1-9 and 1-10). Sand contents continue to be highest near the perimeter of HMI in shallow water depths. At the northeast end of the facility, the broad sand area, as defined by the 90% contour, underwent subtle seasonal shifts. The September 2012 distribution changed very little from the previous September 2011, indicating stable conditions. The sand area defined by the 90% contour shrank by April 2013 due to seasonal conditions, but also as a result of more fine grained material being moved and deposited as a result of Hurricane Sandy. In general though, the distribution of sand around HMI has remained largely unchanged since November 1988, two years after the first release of effluent from the dike.Compared to the distribution of sand, the distribution of clay:mud ratios has tended to be slightly more variable over time (Figures 1-11 and 1-12). The fine (mud) fraction of the sediments around HMI is generally richer in clay than in silt. That is, the clay:mud ratio usually exceeds 0.50, as shown in the ternary diagrams in Figure 1-7. However, slight variations in the most clay-rich (clay:mud ratio ≥ 0.60) and in the most silt-rich (clay:mud ratio < 0.50) of the fine fractions are evident at the mouth of Baltimore Harbor, which continued to be clay-rich for all of the four samplings. The areas of higher silt seen along the south perimeter of HMI are probably related to high turbulence associated with the dike wall, preventing the settling of the finer clay size sediment. These patterns of change are most likely due to the combined effects of the storms and seasonal changes. In previous monitoring years, the April samplings occur during a period of higher turbulence due to weather, whereas the September samplings take place after a comparatively quiet, low flow summer during which more clay size sediment accumulated on the bottom.

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

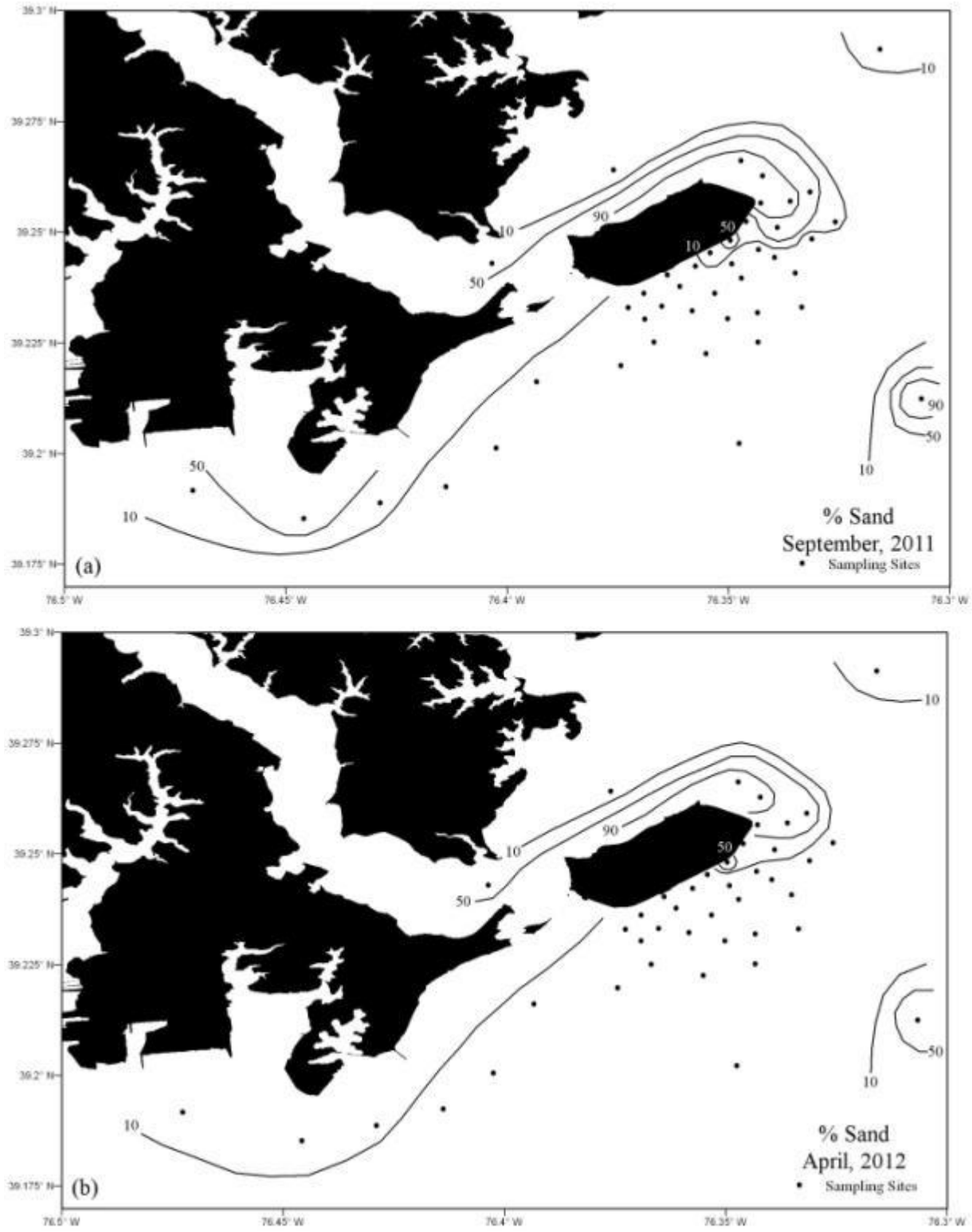


Figure 1- 9: Sand distribution for Monitoring Year 30: (a) September, 2011 (Cruise 63), (b) April, 2012 (Cruise 64). Contour intervals are 10%, 50%, and 90% sand.

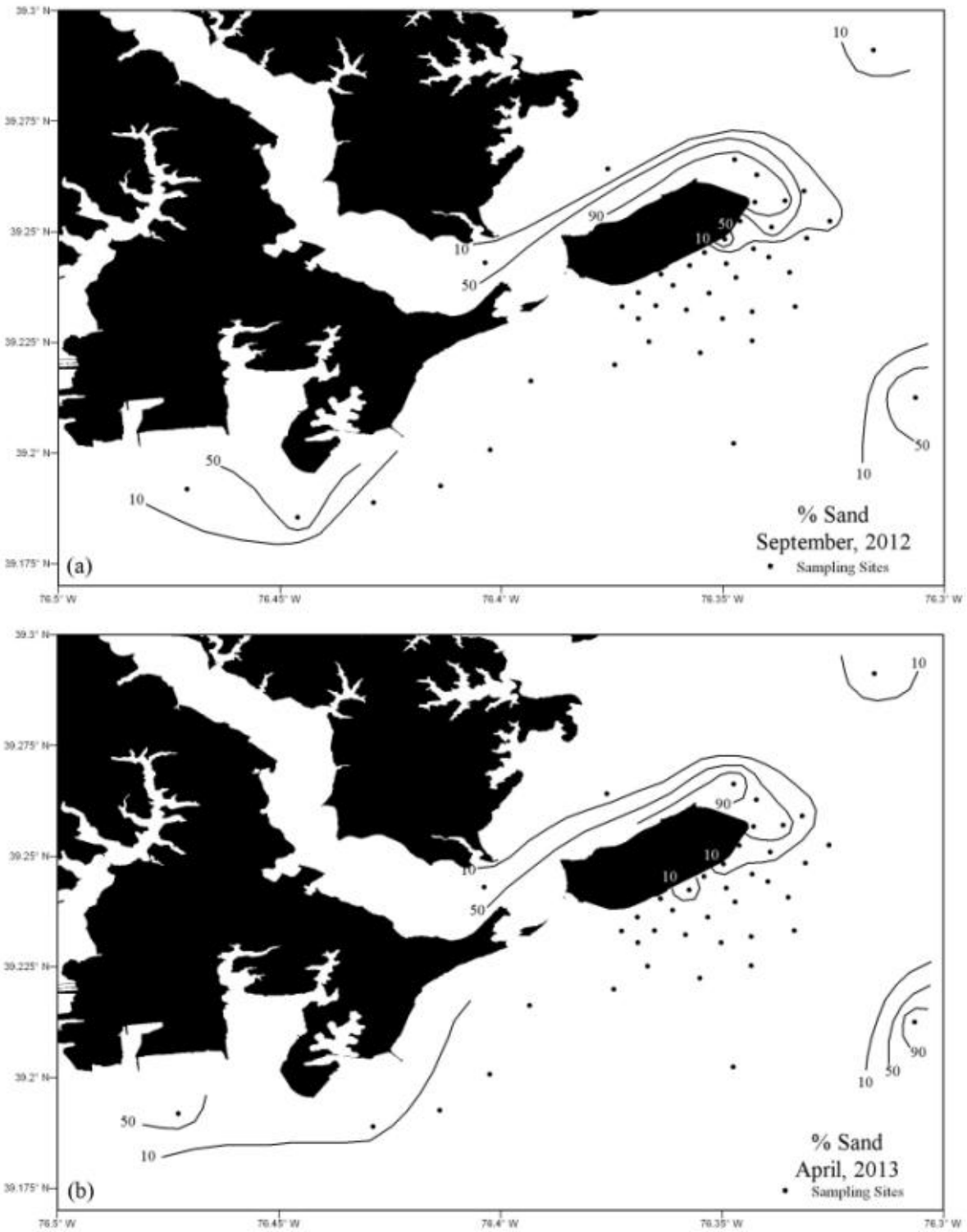


Figure 1- 10: Sand distribution for Monitoring Year 31: (a) September, 2012 (Cruise 65), (b) April, 2013 (Cruise 66). Contour intervals are 10%, 50%, and 90% sand.

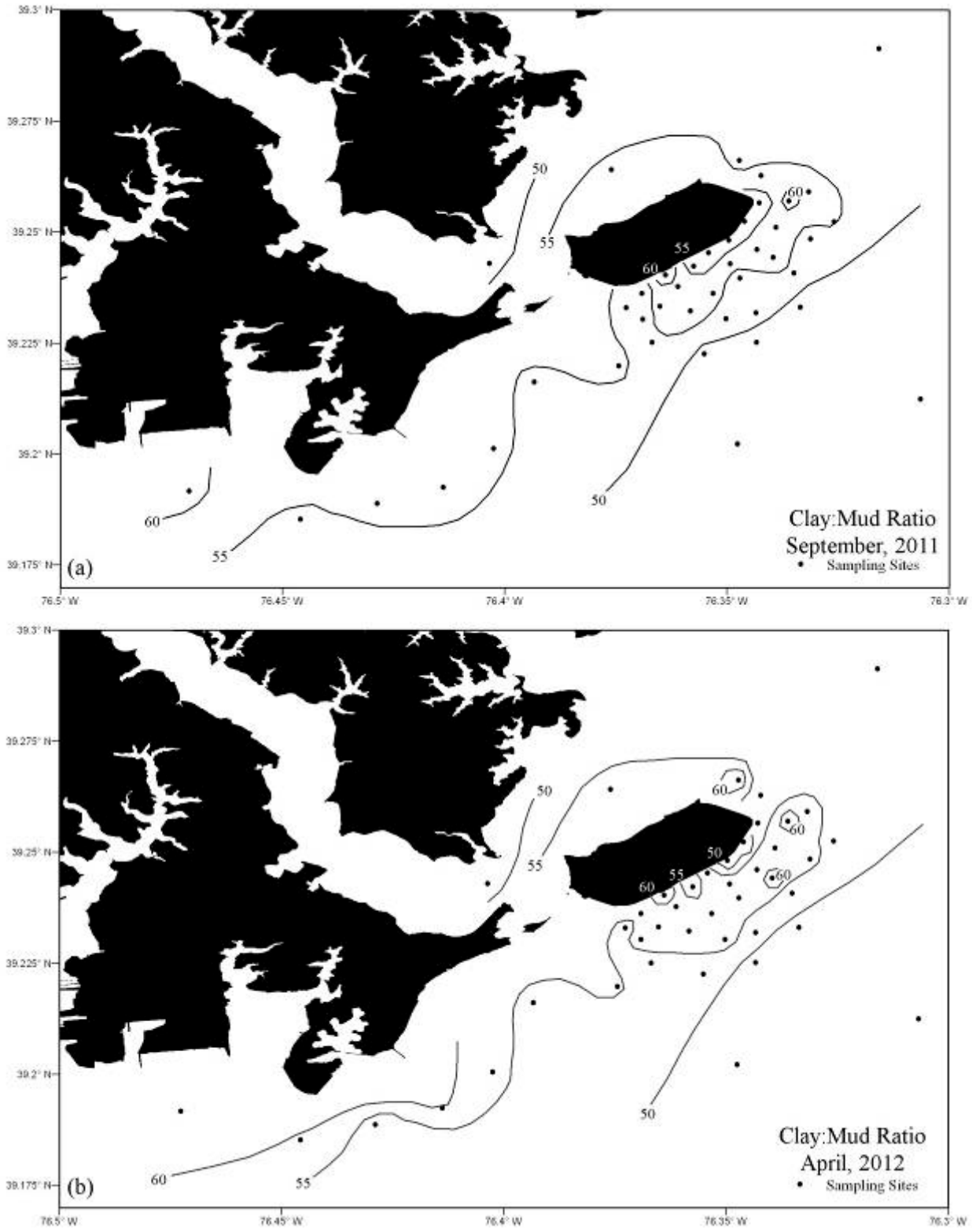


Figure 1- 11: Clay:Mud ratios for Monitoring Year 30: (a) September, 2011 (Cruise 63), (b) April, 2012 (Cruise 64). Contour intervals are 50%, 55%, and 60% (clay:mud ratio expressed as %).

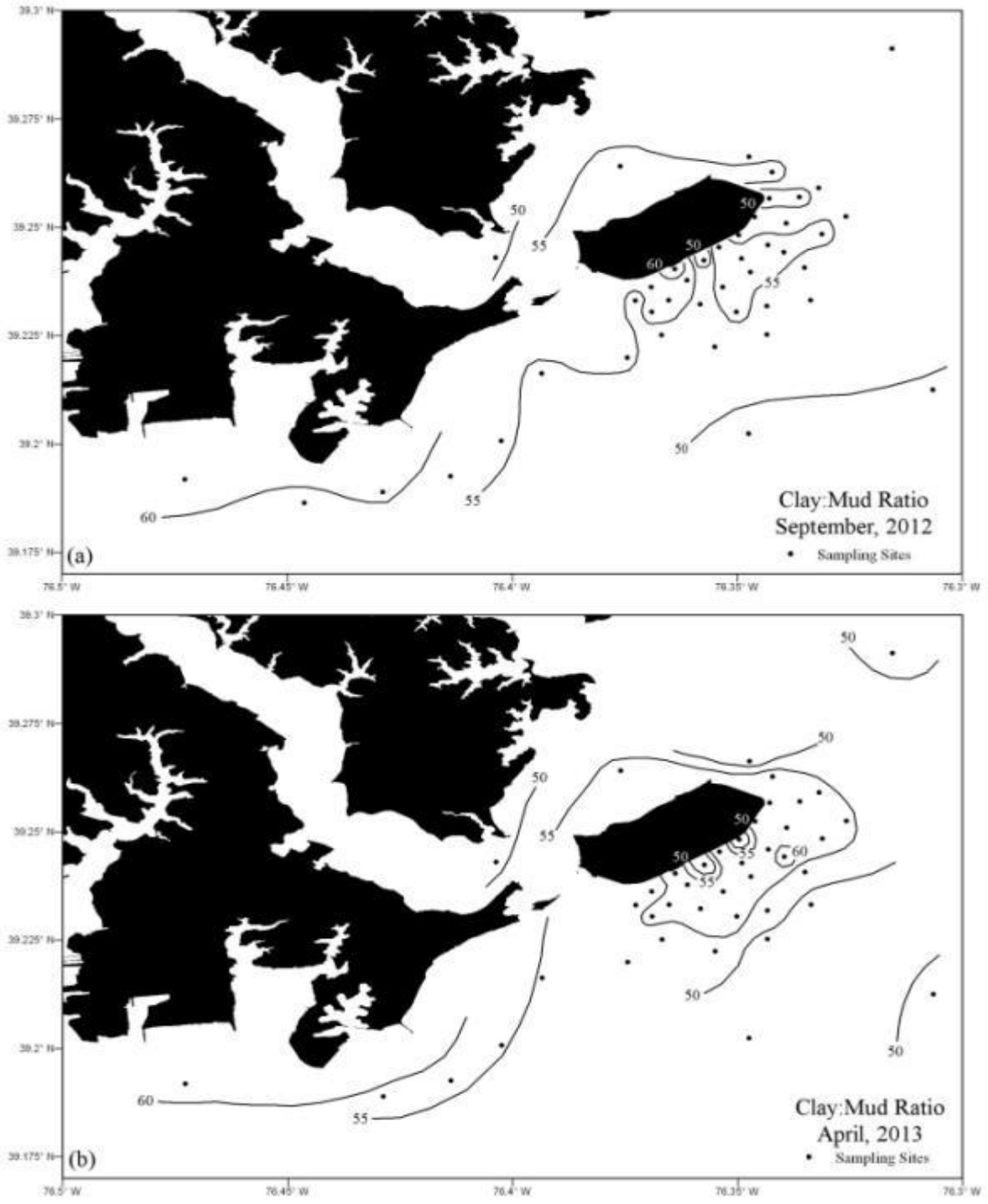


Figure 1-12: Clay:Mud ratios for Monitoring Year 31: (a) September, 2012 (Cruise 65), (b) April, 2013 (Cruise 66). Contour intervals are 50%, 55%, and 60% (clay:mud ratio expressed as %).

Elemental Analyses

Interpretive Technique for Metals

Previous monitoring years have focused on eight metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) 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:

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

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 Cu and Mn are weaker. 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.

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

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. 1σ = 30%, 2σ = 60%, etc.).

General Results

The summary statistics for the concentrations of the elements analyzed are given in Table 1-3. Generally, the statistics are very similar to the previous two years, including an anomalously high Cr value of 604 ppm which was measured from MDE-41 sampled during the September 2012 cruise. This sampling site is the upstream-most sample in the Baltimore Harbor Zone of influence and often has been high in one or more metals. The sample collected at this site in September contained significant gravel ~15%), a portion of which may have been 'slag' from Sparrows Point, which would explain the high Cr content as well as the high sigma levels for the metals (see next section). Included in Table 1-3 are the Effects Range Low (ERL) and Effects Range Median (ERM) values and the number of values reported for each metal exceeding the values (e.g., #>ERL, ERM).

With regard to ERL and ERM values listed in Table 1-3, the following statistics, which are very similar to the previous two years' findings, should be noted:

1. At most sampling sites, concentrations of Niand Zn in the sediment exceed the ERL values; and
2. At more than half of the sampling sites, concentrations of Cr, Cu, and Pb, in the sediment exceed the ERL values; and
3. At 75% of the sampling sites, concentrations of Ni exceed the ERM values; and concentrations of Zn exceed the ERM values at 16% of the 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 differences. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, certain samples are significantly enriched in Pb and to a lesser extent in Zn, compared to the baseline.

Table 1-3: Summary statistics for elements analyzed for Year 31. Both sampling cruises are included in summary. All concentrations are in ug/g (ppm) except Fe which is reported as percent (%). '*N*' is the total number of values reported above detection limits and represents the number of values used in calculating the average. No sediment sample was collected at station MDE-40 in the Spring 2013 (Cruise 66).

	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Avg	0.58	93	41	4.35	2873	70	50	296
Std	0.24	64	17	1.53	1454	28	23	139
Min	0.30	8	3	0.26	256	5	4	16
Max	1.40	604	80	6.39	7660	135	122	778
N	64	85	85	85	85	85	85	85
ERL	1.3	81	34	n/a	n/a	21	47	150
#>ERL	1	62	62			79	53	73
ERM	9.5	370	270	n/a	n/a	52	218	410
#>ERM	0	1	0			64	0	14

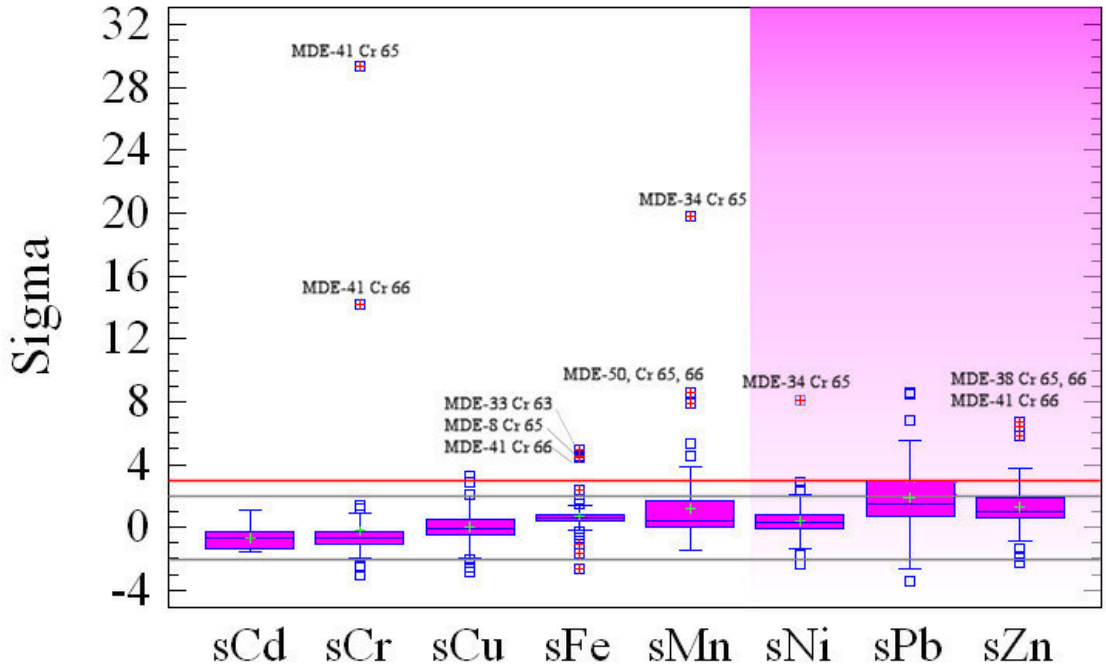


Figure 1- 13: A box and whisker diagram showing the range of the sigma levels for both the September and April cruises for Year 31. The box encloses the middle 50% of the sigma level values for each metal (interquartile range, IQR); the median is indicated by the black line within each box; the mean is indicated by the green +. The vertical lines, or whiskers, bracket the +/- 1.5 IQR. Inside outliers (between 1.5 and 3 IQR) and outside outliers (> 3 IQR), are plotted as individual points (shown as open blue squares, and blue squares with red +, respectively).

The values presented in Table 1-3 are the measured concentrations of metals in the sediment, not normalized with respect to grain size variability, as outlined in the preceding *Interpretive Techniques* section. Figure 1-13 shows the variation of the data from the predicted baseline behavior for each of the elements measured. The values are in units of multiples of standard deviations from the norm; zero values indicate measurements that are identical to the predicted baseline behavior, values within plus or minus two (2) sigma (indicated by grey lines in Figure 1-13) are considered to be within the natural variability of the baseline values. Cd, Cr, Cu, Fe, Mn and Ni at most sites for both sampling cruises are within the range expected for normal baseline behavior in the area. Approximately 26% of the samples contain Pb significantly exceeding the baseline levels (*i.e.*, >3 sigma levels, indicated by red line), 8% of the samples contain Zn levels exceeding the baseline. Only one sample (MDE-34, Cr. 65) contained Ni levels exceeding the baseline, a decrease in overall enrichment of Ni compared to the previous three years. Most of the samples with elevated Pb and Zn sigma levels, as well as many of the other elevated metal outliers shown in Figure 1-13, are in the Baltimore Harbor Zone of Influence, and are not a result of HMI discharge.

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

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

Sediments from several sites met these conditions. Samples for both September 2012 and April 2013 cruises from sites within the Baltimore Harbor Zone of influence (except MDE-22) and within the Back River Zone contained more than one target metal exceeding the ERL or ERM and sigma greater than 2. Within the HMI Zone of influence (both distal and proximal), the sediments containing multiple metals exceeding ERLs or ERMs, and sigma levels greater than 2 included Sites MDE-3, MDE-9, MDE-11, and MDE-46 from the September 2012 cruise, and sites MDE-9, MDE-11, MDE-18, and MDE-19 from the April 2013 cruise.

Metal Distributions

Beginning Year 8, increased metal sigma levels (specifically Zn) have been noted in bottom sediments east and south of Spillway 007; similarly since the Pb was added to the monitoring protocol (Year 15), elevated levels of Pb have been found in the same areas, but with generally higher relative loadings. In the last three monitoring years, elevated levels of Ni have been noted at several sites within the HMI zone of influence. The results of earlier HMI 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. During Year 31, there has been no discharge from the North Cell.

2. *Flow of freshwater into the Bay from the Susquehanna River* - The hydrodynamic environment of the Bay adjacent to HMI is controlled by the mixing of freshwater and brackish water south of the area. Details of the hydrodynamics of this region were determined by a modeling effort presented as an addendum to the *Year 10 Interpretive Report* (Wang, 1993). The effects of Susquehanna flow to the contaminant distribution around HMI follow;
    a. A circulation gyre exists east of HMI. The gyre circulates water in a clockwise pattern, compressing the discharge from the facility against the eastern and southeastern perimeter of the dike;
    b. The circulation gyre is modulated by fresh water flow from the Susquehanna River. The higher the flow from the Susquehanna, the stronger the circulation pattern and the greater the compression against the dike. Conversely, the lower the flow, the less the compression and the greater the dispersion away from the dike; and
    c. Discharge from the facility has no influence on the circulation gyre. This was determined by simulating point discharges of 0-70 MGD from three different spillways. Changes in discharge rate only modulated the concentration of a hypothetical conservative species released from the facility; the higher the discharge, the higher the concentration in the plume outside the facility.

3. *The positions of the primary discharge points from the facility* - The areal distribution of the metals in the sediment also depends on the primary discharge locations to the Bay. The effects of discharge location were determined as part of the hydrodynamic model of the region around HMI. The effects of discharge location are:

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

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

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

Figure 1-14 shows distribution of the sigma levels for Pb for Year 31 monitoring periods in the study area adjacent to HMI; sigma levels for Zn are shown in Figure 1-15. Sigma levels are the multiple of the standard deviation of the baseline data set. Data that fall 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. Levels greater than3 sigma are significantly elevated above background. As shown in Figure 1-1, there are three primary areas of interest that will be referred to as: Back River, Baltimore Harbor, and HMI Zones of Influence.

Back River - The Back River influence is seen for Pb even though only two sites within this zone were sampled this monitoring year. As with previous years, Pb continues to be discharged by Back River during both of the sampling periods. Based on the two sites, Ni (distribution map not shown) and Zn concentrations were within background levels for both sampling cruises.

Baltimore Harbor - Elevated levels of Pb and Zn extend into the area southwest of HMI. In spite of the major storms that have affected the area in the past two years, the distribution of the levels for these metals remain separated from the HMI Zone of Influence adjacent to the island. Pb and Zn showed similar enrichment values as compared to Year 30. The only difference is MDE-38, instead of MDE-41, contained the highest sigma levels for both Pb and Zn for both cruises.

HMI – Pb levels within the HMI Zone are lower, in terms of the number of samples exceeding 3σ, and overall sigma levels, compared to the previous year. The September 2012 spatial extent of Pb enrichment included two areas: two sites (MDE-33 and -34, off northeast tip of the facility); the second area extending from the facility southeast and encompassing 4 sites (MDE-6, -8, -9, and MDE-11). By April 2013, the area of Pb enrichment was confined to two isolated sites (MDE-14, and -18). Only one site (MDE-34) in September 2012 yielded elevated Ni levels; no sites within the HMI Zone of influence yielded elevated Ni levels in April 2013. In September, 2012, Zn enrichment was documented at one isolated site (MDE-11). In April 2013, Zn enrichment (> 3 sigma) was not documented at any sites within the HMI Zone.

Spatial distribution of Pb enriched areas in September, 2012 which is very similar to the pattern seen the previous fall, show that the enrichment of Pb has persisted, even though there has been very little discharge from the facility. There have been no discharges directly from the North Cell since February 2011. The last discharge from the South Cell (SW003) ended on May 8, 2012, prior to the fall sampling. This discharge was very low, less than 2 mgd, and totaled 15 mcy. However, as noted earlier, discharges with flow rates < 10 mgd contribute excess metals to the sediments whereas higher flow rates generally do not. The Pb enriched areas documented in the fall 2012 may be remnants of the discharge from the previous May. The Pb enriched areas most likely were further dispersed when Hurricane Sandy passed through the area at the end of October 2012. By the spring sampling, Pb enriched areas decreased significantly, limited to two sites south of the facility.

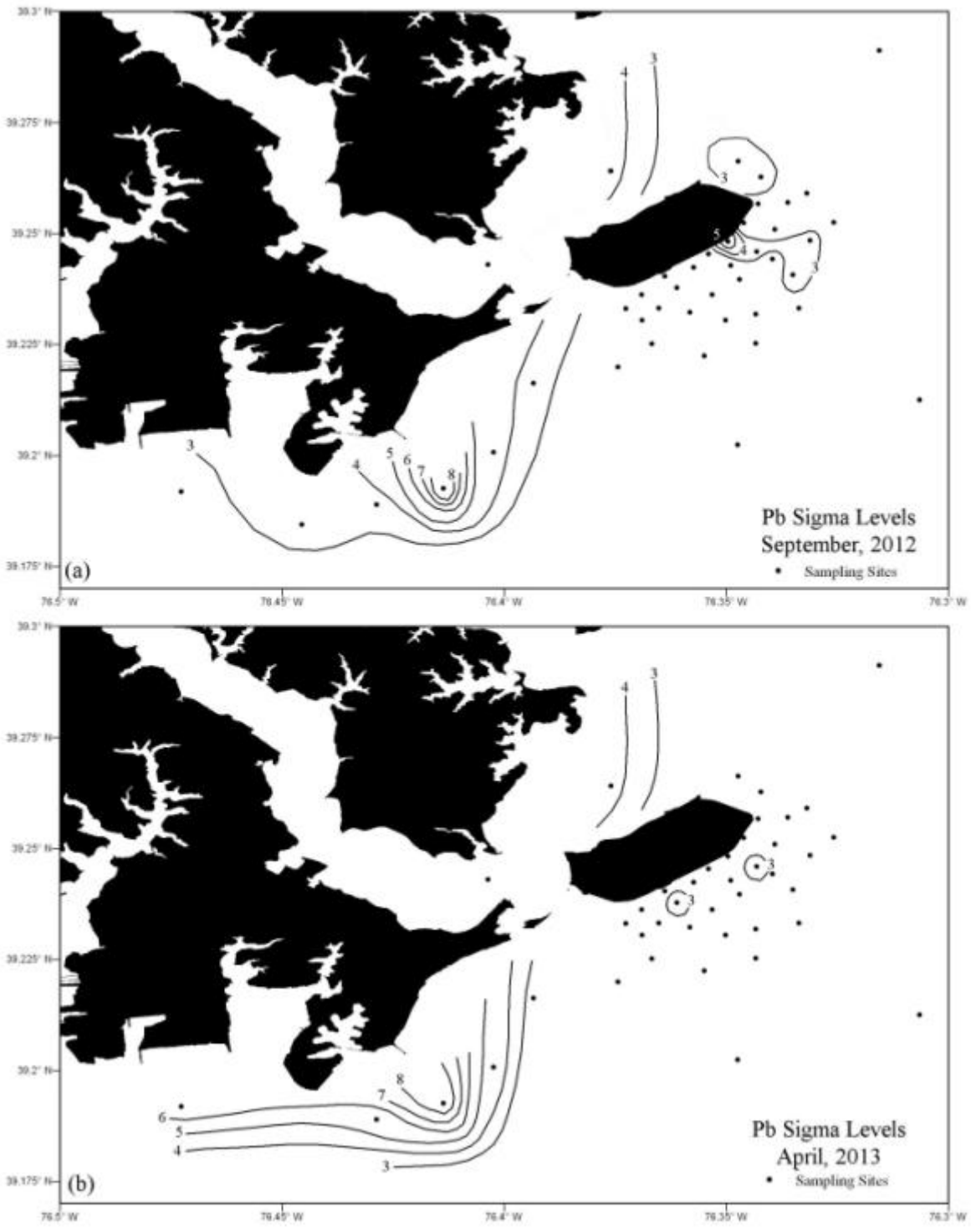


Figure 1- 14: Distribution of Pb in the study area for the September, 2012 and April, 2013 sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (contour intervals less than 3 not shown), >3 = significantly enriched.

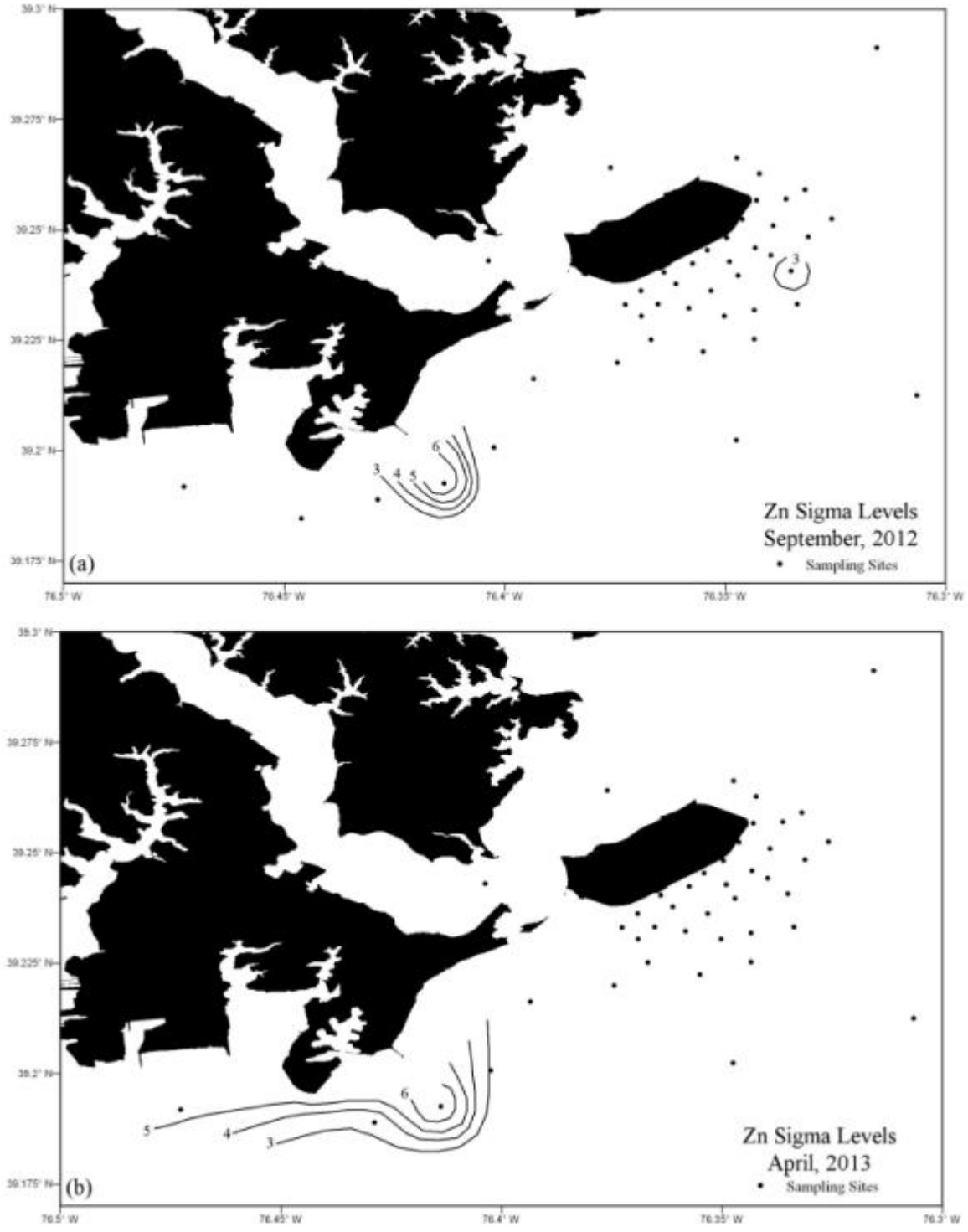


Figure 1- 15: Distribution of Zn in the study area for the September, 2012 and April, 2013 sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional (contour intervals less than 3 not shown), >3 = significantly enriched.

CONCLUSIONS AND RECOMMENDATIONS

The grain size distribution of the Year 31 sediment samples does not show any clear trends in sedimentation patterns from cruise to cruise. Effects from Hurricane Sandy appear minimal around the exterior of the HMI DMCF. The clay:mud ratios show that the depositional environment was similar during the last five 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 31.

Elemental analyses data indicate that the sediments are similar to the previous year including the anomalously high Cr value measured at a sampling site in the Baltimore Harbor Zone of influence; this Zone has consistently been high in metals in previous years.

Based on summary statistics, the elemental data show that:

1. At most of the sampling sites, concentrations of Ni and Zn in the sediment exceed the ERL values;
2. At more than half of the sampling sites, concentrations of Cr, Cu, and Pb, in the sediment exceed the ERL values; and
3. At 75% of the sampling sites, concentrations of Ni exceed the ERM values; and concentrations of Zn exceed the ERM values at 16% of the 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 are significantly enriched in some samples compared to the baseline as in previous years.

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), Zn>Pb>Ni; in regard to the number of samples, Pb>Zn>Ni. From the preliminary toxicology work done in Year 25, enrichments of Zn and Pb are probably the most significant in influencing benthic communities as a result of HMI operations. Pb enriched samples are associated with the three local sources HMI, Baltimore Harbor and Back River. Zn on the other hand shows enrichment

from Baltimore Harbor and a decreasing enrichment from HMI. The two sampling sites in Back River showed no enrichment for Zn. Prior to Year 28 monitoring, most of the samples with potential benthic effects due to high concentrations of Ni were in the Back River and Baltimore Harbor Zones of Influence. Between Monitoring Years 28 and 30 , sigma levels of Ni steadily increased in the HMI Zone. This year, sigma levels of Ni were within normal ranges in the HMI Zone. However, in terms of absolute concentration, Ni exceeds ERL at most sites and ERMs and some sites.

Both Pb and Zn showed lower enriched levels, both in terms of the number of sites and extended spatial distribution, compared to the previous year. Sediments were slightly enriched (3 sigma levels) with Zn at one site in the HMI zone during the fall; no sites were enriched with Zn in the spring. Spatial distribution of Pb enriched areas in September, 2012 which is very similar to the pattern seen the previous fall, show that the high Pb has persisted, even though there has been very little discharge from the facility. By the spring sampling, Pb enriched areas decreased significantly, limited to two sites south of the facility. The lower enrichment of Pb and Zn in the HMI Zone during the spring is attributed to dissipating effects from Hurricane Sandy which occurred just after the fall sampling (Cruise 65) and that there were no discharges from the facility between the fall and spring samplings.

During Year 31, the HMI DMCF continued to experience interior water quality issues related to crust management operations in preparation for environmental restoration efforts and to unusual weather events producing higher than normal rainfall. Similar to the previous year, MES documented very low pH as well as high metals in the North Cell on several occasions during this monitoring year. Therefore, no water was discharged directly from the North Cell spillways, nor was water transferred to the South Cell as it was done during the previous year. Consequently, over 500 million gallons of water still remain in the North Cell at the end of the monitoring year. Due to fragile pond conditions and efforts to control pH in the South Cell, minimal water was discharged from the South Cell. If there are any future discharges from the facility, especially from the North Cell, continued monitoring at the current level (fall and spring sampling at 42 sites) would be necessary in order to document the effect that operations has on the exterior environment and to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of crust and water management inside the facility. Close cooperation with MES is important in this endeavor.

REFERENCES

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

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

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

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

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

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

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

MES, 2012a, January - March 2012 Quarterly Update: Metals and pH treatment at Hart-Miller Island, Cox Creek and Masonville DMCFs, April 6, 2012, Update 205_040612. 3 p

MES, 2012b, April - June 2012 Quarterly Update: Metals and pH treatment at Hart-Miller Island, Cox Creek and Masonville DMCFs, July 6, 2012, Update 206_070612. 2 p

MES, 2012c, July - September 2012 Quarterly Update: Metals and pH treatment at Hart-Miller Island, Cox Creek and Masonville DMCFs, October 5, 2012, Update 207_100912. 2 p

MES, 2012d, HMI pH management, October, 2012, 17 p.

MES, 2013a, October – December 2012 Quarterly Update: Metals and pH treatment at Hart-Miller Island, Cox Creek and Masonville DMCFs, January 4, 2013, Update 208_010413. 2 p

MES, 2013b, January - March 2013 Quarterly Update: Metals and pH treatment at Hart-Miller Island, Cox Creek and Masonville DMCFs, April 5, 2013, Update 209_040513. 2 p

NOAA, 2012, National Weather Service Forecast Office- Local Weather: Baltimore/Washington website: http://www.nws.noaa.gov/climate/local_data.php?wfo=lwx

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

Roth, D., 2011, Weather Prediction Center, NOAA, downloaded from: http://www.hpc.ncep.noaa.gov/tropical/rain/

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

U. S. Geological Survey, 2013, National Water Information System: Web Interface: Susquehanna River at Conowingo, MD, and Patapsco River at Elridge, MD: http://waterdata.usgs.gov/nwis/ (accessed Dec. 12, 2013).

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

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

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

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

Wells, D.V., Sylvia, E., and Van Ryswick, S., 2013, Sedimentary Environment (Project II) in MDE, Assessment of Impacts from the Hart-Miller Island Dredged Material Containment Facility, Maryland: Year 30 Exterior Monitoring Technical Report (Sept. 2011 – August 2012), Appendix II, p. 26-74.

APPENDIX 2: BENTHIC COMMUNITY STUDIES (PROJECT III)

(September 2012 – August 2013)

Technical Report

Prepared by:
Jeff Carter, Principal Investigator
Patricia Brady, Co-principal Investigator
Nicholas Kaltenbach, Co-principal Investigator
Chris Luckett, Taxonomist
Jan Anderson, Research Assistant
Kasey Bolyard, Research Assistant
Cheyenne Owens, Research Assistant
Charles Poukish, Program Manager

Maryland Department of the Environment
Science Services Administration
Field Evaluation Division

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

January 2014

EXECUTIVE SUMMARY

The benthic macroinvertebrate community in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI-DMCF) was studied for the thirty-first 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 11, 2012 and on April 9, 2013.

The salinity regime had returned to its historical average range after heavy freshwater inputs in early Year 30. The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI), a multi-metric index of biotic condition that evaluates summer populations of benthic macro-invertebrates, was calculated for all stations sampled in September 2012. Metrics applicable to the low mesohaline classification (5 - 12 ppt) were used. The B-IBI's and derivative metrics were compared to historical data and were analyze both spacially and statistically.

The health of the benthic macroinvertebrate community around HMI in Year 31 was worse than historical averages. B-BIBI's around the island were at or near historical lows. Eleven of the 22 stations failed to meet the benchmark criteria of 3.00. Nineteen of the 22 stations performed below their historic averages. Two stations tied their historic lows. Four stations set new historic lows; and no stations met their historic highs. Year 31 is the third consecutive year where B-IBI's have been trending downward.

In Year 30, MDE reported that there was a cluster of contiguous stations close to the dike of the island and South Cell outfall/ barge offloading dock that performed poorly. Combined with three nearby passing stations, the group consists of eight stations at the southwest corner of HMI. While six of these eight failed to meet the benchmark criteria of 3.00 in Year 31, poorly performing stations were widespread throughout the HMI region and in every station type. There is not convincing long-term historical evidence that this cluster is consistently or significantly poor. This area will receive more attention in Year 32.

The three year decline in B-IBI's can be attributed to fluctuations in the invertebrate community. They include a greater than 50 percent decrease in abundance of the polychaete worm *M. viridis* (typically dominant) and a decline in the bivalves *R. cuneata* and *M. balthica*. Since these organisms are pollution sensitive their reduction resulted in lower Pollution Sensitive Taxa Abundance (PSTA) metric scores. In addition, because these organisms are typically abundant their decrease serves to increase the proportion of pollution indicative organisms. In Year 31, above average abundance of the polychaete *S. benedicti* (a pollution indicative species) also increased Pollution Indicative Taxa Abundance scores. Lastly, abundances for many

organisms were below historic averages, hence depressing the Total Infaunal Abundance metric scores for some stations.

Multivariate cluster analysis of September 2012 benthic invertebrate communities indicated that there were four distinct station groups (comprising 13 of the 22 total stations) distributed broadly on the southern and northeast tip of the island. Three of the four groups had stressed benthic invertebrate communities. In contrast, eight of the nine stations identified as strong or moderate outliers (stations with benthic invertebrate communities with low similarity to other stations) had healthy benthic invertebrate communities. Thus, the September, 2012 cluster results reflected the prevailing *regional* decline in community health in Year 31 monitoring as identified by the B-IBI results. Friedman's non parametric ANOVA did not indicate any adverse localized impacts to the surrounding benthic community from HMI discharges in Year 31.

INTRODUCTION

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

HMI is a 1,140-acre artificial island surrounded by a 29,000-foot long dike constructed along the historical footprints of Hart and Miller Islands at the mouth of the Back River. Over the years, a series of four spillways periodically discharged excess water released from on-site dredged material disposal operations.

An exterior monitoring program was developed to assess potential environmental impacts associated with HMI operations in support of the environmental permitting process for dredged material containment. Various agencies have worked together since the inception of this program to assess the environmental impacts resulting from facility construction and operation. Studies were completed prior to and during the early construction period to determine baseline environmental conditions in the HMI vicinity. Since Year 17, the Maryland Department of the Environment (MDE) has been responsible for all aspects of benthic community monitoring.

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

The goals of the Year 31 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 stations near the mouth of Back River;

- To facilitate trend analysis by providing data of high quality for comparison with HMI monitoring studies over the operational phase of the project; and,

- To monitor benthic community conditions in areas near all functioning spillways, particularly

South Cell Spillway 003. This will help the State to assess any environmental effects resulting from the South Cell closure and restoration.

METHODS AND MATERIALS

MDE staff collected all macroinvertebrate and water quality samples in Year 31. Field sampling cruises were conducted on board the Maryland Department of Natural Resources vessel "*R/V Kerhin*". Twenty-two fixed benthic stations were monitored during both fall and spring cruises (Table 2-1; Figure 2-1). Environmental parameters recorded at the time of sample collection are included in Tables 2-2 through 2-5.

Table 2-1: Sampling stations (latitudes and longitudes in degrees, decimal minutes), 7-digit codes of stations used for Year 31 benthic community monitoring, and predominant sediment type at each station for September and April.

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

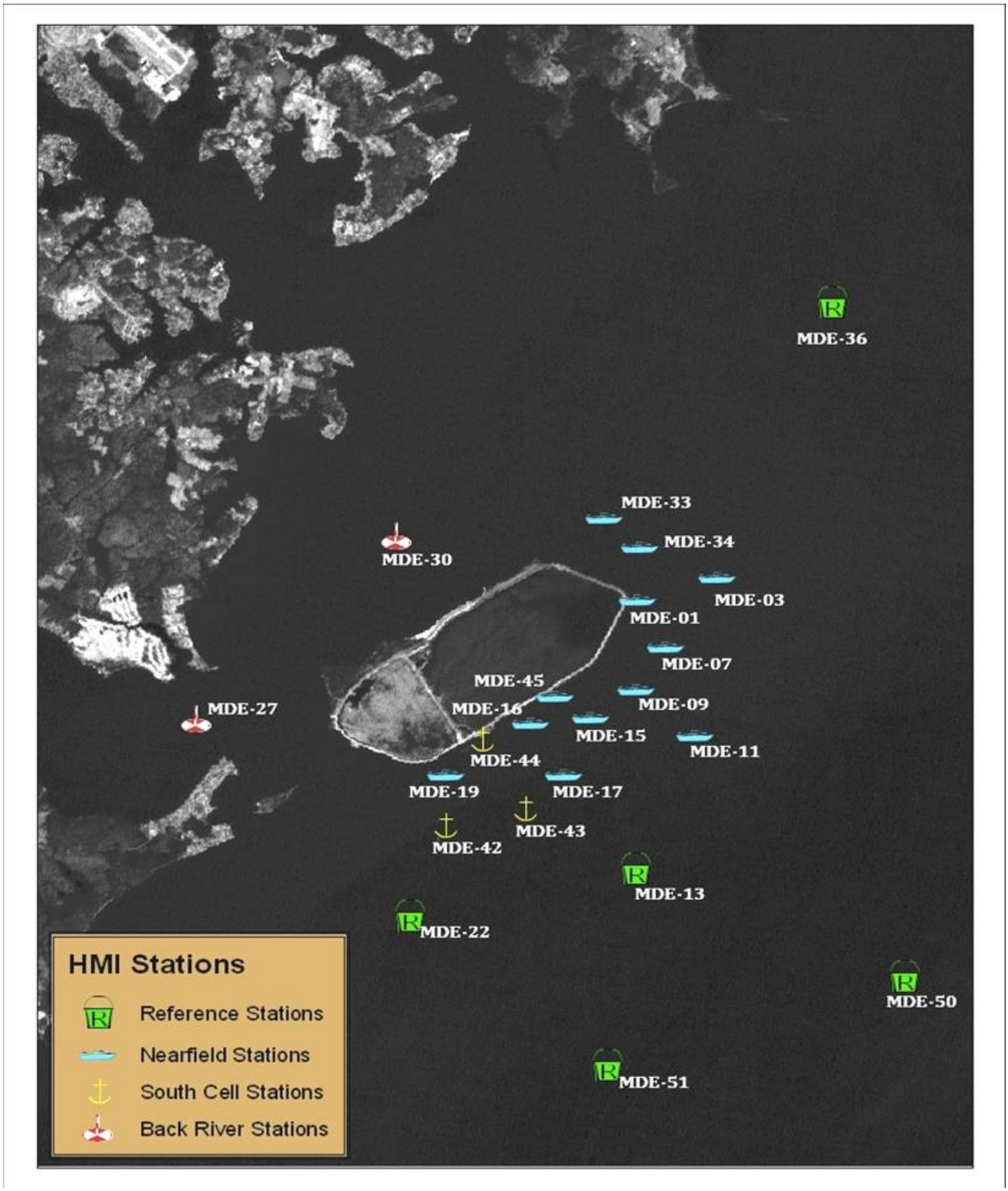


Figure 2-1: Year 31 benthic sampling stations for the HMI exterior monitoring program.

All stations sampled since Year 27 were again sampled for Year 31. Over the years, the list of stations sampled has changed several times. Occasionally old stations were deleted and new stations were added to suit monitoring needs. Year 31 is the fifth year without changes to the list of sampling stations[1]. Stations were classified by location and dominant sediment type (Table 2-1). Stations were divided into four location groups (Nearfield stations, Reference stations, Back River/Hawk Cove stations, and South Cell Exterior Monitoring stations) and five sediment types (silt/clay, shell, detritus, gravel, and sand). All benthic community stations coincided with stations sampled by the Maryland Geological Survey for sediment analysis.

Temperature, depth, salinity, pH, conductivity, and dissolved oxygen (DO) were measured *in situ* using a Yellow Springs Instruments (YSI) 6600 V2 multi-parameter water quality meter in September 2012 and April 2013. 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 (in meters) 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- and Table 2-) 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.

All organisms were identified to the lowest practical taxon (usually to species) using a stereo dissecting microscope. The number of specimens for each taxon collected in each replicate (raw data) is presented in the *Year 31 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.

