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

Year 21 Technical Report (September 2002 – 2003)

Prepared by:

Maryland Department of the Environment

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LIST OF ACRONYMS AND ABBREVIATIONS

AAS - Atomic Absorption Spectrometry

Ag - Silver

As - Arsenic

AVS - Acid Volatile Sulfide

BAF - Bioaccumulation Factor

BCF - Bioconcentration Factor

B-IBI - Benthic Index of Biotic Integrity

CBL - Chesapeake Biological Laboratory

Cd - Cadmium

CDF - Confined Disposal Facility

COC - Citizens' Oversight Committee

COMAR - Code of Maryland Regulations

Cr - Chromium

Cu - Copper

CWA - Clean Water Act

ERL - Effects Range Low

ERM - Effects Range Median

Fe - Iron

GC - Gas Chromatography

GFAAS - Graphite Furnace Atomic Absorption Spectrometry

Hg - Mercury

HMI - Hart-Miller Island Dredged Material Containment Facility

ICAP - Inductively Coupled Argon Plasma

LBP - Lipid Bioaccumulation Potential

MCY -Million Cubic Yards

MDE - Maryland Department of the Environment

MDNR - Maryland Department of Natural Resources

MES - Maryland Environmental Service

MGD - Million Gallons Per Day

MGS - Maryland Geological Survey

Mn - Manganese

MPA - Maryland Port Administration

MS - Mass Spectrometry

NBS - National Bureau of Standards

NEPA - National Environmental Policy Act

Ni - Nickel

NIST - National Institute of Standards and Technology

NOAA - National Oceanic and Atmospheric Administration

NRC - National Research Council of Canada

OC - Organochlorine Pesticide

PAH - Polynuclear Aromatic Hydrocarbon

Pb - Lead

PCB - Polychlorinated Biphenyl

PI(s) - Principal Investigator(s)

PPB - Parts Per Billion

PPM - Parts Per Million

PPT - Parts Per Thousand

QA - Quality Assurance

QC - Quality Control

SOP - Standard Operating Procedure

SQC - Sediment Quality Criteria

SQS - Sediment Quality Standard

SRM - Standard Reference Material

TBP - Theoretical Bioaccumulation Potential

TDL - Target Detection Limit

TEF - Toxicity Equivalency Factor

TOC - Total Organic Carbon

USACE - U.S. Army Corps of Engineers

UMCES - University of Maryland Center for Environmental Science

USCS - Unified Soil Classification System

USEPA - U.S. Environmental Protection Agency

USFDA - U.S. Food and Drug Administration

WMA - Water Management Administration

WQC - Water Quality Criteria

WQS - Water Quality Standards

Zn - Zinc

CONVERSIONS[1]

WEIGHT:

1Kg = 1000g = 2.205lbs.

1g = 1000mg = 2.205 x 10^{-3}lb

1mg = 1000μg = 2.205 x 10^{-6}lb

1 lb = 16oz = 0.454Kg

LENGTH:

1m = 100cm = 3.28ft = 39.370in

1cm = 10mm = 0.394in

1mm = 1000μm = 0.0394in

1ft = 12in = 0.348m

CONCENTRATION:

1ppm = 1mg/L = 1mg/Kg = 1μg/g = 1mL/m^3

1g/cc = 1Kg/L = 8.345 lbs/gallon

1g/m^3 = 1mg/L = 6.243 x 10^{-5}lbs/ft^3

1 lb/gal = 7.481 lbs/ft^3 = 0.120g/cc = 119.826g/L = 119.826Kg/m^3

1oz/gal = 7.489Kg/m^3

VOLUME:

1L = 1000mL

1mL = 1000μL

1cc = $10^{-6}m^3$

1yd^3 = 27ft^3 = 764.55L = 0.764m^3

1acre-ft = 1233.482m^3

1 gallon = 3785cc

1ft^3 = 0.028m^3 = 28.317L

FLOW:

1m/s = 196.850ft/min = 3.281ft/s

1m^3/s = 35.7ft^3/s

1ft^3/s = 1699.011L/min = 28.317L/s

1ft^2/hr = 2.778 x $10^{-4}ft^2$/s = 2.581 x $10^{-5}m^2$/s

1ft/s = 0.031m/s

1yd^3/min = 0.45ft^3/s

1yd^3/s = 202.03gal/s = 764.55L/s

AREA:

1m^2 = 10.764ft^2

1hectare = 10000m^2 = 2.471acres

1ft^2 = 0.093m^2

1acre = 4046.856m^2 = 0.405 hectares

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[1] Modified from the June 1994 Draft "Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. – Testing Manual" published by the U.S. Environmental Protection Agency and the U. S. Army Corp of Engineers.

CHAPTER I: PROJECT MANAGEMENT AND SCIENTIFIC/TECHNICAL COORDINATION

Hart-Miller Island Exterior Monitoring Program
September 2002 - September 2003

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ACKNOWLEDGMENTS

The Year 21 Hart-Miller Island (HMI) Exterior Monitoring Program would not have been successful without the help of several Technical and Regulatory Services Administration (TARSA) staff members, including: Mr. George Harman, Chairman; Mr. Matthew Rowe, Project Manager; Mr. Christopher Luckett, Biologist; Miss Caroline Myers, Biologist; and, Mr. Charles Poukish, Division Chief. The Chairman 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 (TRC) for Year 21. The Technical Coordinator wrote the Project I sections of the HMI reports, standardized the Data and Technical reports among projects, conducted data management, and facilitated the peer review process. The Budget Manager was responsible for assuring that all project related budgetary products, services, and activities had been implemented by each Principal Investigator (PI) and accounted for in a budgetary tracking system. The Environmental Specialist provided insightful comments on and scientific review of the data and technical reports.

The Maryland Department of the Environment would like to thank all the members of the HMI Exterior Monitoring Program's TRC and the HMI Citizens' Oversight Committee (COC) for their useful comments and suggestions throughout the project year. A thank you also goes out to the Maryland Environmental Service (MES) for providing information on dredged material inputs to HMI for Year 21.

Lastly, thanks to Mr. Robin Grove, Director, TARSA, for his guidance, suggestions and commitment to the Hart-Miller Island Exterior Monitoring Program.

INTRODUCTION

Site Background

Baltimore's strategic location in northern Chesapeake Bay has important economic ramifications for the state of Maryland. The Port of Baltimore depends upon annual dredging by the U.S. Army Corps of Engineers (USACE) to maintain the federal approach channels to Baltimore Harbor. The State of Maryland is obligated to provide placement sites for material dredged from these federal maintenance channels. In 1983, the Hart-Miller Island Dredged Materila Containment Facility (HMI) was constructed to accommodate sediments dredged from Baltimore Harbor and its approaches.

HMI is located in the upper Chesapeake Bay at the mouth of Back River, northeast of Baltimore Harbor. Construction of HMI began by building a dike connecting the remnants of Hart and Miller Islands and encompassing an open-water area of approximately 1,100 acres. The dike was constructed of sandy sediments excavated from the proposed interior of the facility. The eastern or Bay side of the dike was reinforced with filter cloth and rip-rap to protect the dike from wave and storm induced erosion. Completed in 1983, the dike is approximately 29,000 feet long and is divided into North and South Cells by a 4,300 foot interior cross-dike. Placement of dredged material within HMI began with dike completion and continues presently.

The last inflow of dredged material into the South Cell of HMI was completed on October 12th, 1990. The process of converting the 300-acre South Cell into a wildlife refuge is currently underway. The North Cell is projected to reach full capacity by the Year 2109, at which time it will also be converted into a wildlife refuge. The remnants of Hart and Miller Islands, which lie outside of the dike, serve as a state park and receive heavy recreational use throughout the summer months.

Environmental Monitoring

Under section 404(b&c) of the Clean Water Act (1987), entitled "Permits for Dredged or Fill Material", permits for dredged material disposal can be rescinded if it is determined that: "the discharge of such materials into such area will have an unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas (including spawning and breeding areas), wildlife, or recreational areas."2 In accordance with this federal mandate and as a special condition of the State Wetlands License 72-127(R), a long-term compliance monitoring program was implemented in 1981 to assess the effects of HMI on local water quality and biota. Results from the monitoring are used to detect changes from baseline environmental conditions (studies conducted from 1981-1983) established in the area surrounding HMI, and to guide decisions regarding possible operational changes and remedial actions.

The Hart-Miller Island Exterior Monitoring Program has evolved over the years in

2 From page 250 of the 1987 Clean Water Act published by the Water Pollution Control Federation.

response to both changes in technology and sampling protocols approved by the project's technical experts. Analytical methods to detect trace metal burdens in sediments and benthic macroinvertebrates, for example, have been changed throughout the monitoring program as improved technologies with lower detection limits and greater sensitivity have been developed. Fish and crab population studies were discontinued after Year 5 due to the ineffectiveness of using the information as a compliance monitoring tool. Furthermore, beach erosion studies were discontinued after Year 13 in response to beach replenishment and stabilization with breakwaters. The Exterior Monitoring Program is flexible enough to incorporate such changes as long as they do not undermine the State's ability top assess aquatic impacts.

Experimental Design

The HMI Exterior Monitoring is currently modeled after the Sediment Quality Triad developed in the mid-1980s (Long and Chapman, 1985). The approach consists of three separate components: sediment chemistry, sediment toxicity, and benthic community composition. The sediment chemistry project (Project 2) assesses contamination by evaluating metals concentrations in exterior sediments1. The sediment toxicity project (Project 4) looks at benthic tissue concentrations of both metals and organics in the brackish-water clam, *Rangia cuneata*. Project 3, benthic community studies, examines the structure of the macroinvertebrate assemblage surrounding HMI. Whereas sediment contamination thresholds, benthic toxicity benchmarks, and benthic macroinvertebrate indices alone require caution in their application and interpretation, combining them into a triad approach provides a greater level of confidence when assessing ecological impacts. Table 1 below illustrates this concept.

Table 1: Information Provided by Different Triad Responses (taken from Chapman, 1990).

Situation	Contamination	Toxicity	Alteration	Possible Conclusions
1.	+	+	+	Strong evidence for pollution-induced degradation
2.	-	-	-	Strong evidence that there is no pollution induced contamination
3.	+	-	-	Contaminants are not bioavailable
4.	-	+	-	Unmeasured chemicals or conditions exist with the potential to cause degradation
5.	-	-	+	Alteration is not due to toxic chemicals
6.	+	+	-	Toxic chemicals are stressing the system
7.	-	+	+	Unmeasured toxic chemicals are causing degradation
8.	+	-	+	Chemicals are not bioavailable or alteration is not due to toxic

1 Project 4 also does some sediment chemistry work for ancillary metals not monitored in Project 2.

Situation	Contamination	Toxicity	Alteration	Possible Conclusions
				chemicals

Responses are shown as either positive (+) or negative (-), indicating whether or not measurable (e.g., statistically significant) differences from control/reference conditions are determined.

Situation number one in the above table demonstrates a clear impact as a result of statistically significant differences from reference conditions in all three components (contamination, toxicity and alteration of the benthic community). Situation number two is negative for all components and suggests no aquatic impacts. Situation numbers 6, 7 and 8 indicate some level of degradation and the need for continued monitoring. Situations 3, 4 and 5 have only a single line of evidence pointing to a potential problem and are likely the lowest priority for follow-up monitoring or remedial action.

The strength of the triad approach is that it uses a weight-of-evidence approach to determine overall environmental impact. Each component is an individual line of evidence that, when coupled with the others, forms a convincing argument for or against pollution induced degradation. The Triad is a particularly useful tool for identifying sediment "hot-spots" and prioritizing remedial actions.

CHAPTER II: SEDIMENTARY ENVIRONMENT

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EXECUTIVE SUMMARY

The Coastal and Estuarine Geology Program of the Maryland Geological Survey (MGS) has been involved in monitoring the physical and chemical behavior of near-surface sediments around the Hart-Miller Island Dredged Material Containment Facility (HMI) from the initial planning stages of construction of the facility through to the present. As part of this year's exterior monitoring program, MGS collected bottom sediment samples from 40 sites on September 4, 2002, and again on April 2, 2003. Survey geologists then analyzed various physical and chemical properties of the samples: (1) grain size composition (relative proportions of sand, silt, and clay) and (2) total elemental concentrations of iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), cadmium (Cd), lead (Pb), phosphorous (P), carbon (C), nitrogen (N), and sulfur (S).

For exterior bottom sediments sampled during Year 21, the pattern of the grain size distribution varies slightly from one cruise to the next. The reasons for the variations are difficult to decipher, due to the complexity of the depositional environment and the multiple sources of material to the area. However, in general, sediment distribution is consistent with the findings of previous monitoring years, dating back to 1988, two years following the initial release of effluent from HMI.

With regard to trace metals some features to note are:

1. Cd, Cr, Cu, Ni, Pb and Zn are found at some sites with concentrations that exceed the Effects Range Low (ERL) values; and
2. Cr, Ni and Zn exceed the ERM values at some sites.

ERL and Effects Range Medium (ERM) are proposed criteria put forward by National Oceanic and Atmospheric Administration (NOAA - Long et al. 1995) to gauge the potential for deleterious biological effects. Sediments with concentrations below the ERL are considered baseline concentrations with no expected adverse effects. Concentrations between the ERL and ERM may have adverse impacts to benthic organisms, while values greater than the ERM have probable adverse biological effects. These criteria are based on a statistical method of termed preponderance of evidence. The method does not allow for unique basin conditions and does not take into account grain size induced variability in metal concentrations in the sediment. The values are useful as a guide, but are limited in applicability due to regional difference. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, Pb, and Zn have significantly enriched samples compared to the baseline; however, based on work done in Baltimore Harbor, the normalized values are well below anticipated biological effects thresholds.

Most of the Pb and Zn enriched samples are associated with Baltimore Harbor and Back River. Material from the Harbor does not influence the sediments adjacent to the dike in the proximal zone ascribed to HMI. This is supported by both the sedimentation and metals distribution patterns in the area.

In the area effected by dike operations, there are only six sites with elevated metal levels, with the levels in Year 21 being higher than Year 20. Placement operations worked in tandem with dewatering and crust management operations that were performed 6 months of the 12 month period. The dewatering operations were not performed in a contiguous period, but in 2 three month periods; this reduced the potential for acid formation. Most of the discharge rates were low (64% less than 10 Mgal/day), especially prior to the Spring sampling period where 59% of the discharges from the dike were below 10 Mgal/day, and no discharge exceeded 30 Mgal/day; there were longer contiguous periods of lower flow. Consequently, the maximum levels of metals would be expected to be found during the Spring sampling, as was the case. However, the discharge rates were intermittently high enough to lower the potential of acid formation, so the metal levels in the exterior sediments are elevated, but relatively low and below levels of concern. This is supported by the low pH values of the discharge never being in the range of free mineral acidity.

Persistent elevated metal levels in sediments around HMI indicate a need for continued monitoring, even though the levels were low during this sampling period. The metal levels in the exterior sediments continued to show a consistent response to the operations of the dike; low discharge rates increasing the metal loads to the sediment. Currently, the dike is actively accepting material, but as the dike reaches its capacity and the volume of effluent is expected to decline, dewatering of the contained material may lead to higher metal levels in the effluent. Exposure of dredged material to the air is likely to result in the mobilization of metals associated with those sediments, an effect analogous to acid mine drainage. Metals released in the effluent, particularly at low discharge rates, are deposited on the surrounding Bay floor and are increasing the long-term sediment load in the Bay. Although these levels are much lower than any biological effects threshold, continued monitoring is needed in order to; detect if the levels increase to a point where action is required, document the effect that operations has on the exterior environment (for future project design), and to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of exposing contained dredged material to the atmosphere. Close cooperation with MES is important in this endeavor.

In order to assess the potential influence of Baltimore Harbor on the HMI exterior sediments better, the additional sampling sites must be maintained, at least temporarily. Further, the South Cell will soon be converted to upland wetlands, with a constant flow of water being circulated through the ponds to produce conditions similar to tidal wetlands. Additional sample locations should be established near the discharge point to assess this new operation of the facility.

INTRODUCTION

Since 1981, the Maryland Geological Survey (MGS) has monitored the sedimentary environment in the vicinity of Hart-Miller Island Dredged Material Containment Facility (HMI). HMI is a man-made enclosure in northern Chesapeake Bay, named for the two natural islands that form part of its western perimeter (Figure 1). Designed specifically to contain material dredged from Baltimore Harbor and its approach channels, the oblong structure was constructed of sediment dredged from the dike 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 and deposited inside the facility also differs 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 dike during dewatering

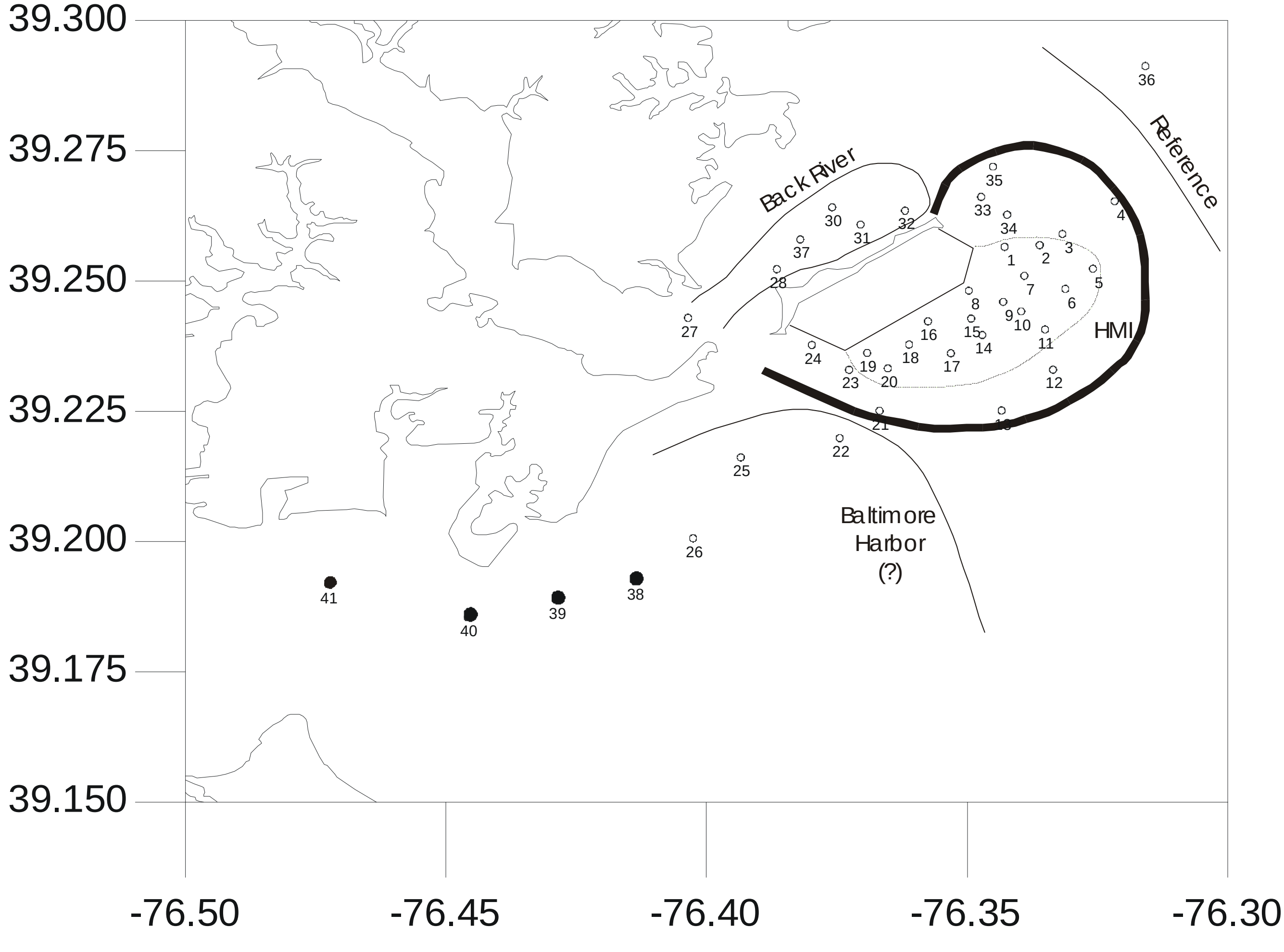


Figure 1: Sampling locations for Year 21. Contours show zones of influence found in previous studies. Solid circles show location of sites added in Year 18 to measure the influence of Baltimore Harbor.

and crust management produces effluent enriched in metals.   These differences in sediment properties and discharge from the facility have allowed the detection of changes attributable to construction and operation of the dike.

Previous Work

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

1. Preconstruction (Summer 1981 and earlier)
2. Construction (Fall 1981 - Winter 1983)
3. Post-construction
    a. Pre-discharge (Spring 1984 - Fall 1986)
    b. Post-discharge (Fall 1986 - present).

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 dike 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.