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

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, taxa richness, and total abundance of all taxa (excluding Bryozoa and Copepoda). Four of these measures (total infaunal abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance of pollution-sensitive infaunal taxa, and the Shannon-Wiener diversity index) were used to calculate the B-IBI for September 2012. The B-IBI is a multi-metric index of biotic integrity used to determine if benthic populations in different areas of the Chesapeake Bay are stressed (Llanso 2002). The B-IBI has not been calibrated for periods outside the summer index period (July 15 through September 30) thus, was not used with the April 2013 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 31 Data Report*. Total infaunal abundance was calculated as the average abundance of infaunal organisms per square meter (#/m^2). These two different measures of 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 2012 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 2012 and April 2013. The statistical analyses were performed using SAS, Version 9.1 and SPSS, Version 11.5.

RESULTS AND DISCUSSION

Water Quality

Minimal variations between surface and bottom values for salinity, temperature, DO, conductivity, and pH values during the September 2012 and April 2013 cruises (Table 2-5) indicated that water column stratification was not prevalent.

Secchi depths were higher in September 2012 (Table 2-3, range=0.50 m-0.70 m, average = 0.60 m ± 0.06 m) than those in April 2013 (Table 2-5, range=0.40 m-0.60 m, average=0.52 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. September 2012 mean Secchi depth is 0.23 m less than the 15-year historic average of 0.83 m.

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 31, bottom water temperatures did not vary much between stations during both sampling seasons. The September 2012 mean bottom water temperature (Table 2-3, mean=24.15°C ± 0.95°C, range= 20.27°C – 25.53°C) was 0.06ºC lower than the 26-year fall average of 24.21ºC. Bottom water temperatures were seasonably lower in April 2013 (Table 2-5) with a range of 9.84°C –12.17°C and an average of 10.65°C ± 0.70°C. April 2013 mean temperature was 1.36°C lower than the 16-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 2012 mean bottom DO (Table 2-3, mean=7.37 ppm ± 0.71 ppm, range=5.55 – 8.80 ppm) was 0.06 ppm higher than the 16-year fall average of 7.31 ppm. The April 2013 mean bottom DO (Table 2-5, mean=10.62 ppm ± 0.29 ppm, range=10.32 ppm – 11.19 ppm) was 0.62 ppm higher than the 16-year spring average of 10.00 ppm. Historically fall DO is 2.69 ppm lower than spring DO due to reduced oxygen solubility with elevated seasonal temperatures. This year there was a 3.25 ppm difference in spring vs. fall mean bottom DO concentration.

This region of the Bay typically ranges between the oligohaline (0.5 ppt – 5 ppt) and mesohaline (>5 ppt – 18 ppt) salinity regimes (Lippson and Lippson 1997). The 27-year mean bottom salinity is 5.09 ppt. Low Mesohaline conditions (5-12 ppt.) were found during the fall 2012 and spring 2013 sampling seasons.

In Year 31 mean salinity values varied slightly between September (Table 2-5, mean=8.66 ppt $\pm$ 0.77 ppt, range = 7.13 ppt – 10.01 ppt) and April (Table 2-5, mean=5.89 ppt $\pm$ 0.91 ppt, range 4.05 ppt – 7.42 ppt). The mean fall salinity was 2.49 ppt higher than the historical average (mean =6.17 ppt, ± 2.90 ppt). Additionally, mean spring salinity was 2.98 ppt higher than the historical mean (3.19 ppt $\pm$ 2.33 ppt). This region of the Bay is subject to significant salinity fluctuations resulting from large inter-annual variation in rainfall in the watershed. In

general, the Bay experiences relatively higher salinity values during the fall, because of dry summer conditions.

Table 2-2: Year 31 physical parameters measured *in situ* at all HMI stations on September 11, 2012.

MDE Station	Time	Tide	Water Depth (m)	Wave Height (m)	Wind Direction	Wind Speed (knots)		Air Temp. (ºC)	Cloud Cover (%)	Weather		Observed Bottom Sediment (%)				
						Min.	Max			Past 24 hrs.	Today	silt/clay	sand	shell	gravel	detritus
MDE-01	12:15	Ebb	2.79	0.0	NW	2	4	24	0	0	0	0	90	10	0	0
MDE-03	11:59	Ebb	6.10	0.0	NW	2	4	24	0	0	0	70	0	30	0	0
MDE-07	11:49	Ebb	5.85	0.0	NW	2	4	24	0	0	0	70	0	30	0	0
MDE-09	11:35	Ebb	6.02	0.0	NW	2	4	24	0	0	0	70	0	30	0	0
MDE-11	11:27	Ebb	5.83	0.0	NW	2	4	24	0	0	0	70	0	30	0	0
MDE-13	10:33	Ebb	4.33	0.1	NW	4	6	21	0	0	0	95	0	5	0	0
MDE-15	10:21	Ebb	5.32	0.1	NW	4	6	21	0	0	0	93	0	7	0	0
MDE-16	9.59	Ebb	2.18	0.1	NW	6	8	20	0	0	0	95	0	5	0	0
MDE-17	9:16	Ebb	4.86	0.1	NW	6	8	20	0	0	0	65	0	35	0	0
MDE-19	9:31	Ebb	4.8	0.1	NW	6	8	20	0	0	0	65	0	35	0	0
MDE-22	8:36	Ebb	3.91	0.1	NW	6	8	19	10	0	0	90	0	10	0	0
MDE-27	13:12	Ebb	3.99	0.0	NW	2	4	25	0	0	0	75	0	15	0	10
MDE-30	12:50	Ebb	3.29	0.0	NW	2	4	25	0	0	0	60	0	40	0	0
MDE-33	12:38	Ebb	2.6	0.0	NW	2	4	24	0	0	0	0	90	10	0	0
MDE-34	12:26	Ebb	3.18	0.0	NW	2	4	24	0	0	0	90	0	10	0	5
MDE-36	13:46	Ebb	3.38	0.0	NW	2	4	25	0	0	0	70	0	30	0	0
MDE-42	8:48	Ebb	4.99	0.1	NW	6	8	19	10	0	0	98	0	2	0	0
MDE-43	9:02	Ebb	4.8	0.1	NW	6	8	19	10	0	0	95	0	5	0	0
MDE-44	9:39	Ebb	5.19	0.1	NW	6	8	20	0	0	0	95	0	3	0	2
MDE-45	10:14	Ebb	2.56	0.1	NW	4	5	21	0	0	0	70	0	30	0	0
MDE-50	11:15	Ebb	4.3	0.0	NW	2	4	24	0	0	0	5	90	5	0	0
MDE-51	10:49	Ebb	4.52	0.0	NW	2	4	24	0	0	0	90	0	10	0	0

Note: The Weather code 0 stands for “Clear”.

Table 2-3: Year 31 water quality parameters measured *in situ* at all HMI stations on September 11, 2012.

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt)	Temp. (C)	Dissolved Oxygen (ppm)	pH	Secchi Depth (m)	Conductivity (µmos/cm)
Nearfield Stations									
MDE-01	XIF5505	Surface	0.50	7.86	23.97	7.94	8.02	0.5	13,640
		Bottom	2.29	8.04	24.16	7.67	8.01		13,920
MDE-03	XIG5699	Surface	0.50	8.20	25.12	10.07	8.38	0.5	14,170
		Bottom	5.60	8.24	24.2	7.48	8.00		12,230
MDE-07	XIF5302	Surface	0.50	8.15	25.13	8.75	8.17	0.7	14,080
		Bottom	5.35	8.19	20.27	7.35	7.96		14,150
MDE-09	XIF4806	Surface	0.50	8.01	24.28	8.16	8.08	0.6	13,890
		Bottom	5.52	8.29	24.28	7.42	7.98		14,310
MDE-11	XIG4501	Surface	0.50	8.48	24.55	8.77	8.18	0.7	14,620
		Bottom	5.33	8.61	24.32	7.82	8.13		14,810
MDE-15	XIF4609	Surface	0.50	7.65	23.74	8.13	8.10	0.5	13,300
		Bottom	4.82	8.63	24.24	7.12	7.95		14,850
MDE-16	XIF4615	Surface	0.50	7.75	23.44	7.90	8.06	0.5	13,940
		Bottom	1.68	8.00	23.97	7.41	7.98		14,070
MDE-17	XIF4285	Surface	0.50	8.26	24.07	7.49	7.98	0.6	14,250
		Bottom	4.36	8.87	24.13	7.26	8.02		15,250
MDE-19	XIF4221	Surface	0.50	8.59	24.22	7.40	7.96	0.6	14,750
		Bottom	4.3	9.78	24.95	5.81	7.38		16,690
MDE-33	XIF6008	Surface	0.5	8.17	24.45	8.51	8.13	0.6	14,110
		Bottom	2.1	8.15	24.39	8.21	8.10		14,090
MDE-34	XIF5805	Surface	0.5	8.14	24.81	9.04	8.19	0.6	14,070
		Bottom	2.68	8.13	24.56	8.04	8.10		14,040
MDE-45	N/A	Surface	0.5	7.90	23.73	7.25	7.95	0.5	13,670
		Bottom	2.06	8.22	24.02	7.20	7.97		14,210
Reference Stations									
MDE-13	XIG3506	Surface	0.5	8.78	24.32	7.94	8.06	0.6	15,070
		Bottom	3.83	8.83	24.28	7.73	8.05		15,160
MDE-22	XIF3224	Surface	0.5	9.6	24.30	7.08	8.08	0.6	16,038
		Bottom	3.41	10.01	24.56	7.04	8.06		17,010
MDE-36	XIG7589	Surface	0.5	6.76	24.27	10.10	8.31	0.7	11,830
		Bottom	2.88	7.13	23.75	8.80	8.17		12,590
MDE-50	N/A	Surface	0.5	8.52	24.28	8.81	8.14	0.6	14,670
		Bottom	3.8	8.97	24.17	7.84	8.00		15,390
MDE-51	N/A	Surface	0.5	9.22	24.50	8.71	8.22	0.7	15,770
		Bottom	4.02	9.56	24.26	7.43	8.05		16,340
Back River/Hawk Cove Stations									
MDE-27	XIF4642	Surface	0.5	7.25	23.97	12.88	8.67	0.6	12,660
		Bottom	3.49	8.12	25.53	7.48	8.18		13,910
MDE-30	XIF5925	Surface	0.5	7.29	23.97	8.3	8.17	0.6	11,900
		Bottom	2.79	7.45	23.68	7.8	8.20		12,940
South Cell Exterior Monitoring Stations									
MDE-42	XIF3879	Surface	0.5	9.22	23.84	7.37	8.08	0.6	15,780
		Bottom	4.49	9.64	24.33	6.83	8.02		16,450
MDE-43	XIF3985	Surface	0.5	8.78	23.84	7.36	8.05	0.6	15,090
		Bottom	4.3	9.30	24.39	6.9	8.00		15,940
MDE-44	XIF4482	Surface	0.5	8.07	23.76	7.54	7.99	0.6	13,940
		Bottom	4.69	9.53	24.81	5.55	7.81		16,340

Table 2-4: Year 31 physical parameters measured *in situ* at all HMI stations on April 09, 2013.

MDE Station	Time	Tide	Water Depth (m)	Wave Height (m)	Wind Direction	Wind Speed (knots)		Air Temp (ºC)	Cloud Cover (%)	Weather		Observed Bottom Sediment (%)				
						Min.	Max.			Past 24 hrs.	Today	silt/clay	sand	shell	gravel	detritus
MDE-01	12:19	Flood	3.27	0.1	SW	5	10	26.1	10	0	0	0	80	20	0	0
MDE-03	12:02	Flood	5.75	0.1	SW	5	10	25.6	10	0	0	70	0	30	0	0
MDE-07	11:53	Flood	5.96	0.1	SW	5	10	25.6	10	0	0	75	0	25	0	0
MDE-09	11:40	Flood	5.46	0.1	SW	5	10	25.0	10	0	0	70	0	30	0	0
MDE-11	11:23	Flood	5.34	0.1	SW	5	10	25.0	10	0	0	75	0	25	0	0
MDE-13	10:30	Flood	4.8	0.1	SSW	1	2	22.2	10	0	0	90	0	10	0	0
MDE-15	10:19	Flood	4.83	0.1	SSW	1	2	22.2	10	0	0	92	0	8	0	0
MDE-16	9:47	Flood	4.68	0.1	SSW	1	2	21.1	10	0	0	90	0	10	0	0
MDE-17	9:06	Flood	5.06	0.1	SSW	5	10	20.6	10	0	0	65	0	35	0	0
MDE-19	9:22	Flood	4.75	0.1	SSW	5	10	20.6	10	0	0	65	0	35	0	0
MDE-22	8:26	Flood	5.65	0.1	SSW	5	10	20.0	10	0	0	90	0	10	0	0
MDE-27	13:21	Flood	3.65	0.1	SW	5	10	26.7	10	0	0	70	0	20	0	10
MDE-30	12:57	Flood	2.94	0.1	SW	5	10	26.1	10	0	0	60	0	40	0	0
MDE-33	12:44	Flood	2.55	0.1	SW	5	10	25.6	10	0	0	0	90	10	0	0
MDE-34	12:36	Flood	3.77	0.1	SW	5	10	25.6	10	0	0	90	0	10	0	0
MDE-36	13:53	Flood	2.94	0.1	SW	5	10	26.1	10	0	0	75	0	25	0	0
MDE-42	8:37	Flood	4.95	0.1	SSW	5	10	20.0	10	0	0	95	0	5	0	0
MDE-43	8:51	Flood	5.22	0.1	SSW	5	10	20.0	10	0	0	90	0	10	0	0
MDE-44	9:29	Flood	5.28	0.1	SSW	5	10	20.6	10	0	0	90	0	5	0	5
MDE-45	10:03	Flood	5.32	0.1	SSW	1	2	21.1	10	0	0	65	0	35	0	30
MDE-50	10:56	Flood	4.94	0.1	SW	5	10	25.0	10	0	0	5	90	5	0	0
MDE-51	10:42	Flood	5.19	0.1	SSW	1	2	24.4	10	0	0	90	0	10	0	0

Note: The weather code 0 stands for “Clear”.

Table 2-5: Water quality parameters measured *in situ* at all HMI stations on April 09, 2013.

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	0.5	5.00	11.98	11.09	7.93	0.5	8,912
		Bottom	2.77	5.02	12.03	10.95	7.96		8,929
MDE-03	XIG5699	Surface	0.5	4.79	10.78	10.62	7.78	0.5	8,566
		Bottom	5.25	4.96	10.37	10.24	7.78		8,852
MDE-07	XIF5302	Surface	0.5	4.93	11.22	10.36	7.77	0.4	8,792
		Bottom	5.46	4.93	11.19	10.33	7.81		8,796
MDE-09	XIF4806	Surface	0.5	4.97	11.43	10.42	7.80	0.6	8,862
		Bottom	4.96	5.29	10.32	10.23	7.76		9,410
MDE-11	XIG4501	Surface	0.5	5.06	11.55	10.71	7.79	0.5	9,015
		Bottom	4.84	5.81	10.02	10.40	7.75		10,260
MDE-15	XIF4609	Surface	0.5	5.04	11.47	10.42	7.74	0.5	8,940
		Bottom	4.33	6.04	10.33	10.38	7.69		10,570
MDE-16	XIF4615	Surface	0.5	5.38	11.21	10.45	7.71	0.5	9,537
		Bottom	4.18	6.27	10.31	10.38	7.67		11,030
MDE-17	XIF4285	Surface	0.5	5.86	10.36	10.86	7.67	0.5	10,340
		Bottom	4.56	6.84	10.30	10.93	7.65		11,940
MDE-19	XIF4221	Surface	0.5	5.68	11.47	10.52	7.69	0.6	10,040
		Bottom	4.25	6.56	10.18	10.59	7.66		11,500
MDE-33	XIF6008	Surface	0.5	4.81	12.07	11.94	7.87	0.5	8,596
		Bottom	2.05	4.89	11.65	10.74	7.85		8,728
MDE-34	XIF5805	Surface	0.5	4.63	11.28	10.59	7.79	0.5	8,372
		Bottom	3.27	4.69	11.18	10.52	7.80		8,406
MDE-45	N/A	Surface	0.5	5.18	10.94	10.29	7.69	0.5	9,213
		Bottom	4.82	5.75	10.66	10.32	7.69		10,160
Reference Stations									
MDE-13	XIG3506	Surface	0.5	5.97	10.71	11.16	7.80	0.6	10,490
		Bottom	4.3	6.73	10.35	10.87	7.76		11,840
MDE-22	XIF3224	Surface	0.5	6.55	10.38	11.17	7.44	0.5	11,460
		Bottom	5.15	7.42	10.07	11.19	7.29		12,890
MDE-36	XIG7589	Surface	0.5	3.76	13.09	11.24	8.04	0.5	6,824
		Bottom	2.44	4.05	10.95	10.78	7.94		7,339
MDE-50	N/A	Surface	0.5	6.14	10.06	10.53	7.71	0.6	10,820
		Bottom	4.44	6.19	9.90	10.44	7.75		10,880
MDE-51	N/A	Surface	0.5	6.70	10.17	10.90	7.76	0.6	11,700
		Bottom	4.69	6.85	9.84	10.68	7.75		11,970
Back River/Hawk Cove Stations									
MDE-27	XIF4642	Surface	0.5	5.67	13.33	11.01	7.98	0.4	10,010
		Bottom	3.15	5.67	12.17	10.58	7.94		10,010
MDE-30	XIF5925	Surface	0.5	5.15	12.46	11.16	7.99	0.5	9,160
		Bottom	2.44	5.35	11.71	10.71	7.87		9,475
South Cell Exterior Monitoring Stations									
MDE-42	XIF3879	Surface	0.5	6.02	10.60	10.77	7.53	0.5	10,600
		Bottom	4.45	6.98	10.31	11.02	7.48		12,180
MDE-43	XIF3985	Surface	0.5	6.60	10.29	10.99	7.62	0.6	11,510
		Bottom	4.72	7.05	10.27	11.05	7.60		12,290
MDE-44	XIF4482	Surface	0.5	5.67	11.27	10.34	7.68	0.5	9,998
		Bottom	4.78	6.31	10.26	10.32	7.64		11,050

BENTHIC MACROINVERTEBRATE COMMUNITY

Taxa Richness and Dominance

A total of 47 taxa were found over the two seasons of sampling during Year 31. This is higher than the 15-year average of 41.20 taxa. This is due to an increase in spring taxa normally associated with freshwater (eight midge taxa vs. a historical average of four, one caddisfly larva, one dance fly larva, and one freshwater isopod).

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-five taxa of Arthropoda were found in Year 31. This is higher than the 15-year mean of 19.67 taxa (range= 12-33 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 similar to the 15-year mean of 7.33 taxa (range= 6-10 taxa). Seven species of bivalve mollusks were found. This is similar to the 15-year mean of 5.80 taxa (range= 4-7 taxa). Overall, bivalve average abundance was higher in April 2013 than in September 2012 (Table 2-6 and Table 2-7).

During the spring, *Macoma balthica*, *Mya arenaria*, *Mulinia lateralis*, *Ischadium recurvum*, *Ameroculodes* spp. complex, *Caecidotea* sp., *Cassidinea ovalis*, *Balanus subalbidus*, *Ortocladiinae* sp. A, *Orthocladiinae* sp. B, *Orthocladius/Cricotopus* sp., *Eukiefferiella* sp., *Cryptochironomus* sp., *Procladius* sp., *Chironomus* sp., *Gyratryx hermaphrodites*, *Pisicola* sp., *Empididae* sp., Trichoptera sp., Hydrobiidae sp., and Copepoda were exclusively found, while *Chirodotea almyra* and *Glycinde solitaria* were only found in fall samples. 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.

Glycind. solitaria and *Mulinia lateralis* were observed for the first time since Year 21, albeit only one organism of each species was found. These two species 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 proximity of the stations to the former Harbor stations and natural variation in recruitment typical in this dynamic region of the Chesapeake Bay probably explain why the taxa re-appeared.

Table 2-6: Average and total abundance (individuals per square meter) of each taxon found at HMI during the September 2012 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	86.98	1913.60	102.76	0.00	21.33	37.87	52.48	508.80	59.73
Carinoma tremophoros	22.69	499.20	26.67	19.20	0.00	16.53	44.80	6.40	21.33
Bivalvia	0.58	12.80	0.71	0.00	0.00	0.00	1.28	3.20	0.00
Macoma sp.	1.16	25.60	1.07	0.00	2.13	0.00	1.28	9.60	0.00
Macoma balthica	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Macoma mitchelli	13.38	294.40	7.82	12.80	46.93	8.53	28.16	19.20	4.27
Rangia cuneata	**15.42**	**339.20**	**12.09**	**6.40**	**38.40**	**20.27**	**16.64**	**0.00**	**4.27**
Ischadium recurvum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mytilopsis leucophaeata	0.29	6.40	0.00	0.00	2.13	0.53	0.00	0.00	0.00
Amphicteis floridus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Capitellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heteromastus filiformis	9.02	198.40	6.04	0.00	29.87	8.00	20.48	0.00	0.00
Spionidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marenzelleria viridis	**77.96**	**1715.20**	**87.82**	**83.20**	**17.07**	**78.40**	**74.24**	**64.00**	**91.73**
Streblospio benedicti	264.73	5824.00	301.51	83.20	104.53	291.73	151.04	672.00	74.67
Polydora cornuta	36.95	812.80	44.44	12.80	0.00	48.53	46.08	0.00	0.00
Boccardiella ligerica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nereidae	5.24	115.20	1.78	0.00	27.73	3.73	14.08	0.00	0.00
Neanthes succinea	44.51	979.20	44.80	12.80	53.33	61.33	42.24	6.40	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	14.25	313.60	13.16	0.00	25.60	19.73	6.40	19.20	2.13
Naididae sp.	271.13	5964.80	307.20	185.60	83.20	230.40	206.08	483.20	401.07
Amphipoda	0.29	6.40	0.36	0.00	0.00	0.00	0.00	0.00	2.13
Gammaridea	6.69	147.20	7.47	6.40	2.13	7.47	5.12	3.20	8.53
Ameroculodes spp complex	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leptocheirus plumulosus	147.20	3238.40	170.67	121.60	14.93	139.73	84.48	128.00	294.40
Gammarus sp.	1.16	25.60	1.42	0.00	0.00	2.13	0.00	0.00	0.00
Melitadae	2.04	44.80	2.49	0.00	0.00	1.07	1.28	3.20	6.40
Melita nitida	36.65	806.40	41.96	25.60	8.53	34.13	16.64	9.60	98.13
Corophiidae	0.87	19.20	1.07	0.00	0.00	1.07	0.00	3.20	0.00
Apocorophium lacustre	6.69	147.20	6.76	0.00	8.53	11.73	1.28	0.00	0.00
Cyathura polita	**54.40**	**1196.80**	**59.38**	**38.40**	**29.87**	**66.67**	**37.12**	**57.60**	**32.00**
Edotea triloba	0.58	12.80	0.71	0.00	0.00	1.07	0.00	0.00	0.00
Chiridotea almyra	1.75	38.40	2.13	0.00	0.00	3.20	0.00	0.00	0.00
Ciripedia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Balanus improvisus	0.58	12.80	0.71	0.00	0.00	1.07	0.00	0.00	0.00
Balanus subalbidus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rhithropanopeus harrisii	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Membranipora sp	+	+	+	+	+	+	+	0.00	+
Chironomide	0.00	0.00	0.00	0.00	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.	12.22	268.80	14.93	0.00	0.00	4.27	16.64	57.60	6.40
Procladius sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cryptochironomus sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chironominae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gammmaridae	0.58	12.80	0.71	0.00	0.00	0.53	0.00	3.20	0.00
Copepoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glycinde solitaria	**0.29**	**6.40**	**0.00**	**0.00**	**2.13**	**0.00**	**1.28**	**0.00**	**0.00**
Mysidacea	4.65	102.40	5.69	0.00	0.00	5.33	3.84	9.60	0.00
Cassidinea ovalis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ostracoda	0.29	6.40	0.36	0.00	0.00	0.00	0.00	3.20	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 31 spring sampling, April 2013, 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	25.89	569.60	29.87	0.00	10.67	31.42	8.53	51.20	14.93
Carinoma tremophoros	14.55	320.00	17.07	6.40	2.13	8.73	12.80	17.07	12.80
Bivalvia	136.44	3001.60	139.73	339.20	49.07	137.89	160.00	64.00	100.27
Macoma sp.	41.31	908.80	45.51	19.20	23.47	40.73	27.73	36.27	34.13
Macoma balthica	**550.69**	**12115.20**	**524.44**	**352.00**	**774.40**	**309.53**	**772.27**	**311.47**	**326.40**
Macoma mitchelli	45.67	1004.80	50.13	44.80	19.20	29.09	34.13	53.33	40.53
Rangia cuneata	**6.40**	**140.80**	**5.69**	**6.40**	**10.67**	**6.98**	**8.53**	**0.00**	**4.27**
Ischadium recurvum	5.53	121.60	3.20	0.00	21.33	10.47	2.13	0.00	0.00
Mytilopsis leucophaeata	1.45	32.00	1.07	0.00	4.27	2.91	0.00	0.00	0.00
Capitellidae	2.91	64.00	0.00	0.00	21.33	0.00	0.00	0.00	0.00
Heteromastus filiformis	112.87	2483.20	120.18	192.00	42.67	79.71	138.67	113.07	93.87
Spionidae	12.80	281.60	0.00	0.00	93.87	25.60	0.00	0.00	0.00
Marenzelleria viridis	**5141.82**	**113120.00**	**4530.13**	**2105.60**	**9824.00**	**6561.75**	**3037.87**	**2944.00**	**2824.53**
Streblospio benedicti	157.09	3456.00	183.47	134.40	6.40	160.58	247.47	140.80	172.80
Polydora cornuta	172.80	3801.60	166.04	0.00	270.93	337.45	27.73	2.13	0.00
Boccardiella ligerica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2-7 (continued)

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Nereidae	33.16	729.60	33.78	0.00	40.53	38.98	98.13	0.00	2.13
Neanthes succinea	110.55	2432.00	109.16	44.80	140.80	130.33	202.67	25.60	55.47
Naididae sp.	1244.22	27372.80	1417.60	1126.40	243.20	1103.13	1145.60	1431.47	2310.40
Amphipoda	209.16	4601.60	203.38	0.00	313.60	395.05	38.40	6.40	17.07
Gammaridea	93.67	2060.80	85.69	467.20	17.07	94.25	174.93	53.33	91.73
Ameroculodes spp complex	2.04	44.80	1.42	0.00	6.40	1.75	0.00	2.13	0.00
Leptocheirus plumulosus	1772.51	38995.20	2008.18	1952.00	298.67	1890.33	1922.13	1171.20	2419.20
Gammaridae	2.04	44.80	2.49	0.00	0.00	0.00	14.93	0.00	0.00
Gammarus sp	4.65	102.40	1.78	0.00	23.47	7.56	4.27	2.13	0.00
Melitadae	2.04	44.80	2.49	0.00	0.00	0.58	0.00	0.00	10.67
Melita nitida	59.93	1318.40	62.22	76.80	40.53	65.75	83.20	27.73	81.07
Corophiidae	21.53	473.60	13.51	0.00	76.80	41.89	0.00	0.00	2.13

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

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	
Apocorophium sp.	1.45	32.00	1.78	0.00	0.00	2.91	0.00	0.00	0.00	
Apocorophium lacustre	1958.69	43091.20	1693.51	204.80	4134.40	3671.85	388.27	174.93	281.60	
Cyathura polita	**36.95**	**812.80**	**43.73**	**19.20**	**2.13**	**34.33**	**49.07**	**23.47**	**36.27**	
Edotea triloba	2.04	44.80	2.49	0.00	0.00	3.49	0.00	2.13	0.00	
Chiridotea almyra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Balanus improvisus	10.47	230.40	2.13	0.00	64.00	20.36	2.13	0.00	0.00	
Balanus subalbidus	0.58	12.80	0.36	0.00	2.13	1.16	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
Caecidotea sp.	0.29	6.40	0.36	0.00	0.00	0.00	0.00	0.00	2.13
Rhithropanopeus harrisii	2.33	51.20	1.42	0.00	8.53	4.07	2.13	0.00	0.00
Membranipora sp	+	+	+	+	+	+	+	0.00	+
Chironomidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Orthocladiinae sp B.	0.29	6.40	0.36	0.00	0.00	0.00	2.13	0.00	0.00
Mya arenaria	**2.04**	**44.80**	**0.00**	**0.00**	**14.93**	**0.00**	**0.00**	**0.00**	**0.00**
Coelotanypus sp.	23.27	512.00	27.73	12.80	0.00	19.20	8.53	72.53	19.20
Procladius sp.	0.29	6.40	0.36	0.00	0.00	0.00	0.00	0.00	2.13
Orthocladiinae	2.33	51.20	0.00	0.00	17.07	4.65	0.00	0.00	0.00
Orthocladius/Cricotopus sp.	0.87	19.20	0.00	0.00	6.40	1.75	0.00	0.00	0.00
Eukiefferiella sp.	0.29	6.40	0.00	0.00	2.13	0.58	0.00	0.00	0.00
Cryptochironomus sp.	0.29	6.40	0.36	0.00	0.00	0.58	0.00	0.00	0.00
Chironomus sp.	0.58	12.80	0.71	0.00	0.00	1.16	0.00	0.00	0.00
Orthocladiinae sp A.	0.29	6.40	0.36	0.00	0.00	0.00	0.00	2.13	0.00
Hydrobiidae	0.29	6.40	0.00	0.00	2.13	0.58	0.00	0.00	0.00

Table 2-7-(continued)

Taxon	Average Abundance, All Stations	Total Abundance All Stations	Average Abundance by Dominant Substrate			Average Abundance by Station Type			
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River	South Cell Exterior Monitoring
Mulinia lateralis	0.29	6.40	0.36	0.00	0.00	0.58	0.00	0.00	0.00
Cirripedia	8.73	192.00	5.33	0.00	32.00	17.45	0.00	0.00	0.00
Copepoda	+	+	+	+	+	+	+	+	+
Ostracoda	28.22	620.80	33.78	12.80	0.00	15.71	40.53	85.33	23.47
Mysidacea	2.62	57.60	2.49	0.00	4.27	3.49	0.00	2.13	0.00
Gyratrix hermaphroditi es	58.47	1286.40	56.89	57.60	68.27	77.38	83.20	17.07	10.67
Trichoptera	0.29	6.40	0.36	0.00	0.00	0.58	0.00	0.00	0.00
Eteone heteropoda	1.75	38.40	2.13	0.00	0.00	0.58	0.00	0.00	0.00
Cassidinea ovalis	1.75	38.40	0.36	0.00	10.67	3.49	0.00	0.00	0.00
Isopoda	0.29	6.40	0.00	0.00	2.13	0.58	0.00	0.00	0.00
Pisicola sp.	0.87	19.20	1.07	0.00	0.00	1.75	0.00	0.00	0.00
Empididae sp.	0.29	6.40	0.36	0.00	0.00	0.58	0.00	0.00	0.00

Of the 47 taxa found in Year 31, nineteen were considered truly infaunal, twenty-one were considered epifaunal, and the remaining seven were considered too general to classify as either infaunal or epifaunal (see Ranasinghe et al. 1994). The most common infaunal species found during Year 31 were the amphipod *L. plumulosus*, the polychaete worms *M. viridis* and *S. benedicti*, the bivalve *R. cuneata*, worms from the family Naididae, and the isopod *C. polita*. The most common epifaunal species was the amphipod *M. nitida*.

Nearfield station MDE-34 had the highest number of taxa in September 2012 (18 taxa, Table 2-8). 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 Nearfield stations but did not vary greatly between station types (average taxa richness: Nearfield=13 taxa, Back River/Hawk Cove=12 taxa, South Cell Exterior Monitoring=11 taxa, Reference=10.60 taxa). It is important to note that there are 12 Nearfield stations, 5 Reference stations, 3 South Cell Exterior Monitoring stations and 2 Back River/Hawk Cove stations. So, historic higher taxa abundances at Nearfield stations may simply be an artifact of sample size. No trend of increasing/decreasing taxa richness associated with distance from HMI could be discerned.

Table 2-8: Summary of metrics for each HMI benthic station surveyed during the Year 31 September 2012 cruise. Total infaunal abundance and total abundance, excluding Polycladida, Nematoda, and Bryozoa, are individuals per square meter.

Station	Total Infauna	Total All	All Taxa	Infaunal Taxa	Shannon-Wiener	PSTA (%)	PITA (%)	Tolerance Score	% Carnivore/ Omnivore	Tanypodinae: Chironomidae	B-IBI
Nearfield Stations											
MDE-01	563.20	569.60	12	10	2.70	28.41%	55.68%	N/A	N/A	N/A	3.50
MDE-03	1,753.60	1,766.40	13	11	2.09	6.57%	68.25%	N/A	N/A	N/A	3.00
MDE-07	1,030.40	1,081.60	13	9	1.92	7.45%	76.40%	N/A	N/A	N/A	2.50
MDE-09	998.40	1,004.80	12	10	2.52	13.46%	53.85%	N/A	N/A	N/A	3.00
MDE-11	2,022.40	2,041.60	14	12	2.81	16.14%	36.39%	N/A	N/A	N/A	3.50
MDE-15	486.40	512.00	10	8	2.23	17.11%	31.58%	N/A	N/A	N/A	2.00
MDE-16	646.40	659.20	11	8	2.23	52.48%	26.73%	N/A	N/A	N/A	3.00
MDE-17	582.40	608.00	11	10	2.67	21.98%	46.15%	N/A	N/A	N/A	3.00
MDE-19	838.40	1,094.40	10	7	2.09	18.32%	29.01%	N/A	N/A	N/A	2.50
MDE-33	320.00	345.60	12	10	2.55	8.00%	60.00%	N/A	N/A	N/A	2.50
MDE-34	2,220.80	2,304.00	18	13	2.61	16.71%	67.44%	N/A	N/A	N/A	3.50
MDE-45	729.60	819.20	15	10	2.38	9.65%	62.28%	N/A	N/A	N/A	2.50
MEAN	**1,016.0**	**1,067.00**	**13.00**	**10.00**	**2.40**	**18.02%**	**51.15%**	**N/A**	**N/A**	**N/A**	**2.88**
Reference Stations											
MDE-13	390.40	396.80	9	8	2.69	19.67%	32.79%	N/A	N/A	N/A	2.50
MDE-22	544.0	576.00	9	8	2.45	27.06%	28.24%	N/A	N/A	N/A	3.00
MDE-36	1,561.60	1,715.20	16	12	2.57	13.11%	63.11%	N/A	N/A	N/A	3.50
MDE-50	563.20	576.00	10	10	2.82	13.64%	23.86%	N/A	N/A	N/A	3.00
MDE-51	832.00	838.40	9	8	2.11	16.92%	60.00%	N/A	N/A	N/A	2.50
MEAN	**778.24**	**820.48**	**10.60**	**9.20**	**2.53**	**18.08%**	**41.60%**	**N/A**	**N/A**	**N/A**	**2.90**
Back River/Hawk Cove Stations											
MDE-27	1,740.80	1,875.20	16	10	2.01	11.03%	84.19%	N/A	N/A	N/A	3.00
MDE-30	1,184.00	1,248.00	8	5	1.71	4.32%	84.32%	N/A	N/A	N/A	2.00
MEAN	**1,462.40**	**1,561.60**	**12.00**	**7.50**	**1.86**	**7.68%**	**84.26%**	**N/A**	**N/A**	**N/A**	**2.50**
South Cell Exterior Monitoring Stations											
MDE-42	1,203.20	1,305.60	13	10	2.01	12.23%	57.45%	N/A	N/A	N/A	2.50
MDE-43	787.20	825.60	11	9	2.29	18.70%	54.47%	N/A	N/A	N/A	2.50
MDE-44	838.40	1,030.40	9	6	1.82	10.69%	39.69%	N/A	N/A	N/A	2.50
MEAN	**942.93**	**1,053.87**	**11.00**	**8.33**	**2.04**	**13.87%**	**50.54%**	**N/A**	**N/A**	**N/A**	**2.50**

In April 2013, the greatest taxa richness (21 taxa) occurred at Nearfield stations MDE-01, MDE-03, MDE-11, and MDE-16 (Table 2-9). The lowest taxa richness (10 taxa) from spring 2013 sampling was recorded at Back River/Hawk Cove station MDE-30. Overall, average taxa richness varied between station types. The average taxa richness was highest at Nearfield stations (19.17 taxa), followed by South Cell Exterior Monitoring stations (18 taxa), Reference stations (17.60 taxa), and Back River/Hawk Cove stations (14 taxa).

Table 2-9: Summary of metrics for each HMI benthic station surveyed during the Year 31 April 2013 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	19,084.80	19,712.00	21	10	1.42	20.93%	3.66%
MDE-03	35,084.80	35,468.80	21	10	1.47	13.97%	1.39%
MDE-07	12,704.00	12,883.20	18	12	2.15	45.34%	31.23%
MDE-09	9,030.40	9,139.20	19	14	1.73	62.44%	8.79%
MDE-11	8,652.80	8,074.40	21	14	2.13	59.84%	8.88%
MDE-15	7,225.60	7,443.20	20	14	2.12	46.86%	13.55%
MDE-16	6,912.00	7,193.60	21	13	2.07	46.20%	16.39%
MDE-17	6,656.00	7,174.40	18	12	2.32	37.31%	19.13%
MDE-19	9,222.40	9,798.40	18	12	2.14	39.49%	29.56%
MDE-33	14,329.60	14,579.20	16	10	0.56	91.25%	0.27%
MDE-34	27,212.80	28,032.00	20	12	1.37	72.06%	1.86%
MDE-45	10,092.80	10,374.40	17	12	2.17	35.13%	31.96%
MEAN	**13,850.67**	**14,214.40**	**19.17**	**12.08**	**1.80**	**45.57%**	**13.89%**
Reference Stations							
MDE-13	8,3020.00	9,331.20	20	14	2.65	44.77%	26.23%
MDE-22	6,380.80	6,822.40	17	11	2.60	30.79%	24.27%
MDE-36	15,136.00	15,488.00	19	12	1.54	60.21%	4.14%
MDE-50	15,654.40	15,916.80	16	13	1.02	94.60%	0.08%
MDE-51	7,444.80	7,865.60	16	11	2.47	60.34%	8.30%
MEAN	**10,547.20**	**11,084.80**	**17.60**	**12.20**	**2.06**	**58.14%**	**12.61%**
Back River/Hawk Cove Stations							
MDE-27	7,136.00	7,456.00	18	11	1.86	59.55%	28.25%
MDE-30	5,900.08	6,067.20	10	5	1.44	61.39%	23.21%
MEAN	**6,518.40**	**6,761.60**	**14.00**	**8.00**	**1.65**	**60.47%**	**25.73%**
South Cell Exterior Monitoring Stations							
MDE-42	9,644.80	10,240.00	19	12	2.43	40.88%	22.43%
MDE-43	7,590.40	7,980.80	19	11	2.28	41.32%	27.82%
MDE-44	8,390.40	8,569.60	16	10	2.09	34.48%	25.93%
MEAN	**8,541.87**	**8,930.13**	**18.00**	**11.00**	**2.27**	**38.89%**	**25.40%**

Since the first benthic survey studies of the Hart-Miller Island area in 1981, a small number of taxa have been dominant. Year 31 was no exception. During both seasons, 7 taxa were consistently dominant (in the top ten taxa in terms of total average abundance both seasons): the amphipods *L. plumulosus,* and *M. nitida*, oligochaete worms of the family Naididae, and the polychaete worms *M. viridis*, *N. succinea, P. cornuta,* and *S. benedicti*,.

Several other taxa were among the most dominant in only one season. In September 2012, the nemertean *C. tremaphoros*, the isopod *C. polita,* and the bivalve *R. cuneata* were within the top ten most dominant taxa, but not in April 2013. Likewise, the amphipod *A. lacustre*, the bivalve *M. balthica,* and the polychaete worm *H. filiformis* were among the most dominant in April 2013, but not in September 2012. The average abundance of each taxon (individuals per square meter) found at each station during September and April are provided in through 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 31 late summer sampling, September 2012, 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	64	12.8	6.4	19.2	0	0	44.8	57.6	0	83.2	0
Carinoma tremaphoros	0	0	25.6	83.2	32	19.2	6.4	6.4	19.2	6.4	38.4
Bivalvia	0	0	0	0	0	0	0	0	0	0	0
Macoma sp.	0	0	0	0	0	0	0	0	0	0	0
Macoma balthica	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Macoma mitchelli	25.6	0	0	6.4	0	0	0	6.4	12.8	0	0
Rangia cuneata	**57.6**	**12.8**	**6.4**	**0**	**12.8**	**12.8**	**6.4**	**0**	**6.4**	**0**	**6.4**
Ischadium recurvum	0	0	0	0	0	0	0	0	0	0	0
Mytilopsis leucophaeata	0	0	0	0	0	0	0	0	0	0	0
Amphicteis floridus	0	0	0	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	0	12.8	6.4	0	51.2	0	0	0	0	0	6.4
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	**19.2**	**44.8**	**19.2**	**76.8**	**76.8**	**32**	**32**	**294.4**	**83.2**	**102.4**	**102.4**
Streblospio benedicti	70.4	1056	204.8	147.2	601.6	25.6	57.6	89.6	83.2	51.2	44.8
Polydora cornuta	0	140.8	0	6.4	416	0	0	0	12.8	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereidae	0	25.6	0	0	6.4	0	0	0	0	0	0
Neanthes succinea	12.8	147.2	6.4	12.8	371.2	76.8	12.8	12.8	12.8	0	0
Eteone heteropoda	25.6	44.8	0	19.2	51.2	0	0	0	0	0	0
Naididae sp.	217.6	96	569.6	371.2	83.2	102.4	96	76.8	185.6	192	108.8
Amphipoda	0	0	0	0	0	0	0	0	0	0	0
Gammaridea	6.4	12.8	0	6.4	0	6.4	6.4	0	6.4	25.6	6.4

Table 2-10– (continued)

Station											
Taxon	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Ameroculodes spp complex	0	0	0	0	0	0	0	0	0	0	0
Leptocheirus plumulosus	38.4	38.4	140.8	211.2	57.6	83.2	224	115.2	121.6	384	192
Gammarus sp.	0	0	0	0	0	0	0	0	0	25.6	0
Melitadae	0	0	0	0	0	0	0	0	0	6.4	0
Melita nitida	6.4	0	32	6.4	12.8	6.4	25.6	6.4	25.6	236.8	32
Corophiidae	0	12.8	0	0	0	0	0	0	0	0	0
Apocorophium lacustre	6.4	51.2	0	0	25.6	0	0	0	0	0	0
Cyathura polita	**83.2**	**57.6**	**51.2**	**57.6**	**236.8**	**32**	**44.8**	**44.8**	**38.4**	**51.2**	**38.4**
Edotea triloba	0	0	0	0	0	0	0	0	0	0	0
Chiridotea almyra	0	0	0	0	0	0	0	0	0	0	0
Ciripedia	0	0	0	0	0	0	0	0	0	0	0
Balanus improvisus	0	0	0	0	0	0	0	0	0	0	0
Balanus subalbidus	0	0	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	0	0	0	0	0	0	0	0	0	0	0
Membranipora sp	0	+	+	+	+	+	+	+	+	0	+
Chironomidae	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	12.8	0	0	0	0	6.4	0	0	0
Procladius sp.	0	0	0	0	0	0	0	0	0	0	0
Cryptochironomus sp.	0	0	0	0	0	0	0	0	0	0	0
Chironominae	0	0	0	0	0	0	0	0	0	0	0
Gammmaridae	0	0	0	0	0	0	0	0	0	0	0
Copepoda	0	0	0	0	0	0	0	0	0	0	0
Glycinde solitaria	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Mysidacea	0	12.8	6.4	0	6.4	0	0	0	0	12.8	0
Cassidinea ovalis	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 31 late summer sampling, September 2012, 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.

Taxon	Station										
	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Nemata	326.4	691.2	0	19.2	256	115.2	0	64	147.2	0	6.4
Carinoma tremaphoros	12.8	0	0	6.4	25.6	25.6	25.6	12.8	12.8	0	140.8
Bivalvia	6.4	0	0	0	0	0	0	0	0	0	6.4
Macoma sp.	19.2	0	0	0	0	0	0	0	0	6.4	0
Macoma balthica	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Macoma mitchelli	38.4	0	12.8	19.2	0	6.4	6.4	0	19.2	102.4	38.4
Rangia cuneata	**0**	**0**	**19.2**	**96**	**25.6**	**6.4**	**6.4**	**0**	**25.6**	**38.4**	**0**
Ischadium recurvum	0	0	0	0	0	0	0	0	0	0	0
Mytilopsis leucophaeata	0	0	6.4	0	0	0	0	0	0	0	0
Amphicteis floridus	0	0	0	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	0	0	6.4	19.2	6.4	0	0	0	0	83.2	6.4
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	**96**	**32**	**6.4**	**153.6**	**166.4**	**102.4**	**89.6**	**83.2**	**32**	**25.6**	**44.8**
Streblospio benedicti	896	448	140.8	780.8	518.4	76.8	70.4	76.8	217.6	102.4	64
Polydora cornuta	0	0	0	6.4	230.4	0	0	0	0	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereidae	0	0	12.8	0	0	0	0	0	0	70.4	0
Neanthes succinea	12.8	0	44.8	102.4	25.6	6.4	12.8	0	0	102.4	6.4
Eteone heteropoda	38.4	0	32	57.6	12.8	6.4	0	0	6.4	19.2	0
Naididae sp.	467.2	499.2	19.2	659.2	371.2	601.6	352	249.6	198.4	12.8	435.2
Amphipoda	0	0	0	0	0	6.4	0	0	0	0	0
Gammaridea	0	6.4	0	12.8	12.8	12.8	12.8	0	12.8	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	0	0	0
Leptocheirus plumulosus	76.8	179.2	6.4	153.6	147.2	313.6	160	409.6	185.6	0	0
Gammarus sp.	0	0	0	0	0	0	0	0	0	0	0
Melitadae	6.4	0	0	0	6.4	0	0	19.2	6.4	0	0
Melita nitida	6.4	12.8	19.2	0	44.8	96	32	166.4	38.4	0	0
Corophiidae	6.4	0	0	0	0	0	0	0	0	0	0
Apocorophium lacustre	0	0	19.2	32	6.4	0	0	0	6.4	0	0
Cyathura polita	**96**	**19.2**	**0**	**121.6**	**12.8**	**38.4**	**51.2**	**6.4**	**12.8**	**6.4**	**96**
Edotea triloba	0	0	0	12.8	0	0	0	0	0	0	0
Chiridotea almyra	0	0	0	38.4	0	0	0	0	0	0	0
Ciripedia	0	0	0	0	0	0	0	0	0	0	0
Balanus improvisus	0	0	0	12.8	0	0	0	0	0	0	0
Balanus subalbidus	0	0	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	0	0	0	0	0	0	0	0	0	0	0
Membranipora sp	0	0	0	+	0	+	+	0	0	0	0
Chironomidae	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	64	51.2	0	0	83.2	6.4	6.4	6.4	32	0	0
Procladius sp.	0	0	0	0	0	0	0	0	0	0	0
Cryptochironomus sp.	0	0	0	0	0	0	0	0	0	0	0
Chironominae	0	0	0	0	0	0	0	0	0	0	0
Gammmaridae	6.4	0	0	0	0	0	0	0	6.4	0	0
Copepoda	0	0	0	0	0	0	0	0	0	0	0
Glycinde solitaria	0	0	0	0	0	0	0	0	0	6.4	0
Mysidacea	19.2	0	0	19.2	19.2	0	0	0	6.4	0	0
Cassidinea ovalis	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 31 spring sampling, April 2013, 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	25.6	0	128	0
Carinoma tremaphoros	0	0	25.6	0	6.4	44.8	6.4	12.8	6.4	6.4	44.8
Bivalvia	0	25.6	0	57.6	70.4	614.4	32	121.6	339.2	185.6	192
Macoma sp.	0	0	19.2	0	0	281.6	0	38.4	19.2	38.4	108.8
Macoma balthica	**19.2**	**32**	**672**	**89.6**	**211.2**	**985.6**	**409.6**	**352**	**352**	**160**	**742.4**
Macoma mitchelli	0	0	44.8	25.6	44.8	134.4	57.6	12.8	44.8	19.2	51.2
Rangia cuneata	**0**	**0**	**6.4**	**6.4**	**19.2**	**6.4**	**0**	**6.4**	**6.4**	**6.4**	**0**
Ischadium recurvum	64	51.2	0	0	6.4	0	0	0	0	0	0
Mytilopsis leucophaeata	12.8	19.2	0	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	12.8	44.8	108.8	44.8	64	313.6	83.2	25.6	192	115.2	320
Spionidae	0	0	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	**3974.4**	**4832**	**5036.8**	**5504**	**4870.4**	**2668.8**	**2931.2**	**2796.8**	**2105.6**	**3449.6**	**1196.8**
Streblospio benedicti	6.4	44.8	377.6	64	134.4	512	134.4	134.4	134.4	448	256
Polydora cornuta	812.8	2828.8	0	6.4	83.2	6.4	0	0	0	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereidae	121.6	198.4	0	44.8	294.4	25.6	0	0	0	0	0
Neanthes succinea	313.6	659.2	19.2	134.4	544	76.8	6.4	19.2	44.8	19.2	64
Naididae sp.	691.2	441.6	3532.8	716.8	633.6	1664	793.6	972.8	1126.4	2252.8	1286.4
Amphipoda	940.8	2822.4	6.4	96	115.2	147.2	0	0	0	0	0
Gammaridea	0	204.8	12.8	19.2	0	57.6	224	192	467.2	204.8	83.2
Ameroculodes spp. complex	0	0	0	6.4	0	0	6.4	0	0	0	0
Leptocheirus plumulosus	19.2	768	2540.8	1811.2	793.6	1420.8	2336	2188.8	1952	2278.4	2099.2

Table 2-12-Continued

Taxon	Station										
	MDE-01	MDE-03	MDE-07	MDE-09	MDE-11	MDE-13	MDE-15	MDE-16	MDE-17	MDE-19	MDE-22
Gammaridae	0	0	0	0	0	0	0	0	0	0	0
Gammarus sp	57.6	0	0	0	12.8	0	12.8	0	0	0	6.4
Melitadae	0	0	6.4	0	0	0	0	0	0	0	0
Melita nitida	115.2	70.4	64	25.6	25.6	44.8	83.2	38.4	76.8	179.2	83.2
Corophiidae	224	0	0	0	0	0	6.4	0	0	6.4	0
Apocorophium sp.	0	0	32	0	0	0	0	0	0	0	0
Apocorophium lacustre	11891.2	22169.6	243.2	422.4	748.8	185.6	172.8	153.6	204.8	230.4	204.8
Cyathura polita	0	38.4	44.8	38.4	76.8	64	44.8	38.4	19.2	25.6	25.6
Edotea triloba	0	0	0	0	0	0	0	0	0	0	0
Chiridotea almyra	0	0	0	0	0	0	0	0	0	0	0
Balanus improvisus	192	32	0	0	6.4	0	0	0	0	0	0
Balanus subalbidus	6.4	6.4	0	0	0	0	0	0	0	0	0
Caecidotea sp.	0	0	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	25.6	19.2	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
Orthocladiinae sp B.	0	0	0	0	0	0	0	0	0	0	0
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	57.6	12.8	0	0	44.8	12.8	12.8	25.6	6.4
Procladius sp.	0	0	0	0	0	0	0	0	0	0	0
Orthocladiinae	51.2	0	0	0	0	0	0	0	0	0	0
Orthocladius/Cricotopus sp.	19.2	0	0	0	0	0	0	0	0	0	0

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
Eukiefferiella sp.	6.4	0	0	0	0	0	0	0	0	0	0
Cryptochironomus sp.	0	0	0	0	0	0	0	0	0	0	0
Chironomus sp.	0	0	0	0	0	0	6.4	6.4	0	0	0
Orthocladiinae sp A.	0	0	0	0	0	0	0	0	0	0	0
Hydrobiidae	0	0	0	0	0	0	0	0	0	0	0
Mulinia lateralis	0	0	0	0	0	6.4	0	0	0	0	0
Cirripedia	96	96	0	0	0	0	0	0	0	0	0
Copepoda	+	0	+	+	+	+	+	+	+	+	+
Ostracoda	0	0	6.4	6.4	0	0	44.8	32	12.8	51.2	6.4
Mysidacea	0	0	25.6	0	0	6.4	0	0	0	0	0
Gyratrix hermaphrodites	0	44.8	0	6.4	6.4	57.6	0	32	57.6	96	44.8
Trichoptera	0	0	0	0	0	6.4	0	0	0	0	0
Eteone heteropoda	0	0	0	0	0	0	0	6.4	0	0	0
Cassidinea ovalis	32	6.4	0	0	0	0	0	0	0	0	0
Isopoda	6.4	0	0	0	0	0	0	0	0	0	0
Pisicola sp.	0	6.4	0	0	0	0	6.4	0	0	0	0
Empididae sp.	0	6.4	0	0	0	0	0	0	0	0	0

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

Table 2-13: Average number of individuals collected per square meter at each station during the HMI Year 31 spring sampling, April 2013, 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.