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 #1 (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 is in term normalized to the same ratio in a standard reference material; this number is dimensionless. Effluent discharged during normal operation of the dike 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 (<10MGD); 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 *10th Year Interpretive 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 #1 and #4 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.

   Releases from Spillway #2 are spread more evenly to the north, east, and west. However, dispersion is not as great as from Spillways #1 and #4 because of the lower shearing and straining motions away from the influence of the gyre.

3. 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.

4. Discharge from the HMI spillways has no influence on the circulation gyre. This was determined by simulating point discharges of 0-70 million gallons/day (MGD) from three different spillways. Changes in discharge rate only modulated the concentration of a hypothetical conservative species released from the dike; the higher the discharge, the higher the concentration in the plume outside the dike.

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 dike was examined, as reported in the *11th Year Interpretive 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 dike. The model has two components: (1) loading due to material similar to the sediment in place and (2) loading of enriched material as predicted from a regression line based on discharge data supplied by the Maryland Environmental Service (MES). The behavior of this model supports the hypothesis of metal contamination during low flow conditions. Sediments discharged from the facility are the source of metals that enrich the exterior sediments. When exposed to the atmosphere, these sediments oxidize in a process analogous to acid mine drainage (i.e., sulfide minerals oxidize to produce sulfuric acid, which leaches acid-soluble metals, nutrients, and organic compounds that are released with the discharged waters). Since the initial detection of Zn, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, in the vicinity of the dike higher than expected levels of Zn have persisted through Year 19, and elevated levels of Pb persist in Year 21. Figure 1, in addition to showing the sampling sites for Year 20, show zones which indicate influence of sources of material to the exterior sedimentary environment based on a 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 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 dike 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* – A few monitored sites in the southern portion of the area have consistently shown a gradient, suggesting a source of metals south of HMI in the direction of Baltimore Harbor. The pattern frequently seen in the monitoring studies is base level values near HMI which increase towards Baltimore Harbor. Baltimore Harbor, as the source of the material, was further implicated by 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). This analysis showed the potential of movement of material from the mouth of the harbor extending northward toward HMI. To assess the effect of Baltimore Harbor on the HMI external sedimentary environment, four sites were added in Year 18 and maintained through Year 21. These sites are indicated by solid circles in Figure 1.

Dike Operations

Certain activities associated with the operation of HMI have a direct impact on the exterior sedimentary environment. Local Bay floor sediments appear to be sensitive, both physically and geochemically, to the release of effluent from the dike. Events or operational decisions that affect the quality or quantity of effluent discharged from the dike account for some of the changes in exterior sediment properties observed over time. For this reason, dike operations during the periods preceding each of the Year 21 cruises are summarized below. Information was extracted from *Operations Reports* prepared by MES, covering the periods April 1, 2002 - April 30, 2003; a detailed synopsis of this period and digital discharge records were provided to MGS for this report by MES (Jennifer Harlan, personal communication)

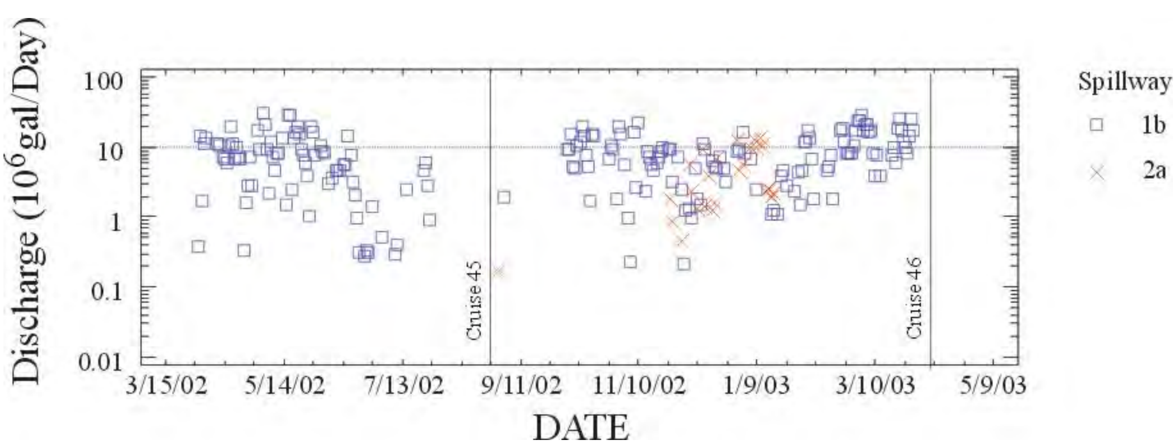


Figure 2:Discharge from HMI during the Year 21 monitoring period. Note that discharge is presented as a logarithmic scale. Vertical lines denote sampling days.

HMI was accepting material throughout the monitoring year; the only month where no material was accepted was July. Both periods prior to each cruise had high usage with approximately 2.5 million cubic yards placed in HMI prior to the Fall Sampling and 1.8 million cubic yards prior to the Spring Sampling. During the monitoring year there were no extended intervals of low discharge (<10 Mgal/day; see Figure 2). However, discharge rates were generally low from July 2002 through April 2003 with sporadic higher discharges; during this period, there were two 3-month periods of crust management and dewatering (6/11/02 - 9/30/02 & 11/13/02 - 2/1/03). Low flow and dewatering operations are conducive to the production of acidic conditions resulting from oxidation of the sediment. From previous observations, it takes a period longer than six months to establish oxidizing conditions which would show a significant effect on the discharge. Consequently, low pH discharge and optimal leeching conditions would not be expected to develop significantly, though some effects might occur. The discharge water stayed at values near or greater than neutral see (Figure 3), with some samples below pH 7 (neutral) and a few with pH values nearing the conditions where free mineral acidity is stable. Therefore based on previous monitoring years, the external sedimentary environment would not be expected to be *greatly* affected by the dike operations during this period, though there is more potential for effect than in the Year 20 monitoring period. This is additionally supported in that the effluent was in compliance with the discharge permit for the entire monitoring period.

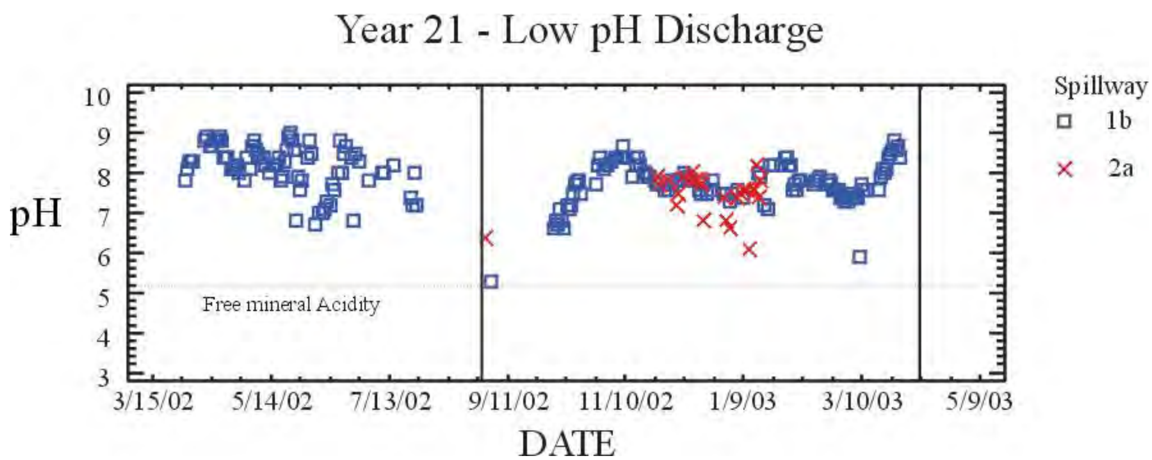


Figure 3: Low pH measured for daily discharge from HMI. Vertical lines denote sampling dates. pH readings below the horizontal line indicates free mineral acidity.

OBJECTIVES

As in the past, the main objectives of the Year 21 study were (1) to measure specific physical and geochemical properties of near-surface sediments around HMI and (2) to assess detected changes in the sedimentary environment. Tracking the extent and persistence of the area of historically elevated Zn 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 4, 2002, and the second, on April 2, 2003.

Sampling sites (Fig. 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 station during sample retrieval. At most sites, the captain recorded station coordinates and water depth. Target and actual coordinates (latitude and longitude -- North American Datum of 1983) of Year 21 sample locations are reported in the companion *Year 21 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 40 sites, MDE-1 through MDE-28 and MDE-30 through MDE-41. The same 40 stations were occupied during both Year 21 cruises. Stations were identical to those sampled during Years 19 and 20.

At 36 stations, a single grab sample was collected, described lithologically, and split. Triplicate grab samples were collected at the remaining four stations (MDE-2, MDE-7, MDE-9 and MDE-31) and, likewise, described and split. MGS analyzed one split for grain size composition, a suite of trace metals, and carbon/sulfur/nitrogen. The Chesapeake Biological Laboratory (CBL) analyzed the second split collected for a different suite of trace metals. Field descriptions of samples are included as appendices in the *Year 21 Data Report*.

Using plastic scoops rinsed with deionized water, the crew took sediment sub-samples from below the flocculent layer, usually several centimeters from the top, and away from the sides of the sampler to avoid possible contamination by the sampler itself. MGS's sub-samples were placed in 18-oz Whirl-Pak™ bags and refrigerated. They were maintained at 4°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, sub-samples from both the surficial grabs and gravity cores 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:

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

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 (Blatt et al. 1980). Each fraction was weighed; percent sand, silt, and clay were determined; and the sediments were categorized according to Pejrup's (1988) classification (Figure 4).

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.

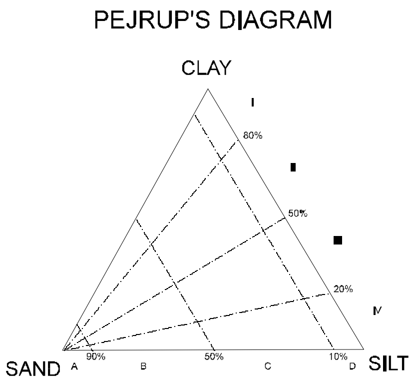


Figure 4: Pejrup's (1988) classification of sediment type.

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.

Trace Metal Analysis

Sediment solids were analyzed for eight trace metals, including iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb) and cadmium (Cd). In addition to the trace metals, total phosphorus (P) was analyzed. Samples were digested using a microwave digestion technique followed by analysis on an Inductively Coupled Argon Plasma Spectrometer (ICAP). The digestion method was modified from USEPA Method #3051 in order to achieve total recovery of the elements analyzed; the same method as used since 1990.

The dissolved samples were analyzed with a Jarrel-Ash AtomScan 25 sequential ICAP spectrometer using the method of bracketing standards (Van Loon 1980). The instrumental parameters used to determine the solution concentrations were the recommended, standard ICAP conditions given in the Jarrel-Ash manuals, optimized using standard reference materials (SRM) from the National Institute of Standards and Technology (NIST) and the National Research Council of Canada. Blanks were run every 12 samples, and SRM's were run five times every 24 samples.

Results of the analyses of three SRM's (NIST-SRM #1646a - Estuarine Sediment; NIST-SRM #8704 - Buffalo River Sediment; National Research Council of Canada #PACS-1 - Marine Sediment) by the microwave/ICAP method has recoveries (accuracies) within one standard deviation of replicate analyses for all of the metals analyzed (see the Year 21 Data Report)

Carbon-Sulfur-Nitrogen Analysis

Sediments were analyzed for total nitrogen, carbon 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 is configured for CNS analysis using the manufacturer's recommended settings. As a primary standard, 5-chloro- 4-hydroxy- 3-methoxy-benzylisothiourea phosphate is 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 fifth sample are run. As a secondary standard, a NIST reference material (NIST SRM #1646 - Estuarine Sediment) is run after every 6 to 7 sediment samples. The recovery of the SRM is excellent with the agreement between the NIST certified values and MGS's results well within the one standard deviation of replicate analyses.

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. Therefore, for this report, the current Year 21 results are discussed with respect to the preceding Year 20 results.

Thirty-eight of the 40 sampling sites visited during Year 21 yielded results that can be compared to those measured during Year 20. The grain size composition (proportions of sand, silt, and clay) of the 38 samples is depicted as a series of Pejrup’s diagrams in Figure 5. Within a diagram, each solid circle represents one sediment sample. Related statistics, by cruise, are presented in Table 2.

Table 2: Summary statistics for Years 20-21, for 38 sediment samples common to all four cruises.

Variable	Sept 2001 Cruise 43	Apr 2002 Cruise 44	Sept 2002 Cruise 45	Apr 2003 Cruise 46
Sand (%)				
Mean	24.01	22.28	22.34	23.69
Median	5.14	4.96	3.83	5.60
Minimum	0.64	0.68	0.62	0.68
Maximum	95.33	98.08	99.21	98.37
Range	94.69	97.40	98.59	97.69
Count	38	38	38	38
Clay:Mud				
Mean	0.54	0.55	0.56	0.55
Median	0.56	0.56	0.56	0.55
Minimum	0.40	0.48	0.49	0.47
Maximum	0.64	0.63	0.67	0.62
Range	0.24	0.15	0.18	0.15
Count	38	38	38	38

The ternary diagrams show similar distributions of sediment type. The samples range widely in composition, from very sandy (>90% sand) to very muddy (<10% sand). Muddy sediments predominate; at least two-thirds 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). In general, points lie above the 0.50 line, indicating that the fine (muddy) fraction of the sediments tends to be somewhat richer in clay than in silt.

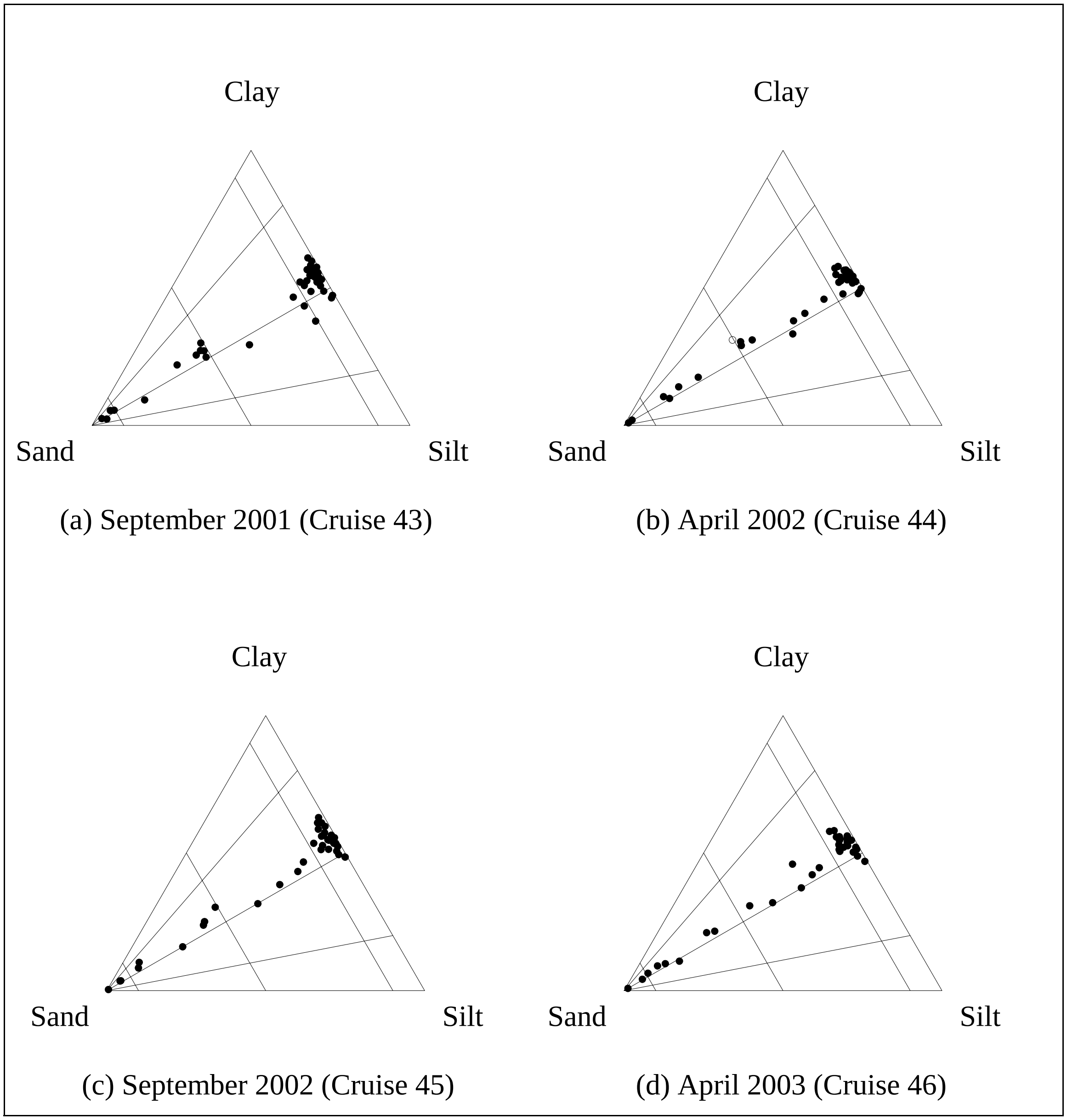


Figure 5: Ternary diagrams showing the grain size composition of sediment samples collected in Years 20 and 21 from the 38 sampling sites common to all four cruises: (a) September 2001, (b) April 2002, (c) September 2002, and (d) April 2003.

Based on the summary statistics (Table 2), average grain size composition, reported as % sand and as clay:mud ratios, varied little over the four sampling periods. As in the past, no clear seasonal trends are evident in either sand content or the clay:mud ratios.

For the two monitoring years, the grain-size distribution of bottom sediments around HMI is depicted in contour maps showing (1) the percentage of sand in bottom sediments and (2) the clay:mud ratios. In Figure 7, three contour levels represent 10%, 50%, and 90% sand, coinciding with the parallel lines in Pejrup's diagram. 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 (Fig. 6). 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 and MDE-32) contain less than 10% sand. Sand distribution maps for Years 20 and 21 are similar in appearance. Sand contents continue to be highest near the perimeter of HMI in shallow water depths. No significant changes in sand content occurred during monitoring Year 21. In general, the distribution of sand around HMI has remained largely unchanged since November 1988, two years after the first release of effluent from the dike.

Figure 6: Average water depths, based on Year 17 Monitoring. Contour interval = 5 ft.

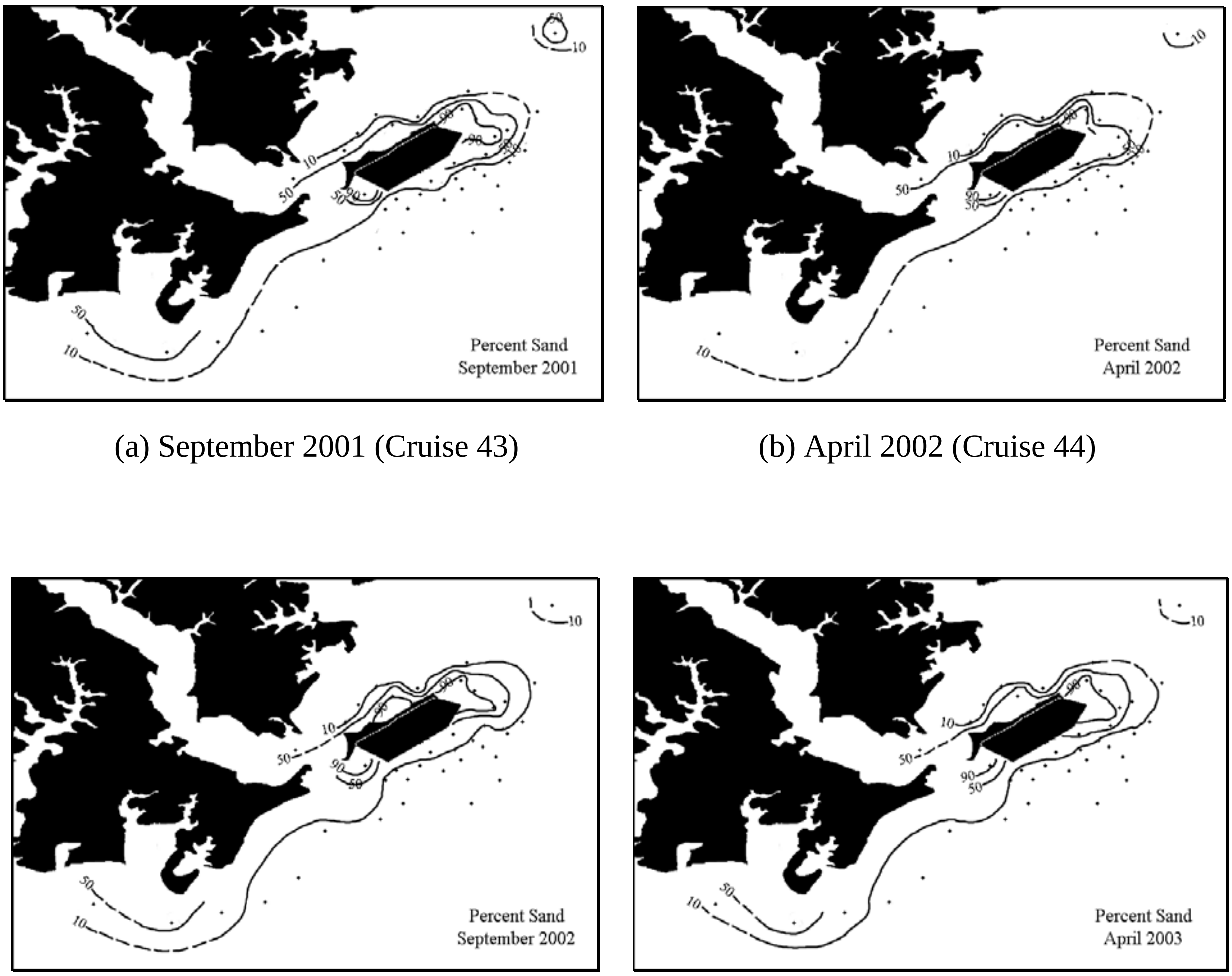
Compared to the distribution of sand, the distribution of clay:mud ratios has tended to be more variable over time. The fine (mud) fraction of the sediments around HMI is generally richer in clay than in silt. That is, the clay:mud ratio usually exceeds 0.50, as shown in the ternary diagrams above. However, 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 (Fig. 7). In September 2001, the most clay-rich sediments occurred as four isolated pockets, three southeast of the dike and one in the mouth of Baltimore Harbor. In April 2002, the clay:mud ratios of only three samples equaled or exceeded 0.60. Two (MDE-10 and MDE-41) had been high the previous September. Samples at MDE-41 continued to be at or above 0.60 in both September 2002 and April 2003. There were two most clay-rich pockets in September 2002 in addition to the pocket at MDE-41. Each of these two pockets contained two sample locations: one just south of HMI (MDE-18 and MDE-20) and one in Hawk Cove (MDE 37 and MDE 31). The pocket south of HMI, closest to spillway #3, is located in a zone where clay:mud values have occurred regularly in the past. A very minimal increase in clay content was required at MDE-31 in order to increase the clay:mud ratio to above 0.60 due to the high sand content, which also accounts for the change in the contour lines in Hawk Cove for September 2002 (Fig. 8 c).

In April 2003, four pockets occur with caly:mud ratio values at or above 0.60, including the pocket at MDE-41 (Fig. 8 d). The two pockets from September 2002, the one just south of HMI and the one in Hawk Cove, continue to be present in April 2003 but have become smaller with the decreased clay:mud ratio values at MDE-20 and MDE-31 respectively. Though MDE-

18 and MDE-37 still have values greater than 0.60, the data shows both a slight increase in sand content along with a slight decrease in clay content for both sampling sites. This suggests that the environment in Hawk Cove and in the vicinity of spillway #3 south of HMI was slightly more turbulent and or had less fine sediment inputs in April 2003 than in September 2002. The fourth pocket with values at or above 0.60 in April 2003 occurs just to the east of HMI in the vicinity of spillway #1. Here, stations MDE-2 and MDE-34 show an increased clay:mud ratio in comparison to September 2002. The increase is not significant at either of these stations with values of 0.58 and 0.59 respectively in September 2002.

Silt-rich sediments (clay:mud ratio < 0.50) are generally found immediately adjacent to the walls of the dike, commonly in the vicinity of spillways. Silt-rich sediments occurred slightly more frequently in September 2001 (eight sites) than in April 2002 (four sites). The contrast between years was greater. In September 2002, the fine fraction of only one sample was silt-rich (MDE-12). In April 2003, the fine fraction of three samples was silt rich (MDE-12, MDE-8 adjacent to the wall of the dike to the southeast, and MDE-33 just to the northeast of the dike). At MDE-33, the sand fraction was so great (>98%), that analysis of the fine fraction was problematic. Although there were fewer silt-rich areas in Year 21 in comparison to Year 20 on a station specific basis, the results do not differ significantly from the past. Many of the sampling sites that had a clay:mud ratios below 0.50 in Year 20 continued to be at or just above 0.50 in Year 21. One exception was MDE-24, which also has very high sand content making the fine fraction analysis problematic.

Understanding the specific reasons for these variations in grain size is difficult. They involve the amount, quality, and timing of discharge from particular spillways and the interaction of the effluent with tides and currents in the receiving waters. Those, in turn, are influenced by flow from the Susquehanna River. Based on the relatively clayey nature of the fine fraction in Year 21, one may conclude that the depositional environment in the vicinity of HMI was somewhat less turbulent and or had more fine sediment inputs than during Year 20 .The exact cause of that lower turbulence is unknown. Regardless, no clear trends, affecting many samples from a large area, are evident. The grain size distribution of Year 21 samples is largely consistent with the findings of past monitoring years.



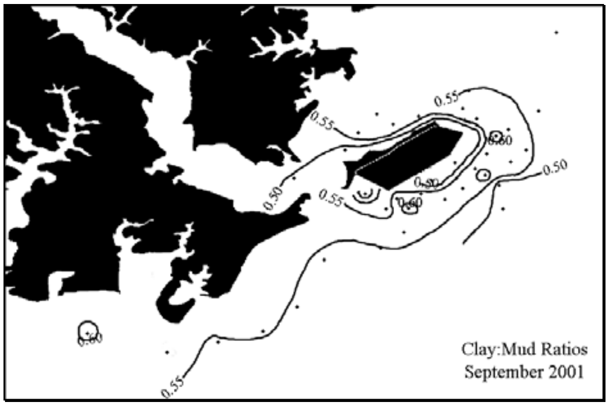
(a) September 2001 (Cruise 43)

(b) April 2002 (Cruise 44)

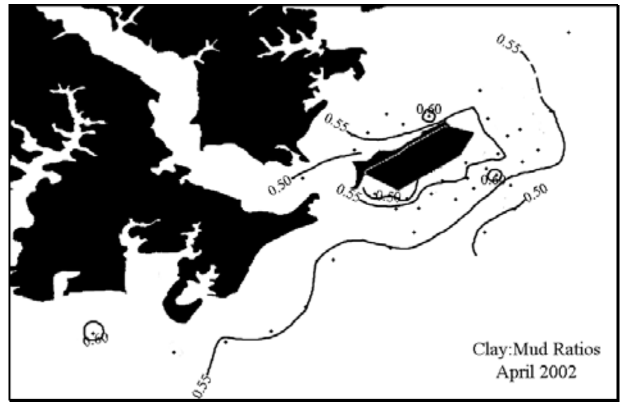
(c) September 2002 (Cruise 45)

(d) April 2003 (Cruise 46)

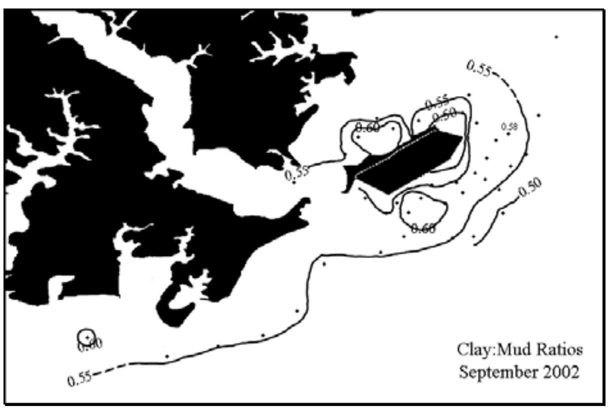
Figure 7: Sand distribution for Monitoring Years 20 and 21: (a) September 2001, (b) April 2002, (c) September 2002, and (d) April 2003. Contour intervals are 10%, 50%, and 90% sand.



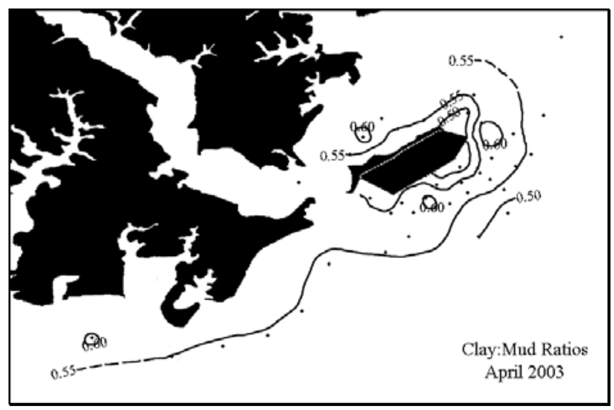
(a) September 2001 (Cruise 43)



(b) April 2002 (Cruise 44)



(c) September 2002 (Cruise 45)



(d) April 2003 (Cruise 46)

Figure 8: Clay:Mud ratios for Monitoring Years 20 and 21. Contour intervals are 0.50, 0.55, and 0.60.

Elemental Analyses

Interpretive Technique for Trace Metals

Eight trace metals were analyzed 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 trace 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 trace metal levels. Normalization of grain size induced variability of trace element concentrations was accomplished by fitting the data to the following equation:

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

where X = the element 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 3. The correlations are excellent for Cr, Fe, Ni, and Zn, indicating that the concentrations of these metals are directly related to the grain size of the sediment. The correlations for Mn and Cu are weaker, though still strong. In addition to being part of the lattice and adsorbed structure of the mineral grains, Mn occurs as oxy-hydroxide chemical precipitate coatings. These coatings cover exposed surfaces, that is, they cover individual particles as well as particle aggregates. Consequently, the correlation between Mn and the disaggregated sediment size fraction is weaker than for elements, 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 elements. 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 3: Coefficients and R^2 for a best fit of trace 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.

$$X = [\ a*Sand + b*Silt + c*Clay\ ]/100$$

	Cr	**Mn**	**Fe**	**Ni**	**Cu**	**Zn**	**Pb**	**Cd**
a	25.27	668	0.553	15.3	12.3	44.4	6.81	0.32
b	71.92	218	1.17	0	18.7	0	4.10	0.14
c	160.8	4158	7.57	136	70.8	472	77	1.373
R^2	0.733	0.36	0.91	0.82	0.61	0.77	0.88	0.12

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 3 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.

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

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 (0%) 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 $\pm2\sigma$

(±2 standard deviations) are within normal background variability for the region. Samples with a value of ±3σ can be within accepted background variability, but it is 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 3. The sigma level for Zn is ~30% (e.g. 1σ = 30%, 2σ = 60%, etc.).

General Results

A listing of the summary statistics for the elements analyzed is given in Table 4. Some features to note are:

1. Cd, Cr, Cu, Ni, Pb and Zn are found at some sites with concentrations that exceed the Effects Range Low (ERL) values; and
2. Cr, Ni and Zn exceed the ERM values at some sites.

ERL and Effects Range Medium (ERM) are proposed criteria put forward by National Oceanic and Atmospheric Administration (NOAA - Long et al. 1995) to gauge the potential for deleterious biological effects. Sediments with concentrations below the ERL are considered baseline concentrations with no expected adverse effects. Concentrations between the ERL and ERM may have adverse impacts to benthic organisms, while values greater than the ERM have probable adverse biological effects. These criteria are based on a statistical method of termed preponderance of evidence. The method does not allow for unique basin conditions and does not take into account grain size induced variability in metal concentrations in the sediment. The values are useful as a guide, but are limited in applicability due to regional difference. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, Pb, and Zn have samples significantly enriched compared to the baseline; however, based on work done in Baltimore Harbor, the normalized values are well below anticipated biological effects thresholds.

Table 4: Summary statistics for elements analyzed. ***[All concentrations are in ug/g unless otherwise noted]***

	Cd	Cr	Cu	Fe	Mn	Ni
Count	73	73	73	73	73	73
Ave.	1.3	117	45.4	4.78	4013	77
Std.	0.5	109	13.7	1.39	2180	25
Min.	0.4	23	9.4	0.89	485	18
Max.	2.2	995	74.9	8.12	11072	149
ERL	1.3	81	34	*N/A*	*N/A*	20.9
Exceed ERL	39	61	59.0	*N/A*	*N/A*	71
ERM	9.5	370	270	*N/A*	*N/A*	51.6
Exceed ERM	0	1	0	*N/A*	*N/A*	64

	Pb	Zn	P	N	C	S
Count	73	73	73	73	73	73
Ave.	58	311	0.093	0.227	3.164	0.255
Std.	20	107	0.027	0.066	0.923	0.136
Min.	10	56	0.019	0.039	0.449	0.008
Max.	102	598	0.144	0.325	4.601	0.635
ERL	46.7	150	*N/A*	*N/A*	*N/A*	*N/A*
Exceed ERL	57	66	*N/A*	*N/A*	*N/A*	*N/A*
ERM	218	410	*N/A*	*N/A*	*N/A*	*N/A*
Exceed ERM	0	11	*N/A*	*N/A*	*N/A*	*N/A*

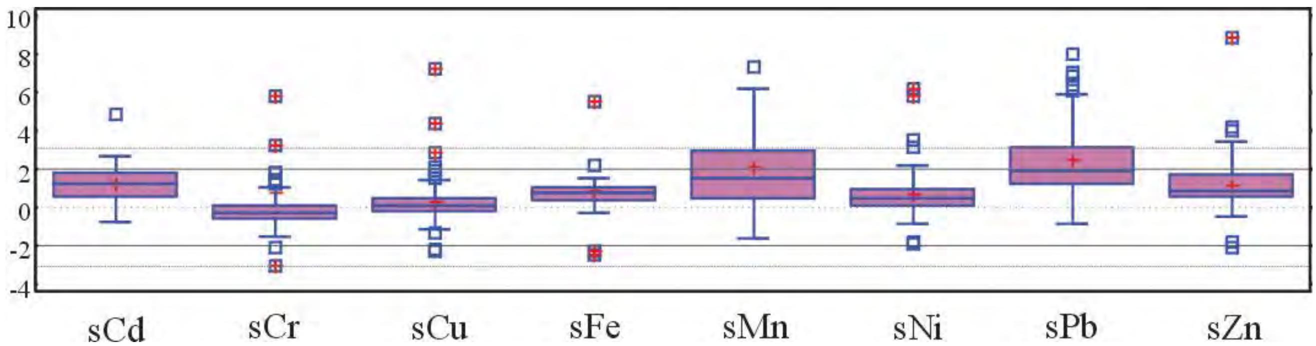


Figure 9: A box and whisker diagram showing the range of the data for both the fall and spring cruise. Cd is not shown due to the concentrations being below the detection limit for all but three samples.

The values presented in Table 4 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 9 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 sigma are considered to be within the natural variability of the baseline values. For both sampling cruises, all of the metals except Pb and Zn are within the range expected for normal baseline behavior in the area (Mn also exceeds the baseline but it is not on the list of Toxics of Concern). Pb has approximately half of the samples significantly exceeding the baseline levels, and Zn approximately a quarter of the samples. Zn and Pb will be discussed in the following sections.

Metal Distributions

Since the eighth monitoring year, increased metal levels (specifically Zn) have been noted in bottom sediments east and south of spillway #1. The results of previous monitoring studies have shown that the areal extent and magnitude of metals loadings to the exterior sedimentary environment is controlled by three primary factors. These factors are:

1.Discharge rate - controls the amount of metals discharged to the external sedimentary environment. Discharge from HMI at flows less than 10 MGD contribute excess metals to the sediment (see *Twelfth Year Interpretive Report*). The high metal loading to the exterior environment is the result of low input of water, 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. The process is similar to acid mine drainage. At discharge rates greater than 10 MGD, the water throughput (input from dredge disposal to release of excess water) submerges the sediment within the dike, minimizing atmospheric exposure, and dilutes and buffers any acidic leachate. As a result, higher discharge rates produce metal loadings that are close to background levels.

2.Flow of freshwater into the Bay from the Susquehanna River - The hydrodynamics of the Bay in the area of HMI are 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 *10th Year 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 dike 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 dike; the higher the discharge, the higher the concentration in the plume outside the dike.

3. The positions of the primary discharge points from the dike - 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 #1 and #4 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 #2 are spread more evenly to the north, east, and west. However, dispersion is not as great as from spillways #1 and #4 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 10 shows the sigma levels for Pb for the Year 21 monitoring period in the study area adjacent to HMI; sigma levels for Zn are shown in Figure 11. Sigma levels are the multiple of the standard deviation of the baseline data set. Data that falls within +/-2 sigma are considered within normal baseline variability. Data within the 2 -3 sigma range are transitional; statistically one sample in 100 would normally be expected to occur, in a small data set. The occurrence of 2 or more spatially contiguous stations in this range is significant. Any sample >3 sigma is significantly elevated above background. The shading in Figures 10 & 11 is used to highlight the areas that are significantly elevated above baseline levels. There are three primary areas that are highlighted in the Figures: Back River, Baltimore Harbor, and HMI.

Back River - The Back River influence is strongly seen for Pb. Pb apparently is being discharged by Back River during both of the sampling periods with the Spring levels being slightly more elevated than the Fall, with a larger spatial extent. Zn concentrations are within background levels.

Baltimore Harbor - Elevated levels of Pb and Zn extend into the area south of HMI, but do not reach the area adjacent to the island. The levels are comparable for the two sampling periods; the Fall cruise has the highest levels (reaching highs of ~12 sigma for Pb and ~8 sigma for Zn). Both metals in both sampling periods show a gradational change from higher values in the Baltimore Harbor diminishing to background levels near HMI.

HMI - In contrast to Year 20, the Spring cruise showed the highest elevated levels of both Zn and Pb. For Zn, there are only two samples (adjacent to Spillway 1b and 3) one station is considered transitional, with the other station slightly elevated, neither are of concern. The higher site near may be related to sediment off-loading operations or dewatering discharge from the south cell. The Fall cruise did not show any station with significantly elevated levels of Zn. Lead on the other hand, had enriched values in both sampling cruise in areas adjacent to Spillways 1b and 3. The southern site corresponded to the area of Zn enrichment off of Spillway 3, with levels reaching 5 sigma in the Spring increasing from 3 in the Fall. The northern site differed from the area of Zn enrichment, but corresponded to a pocket of finer sediments (see Figure 8). The levels at the northern site were the effectively the same for both cruises.

The distribution of Zn and Pb are similar, showing elevated metals levels in the three zones of acitivity seen in previous monitoring years as described above. The spatial extent and the levels found in the Baltimore Harbor and Back River zones vary according to seasonal climatic changes, that influence the hydroynamic conditions and sediment loading, and activity within those sources. The HMI zone is independent of these two source areas. The levels within the HMI zone are influenced by operations in the dike and input from the regional background. In regard to dike operations, this was an active year for placement of material in the dike. Discharge rate less than 10 Mgal/day, in conjunction with dewatering operations that have been operating for 6 months or more, produce the highest levels of metals in the exterior sedimentary environment. These conditions did not exist in Year 21. Placement operations worked in tandem with dewatering and crust management operations that were performed 6 months of the 12-month period. The dewatering operations were not performed in a contiguous period, but in 2 three-month periods; this reduced the potential for acid formation. Most of the discharge rates were low (64% less than 10 Mgal/day), especially prior to the Spring sampling period where 59% of the discharges from the dike were below 10 Mgal/day, and no discharge exceeded 30 Mgal/day; there were longer contiguous periods of lower flow. Consequently, the maximum levels of metals would be expected to be found during the Spring sampling; as seen in Figures 10 and 11. However, the discharge rates were intermittently high enough to lower the potential of acid formation (see Figures 2 & 3), so the metal levels in the exterior sediments are elevated, but relatively low and below levels of concern. The historical trend for Zn loading is shown in Figure 12. This figure shows the maximum % excess Zn found within the zone historically influenced by HMI for each of the monitoring cruises, with criteria indicating severity of the metals levels. The last two points represent the maxima found during the cruises for Year 21. The Fall cruise is border line transitional, comparable to the fall of the previous monitoring year. The Year 21 Spring cruise rebounds to a significantly elevated level, comparable to what was found between 1990 - 1999; however the high value is localized to one site while during the 1990 - 1999 period the spatial extent of the enriched area was much larger. This site is not a spurious point in that it is supported by the Pb distribution.