Taxon	Station										
	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Nemata	6.4	147.2	32	0	160	25.6	6.4	0	38.4	0	0
Carinoma tremaphoros	6.4	0	0	0	0	25.6	6.4	0	32	6.4	89.6
Bivalvia	0	0	12.8	403.2	64	70.4	217.6	0	83.2	134.4	377.6
Macoma sp.	0	0	70.4	0	0	64	51.2	51.2	0	0	166.4
Macoma balthica	**192**	**0**	**185.6**	**313.6**	**185.6**	**1753.6**	**480**	**115.2**	**384**	**2118.4**	**2361.6**
Macoma mitchelli	108.8	0	6.4	12.8	6.4	12.8	76.8	32	12.8	51.2	249.6
Rangia cuneata	**0**	**0**	**6.4**	**19.2**	**19.2**	**0**	**0**	**0**	**12.8**	**25.6**	**0**
Ischadium recurvum	0	0	0	0	0	0	0	0	0	0	0
Mytilopsis leucophaeata	0	0	0	0	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	64	0
Heteromastus filiformis	19.2	0	0	89.6	38.4	160	160	64	57.6	115.2	454.4
Spionidae	0	0	281.6	0	0	0	0	0	0	0	0
Marenzelleria viridis	**4012.8**	**3622.4**	**12883.2**	**19206.4**	**8896**	**2137.6**	**2611.2**	**2758.4**	**3104**	**12614**	**1907.2**
Streblospio benedicti	166.4	0	6.4	6.4	32	473.6	160	83.2	275.2	6.4	0
Polydora cornuta	0	6.4	0	57.6	0	0	0	0	0	0	0
Boccardiella ligerica	0	0	0	0	0	0	0	0	0	0	0
Nereidae	0	0	0	38.4	0	0	6.4	0	0	0	0
Neanthes succinea	12.8	0	19.2	121.6	44.8	19.2	102.4	6.4	57.6	89.6	57.6
Naididae sp.	1772.8	1235.2	32	499.2	537.6	1676.8	1932.8	2080	2918.4	6.4	569.6
Amphipoda	0	19.2	0	172.8	160	0	38.4	0	12.8	0	70.4
Gammaridea	19.2	57.6	25.6	38.4	57.6	57.6	108.8	108.8	57.6	25.6	38.4
Ameroculodes spp. complex	6.4	0	0	0	6.4	0	0	0	0	19.2	0
Leptocheirus plumulosus	588.8	825.6	512	2604.8	4313.6	3020.8	1804.8	2534.4	2918.4	364.8	1299.2

Table 2-13– (continued)

Taxon	Station										
	MDE-27	MDE-30	MDE-33	MDE-34	MDE-36	MDE-42	MDE-43	MDE-44	MDE-45	MDE-50	MDE-51
Gammaridae	0	0	0	0	0	44.8	0	0	0	0	0
Gammarus sp	0	0	12.8	0	0	0	0	0	0	0	0
Melitadae	0	0	0	0	0	0	0	0	32	0	6.4
Melita nitida	0	0	6.4	32	64	147.2	57.6	89.6	96	0	19.2
Corophiidae	0	0	0	224	0	0	0	6.4	0	6.4	0
Apocorophium sp.	0	0	0	0	0	0	0	0	0	0	0
Apocorophium lacustre	185.6	134.4	358.4	3737.6	825.6	211.2	57.6	582.4	204.8	153.6	12.8
Cyathura polita	**44.8**	**0**	**0**	**70.4**	**12.8**	**51.2**	**44.8**	**19.2**	**44.8**	**6.4**	**102.4**
Edotea triloba	6.4	0	0	12.8	25.6	0	0	0	0	0	0
Chiridotea almyra	0	0	0	0	0	0	0	0	0	0	0
Balanus improvisus	0	0	0	0	0	0	0	0	0	0	0
Balanus subalbidus	0	0	0	0	0	0	0	0	0	0	0
Caecidotea sp.	0	0	0	0	0	0	6.4	0	0	0	0
Rhithropanopeus harrisii	0	0	0	0	0	0	0	0	0	0	0
Membranipora sp	0	0	0	+	+	0	+	0	0	0	+
Chironomidae	0	0	0	0	0	0	0	0	0	0	0
Orthocladiinae sp B.	0	0	0	0	0	6.4	0	0	0	0	0
Mya arenaria	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**44.8**	**0**
Coelotanypus sp.	76.8	134.4	0	0	57.6	12.8	19.2	6.4	32	0	0
Procladius sp.	0	0	0	0	0	0	0	6.4	0	0	0
Orthocladiinae	0	0	0	0	0	0	0	0	0	0	0
Orthocladius/Cricotopus sp.	0	0	0	0	0	0	0	0	0	0	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
Eukiefferiella sp.	0	0	0	0	0	0	0	0	0	0	0
Cryptochironomus sp.	0	0	0	6.4	0	0	0	0	0	0	0
Chironomus sp.	0	0	0	0	0	0	0	0	0	0	0
Orthocladiinae sp A.	0	6.4	0	0	0	0	0	0	0	0	0
Hydrobiidae	0	0	6.4	0	0	0	0	0	0	0	0
Mulinia lateralis	0	0	0	0	0	0	0	0	0	0	0
Cirripedia	0	0	0	0	0	0	0	0	0	0	0
Copepoda	+	+	+	+	+	+	+	+	+	+	+
Ostracoda	224	25.6	0	25.6	6.4	108.8	12.8	19.2	38.4	0	0
Mysidacea	6.4	0	6.4	0	0	0	0	0	0	6.4	6.4
Gyratrix hermaphrodites	6.4	0	147.2	332.8	134.4	185.6	25.6	6.4	0	57.6	44.8
Trichoptera	0	0	0	0	0	0	0	0	0	0	0
Eteone heteropoda	0	0	0	0	0	0	0	0	0	0	32
Cassidinea ovalis	0	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0
Pisicola sp.	0	0	0	6.4	0	0	0	0	0	0	0
Empididae sp.	0	0	0	0	0	0	0	0	0	0	0

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

Infaunal Taxa Abundance

Average total infaunal abundance was lower in the fall (September 2012) than in the spring (April 2013) (Figure 2-2). Typically spring abundance is much higher than the fall due to recruitment. This trend has been repeated in 13 of the past 14 years (excluding Years 23 and 30). In September 2012, total infaunal abundance ranged from 320.00 to 2,220.80 organisms per square meter (individuals/m^2) and averaged 992.58 individuals/m^2 (Table 2-8).The highest September 2012 abundance was found at the Nearfield station MDE-34, due primarily to large numbers of *S. benedicti*, and worms of the family Naididae. The lowest infaunal abundance in September 2012 was found at the Nearfield station MDE-33 (Table 2-8). The average total infaunal abundance was highest at Back River/Hawk Cove stations (1,462.40 individuals/m^2) followed by Nearfield stations (1,016.00 individuals/m^2), South Cell Exterior Monitoring stations (942.93 individuals/m^2), and Reference stations (778.24 individuals/m^2) in September. Based on station type, no trend of increasing/decreasing abundances associated with distance from HMI could be discerned. The 31-year mean (4,650.41 individuals/m^2) of fall abundance for the Back River stations is much higher than the Reference (1,914.08 individuals/m^2) and Nearfield (2,172.28 individuals/m^2) means. Mean abundance in the South Cell stations has a nine-year average of 1,313.00 individuals/m^2.

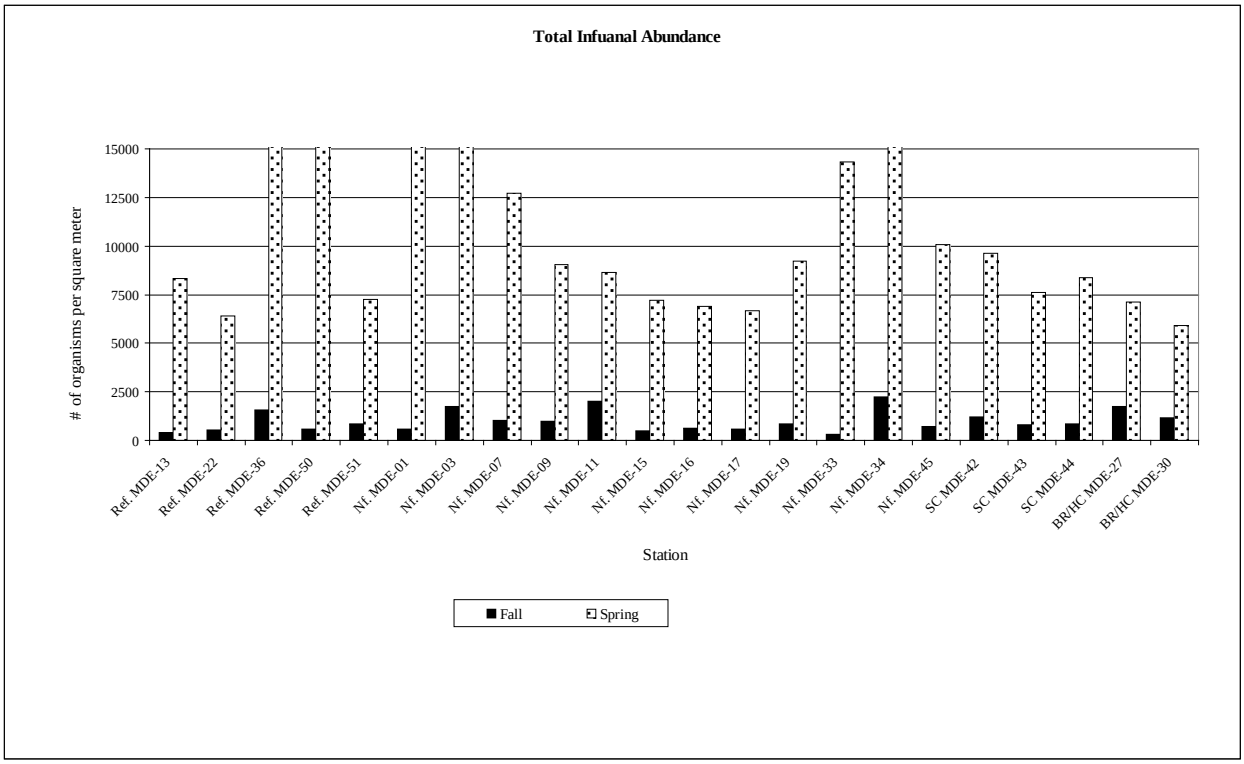


Figure 2-2: Total abundance of infaunal taxa collected at each HMI station in Year 31, September 2012 and April 2013 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

In April 2013, total infaunal abundance ranged from 5,900.80 to 35,084.80 individuals/m^2 and averaged 11,709.38 individuals/m^2. The station with the highest abundance was the Nearfield station MDE-03, due primarily to a large number of *A. lacustre*. The lowest spring abundance occurred at the Back River/Hawk Cove station MDE-30, which is shown in 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 Back River/Hawk Cove stations (6,518.40 individuals/m^2) followed by South Cell Exterior Monitoring stations (8,541.87 individuals/m2), Reference stations (10,547.20 individuals/m2), and highest at Nearfield stations (13,850.67 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 31, total infaunal abundance was similar to total abundance, typically accounting for ≥85 percent of all organisms at all stations, except MDE-19 (76.61% fall only) and MDE-44 (81.37% fall only), during both seasons. This ratio is historically typical for this project.
.

Diversity

Species diversity was examined using the Shannon-Wiener Diversity Index (SWDI), which measures diversity on a numerical scale from zero to four. A lower score indicates an unbalanced benthic community dominated by only one or two species whereas a higher score suggests a balanced, diverse benthic community. Pfitzenmeyer et al. (1982) suggested that diversity, as measured by SWDI, would be higher in the summer when recruitment decreased and predation increased as opposed to spring, thus reducing the numbers of the dominant taxa. Correspondingly, diversity has often been lowest at most stations in spring (April or May) due to an influx of juveniles, especially of the dominant species (Duguay et al. 1998, Duguay et al. 1995a, Duguay et al. 1995b, Duguay 1992, Duguay 1990, Pfitzenmeyer and Tenore 1987). Diversity values for Year 31 are presented in Table 2- and 2-9. In Year 31, SWDI was calculated for the spring, however, because of the above reasons SWDI is not applied in the spring.

SWDI values in Year 31 averaged 2.33± 0.33 in September 2012. The fall average diversity was comparable to the 15-year mean fall diversity of 2.30. The lowest diversity value in September 2012 occurred at Back River/Hawk Cove station MDE-30 (1.70, Figure 2-3). This was due to the large percentage of Naididae worms and *S. Benedicti*, which accounted for 80 percent of total infaunal abundance at this station. The

highest September 2012 diversity value (2.80) occurred at Nearfield station MDE-11 and Reference station MDE-50.

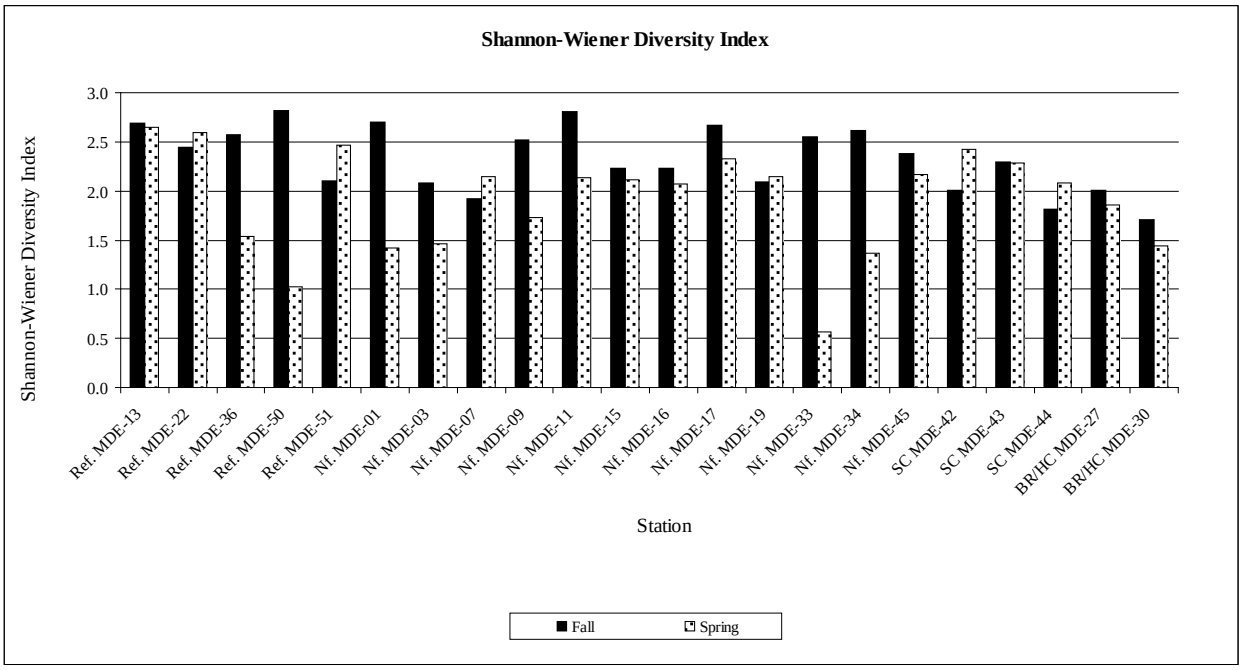


Figure 2-3: Shannon-Wiener Diversity Index (SWDI), HMI Year 31, September 2012 and April 2013 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell; BR/HC = Back River Hawk Cove).

On average, Nearfield stations had diversity values similar to Reference stations in September 2012. Comparing station types from the fall only, the lowest average SWDI was 1.86 at the Back River/Hawk Cove stations followed by the South Cell Exterior Monitoring stations at 2.04, and Nearfield stations at 2.40. The highest average SWDI occurred at the Reference stations at 2.53 (Table 2- Historically, the 25-year mean SWDI values, ranked from lowest to highest, are associated with the following station types: Back River/Hawk Cove (2.13), Nearfield (2.34), Reference (2.41), and South Cell Exterior Monitoring (2.52, n=9 yrs). No trend of increasing/decreasing diversity associated with distance from HMI could be discerned.

Pollution Sensitive Taxa Abundance (PSTA)

Six taxa found during the September 2012 and April 2013 sampling cruises were designated as "pollution-sensitive" according to Alden et al. (2002). These were the polychaete worms *M. viridis* and *G. solitaria,* the bivalves *R. cuneata*, *M. balthica,* and

M. arenaria, and the isopod crustacean *C. polita.* 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 accounted for prior to some historical analyses of PSTA fall data. In Year 31, the fall salinity regime was low mesohaline, the last time the fall salinity regime was oligohaline was Year 29.

In Year 31, pollution sensitive taxa occurred at all station types. In September 2012, PSTA ranged from 4.32 percent at MDE-30 (Back River/Hawk Cove station) to 52.48 percent at MDE-16 (Nearfield station –Table 2-8; Figure 2-4). The average PSTA for all stations in September 2012 was 16.53 percent. Comparing station types, the lowest average PSTA was 7.68 percent at the Back River/Hawk Cove stations, followed by the South Cell Exterior Monitoring stations at 13.87 percent, followed by the Nearfield stations at 18.02 percent. The highest average PSTA was 18.08 percent at Reference stations. Historically, the 31-year mean fall PSTA values, ranked from lowest to highest, are associated with the following station types: South Cell Exterior Monitoring (26.09 percent, n=8 years), Back River/Hawk Cove (29.89 percent), Nearfield (37.80 percent), and Reference (41.05 percent).

In April 2013, PSTA ranged from 13.97 percent at MDE-03 (Nearfield station) to 94.60 percent at MDE-50 (Reference station –Table 2-8; Figure 2-4). The average PSTA for all stations in April 2013 was 49.96 percent. Comparing station types, the lowest average PSTA was 38.89 percent at the South Cell Exterior Monitoring stations, followed by the Nearfield stations at 47.57 percent, followed by the Reference stations at 58.14 percent. The highest average PSTA was 60.47 percent at Back River/Hawk Cove stations.

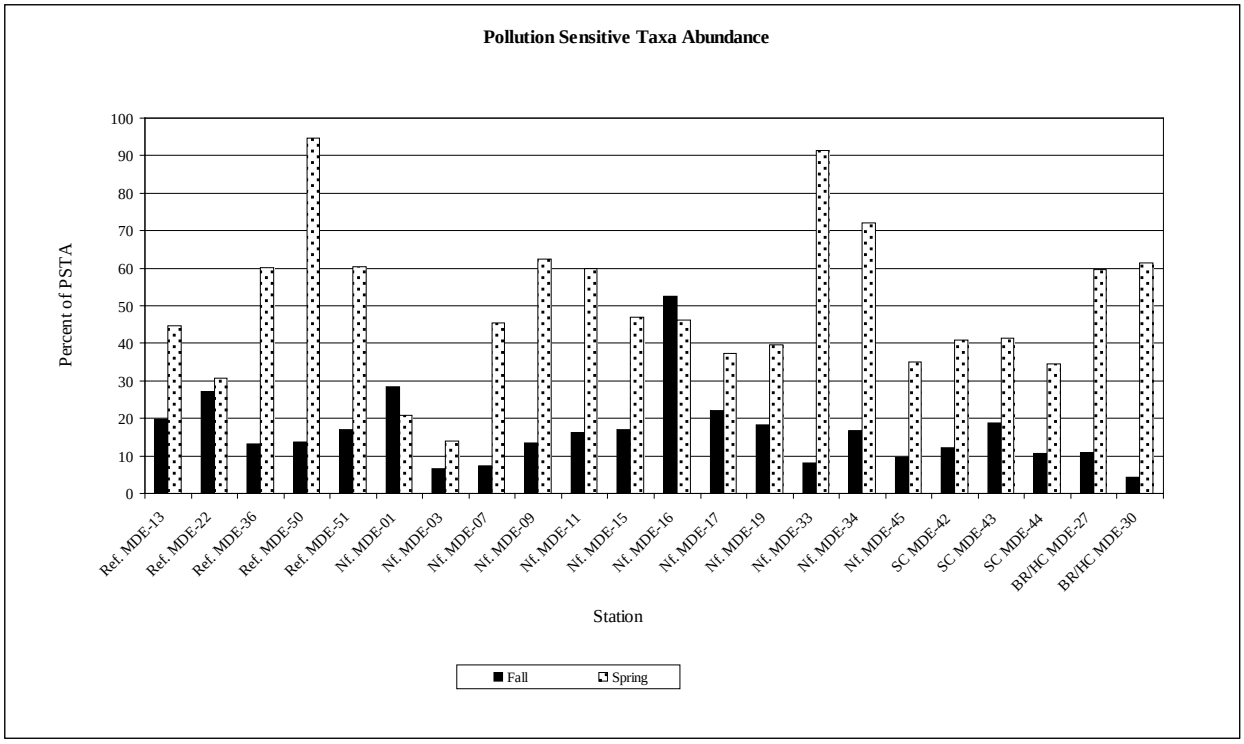


Figure 2-4: Percent abundance comprised of pollution sensitive species (PSTA), HMI Year 31 September 2012 and April 2013 grouped by station type (Ref. = Reference; Nf. = Nearfield; SC = South Cell Exterior Monitoring; BR/HC = Back River Hawk Cove).

Pollution Indicative Taxa Abundance (PITA)

Four taxa found during the September 2012 sampling of Year 31 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 2013 sampling cruise were designated as "pollution-indicative" according to Alden et al. (2002): the Chironomids *Coelotanypus* sp., *Procladius* sp., and *Chironomus* sp., the polychaete worms *S. benedicti* and *E. heteropoda*, the bivalve *M. lateralis*, and oligochaete worms of the family Naididae. The calculation of the PITA is a ratio of the relative PITA abundance to total infaunal abundance.

In Year 31, pollution indicative taxa occurred at all station types. In September, the PITA ranged from 23.06 percent at MDE-50 (Reference station) to 84.32 percent at MDE-30 (Back River/Hawk Cove station) (Table 2-8; Figure 2-5). The average PITA for all stations in September 2012 was 51.90 percent. Comparing station types, the lowest average PITA was 41.60 percent at the Reference stations, followed by 50.54 percent at the South Cell Exterior Monitoring stations, and 51.15 percent at Nearfield stations. The highest average PITA occurred at the Back River/Hawk Cove stations at 84.26 percent.

Historically, the 31-year mean fall PITA values, ranked lowest to highest, are associated with the following station types: Reference (22.06 percent), Nearfield (24.49 percent), Back River/Hawk Cove (38.53 percent), and South Cell Exterior Monitoring (38.54 percent, n = 9 years).

In April 2013, the lowest PITA was 0.08 percent at MDE-50 (Reference station) and the highest was 31.96 percent at MDE-45 (Nearfield station –Table 2-9; Figure 2-5). The average PITA for all stations in April was 16.24 percent. Reference stations had the lowest average PITA at 12.61 percent, followed by the Nearfield stations at 13.89 percent, and the South Cell Exterior Monitoring stations at 25.40; the Back River/Hawk Cove had the highest average PITA of 25.73 percent.

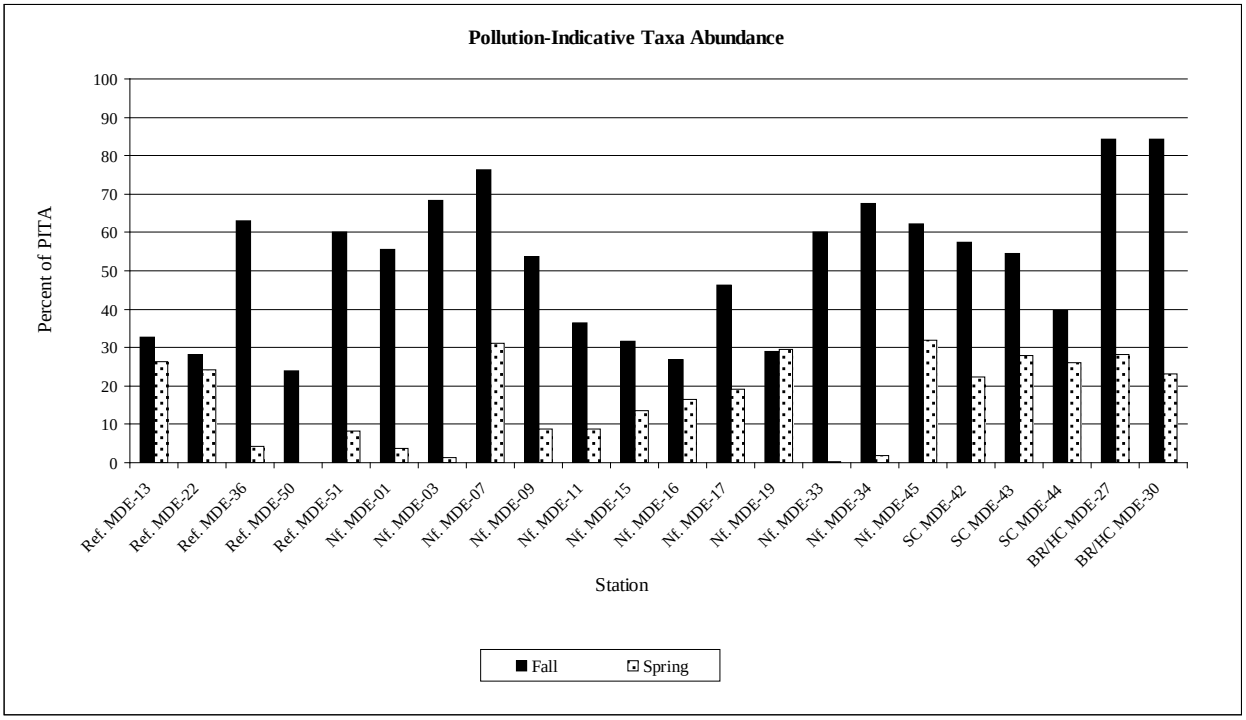


Figure 2-5: Percent abundance comprised of pollution indicative species (PITA), HMI Year 31 September 2012 and April 2013 grouped by station type (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

Benthic Index of Biotic Integrity

The B-IBI was calculated for all stations based on September 2012 data only (see *Methods and Materials*). Four metrics were used to calculate the B-IBI for stations under the low mesohaline classification (5 - 12 ppt). These metrics were total infaunal abundance, relative abundance of pollution-indicative taxa, relative abundance of

pollution-sensitive taxa, and Shannon-Wiener diversity index. The specific scoring criteria for the low mesohaline metrics are presented in Table-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 31 were compared to this benchmark.

Table 2-14: Low mesohaline scoring criteria for measures used in calculating the Chesapeake Bay B-IBI in September 2012 (Weisberg et al. 1997).

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

Compared to Year 30, individual station B-IBI Scores decreased at 16 stations, remained the same at 1, and increased at 5 stations. Eleven of the twenty-two stations met or exceeded the benchmark criteria of 3.0 in Year 31. In Year 31, Back River/Hawk Cove station MDE-30 (2.00), Reference stations MDE- 13 (2.50) and MDE-51 (2.50), Nearfield Stations MDE-7 (2.50), MDE-15 (2.00), MDE-19 (2.50), MDE-33 (2.50), and MDE-45 (2.50), and South Cell Exterior Monitoring StationsMDE-42 (2.50), MDE-43 (2.50), and MDE-44 (2.50) failed to meet the benchmark criteria of 3.0 (Table 2-8, Figure 2-6). Nineteen stations were below their historic averages and three stations (one Nearfield, one Reference, and one Back River/Hawk Cove) were above their historic averages for B-IBI. In addition to nineteen stations being below their historic average two tied a historic low (Nearfield station MDE-09 and Reference station MDE-50). Four stations (Nearfield station MDE-15, Reference station MDE-13, Back River/Hawk Cove station MDE-30, and South Cell Exterior Monitoring station MDE-44) set new historic lows; however this is only the fifth year station MDE-15 has been sampled. No stations set new historic highs.

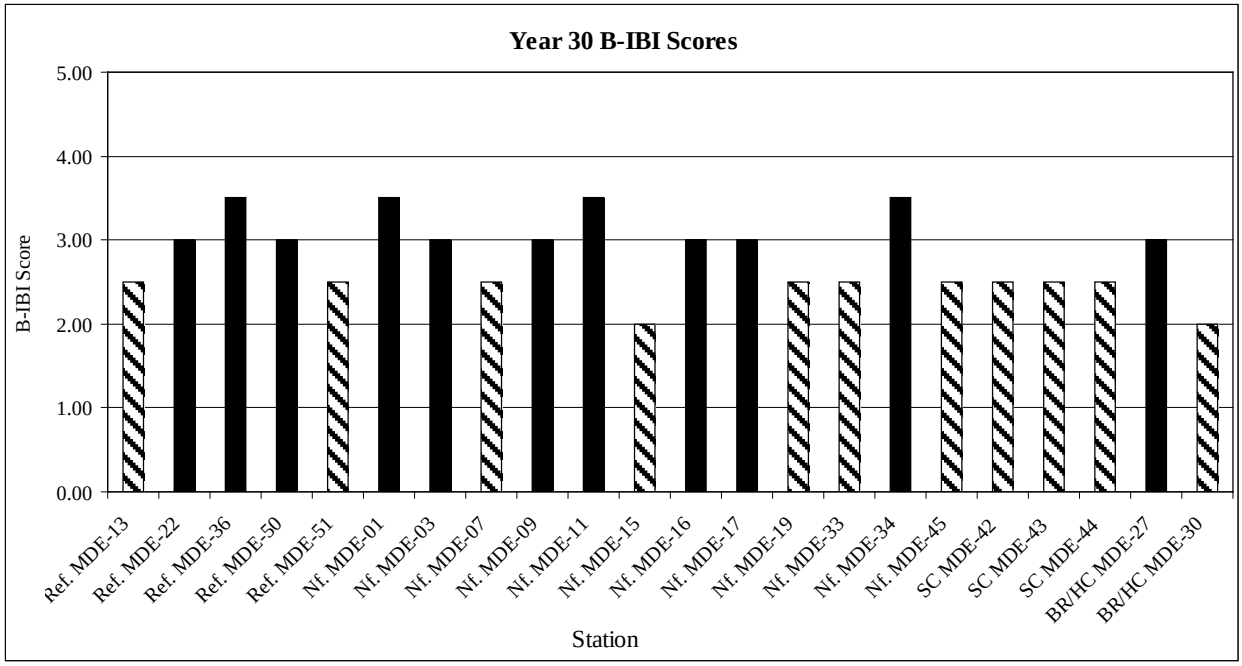


Figure 2-6: B-IBI Scores for all stations in September 2012 grouped by station type (Ref.=Reference; Nf.=Nearfield; SC=South Cell Exterior Monitoring; BR/HC=Back River Hawk Cove).

The mean B-IBI for Nearfield, South Cell Exterior Monitoring, Back River/Hawk Cove and Reference stations failed to meet the benchmark of 3.0. Average B-IBI scores by station type are shown in Figure 2-7. Compared to Year 30, the mean B-IBI decreased for Nearfield, South Cell Exterior Monitoring, and Reference station types and remained the same for Back River/Hawk Cove stations. The Year 31 mean B-IBI's for all station types were below their historic averages (nine year average for South Cell Exterior Monitoring Stations, Table 2-).

The mean B-IBI for South Cell Exterior Monitoring stations set an all time low record (nine years of data). The mean B-IBI for Reference stations was the second lowest in 31 years (lowest since year 12). The mean B-IBI for Nearfield stations was the fourth lowest since Year 1. The mean B-IBI for Back River/Hawk Cove stations was the fifth lowest since Year 1 (five way tie).

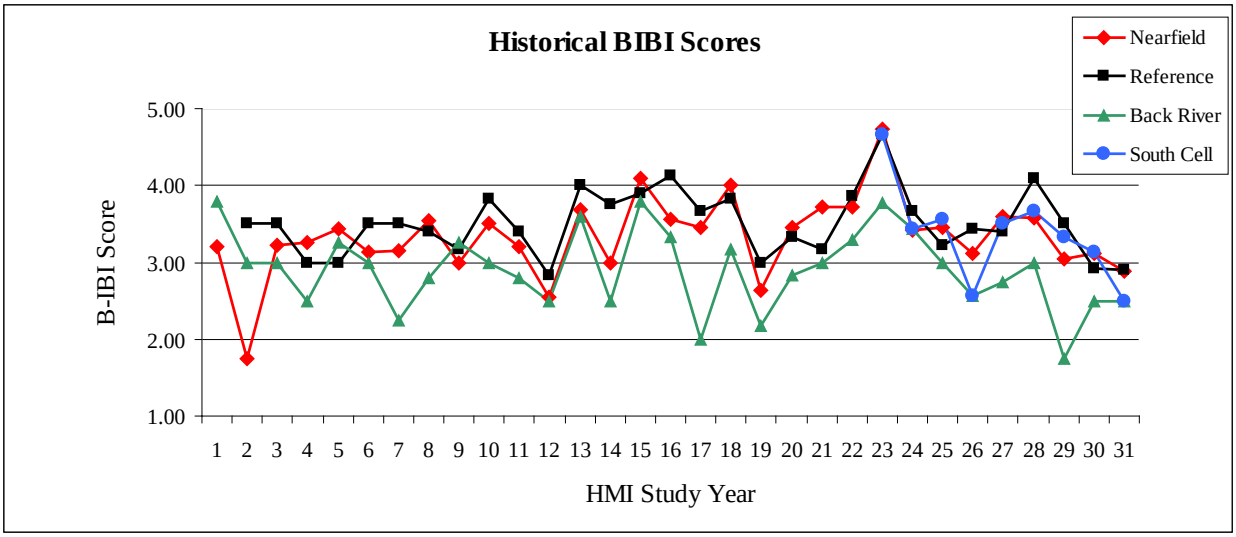


Figure 2-7: Average B-IBI Scores at HMI for Monitoring Years 1-31.

There was no trend of increasing or decreasing B-IBI scores associated with proximity to HMI in Year 31. Compared to other station types, South Cell Exterior Monitoring and Back River/Hawk Cove stations had the lowest mean IBI's in Year 31. Back River/Hawk Cove stations have had the lowest average 26 of 31 years.

The Year 31 low B-IBI's were attributable to several variations in the invertebrate community. Below average abundances (approximately 50%) of the polychaete worm *M. viridis* and the isopod, *C. polita*, reduced PSTA and increased PITA metric scores. Above average abundance of the polychaete *S. benedicti* (a species with highly variable abundance from year to year) increased PITA scores.

Clam Length Frequency Distribution

In September 2012, 55 *R. cuneata* were collected. The greatest average abundance of *R. cuneata* occurred at the Nearfield stations (3.33 clams/station), followed by the Reference stations (2.60 clams/station), the South Cell Exterior Monitoring stations (0.67 clams/station), and the Back River/Hawk Cove stations (0.00 clams/station). The greatest abundance of *R. cuneata* during the fall was found in the 1-5 and 6-10 mm size classes. In April 2013, 22 *R. cuneata* were collected. The greatest average abundance for this species occurred at the Reference stations (1.60 clams/station), followed by the Nearfield stations (1.17 clams/station). None were found at the Back River/Hawk Cove stations and South Cell Exterior Monitoring stations. The greatest abundance of *R. cuneata* during the spring was found in the 1-5 and 41-45 mm size classes.

Historically, *R. cuneata* tends to be the most abundant bivalve mollusk found in this benthic monitoring project. It is classified as pollution sensitive during higher

salinity years (≥5ppt). The population has historically been very dynamic in terms of overall abundance and distribution by size or station type. The main drivers of *R. cuneata* variability appear to be temperature and salinity. In the Chesapeake Bay, this species exists at the northern extent of its range. Because of this, it is subject to high winter mortality during cold winters (Hopkins, et al., 1973). Additionally, ideal salinity conditions for reproduction and recruitment do not occur regularly. The reduction in *Rangia* abundance from Year 30 (1,731 clams) to Year 31 (77 clams) (95.6 %) is greater than the typical winter die-off which usually ranges between 5 and 68%. This is probably explained by the fact that the bulk of the *Rangia* were in the smallest size classes. Reproduction in the Year 30 clams was especially high, resulting in a population of mostly small clams, which were more prone to predation, siltation, and cold stress. In Maryland, *R. cuneata* rarely if ever reaches its reported maximum age (15-20 years) or size (79 mm). Looking at 15 years of frequency distribution data around HMI, it is difficult to identify more than four age classes of clams at any time. This implies very few clams survive longer than five years.

In September 2012, no *M. balthica* were collected. In April 2013, 1,893 *M. balthica* were collected with 999 coming from Reference stations, 497 from Nearfield stations, 367 from South Cell Exterior Monitoring stations, and 30 from Back River/Hawk Cove stations. The greatest abundance of *M. balthica* during the spring was found in the 1-5 mm size class.

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

In September 2012, 44 *M. mitchelli* were collected, with 14 coming from Nearfield stations, 22 from Reference stations, 2 from South Cell Exterior Monitoring stations, and 6 from Back River/Hawk Cove stations. The greatest abundance of *M. mitchelli* during the fall was found in the 1-2 and 7-8 mm size classes. In April, 156 *M. mitchelli* were collected with 44 coming from Nearfield stations, 76 from Reference stations, 19 from South Cell Exterior Monitoring stations, and 17 from Back River/Hawk Cove stations. The *M. mitchelli* found during the spring were equally distributed in the 1-15 mm size classes. Similar to *M. balthica, M. mitchelli* populations declined in the spring of Year 22 and remained depressed for several years. Based on 16 years of historical HMI frequency distribution data, a strong freshet in Year 23 caused high mortality in this species; however, by Year 29 it appeared to have recovered to previous

densities. The freshet of spring 2011 induced another regional mass *Macoma* mortality responsible for the low abundances observed in this study.

MULTIVARIATE AND FRIEDMAN'S ANALYSES

Multivariate Analysis

Multivariate cluster analysis was applied to Year 31 station invertebrate abundances to examine the patterns of variability among the HMI stations. Multivariate methods are used to make sense of large, complex data sets where several variables (for HMI, the invertebrate taxa abundances) are measured at each sampling location (the 22 HMI stations). In general, the purpose of multivariate methods is to simplify the complex data and identify patterns (Johnson, 1998a). Specifically, the cluster procedure was applied to the HMI data to identify groups of stations with similar benthic invertebrate assemblages.

Clustering analysis was applied only to the September 2012 data, and not to the April 2013 data. Cluster analysis of April data consistently yielded weak results that were difficult to interpret. This was likely due to reproduction/recruitment and the associated unstable benthic macroinvertebrate population dynamics that occur during the spring. Limiting the multivariate analysis to the September data was established with the Year 28 report.

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

The cluster tree figure for September 2012 showed a clear articulation of several HMI station groups (Figure 2-8). Using an $R^2 > 0.95$ as the threshold for identifying the strongest multi-station groups, eleven stations formed into three unique station group combinations. The identified station groups were: **Group 1** (MDE-19 and MDE-44), **Group 2** (MDE-13, MDE-15, MDE-17, MDE-22, MDE-43, and MDE-45) and **Group 3** (MDE-07, MDE-30, and MDE-42). The stations within each group have very similar benthic invertebrate assemblages, but there is also fairly high similarity of benthic invertebrate assemblages among the three groups because they join to form one large group at an $R^2 = 0.90$. One final identifiable station group in the cluster dendrogram, **Group 4**, is composed of stations MDE-01 and MDE-33, which link together with an $R^2 = 0.86$, indicating moderate similarity between the benthic invertebrate assemblages at these two stations. In addition, stations MDE-09 and MDE-36 combined with the stations of Groups 1, 2 and 3 at $R^2 = 0.88$ and 0.82, respectively, indicating that benthic

invertebrate assemblages at these two stations were moderately similar to the to the combined taxa assemblages of stations at Groups 1 + 2 + 3. The cluster dendrogram indicated that four stations (MDE-11, MDE-50, MDE-03 and MDE-34) were strong outliers, with weak linkage to other stations ($R^2 < 0.40$), indicating that the benthic invertebrate assemblages at these stations were unique and dissimilar from other stations. The remaining three stations (MDE-27, MDE-16, and MDE-51) linked to Groups 1 - 4 stations at $R^2 = 0.73$, 0.67, and 0.59 respectively, indicating that the benthic invertebrate assemblages at these three stations were moderately to weakly similar to stations of the other three groups.

The cluster dendrogram results viewed in context with the B-IBI results presented earlier (see section "Benthic Index of Biotic Integrity"), indicate that stations of Groups 1 – 3 all had in common a stressed benthic invertebrate assemblage in September 2012. In contrast, the outlier stations (MDE-03, MDE-11, MDE-34 and MDE-50) were all characterized as having unstressed benthic invertebrate assemblages in September 2012.

As in previous years, the relationship between identified station groups and station type (Nearfield, Reference, Back River and South Cell) was poor except for Group 4 (both Nearfield stations). Likewise, the association of three of the four identified Groups (Groups 1 – 3) with bottom type was also weak, due to the prevalence of silt/clay bottom at all but four stations. Group 4 did correlate well with bottom type, as both stations had sand bottoms.

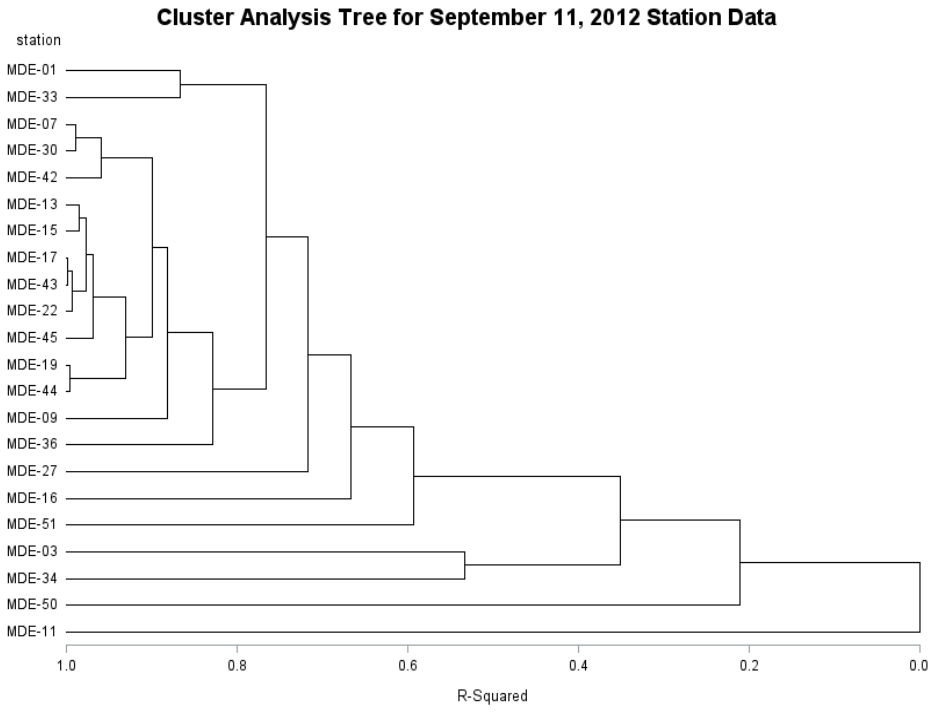


Figure 2-8: September 2011 Cluster Analysis tree.

Average distance between stations in Group 1 (638 meters), Group 2 (1,502 meters), and 4 (1,135 meters) were less than the overall average distance between all stations (3,427 m), indicating that spatial proximity was an influencing factor in group formation. However, spatial proximity was less of an influencing factor in Group 3 formation, with average distance between stations (4,570 meters) greater than the overall station to station average distance.

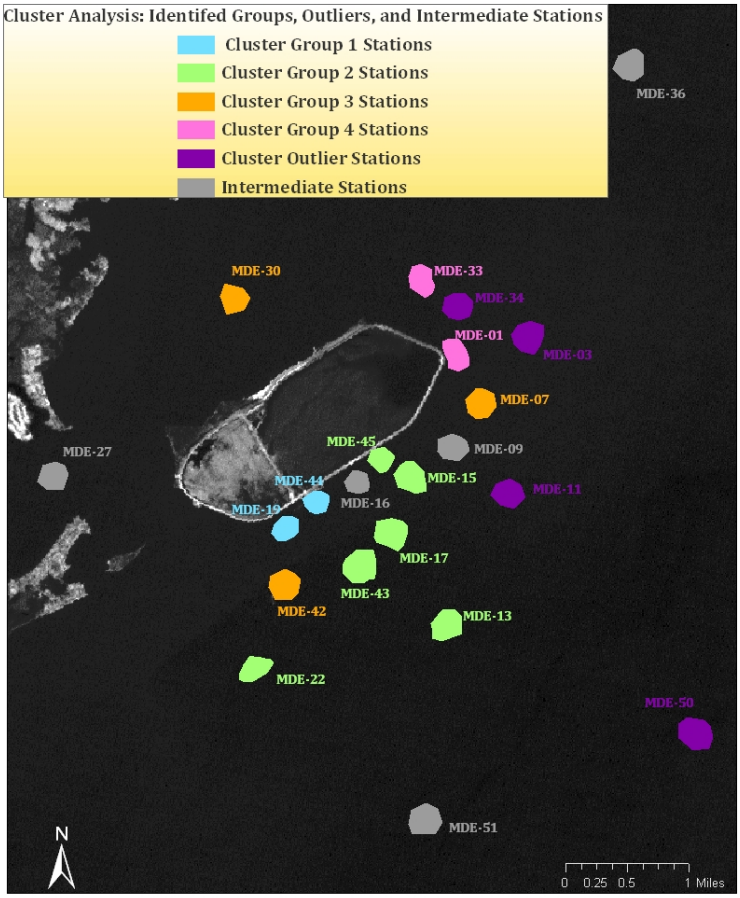


Figure 2-9: Identified Cluster Groups, Strong Outiers and Intermediate Areas

Color-coding of identified cluster groups, strong outliers, and intermediate stations (stations that have benthic invertebrate communities that did not have either strong grouping characteristics or strong outlier characteristics) are shown in Figure 2.9. Cluster Groups 1 – 3, with stressed invertebrate communities are located on the south side of the island, while the strong outliers, with unstressed invertebrate communities are located north and east of the island.

Friedman's Analysis

As in previous HMI annual reports (Years 12 – 15; Years 19 - 28), Friedman's nonparametric ANOVA test was applied to Year 31 benthic macroinvertebrate data. The Friedman's nonparametric test determines if significant differences in the top ten most abundant invertebrate taxa occur between station types. For Year 31 the Friedman's test was run on the conventional four station groups – Reference, Nearfield, South Cell Exterior Monitoring, and Back River. Modified station groups were tested with the Friedman's in Year 29 and Year 30 based on B-IBI result patterns in those years, which indicated unique conditions occurring at several stations near the North Cell and to a subset of Nearfield + South Cell stations. However, this was not evident with Year 31 B-IBI scores so no modified station groups were tested.

Friedman test results (Tables 2-15 and 2-16) indicated no significant differences in the ten most abundant infaunal taxa between the four station types in September 2012 (P = 0.062) but differences between station types were significant in April 2013 (P = 0.013). Significant Friedman results have occurred eight times since Year 12. Significance typically occurs as a result of either unique macroinvertebrate assemblages at Back River and/or South Cell stations.

Table 2-15: Friedman Analysis of Variance for September 2012's 10 most abundant species among: Back River/Hawk Cove, Nearfield, South Cell Exterior Monitoring, and Reference stations. ANOVA Chi-Square. (N = 10, df = 3) = 7.32, p = 0.062.

Station Type	Average Rank	Mean	Std. Dev.
Nearfield	2.8	97	118
Reference	3.2	110	113
Back River	1.8	92	131
South Cell	2.1	80	105

Table 2-16: Friedman Analysis of Variance for April 2013's 10 most abundant species among: Back River/Hawk Cove, Nearfield, South Cell Exterior Monitoring Stations, and Reference stations. ANOVA Chi-Square. (N = 10, df = 3) = 10.8, p = 0.013.

Station Type	Average rank	Mean	Std. Dev
Nearfield	2.8	1379	2088
Reference	3.2	1417	1988
Back River	1.4	825	1666
South Cell	2.6	782	1020

A Wilcoxon Signed-Rank post-hoc test was run to identify which station groups differed from each other in April 2013. This test requires a Bonferroni correction applied to determine significance level. The procedure tests significance between pairs of station groups. The Bonferroni corrected level of significance was $p \leq 0.008$. Six comparisons were tested for significance: Reference stations and Nearfield stations, Reference stations and South Cell stations, Reference stations and Back River stations, Nearfield stations and South Cell stations, Nearfield stations and Back River stations, and lastly, South Cell stations and Back River stations. This represents all possible pair-wise comparisons.

Of all the comparisons tested, results indicate statistical significance only between Back River stations and Nearfield stations ($p = 0.007$). Significantly different benthic communities are common at Back River stations because these sites are more strongly influenced by river discharge than the other station types.

CONCLUSIONS

In Year 31, the benthic macroinvertebrate community was examined. The salinity regime had returned to its historical average range after heavy freshwater inputs in early Year 30. As usual, little stratification of water quality was evident during either the fall or spring cruises. Dissolved oxygen at all stations exceeded the State standard of 5.0 ppm deemed necessary to support healthy aquatic communities. Salinity, Dissolved oxygen, and turbidity were slightly higher than normal in Year 31. Temperature was slightly lower than the historical mean. None of the differences from the mean were statistically significant. The B-IBI was calculated for all fall stations using four metrics applicable to the low mesohaline classification (5 - 12 ppt). The B-IBI's and derivative metrics were compared to historical data and analyzed both spacially and statistically.

The health of the benthic macroinvertebrate community around HMI in Year 31 was worse than historical averages. B-BIBI's around the island were at or near historical lows. Eleven of the 22 stations failed to meet the benchmark criteria of 3.00. Nineteen of the 22 stations performed below their historic averages. Two stations tied their historic lows. Four stations set new historic lows; and no stations met their historic highs. Year 31 is the third consecutive year where B-IBI's have been trending downward.

The mean B-IBI for Nearfield, South Cell Exterior Monitoring, Back River/Hawk Cove and Reference stations failed to meet the benchmark of 3.0 and were below historic averages. The mean B-IBI score for Nearfield stations (2.88) was 0.45 lower than the historic average and the fourth lowest in 31 years. The South Cell Exterior Monitoring stations mean (2.50) was 0.87 below average and at a historic low (nine years). The Reference stations mean (2.90) was 0.60 below average and the second lowest in 31 years. The Back River/Hawk Cove stations mean (2.50) was 0.41 below average and tied for fifth lowest in 31 years.