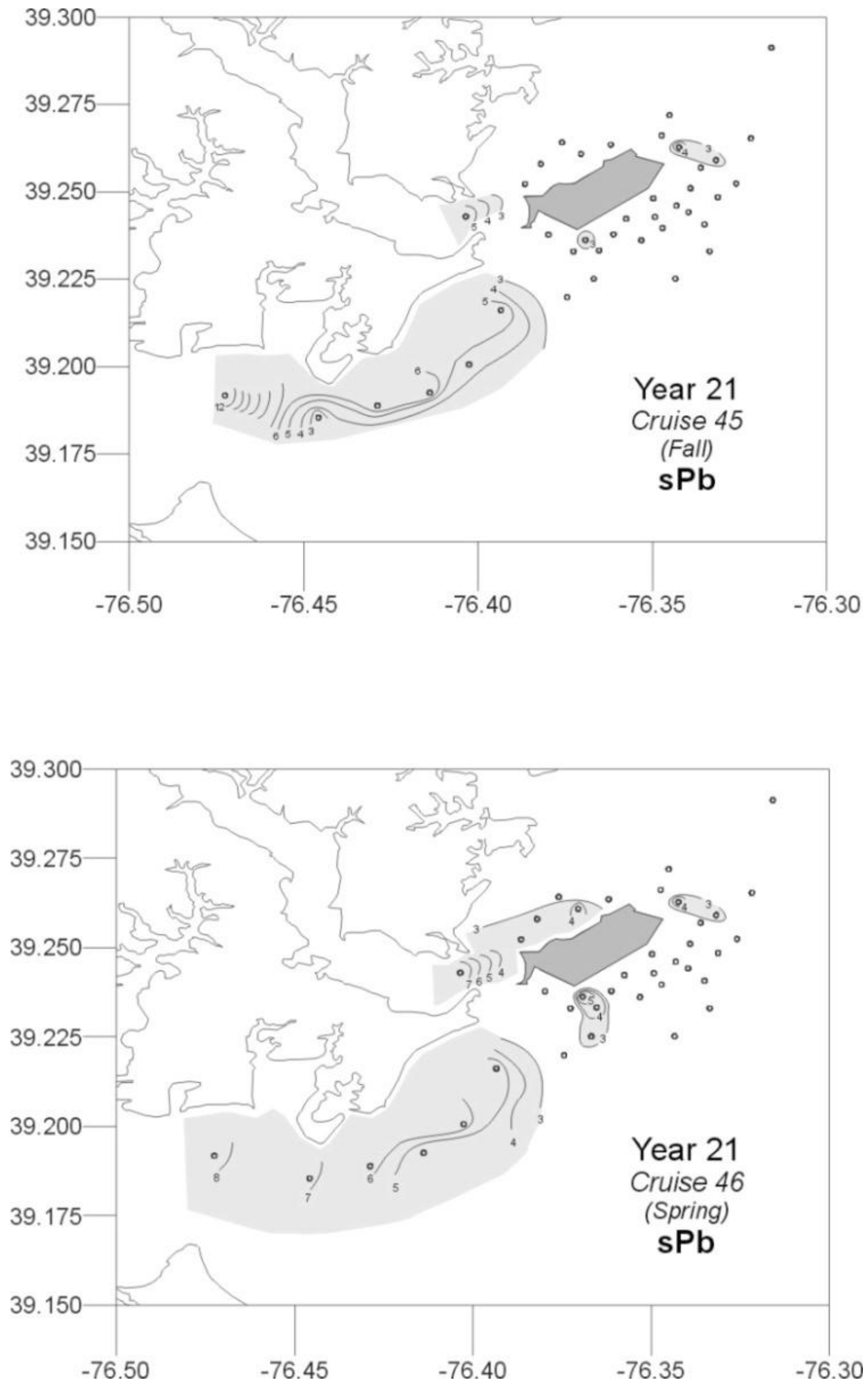


Figure 10: Distribution of Pb in the study area for the Fall and Spring sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional(values less than 3 not shown), >3 = significantly enriched (shaded in figures).

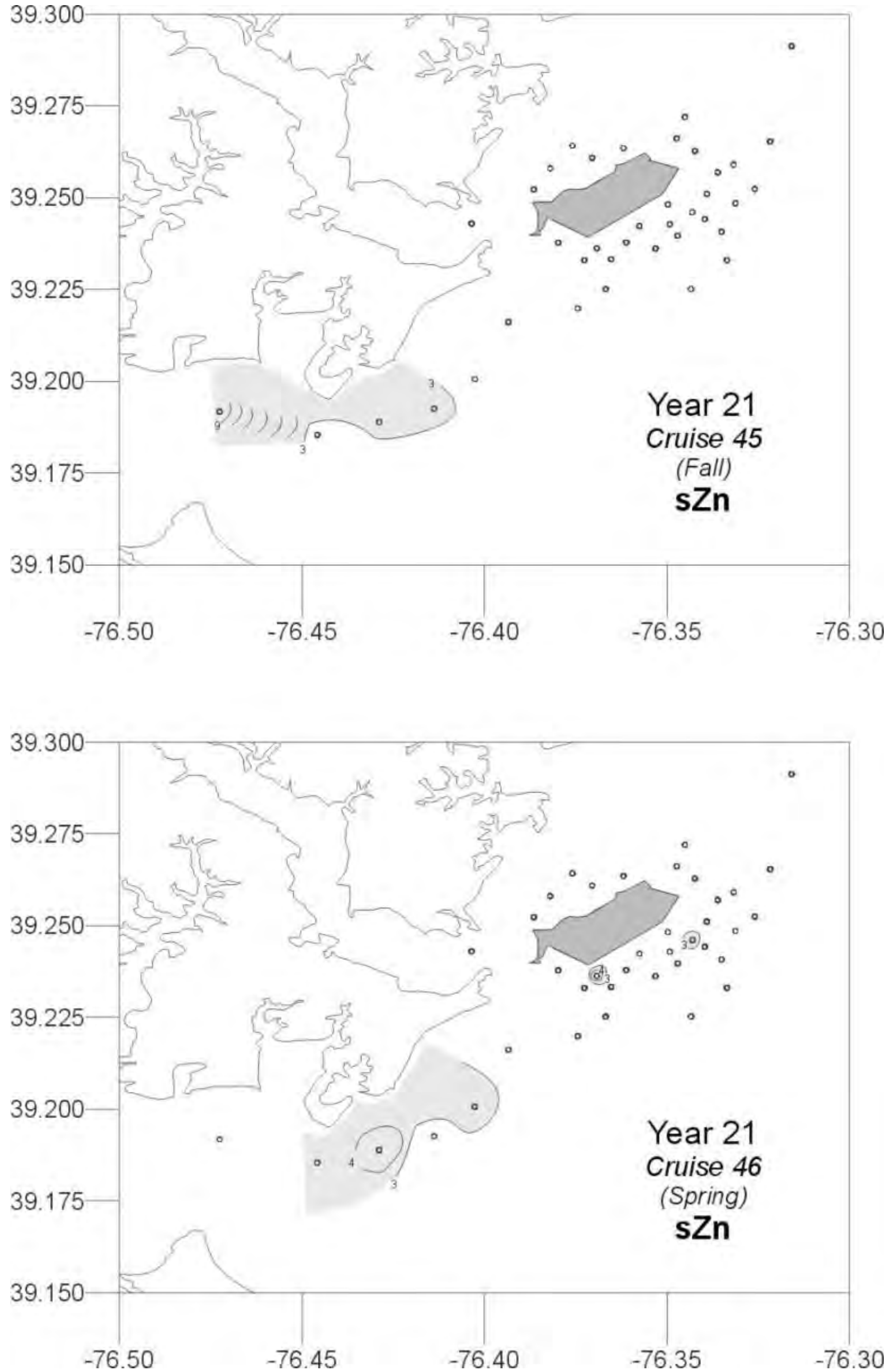


Figure 11: Distribution of Zn in the study area for the Fall and Spring sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional(values less than 3 not shown), >3 = significantly enriched (shaded in figures).

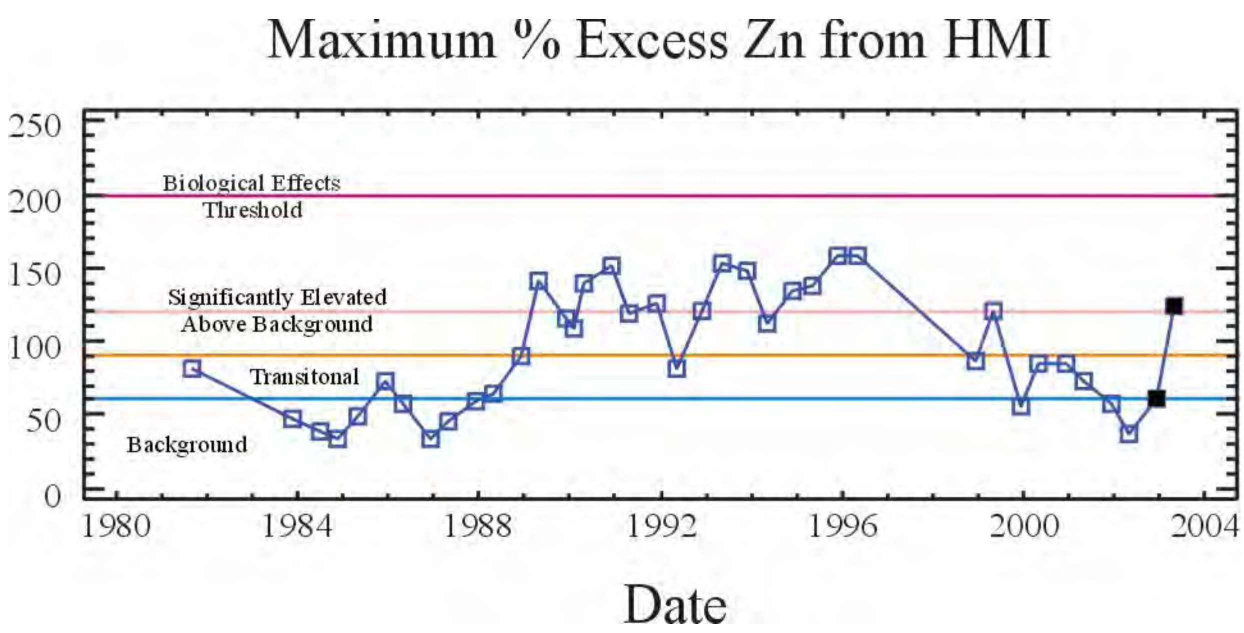


Figure 12: Record of the maximum % Excess Zn for all of the cruises MGS analyzed the sediments.

CONCLUSIONS AND RECOMMENDATIONS

The grain size distribution of the Year 21 sediment samples does not show any clear trends in sedimentation patterns from cruise to cruise. This is due to the complexity of the environmental conditions and source of material to the area. The clay:mud ratios show signs that the depositional environment was slightly less turbulent during Year 21 than in Year 20. In particular, in the areas near spillway #3 and in Hawk Cove, clay-rich sediments were found more predominately in September 2002. However, 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 21. The main reason for adding the Baltimore Harbor samples was to determine if the Harbor was a possible source of the trace metals often concentrated in sediments deposited between spillways #3 and #4. As was the case in previous monitoring years, the clay:mud distributions continued to argue against that possibility. In April 2003, there was a decrease in the extent of clay-rich sediments in the vicinity of the dike coupled with no changes at the Harbor mouth, again indicating two distinct depositional environments, as has been the case in the past. Presumably, trace metals derived from Baltimore Harbor are more likely to settle with clay-rich sediments at the mouth of the Harbor; whereas, those derived from the containment facility are deposited in the vicinity of the dike.

With regard to trace metals some features to note are:

1. Cd, Cr, Cu, Ni, Pb and Zn are found at some sites with concentrations that exceed the Effects Range Low (ERL) values; and
2. Cr, Ni and Zn exceed the ERM values at some sites.

ERL and Effects Range Medium (ERM) are proposed criteria put forward by National Oceanic and Atmospheric Administration (NOAA - Long et al. 1995) to gauge the potential for deleterious biological effects. Sediments with concentrations below the ERL are considered baseline concentrations with no expected adverse effects. Concentrations between the ERL and ERM may have adverse impacts to benthic organisms, while values greater than the ERM have probable adverse biological effects. These criteria are based on a statistical method of termed preponderance of evidence. The method does not allow for unique basin conditions and does not take into account grain size induced variability in metal concentrations in the sediment. The values are useful as a guide, but are limited in applicability due to regional difference. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, Pb, and Zn have significantly enriched samples compared to the baseline; however, based on work done in Baltimore Harbor, the normalized values are well below anticipated biological effects thresholds.

Most of the Pb and Zn enriched samples are associated with Baltimore Harbor and Back River. Material from the Harbor does not influence the sediments adjacent to the dike in the proximal zone ascribed to HMI. This is supported by both the sedimentation and metals distribution patterns in the area.

In the area effected by dike operations, there are only six sites with elevated metal levels, with the levels in Year 21 being higher than Year 20. Placement operations worked in tandem with dewatering and crust management operations that were performed 6 months of the 12-month period. The dewatering operations were not performed in a contiguous period, but in 2 three-month periods; this reduced the potential for acid formation. Most of the discharge rates were low (64% less than 10 Mgal/day), especially prior to the Spring sampling period where 59% of the discharges from the dike were below 10 Mgal/day, and no discharge exceeded 30 Mgal/day; there were longer contiguous periods of lower flow. Consequently, the maximum levels of metals would be expected to be found during the Spring sampling, as was the case. However, the discharge rates were intermittently high enough to lower the potential of acid formation, so the metal levels in the exterior sediments are elevated, but relatively low and below levels of concern. This is supported by the low pH values of the discharge never being in the range of free mineral acidity.

Persistent elevated metal levels in sediments around HMI indicate a need for continued monitoring, even though the levels were low during this sampling period. The metal levels in the exterior sediments continued to show a consistent response to the operations of the dike; low discharge rates increasing the metal loads to the sediment. Currently, the dike is actively accepting material, but as the dike reaches its capacity and the volume of effluent is expected to decline, dewatering of the contained material may lead to higher metal levels in the effluent. Exposure of dredged material to the air is likely to result in the mobilization of metals associated with those sediments, an effect analogous to acid mine drainage. Metals released in the effluent, particularly at low discharge rates, are deposited on the surrounding Bay floor and are increasing the long-term sediment load in the Bay. Although these levels are much lower than any biological effects threshold. Continued monitoring is needed in order to; detect if the levels increase to a point where action is required, document the effect that operations has on the exterior environment (for future project design), and to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of exposing contained dredged material to the atmosphere. Close cooperation with MES is important in this endeavor.

In order to assess the potential influence of Baltimore Harbor on the HMI exterior sediments better, the additional sampling sites be maintained, at least temporarily. Further, the South Cell will soon be converted to upland wetlands, with a constant flow of water being circulated through the ponds to produce conditions similar to tidal wetlands. Additional sample locations should be established near the discharge point to assess this new operation of the facility.

REFERENCES

Birkemeier, W.A., 1986, The Interactive Survey Reduction Program: Users's Manual to ISRP-PC 1.21, Waterways Experiment Station Coastal Engineering Research Center, Vicksburg, MS, 38 p.

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

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

Blatt, H., Middleton, G., and Murray, R., 1980, Origin of Sedimentary Rocks: Englewood Cliffs, NJ, Prentice-Hall, Inc., 782 p.

Butler, L.R.P., 1975, Application of atomic absorption in geochemistry, in Dean, J.A., and Rains, T.C., eds., Flame Emission and Atomic Absorption Spectrometry: Volume 3 - Elements and Matrices: New York, Marcel Dekker, Inc., p. 510-547.

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

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

Cuthbertson, R., 1992, Beach Erosion Study, in Assessment of the Environmental Impacts of the Hart and Miller Island Containment Facility: 9th Annual Interpretive Report Aug. 89 - Aug. 90: Annapolis, MD, Maryland Dept. of Natural Resources, Tidewater Admin., p. 46-60.

Cuthbertson, R., 1993, Beach Erosion Study, *in* Assessment of the Environmental Impacts of the Hart and Miller Island Containment Facility: 10th Annual Interpretive Report Aug. 90 - Aug. 91: Annapolis, MD, Maryland Dept. of Natural Resources, Tidewater Admin., p. 43-56.

Halka, J.P., 1987, LORAN-C Calibration in Chesapeake Bay: Baltimore, MD, Maryland Geol. Survey Report of Investigations No. 47, 34 p.

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

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

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

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

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

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

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

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

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

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

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

Kerhin, R.T., Hill, J., Wells, D.V., Reinharz, E., and Otto, S., 1982a, Sedimentary environment of Hart and Miller Islands, in Assessment of the Environmental Impacts of Construction and

Operation of the Hart and Miller Islands Containment Facility: First Interpretive Report August 1981 - August 1982: Shady Side, MD, Chesapeake Research Consortium, p. 64-99.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

PROJECT III: BENTHIC COMMUNITY STUDIES

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ABSTRACT

The benthic macroinvertebrate community in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI) was studied for the twenty-first consecutive year under Project III of the HMI Exterior Monitoring Program. The communities living at stations close to the facility (Nearfield and Back River/Hawk Cove) were compared to communities located at some distance from the facility (Reference). Water quality parameters, including dissolved oxygen concentrations, salinity, temperature, pH, conductivity and secchi depth were measured *in situ.*

Seventeen stations (11 Nearfield, 3 Reference, and 3 Back River/Hawk Cove stations) were sampled on September 12, 2002, and again on April 14, 2003. Infaunal samples were collected using a Ponar grab sampler, which collects 0.05 m^2 of substrate. Water quality parameters were measured using a Hydrolab Surveyor II at one-half meter from the bottom and at one-half meter from the surface to develop vertical water quality profiles.

A total of 43 taxa of benthic macroinvertebrates were found at these seventeen benthic community stations during Year 21 of monitoring. Several of the 43 taxa were clearly dominant. *Leptocheirus plumulosus* and Oligochaete worms of the family Tubificidae were among the numerically dominant taxa on both sampling dates, while *Rangia cuneata* and *Cyathura polita* were numerically dominant only in the September 2002 samples, and *Marenzelleria virdis* and Copepods were numerically dominant only in the April 2003 samples. Polychaete taxa richness was much higher in September 2002 than in April 2003 as a result of the complete absence of *Streblospio benedicti, Polydora cornuta, Glycinde solitaria, and Eteone heteropoda* in April 2003. Total abundance of all invertebrates (excluding Bryozoa) was higher at most stations in April 2003 than September 2002 due to high seasonal recruitment, especially of the polychaete worm *M. viridis.*

Species diversity was examined using the Shannon-Wiener diversity index. Diversity was twice as high in September 2002 than in April 2003. The proportion of pollution-sensitive taxa (*C. polita*, *R. cuneata*, *M. viridis*, *G. solitaria*, *Macoma balthica*, *Mya arenaria*) was higher in April 2003 than in September 2002. This was primarily due to the high spring recruitment of *M. viridis*. The proportion of pollution-indicative taxa (the polychaete worms *E. heteropoda, S. benedicti*, the oligochaete worms in the family Tubificidae, the clam *Mulinia lateralis*, and the chironomid *Coelotanypus* sp.) was higher in September 2002 than in April 2003. This was primarily due to the absence of *S. benedicti* in April 2003.

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI, Weisberg et al. 1997), a multi-metric index of biotic condition that evaluates summer populations (during the July 15th to September 30th timeframe) of benthic macroinvertebrates, was calculated for all stations sampled during the September 2002 cruise. Overall, the Benthic Index of Biotic Integrity scores improved or remained the same when compared to Year 20 and were generally similar to the B-IBI scores of the previous 6 years of monitoring at Hart-Miller Island. This year, twelve stations exceeded the benchmark criteria of 3.0, three stations met it and only 2 stations failed to meet the benchmark.

Statistical analyses found no significant differences between the ten most abundant infaunal taxa of Nearfield, Reference, and Back River/Hawk Cove stations for September 2002 and April 2003.

INTRODUCTION

Annual dredging of the approach channels to the Port of Baltimore is necessary for removal of navigational hazards to shipping. An average of 4-5 million cubic yards of Bay sediments are dredged each year so that Baltimore can remain competitive with ports in New York and Virginia. This requires the State of Maryland to develop environmentally responsible containment sites for placement of dredged material. In 1981, the Hart-Miller Island Dredged Material Containment Facility (HMI) was constructed to accommodate the dredged material management needs for the Port of Baltimore and specifically the need to manage contaminated sediments dredged from Baltimore's Inner Harbor. HMI is a 1,140-acre artificial island surrounded by a 29,000-foot long dike constructed along the historical footprints of Hart and Miller Islands at the mouth of the Back River. A series of five spillways are located around the perimeter of the facility to discharge excess water released from on-site dredged material disposal operations.

As part of the environmental permitting process for dredged material containment facilities, an exterior monitoring program was developed to assess any environmental impacts associated with HMI. Various agencies have worked together since the inception of this program to monitor for environmental impacts resulting from dike construction and dredged material management activities. Studies were completed prior to and during the early construction period to determine baseline environmental conditions in the HMI vicinity. The results of post-construction monitoring have then been compared to this baseline, as well as to interseasonal and interannual data. This report represents the twenty-first consecutive year of the benthic macroinvertebrate community monitoring since 1981. In Year 21, the Maryland Department of the Environment was responsible for all aspects of benthic community monitoring.

The goals of the Year 21 benthic community monitoring were:

- To monitor the benthic community condition in fulfillment of environmental permit requirements;

- To examine the condition of the benthic macroinvertebrate community using, among other analytical tools, the Chesapeake Bay Benthic Index of Biological Integrity (B-IBI; Weisberg et al. 1997), and to compare the results at Nearfield stations to present local reference conditions;

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

- To facilitate trend analysis by providing data of high quality for comparison with past HMI monitoring studies.

METHODS AND MATERIALS

For the Year 21 benthic community studies, staff from the Maryland Department of the Environment's Biological Assessment Section collected benthic macroinvertebrate samples and measured several *in situ* water quality parameters. Field sampling cruises were conducted from the Maryland Department of Natural Resources vessel, the *Kerhin*, in late summer on September 12, 2002, and in spring on April 14, 2003. Seventeen benthic stations (Table 5; Figure 13) in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI) were included in the study.

Table 5: Target Locations (latitudes and longitudes in degrees, decimal minutes), and 7-digit codes of stations used for Year 21 benthic community monitoring and Predominant sediment type at each station for September and April.

Station #	Latitude	Longitude	Sediment Type		Maryland 7-Digit Station Designation
Nearfield Station			Sept	April	
MDE-01	39° 15.3948	76° 20.568	Sand	Shell	XIF5505
MDE-03	39° 15.5436	76° 19.9026	Sand	Silt/clay	XIG5699
MDE-07	39° 15.0618	76° 20.3406	Shell	Silt/clay	XIF5302
MDE-09	39° 14.7618	76° 20.5842	Shell	Silt/clay	XIF4806
MDE-16	39° 14.5368	76° 21.4494	Silt/clay	Silt/clay	XIF4615
MDE-17	39° 14.1690	76° 21.1860	Shell	Silt/clay	XIF4285
MDE-19	39° 14.1732	76° 22.1508	Silt/clay	Silt/clay	XIF4221
MDE-24	39° 14.2650	76° 22.7862	Sand	Sand	XIF4372
MDE-33	39° 15.9702	76° 20.8374	Sand	Sand	XIF6008
MDE-34	39° 15.7650	76° 20.5392	Sand	Silt/clay	XIF5805
MDE-35	39° 16.3182	76° 20.7024	Silt/clay	Silt/clay	XIF6407
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	Shell	Silt/clay	XIG7589
Back River/Hawk Cove Stations					
MDE-27	39° 14.5770	76° 24.2112	Silt/clay	Silt/clay	XIF4642
MDE-28	39° 15.3900	76° 22.7304	Silt/clay	Silt/clay	XIF5232
MDE-30	39° 15.8502	76° 22.5528	Silt/clay	Silt/clay	XIF5925

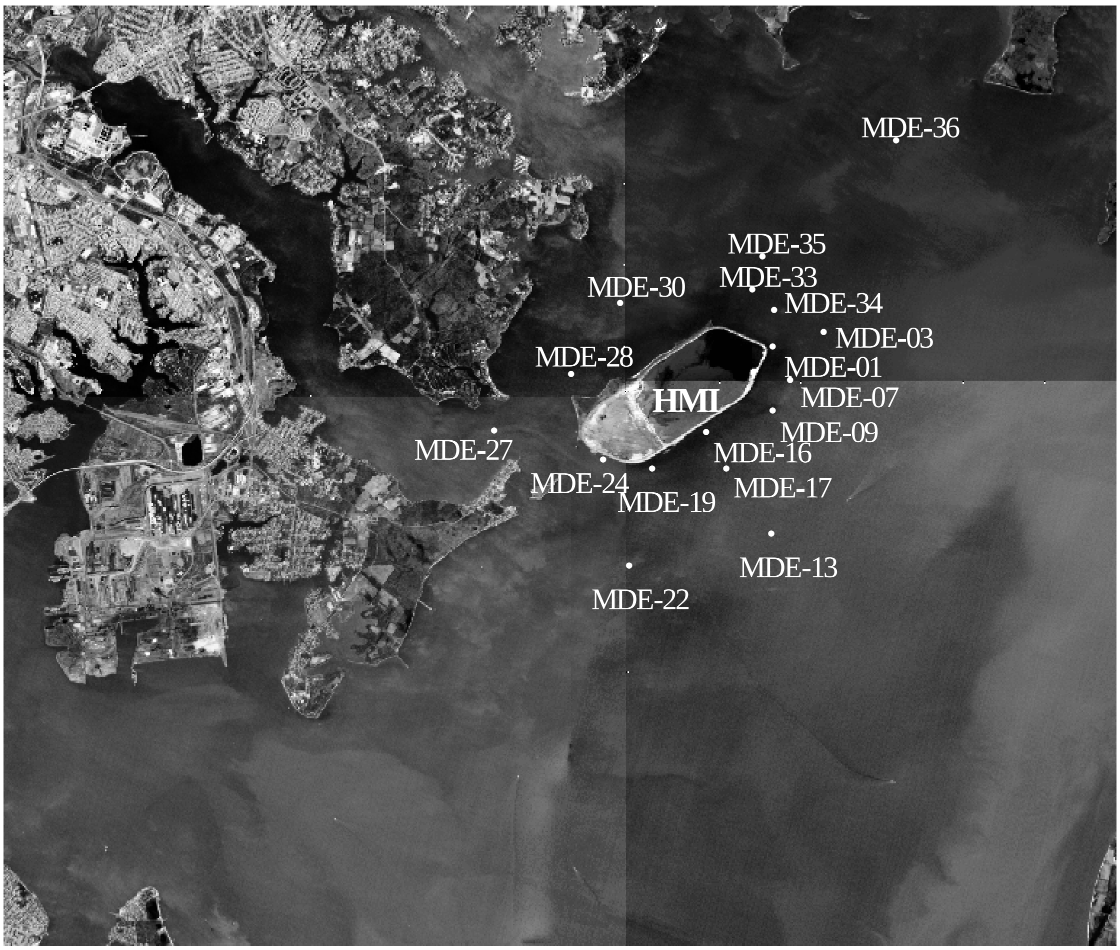

Figure 13: Year 21 Benthic Sampling Stations for the HMI Exterior Monitoring Program.

All stations sampled during Year 20 of monitoring were again sampled for Year 21 except for the Harbor stations, MDE-38, MDE-39, MDE-40 and MDE-41. In Year 18, station MDE-41 was the only Baltimore Harbor station sampled. Three additional stations (MDE-38, MDE-39, and MDE-40) were added in Year 19 to form a transect from the Baltimore Harbor area to HMI. This transect was sampled in conjunction with sediment and benthic tissue analysis studies as part of a comprehensive study to assess the Harbor's influence on environmental conditions in the HMI vicinity. These stations were eliminated from the study in Year 21 because no significant impact from the Harbor was detected in Year 18, 19 or 20. Stations were classified by location and dominant sediment type (Table 5). There were three location groups (Nearfield stations, Reference stations, and Back River/Hawk Cove stations) and three sediment types (silt/clay, shell, and sand). All benthic community sampling stations coincided with stations sampled by the Maryland Geological Survey (MGS) for sedimentary analysis. Stations were located using a differential global positioning system (GPS) navigation unit.

Temperature, depth, salinity, pH, conductivity, and dissolved oxygen were measured *in situ* using a Hydrolab Surveyor II water quality meter in September 2002 and April 2003. Water quality parameters were measured at approximately 0.5 m (1.6 feet) below the surface and 1.0 m (3.3 feet) above the bottom in order to develop a vertical water quality profile at each station. The secchi depth was measured at all stations during both seasons. Water quality data from all depths are found under Project III of the *Year 21 Data Report*.

All benthic 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 all stations. A subjective estimate of the substrate composition [percent contributions of detritus, gravel, shell, sand, and silt/clay (mud)] was made at each station. Samples were then rinsed through a 0.5-mm sieve on board the vessel and preserved in a solution of 10% formalin and bay water, with rose bengal dye added to stain the benthic organisms.

In the laboratory, each benthic macroinvertebrate sample was placed into a 0.5-mm sieve and rinsed to remove the field preservative and sediment. Organisms were sorted from the remaining debris, separated into vials by major taxonomic groups, and preserved in 70% ethanol. Large organisms were identified to the lowest practical taxon using a stereo dissecting microscope. Members of the insect family Chironomidae were mounted on slides and identified to the lowest practical taxon using a binocular compound microscope. In cases where an animal was fragmented, only the head portion, if fully intact and identifiable, was counted as an individual organism. 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.

All laboratory staff were required to achieve a minimum baseline sorting efficiency. Each staff member was required to achieve three consecutive lab sample sorts equal to or greater than 95% recovery of all organisms, as determined by a qualified laboratory technician. In addition to the QA/QC procedure for sorting efficiency, 10% of all samples identified were sent to an outside taxonomist with the EPA for a blind QA/QC and achieved ≥ 90% efficiency.

Six main 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 Nematoda and Bryozoa). The first four of these measures were used to calculate the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) for September 2002. 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 (Weisberg et al. 1997). The B-IBI has not been calibrated for periods outside the summer index period (July 15 through September 30) and, thus, was not used with the April 2003 data. In addition to the above metrics, we examined 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*).

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 meter squared (#/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 21 Data Report*. Total Infaunal Abundance was calculated as the average abundance of infaunal organisms per meter squared (#/m^2). Two different measures of total abundance were calculated because epifaunal organisms are not included in the calculation of the B-IBI (Ranasinghe et al. 1994).

Pollution-Sensitive Taxa Abundance was calculated as the percentage of total infaunal abundance represented by pollution-sensitive taxa (the clams *M. balthica, R. cuneata*, and *Mya arenaria* the worms *Marenzelleria viridis* and *Glycinde solitaria,* and the isopod *Cyathura polita*). Pollution-indicative taxa abundance was calculated as the percentage of total infaunal abundance represented by pollution-indicative taxa (the clam *Mulinia lateralis,* the polychaete worms *Streblospio benedicti,* and *Eteone heteropoda,* and oligochaete worms of the family Tubificidae). Taxa were designated as pollution-indicative or pollution-sensitive according to Weisberg et al. (1997).

The Shannon-Wiener Diversity Index (H') was calculated for each station after data conversion to base 2 logarithms (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. Infaunal taxa richness was calculated as the number of infaunal taxa found in all three replicates. The abundance of the three most common taxa at reference and monitoring stations was also examined.

To evaluate the numerical similarity of the infaunal abundances among the 17 stations, a single-linkage cluster analysis was performed on an Euclidean distance matrix comprised of station infaunal abundance values for all 21 stations. This analysis was performed separately for September 2002 and April 2003 data. Friedman's nonparametric test was used to analyze the differences of the 10 most abundant infaunal species among the Nearfield, Reference and Back River/Hawk Cove stations for both September 2002 and April 2003. The statistical analyses were performed using Statistica, Version 6.0.

RESULTS AND DISCUSSION

Water Quality

Variations in secchi depth, salinity, temperature, dissolved oxygen, conductivity, and pH water quality values throughout the water column were generally small, indicating that no major vertical stratification occurred. Exceptions were stations MDE-13 and MDE-35 in April 2003, where steep gradients in dissolved oxygen and salinity were measured. Water quality data for all parameters at all stations are found in the *Year 21 Project III Data Report*. The following discussion will be limited to bottom values for the first four parameters with non-stratified water column conditions prevailing, bottom water quality measurements are most relevant for benthic macroinvertebrate health. Secchi depths were greater in September 2002 (Table 6, range=0.7m-1.4m, average=1.28m ± 0.22m) than those in April 2003 (Table 7, range=0.5m-0.8m, average=0.80m ± 0.09m). Stations MDE-13 and MDE-24 had the lowest Secchi depth (0.7m) in September 2002. All Secchi depth at all stations increased in September 2002 except MDE-13, which remained at 0.7 m for both September 2002 and April 2003. It should be kept in mind that secchi depth measurements provide a snapshot of the conditions prevalent at the time of sampling, but do not necessarily reflect the dominant water clarity conditions for the entire season.

In Year 21, bottom water temperatures did not vary much between stations during both sampling seasons. The September 2002 bottom water temperatures in Year 21 (Table 6, range= 23.0 °C – 24.4 °C, average=23.61°C ± 0.38°C) were greater than those seen at HMI in the previous four monitoring years. Bottom water temperatures were seasonably lower in April 2002 with a range of 7.29°C –10.02 °C and an average of 8.67°C ± 0.76°C. In addition, the April 2003 bottom water temperatures were lower than those recorded in April 2002.

The bottom dissolved oxygen (DO) concentrations remained above the Maryland water quality criterion of 5 ppm [COMAR 26.08.02.03 – 3A(2)] during both seasons. Bottom DO concentrations were lower in September 2002 (Table 6, range=6.0 ppm-7.66 ppm, average=6.85 ppm ± 0.47 ppm) than those in April 2003 (Table 7, range=7.46 ppm-10.5 ppm, average=9.26 ppm ± 0.91 ppm).

In September 2002, the lowest bottom DO concentration was 6.0 ppm, recorded at station MDE-17. It is important to note that this station had the second highest temperature (24.1°C) in September 2002. The low bottom DO concentration at station MDE-17 may have been due to the fact that the solubility of a gas in water decreases as the temperature increases (Smith 1996). The highest bottom DO concentration in September 2002 (7.66 ppm) was recorded at station MDE-35, which had the lowest temperatures recorded (23.0°C). Similarly, since cold water holds more gas (Smith 1996), station MDE-35 may have held a high bottom DO concentration compared to other stations with warmer bottom temperatures.

In April 2003, the lowest bottom DO concentration was 7.46 ppm, recorded at station MDE-22. Since this station also had one of the lowest bottom temperatures (7.29°C), it may have had low bottom DO concentrations due to reasons similar to ones stated above. The highest bottom DO concentration (10.5 ppm) was seen at Station MDE-33, but there was no link to temperature.

Bottom salinity was greater in September 2002 (6, range=9.3 - 11.8 ppt, average=10.88 ± 0.79 ppt) than in April 2003 (Table 7, range=2.16 ppt-6.45 ppt, average=3.52 ± 1.17 ppt). This variation is typical of seasonal variations in salinity in the upper region of the Chesapeake Bay. This region of the Bay typically ranges between the oligohaline (0.5 – 5 ppt) and mesohaline (>5ppt – 18 ppt) salinity regimes (Lippson and Lippson 1997).

In Year 21, the highest bottom salinity was seen at Nearfield station MDE-17 in September 2002 (11.8 ppt) and at Reference station MDE-13 in April 2003 (6.45 ppt). This varied from Year 20, where Harbor transect stations showed the greatest salinity for both seasons. However, these stations were not sampled in Year 21.

The stations with the lowest bottom salinity for Year 21 were mostly different from those in Year 20. In Year 21, the lowest salinity was seen at station MDE-28 and MDE-30 in September 2002 (9.3 ppt) and station MDE-34 in April 2003 (2.16 ppt). This varied from Year 20, where the lowest salinity was seen at MDE 28 for April 2002 and at MDE 30 for September 2001. However, the salinity at MDE-30 was similar to Year 20. Stations MDE-28 and MDE-30 are Back River/Hawk Cove stations, which receive freshwater input and also recorded the lowest bottom salinity in Year 20. Station MDE-34 is a Nearfield station. Three stations varied in salinity in April 2003 within the measured vertical layers in comparison to the rest of the stations. Station MDE-13 had a vertical salinity range of 2.44 - 6.45 ppt (Table 7). In addition, station MDE-22 had a vertical salinity range of 2.14 - 5.74 ppt (Table 7). Lastly, station MDE-35 had a vertical salinity range of 1.98 - 4.13 ppt (Table 7).

Table 6: Water quality parameters measured *in situ* at all HMI stations on September 12, 2002

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt; ‰)	Temp. (C)	Dissolved Oxygen (mg/l)	pH	Secchi Depth (m)
Nearfield Stations								
MDE-01	XIF5505	Surface	0.5	11.0	23.6	6.96	7.25	1.0
		Bottom	3.3	11.1	23.7	6.75	7.22	
MDE-03	XIG5699	Surface	0.5	10.4	23.3	7.4	7.3	1.4
		Bottom	4.8	10.8	23.3	7.09	7.3	
MDE-07	XIF5302	Surface	0.5	10.5	23.2	7.23	7.21	1.0
		Bottom	4.5	11.2	23.6	6.99	7.24	
MDE-09	XIF4806	Surface	0.5	10.7	23.3	7.2	7.23	1.1
		Bottom	4.7	11.2	23.6	6.99	7.25	
MDE-16	XIF4615	Surface	0.5	10.7	23.4	7.11	7.2	0.8
		Bottom	3.9	11.7	24.18	6.27	7.17	
MDE-17	XIF4285	Surface	0.5	10.8	23.5	7.0	7.22	1.0
		Bottom	4.2	11.8	24.1	6.0	7.15	
MDE-19	XIF4221	Surface	0.5	10.7	23.4	6.9	7.17	1.0
		Bottom	3.8	11.7	23.6	6.67	7.16	
MDE-24	XIF4372	Surface	0.5	10.7	23.6	6.67	7.17	0.7
		Bottom	1.3	11.4	24.4	6.3	7.18	
MDE-33	XIF6008	Surface	0.5	10.6	23.4	6.94	7.18	0.8
		Bottom	1.8	10.6	23.38	6.92	7.18	
MDE-34	XIF5805	Surface	0.5	11.0	23.5	7.1	7.22	0.8
		Bottom	2.1	11.0	23.5	7.03	7.23	
MDE-35	XIF6407	Surface	0.5	10.0	23.0	7.68	7.22	1.4
		Bottom	2.8	10.2	23.0	7.66	7.23	
Reference Stations								
MDE-13	XIG3506	Surface	0.5	11.4	23.5	6.9	7.28	0.7
		Bottom	4.1	11.4	23.5	6.93	7.28	
MDE-22	XIF3224	Surface	0.5	11.0	23.57	6.63	7.21	1.0
		Bottom	4.3	11.5	24.11	6.32	7.23	
MDE-36	XIG7589	Surface	0.5	9.3	22.9	7.53	7.09	1.0
		Bottom	2.5	9.6	23.1	7.27	7.08	
Back River/Hawk Cove Stations								
MDE-27	XIF4642	Surface	0.5	10.7	23.2	7.06	7.34	0.8
		Bottom	3.0	11.2	23.57	6.3	7.2	
MDE-28	XIF5232	Surface	0.5	9.3	23.4	7.5	7.13	0.8
		Bottom	1.9	9.3	23.3	7.5	7.2	
MDE-30	XIF5925	Surface	0.5	9.3	23.5	7.76	7.2	0.8
		Bottom	2.5	9.3	23.4	7.5	7.21	

Table 7: Water quality parameters measured *in situ* at all HMI stations on April 14, 2003.

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt)	Temp. (C)	Dissolved Oxygen (mg/l)	pH	Secchi Depth (m)
Nearfield Stations								
MDE-01	XIF5505	Surface	0.5	1.9	9.9	10.6	7.59	0.6
		Bottom	4.3	2.3	9.28	10.4	7.54	
MDE-03	XIG5699	Surface	0.5	2.44	9.48	10.35	7.5	0.7
		Bottom	3.0	3.0	8.8	9.7	7.39	
MDE-07	XIF5302	Surface	0.5	3.18	8.78	9.7	7.4	0.5
		Bottom	5.0	3.4	8.51	9.5	7.41	
MDE-09	XIF4806	Surface	0.5	2.81	9.0	9.9	7.49	0.6
		Bottom	5.5	3.73	8.35	9.1	7.35	
MDE-16	XIF4615	Surface	0.5	3.38	8.6	8.9	7.36	0.6
		Bottom	4.4	3.9	8.27	9.0	7.3	
MDE-17	XIF4285	Surface	0.5	2.26	9.2	9.9	7.52	0.8
		Bottom	4.6	4.32	8.16	8.9	7.29	
MDE-19	XIF4221	Surface	0.5	3.44	8.79	9.4	7.35	0.5
		Bottom	1.8	3.5	8.68	9.5	7.35	
MDE-24	XIF4372	Surface	0.5	2.0	9.42	9.9	7.5	0.5
		Bottom	3.0	3.79	8.38	9.1	7.26	
MDE-33	XIF6008	Surface	0.5	1.8	10.0	10.67	7.6	0.7
		Bottom	2.4	2.3	9.62	10.5	7.58	
MDE-34	XIF5805	Surface	0.5	2.09	9.85	10.42	7.58	0.7
		Bottom	4.0	2.16	9.6	10.5	7.58	
MDE-35	XIF6407	Surface	0.5	1.98	10.3	10.4	7.61	0.7
		Bottom	3.5	4.13	7.8	8.6	7.22	
Reference Stations								
MDE-13	XIG3506	Surface	0.5	2.44	9.46	10.4	7.55	0.7
		Bottom	5.0	6.45	7.29	7.6	7.15	
MDE-22	XIF3224	Surface	0.5	2.14	9.52	10.61	7.58	0.7
		Bottom	5.4	5.74	7.5	7.46	7.19	
MDE-36	XIG7589	Surface	0.5	1.68	10.3	10.39	7.6	0.6
		Bottom	3.3	2.6	8.7	10.0	7.48	
Back River/Hawk Cove Stations								
MDE-27	XIF4642	Surface	0.5	1.12	11.0	10.8	8.05	0.7
		Bottom	3.4	2.32	9.7	9.45	7.52	
MDE-28	XIF5232	Surface	0.5	1.08	11.8	10.9	7.8	0.6
		Bottom	2.5	2.55	10.02	10.1	7.7	
MDE-30	XIF5925	Surface	0.5	1.23	11.2	10.7	7.8	0.6
		Bottom	3.2	3.7	8.8	8.0	7.25	

Benthic Macroinvertebrate Community

Taxa Richness and Dominance

A total of 43 taxa were found over the two seasons of sampling during Year 21 of benthic community monitoring in the vicinity of Hart- Miller Island. This is similar to the previous three years where Year 20 had a total of 41 taxa, Year 19 had a total of 42 taxa, and Year 18 had a total of 41 taxa. In terms of station type, 9 taxa were found only at Silt/Clay stations. These nine taxa were: *M. lateralis*, *Procladius* sp., *Callinectes sapidus, Morone americana, Anguilla rostrada,* an undetermined species from the Class Ostracoda, an undetermined species from the Order Lophogastrida, an undetermined species from the Class Anthozoa, and an undetermined species from the Order Hemiptera. In addition, three taxa were only found at Shell stations. These three taxa were: *Balanus subalbidus, Gobiosoma bosci*, and an undetermined species from the Subfamily Orthocladiinae. Furthermore, *M. arenaria* was only found at Sand stations. In terms of station type, nine taxa were only found at Nearfield stations. These nine taxa were: *Mytilopsis leucophaeata, B. subalbidus, G. bosci, M. arenaria, C. sapidus, M. americana, A. rostrada,* an undetermined species from the Subfamily Orthocladiinae, and an undetermined species from the Suborder Cladocera. In addition, *M. lateralis* and an undetermined species from the Class Anthozoa were only found at reference stations. Furthermore, an undetermined species from the Order Hemiptera was only found at Back River/Hawk Cove stations.