In Year 30, MDE reported that there was a cluster of contiguous stations that performed poorly. The group of Nearfield stations MDE-15, MDE-16, MDE-19, and MDE-45 and South Cell Exterior Monitoring station MDE-44, is closer to the dyke of the island and South Cell outfall/ barge offloading dock. Combined with Nearfield station MDE-17 and South Cell Exterior Monitoring stations MDE-42 and MDE-43, a group of eight stations exist in close proximity to the southwest corner of HMI. While six of these eight failed to meet the benchmark criteria of 3.00 in Year 31, poorly performing stations were widespread throughout the HMI region and in every station type. Explanations for this cluster of poorly performing stations may lie with conditions unique to the proximity of the dike or to the South Cell outfall/ barge offloading dock. The cluster's historic performance is more like the Nearfield, Reference, or South Cell Exterior Monitoring stations than like the "degraded" Back River/Hawk Cove station group. Hence, there is not convincing historical evidence that this cluster is consistently or significantly poor. This area will receive more attention in Year 32.

The three year decline in B-IBI's can be attributed to several variations in the invertebrate community. There has been a greater than 50 percent decrease in abundance of the typically dominant polychaete worm *M. viridis*. *M. viridis* is pollution sensitive and its decrease in abundance lowers PSTA scores. Since the organism is also typically very abundant, this decrease amplifies the proportion of pollution indicative organisms thus raising PITA scores. Recent decreases in the bivalves, *R. cuneata* and *M. balthica* (also pollution sensitive) have also been observed and have the same B-IBI depressing effect. Decreases in the bivalve population have also been occurring over the last three years. To a lesser extent, abundance of the isopod *C. polita* has recently contributed to reduced PSTA and increased PITA metric scores. In Year 31, above average abundance of the polychaete *S. benedicti* (a pollution indicative species with highly variable abundance from year to year) increased PITA scores.

The multivariate cluster analysis identified three station groups that had strongly similar benthic invertebrate assemblages within each group. Group 1 (MDE-19 and MDE-44) and Group 2 (MDE-13, MDE-15, MDE-17, MDE-22, MDE-43, and MDE-45) were composed of stations with fairly close spatial proximity, while Group 3 was composed of three broadly dispersed stations (MDE-7, MDE-30 and MDE-42). Similarity among Groups 1 – 3 was also quite strong, and the benthic invertebrate communities at these stations were stressed communities (as indicated by the B-IBI). The final identified station group, Group 4 (MDE-1 and MDE-33) had moderately similar benthic invertebrate assemblages and good spatial proximity. The strong outlier stations identified by the cluster dendrogram (MDE-3, MDE-11, MDE-34, and MDE-50) were all characterized as having healthy benthic invertebrate communities. The remaining three stations (MDE-16, MDE-27, and MDE-51) were all characterized as neither belonging to one of the identified groups nor being strong outliers, indicating the benthic macroinvertebrate communities at these stations were weakly similar to Groups 1 – 3.

The Friedman's nonparametric ANOVA test indicated that Back River stations were significantly different from Nearfield stations in April, primarily due to low average abundance of the top ten most abundant invertebrate taxa at Back River stations. Back

River stations receive the strongest influence from river discharge, and invertebrate communities there are typically highly aberrant from the other HMI monitored sites. Friedman's results did not pinpoint any localized adverse impacts to the surrounding benthic community from HMI operational discharges, although results did indicate a general pattern of stressed benthic invertebrate communities south of the island, in the general vicinity of South Cell discharges.

Future monitoring plans: MDE has proposed to continue benthic monitoring at a reduced level until stabilization of the island is complete. This will involve sampling fifteen select sites, every fall, starting in 2014.

REFERENCES

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

APPENDIX 3: ANALYTICAL SERVICES (PROJECT IV)

(September 2012 – August 2013)

Technical Report

Prepared by
Andrew Heyes, Principal Investigator

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

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

March 2014

OBJECTIVES

The 2012-2013 project goals were to continue to measure and evaluate the levels of contaminants in the sediment in the vicinity of HMI and to relate these, as far as possible, to historical data. Continued comparison and correlation of annual data with the historical HMI data, will indicate the extent of any contamination, biological exposure and if any trend in concentrations are developing at locations around the island.

Specific objectives for Year 31 were:

- To collect clams and associated sediment for analyses of trace elements, in the fall of 2012 and spring of 2013. 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), methylmercury (MeHg), silver (Ag), Selenium (Se), Arsenic (As), Lead (Pb) and Cadmium (Cd);

- To determine the concentrations of target trace elements in surface sediments at the larger number of stations around HMI visited by the Maryland Geological Survey (MGS) in September 2012. Metal analysis focused on those metals not measured by MGS, specifically Hg, MeHg, Ag, Se and As; and

- To determine polychlorinated biphenyls (PCB) and polycyclic aromatic hydrocarbon (PAH)concentrations sediment and clams collected in the fall of 2012 by CBL.

The results of the quality assurance (QA/QC) procedures and the description of the analytical and field protocols are contained in the *Year 31 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 31 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 2012. Samples from this survey were collected by MGS personnel for CBL using a Ponar grab sampler. Samples were placed in acid washed plastic containers, frozen and delivered to CBL for trace element analysis. In September 2012 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 2013, but sediments and clams were collected only for trace element analysis. Sediment for trace element and organic contaminants analyses were collected using plastic and stainless steel spatulas, respectively, integrating the top several centimeters and avoiding the sides of the sampler to minimize the possibility of contamination. Sediments for metals were placed in plastic sampling cups and were kept cooled in an ice chest or refrigerator until they could be processed in the laboratory. Sediments for organics were placed in glass jars with foil lined caps.

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

Procedures for Trace Element Analyses

For trace element analysis other than T-Hg and MeHg, EPA Method 3052 is generally followed. The Milestone EOTHO-EZ uses quartz reaction vessels placed inside Teflon cups, which are pressure sealed during digestion. For digestion, 1-2 grams of sediment is placed in the vessel with 9 ml of concentrated ultra pure Nitric Acid (HNO_3) and 2 ml of concentrated ultrapure Hydrochloric Acid (HCl). The vessel is covered with a loose fitting quartz cap, and placed in the Teflon cup. 5 ml of 30% Hydrogen Peroxide (H_2O_2) is added to the Teflon cup and the cup sealed. The sample is heated to 180°C and allowed to reflux for 15 minutes. The samples are then cooled and filtered through

Whatman No. 41 filter paper by suction filtration and diluted to 100 ml with deionized water. Clams are digested in a similar fashion. These extracts are analyzed for Ag, As, Se, Pb and Cd using a Hewlett-Packard 4500 Inductively Coupled Plasma-Mass Spectrometer (ICP-MS).

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

For the determination of MeHg, clams and sediments were first extracted by sub-boiling distillation (Horvat et al. 1993). Clam or sediment tissue was weighed into Teflon vessels along with 1 ml of 50% sulfuric acid solution, 1 ml of a 20% potassium chloride solution and 18 ml of ultra pure water. The vessels were heated to approximately 90^{o}C and volatiles and water distilled under a nitrogen stream for three hours. The distillate was reacted with a sodium tetraethylborate solution to convert the nonvolatile MeHg to gaseous MeHg (Bloom 1989). The volatile adduct was purged from solution and recollected on a graphitic carbon column at room temperature. The MeHg was then thermally desorbed from the column and analyzed by gas chromatography with CVAFS detection. Detection limits for T-Hg and MeHg are based on three standard deviations of the blank measurement.

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

Analytical Procedures for Organics

The sediment and clam homogenates were extracted and purified using the method described by Kucklick et al. (1996). For this method, a subsample of clam homogenate, 5 g wet weight, is removed and ground with anhydrous sodium sulfate (~50 g). A perdeuterated PAH cocktail (d_8-napthalene, d_{10}-fluorene, d_{10}-fluoranthene, d_{12}-perylene) and a noncommercial PCB solution (IUPAC #'s 14, 65, 166) are added as surrogates to each sample to track extraction efficiency. The mixture is then extracted in a Soxhlet apparatus with 250 mL of dichloromethane (DCM) for 24 hours. The extracts are then concentrated to 2 mL using a vacuum rotary evaporator and transferred into

hexane. Each sample is transferred to a 4 ml Waters autosampler vial with sample and rinses amounting to approximately 4 mL. Gravimetric lipid analysis is performed on each sample with subsampled fractions determined gravimetrically (Kucklick et al. 1996). Samples are again concentrated in similar fashion as above, then solvent exchanged to hexane. To remove lipids the extracts are then eluted with 25 mL petroleum ether over 4 g deactivated Alumina [6% (w/w) water]. After concentrating, the extracts are spiked with a perdeuterated PAH mixture (d_{10}-acenapthene, d_{10}-phenanthrene, d_{12}-benz[*a*]anthracene, d_{12}-benzo[*a*]pyrene, d_{12}-benzo[*g,h,I*]perylene) for quantification of PAH's. The samples are then analyzed using a Hewlett Packard 5890 gas chromatograph (GC) with a HP-5MS (cross linked 5% phenyl methyl siloxane) capillary column (30m x 0.25mm x 0.25um film thickness) and a HP-5972 series mass spectrometer (MS) for PAH's (Ko and Baker 1995). Each sample is separated after GC/MS analysis into two fractions with 35 mL of petroleum ether and 50 mL of DCM/PET (1:1), respectively, over 8 g of deactivated Florisil [(2.5% (w/w) water (Kucklick et al.1996)]. The first fraction (F-1), contains PCBs and 1-100%, by weight of the less polar organochlorine pesticides [heptachlor (100%), 4,4-DDT (40%), 4,4-DDE (100%), t-nonachlor (24%), heptachlor (1%), 4,4-DDT(44%)]. The second extracted fraction, (F-2), contains 56-100% of the more polar organochlorine pesticides [a-HCH (100%), g-HCH (100%), c-chlordane (100%), t-chlordane (100%), t-nonachlor (76%), heptachlor (99%), heptachlor epoxide (100%), dieldrin (100%), 4,4-DDD (100%), 4,4-DDT (56%)]. Both fractions are solvent exchanged to hexane and concentrated to ~ 1 mL.

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

RESULTS AND DISCUSSION

Trace Elements in Sediment for September 2012

Concentrations of As in the sediment collected around HMI in Year 31 (fall 2012) are generally close to the running mean and median (Figure 3-1). Only site MDE 11 had elevated As concentrations, and even so, it fell with the standard deviation of the running mean. Concentrations of Se were below the mean and median concentrations at all stations with exceptions being MDE 17 and MDE 21, which had concentrations barely above each respective sites running mean (Figure 3-1).

Concentrations of Ag in the sediment collected from sites MDE-1 to MDE-41in the fall of 2012 were again lower than the median and average concentrations collected around HMI in previous years (Figure 3-2). This same condition, lower than average Ag concentrations in sediment has been observed for the past 4 years. Sites with a shorter history (sites numbered MDE-42 to MDE-51) had concentrations in 2012 that were average. As reported in the past, elevated Ag concentrations in 2000 and 2001 continue to bias the mean sediment concentration and thus the median concentration (red line Figure 3-2) better reflects the general condition. Annual fluctuations in the concentration of Ag in sediment are system wide and appear unrelated to HMI operations.

Concentrations of mercury (T-Hg) in sediment were generally close to or above the running mean calculated from previous years but with most concentrations falling within the standard deviation of measurements made between 1998 and 2011 (Figure 3-2). Sites which fell outside the standard deviation were MDE-17 and MDE-19. These sites were slightly elevated above the upper standard deviation around the mean of historic levels. Both of these sites are located off the south side of the island.

Concentrations of MeHg in sediment collected in the fall of 2012 were generally comparable to previous years (Figure 3-3). Sites MDE-9, MDE-15 and MDE-42 had elevated concentrations with only MDE-42 marginally outside the standard deviation of the sites running mean. The percent of mercury that occurred as MeHg was less than 1% at all sites (Figure 3-3).

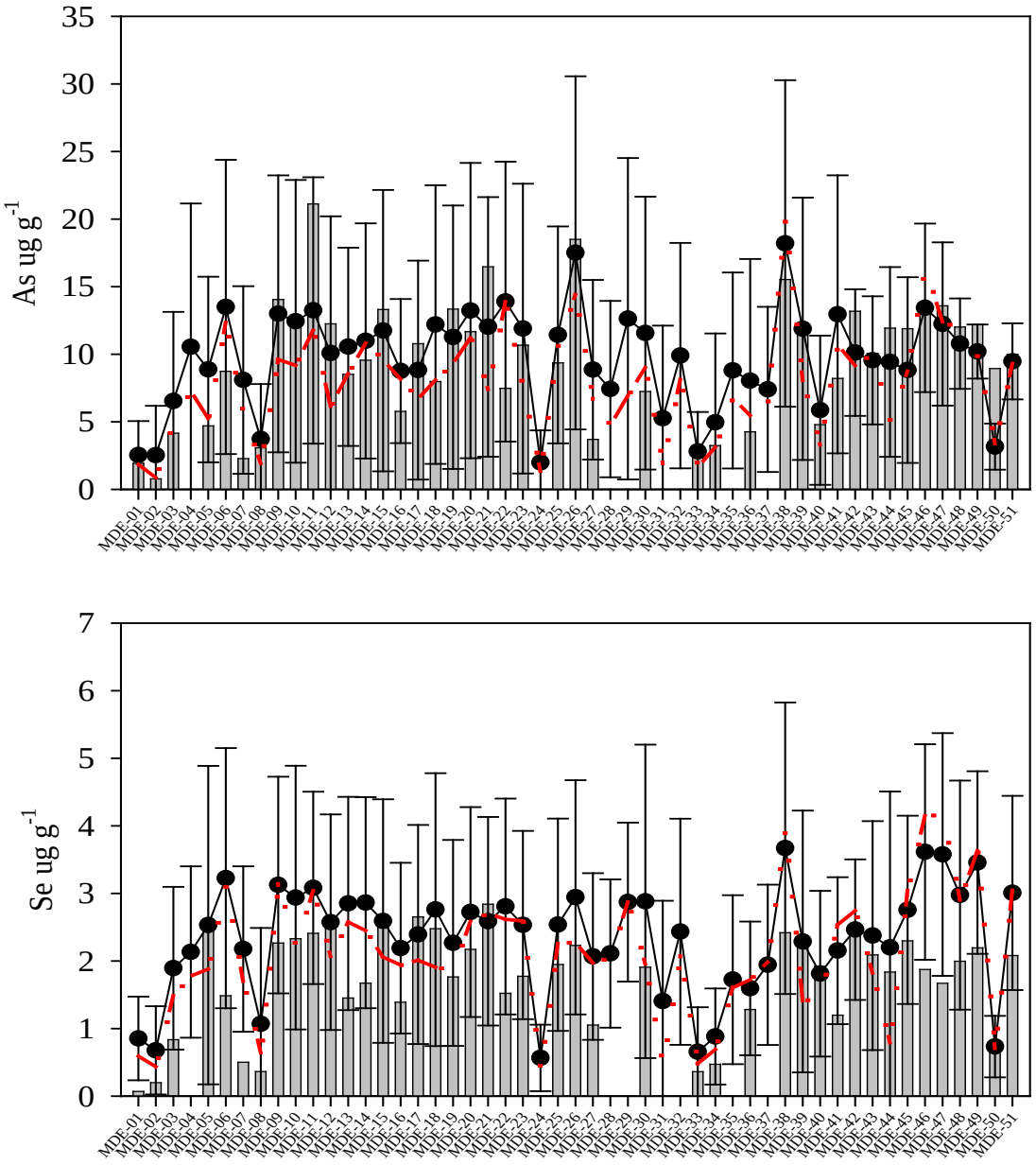


Figure 3- 1: As and Se in sediment, expressed as dry weight concentration, collected by MGS in the fall of 2012 (bars) and the 1998-2011 mean (circles) with standard deviation (error bars) and the 1998-2011 median (dashed line). Sites 4, 24, 28, 29, 31, 32, 35, 37 are no longer sampled.

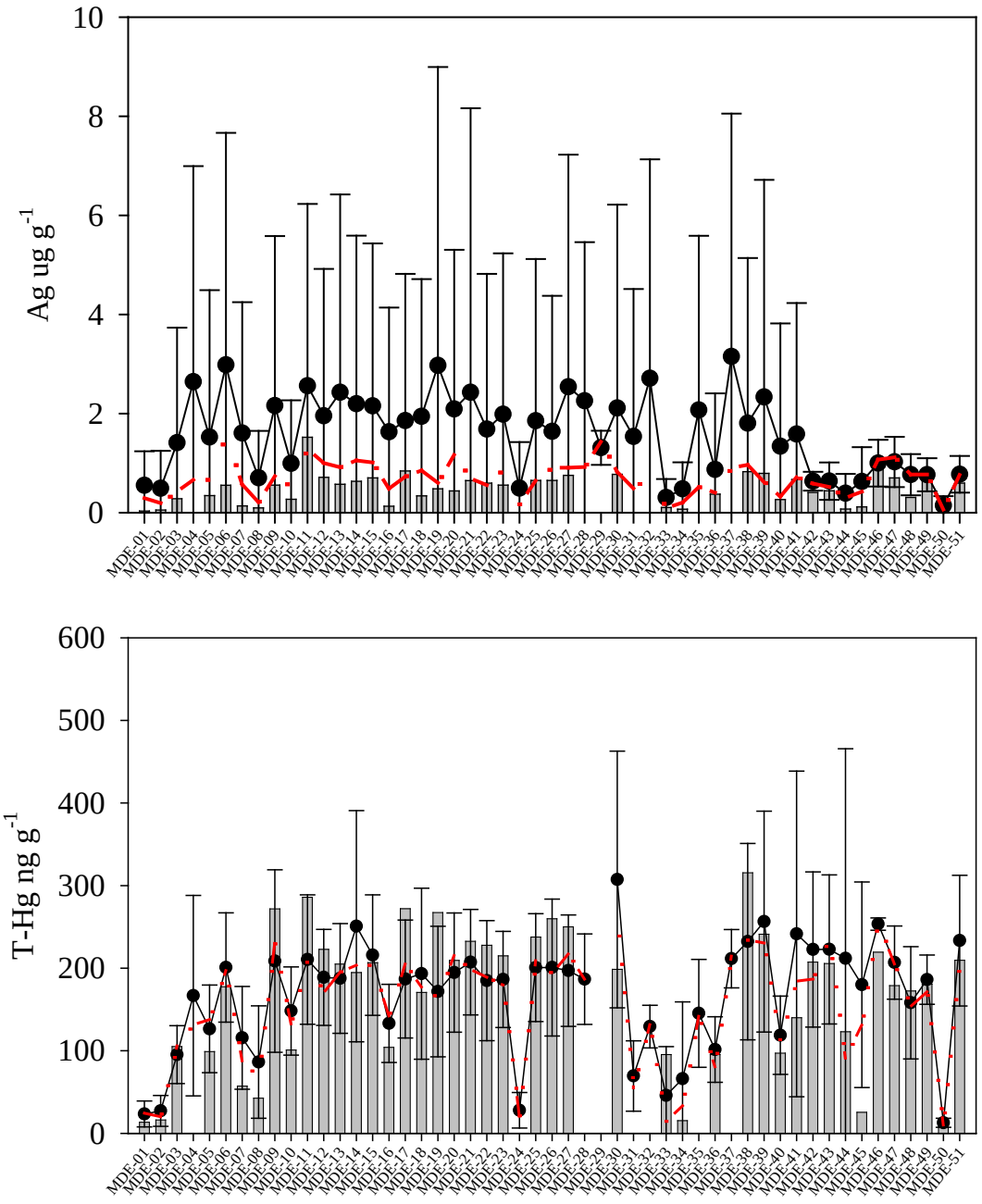


Figure 3- 2: Ag and T-Hg concentrations in sediment, expressed as dry weight concentration, collected by MGS in the fall of 2012 (bars) and the 1998-2011 mean (circles) with standard deviation (error bars) and the 1998-2011 median (dashed line). Sites 4, 24, 28, 29, 31, 32, 35, 37 are no longer sampled.

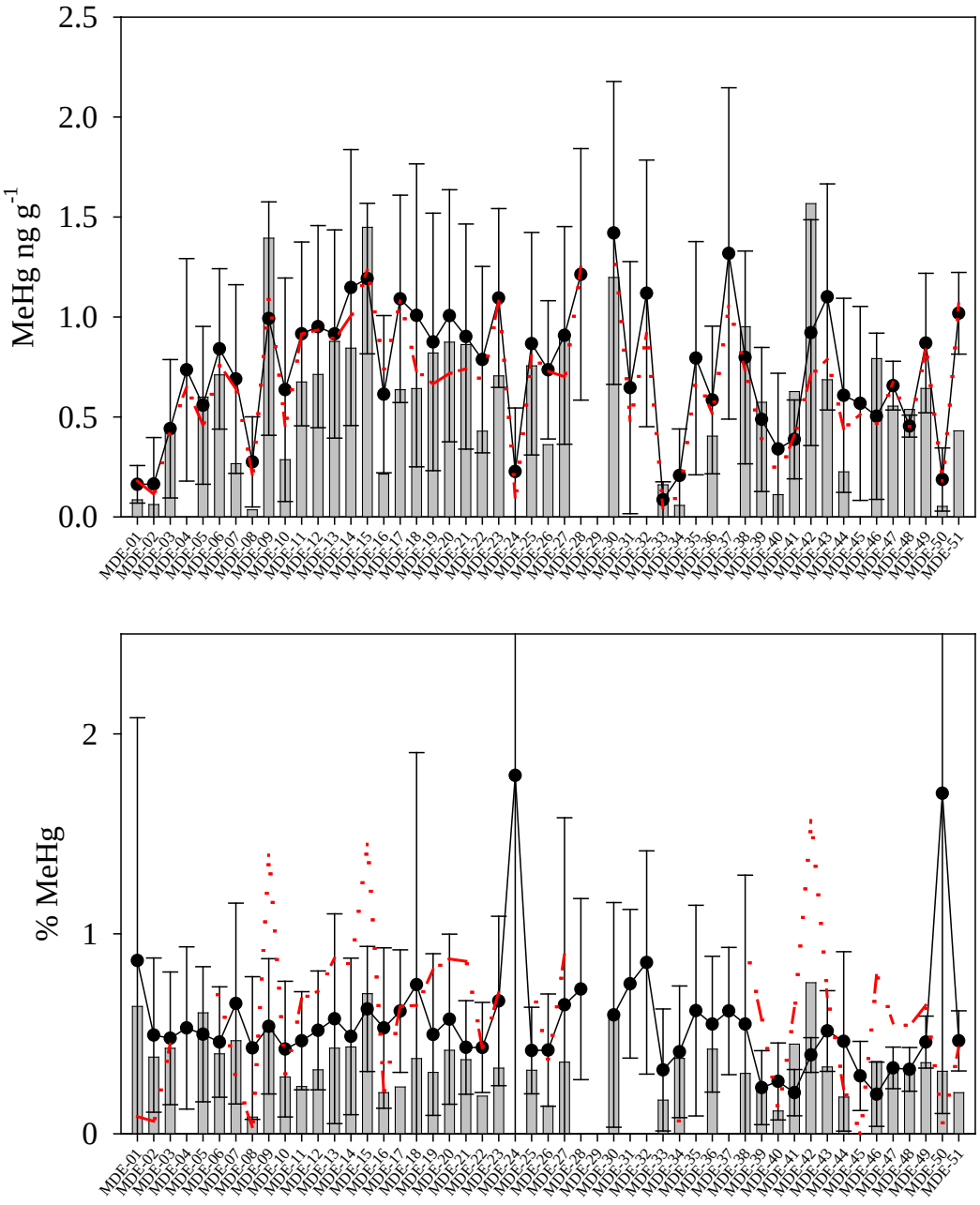


Figure 3- 3: MeHg, expressed as dry weight concentrations, and percent of T-Hg as MeHg in sediment collected by MGS in the fall of 2012 (bars), and the 1998-2011 mean (circles), with standard deviation (error bars), and the 1998-2011 median (dashed line). Sites 4, 24, 28, 29, 31, 32, 35, 37 are no longer sampled.

Relationships between trace elements (As, Se, Ag, Hg) in sediment among sites and years

If the sources of the trace elements to the sediment around HMI are similar, correlations would be expected to exist between some elements in both time and space. Having a basic understanding of such trends allows anomalous stations and years to be identified especially if multiple elements can be used to confirm the existence of an anomaly. Stations located near the Back River and Baltimore Harbor need to be treated with care because the potential for contaminants to migrate from sources within these water bodies to the vicinity around the HMI complex is great. MDE sites 1 to 44 have been monitored for greater than 10 years and provide the best data for which to perform such an analysis. In this section we will examine temporal trends of elements across the individual sites and the relationships between elements among sites, and finally the influence of site characteristics on element concentrations.

To examine the temporal trends at individual sites, the sites have been broken into regions based on proximity to one another and to reduce the number of figures. Such divisions are easy to see with sites from Back River, Harbor and far afield "reference" stations falling into obvious clusters, but for the rest of the sites, dividing the sites up is more arbitrary and the divisions chosen simply reflect geographical distribution around the island, and broken into near and far sites. The sites could have been divided based on other criteria such as sediment type, but the primary focus of the study is on identifying emerging hot spots, thus geographic location is the top priority.

Arsenic in Sediment 1998-2012

In general concentrations of As in sediment are temporally coupled, meaning concentrations in an area around HMI increase and decrease together over time (Figure 3-4 and 3-5). Sites near Baltimore Harbor show the greatest variation in As concentrations, ranging from less than 1 ug $g^{-1}$to nearly 50 ug g^{-1}. Between 1998 and 2001, variations were most extreme at all the sites including those classed together as the Far Afield sites (Figure 3-5). While year to year variability in sediment As concentrations was still present after 2001, changes were less severe. Also of interest is a general upward trend in As concentration from 2005 to 2012 at a large number of sites. Thenorth Central Far stations plotted inFigure 3-6 to illustrate this observation. Since this increasing trend occurs in the reference stations (shown in the Far Afield plot), the patterns is not likely associated with HMI activities (Figure 3-5). This increasing trend in As concentration is not present in the sediment from the Back River side of the island. This is probably because variability at these sites has remained high over the entire study, but also many of the sites were not measured after 2009 when the increase was observed elsewhere.

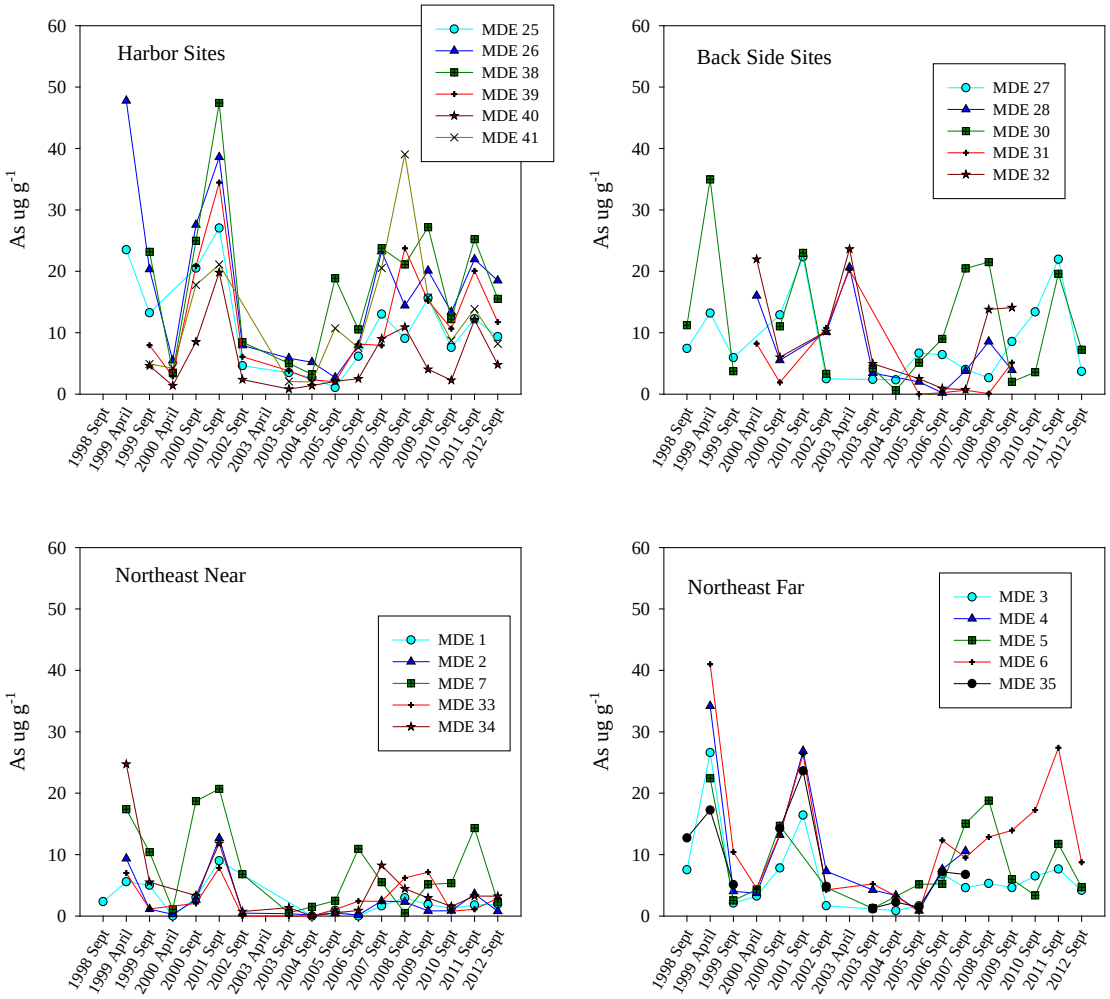


Figure 3- 4: Arsenic (As) concentrations in sediment from 1998 to 2012 at the Harbor sites, Back River Sites, and sites of the Northeast side of the island.

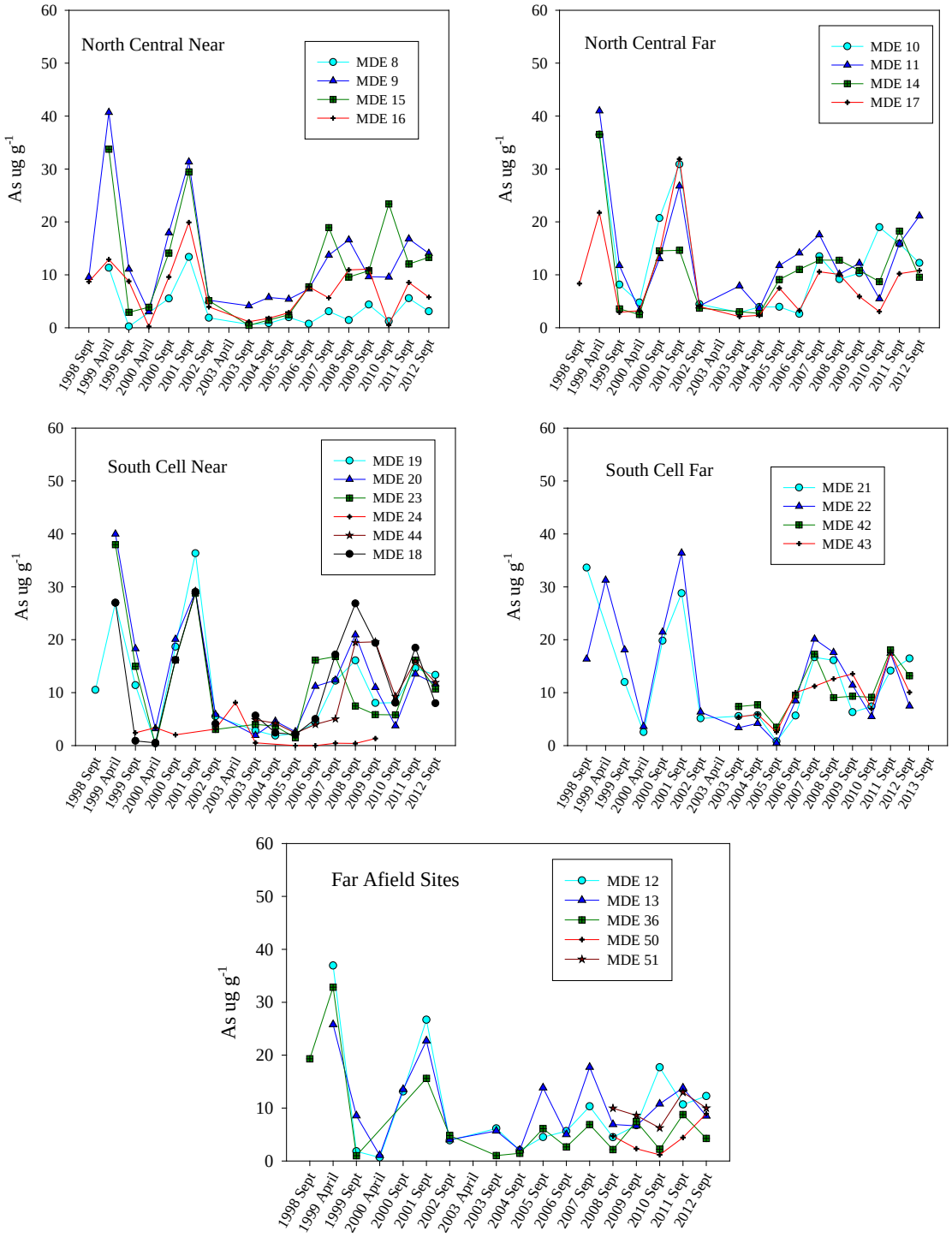


Figure 3- 5: Arsenic (As) concentrations in sediment from 1998 to 2012 sites located of the north east central side of the island, of the south cell and stations far afield from the island including reference stations.

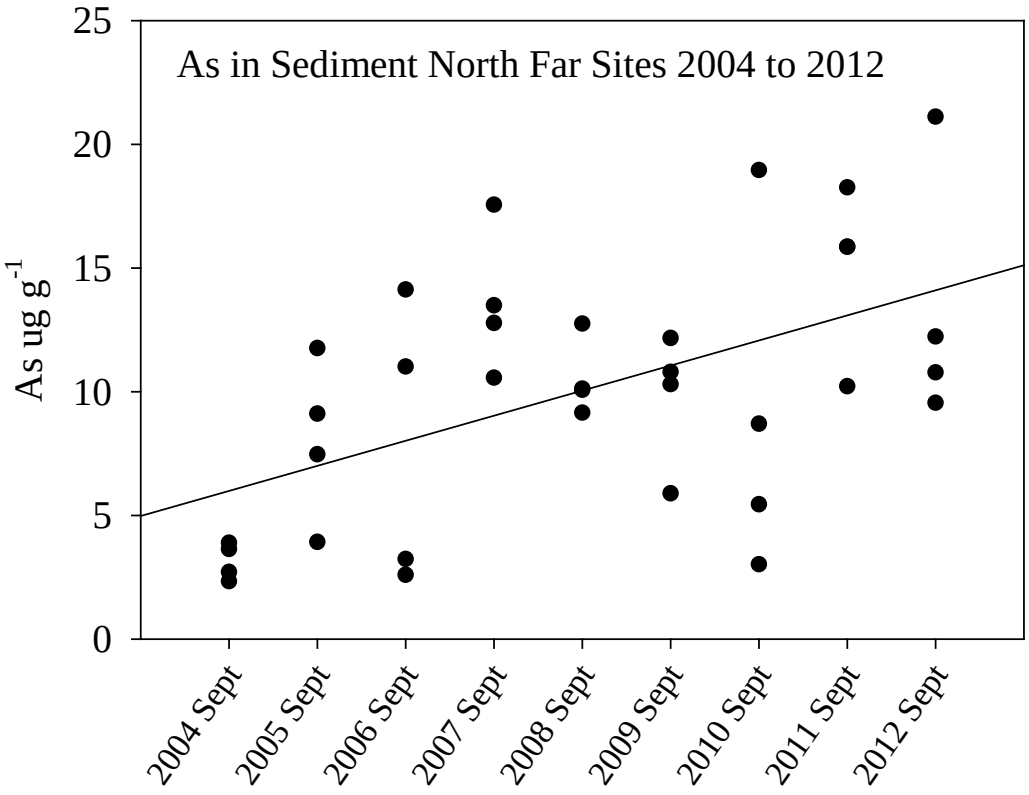


Figure 3- 6: Arsenic (As) concentrations in sediment from 2004 to 2012 for North Far sites. R^2 is 0.28.

Concentrations of Se sediment concentrations have a temporal synchronicity across sites, meaning the concentrations largely rise and fall together (Figure 3-7, 3-8). Se concentrations range from undetectable to 8 ug g^{-1}. There appears to be three time periods in the sediment concentration data; a period of elevated Se concentrations that extended from the onset of measurements up to 2002, followed by a period of lower concentrations from 2002 to 2006 and then a return to a period of elevated Se concentrations from 2006 to 2011. In 2012, lower Se concentrations prevailed. While more subdued than at many of the site groups, the Far Afield sites also followed the same temporal pattern of sediment Se concentrations (Figure 3-8). The spike in Se in 2000 to 2002 coincides with the rise in As (discussed above) and an increase in Ag (discussed below). The peak in 2006 to 2011 also coincides with a small increases in As and Ag, but the increases in As and Ag do not continue for a period as long as the elevated Se concentrations.

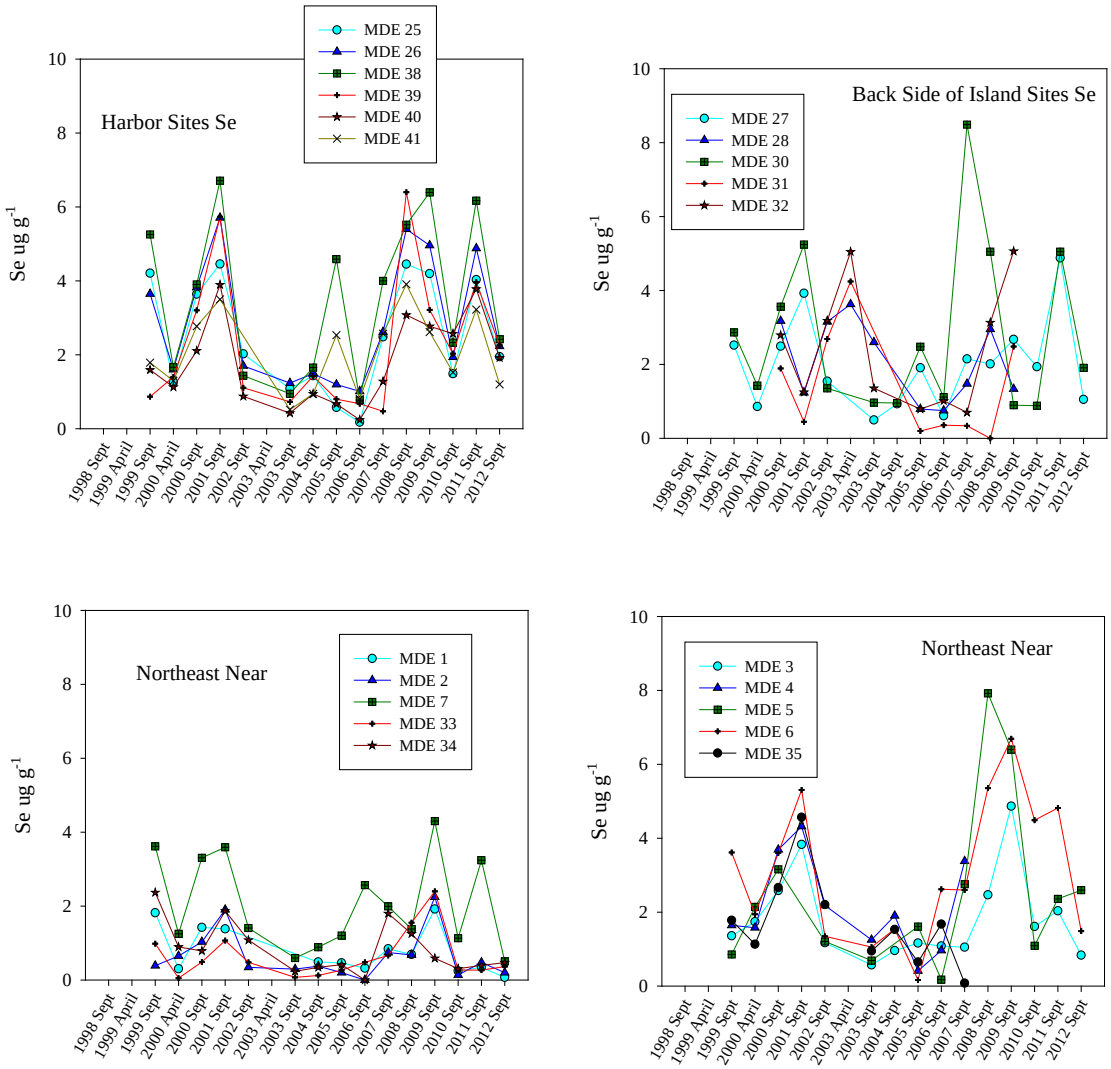


Figure 3- 7: Selenium (Se) concentrations in sediment from 1998 to 2012 at the Harbor sites, Back River Sites, and sites of the Northeast side of the island.

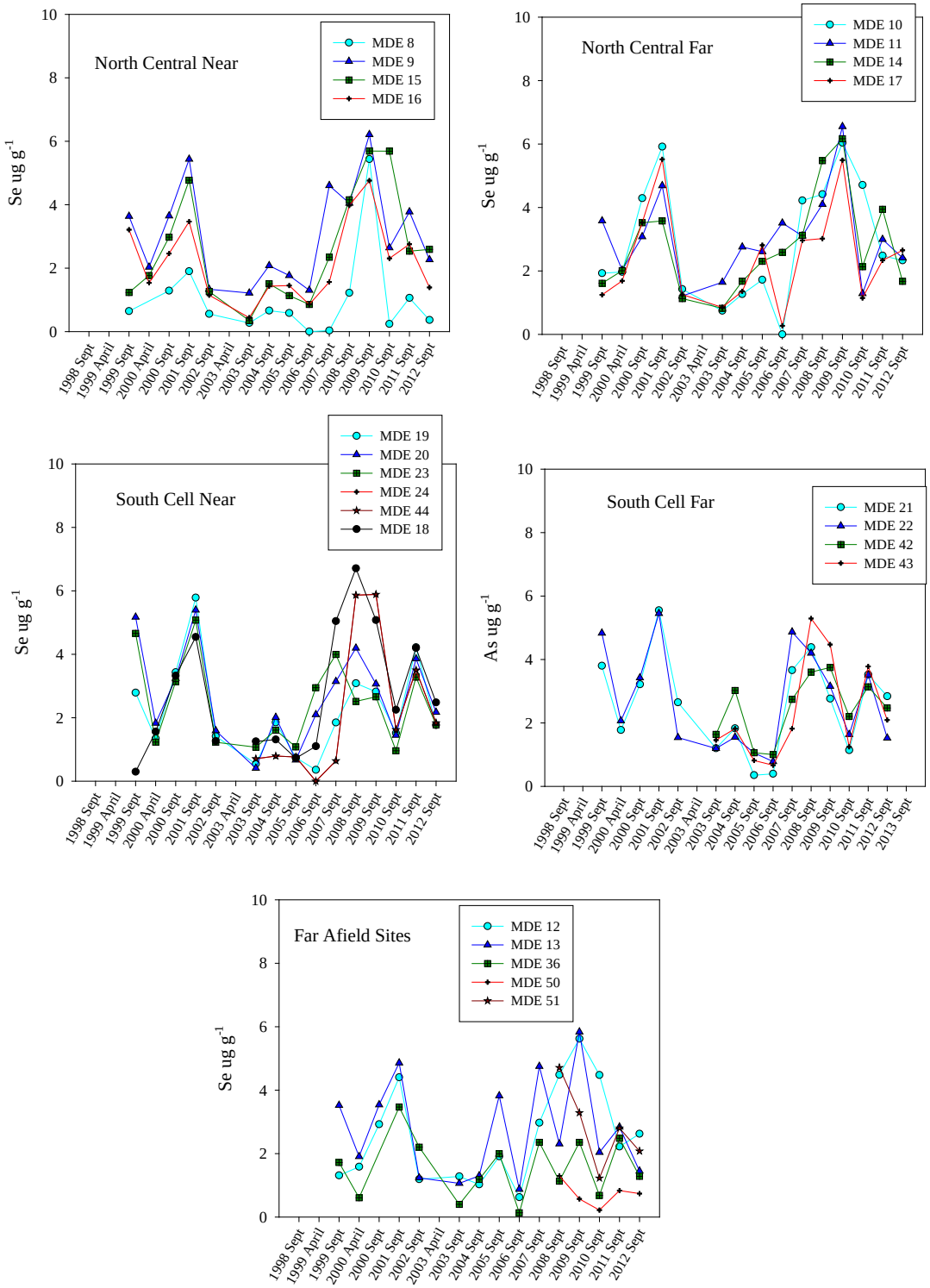


Figure 3- 8: Selenium (Se) concentrations in sediment from 1998 to 2012 sites located of the north east central side of the island, of the south cell and stations far afield from the island including reference stations.

Silver in Sediment 1998 to 2012

As reported for the other trace elements the concentrations of Ag in sediment vary in temporal synchrony and the concentrations of Ag in sediment around HMI can be divided into distinct periods (Figure 3-9, Figure 3-10). Following a period of low concentrations from 1998 and 1999, sediment concentrations between 2000 and 2002 were very high, almost a factor of 10 higher than at any other period. It has been difficult to provide an explanation of these observations given elevated concentrations were observed at all sites including the reference site. From 2002 to 2006, concentrations were low, generally being less than 1 ug g^{-1}. In years after 2007, sediment concentrations increased each year peaking in 2009 with concentrations as high as 3 ug g^{-1} observed for some stations (e.g. MDE-6, MDE-11 and MDE-23). While the two peaks in Ag sediment concentrations differ in magnitude, the pattern of a slow rise from 1998-2002 and 2006 to 2009 are followed by dramatic falls. From 2010 to 2012, Ag concentrations in sediment are low and generally less than 1 ug g^{-1} as was seen from 2003-2006.

Ag, As and Se concentrations in sediment have a similar general behavior, but the timing of the transitions differ among the trace elements. For example, As and Ag concentrations increased over the 2006 to 2009 period but in the case of As, the increase persisted for 2 more years extending to 2011. It is not known whether these shifts are source driven or caused by differing behaviors post deposition to the sediment.

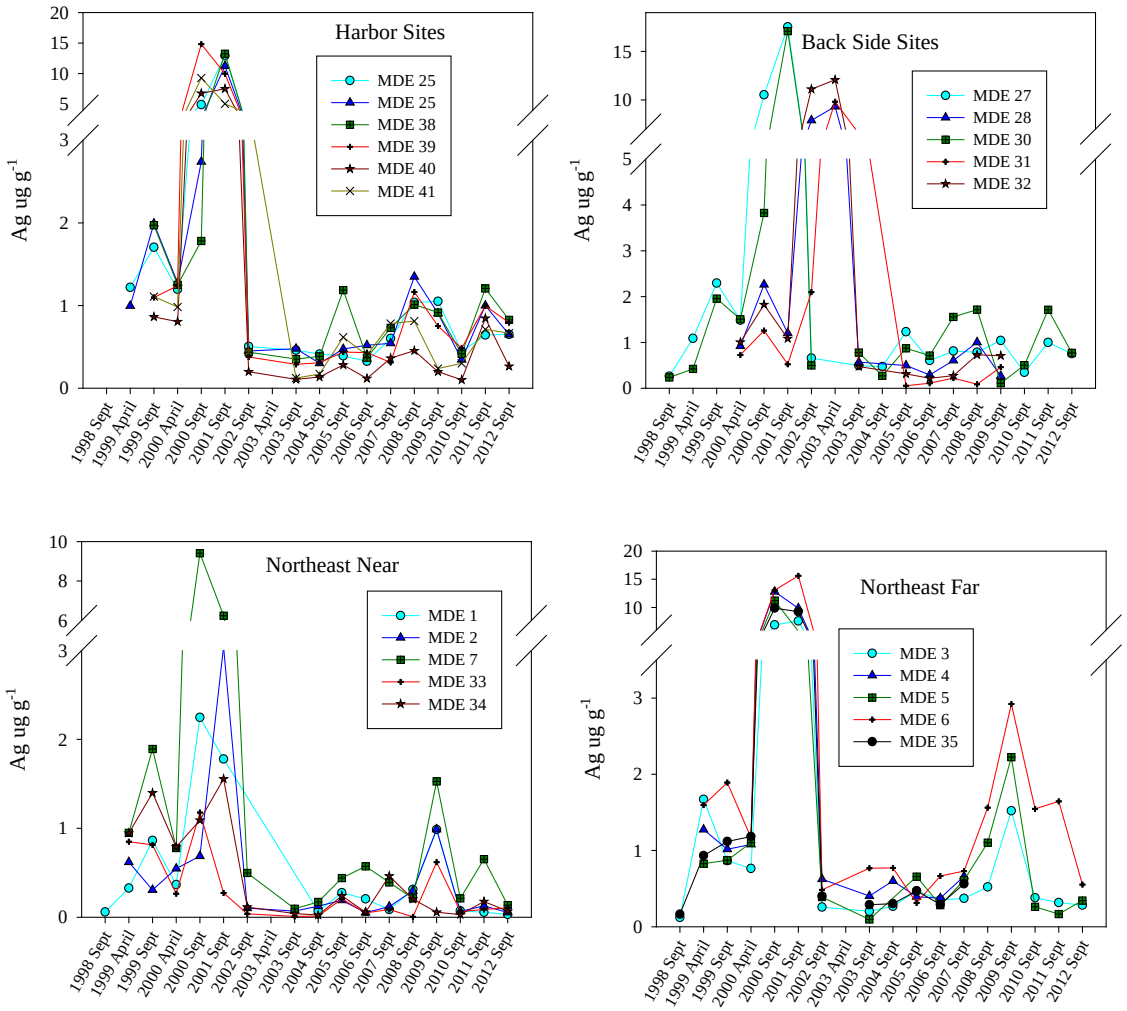


Figure 3- 9: Silver (Ag) concentrations in sediment from 1998 to 2012 at the Harbor sites, Back River Sites, and sites of the Northeast side of the island. Note the broken scale.

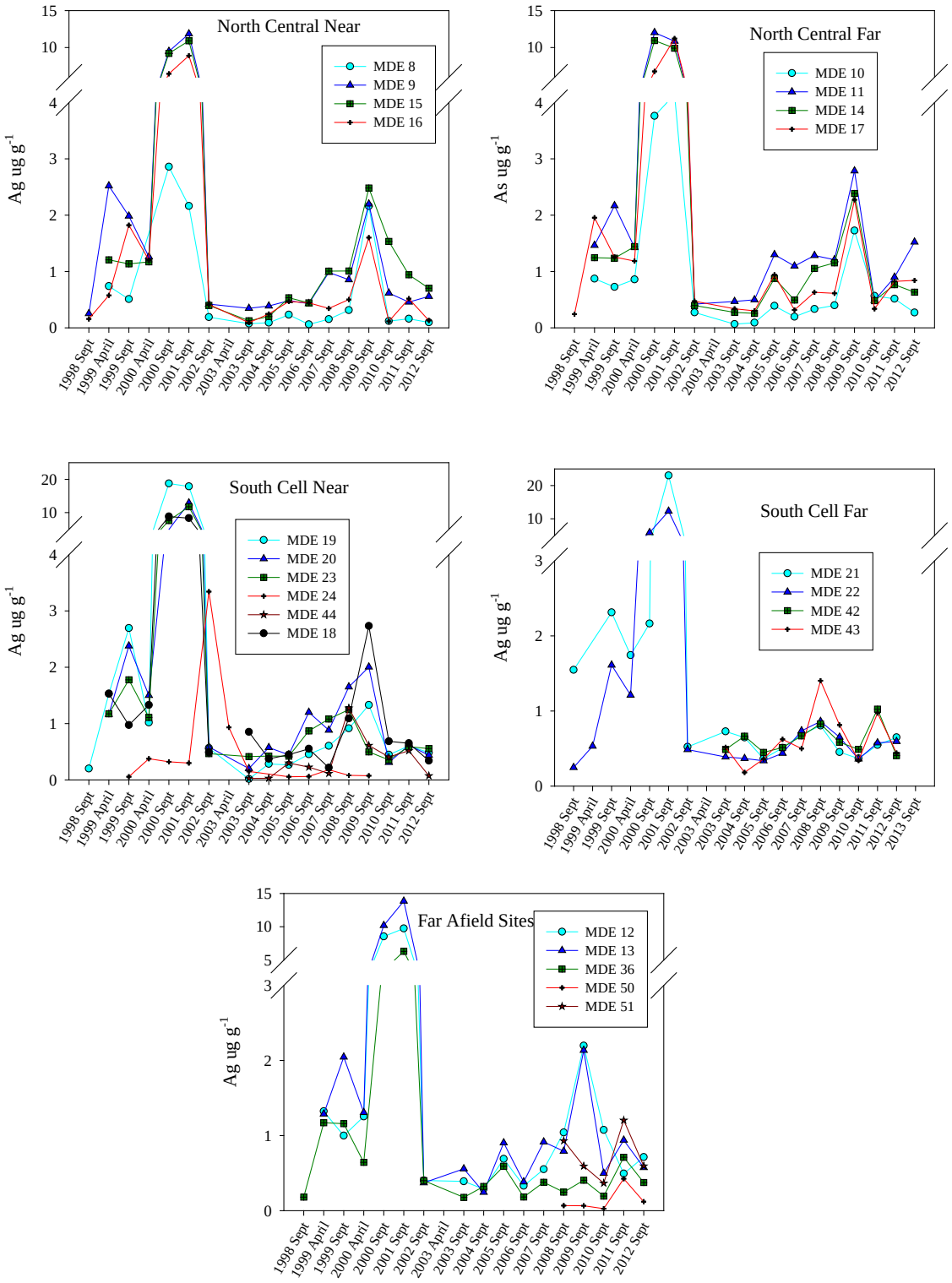


Figure 3- 10: Silver (Ag) concentrations in sediment from 1998 to 2012 sites located of the north east central side of the island, of the South Cell and stations far afield from the island including reference stations. Note the broken scales.

Mercury in Sediment 1998 to 2012

During the 1998-2012 period T-Hg concentrations in sediment fluctuated by as much as a factor of 5 at individual sites (e.g. MDE 4, MDE 32, MDE 41 and MDE 44) (Figure 3-11, 3-12). Even site MDE-36 has shown considerable variation with as much as a 2X variation of concentration in 2000 and 2010. Little in the way of a temporal trend is apparent at the vast majority of sites over the study period. Three of the 4 North Central Far sites, MDE 11, MDE 14 and MDE 17 are trending upward and these stations should be watched over the coming years. No changes in carbon or clay content have been observed at these three sites (discussed below), so the increases in concentration are the result of an increase on Hg, not a change in sediment composition.

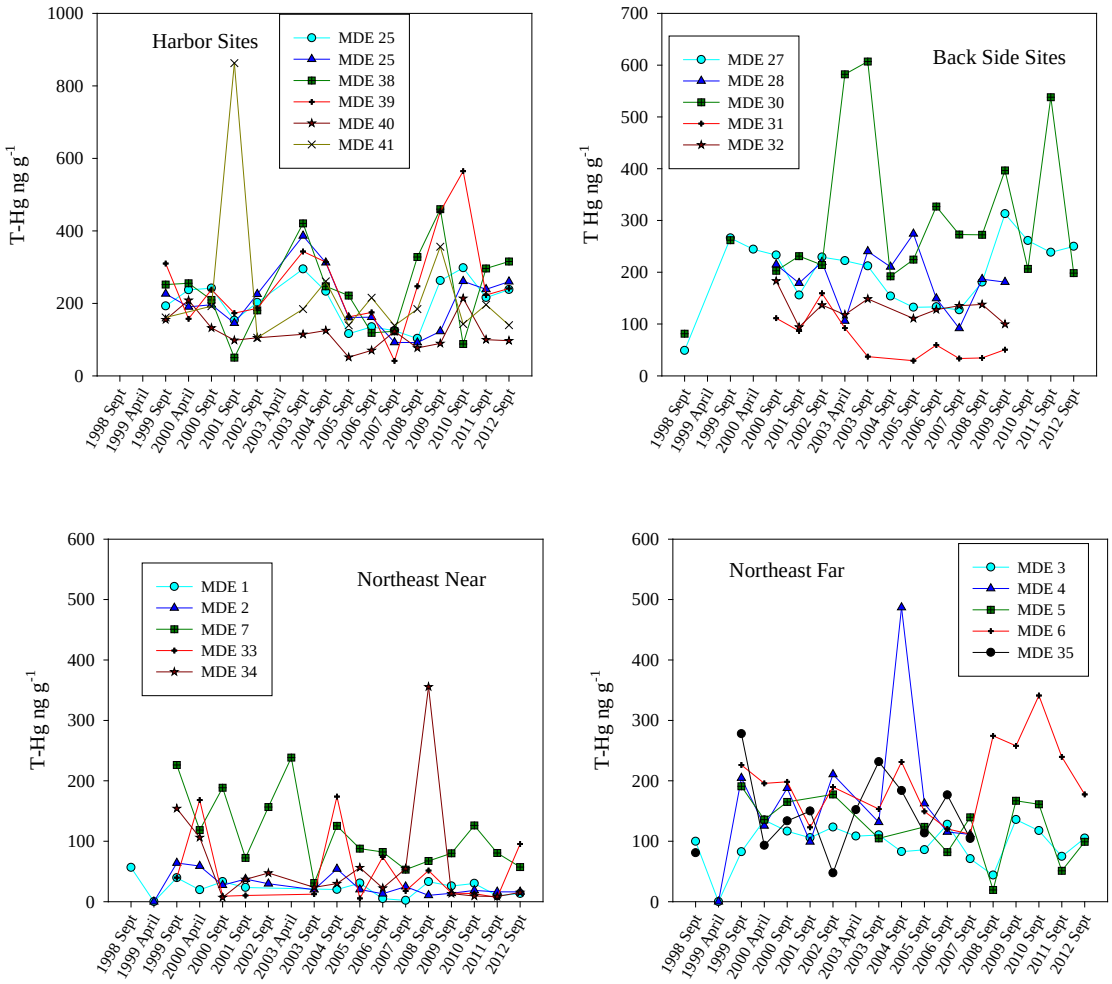


Figure 3-11: Total mercury (T-Hg) concentrations in sediment from 1998 to 2012 at the Harbor sites, Back River Sites, and sites of the Northeast side of the island.

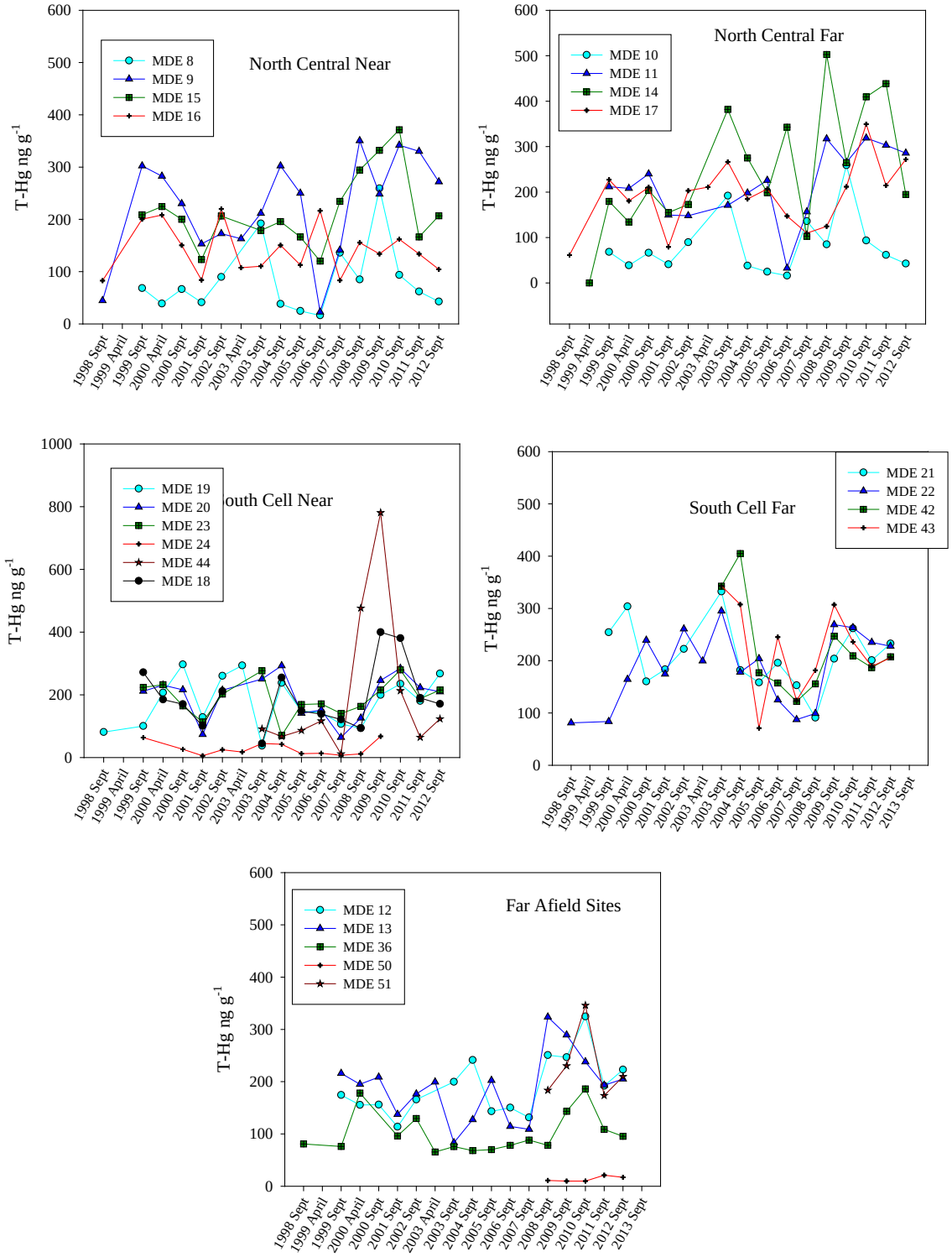


Figure 3- 12: Total mercury (Hg) concentrations in sediment from 1998 to 2012 sites located of the north east central side of the island, of the South Cell and stations far afield from the island including reference stations.

Methylmercury in Sediment 1998-2012

The concentrations of methylmercury (MeHg) were generally less than 2 ng g^{-1} at all sites over the study period. While MeHg concentrations at individual sites fluctuated over time, no strong temporal trend was apparent. Northeast Far sites maybe trending downward but the temporal variation was too great at other regions for any trend to be observed.

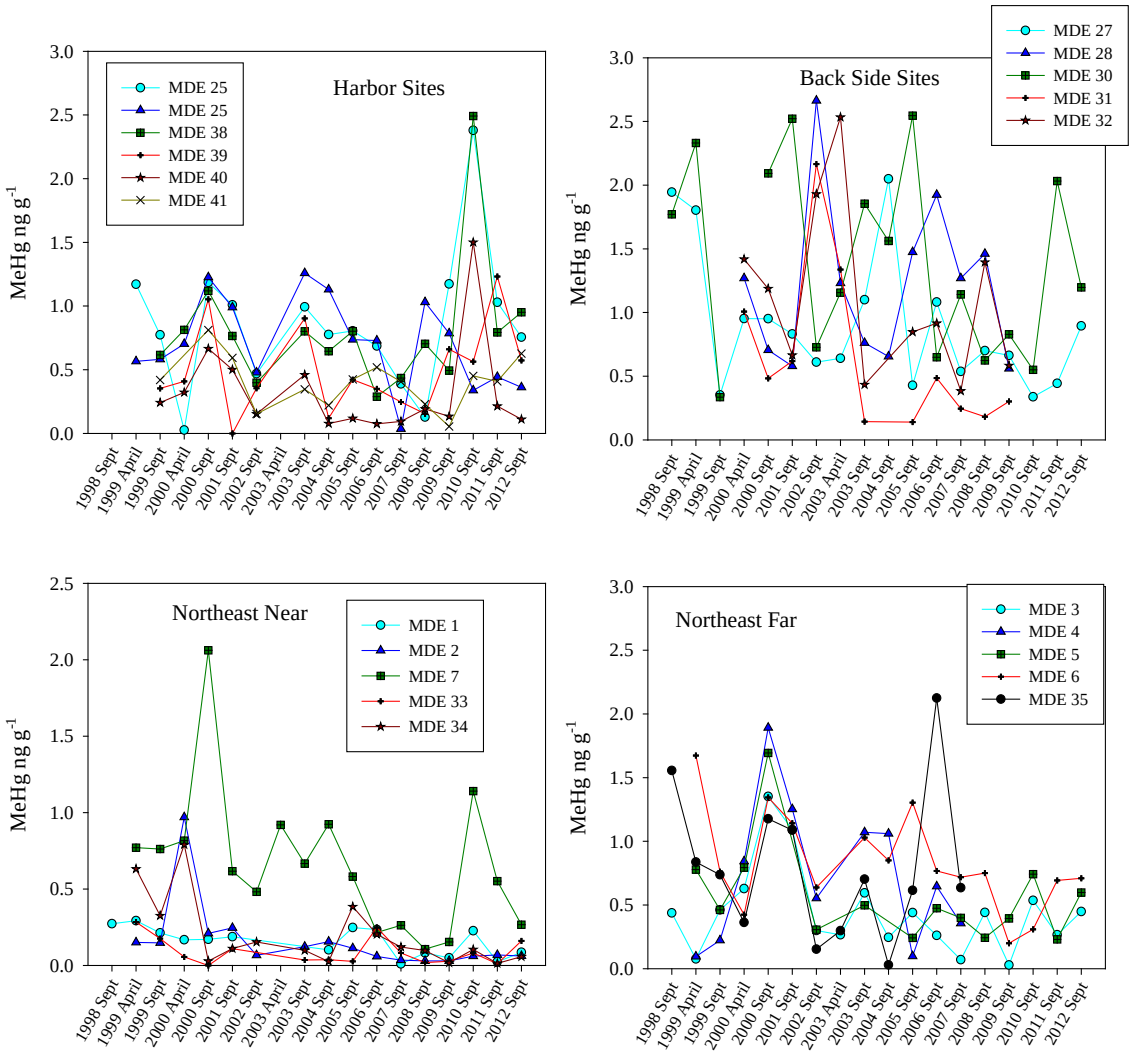


Figure 3-13: Methylmercury (MeHg) concentrations in sediment from 1998 to 2012 at the Harbor sites, Back River Sites, and sites of the Northeast side of the island.

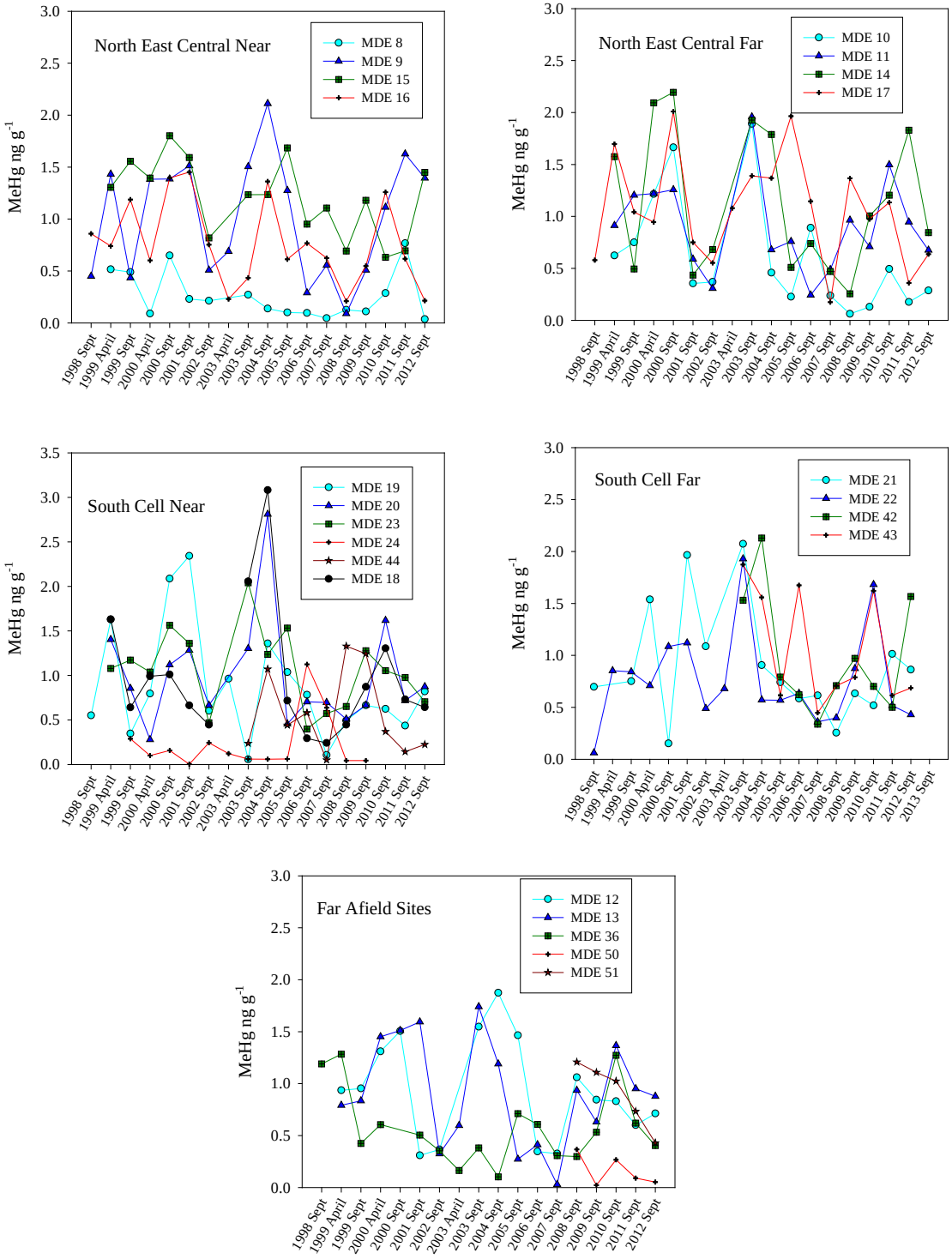


Figure 3- 14: Methylmercury (MeHg) concentrations in sediment from 1998 to 2012 sites located of the north east central side of the island, of the south cell and stations far afield from the island including reference stations.

Relationships among trace elements in Sediment

Trace elements may be co-released from activities such as coal combustion and industrial activity, so relations and temporal deviations among the elements may help in determining sources. Such relationships between trace elements in sediment are seldom reported in the literature.

Arsenic and Selenium

From the data collected around HMI , a generally strong correlation between As and Se concentrations in sediment is present when all the data from all years and all sites is compiled and examined independent of location and year (Figure 3-15a). There is some variability in the strength of the relationship between As and Se, when the data is broken out by years (not shown). The annual correlation r^2, have ranged from 0.22 to 0.84 between 1999 and 2011. In the fall of 2012 the relationship between As and Se was strong ($r^2 = 0.58$) (Figure 3-4b). At the level of individual sites, the correlation between the two elements is generally not as strong, with the r^2 ranging from 0.30 to 0.86 between 1999 and 2012. No relationship was found between As and Se at 4 sites [MDE-27, MDE-24 (no longer sampled), MDE-8 and MDE-2]. In general. As and Se concentrations are related and should increase and decrease together. Sustained departures from this relationship may suggest a change in source.

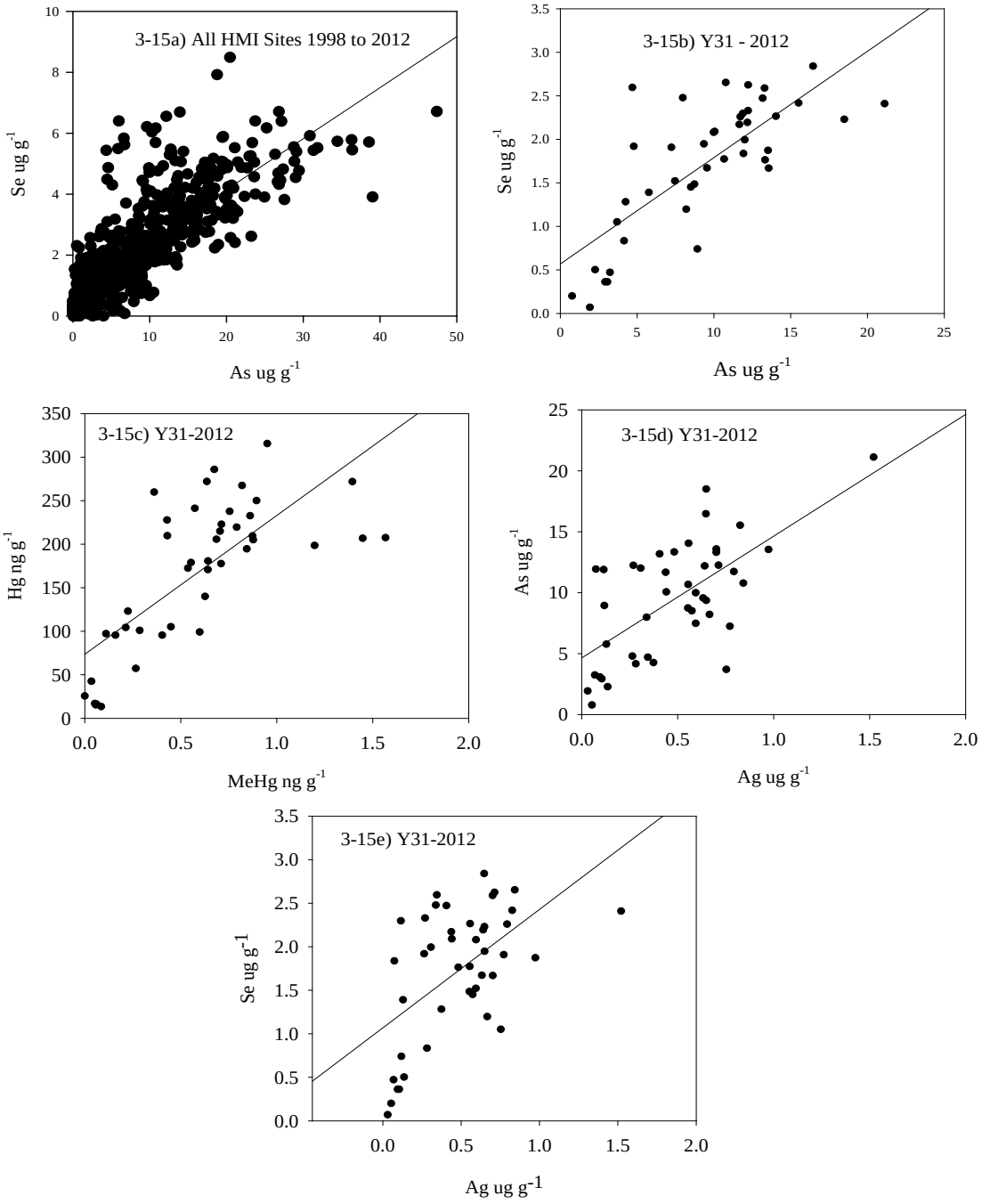


Figure 3- 15: Correlation of concentrations of Se and As in sediment (ug g^{-1} dry weight) for a) all HMI stations sampled from 1998 – 2012; b) sampled in the fall of 2012; c) correlation of T-Hg and MeHg concentration in September 2012, d) As and Ag concentrations in September 2012 and e) Se and Ag concentrations in September 2012.

Mercury and Methylmercury

T-Hg is not well correlated with Se, As or Ag at the HMI stations in time or space. Site MDE-44 remained the only site with a strong correlation between T-Hg and As, T-Hg and Se and T-Hg and Ag. When all sites are pooled, T-Hg is generally weakly correlated with MeHg over most of the years with r^2 from linear regressions ranging for 0.11 to 0.48. In 2010, 2008 and 1998, no relationship was observed between T-Hg and MeHg. In 2012, the relationship between T-Hg and MeHg was strong when all sites are pooled ($r^2 = 0.53$) (Figure 3-15c). The relationship between T-Hg and MeHg ranges from non-existent at about half the study sites to strong at sites MDE-21, MDE-31, MDE-37, MDE-41, MDE-43, MDE-44, and MDE-45. The small amount of data we have collected for sites MDE 45-51 makes this assessment much less robust. The dependence of MeHg on T-Hg is expected but in the Chesapeake Bay the relationship is often weakened by factors other than T-Hg concentration influencing MeHg production (Heyes et al. 2006).

Silver

As discussed in previous reports, Ag is poorly correlated with most other elements over the 1998 to 2012 study period. The high concentrations of Ag observed in 2000 and 2001 drastically skew the temporal results. When the data from these two years are removed, correlations between Ag and As and Ag and Se are generally strong. On an annual basis and independent of location, regressions between As and Ag concentrations in sediment generated r^2 ranged from 0.32 to 0.71 between 2002 and 2011. The exception occurred in 2009 when no relationship between As and Ag was found. In 2012, concentrations of As in sediment was again well correlated with concentrations of Ag ($r^2 = 0.42$) in sediment (Figure 3-41d).

Concentrations of Ag and Se in sediment were also well correlated across the years, with r^2 ranging from 0.44 to 0.70 between 2002 and 2011. In 2012, the relationship was the weakest of all (r^2 of 0.31) (Figure 3-15e). A continued decrease in the strength of the relationship would suggest a divergence of source or change in diagentic state, and is something to be monitored in the coming years.

When individual sites are examined over time, concentrations of Ag are not often well correlated with concentrations of the other elements. If the anomalous years of 2000 and 2001 are removed from the data set, correlations between Ag and other elements strengthen somewhat at most sites, but r^2 are generally less than 0.5. Interestingly, the temporal correlations between Ag and As and Ag and Se are fewest in number from the sites on NE side of the island. The strongest relationships are at sites MDE-43 (Ag-Se r^2

= 0.70) (Ag-As r^2 = 0.51) and 44 (Ag-Se r^2 = 0.70) (Ag-As r^2 = 0.58) which lie off the south side of the island.

Relationships between trace element concentrations with other site characteristics

The relationship between trace elements and other site variables such as organic carbon content, clay, silt and sand content was investigated. Some trace elements associate with clay sized particles, while others bind strongly with organic matter. A high sand content is indicative of an environment where trace elements are unlikely to accumulate.

As and Se concentrations in sediment seldom correlate with these other site variables over time at any one site. Thus changes in carbon or clay content do not influence As and Se concentrations at individual sites. This is also true when all sites are examined for any given year or over the entire study period.

When the data from all sites and times is combined and examined together, Hg is well correlated with carbon and clay content, unlike As and Se. (Figure 3-16). Furthermore, sediment T-Hg concentration is usually well correlated with carbon content and clay content among the sites in any one year; with the exception being1998. In 2012, the relationship between T-Hg and carbon was strong (Figure 3-17). However, when individual sites are examined over time T-Hg and carbon and T-Hg and clay content the relationship is not nearly as strong with Hg concentration correlated with sediment carbon content at only 8 sites and with clay content at only 6 sites. The reason for this is that the concentration of carbon and clay at a single site does not vary much over time thereby weakening the potential for temporal relationships. Hence, when the range in carbon and clay content are expanded by looking across sites within a year, the relationship between carbon and Hg strengthens greatly.

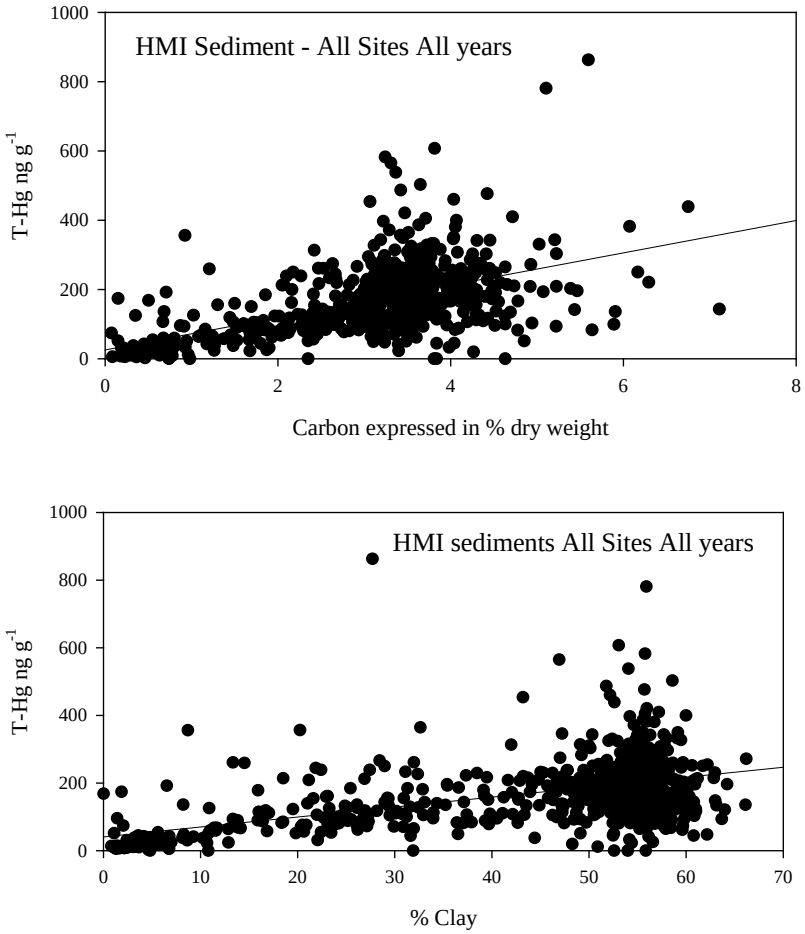


Figure 3-16: Total-Hg concentration and carbon content (upper) and clay (lower) in sediment for all sites and all years.

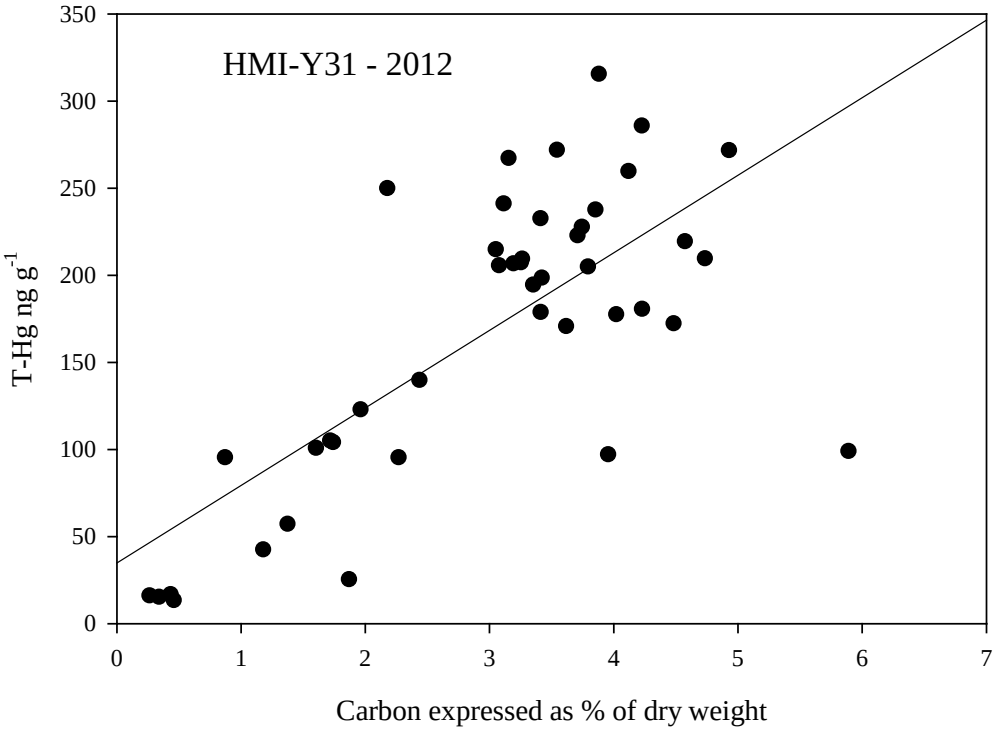


Figure 3-17: Sediment total mercury and carbon concentration in Y31 – September 2012 (r^2 = .52).

General Conclusions Regarding Trace Element Concentrations

In the past, some stations have shown enrichments of more than one trace element when compared to a sites running mean. No sites investigated in 2012 had an enrichment of more than one trace element. In general, concentrations were very close the sites running median for 1998-2011. Sites MDE-11, MDE-14 and MDE-17 are trending upward in T-Hg concentration. Concentrations of As in sediment have been trending upward at a large number of sites since 2005. The concentrations do not exceed concentrations seen in the early years of the study 1998-2001, thus the mean and median concentrations for the study period are not changing very quickly in response. The trend is worth watching and maybe simply be part of a normal oscillation, following a period of low concentrations between 2002 and 2005. Increases are not occurring at all sites, nor have they increased to pre 2002 levels.

The relationships between As, Se and Ag concentrations in sediment suggest either that they have a similar origin or they had a similar diagenetic behavior once deposited in the sediments around HMI complex for most of the study period. The continued lack of a correlation between Ag and As at sites located NE of the island suggest a different mechanism of delivery or retention for these elements in this area compared to sites elsewhere around the complex. The weakening relationship between Ag and Se in 2011 and 2012 may indicate a divergence of the respective metal sources at some sites or a shift in the diagenetic behavior is becoming apparent. The behavior of T-Hg in HMI sediments is different from the other trace elements. T-Hg is seldom correlated with other trace elements, and is more dependent on organic matter and clay content of sediment than the other elements. This might imply a different source such as broad scale atmospheric deposition is the main driver of Hg distribution but this does not explain the spikes in T-Hg concentration seen in some years at some sites.

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

Trace Elements in Clams

The clam *Rangia* was collected from 11 stations in the fall (September) of 2012 and 12 stations in the spring (April) of 2013. In the fall of 2012, the stations visited included MDE-3, 9, 13, 16, 17, 27, 30, 36, 42, 43 and 44. In general, concentrations of As, Se, and Cd in these clams were similar to the running mean determined from the measurements made in previous years; with the exception of MDE-44 (Figure 3-18). Only clams from site MDE-44 exceeded the standard deviation of previous concentrations for all metals. Concentrations of Se fell just above the historic mean at stations MDE-16 and 42. The concentration of As was above the historic mean at the station MDE-16. Concentrations of Pb and Ag were generally below the historic concentrations. Concentrations of T-Hg and MeHg were close to the running mean of the station from which they were collected (Figure 3-19). The proportion of Hg that occurred as MeHg also fell within the historic values.

Clams were collected from MDE-3, 9, 11, 16, 17, 27, 30, 36, 42, 43, 44, and 45 in April 2013. Concentrations of As and Se in these clams were similar to each sites

historic concentration (Figure 3-20). Concentrations of Ag, Pb and Cd were much lower than historic levels. In the case of Cd, concentrations often fell below the standard deviation observed at the site (MDE-11, 42, 43, 44 and 45). Concentrations of T-Hg and MeHg generally followed the historic mean, with exception of clams from MDE-17, where concentrations were above the upper limit of the standard deviation. Clam concentrations of T-Hg at sites MDE-43, 44 and 45 were so low they were below the observed standard deviations of the respective sites. Concentrations of MeHg were typical of past years, as was the % of mercury occurring as MeHg at each site. The exception was site MDE-44, which had a % MeHg level well above the sites standard deviation. This was driven by a lower than normal T-Hg concentration.

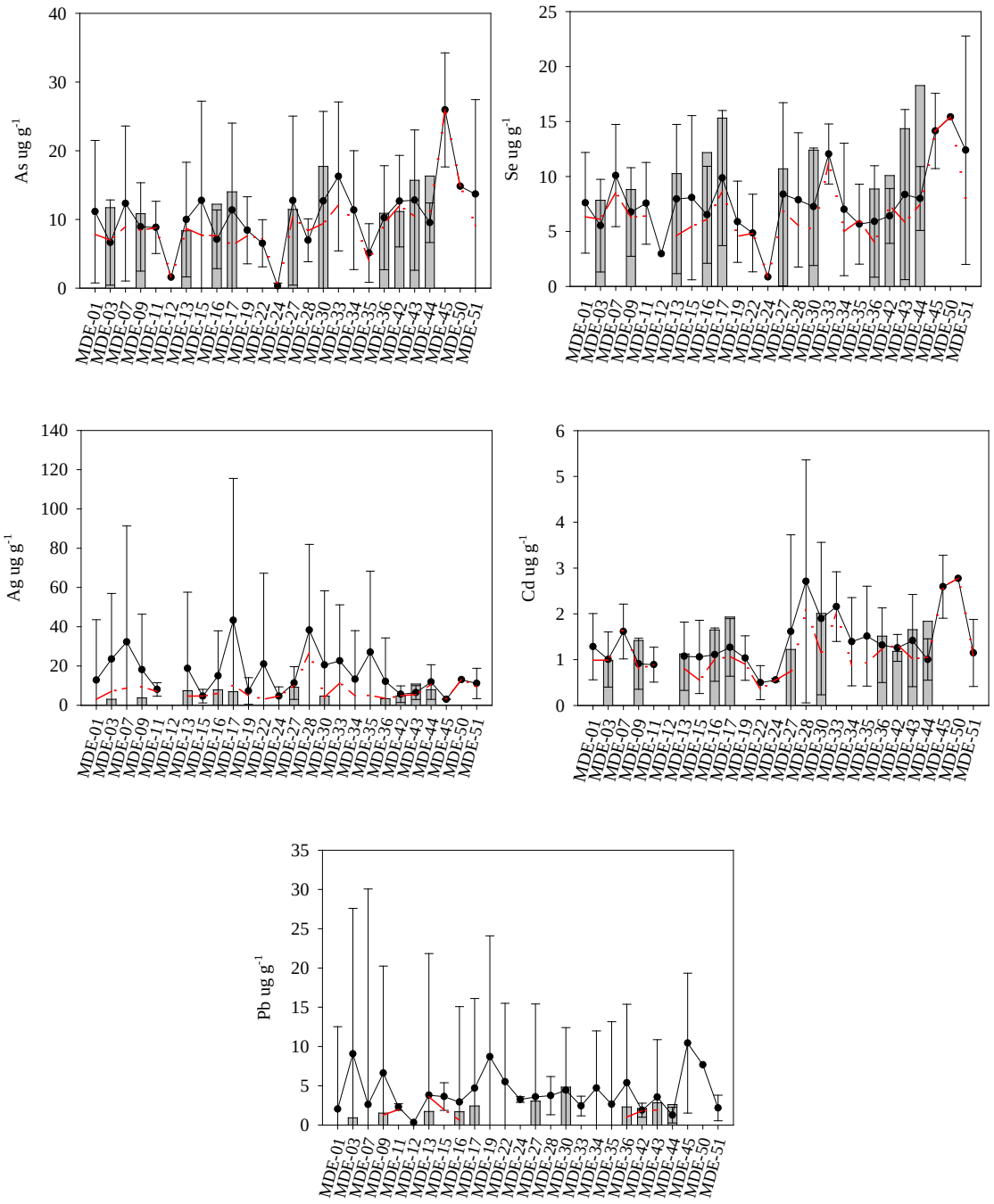


Figure 3- 18: Concentrations of Pb, Cd, As, Se, Ag in clams collected in September 2012. Concentrations (bars) are dry weight based and the 1998-2011 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2011 median (dashed line).

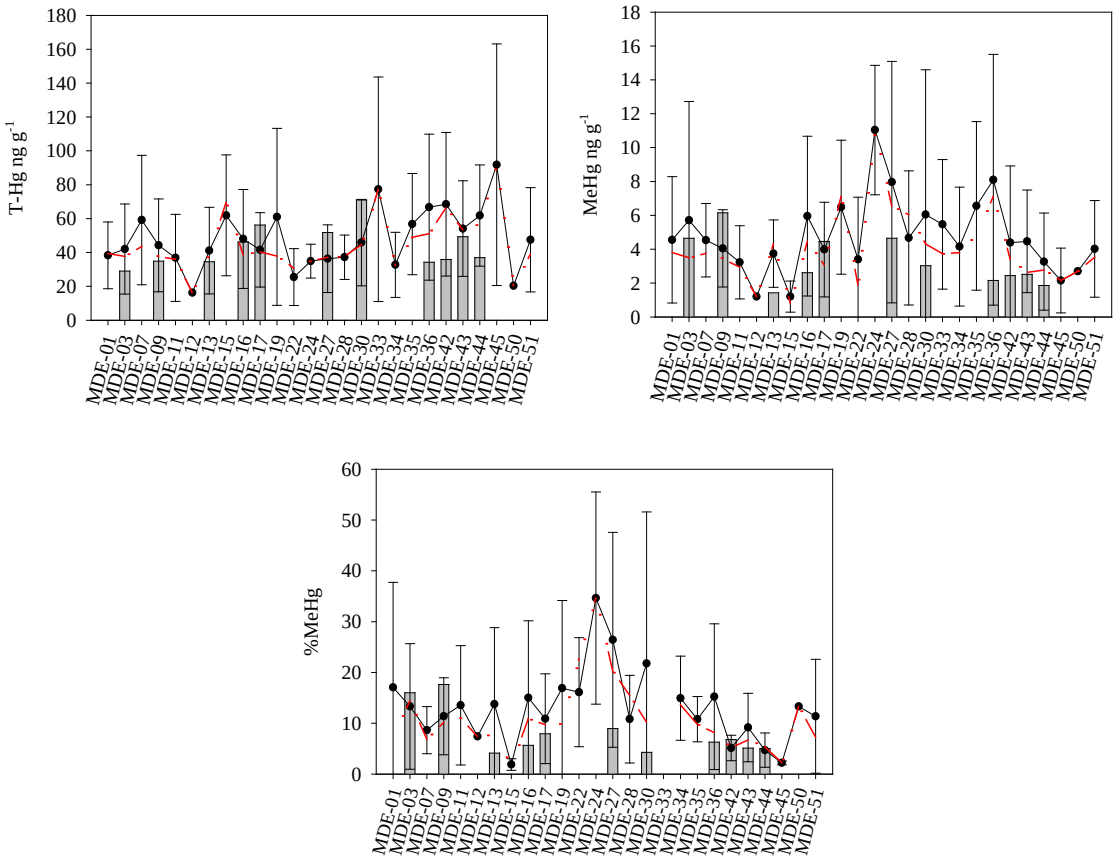


Figure 3- 19: Mercury (Hg) and methylmercury (MeHg) concentrations, expressed on a dry weight basis, and percent of Hg that is MeHg in clams, collected in September 2012 (bars) and the 1998-2011 mean (circles) with standard deviation (error bars) and the 1998-2011 median (dashed line).

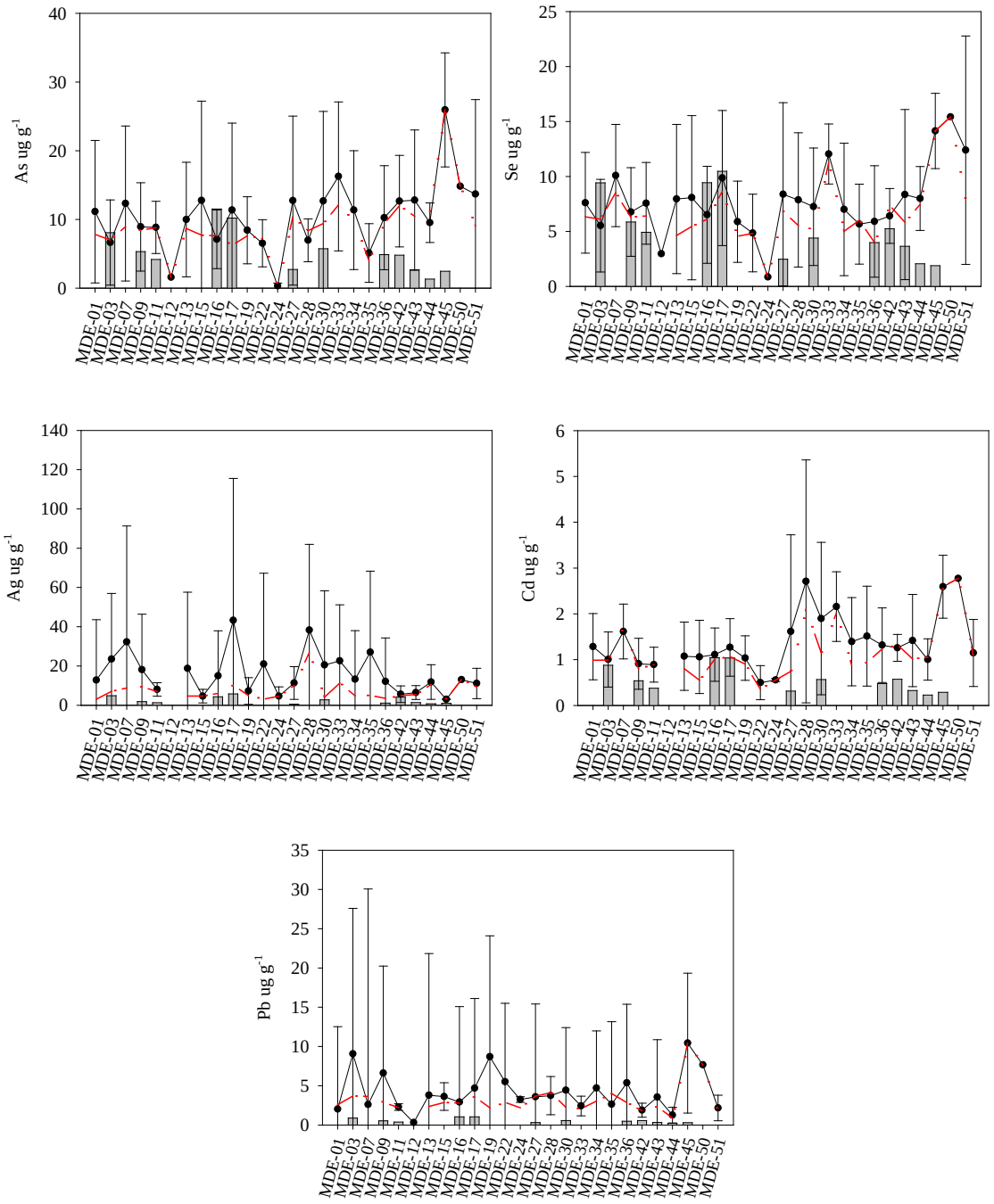


Figure 3- 20: Concentrations of Pb, Cd, As, Se, Ag in clams collected in April 2013. Concentrations (bars) are dry weight based, and the 1998-2012 mean (circles) with standard deviation (error bars) for each site is presented along with the 1998-2012 median (dashed line).

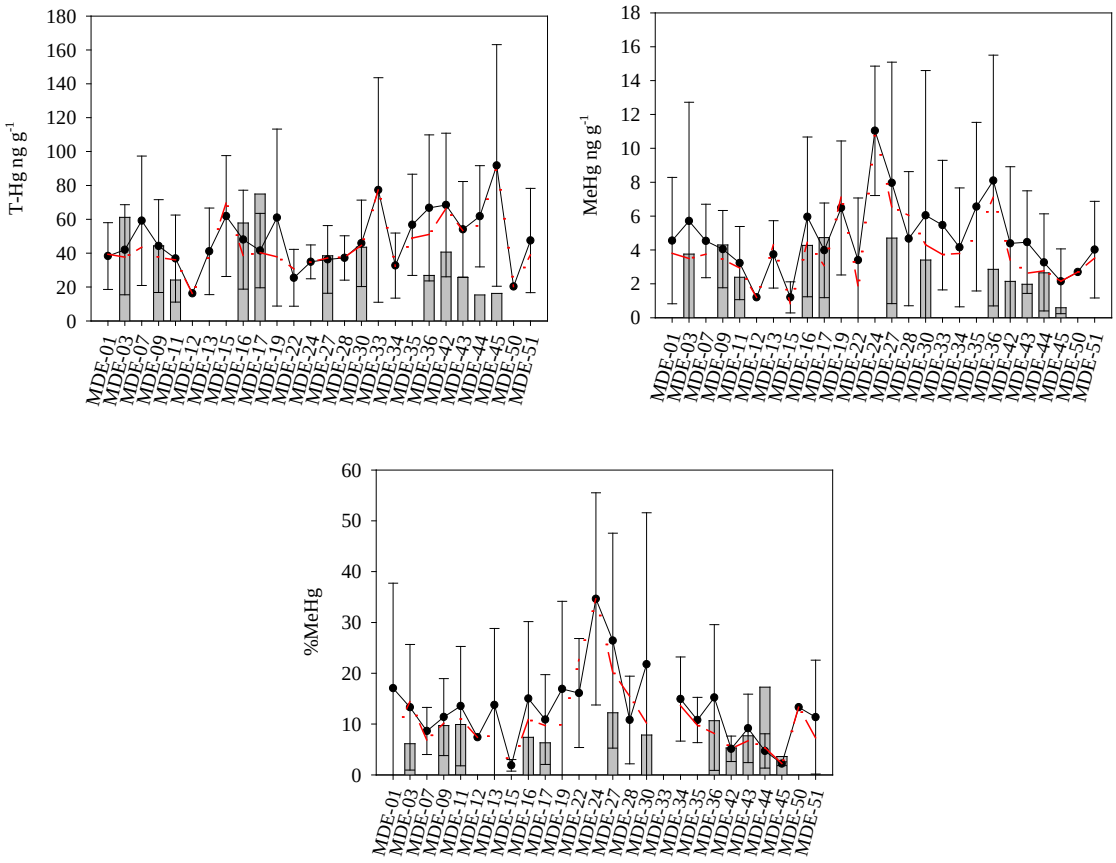


Figure 3- 21: Mercury (Hg) and methylmercury (MeHg) concentrations, expressed on a dry weight basis, and percent of Hg that is MeHg in clams, collected in April 2013 (bars) and the 1998-2012 mean (circles) with standard deviation (error bars) and the 1998-2012 median (dashed line).

Bioaccumulation Factors

The bioaccumulation factors (BAFs) for the trace elements Cd, Pb, As, Ag, Se, T-Hg and MeHg (Figure 3-22, 3-23) were calculated using clam concentrations in Figures 3-18 to 3-20) and sediment concentrations presented in Table 3-1. While the station co-ordinates are the same as MGS, boat drifting might result in poor day to day sample co-ordination. Thus, to ensure the best sediment-clam matching, sediment was collected along with the clam collection and analyzed for Cd, Pb, As, Ag, Hg and MeHg.

In both September 2012 and April 2013, the BAFs for Pb (not shown in Figures 3-22 and 3-23) were less than 1 for all sites, indicating no bioaccumulation of Pb from sediment to clams occurred. BAFs of less than 1 for Pb have been occurring for the duration of the study.

In September 2012 little bioaccumulation of As and T-Hg by the clams was observed (BAFs typically less than 10, Figure 3-22). Moderate bioaccumulation of Ag, Cd, Se and MeHg was observed, as BAFs were on the order of 10 or less. In April 2013, little to no bioaccumulation of As, Cd and T-Hg was apparent but moderate accumulation of Ag, Se and MeHg was observed as BAFs approached 10 (Figure 3-23). The pattern in metal bioaccumulation was very similar in both seasons and no sites appeared to stand out as being different than the rest.