The most common taxa were members of the phyla Arthropoda (joint-legged organisms), Annelida (segmented worms), and bivalve mollusks (shellfish having two separate shells joined by a muscular hinge). Twenty species of Arthropoda were found in the course of the study. This is higher than the fifteen species of arthropods found in Year 20. The most common types of arthropods were the copepods followed by amphipods (such as *Leptocheirus plumulosus*) and the isopods (such as *C. polita*). Seven species of annelid worms in the class Polychaeta were found. This is lower than the ten species of polychaetes found in Year 20. It is important to note that Polychaete Taxa Richness was much higher in September 2002 (7) than in April 2003 (3). For example, *S. benedicti, Polydora cornuta, G. solitaria, and E. heteropoda* were completely absent in April 2003. This may have been due to a die-off of polychaetes in the winter of 2002/2003. The unusually cold winter resulted in lower April 2003 bottom water temperatures than those recorded in April 2002, which may have caused mortality to the indigenous benthos. Seven species of bivalve mollusks were found. Bivalve mollusk taxa richness in Year 21 (7) was equivalent to that of year 20. However, bivalve mollusk average abundances were much lower in April 2003 than in September 2002 (Tables 8 & 9). This may have also been due to a winter die-off of bivalve mollusks.

Table 8: Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 21 late summer, September 2002 sampling, by substrate and station type.

Taxon	Average Abundance, All stations	Total Abundance, All stations	Substrate			Station Type		
			Silt/Clay	Shell	Sand	Near-field	Ref.	Back River
Nemata	3.4	57.6	6.4	1.6	0.0	1.2	2.1	12.8
Carinoma tremophoros	44.0	748.8	52.0	46.4	29.4	41.3	55.5	42.7
Bivalvia	22.2	377.6	27.2	12.8	21.8	18.6	36.3	21.3
Macoma sp	32.0	544.0	28.0	8.0	57.6	38.4	17.1	23.5
Macoma balthica	106.2	1804.8	111.2	158.4	56.3	118.1	93.9	74.7
Macoma mitchelli	23.7	403.2	16.8	11.2	44.8	29.1	19.2	8.5
Rangia cuneata	286.5	4870.4	200.0	307.2	408.3	329.9	187.7	226.1
Mulinia lateralis	1.9	32.0	4.0	0.0	0.0	0.0	10.7	0.0
Ischadium recurvum	12.4	211.2	0.0	49.6	2.6	19.2	0.0	0.0
Mytilopsis leucophaeata	8.7	147.2	0.0	12.8	19.2	13.4	0.0	0.0
Capitellidae	3.8	537.6	0.0	8.0	6.4	5.8	0.0	0.0
Heteromastus filiformis	31.6	889.6	20.8	41.6	41.0	36.7	42.7	2.1
Marenzellaria viridis	52.3	1664.0	40.8	67.2	58.9	41.3	66.1	78.9
Streblospio benedicti	97.9	198.4	91.2	161.6	57.6	82.6	117.3	134.4
Polydora cornuta	11.7	582.4	20.0	8.0	1.3	1.7	6.4	53.3
Nereididae	34.3	1209.6	12.8	105.6	11.5	44.2	10.7	21.3
Neanthes succinea	71.2	19.2	42.4	153.6	51.2	90.8	14.9	55.5
Glycinde solitaria	1.1	160.0	1.6	0.0	1.3	1.2	2.1	0.0
Eteone heteropoda	9.4	320.0	12.0	9.6	5.1	7.6	2.1	23.5
Tubificidae	151.3	2572.8	188.0	217.6	39.7	108.2	179.2	281.6
Amphipoda	16.9	38.4	29.6	4.8	6.4	8.7	25.6	38.4
Gammaridea	2.3	371.2	4.8	0.0	0.0	0.6	8.5	2.1
Ameroculodes spp complex	21.8	2515.2	13.6	20.8	35.8	23.3	14.9	23.5
Leptocheirus plumulosus	148.0	339.2	262.4	44.8	47.4	74.5	249.6	315.7
Melita nitida	20.0	19.2	40.0	4.8	0.0	7.0	25.6	61.9
Corophiidae	1.1	96.0	0.0	0.0	3.8	1.7	0.0	0.0
Apocorophium lacustre	5.6	96.0	3.2	1.6	12.8	7.6	0.0	4.3
Cyathura polita	219.1	3724.8	256.8	230.4	149.8	216.4	209.1	238.9
Edotia triloba	11.3	192.0	5.6	9.6	21.8	10.5	14.9	10.7
Chiridotea almyra	3.4	57.6	0.0	0.0	11.5	5.2	0.0	0.0
Balanus improvisus	24.8	422.4	0.8	104.0	0.0	38.4	0.0	0.0

Table 8: Continued.

Taxon	Average Abundance, All stations	Total Abundance, All stations	Substrate			Substrate		
			Silt/Clay	Shell	Sand	Near-field	Ref.	Back River
Balanus subalbidus	0.8	12.8	0.0	3.2	0.0	1.2	0.0	0.0
Xanthidae	0.4	6.4	0.0	1.6	0.0	0.6	0.0	0.0
Rhithropanopeus harrisii	8.7	147.2	2.4	25.6	5.1	13.4	0.0	0.0
Membranipora sp	+	+	+	+	+	+	+	0.0
Tanypodinae	0.4	6.4	0.8	0.0	0.0	0.0	0.0	2.1
Coelotanypus sp.	17.3	294.4	33.6	6.4	0.0	4.1	8.5	74.7
Coelotanypodini	0.4	6.4	0.8	0.0	0.0	0.0	0.0	2.1
Anthozoa	0.4	6.4	0.8	0.0	0.0	0.0	2.1	0.0
Nudibranchia	4.5	76.8	4.8	9.6	0.0	3.5	12.8	0.0
Gobiosoma bosci	1.1	19.2	0.0	4.8	0.0	1.7	0.0	0.0
Lophogastrida	4.5	76.8	9.6	0.0	0.0	1.7	17.1	2.1
Spionidae	0.4	6.4	0.0	1.6	0.0	0.6	0.0	0.0

Table 9: Average and total abundance (individuals per square meter) of each taxon found

at HMI during Year 21 Spring sampling, April 2003, by substrate and station type.

Taxon	Average Abundance All	Total Abundance All	Substrate			Station Type		
			Silt/Clay	Shell	Sand	Near-field	Ref.	Back River
Nemata	3.4	57.6	0.9	0.0	22.4	4.1	0.0	4.3
Carinoma tremophoros	12.8	217.6	15.1	0.0	3.2	10.5	10.7	23.5
Bivalvia	24.5	416.0	28.3	6.4	6.4	12.2	70.4	23.5
Macoma sp	55.0	934.4	53.5	0.0	92.8	26.2	200.5	14.9
Macoma balthica	76.4	1299.2	87.3	0.0	38.4	60.5	196.3	14.9
Macoma mitchelli	7.2	121.6	2.3	0.0	44.8	8.1	4.3	6.4
Rangia cuneata	45.9	780.8	54.4	6.4	6.4	47.7	17.1	68.3
Ischadium recurvum	22.6	384.0	20.6	89.6	3.2	34.3	2.1	0.0
Mytilopsis leucophaeata	4.5	76.8	0.9	51.2	6.4	7.0	0.0	0.0
Capitellidae	8.7	147.2	5.9	0.0	32.0	11.6	4.3	2.1
Heteromastus filiformis	28.6	486.4	23.8	19.2	67.2	33.7	23.5	14.9
Spionidae	18.8	320.0	8.7	147.2	25.6	26.2	8.5	2.1
Marenzellaria viridis	4885.8	83059.2	3515.4	6393.6	13724.8	6750.8	1879.5	1053.9
Nereididae	19.6	332.8	16.0	76.8	16.0	30.3	0.0	0.0
Neanthes succinea	30.1	512.0	24.2	38.4	67.2	36.7	8.5	27.7
Tubificidae	456.3	7756.8	448.0	908.8	288.0	449.2	277.3	661.3
Amphipoda	58.4	992.0	66.7	12.8	22.4	29.7	76.8	145.1
Gammaridea	7.2	121.6	7.8	0.0	6.4	3.5	14.9	12.8
Ameroculodes spp complex	34.3	582.4	37.0	6.4	28.8	42.5	17.1	21.3
Leptocheirus plumulosus	282.7	4806.4	284.8	6.4	406.4	153.0	285.9	755.2
Gammarus sp	10.2	172.8	9.1	0.0	22.4	13.4	6.4	2.1
Melitadae	0.8	12.8	0.9	0.0	0.0	0.0	0.0	4.3
Melita nitida	20.3	345.6	19.2	51.2	12.8	15.7	6.4	51.2
Corophiidae	3.4	57.6	3.2	6.4	3.2	3.5	6.4	0.0
Apocorophium lacustre	35.8	608.0	19.7	96.0	118.4	46.0	27.7	6.4
Cyathura polita	182.6	3104.0	215.3	12.8	38.4	162.9	262.4	174.9
Edotia triloba	21.5	364.8	19.7	0.0	44.8	20.9	17.1	27.7
Chiridotea almyra	1.9	32.0	0.9	0.0	9.6	2.3	2.1	0.0
Cirripedia	0.4	6.4	0.0	6.4	0.0	0.6	0.0	0.0
Balanus improvisus	56.1	953.6	37.0	435.2	0.0	85.5	4.3	0.0
Rhithropanopeus harrisii	15.4	262.4	13.3	76.8	0.0	23.3	0.0	2.1
Membranipora sp	+	+	+	+	+	+	+	0.0

Table 9: Continued.

Taxon	Average Abundance All	Total Abundance All	Substrate			Station Type		
			Silt/Clay	Near-field	Sand	Near-field	Ref.	Back River
Tanypodinae	0.8	12.8	0.9	0.0	0.0	0.0	0.0	4.3
Orthocladiinae	0.4	6.4	0.0	6.4	0.0	0.6	0.0	0.0
Coelotanypus sp.	9.4	160.0	11.4	0.0	0.0	1.2	0.0	49.1
Coelotanypodini	0.8	12.8	0.9	0.0	0.0	0.0	0.0	4.3
Procladiini	0.4	6.4	0.5	0.0	0.0	0.0	0.0	2.1
Procladius	0.8	12.8	0.9	0.0	0.0	0.6	2.1	0.0
Mya arenaria	0.4	6.4	0.0	0.0	3.2	0.6	0.0	0.0
Copepoda	757.1	12870.4	676.6	518.4	1440.0	932.7	667.7	202.7
Callineates sapidus	0.4	6.4	0.5	0.0	0.0	0.6	0.0	0.0
Cladocera	0.8	12.8	0.5	6.4	0.0	1.2	0.0	0.0
Morone americana	0.4	6.4	0.5	0.0	0.0	0.6	0.0	0.0
Anguilla rostrata	0.4	6.4	0.5	0.0	0.0	0.6	0.0	0.0
Spionidae	0.4	6.4	0.0	0.0	3.2	0.6	0.0	0.0
Hemiptera	0.4	6.4	0.5	0.0	0.0	0.0	0.0	2.1
Ostracoda	8.3	140.8	10.1	0.0	0.0	2.9	2.1	34.1
Diptera	0.4	6.4	0.5	0.0	0.0	0.0	0.0	2.1
Crustacea	0.4	6.4	0.0	0.0	3.2	0.6	0.0	0.0

Of the 43 taxa found in Year 21, twenty-two are considered truly infaunal, fifteen are considered epifaunal, and the remaining six are considered too general to classify as either infaunal or epifaunal (see Ranasinghe et al. 1994). The most common infaunal species found during Year 21 were the polychaete worm *M. viridis*, worms from the family Tubificidae, the amphipod *L. plumulosus*, and the isopod *C. polita*. The most common epifaunal species were the copepods and the barnacle *Balanus improvisus*. Epifaunal taxa, such as the barnacles (*B. improvisus* and *B. subalbidus*), and mud crabs (*Rhithropanopeus harrisii*), were found more often at stations where the substrate (sediment) contained a large amount of shell (Tables 8 & 9).

Nearfield station MDE-07 had the highest number of taxa in the September 2002 (21), followed by the Nearfield stations MDE-03 (18) and MDE-16 (18) (Table 10). The stations with the fewest taxa in September 2002 of Year 21 were Nearfield station MDE-33 (9), Back River/Hawk Cove station MDE-30 (11), and Nearfield station MDE-1 (13) and MDE-09 (13) (Table 10). Overall, average taxa richness was highest at the Reference stations but did not vary greatly between stations types (average taxa richness: Nearfield=15 taxa, Reference=16 taxa, Back River/Hawk Cove=15 taxa).

Table 10: Summary of metrics for each HMI benthic station surveyed during the Year 21

late summer sampling cruise, September 2002. Total Infaunal Abundance and Total Abundance, excluding Polycladida, Nematoda, and Bryozoa, are individuals per square meter.

Station	Total Infauna	Total All (excluding Polycladida, Nematoda, & bryozoans)	All Taxa	Infaunal Taxa	Shannon-Wiener	PSTA	PITA	B-IBI
Nearfield Stations								
MDE-01	601.6	640.0	13.0	11.0	2.6	73.4	4.3	4.0
MDE-03	1657.6	1830.4	18.0	14.0	3.2	57.9	17.0	4.0
MDE-07	1958.4	2841.6	21.0	13.0	3.0	22.3	18.0	3.5
MDE-09	1318.4	1324.8	13.0	13.0	3.0	68.9	5.8	4.0
MDE-16	2310.4	2348.8	18.0	14.0	3.0	67.0	16.1	3.0
MDE-17	1587.2	1612.8	15.0	12.0	3.1	58.9	22.6	3.5
MDE-19	998.4	1049.6	15.0	13.0	3.1	44.2	14.7	3.5
MDE-24	1011.2	1094.4	14.0	13.0	3.5	47.5	5.7	4.0
MDE-33	563.2	601.6	9.0	7.0	1.6	83.0	0.0	3.5
MDE-34	1772.8	1875.2	15.0	13.0	3.3	57.8	8.3	4.5
MDE-35	620.8	716.8	17.0	13.0	3.3	33.0	23.7	2.5
Reference Stations								
MDE-13	1049.6	1164.8	17.0	12.0	3.3	29.3	18.9	4.0
MDE-22	1369.6	1555.2	15.0	12.0	3.0	38.3	16.4	3.0
MDE-36	1580.8	1632.0	17.0	15.0	3.0	53.4	33.6	3.5
Back River/Hawk Cove Stations								
MDE-27	2918.4	3116.8	17.0	14.0	3.0	67.0	16.1	2.5
MDE-28	1593.6	1657.6	16.0	13.0	3.1	58.9	22.6	3.5
MDE-30	652.8	697.6	11.0	10.0	3.1	44.2	14.7	3.0

In April 2003 the Nearfield station MDE-07 had the highest number of taxa (20), followed closely by the Nearfield station MDE-03 (19) and Back River/Hawk Cove station MDE-27 (18) (Table 11). The Nearfield station MDE-19 and the Back River/Hawk Cove station MDE-30 both had the lowest number of taxa (12 each), followed by Nearfield station MDE-35 (13 taxa, Table 11). Overall, the average taxa richness was highest at the Back River/Hawk Cove stations, but did not vary greatly between station types (average taxa richness: Nearfield=15 taxa, Reference=14 taxa, Back River/Hawk Cove=16 taxa).

Table 11: Summary of metrics for each HMI benthic station surveyed during the Year 21 spring sampling cruise, April 2003. Total Infaunal Abundance and Total Abundance, excluding Polycladida, Nematoda, and Bryozoa, are individuals per square meter.

Station	Total Infauna	Total All (excluding Polycladida, Nematoda, & bryozoans)	All Taxa	Infaunal Taxa	Shannon-Wiener	PSTA	PITA
Nearfield Stations							
MDE-01	7635.2	8979.2	15.0	8.0	0.9	84.0	11.9
MDE-03	7212.8	8102.4	19.0	11.0	0.8	94.2	3.0
MDE-07	13100.8	15820.8	20.0	11.0	0.9	83.0	13.3
MDE-09	6176.0	7168.0	16.0	11.0	1.5	87.6	6.7
MDE-16	5868.8	7392.0	14.0	11.0	1.2	91.1	3.9
MDE-17	3744.0	4217.6	14.0	10.0	2.0	74.7	16.4
MDE-19	3283.2	4153.6	12.0	10.0	1.1	86.9	0.8
MDE-24	7462.4	10099.2	17.0	13.0	1.6	74.7	6.8
MDE-33	22412.8	23072.0	14.0	8.0	0.2	98.4	0.3
MDE-34	7155.2	7404.8	14.0	11.0	0.7	96.0	1.0
MDE-35	2828.8	3584.0	13.0	9.0	1.4	80.3	5.2
Reference Stations							
MDE-13	2848.0	3193.6	14.0	10.0	1.7	76.9	4.7
MDE-22	4012.8	5107.2	15.0	12.0	2.8	56.6	11.8
MDE-36	2988.8	4006.4	14.0	9.0	1.2	87.2	7.5
Back River/Hawk Cove Stations							
MDE-27	5369.6	5849.6	18.0	13.0	2.3	21.8	32.4
MDE-28	1958.4	2316.8	17.0	12.0	2.5	69.0	12.7
MDE-30	1817.6	2086.4	12.0	8.0	1.6	77.8	7.7

Since the first benthic survey studies of the Hart-Miller Island area in 1981, a small number of taxa have been dominant. Year 21 was no exception. During both seasons, 4 taxa were clearly dominant. In September 2002, these taxa were the bivalve mollusk *R. cuneata*, the isopod *C. polita*, the amphipod *L. plumulosus*, and oligochaete worms of the family Tubificidae. The average abundance of each taxon (individuals per meter squared) found at each station during September 2002 is provided in Tables 12 & 13.

Table 12: Average number of individuals collected per square meter at each station during the HMI Year 21 late summer sampling, September 2002, stations MDE-1 to MDE-22.