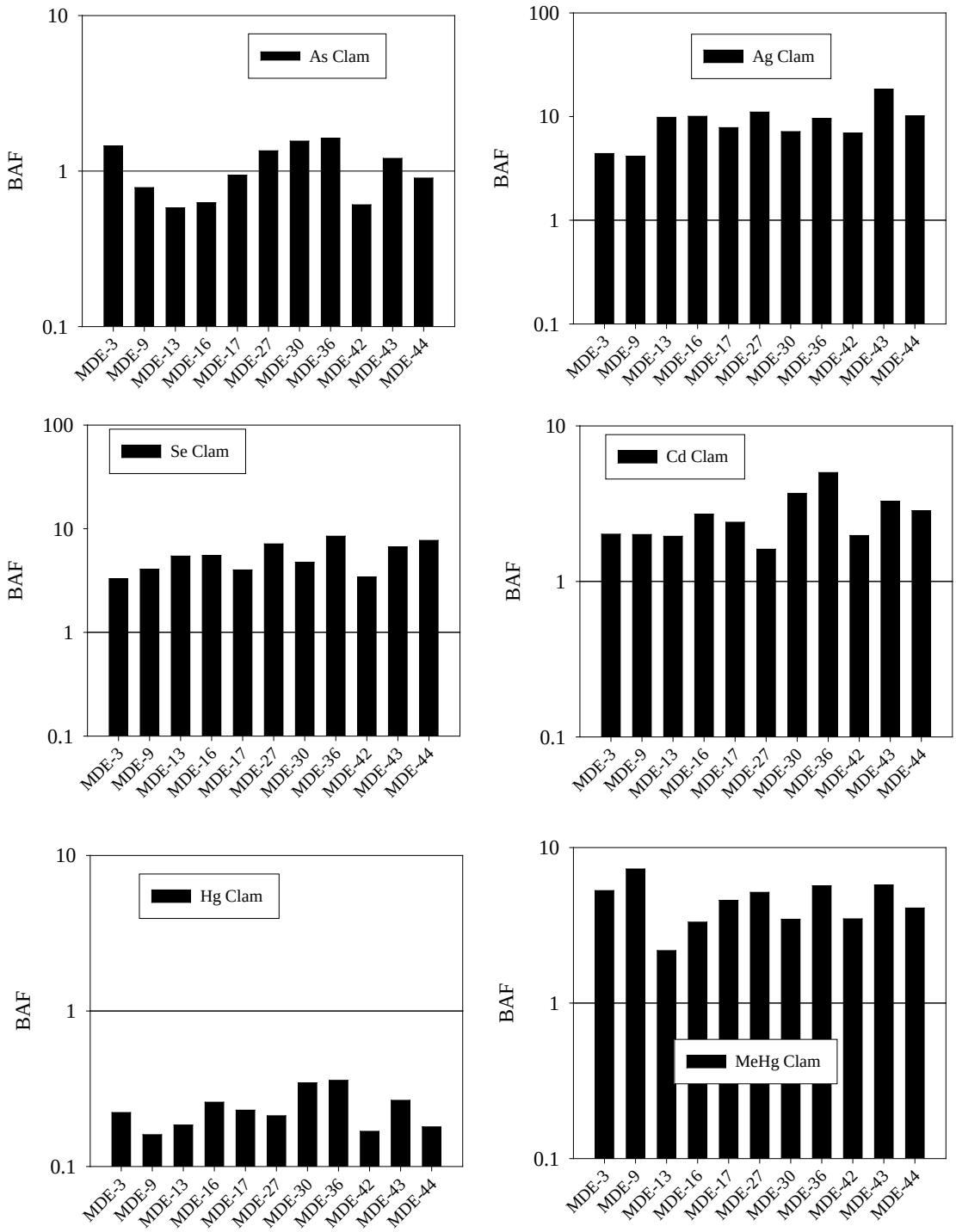


Figure 3- 22: Bioaccumulation factors (BAF) for the metals As, Ag, Se, Cd, Hg and MeHg September 2012. Note BAF is presented on a log scale.

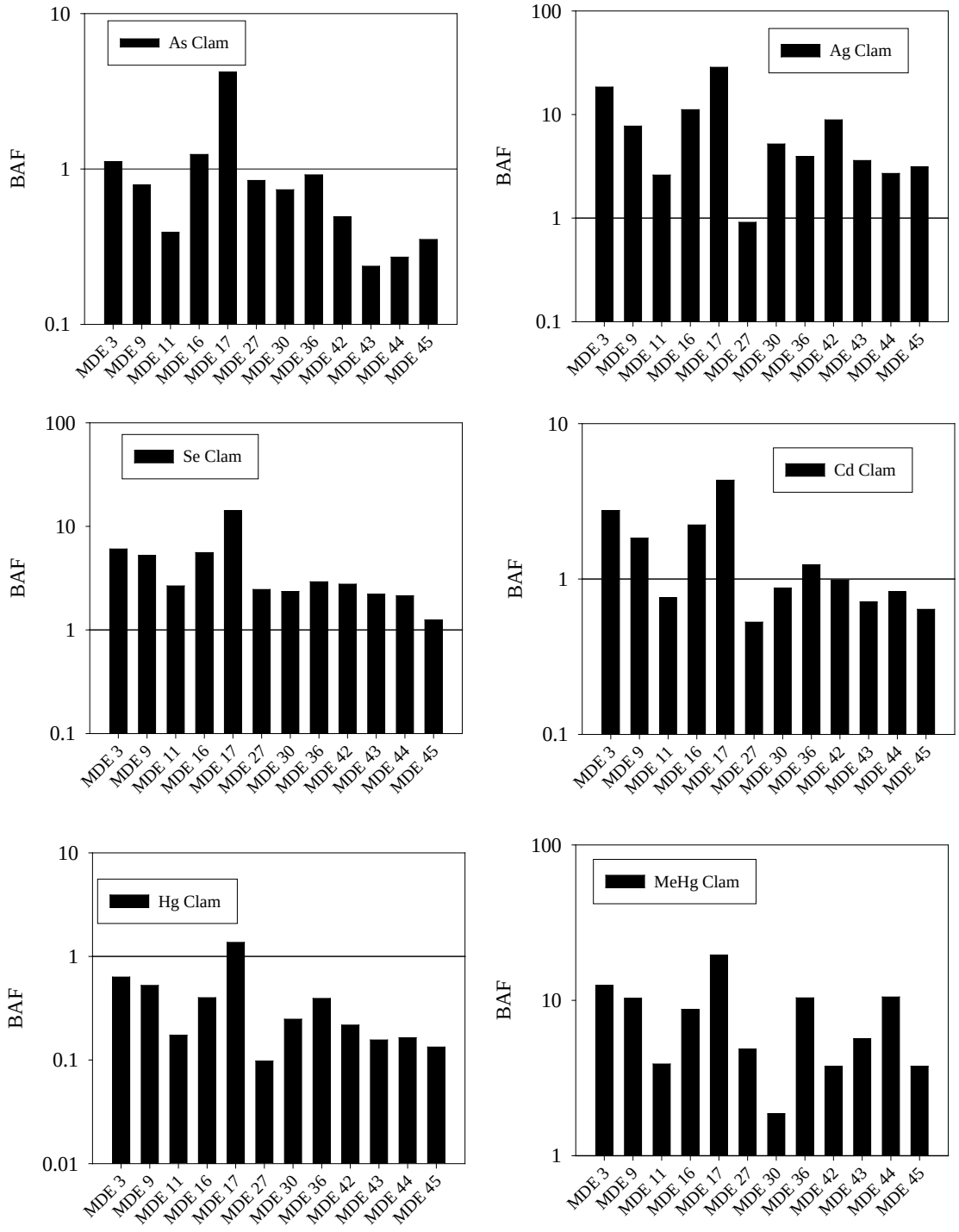


Figure 3-23: Bioaccumulation factors (BAF) for the metals As, Ag, Se, Cd, Hg and MeHg April 2013. Note BAF is presented on a log scale.

Table 3- 1: Trace element concentrations in sediment (dry weight) collected along with clams by CBL and MDE in September 2012 and April 2013. The sediment was taken from the same sites but on different dates hence the data is different from what is shown in figures 3-22 to 3-23.

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-3	8.07	2.37	0.69	0.49	34.44	130.5	0.88
MDE-9	13.84	2.16	0.90	0.71	52.33	218.3	0.85
MDE-13	14.38	1.89	0.75	0.58	46.28	186.5	0.66
MDE-16	19.51	2.21	0.78	0.61	55.68	178.5	0.79
MDE-17	14.94	3.82	0.88	0.80	62.43	244.3	0.97
MDE-27	8.48	1.50	0.84	0.76	48.37	244.8	0.90
MDE-30	11.37	2.61	0.65	0.55	52.19	205.4	0.88
MDE-36	6.69	1.05	0.35	0.30	26.08	95.6	0.38
MDE-42	18.41	2.95	0.68	0.60	58.17	213.1	0.70
MDE-43	13.01	2.15	0.59	0.50	48.95	185.1	0.44
MDE-44	18.08	2.37	0.78	0.65	59.87	205.5	0.46

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	7.24	1.56	0.27	0.32	32.44	96.9	0.30
MDE 9	6.74	1.12	0.24	0.29	29.25	84.3	0.42
MDE 11	10.66	1.85	0.51	0.50	47.49	138.9	0.62
MDE 16	9.28	1.69	0.38	0.47	45.24	144.9	0.49
MDE 17	2.42	0.74	0.20	0.24	20.28	54.9	0.24
MDE 27	3.21	1.01	0.60	0.59	45.17	393.6	0.97
MDE 30	7.79	1.87	0.54	0.65	56.30	175.6	1.83
MDE 36	5.31	1.37	0.28	0.39	31.87	68.4	0.28
MDE 42	9.73	1.90	0.47	0.58	54.42	186.7	0.57
MDE 43	11.27	1.64	0.39	0.46	47.82	164.5	0.35
MDE 44	4.87	0.96	0.27	0.27	28.73	93.4	0.25
MDE 45	6.95	1.51	0.33	0.45	38.84	122.0	0.16

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 as a frame of reference for the overall condition of the sediment around HMI for the elements available. The Probable Effects Levels (PEL) has been plotted along with the sediment trace element concentrations (Figures 3-24 and 3-25). For the metals As, Ag and Hg; sediment concentrations are below the PEL.

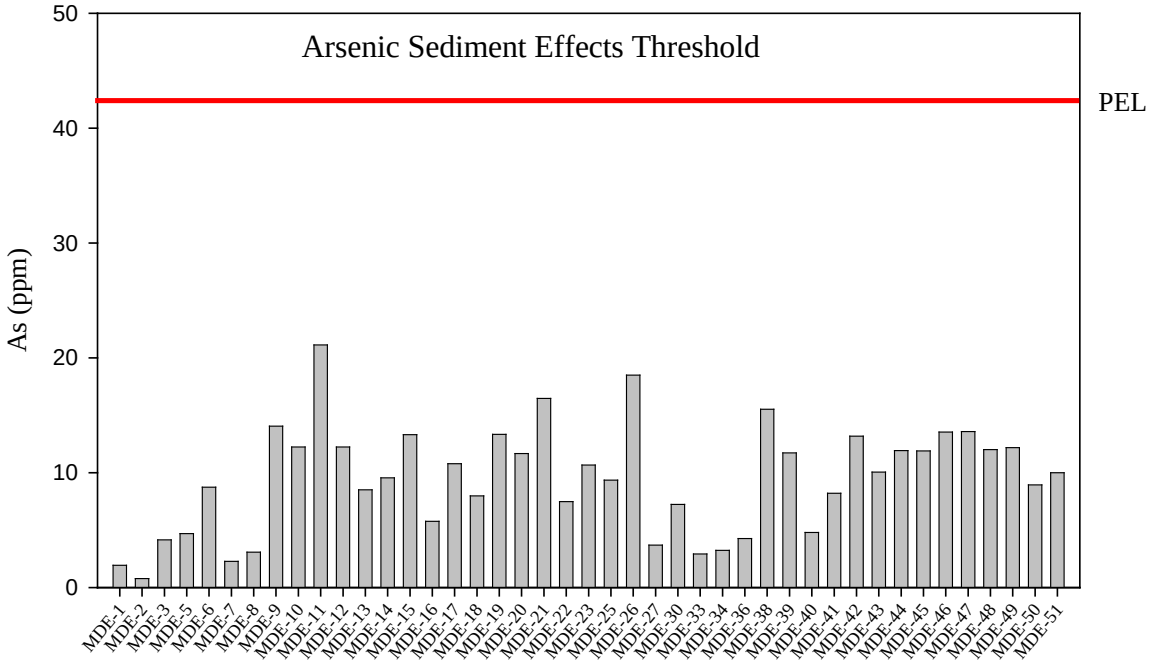


Figure 3- 24: Arsenic (As) concentrations in sediment (MGS collections) along with the Probable Effects Level (PEL) as identified by NOAA for marine sediment.

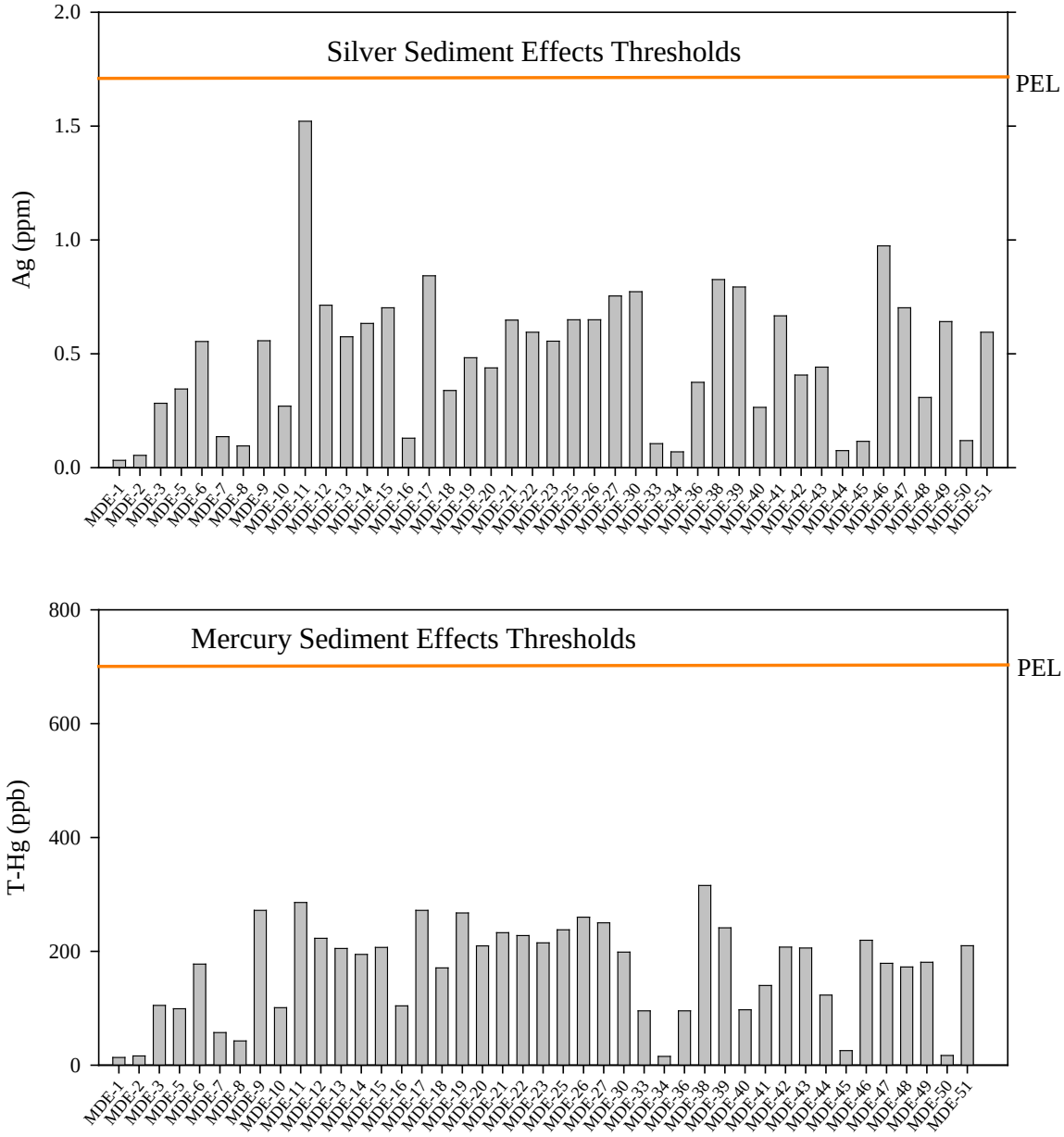
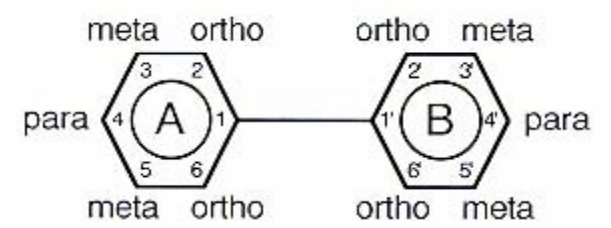


Figure 3- 25: Mercury (Hg) and Silver (Ag) concentrations in sediment (MGS collections) along with Probable Effects Level (PEL) as identified by NOAA for marine sediment.

PCBs in Sediment

The PCB congeners analyzed in the sediments collected in September of 2012 are listed in Table 3-2. Each congener number indicates a different biphenyl molecule which has from 1 to 10 chlorine atoms attached at 10 possible sites as seen here.



The number of chlorine atoms attached and the placement around the biphenyl molecule is used in naming (Table 3-2). The degree of chlorination results in 10 groups: mono, tri, di, tetra, penta, hexa, hepta, octa, nona and decachlorobiphenyl. Within each group there exists the potential for a number of positional isomers and the sum of all the combinations is 209. More importantly, with increasing congener number the congeners become less soluble and bioavailable. Microorganisms have difficulty breaking down the more chlorinated molecules (5 or more chlorines). Because of continued refinement of analytical performance, more congeners were able to be measured in 2012 than in the years preceding 2010. The congeners were regrouped to match previous years in order to perform a historical comparison and the congeners listed in this table match those shown in Figures 3-26 a-k (Table 3-3).The PCB congeners measured around HMI in 2012 are summarized in Figure 3-26 a-k. These figures provide a "signature" from which to investigate trends within and among sites. Not all congeners can be differentiated by CBL analysis, and some congeners must be combined. For example congeners 31 and 38 cannot be separated by the GC column and are said to co-elute. As a resultBL designate the peak 31+ 38.

The sediments collected in 2012 contain high concentrations of the PCB congeners 31+28, 52, 66+95, 77+110, 132+153+105, 163+138, 201, 208+195, 206 and 209. The concentrations of these congeners define the sediment sample signatures in 2012. High concentrations of these congeners occurred in sediment in most of the previous years, and this is very evident in the plots of the running means and medians for each of the sites. Sediment from station MDE-16 has a series of congeners that are not commonly found at other sites. These are congener 83, and the congener pair 129+178. Sediment from MDE-13 had a large amount of the PCB congener pair 47+48. While these congeners are present at most other sites, the concentrations at the other sites are much lower. PCB congener 157 may have been present in many samples but we could not quantify the amount because of an interfering compound. In general, concentrations of many PCB congeners were consistent with station means of previous years. The congener concentrations are weighted toward the higher numbers which is to be

expected, as with the increasing degree of chlorination PCBs are less soluble and more likely to stay bound to sediment (Table 3-4).

Table 3-2: Polychlorinated Biphenyl congeners measured by CBL in 2012. The congeners that can be detected vary slightly from year to year. In 2012 more congeners could be accurately measured than in 2010 (table 3-3). Most of the additional congeners that could be measured were not detected, hence they add little to the total PCB concentration.

1	Cong-1	Mono	38	Cong-63	Tetra	74	Cong-176	Hepta
2	Cong-2	Mono	39	Cong-74,61	Tetra	75	Cong-130,137	Hexa,Hexa
3	Cong-3	Mono	40	Cong-70,76	Tetra	76	Cong-164,163,138	Hexa,Hexa,Hexa
4	Cong-4,10	Di	41	Cong-93	Penta	77	Cong-158	Hexa
5	Cong-7,9	Di	42	Cong-66	Tetra	78	Cong-129	Hexa
6	Cong-6	Di	43	Cong-95	Penta	79	Cong-178	Hepta
7	Cong-8,5	Di	44	Cong-91	Penta	80	Cong-187	Hepta
8	Cong-19	Tri	45	Cong-56,60	Tetra	81	Cong-183	Hepta
9	Cong-12,13	Di	46	Cong-92	Penta	82	Cong-128,167	Hexa
10	Cong-18	Tri	47	Cong-84	Penta	83	Cong-185	Hepta
11	Cong-15	Di	48	Cong-101,90,89	Penta,Penta,Penta	84	Cong-174	Hepta
12	Cong-17	Tri	49	Cong-99	Penta	85	Cong-177	Hepta
13	Cong-24	Tri	50	Cong-119	Penta	86	Cong-156	Hexa
14	Cong-16,32	Tri	51	Cong-83	Penta	87	Cong-202	Octa
15	Cong-29	Tri	52	Cong-97	Penta	88	Cong-171	Hepta
16	Cong-26	Tri	53	Cong-81	Tetra	89	Cong-157	Hexa
17	Cong-25	Tri	54	Cong-87,115	Penta,Penta	90	Cong-200	Octa
18	Cong-28	Tri	55	Cong-85	Penta	91	Cong-172	Hepta
19	Cong-31	Tri	56	Cong-85	Penta	92	Cong-197	Hepta
20	Cong-20.33,41	Tri	57	Cong-136	Hexa	93	Cong-180	Hepta
21	Cong-51	Tetra	58	Cong-77	Tetra	94	Cong-193	Hepta
22	Cong-53	Tetra	59	Cong-110	Penta	95	Cong-191	Hepta
23	Cong-22	Tri	60	Cong-82	Penta	96	Cong-199	Octa
24	Cong-45	Tetra	61	Cong-151	Hexa	97	Cong-170,190	Hepta
25	Cong-46	Tetra	62	Cong-135,144	Hexa	98	Cong-198	Octa
26	Cong-52	Tetra	63	Cong-107,108	Penta	99	Cong-201	Octa
27	Cong-49	Tetra	64	Cong-149	Hexa	100	Cong-203,196	Octa
28	Cong-47,48	Tetra	65	Cong-118,106	Penta	101	Cong-189	Hepta
29	Cong-44	Tetra	66	Cong-134	Hexa	102	Cong-195	Octa
30	Cong-37	Tri	67	Cong-114	Penta	103	Cong-208	Nona, Octa
31	Cong-42	Tetra	68	Cong-146	Hexa	104	Cong-207	Nona
32	Cong-41,64,71	Tetra	69	Cong132,168	Hexa,Hexa,	105	Cong-194	Octa
33	Cong-103	Penta	70	Cong-105	Penta	106	Cong-205	Octa
35	Cong-40	Tetra	71	Cong-141	Hexa	107	Cong-206	Nona
36	Cong-100	Penta	72	Cong-179	Hepta	108	Cong-209	Deca
37	Cong-100	Penta	73	Cong-176	Hepta			

Table 3- 3: The polychlorinated biphenyl congeners shown in Figures 3-26a-k and 3-27 a-k. For continuity in finger printing only the PCB congeners that have been detected over the life of the project are listed here. Thus, not all the PCB congeners measured (table 3-2), are shown in figures 3-26 and 3-27 a-k. This was done to allow inter year comparisons.

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

Table 3- 4: Polychlorinated biphenyl homologs and properties.

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

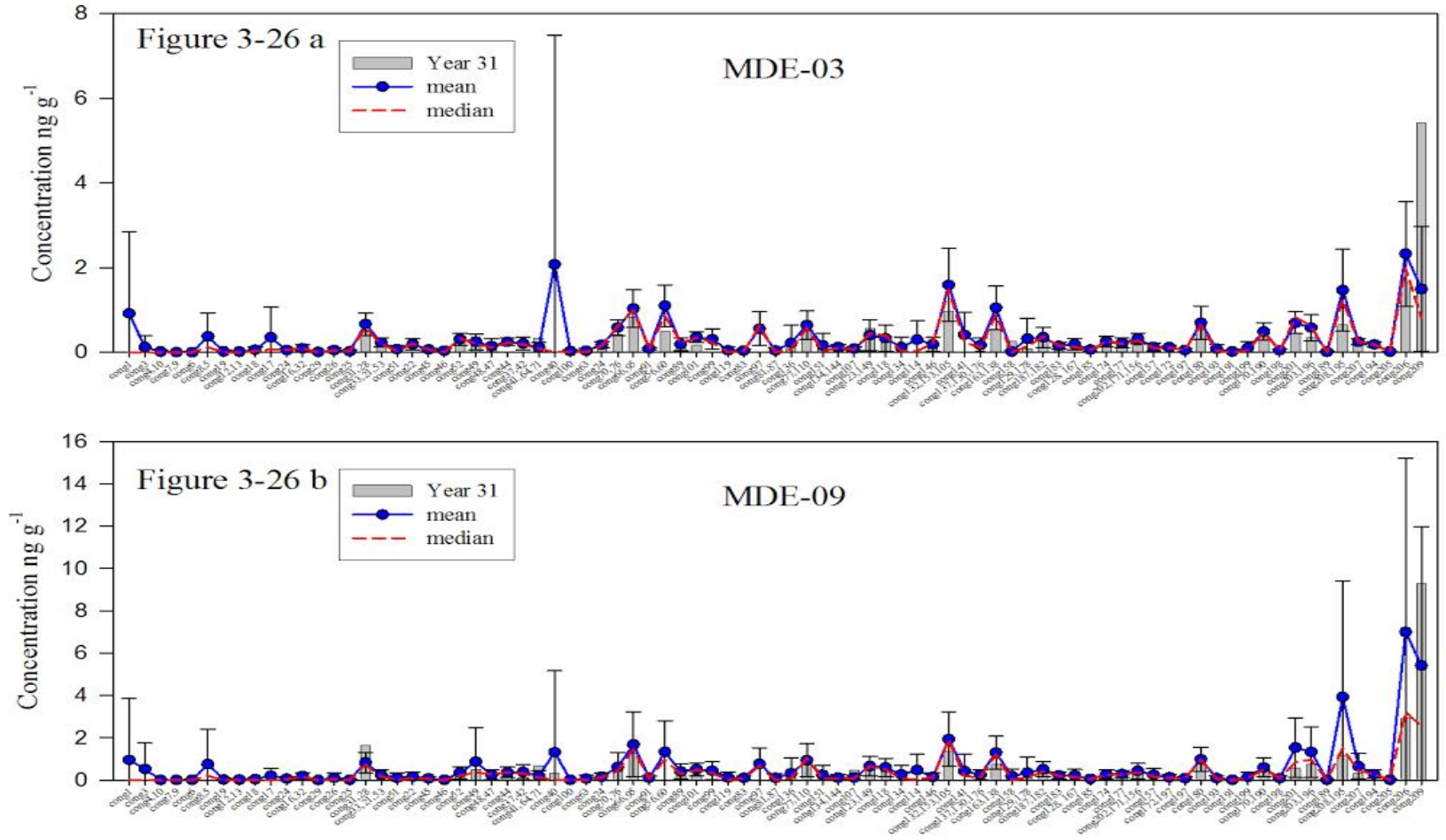


Figure 3- 26: Concentrations of PCB congeners in sediments from sites MDE-03 and MDE-09 from the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line) expressed in ng g-1 dry weight.

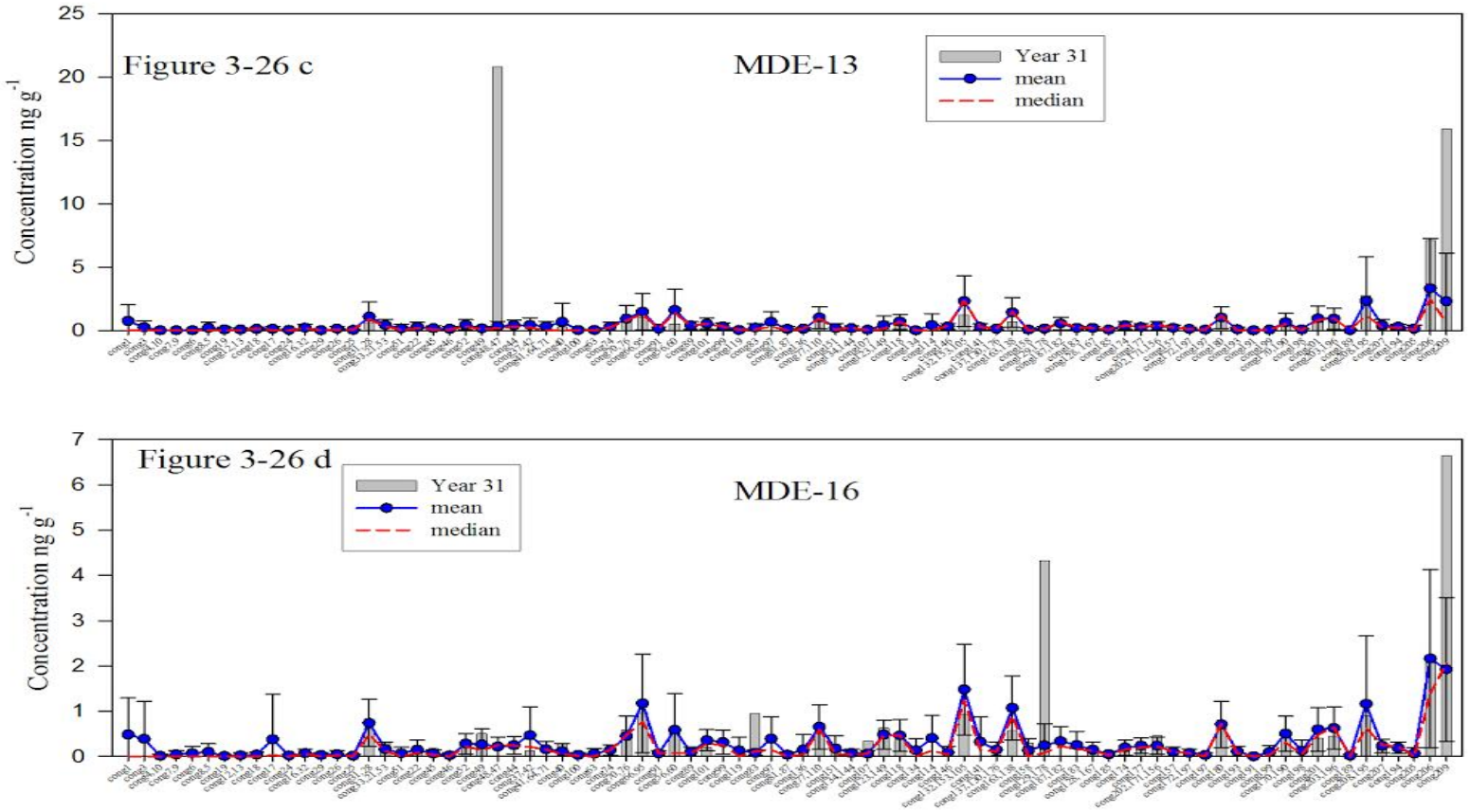


Figure 3-26 continued. Concentrations of PCB congeners in sediments from sites MDE-13 and MDE-16 from the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line) expressed in ng g^{-1} dry weight.

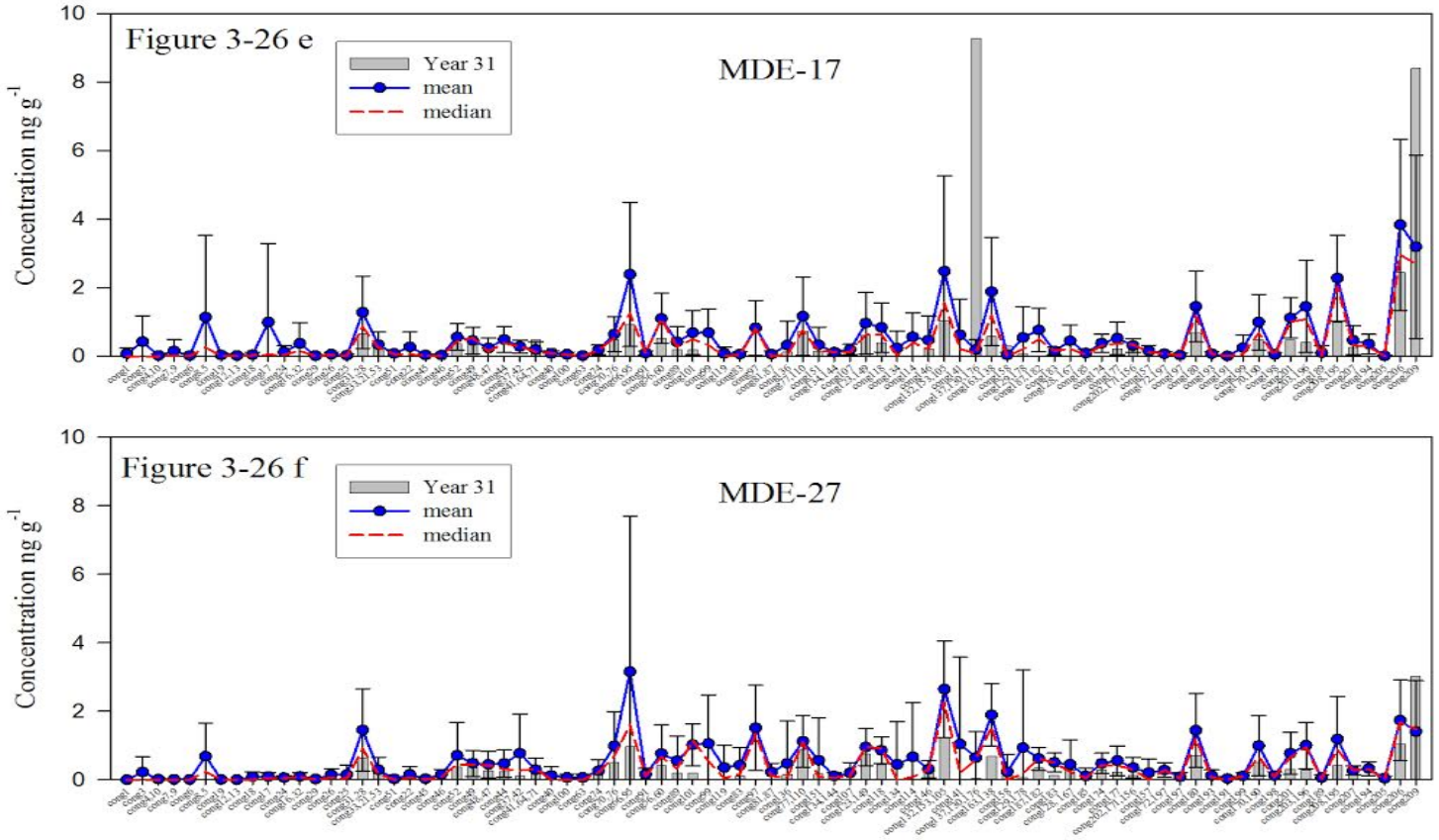


Figure 3-26 continued. Concentrations of PCB congeners in sediments from sites MDE-17 and MDE-27 from the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line) expressed in ng g^{-1} dry weight.

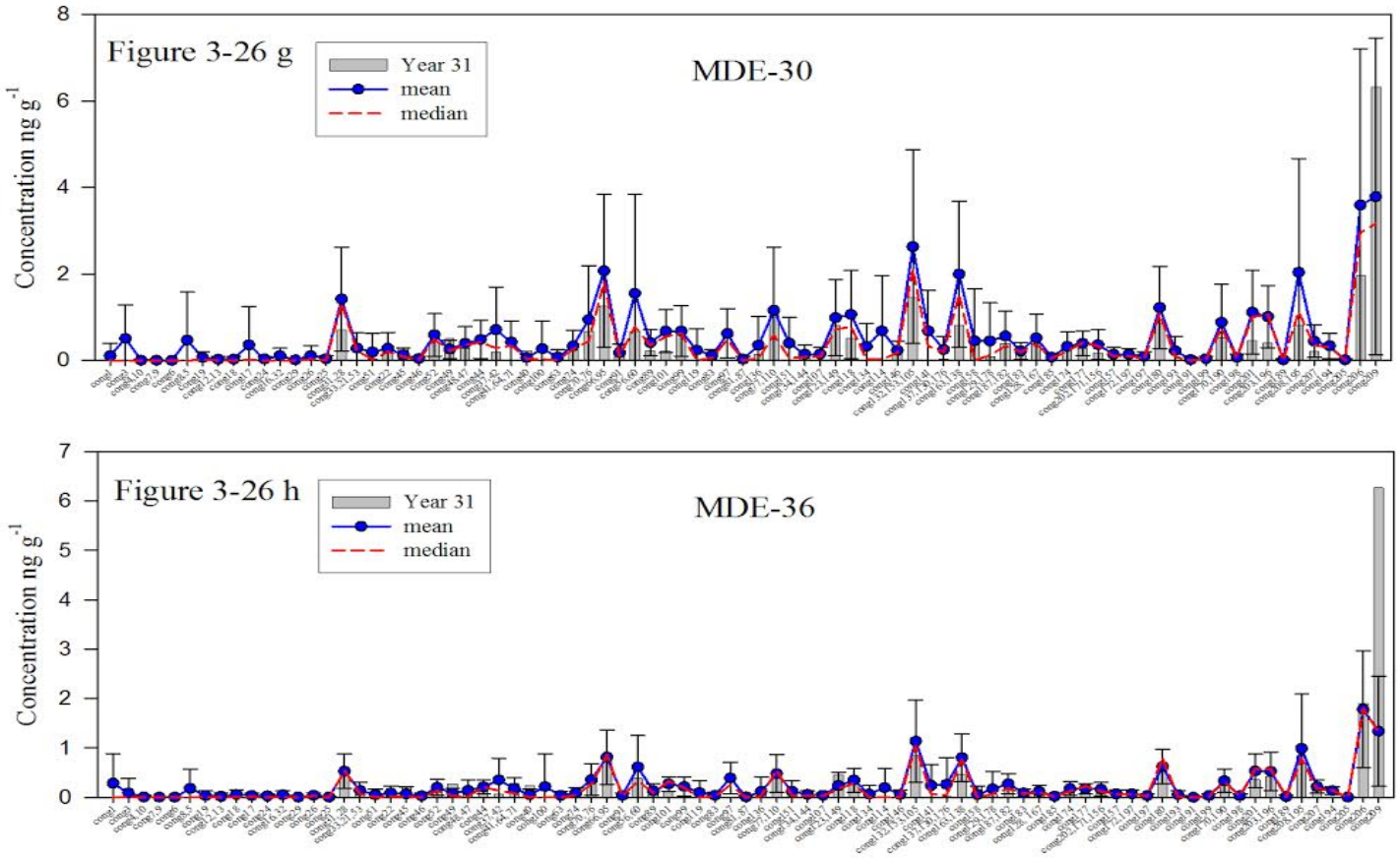


Figure 3-26 continued. Concentrations of PCB congeners in sediments from sites MDE-30 and MDE-36 from the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line) expressed in ng g^{-1} dry weight.

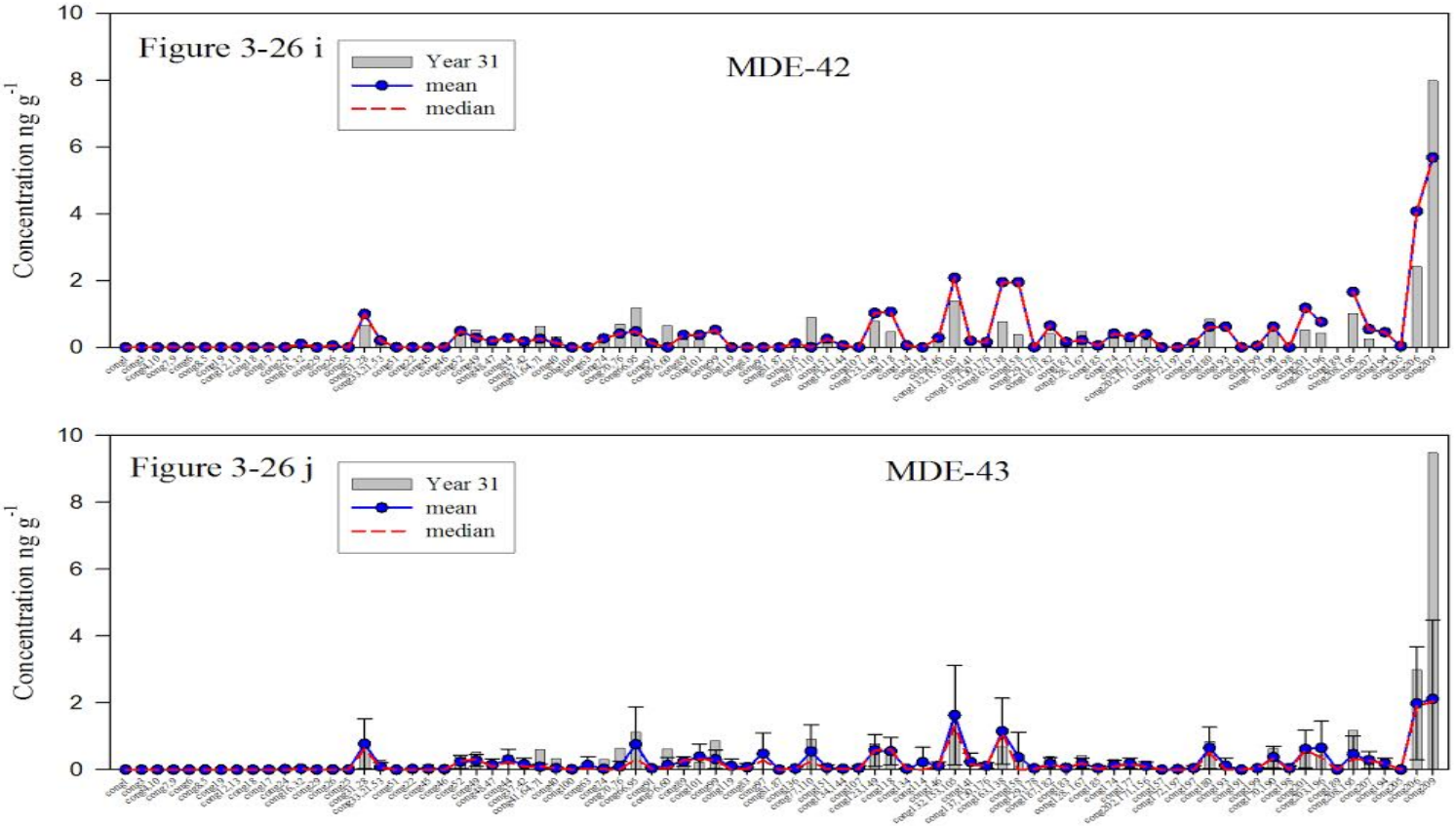


Figure 3-26 continued. Concentrations of PCB congeners in sediments from sites MDE-42 and MDE-43 from the fall of 2012, the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line) expressed in ng g^{-1} dry weight.

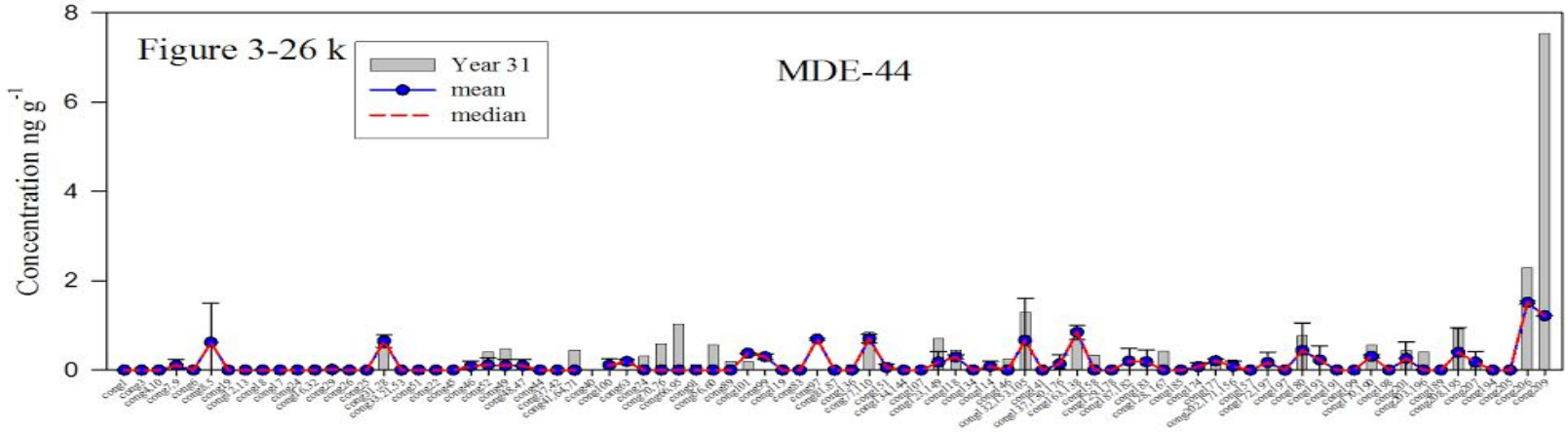


Figure 3-26 continued. Concentrations of PCB congeners in sediments from site MDE-44 collected in the fall of 2012. The 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line) expressed in ng g^{-1} dry weight.

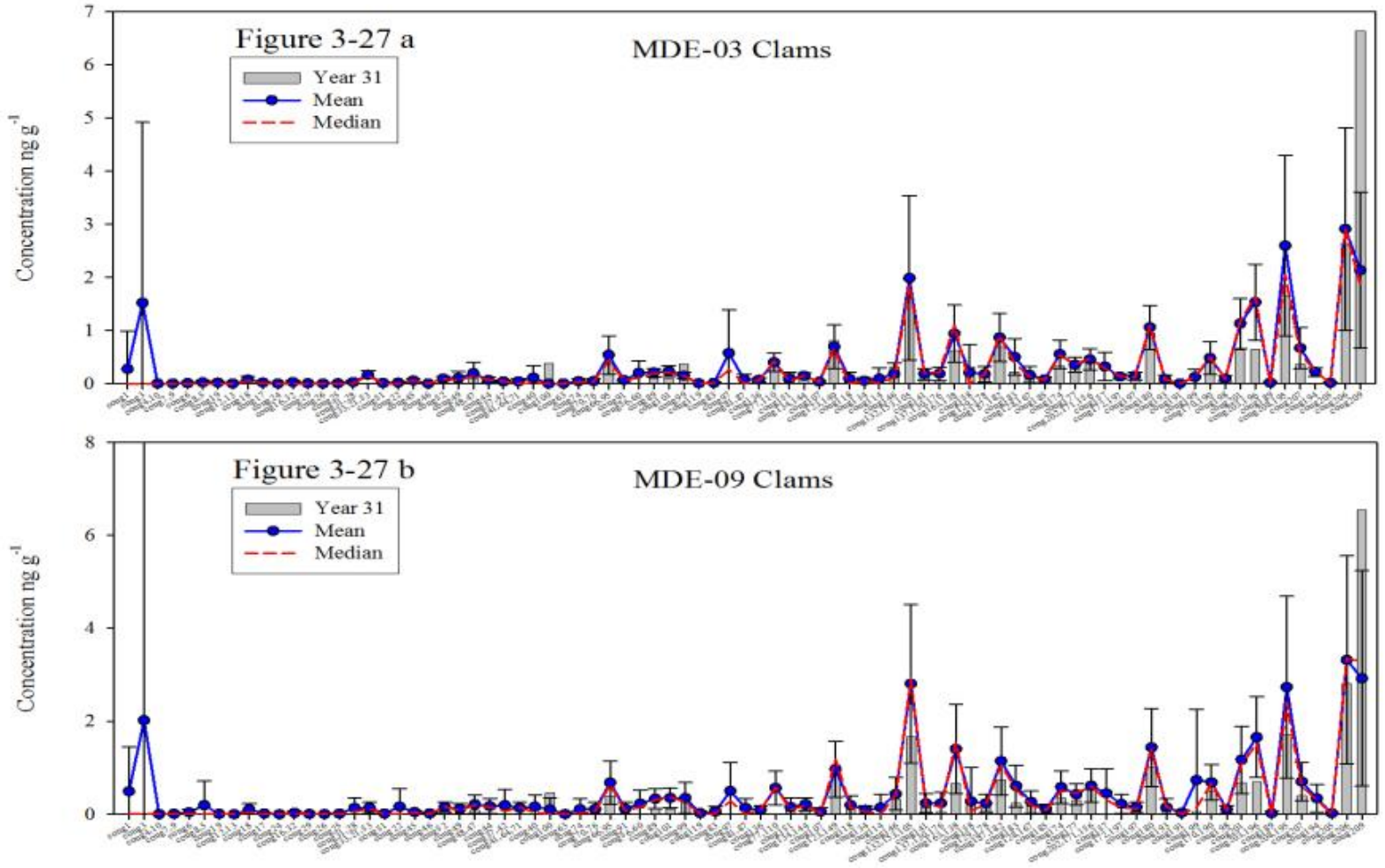


Figure 3- 27: Concentrations of PCB congeners in clams from sites MDE-03 and MDE-09 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line) expressed in ng g-1 wet weight.

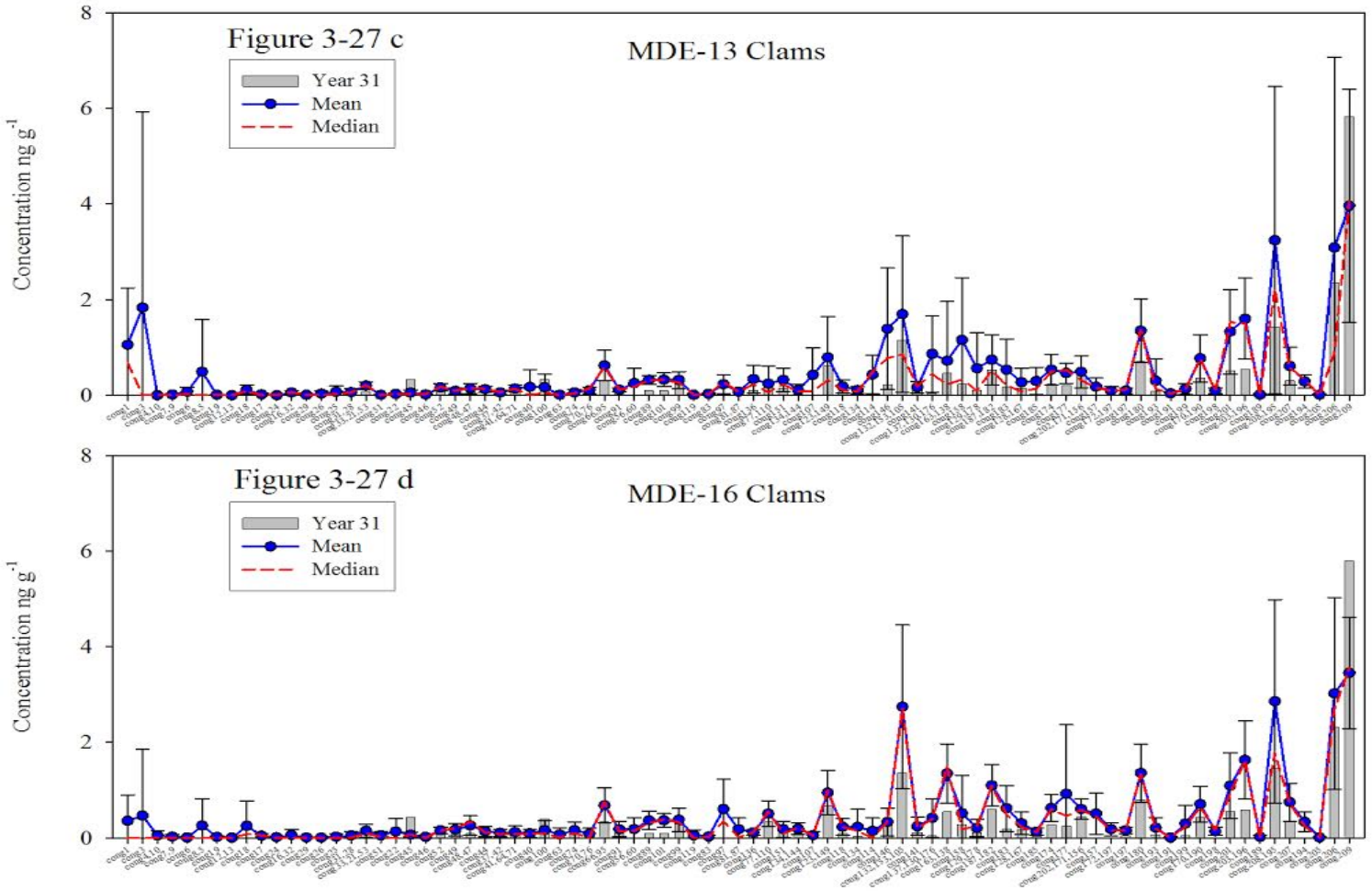


Figure 3-27 continued. Concentrations of PCB congeners in clams from sites MDE-13 and MDE-16 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line) expressed in ng g^{-1} wet weight.