Taxon	Station								
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19	MDE-22
Nemata	0	0	0	0	0	0	0	0	0
Carinoma tremophoros	0	76.8	64	57.6	44.8	89.6	19.2	57.6	76.8
Bivalvia	19.2	32	32	6.4	25.6	6.4	0	19.2	70.4
Macoma sp	51.2	25.6	0	6.4	38.4	44.8	25.6	12.8	12.8
Macoma balthica	32	83.2	12.8	364.8	57.6	313.6	236.8	83.2	204.8
Macoma mitchelli	6.4	12.8	0	6.4	0	12.8	19.2	32	38.4
Rangia cuneata	294.4	537.6	102.4	281.6	57.6	691.2	396.8	70.4	57.6
Mulinia lateralis	0	0	0	0	25.6	0	0	0	6.4
Ischadium recurvum	0	12.8	198.4	0	0	0	0	0	0
Mytilopsis leucophaeata	0	83.2	51.2	0	0	0	0	0	0
Capitellidae	0	6.4	12.8	0	0	0	19.2	0	0
Heteromastus filiformis	38.4	57.6	108.8	6.4	64	25.6	25.6	6.4	38.4
Marenzellaria viridis	32	83.2	32	25.6	6.4	19.2	19.2	19.2	0
Streblospio benedicti	25.6	140.8	262.4	25.6	70.4	89.6	134.4	70.4	57.6
Polydora cornuta	0	6.4	6.4	0	0	0	6.4	0	0
Nereididae	6.4	25.6	345.6	25.6	12.8	25.6	32	0	0
Neanthes succinea	19.2	172.8	384	115.2	32	108.8	102.4	25.6	0
Glycinde solitaria	6.4	0	0	0	0	6.4	0	0	6.4
Eteone heteropoda	0	12.8	19.2	12.8	0	6.4	0	12.8	0
Tubificidae	0	128	12.8	38.4	102.4	275.2	224	64	160
Amphipoda	0	0	0	12.8	51.2	38.4	6.4	6.4	25.6
Gammaridea	0	0	0	0	19.2	0	0	0	6.4
Ameroculodes spp complex	6.4	25.6	19.2	38.4	6.4	6.4	0	12.8	12.8
Leptocheirus plumulosus	6.4	6.4	38.4	64	294.4	38.4	38.4	256	416
Melita nitida	0	0	12.8	0	6.4	6.4	0	25.6	64
Corophiidae	0	0	0	0	0	0	0	0	0
Apocorophium lacustre	6.4	19.2	0	0	0	6.4	6.4	0	0
Cyathura polita	76.8	256	217.6	236.8	185.6	518.4	281.6	268.8	256
Edotia triloba	12.8	0	0	0	6.4	0	6.4	0	6.4
Chiridotea almyra	0	0	0	0	0	0	0	0	0
Balanus improvisus	0	0	416	0	0	6.4	0	0	0
Balanus subalbidus	0	0	12.8	0	0	0	0	0	0

Table 12: Continued.

Taxon	Station								
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19	MDE-22
Xanthidae	0	0	6.4	0	0	0	0	0	0
Rhithropanopeus harrisii	0	25.6	96	0	0	12.8	6.4	0	0
*Membranipora sp**	+	+	+	+	+	+	+	+	+
Tanypodinae	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	0	0	0	0	0	0	0
Coelotanypodini	0	0	0	0	0	0	0	0	0
Anthozoa	0	0	0	0	6.4	0	0	0	0
Nudibranchia	0	0	38.4	0	38.4	0	0	0	0
Gobiosoma bosci	0	0	19.2	0	0	0	0	0	0
Lophogastrida	0	0	0	0	12.8	0	0	6.4	38.4
Spionidae	0	0	0	0	0	0	6.4	0	0

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

Table 13: Average number of individuals collected per square meter at each station during the HMI Year 21 late summer sampling, September 2002, stations MDE-24 to MDE-36.

Taxon	Station							
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36
Nemata	0	0	38.4	0	0	0	12.8	6.4
Carinoma tremophoros	6.4	89.6	38.4	0	0	64	19.2	44.8
Bivalvia	25.6	32	12.8	19.2	0	32	32	12.8
Macoma sp	121.6	32	19.2	19.2	25.6	64	44.8	0
Macoma balthica	83.2	153.6	12.8	57.6	0	83.2	6.4	19.2
Macoma mitchelli	83.2	12.8	0	12.8	6.4	115.2	25.6	19.2
Rangia cuneata	243.2	102.4	524.8	51.2	409.6	556.8	44.8	448
Mulinia lateralis	0	0	0	0	0	0	0	0
Ischadium recurvum	0	0	0	0	0	0	0	0
Mytilopsis leucophaeata	0	0	0	0	12.8	0	0	0
Capitellidae	0	0	0	0	0	25.6	0	0
Heteromastus filiformis	44.8	6.4	0	0	0	64	25.6	25.6
Marenzellaria viridis	51.2	64	140.8	32	0	128	44.8	192
Streblospio benedicti	38.4	44.8	172.8	185.6	0	83.2	38.4	224
Polydora cornuta	0	0	140.8	19.2	0	0	0	19.2
Nereididae	25.6	19.2	44.8	0	0	0	0	19.2
Neanthes succinea	32	57.6	108.8	0	12.8	19.2	6.4	12.8
Glycinde solitaria	0	0	0	0	0	0	0	0
Eteone heteropoda	12.8	57.6	12.8	0	0	0	6.4	6.4
Tubificidae	6.4	748.8	76.8	19.2	0	64	57.6	275.2
Amphipoda	19.2	96	0	19.2	6.4	6.4	0	0
Gammaridea	0	6.4	0	0	0	0	6.4	0
Ameroculodes spp complex	32	64	6.4	0	12.8	102.4	0	25.6
Leptocheirus plumulosus	108.8	844.8	57.6	44.8	12.8	102.4	147.2	38.4
Melita nitida	0	140.8	19.2	25.6	0	0	32	6.4
Corophiidae	0	0	0	0	19.2	0	0	0
Apocorophium lacustre	0	0	12.8	0	6.4	32	6.4	0
Cyathura polita	102.4	403.2	166.4	147.2	57.6	256	108.8	185.6
Edotia triloba	57.6	12.8	19.2	0	0	38.4	0	32
Chiridotea almyra	0	0	0	0	19.2	38.4	0	0
Balanus improvisus	0	0	0	0	0	0	0	0
Balanus subalbidus	0	0	0	0	0	0	0	0

Table 13: Continued.

Taxon	Station							
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36
Xanthidae	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	0	0	0	0	0	0	6.4	0
Membranipora sp*	0	0	0	0	0	+	0	+
Tanypodinae	0	6.4	0	0	0	0	0	0
Coelotanypus sp.	0	108.8	70.4	44.8	0	0	44.8	25.6
Coelotanypodini	0	6.4	0	0	0	0	0	0
Anthozoa	0	0	0	0	0	0	0	0
Nudibranchia	0	0	0	0	0	0	0	0
Gobiosoma bosci	0	0	0	0	0	0	0	0
Lophogastrida	0	6.4	0	0	0	0	12.8	0
Spionidae	0	0	0	0	0	0	0	0

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

In April 2003, *L. plumulosus* and Oligochaete worms of the family Tubificidae continued to numerically dominate the benthic macroinvertebrate community, while the polychaete *M. viridis* and Copepods replaced the bivalve mollusk *R. cuneata* and the isopod *C. polita*. This is similar to Year 19, where heavy seasonal recruitment of *M. viridis* replaced *S. benedicti* as dominant species. The average abundance of each taxon (individuals per meter squared) found at each station during April 2003 is provided in Tables 14 & 15.

Table 14: Average number of individuals collected per square meter at each station during the HMI Year 21 spring sampling, April 2003, stations MDE-1 to MDE-22.

Taxon	Station								
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19	MDE-22
Nemata	0	0	0	0	0	0	0	0	0
Carinoma tremophoros	0	12.8	12.8	19.2	6.4	25.6	25.6	6.4	19.2
Bivalvia	6.4	0	0	6.4	0	32	57.6	19.2	211.2
Macoma sp	0	0	0	12.8	0	32	44.8	12.8	601.6
Macoma balthica	0	51.2	12.8	211.2	32	147.2	89.6	12.8	544
Macoma mitchelli	0	0	0	0	0	0	0	0	12.8
Rangia cuneata	6.4	89.6	12.8	147.2	12.8	128	89.6	0	25.6
Ischadium recurvum	89.6	12.8	243.2	12.8	6.4	0	6.4	0	0
Mytilopsis leucophaeata	51.2	6.4	6.4	0	0	0	0	0	0
Capitellidae	0	0	57.6	0	12.8	0	6.4	0	0
Heteromastus filiformis	19.2	51.2	83.2	51.2	44.8	6.4	19.2	6.4	25.6
Spionidae	147.2	0	0	12.8	12.8	51.2	6.4	6.4	6.4
Marenzellaria viridis	6393.6	6419.2	10790.4	4691.2	1971.2	4806.4	2272	2771.2	1292.8
Nereididae	76.8	25.6	115.2	19.2	0	32	19.2	6.4	0
Neanthes succinea	38.4	25.6	96	32	19.2	6.4	51.2	19.2	6.4
Tubificidae	908.8	217.6	1747.2	416	134.4	230.4	614.4	25.6	473.6
Amphipoda	12.8	12.8	19.2	51.2	83.2	44.8	51.2	19.2	128
Gammaridea	0	0	0	6.4	32	12.8	6.4	0	12.8
Ameroculodes spp complex	6.4	6.4	6.4	44.8	0	44.8	12.8	185.6	51.2
Leptocheirus plumulosus	6.4	51.2	70.4	102.4	332.8	44.8	96	115.2	409.6
Gammarus sp	0	12.8	19.2	6.4	12.8	6.4	0	25.6	0
Melitadae	0	0	0	0	0	0	0	0	0
Melita nitida	51.2	0	70.4	6.4	6.4	0	0	6.4	6.4
Corophiidae	6.4	6.4	12.8	0	0	6.4	0	0	0
Apocorophium lacustre	96	19.2	96	25.6	0	6.4	19.2	0	0
Cyathura polita	12.8	236.8	57.6	358.4	172.8	262.4	345.6	70.4	409.6
Edotia triloba	0	6.4	6.4	0	0	12.8	0	0	19.2
Chiridotea almyra	0	0	0	0	0	0	0	0	6.4
Cirripedia	6.4	0	0	0	0	0	0	0	0
Balanus improvisus	435.2	6.4	499.2	0	12.8	0	0	0	0
Rhithropanopeus harrisii	76.8	32	147.2	0	0	0	0	0	0
Membranipora sp*	0	+	+	+	+	+	+	+	0
Tanypodinae	0	0	0	0	0	0	0	0	0
Orthocladiinae	6.4	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	0	0	0	0	0	0	0
Coelotanypodini	0	0	0	0	0	0	0	0	0
Procladiini	0	0	0	0	0	0	0	0	0
Procladius sp.	0	0	0	0	0	0	0	0	0

Table 14: Continued.

Taxon	Station								
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19	MDE-22
Mya arenaria	0	0	0	0	0	0	0	0	0
Copepoda	518.4	793.6	1632	928	288	1452.8	377.6	844.8	844.8
Callineates sapidus	0	6.4	0	0	0	0	0	0	0
Cladocera	6.4	0	6.4	0	0	0	0	0	0
Morone Americana	0	0	0	6.4	0	0	0	0	0
Anguilla rostrata	0	0	0	0	0	0	6.4	0	0
Spionidae	0	0	0	0	0	0	0	0	0
Hemiptera	0	0	0	0	0	0	0	0	0
Ostracoda	0	0	0	0	0	0	0	0	0
Diptera	0	0	0	0	0	0	0	0	0
Crustacea	0	0	0	0	0	0	0	0	0

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

Table 15: Average number of individuals collected per square meter at each station during the HMI Year 21 spring sampling, April 2003, stations MDE-24 to MDE-36.

Taxon	Station							
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36
Nemata	32	12.8	0	0	12.8	0	0	0
Carinoma tremophoros	6.4	57.6	12.8	0	0	6.4	0	6.4
Bivalvia	12.8	57.6	6.4	6.4	0	0	0	0
Macoma sp	185.6	32	12.8	0	0	0	0	0
Macoma balthica	76.8	38.4	6.4	0	0	57.6	6.4	12.8
Macoma mitchelli	89.6	19.2	0	0	0	0	0	0
Rangia cuneata	12.8	38.4	147.2	19.2	0	32	6.4	12.8
Ischadium recurvum	0	0	0	0	6.4	6.4	0	0
Mytilopsis leucophaeata	0	0	0	0	12.8	0	0	0
Capitellidae	64	6.4	0	0	0	0	0	0
Heteromastus filiformis	134.4	38.4	6.4	0	0	0	0	0
Spionidae	0	6.4	0	0	51.2	0	12.8	6.4
Marenzellaria viridis	5433.6	832	1043.2	1286.4	22016	6540.8	2124.8	2374.4
Nereididae	12.8	0	0	0	19.2	6.4	0	0
Neanthes succinea	25.6	32	44.8	6.4	108.8	0	0	0
Tubificidae	505.6	1721.6	153.6	108.8	70.4	70.4	134.4	224
Amphipoda	32	313.6	64	57.6	12.8	19.2	51.2	19.2
Gammaridea	6.4	25.6	6.4	6.4	6.4	0	0	0
Ameroculodes spp complex	12.8	32	19.2	12.8	44.8	57.6	44.8	0
Leptocheirus plumulosus	780.8	1913.6	166.4	185.6	32	89.6	294.4	115.2
Gammarus sp	19.2	6.4	0	0	25.6	32	0	6.4
Melitadae	0	6.4	0	6.4	0	0	0	0
Melita nitida	19.2	140.8	6.4	6.4	6.4	0	12.8	6.4
Corophiidae	0	0	0	0	6.4	0	0	19.2
Apocorophium lacustre	172.8	12.8	0	6.4	64	0	6.4	83.2
Cyathura polita	51.2	262.4	153.6	108.8	25.6	236.8	134.4	204.8
Edotia triloba	89.6	51.2	32	0	0	115.2	0	32
Chiridotea almyra	19.2	0	0	0	0	6.4	0	0
Cirripedia	0	0	0	0	0	0	0	0
Balanus improvisus	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii	0	6.4	0	0	0	0	0	0
Membranipora sp*	0	0	0	0	+	+	0	0
Tanypodinae	0	0	12.8	0	0	0	0	0
Orthocladiinae	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	19.2	96	32	0	0	12.8	0
Coelotanypodini	0	0	12.8	0	0	0	0	0
Procladiini	0	0	6.4	0	0	0	0	0

Table 15: Continued.

Taxon	Station							
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36
Procladius sp.	0	0	0	0	0	0	6.4	6.4
Mya arenaria	0	0	0	0	6.4	0	0	0
Copepoda	2329.6	179.2	230.4	198.4	550.4	128	704	870.4
Callineates sapidus	0	0	0	0	0	0	0	0
Cladocera	0	0	0	0	0	0	0	0
Morone americana	0	0	0	0	0	0	0	0
Anguilla rostrata	0	0	0	0	0	0	0	0
Spionidae	6.4	0	0	0	0	0	0	0
Hemiptera	0	0	6.4	0	0	0	0	0
Ostracoda	0	0	64	38.4	0	0	32	6.4
Diptera	0	0	6.4	0	0	0	0	0
Crustacea	0	0	0	0	6.4	0	0	0

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

Taxa Abundance

Total abundance was higher in the spring (April 2003) than in the late summer (September 2002) due to seasonal recruitment in April 2003 (see Figure 14). In the September 2002 total abundance in the vicinity of HMI ranged from 602 to 3117 organisms per meter squared (individuals/m^2) and averaged 1515 individuals/m^2. This number does not include the Bryozoa, which are colonial epifauna and can reach high numeric densities on shell and other hard substrates. The highest September 2002 abundance was found at the Back River/Hawk Cove station MDE-27, due primarily to large numbers of the amphipod *L. plumulosus* and members of the oligochaete family Tubificidae. The lowest abundance in September 2002 was found at the Nearfield station MDE-33 (Table 10). Average total abundance was very similar between Reference stations and Nearfield stations in September 2002 (1450.7 individuals/m^2 and 1448.7 individuals/m^2 respectively); however, total abundance was much higher at the Back River/Hawk Cove stations (1824.0 individuals/m^2).

In April 2003, total abundance ranged from 2086 to 23,072 organisms per meter squared and averaged 7209 individuals/m^2. The station with the highest abundance was the Nearfield station MDE-33, due to very high numbers of the polychaete *M. viridis*. The lowest spring abundance occurred at the Back River/Hawk Cove station MDE-30 (Table 11). This was due in part to the low numbers of the polychaete worm *M. viridis* and worms from the family Tubificidae, which generally occurred in high numbers at other stations (Table 11). The average total abundance was lowest at the Back River/Hawk Cove stations (3417.6 individuals/m^2) and highest at the Nearfield stations (9090.3 individuals/m^2), with the Reference stations falling in between (4102.4 individuals/m^2).

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 21, total infaunal abundance was similar to total abundance, accounting for ≥75% of all organisms at most stations during both seasons. The only exception was for September 2002 at Nearfield station MDE-07, where 69% of total abundance was epifaunal.

Diversity

Species diversity was examined using the Shannon-Wiener diversity index, which measures diversity on a numerical scale from 1 to 4. A lower score indicates an unbalanced 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 the Shannon-Wiener Diversity Index (SWDI), would be higher in the summer than the spring, when recruitment decreased and predation increased thus reducing the numbers of the dominant taxa. 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 21 are presented in Tables 10 and 11. In this monitoring year, on average, diversity was twice as high in September 2002 than in April 2003. These results are different from Year 20, where diversity values were not distinctly higher in one season versus the other.

The Shannon-Wiener diversity Index (SWDI) values in Year 21 averaged 3.01 ± 0.42 in

September 2002 and 1.43 ± 0.69 in April 2003. The lowest diversity value in September 2002 occurred at Nearfield station MDE-33 (1.56). This was due to the predominance of the bivalve mollusk *R. cuneata*, which accounted for 73% of total infaunal abundance at this station. The highest September 2002 diversity value occurred at Nearfield station MDE-24 (3.46). This is similar to September 2001, where the highest diversity value also occurred at Nearfield station MDE-24 (3.27). Similar to September 2002, the lowest diversity value in April 2003 occurred at Nearfield station MDE-33 (0.18); however, this was due to the large percentage of the polychaete worm *M. viridis*, which accounted for 98% of total infaunal abundance at this station. The highest April 2002 diversity value occurred at Reference station MDE-22 (2.80).

For the most part, Nearfield stations had diversity values similar to Reference stations in September 2002, with the exception of Nearfield station MDE-33, which had the lowest diversity value for that season (1.56). However, in April 2003, Nearfield stations had much lower diversity than Reference stations. This may have been due to the winter die-off of benthos and the high recruitment of *M. viridis*, which was not affected by the cold temperatures.

Pollution Sensitive Taxa Abundance

There were six taxa found during Year 21 benthic monitoring that were designated as "pollution-sensitive" according to Weisberg et al. (1997). These were the clams, *R. cuneata, M. balthica* and *M. arenaria;* the polychaete worms *M. viridis* and *G. solitaria;* and the isopod crustacean *C. polita.* Relative abundance of these taxa was calculated as a proportion of total infaunal abundance. In September 2002, the average pollution-sensitive taxa abundance (PSTA) ranged from 22.3% at MDE-07 (Nearfield station), to 83.0% at MDE-33 (Nearfield station) (Table 10 and Figure 15). The average PSTA for September 2002 was 50.2%. In April 2003, the lowest PSTA was 21.8% at MDE-27 (Back River/Hawk Cove station) and the highest was 98.4% at MDE-33, (Nearfield station) (Table 11 and Figure 16). The average PSTA in April 2003 was 78.8%. The Nearfield stations had the highest PSTA at 86.4%, followed by the Reference stations at 73.6% and the Back River/Hawk Cove stations had the lowest PSTA of 56.2%.

In September 2002, the average lowest PSTA was 40.3% at the Reference stations followed by the Back River/Hawk Cove stations at 40.6%. The highest average PSTA occurred at the Nearfield stations with an average PSTA of 55.5%. Historically, the PSTA's of April are usually higher than September, and in year 21, MDE-28 (Back River/Hawk Cove station) was the only station where this wasn't the case.

Pollution Indicative Taxa Abundance

Five taxa found during Year 21 benthic monitoring were designated as "pollution-indicative" according to Weisberg et al. (1997). These were the clam *M. lateralis*, the Chironomid *Coelotanypus* sp., and the polychaete worms *S. benedicti* and *E. heteropoda*. In addition, oligochaete worms of the family Tubificidae were classified as pollution-indicative because past studies have shown the tubificid, *Limnodrillus hoffmeisteri*, which is considered pollution-indicative, to be common in the vicinity of HMI. Relative abundance of these taxa was calculated as a proportion of total infaunal abundance. In September 2002, the relative abundance of pollution-indicative taxa (PITA) ranged from 0.0% at MDE-33 (Nearfield station) and 33.6% at MDE-36 (Reference station) (Table 10, Figure 17). The average PITA for September 2002 was 18.3%. In April 2003 the PITA ranged from 0.3% at MDE-33 (Nearfield station), to 32.4% at MDE-27 (Back River/Hawk Cove station) (Table 11, Figure 17). The average PITA was 8.6%.

In September 2002, the Nearfield stations had an average PITA of 13.6%, the Reference stations had an average of 23.0 %, and the Back River/Hawk Cove stations had average PITA of 30.7%. In April 2003, the PITA averaged 6.3% for Nearfield stations, 8.0% for Reference stations, and 17.6% for Back River/Hawk Cove stations.

Clam Length Frequency Distribution

In September 2002, the greatest average abundance of *R. cuneata* occurred at the Nearfield stations, followed by the Back River/Hawk Cove, and then the Reference stations. The greatest abundance of *R. cuneata* was found in the 11-15 mm size class. In April 2003, the greatest average abundance of *R. cuneata* occurred at the Nearfield stations, followed by the Back River/Hawk Cove, and then the Reference stations. The greatest abundance of *R. cuneata* was found in the 31-35 mm size class.