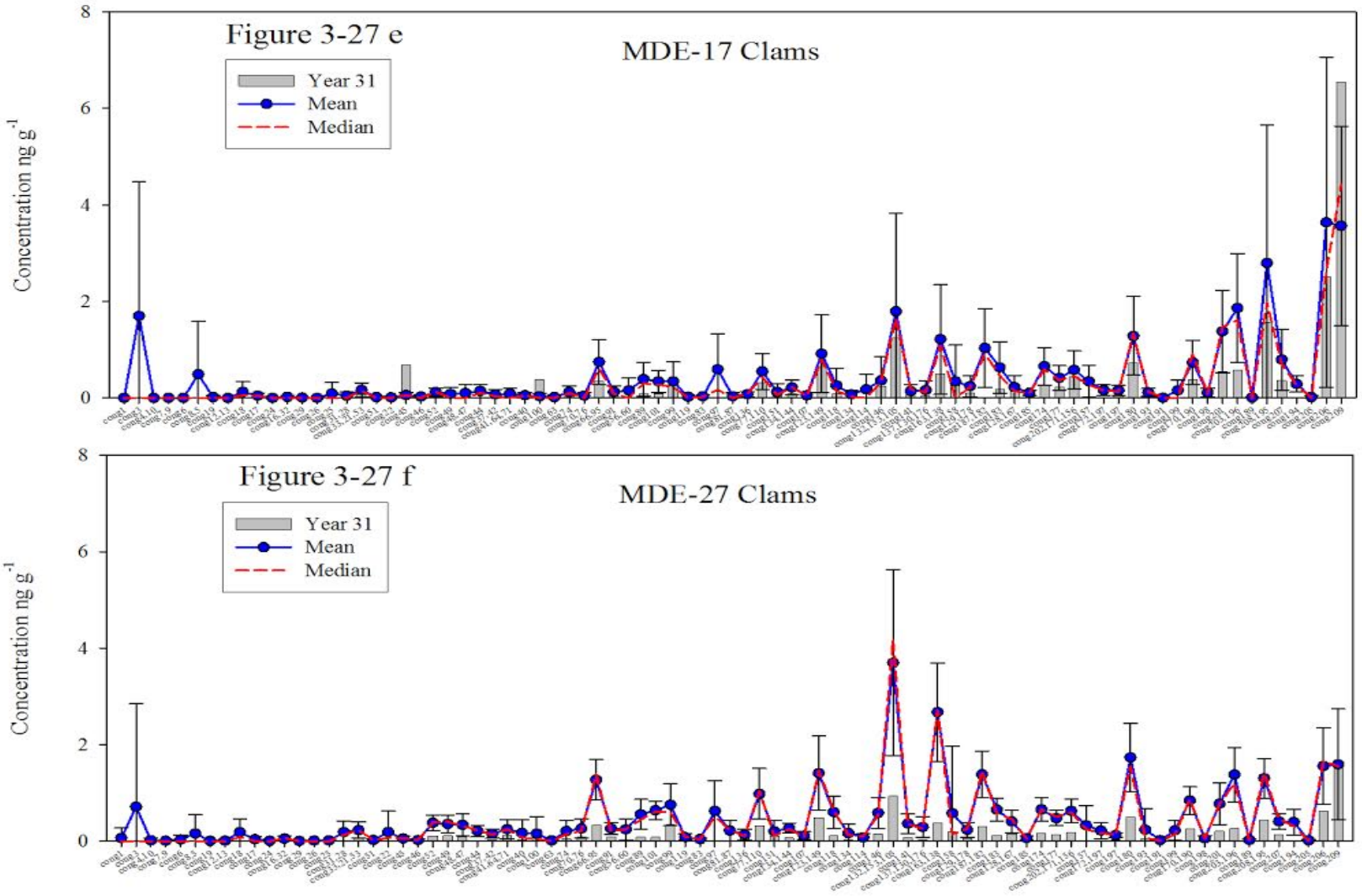


Figure 3-27 continued. Concentrations of PCB congeners in clams from sites MDE-17 and MDE-27 obtained in the fall of 2012(bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line) expressed in ng g^{-1} wet weight.

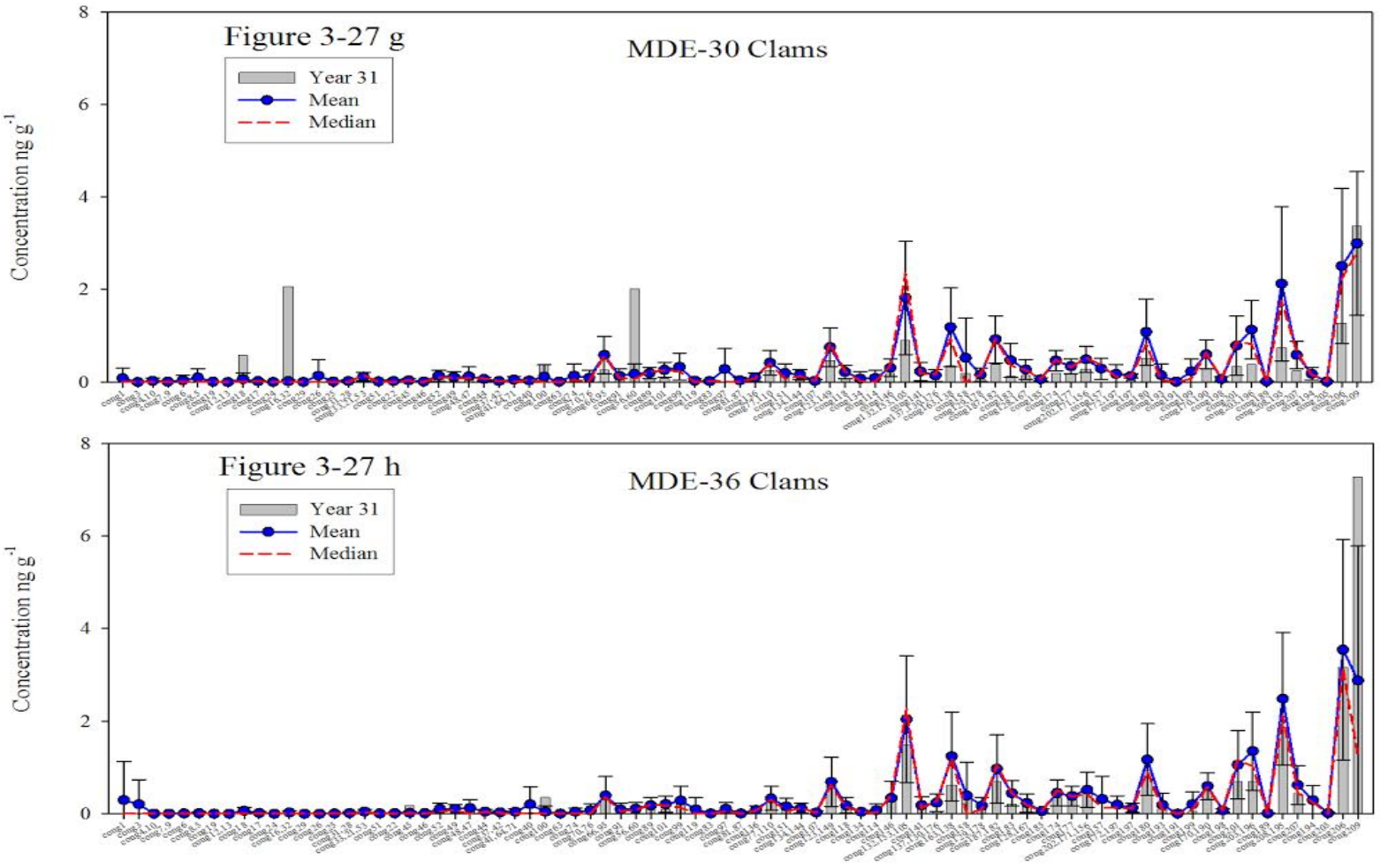


Figure 3-27 continued. Concentrations of PCB congeners in clams from sites MDE-30 and MDE-36 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line) expressed in ng g^{-1} wet weight.

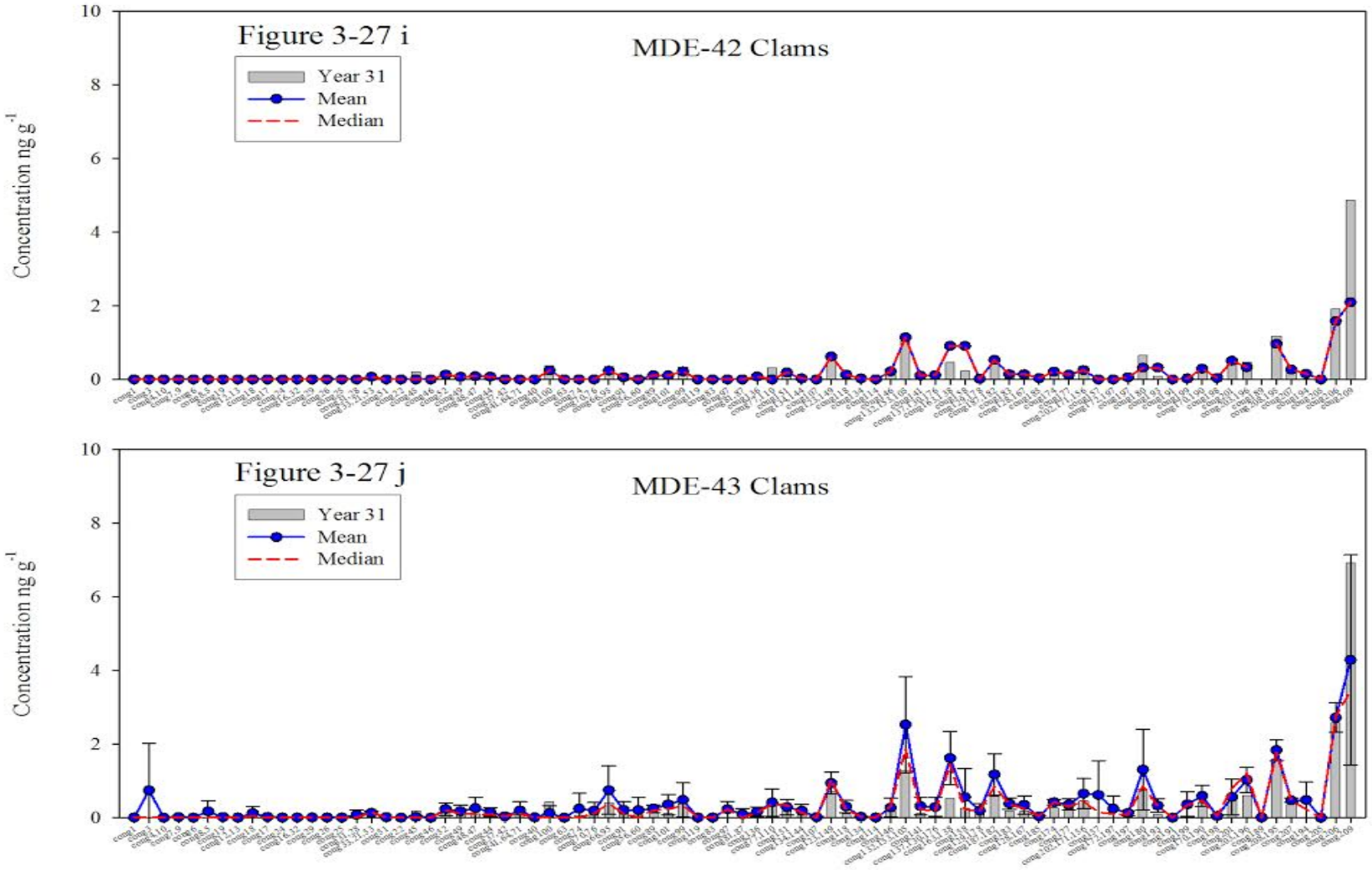


Figure 3-27 continued. Concentrations of PCB congeners in clams from sites MDE-42 and MDE-43 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line) expressed in ng g^{-1} wet weight.

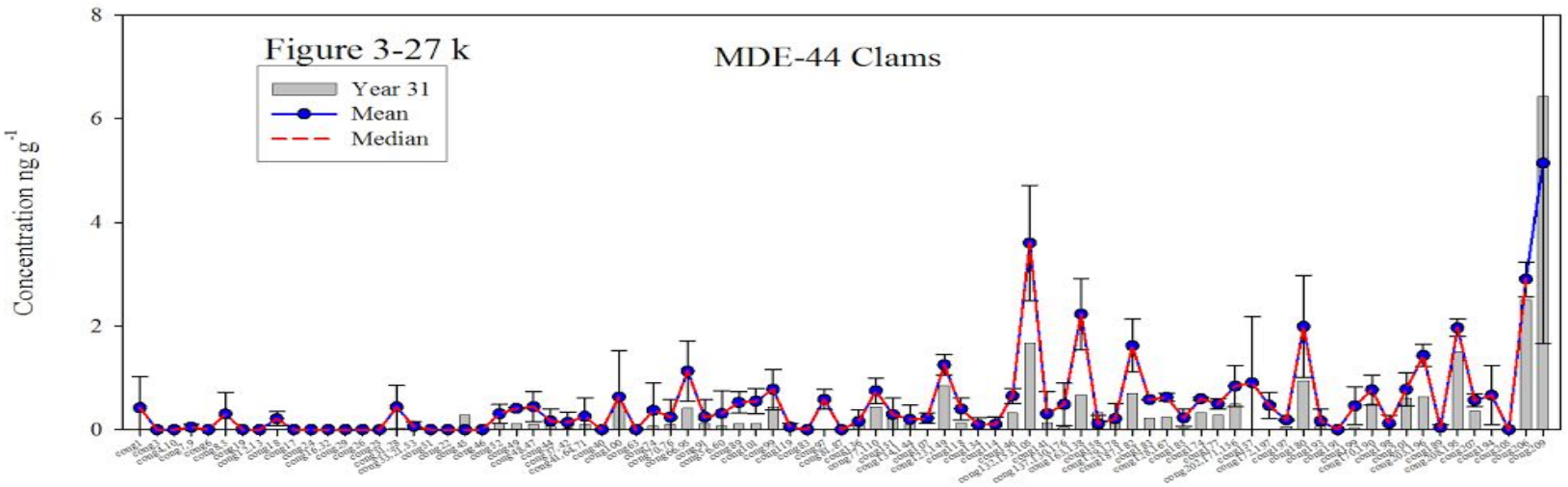


Figure 3-27 continued. Concentrations of PCB congeners in clams from site MDE-44 obtained in the fall of 2012 expressed in ng g^{-1} wet weight (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line) expressed in ng g^{-1} wet weight.

PCB congener profiles in Clams

The PCBs congeners determined in the clams collected in September of 2012 are listed in Table 3-3. As was the case for sediments, for continuity of examining change over time, only the PCBs listed in table 3-4 are plotted in figure 3-26a-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 some congener and congener groups. In 2012 these include 123 + 149, 132+153+105, 163+138, 180, 208+195, 206 and 209; and while some sites have other congener and congener groups present in significant amounts, these congener groups largely define the pattern across the sites. In addition, stations MDE-3 and MDE-17 have elevated concentrations of congener 201, MDE-17 and MDE-44 have elevated concentrations of congener 45 and 100 and MDE-30 has an elevated concentration of congener 18. The major components of the congener patterns observed in clams are similar to those seen in the sediments.

Total PCB concentrations in sediments and clams

The total concentration of PCBs in sediments and clams at each site were calculated by summing the individual PCB congener concentrations and these totals were compared to previous years for the same stations (Figure 3-28). The total PCB concentrations in sediment collected in September 2012 were generally similar to or below the historical site averages, being within the standard deviation of the mean. Site MDE-44 had a concentration outside the standard deviation and station MDE 42 has only 2 observations so no standard deviation could be calculated. Total PCB concentrations in clams were also similar to or below the running mean for all sites.

Many older studies have relied on grouping PCBs of similar structure into classes or homologs. The homolog distributions for sediment and clams for each site are plotted as percentage of the total PCB concentration in Figure 3-29, 3-30. Date from station MDE-36 is plotted along with each station to act as a guide. The assumption being that MDE-36 represents the bay as a whole.

The homolog distribution at MDE-9, 27, 30, 43 and 44, follow the same pattern as MDE-36, even if concentrations of homolog groups are slightly higher or lower. At sites MDE-3, 13, 16, 17 and 42 some deviations in the patterns occur. In the case of MDE-3 and 13, this change is largely driven by elevated concentrations of Deca and Tetra PCB congener homologs, respectively. In the case of MDE 16 and 17, elevated concentrations in the Penta through Hepta homologs create a different pattern. Station MDE-42 is also elevated in the Nona group. While MDE-16, 17 and 42 lie relatively close together off the south side of the island, so do sites MDE 43 and MDE 44 which do not deviate from the pattern observed at MDE-36.

The distribution of homologs measured in clams at all sites track the control site (MDE-36) very well (Figure 3-30), as the pattern of homologs in clams are largely the same. Even the concentrations of PCB homolog classes are very similar to the control site with only for site MDE-27 being substantially lower in concentration.

To compare sediments with clams, PCB homologs concentrations Figure 3-31 and percentages 3-32 for each site were overlaid. The sediment and clams are very similar with perhaps a little bias to the lower molecular weight complexes in the sediment. This same relationship was observed in 2011. The spikes in the tetrachlor homologs seen in the sediment of some sites are not reflected in the clams.

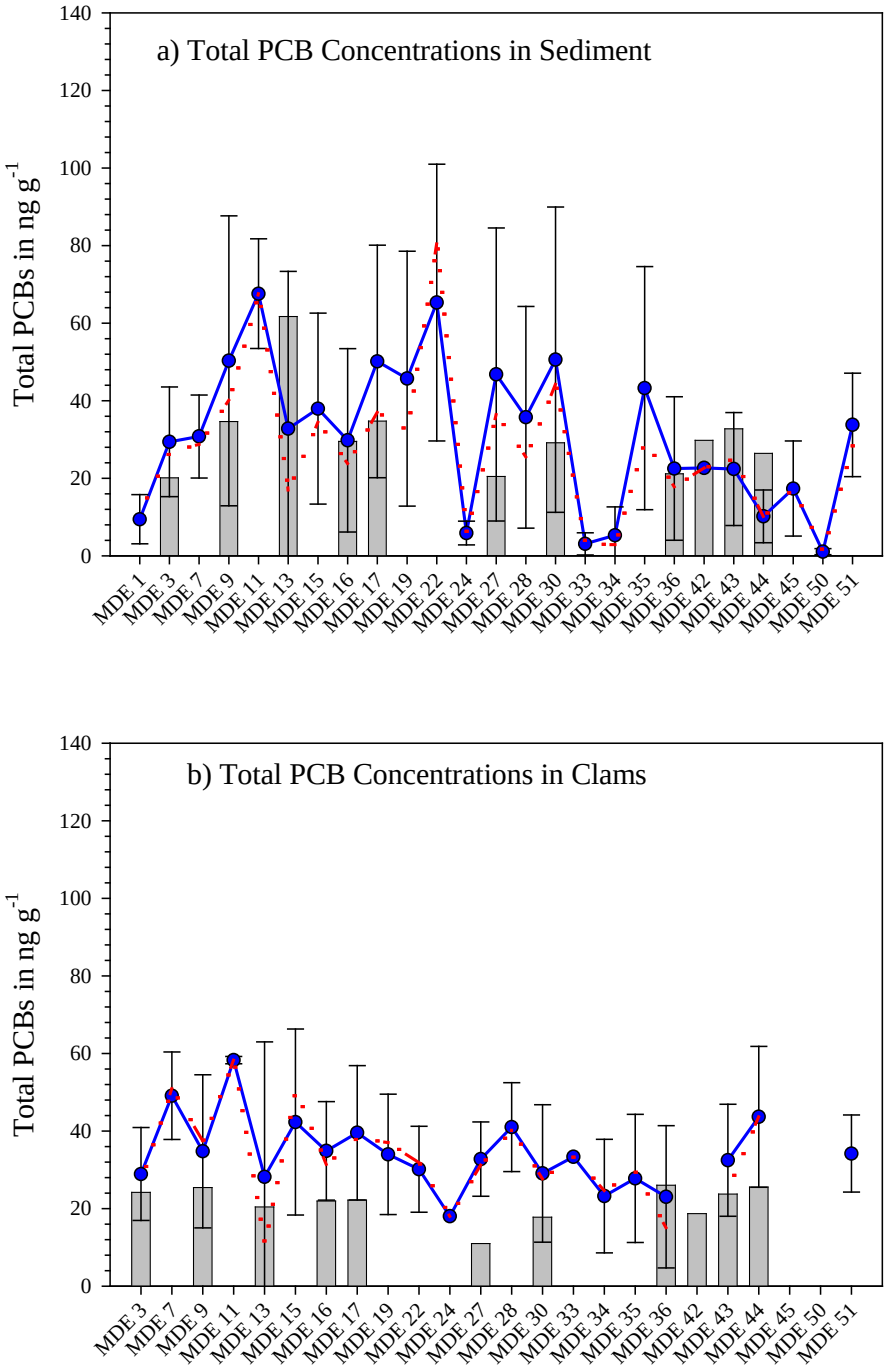


Figure 3- 28: Total PCB concentrations in sediments (a) (ng g^{-1} dry weight) and total PCB concentrations in clams (ng g^{-1} wet weight) collected in September 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line).

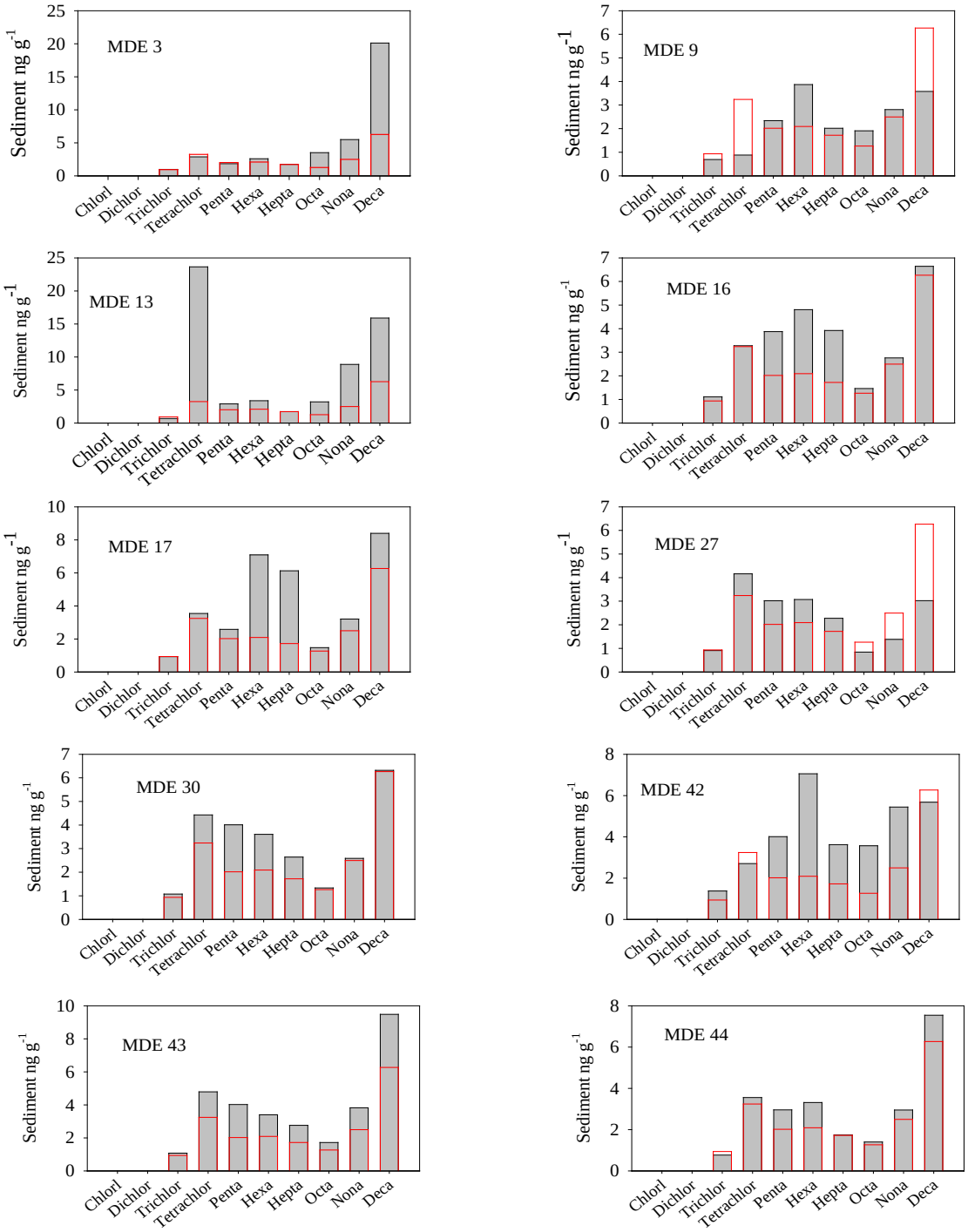


Figure 3- 29: PCB homolog distributions in sediment. The reference site MDE-36 is plotted in red on all plots as guide.

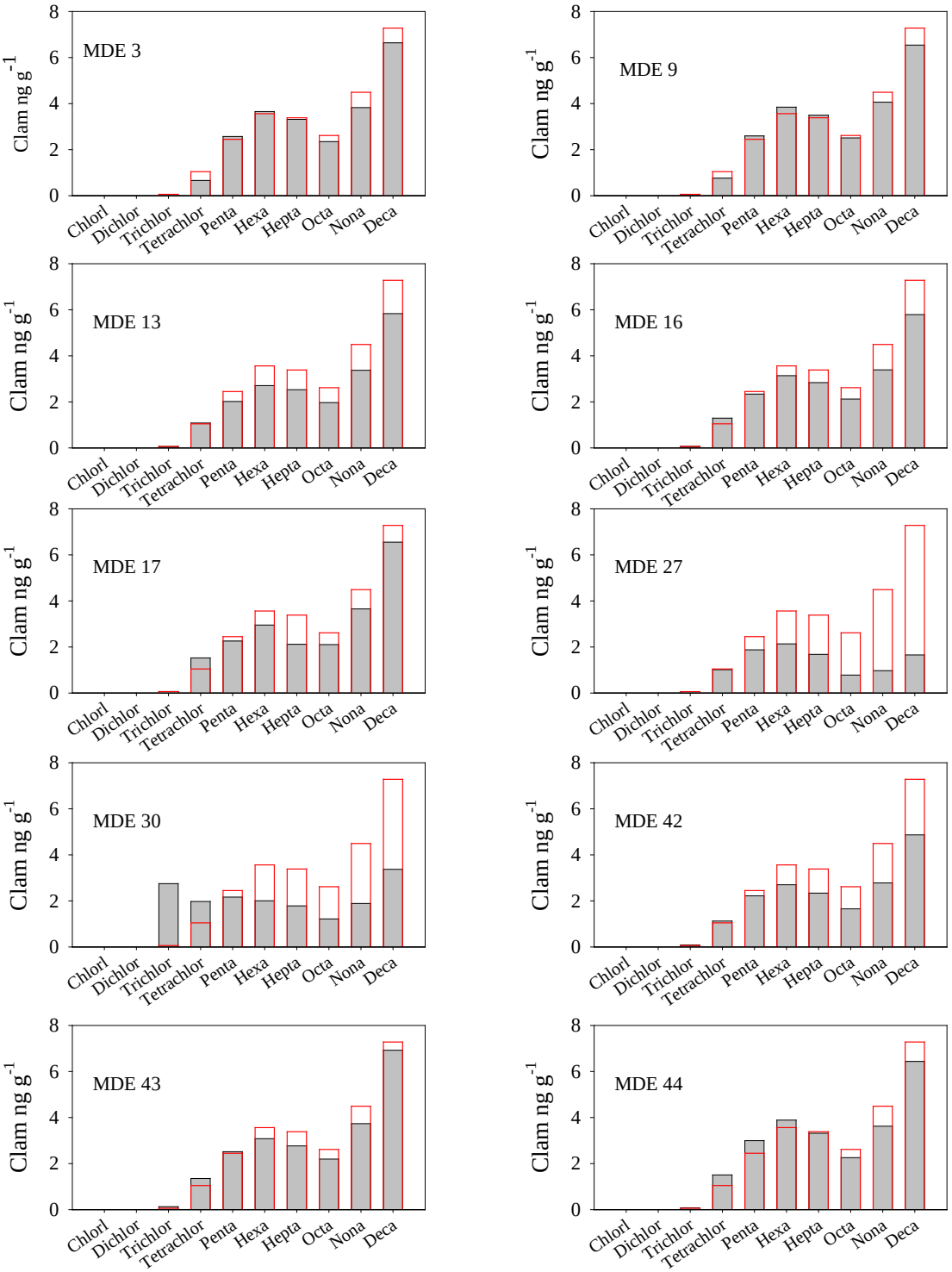


Figure 3-30 PCB homolog distributions in clams (ng g^{-1}) wet weight. The reference site MDE-36 is plotted in red on all plots as guide.

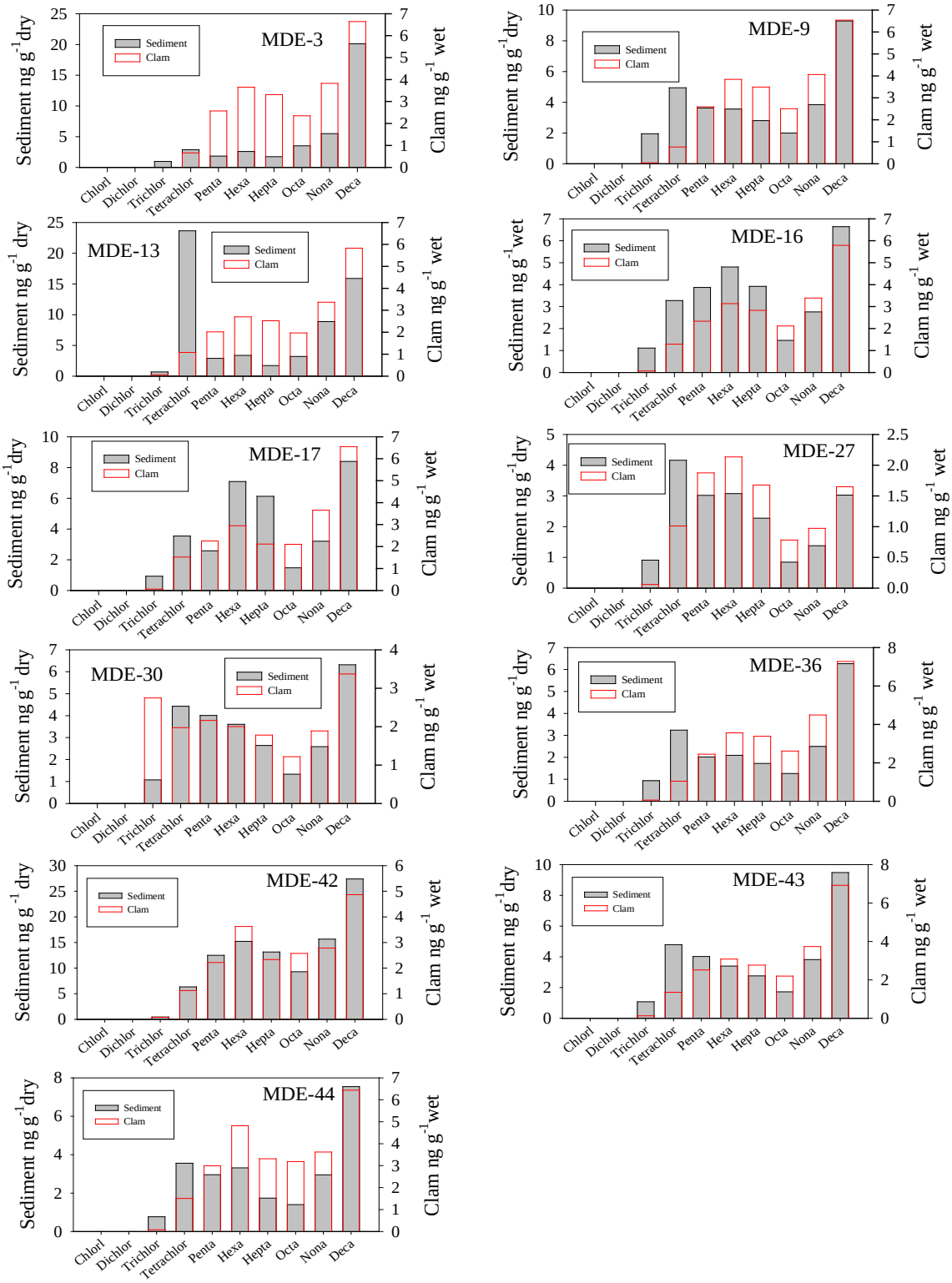


Figure 3- 31 PCB homolog distributions in sediment and clams of each HMI site.

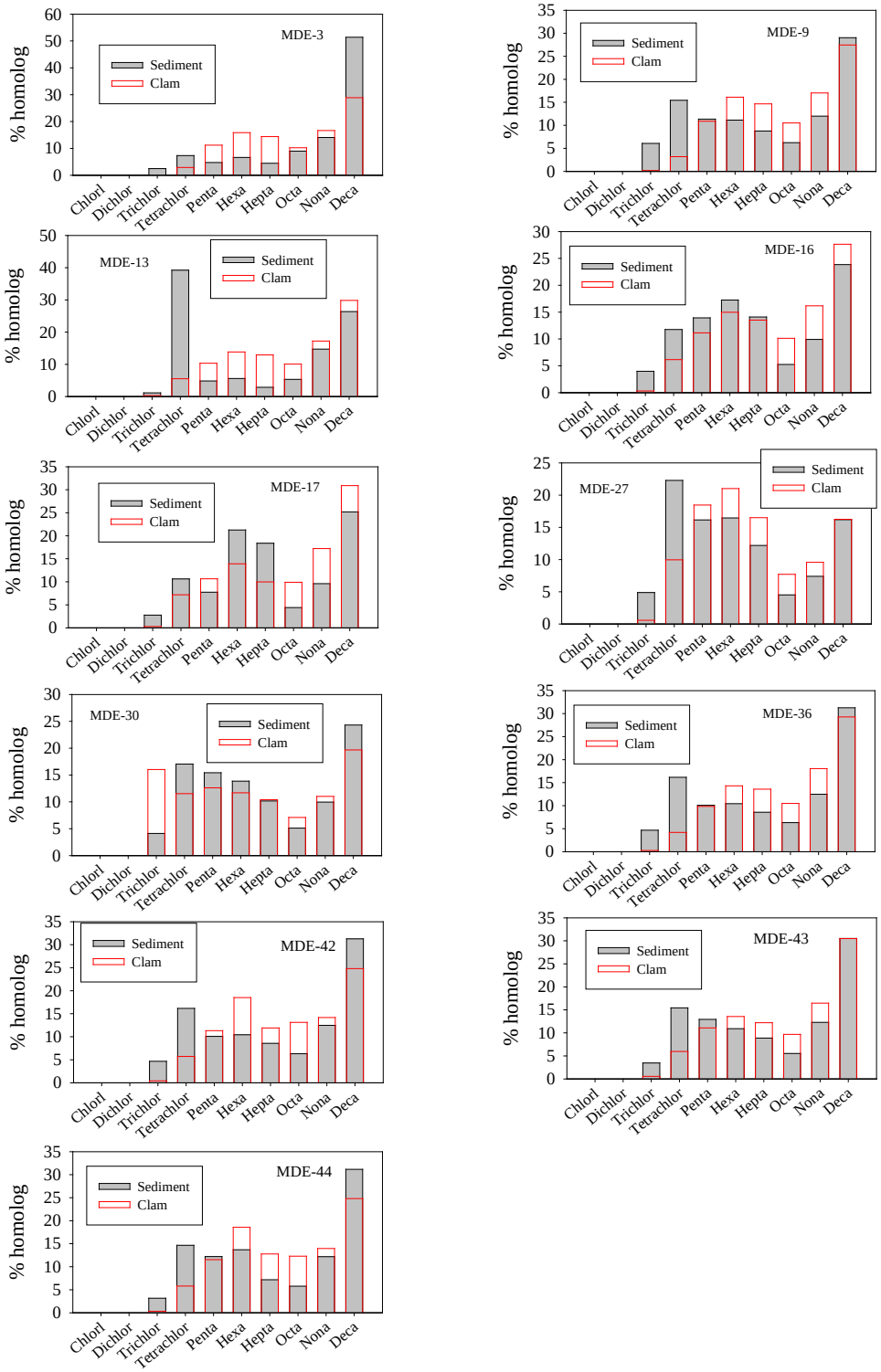


Figure 3- 32 PCB homolog distribution in sediment and clams as a % of total.

PCB Concentrations from 1998-2012

To assess if sediment PCB concentrations in sediment have changed since the onset of the project, sites were selected having the longest continuous record. The total-PCB concentrations from those sites are shown in Figure 3-33. From these records it appears that PCB concentrations in sediments have decreased since the first few years of the project. Prior to 2002, concentrations nearly 2-3 times that of today were regularly observed. Since that time concentrations have fluctuated around a more consistent site mean. PCB concentrations at site MDE-36 were on the order of 60 ng g-1 in 1998 but are now less than 20 ng g-1. This finding is consistent with PCB concentrations in fish generally decreasing in the Chesapeake Bay (http://www.mde.state.md.us/programs/PressRoom/Pages/041311.aspx).

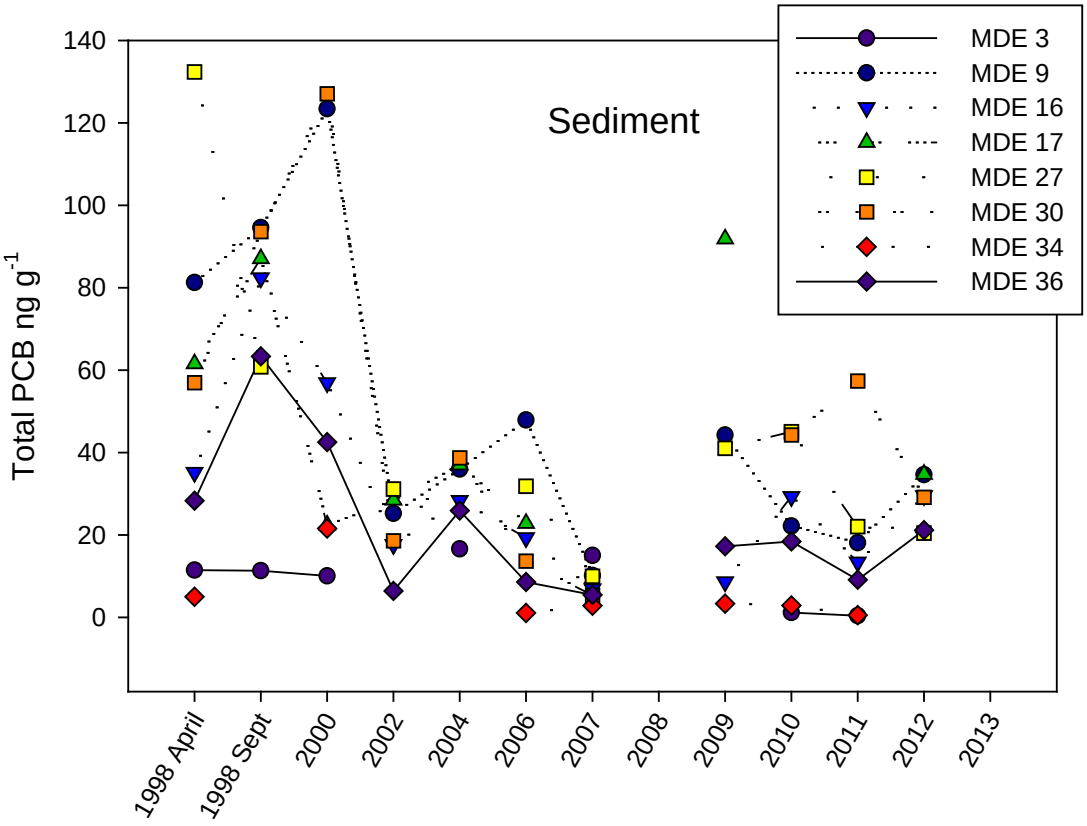


Figure 3 -33 Total PCB concentrations at sites MDE-3, MDE-9, MDE-16, MDE-17, MDE-27, MDE-30, MDE-34 and MDE-36 in ng g-1 dry weight.

Polycyclic Aromatic Hydrocarbons in Sediments

The concentrations of a series of polycyclic aromatic hydrocarbons (PAHs) (Table 3-5) from sites in the vicinity of HMI are shown in Figure 3-34a-k. As described for PCBs, when examined as a group the PAHs provide a fingerprint with which to look for differences among stations and if any trends among locations are apparent in time and space. The most common compounds found were: naphthalene, 2-methylnaphthalene, phenanthrene, fluoranthene, pyrene, benzo[b]fluoranthene, perylene and indeno(1,2,3-cd)pyrene. The relative proportions of these compounds together form the pattern that is found at almost all the HMI stations sampled in 2012. 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. The only significant change from the pattern observed in 2011 was an increase in the concentration of indeno(1,2,3-cd)perylene, at some sites. The increase was such that indeno(1,2,3-cd)perylene became a major contributor the total load of PAHs at some sites. As can be seen by the deviation from the mean and median in figure 3-34 , the concentrations of PAHs at sites MDE-43 and MDE-44 were higher than has been observed in past samplings. Sediment at stations MDE-42 and MDE-44 had higher concentrations of the low molecular weight PAHs (naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, Biphenyl, 2,6 Dimethylnaphthalene, 1-3 Dimethylnaphthalene) which resulted in the pattern for these sites being slightly different in appearance.

Table 3- 5: Polycyclic aromatic hydrocarbons given in the same order as in Figure 3-34 a-k (left to right). Note: 1,4 + 1,5 + 2,3-Dimethylnaphthalene was split into 4-Dimethylnaphthalene and 1,5-Dimethylnaphthalene to enable a historical comparison.

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

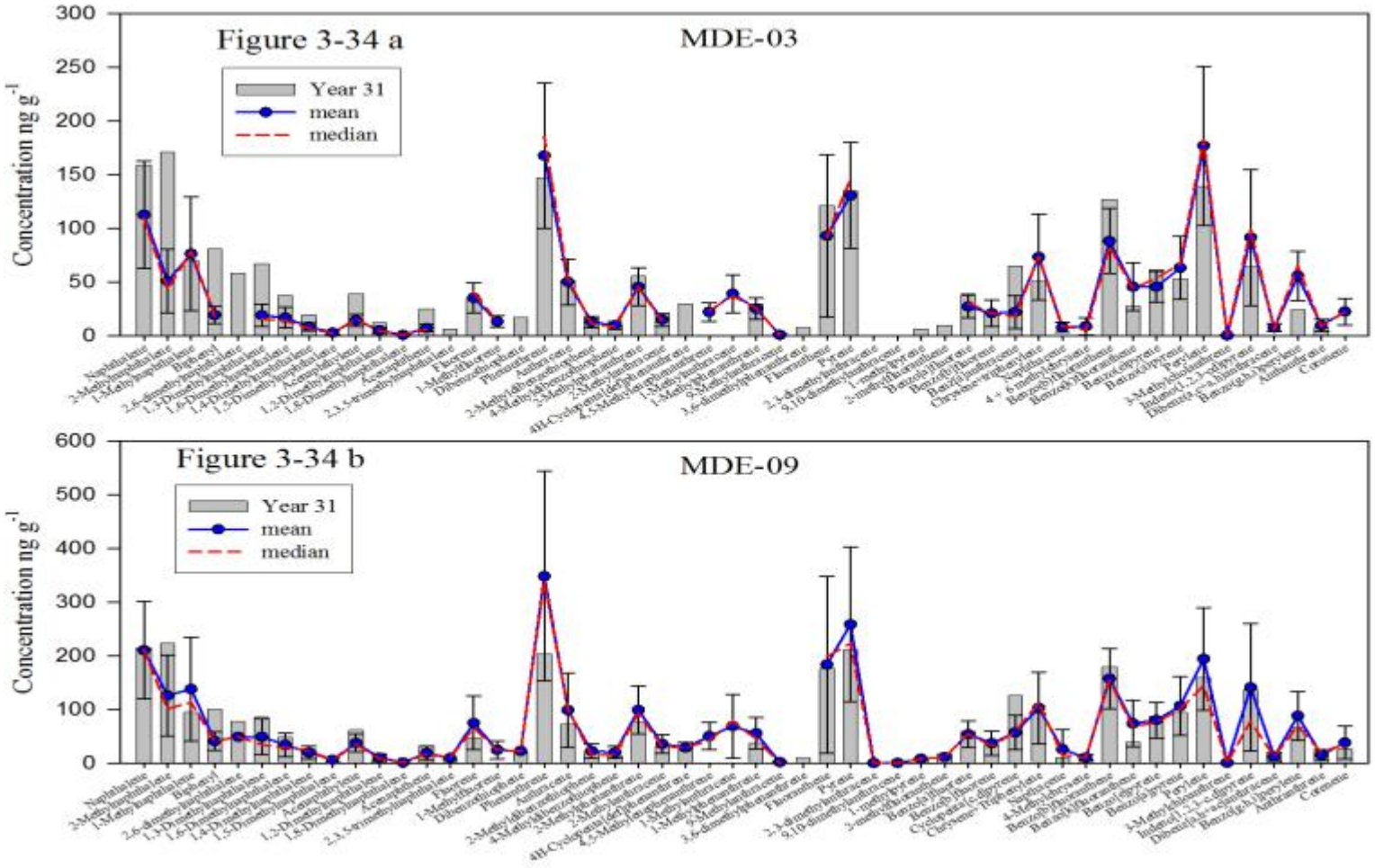


Figure 3- 34: Concentrations of PAHs in sediments from site MDE-03 and MDE-09 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line), expressed in ng g^{-1} dry weight.

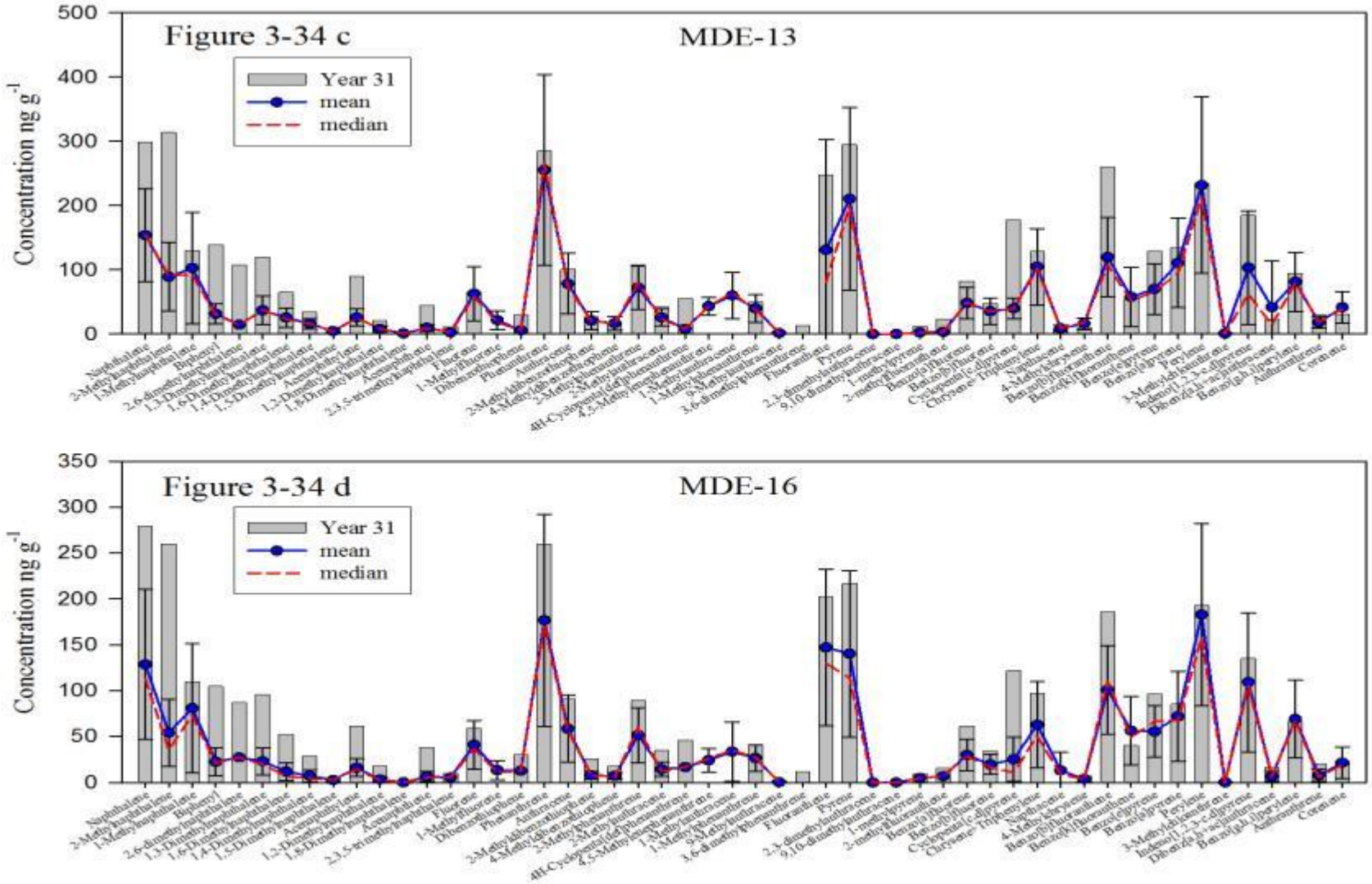


Figure 3-34 continued. Concentrations of PAHs in sediments from site MDE-13 and MDE-16 obtained in the fall of 2011 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line), expressed in ng g^{-1} dry weight.

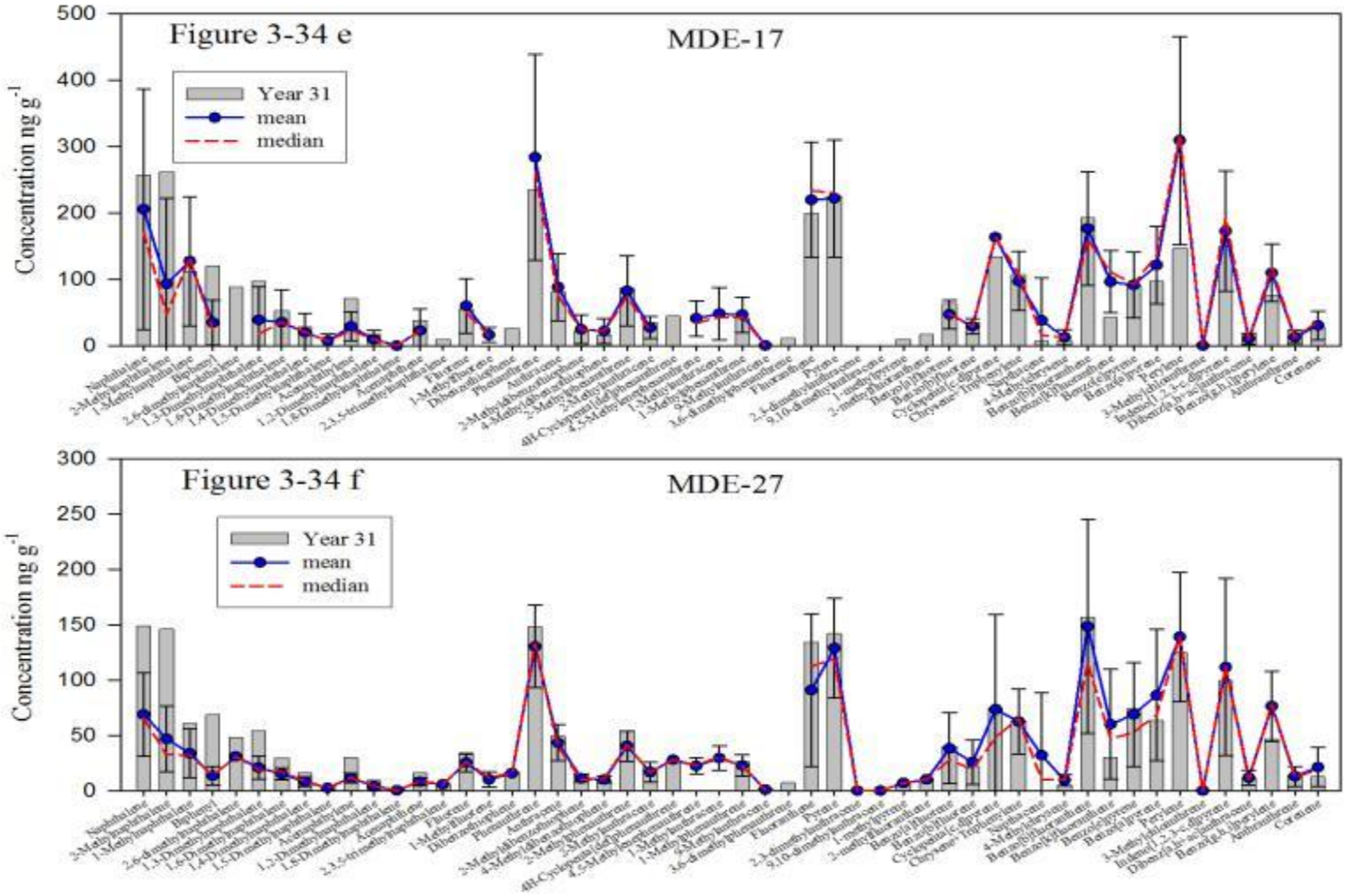


Figure 3-34 continued. Concentrations of PAHs in sediments from site MDE-17 and MDE-27 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line), expressed in ng g^{-1} dry weight.

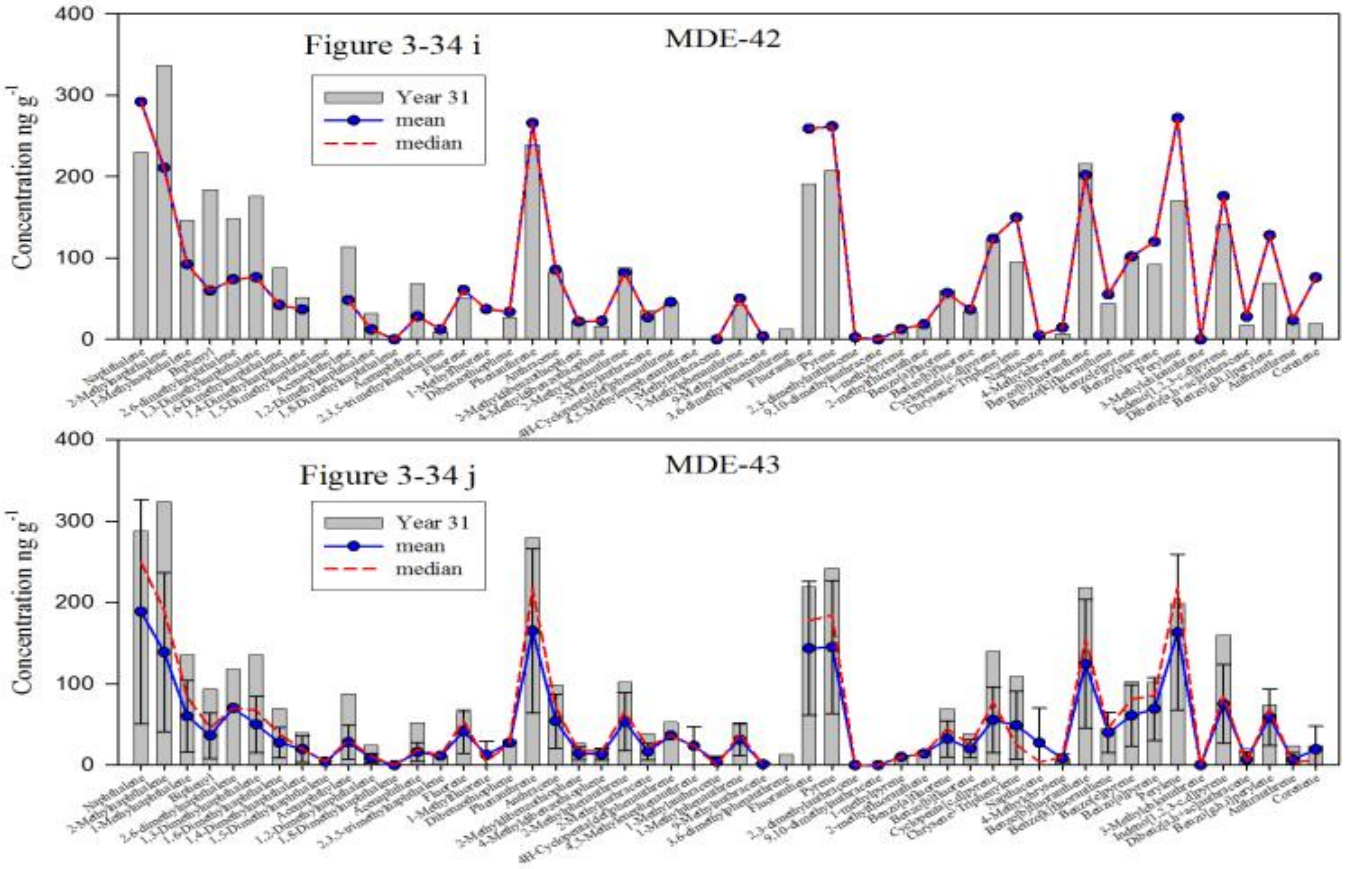


Figure 3-34 continued. Concentrations of PAHs in sediments from site MDE-42 and MDE-43 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line), expressed in ng g^{-1} dry weight.

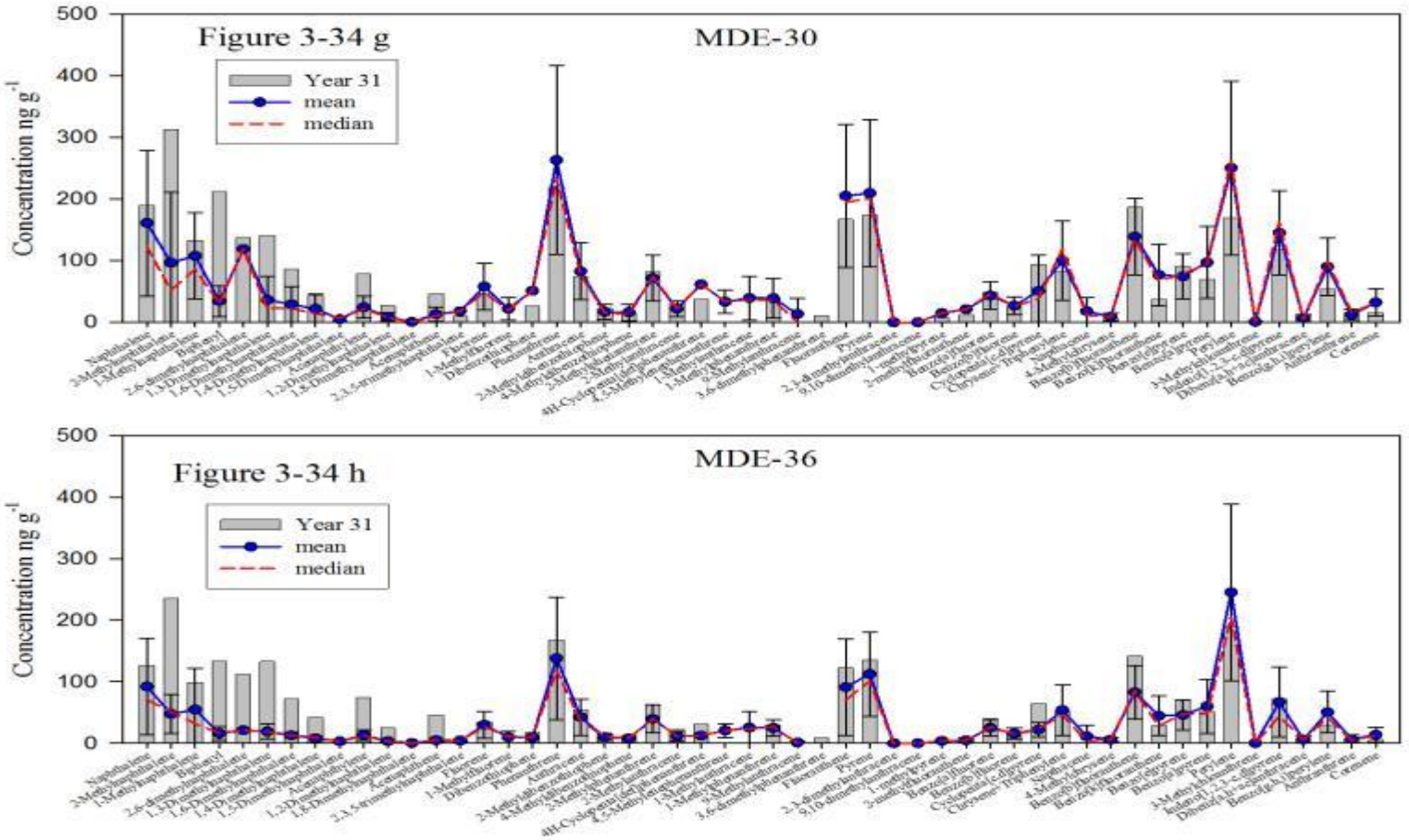


Figure 3-34 continued. Concentrations of PAHs in sediments from site MDE-30 and MDE-36 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line), expressed in ng g^{-1} dry weight.

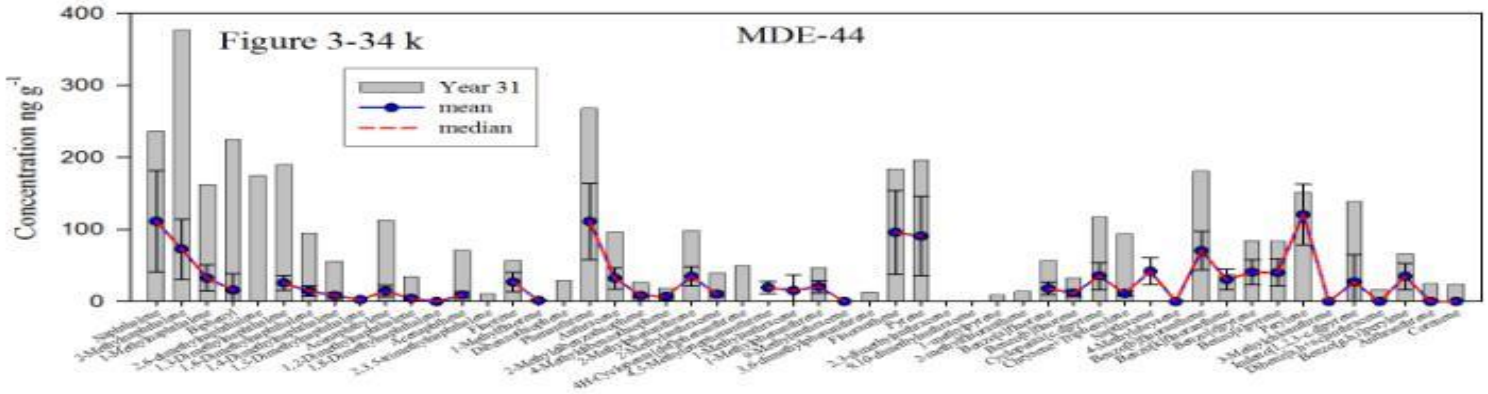


Figure 3-34 continued. Concentrations of PAHs in sediments from site MDE-44 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line), expressed in ng g^{-1} dry weight.

Polycyclic Aromatic Hydrocarbons in Clams

The concentrations of PAHs found in clams collected in the vicinity of HMI are shown in Figure 3-35 a-k and order listed in Table 3-6. The compounds most common in sediments are also found in the clams, and are Naphthalene, 2-methylnaphthalene, phenanthrene, fluoranthene, pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, benzo[e]pyrene and perylene. Concentrations of some PAH compounds were much higher in concentration than in past years. These are biphenyl, 2-6 dimethylnaphthalene, 1-methylfluorene and perylene. Most of these compounds are combustion products of coal, wood and oil. As in the case of the sediment, together the relative proportions of the PAHs in clams form the same distinct pattern at all the study sites. One exception is Station MDE-13 where a large concentration of anthanthrene was found.

Clam and sediment PAH signatures from the same site are similar but sediments concentrations are orders of magnitude higher in all the measured compounds and more compounds are detectable. This effectively creates a different fingerprint. The ability of organisms to accumulate and modify PAHs is not well studied. While selective accumulation or metabolism of PAHs by clams could be partially responsible for the difference, the elevated concentrations of a few compounds in the clams stand out. It is not clear why these compounds are present at high concentrations in 2012 and not in other years. Biphenyl is a simple compound that could be formed by dealkylation of other compounds. Biphenyl can in turn be readily broken down by bacteria so timing of collection relative to exposure influences concentrations.

Table 3- 6: Polycyclic aromatic hydrocarbons given in the same order as in Figure 3-35 a-k (left to right). Note: 1,4 + 1,5 + 2,3-Dimethylnaphthalene was split into 4-Dimethylnaphthalene and 1,5-Dimethylnaphthalene to enable a historical comparison

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

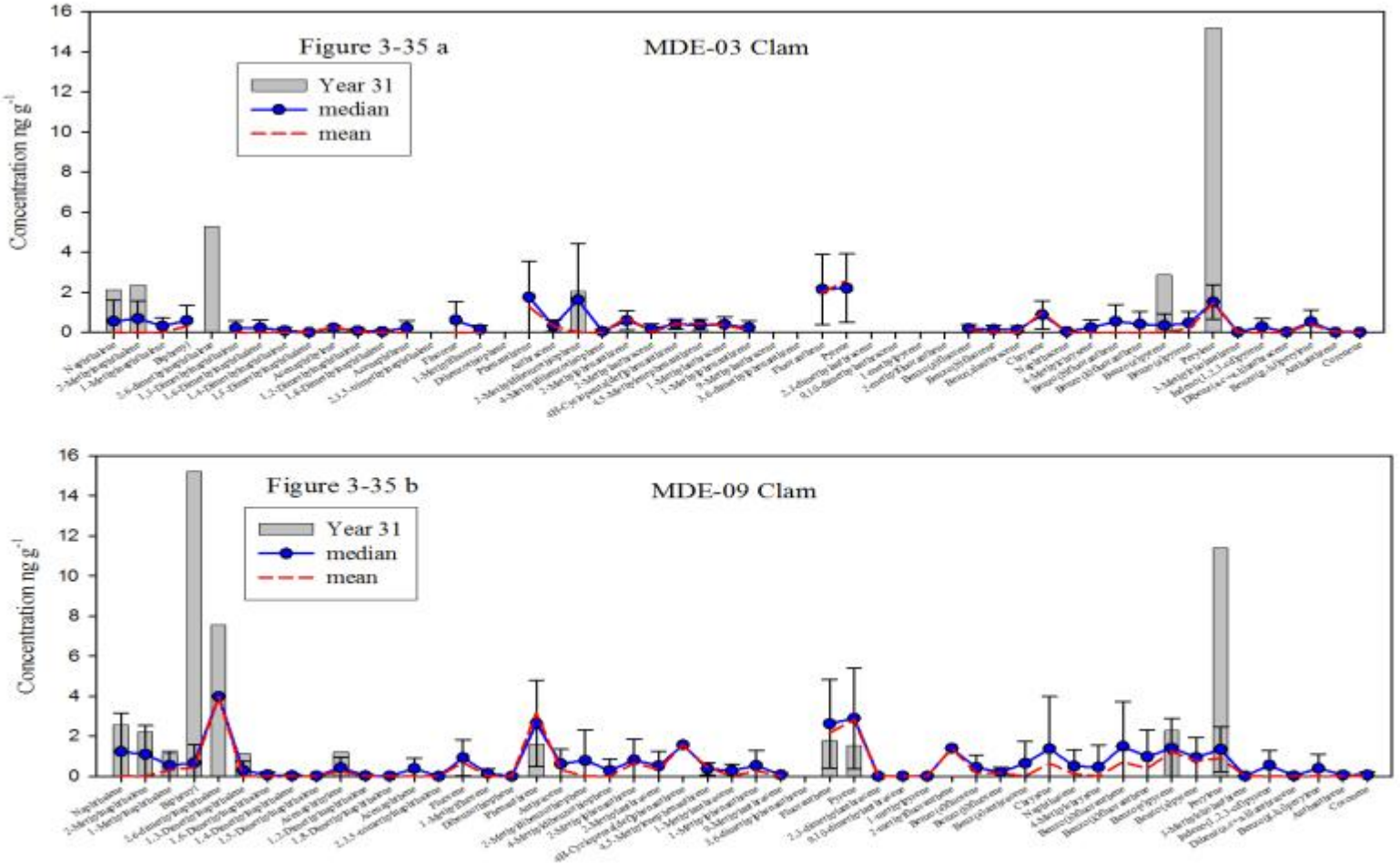


Figure 3- 35: Concentrations of PAHs in clams from site MDE-03 and MDE-09 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line), expressed in ng g^{-1} wet weight.

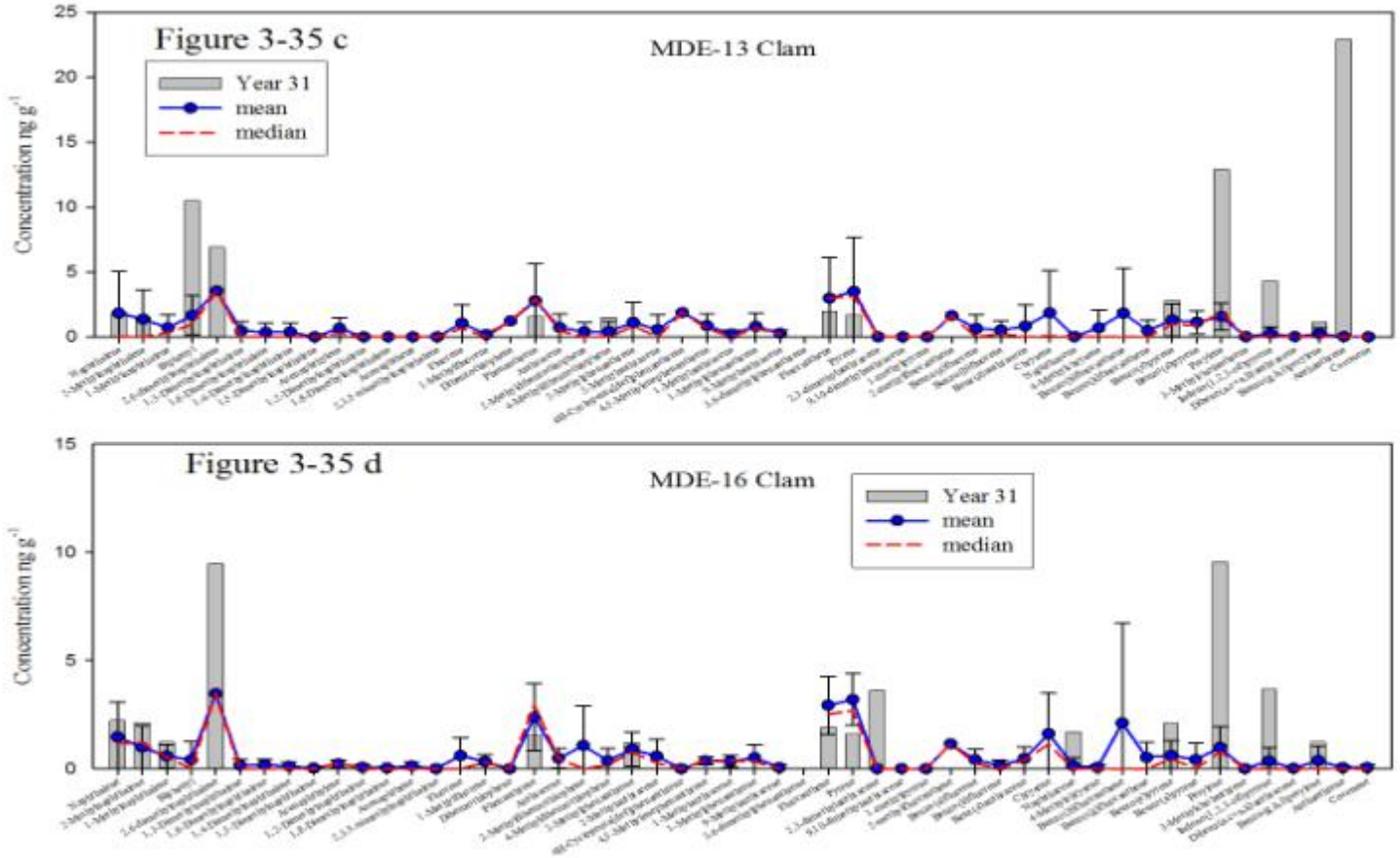


Figure 3-35 continued. Concentrations of PAHs in clams from site MDE-13 and MDE-16 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line), expressed in ng g^{-1} wet weight.

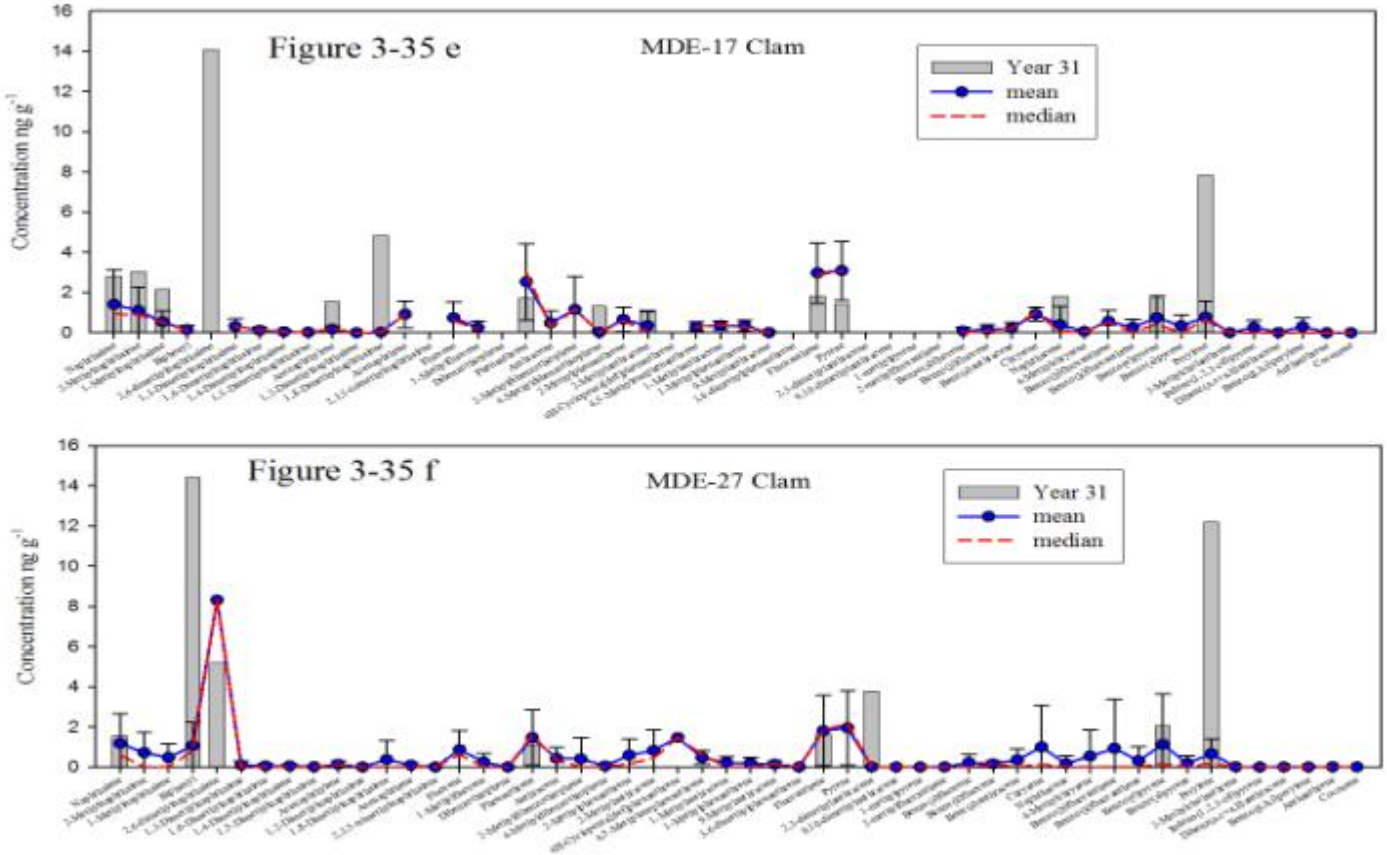


Figure 3-35 continued. Concentrations of PAHs in clams from site MDE-17 and MDE-27 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line), expressed in ng g^{-1} wet weight.

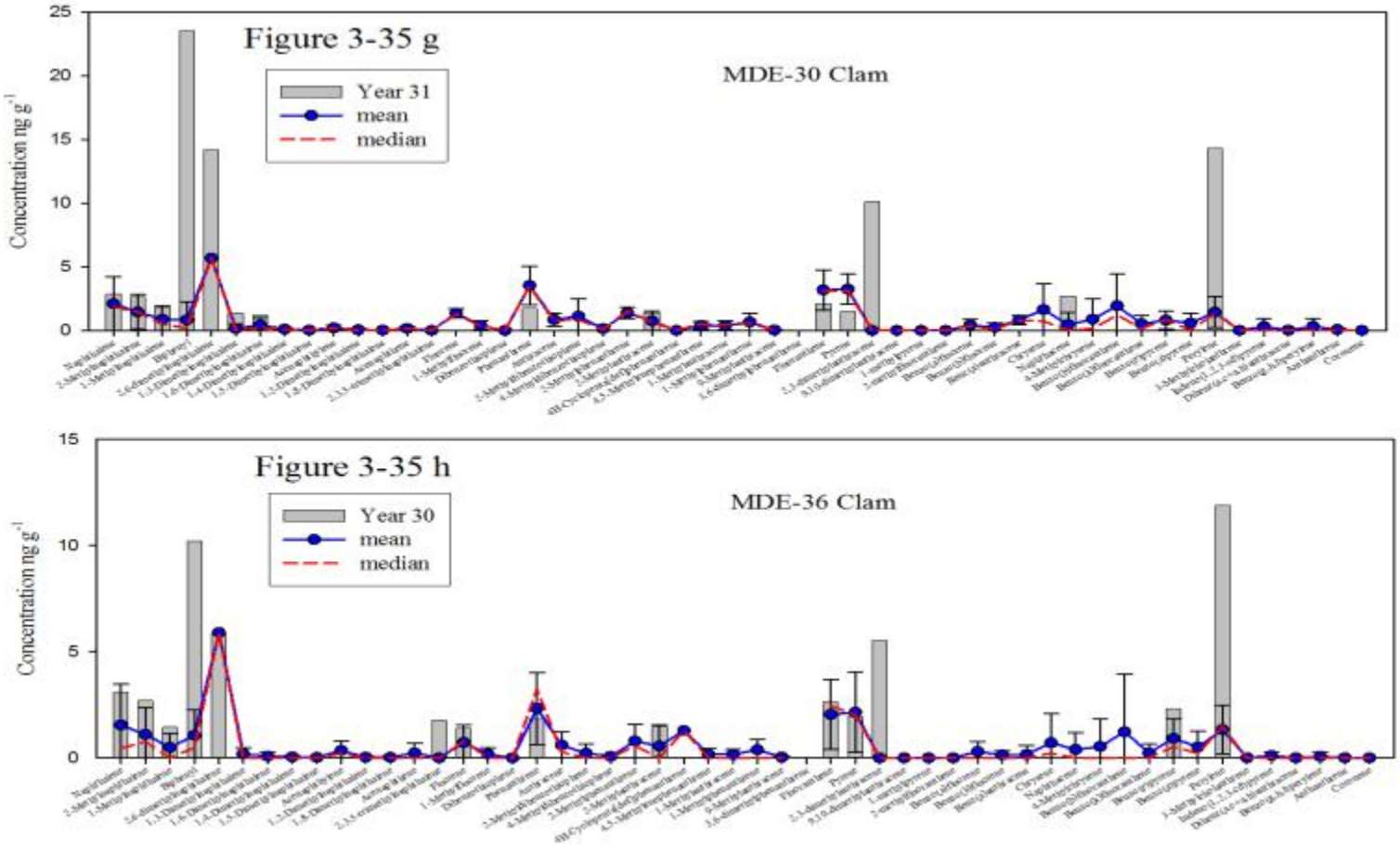


Figure 3-35 continued. Concentrations of PAHs in clams from site MDE-30 and MDE-36 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line), expressed in ng g^{-1} wet weight.

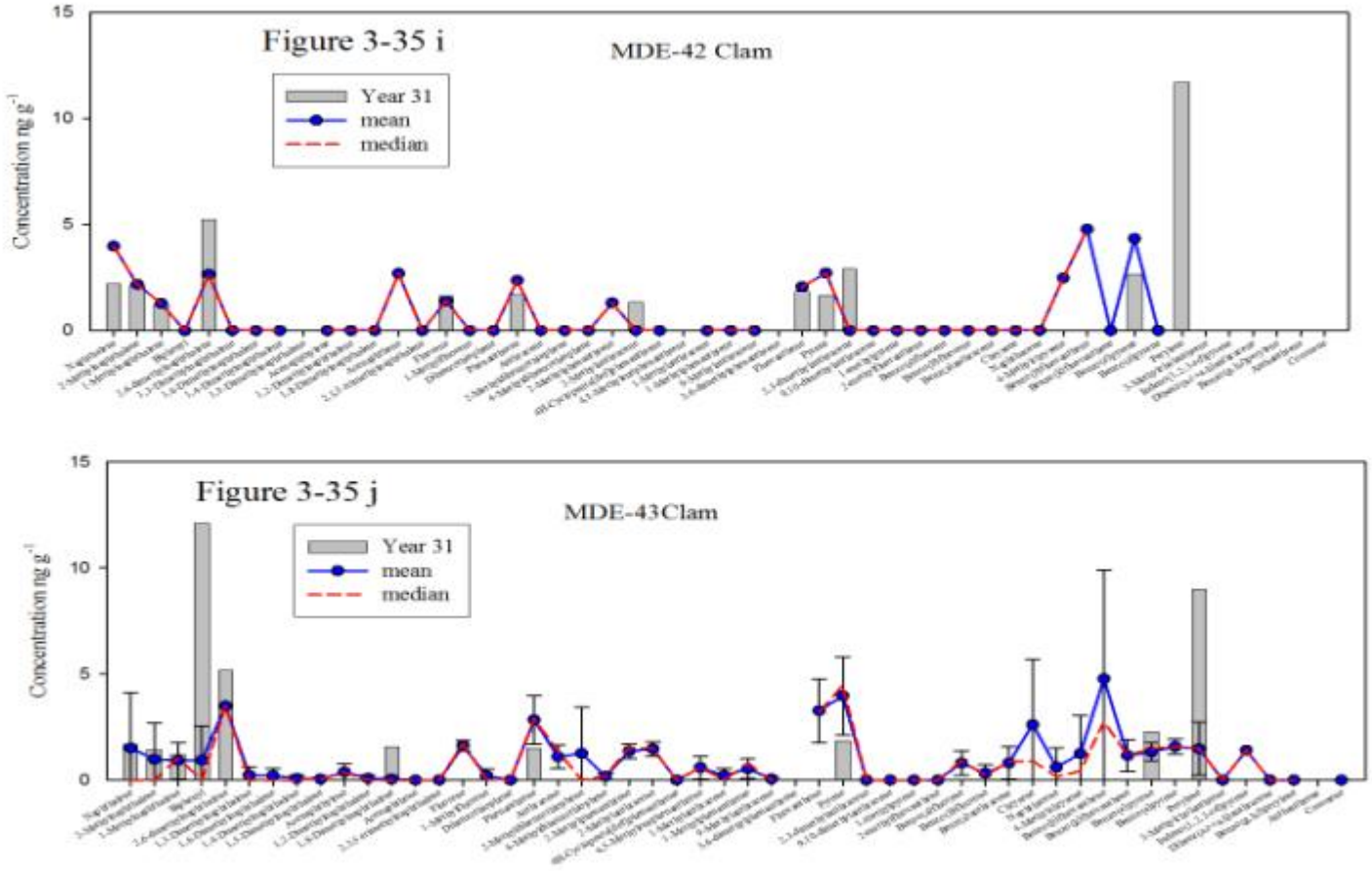


Figure 3-35 continued. Concentrations of PAHs in clams from site MDE-42 and MDE-43 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line), expressed in ng g^{-1} wet weight.

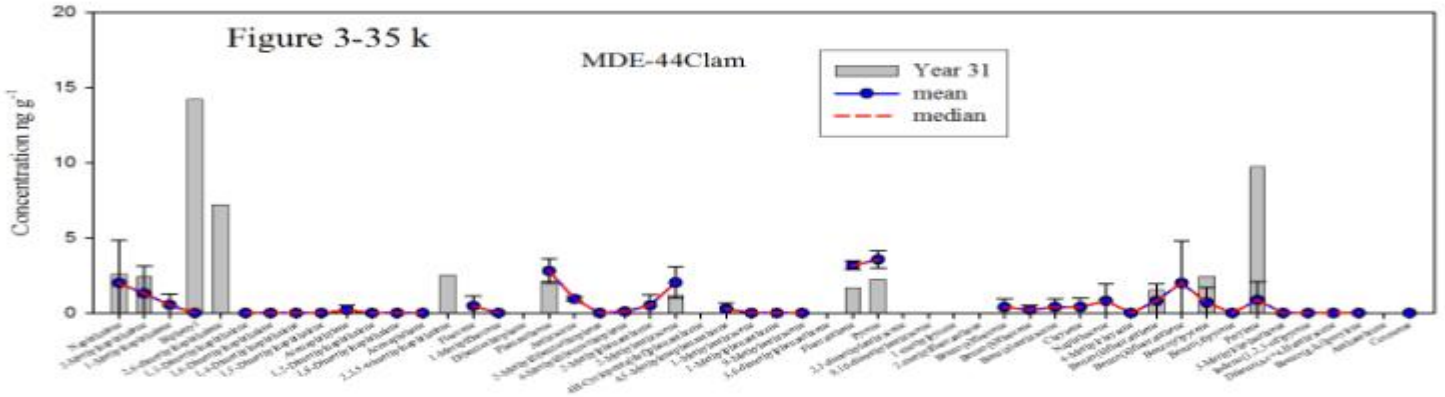


Figure 3-35 continued. Concentrations of PAHs in clams from site MDE-44 obtained in the fall of 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line), expressed in ng g^{-1} wet weight.

Total PAH concentrations in sediments and clams

The total concentrations of PAHs in sediment collected in 2012 from sites around the HMI complex were similar to or above historical levels (Figure 3-36a). PAH concentrations at site MDE-13, 16, 43 and 44 were above the standard deviation of the average of historic concentrations. Even concentrations at the reference site MDE 36 were slightly above the historic standard deviation.

Concentrations of PAHs in clams were also at or above historical levels at all sites, including the reference sites MDE-36 (Figure 3-36b). The concentrations of PAHs in clams from MDE-30 are substantially higher than we have observed in the past. While PAH concentrations in clams were elevated above historical levels, PCB concentrations were not. This likely indicates that PAHs and PCBs in clams have different sources. PCBs are a legacy contaminant whereas PAHs remain a constant input to the water column. The elevated concentrations in clams can be attributed to a change in regional deposition but go undetected in the sediment given the high levels seen in sediment relative to clams.

Figure 3-36 a

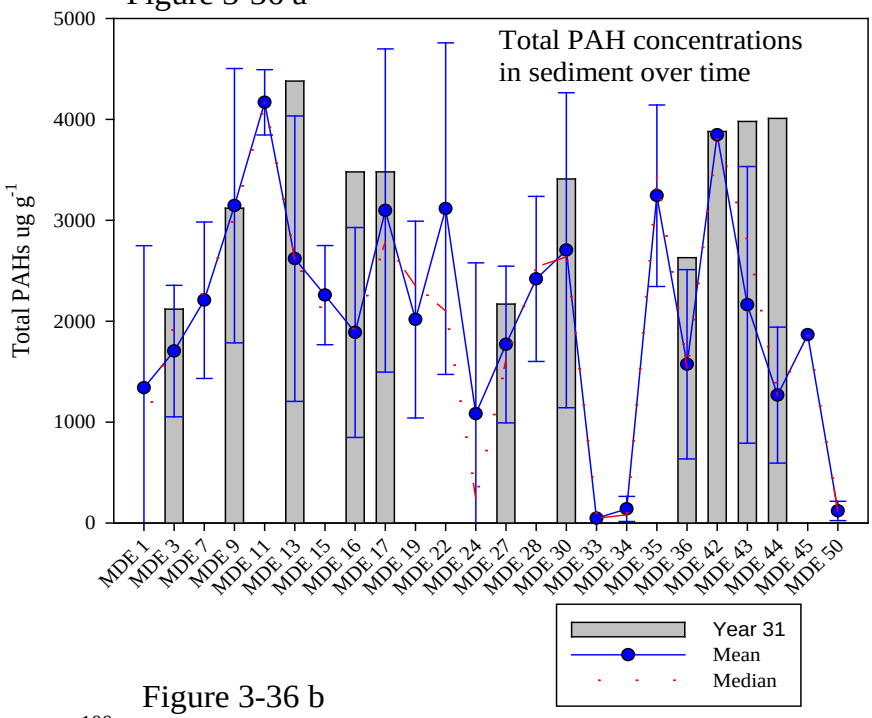


Figure 3-36 b

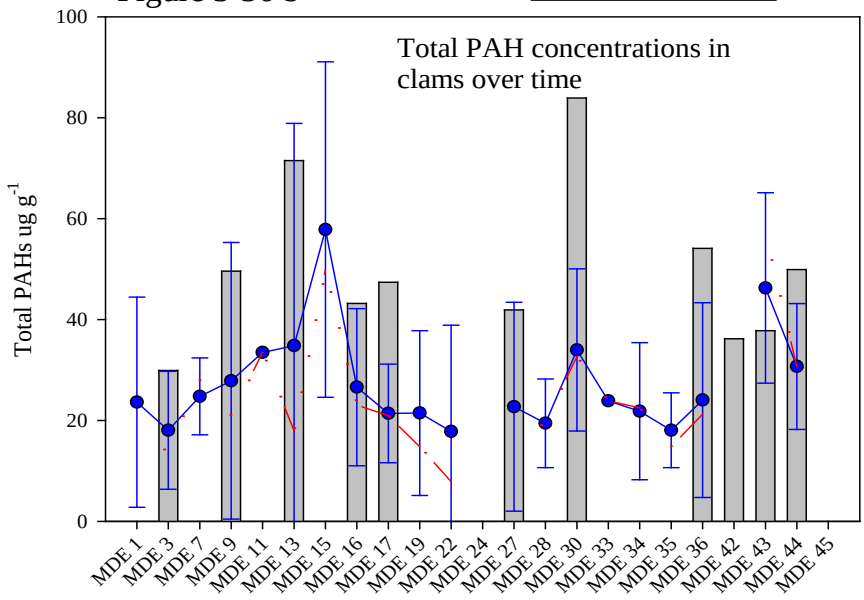


Figure 3- 36: Total PAH concentrations in sediments (a) (ng g^{-1} dry weight) and total PAH concentrations in clams (b) (ng g^{-1} wet weight) collected in September 2012 (bars), the 1998-2011 mean with standard deviation (blue circles and error bars) and the 1998-2011 median (dashed line).

Bioaccumulation Factors for PCBs and PAHs

PAHs are typically not accumulated in organisms to the same degree as PCBs. Organisms have varying abilities to metabolize and depurate PAHs although this ability in shellfish and clams is thought to be more limited. Exposure to PAHs has a metabolic cost stems from the need to repair DNA damage. Concentrations do not reflect the overall exposure in the life of the clam but do give an indication of recent exposure. Because they do not accumulate particularly well PAHs are not transferred up the food web to the same degree of PCBs. PAH concentrations in clams are orders of magnitude below the sediment concentrations, hence no bioconcentration from sediment is observed in 2012 as has been the case in previous years. PCBs accumulate in organisms because they are metabolized at a rate slower than the rate of accumulation; hence Bioaccumulation Factors (BAFs) can be calculated as a means of assessing the relative bioavailability in a given area. PCB BAFs calculated on a wet weight basis are less than 2 for most of the sites studied in 2012 (Figure 3-37).

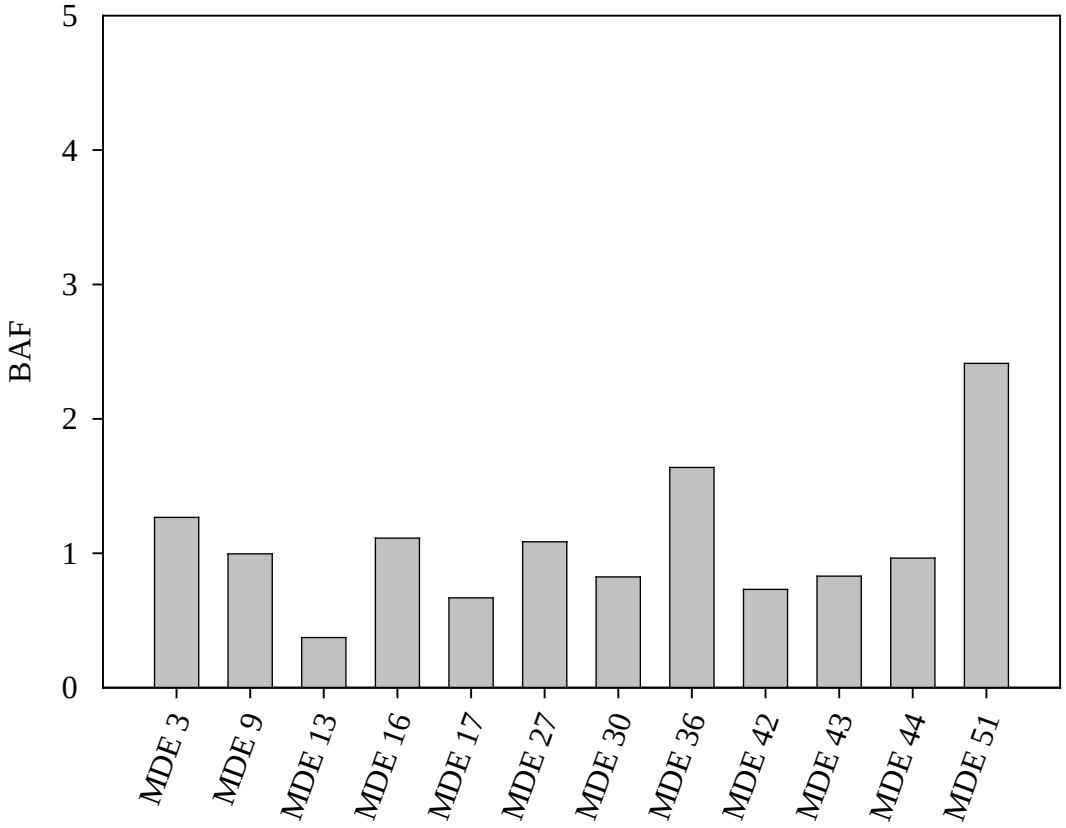


Figure 3- 37: 2012 PCB bioaccumulation factors between sediment and clams.

The Potential Sediment Toxicity from Organic Contaminants

The potential toxicity of the PAH and PCB concentrations in sediments around HMI was assessed by comparing the total concentrations to the Threshold Effects Level (TEL) and Probable Effects Level (PEL) as developed by NOAA for marine sediments. The TEL is surpassed at a number of the sites, which is not surprising given Baltimore's industrial and urban influence on sediments (Figure 3-38). The PEL was not surpassed by any of the sites for either PCBs or PAHs (Figure 3-38). Concentrations of individual compounds, for which criteria have been established, fall below the established PELs.

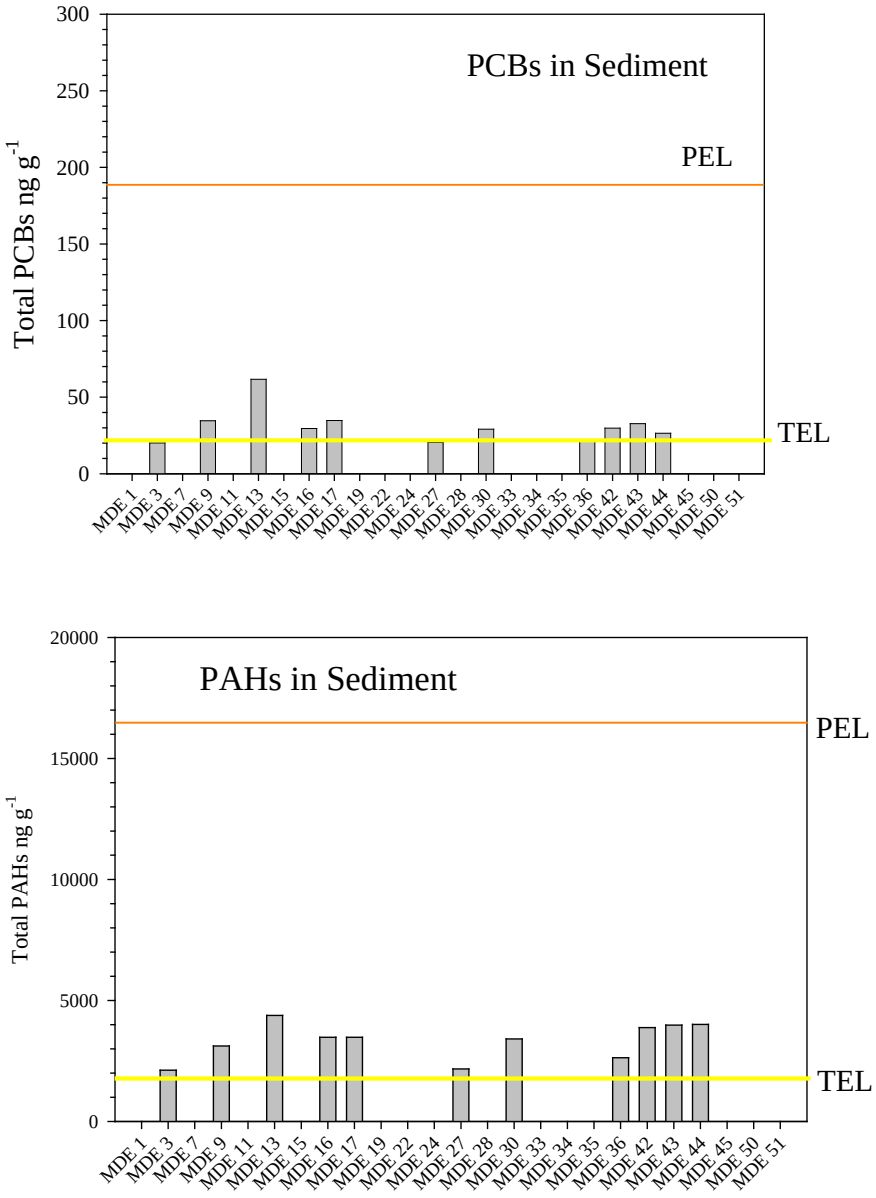


Figure 3-38 : Total PCB and total PAH concentrations in relation to the Threshold Effects Level (TEL) and the Probable Effects Level (PEL) for samples collected in September 2011.

SECTION SUMMARY

In past years, sediments of a few sites have been enriched in more than one trace element to a degree well above the historic means. This was not the case in 2012. In general, concentrations were very close the sites running median for 1998-2011. Some trace element concentrations have been trending upward in recent years, such as MDE-11, MDE-14 and MDE-17 for T-Hg, but this may simply be part of an oscillation as we have seen in previous years. Some deviations in the relationships between trace elements in sediment suggest changes in source or are the result of differences in diagenetic behavior. Concentrations of trace elements in clams were similar to or below concentrations observed in previous years. Bioaccumulation of some trace elements such as MeHg occurred as expected. The pattern in metal bioaccumulation was very similar in both seasons and no sites appeared to stand out as being different than the rest.

In the case of the organic contaminants, concentrations of PCBs in sediment were similar to historic values and the concentration in clams was below historic levels. The sediments contained high concentrations of the PCB congeners 31+28, 52, 66+95, 77+110, 132+153+105, 163+138, 201, 208+195, 206 and 209 which were found in most of the previous years. In the case of clams, congeners 123 + 149, 132+153+105, 163+138, 180, 208+195, 206 and 209 dominated. Some sites were enriched in other PCB congeners and it is not clear why this is the case. The sediment and clams display similar distributions of congeners and bioaccumulation from sediment top clams was low in 2012.

As in past years naphthalene, 2-methylnaphthalene, phenanthrene, fluoranthene, pyrene, benzo[b]fluoranthene, perylene and indeno(1,2,3-cd)pyrene make up the majority of PAHs in sediment. Sites MDE-13, 16, 43 and 44 had concentrations above the upper level of the historic standard deviation around the mean, but reference site MDE-36 also displayed this trend. The only significant change from the pattern observed in 2011 was an increase in the concentration of indeno(1,2,3-cd)perylene, at some sites, and this compound was a major contributor the total PAHs concentration at some sites. In the case of clams, they were enriched in biphenyl, 2-6 dimethylnaphthalene, 1-methylfluorene and perylene and at one station, MDE-13, clams had a large concentration of anthanthrene. Most of these compounds are combustion products of coal, wood and oil. The distribution of PAHs in clams was similar to the sediment but concentrations in clams are orders of magnitude lower than in sediment. Metabolism of PAHs by clams could be partially responsible for the difference in patterns, but also the type of particle the clam ingests.

REFERENCES

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

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

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

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

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

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

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

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

Mullin, M.D., 1985. PCB Workshop, US EPA Large Lakes Research Station, Grosse, MI, June 1985.

Sigala, M., R. Fairey, and M. Adams. 2007. Environmental Condition of Water, Sediment, and Tissue Quality in Central Coast Harbors under the Surface Water Ambient Monitoring Program Fiscal Year 2002-2003. State Water Resources Control Board, California Environmental Protection Agency, Sacramento, CA.

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