The greatest average abundance of *M. mitchelli* in September 2002 was found at the Nearfield stations, followed by the Reference and then the Back River/Hawk Cove stations. The strongest recruitment for all station types was in the 1-2 mm size class range. In April 2003 the greatest average abundance of *M. mitchelli* were found at the Nearfield stations, followed by the Back River/Hawk Cove and then the Reference stations. The strongest recruitment for all station types was in the 1-4 mm size class range.

In September 2002 *M. balthica* had the greatest average abundance at the Nearfield stations, followed by the Reference and then the Back River/Hawk Cove stations. The greatest abundance of *M. balthica* was found in the in the 9-10 mm size class. In April 2003 *M. balthica* had the greatest average abundance at the Nearfield stations, followed by the Reference and then the Back River/Hawk Cove stations. For all the stations in April 2003 *M. balthica* had its greatest abundance in the 1-2 mm size class. All size class data for clams is available in the *Year 21 Data Report.*

Benthic Index of biotic Integrity

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) was calculated for all stations based on September 2002 data only (see Methods and Materials). Four metrics were used to calculate the B-IBI for these stations under the low mesohaline classification (= 5-12 ppt). These metrics were total infaunal abundance, the Shannon-Wiener diversity index, relative abundance of pollution-sensitive taxa, and relative abundance of pollution-indicative taxa [Note: the relative abundance of pollution-sensitive taxa was included as an accepted substitution for biomass-based metrics (Weisberg et al 1997)]. 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 17 benthic stations studied during Year 20 were compared to this benchmark.

Overall, B-IBI scores improved or remained the same when compared to Year 20 and were generally similar to the B-IBI scores of the previous 6 years of monitoring at Hart-Miller Island. The B-IBI scores increased at 11 stations, decreased at 4 stations and remained the same at 2 stations. Twelve stations exceeded the benchmark criteria of 3.0, three stations met it and only 2 stations failed to meet the benchmark (Figure 18). In Year 20, only 7 stations exceeded the benchmark and 5 failed to meet it. In Year 21, the stations that failed to meet the benchmark were MDE-27 (Back River/Hawk Cove) and MDE-35 (Nearfield station). The Back River/Hawk Cove station MDE-27 failed to meet the benchmark in the previous year of monitoring and Nearfield station MDE-35 had failed to meet the benchmark score of 3.0 in monitoring year 19.

The highest B-IBI scores were at the Nearfield stations, which had an average B-IBI score of 3.7, followed by the Reference stations that had an average score of 3.2. The Back River/Hawk Cove stations had the lowest average B-IBI score of 3.0 for the second monitoring year in a row. The Back River has a history of poor water quality and the conditions present at these stations may have been more representative of the conditions of the Back River than the Hart-Miller Island facility. For the past 6 years, the average B-IBI scores of the Back River/Hawk Cove stations have been substantially lower than the average Nearfield and Reference stations scores (Figure 19).

Statistical Analysis

Cluster analyses were employed in this year's study to examine relationships among the different groups of stations based upon the numerical distribution of the numbers of species and individuals of a species. In Figures 20 and 21, the stations with faunal similarity (based on a Euclidean distance matrix comprised of station infaunal abundance values for all 17 stations), are linked by vertical connections in the dendrograms. Essentially, each station was considered to be a cluster of its own and at each step (amalgamated distances) the clusters with the shortest distance between them were combined (amalgamated) and treated as one cluster. Cluster analysis in past studies at HMI has clearly indicated a faunal response to bottom type (Pfitzenmeyer, 1985; Duguay et al, 1999). Thus, any unusual grouping of stations tends to suggest changes are occurring due to factors other than bottom type and further examinations of these stations may be warranted. Experience and familiarity with the area under study can usually help to explain the differences. However, when they cannot be explained other potential outside factors must be considered.

The dendrogram of the cluster analysis for September 2002 is presented in Figure 20, indicating the familiar pattern of faunal response to sediment type. The first stations to join the dendrogram were the Nearfield, sand stations MDE-01, MDE-33 and MDE-24. Stations MDE-13, MDE-19, MDE-30, MDE-35 and MDE-22 were the next to join and formed a grouping of silt/clay stations and MDE-17, MDE-36 and MDE-09 also formed a grouping of shell stations. As in previous years for which a cluster analysis was performed, Back River/Hawk Cove station MDE-27 was the last to join. Overall the Nearfield, Reference, and Back River/Hawk Cove stations are well mixed throughout the dendrogram and show no distinct grouping by station location. A grouping of stations by location could indicate that the HMI facility was impacting the surrounding environment and affecting the faunal composition.

The cluster analysis for April 2003 is presented in Figure 21. The first station to join the dendrogram was Nearfield, shell station MDE-01 followed by Nearfield, Silt/Clay stations MDE-03, MDE-34, MDE-09 and MDE-16. The last station to join the first cluster was Nearfield, sand station MDE-24. Silt/Clay stations MDE-13, MDE-35, MDE-36, MDE-17, MDE-19, MDE-28, MDE-30, MDE-22 and MDE-27 formed a grouping of silt/clay stations, followed by Nearfield station MDE-07 and Nearfield, sand station MDE-33, which were the last stations to join the dendrogram. The faunal relationship to sediment type was not evident in this dendrogram, because all but three of the stations in April 2003 were silt/clay. Overall, the Nearfield, Reference and Back River/Hawk Cove stations were well mixed throughout the dendrogram and show no distinct grouping by station type as has been shown in previous monitoring years. The cluster analyses for September and April showed no unusually isolated stations, which suggests that the area is not being adversely affected.

Friedman's nonparametric test was used to determine if a significant difference could be detected among the various sampling stations for the average abundance of the 10 most abundant infaunal species. The test indicated there were no significant ($P < 0.05$) differences in the 10 most abundant infaunal species between Nearfield, Reference and Back River/Hawk Cove for September 2002 or April 2003 (Tables 16 & 17).

Table 16: Friedman Analysis of Variance for September 2002's 10 most abundant species among; Back River/Hawk Cove, Nearfield, and Reference stations. ANOVA Chi Sqr. (N = 30, df = 3) = 0.328, P < 0.85; Average rank = -0.03

Station Type	Average Rank	Sum of Ranks	Mean	Std. Dev.
Nearfield	2.03	61.00	120.75	132.22
Reference	2.05	61.50	121.60	121.70
Back River	1.92	57.50	145.07	211.57

Table 17: Friedman Analysis of Variance for April, 2003's 10 most abundant species among; Back River/Hawk Cove, Nearfield, and Reference stations. ANOVA Chi Sqr. (N = 30, df = 3) = 0.24, P < 0.89, Average Rank = -0.030

Station Type	Average rank	Sum of ranks	Mean	Std. Dev
Nearfield	1.95	58.50	914.13	2473.82
Reference	2.07	62.00	296.53	577.82
Back River	1.98	59.50	280.11	523.34

CONCLUSIONS AND RECOMMENDATIONS

The condition of the benthic macroinvertebrate community for Year 21, as measured by the Chesapeake Bay Benthic of Biotic Integrity (B-IBI) was similar to previous monitoring years. Overall, scores improved or remained the same when compared to Year 20 and were generally similar to the B-IBI scores of the previous 6 years of monitoring at Hart-Miller Island. The B-IBI scores increased at 11 stations, decreased at 4 stations and remained the same at 2 stations. Twelve stations exceeded the benchmark criteria of 3.0, three stations met it and only 2 stations failed to meet the benchmark. Statistical analyses confirmed that there were no significant differences in infauna among the Reference, Nearfield, and Back River/Hawk Cove stations. The cluster analysis for September 2002 indicated that the dominant bottom strata at each station could explain infaunal differences. The Hart-Miller Island Dredged Material Containment Facility will continue to operate at least until the year 2009. To date, there have been no measurable impacts from HMI on the benthic community in the adjacent area. However, a comprehensive analysis of all the historical HMI data for all projects needs to be undertaken before any conclusions about HMI's impact on the surrounding community can be made. It is further recommended that benthic community monitoring continue throughout the operational life-time of HMI as well as the post-operational periods in order to be certain that changes in site management do not have adverse effects on the surrounding biological community.

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.

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

Maryland Department of the Environment. *in review*. Assessment of the Environmental Impacts of the Hart-Miller Island Dredged Material Containment Facility Dredged material containment facility, Maryland. Year 21 Exterior Monitoring Data Report, September 2001-April 2002. *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. HarperCollins 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.

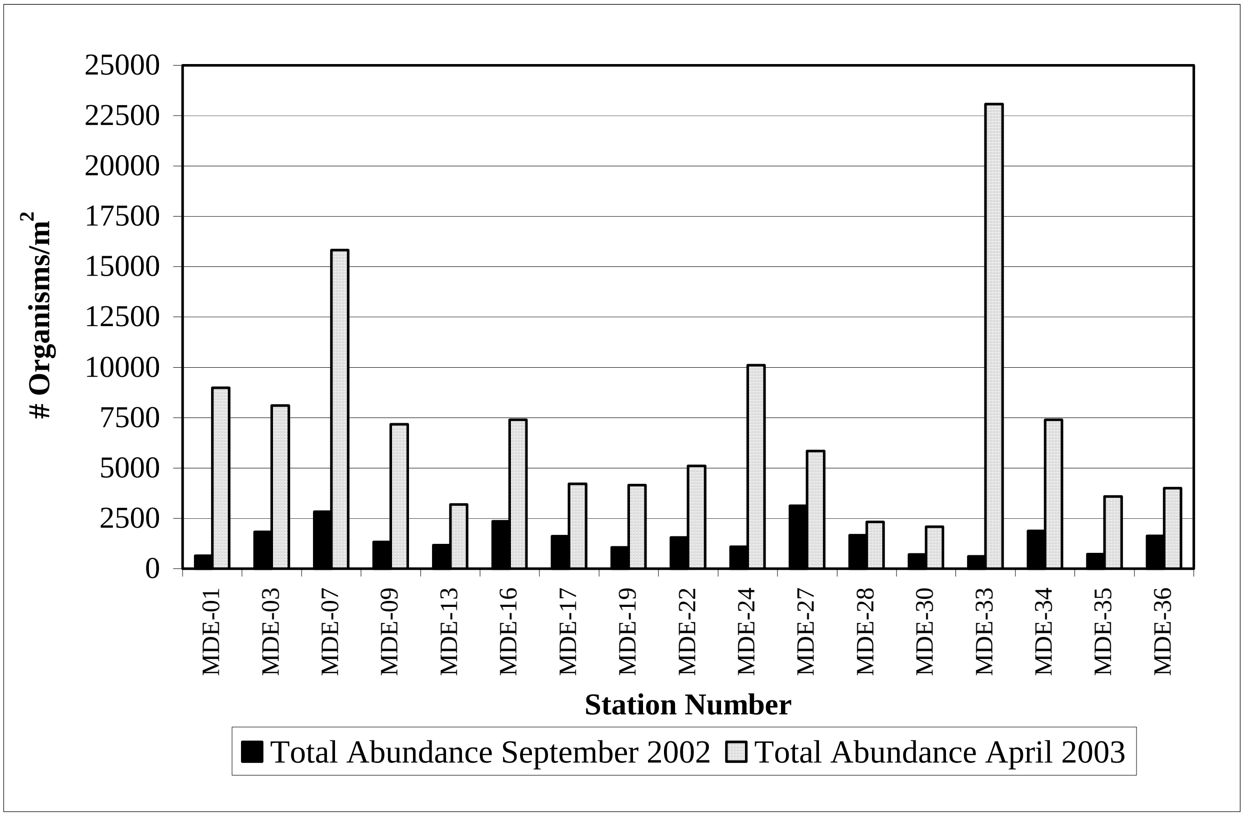

Figure 14: Total average abundance of infauna and epifauna taxa collected at each HMI station in year 21, September 2002 and April 2003.

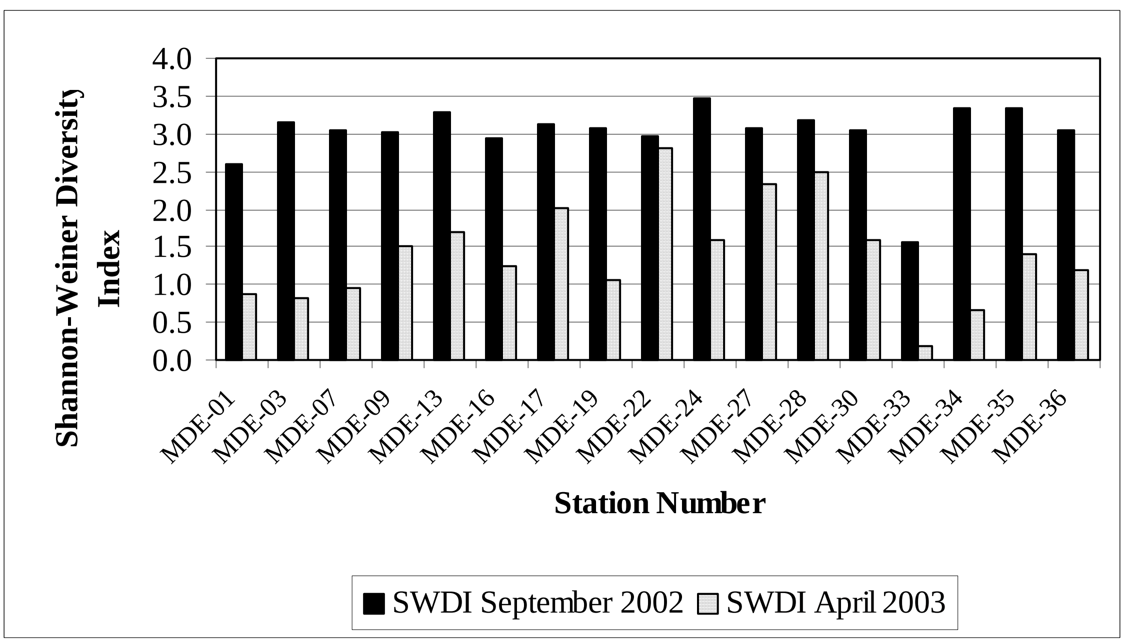

Figure 15: Shannon-Weiner Diversity Index (SWDI) in September 2002 and April 2003.

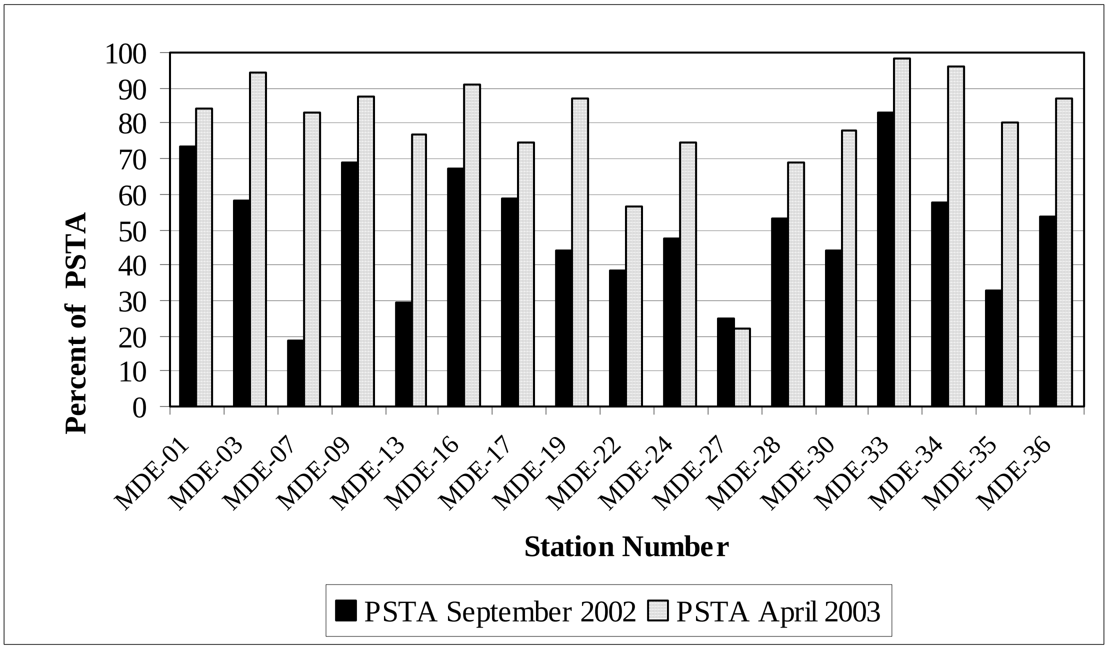

Figure 16: Percent abundance comprised of pollution sensitive taxa abundance (PSTA), HMI year 21 September 2002 and April 2003.

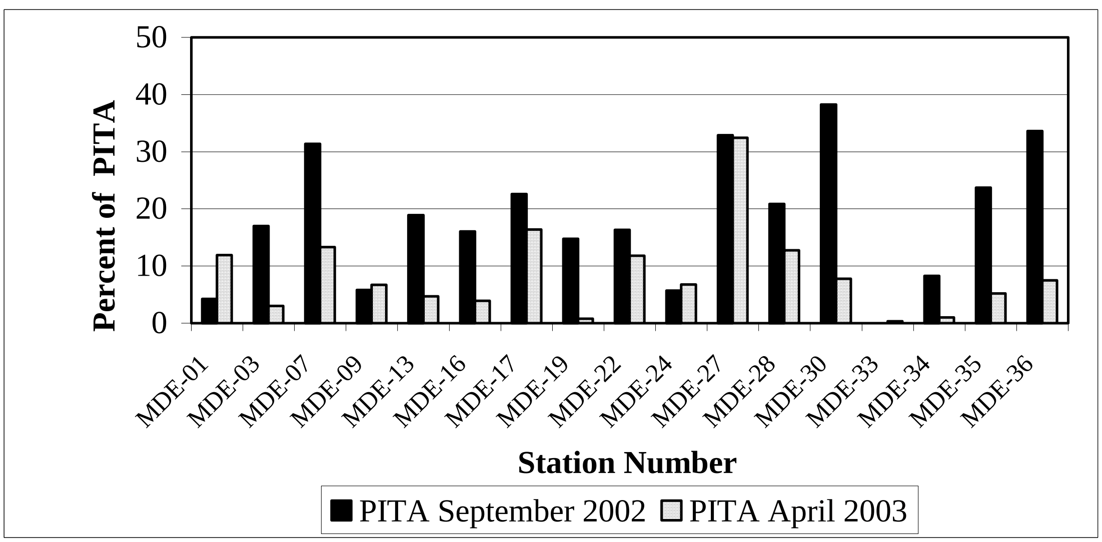

Figure 17: Percent abundance comprised of pollution indicative species (PITA), HMI year 21 September 2002 and April 2003.

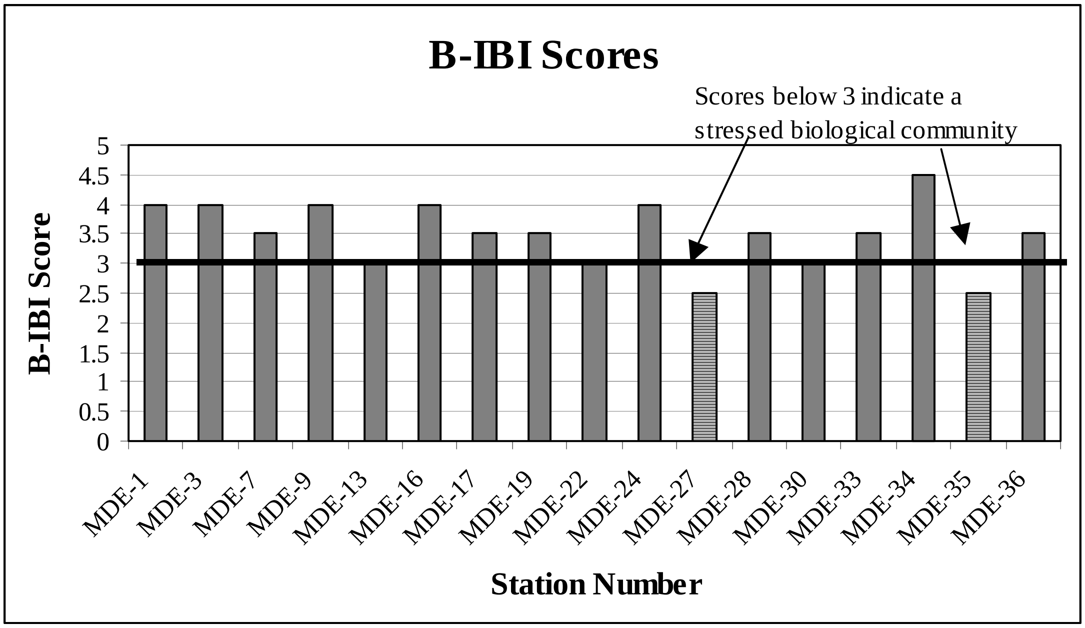

Figure 18: B-IBI Scores for all stations in September 2002.

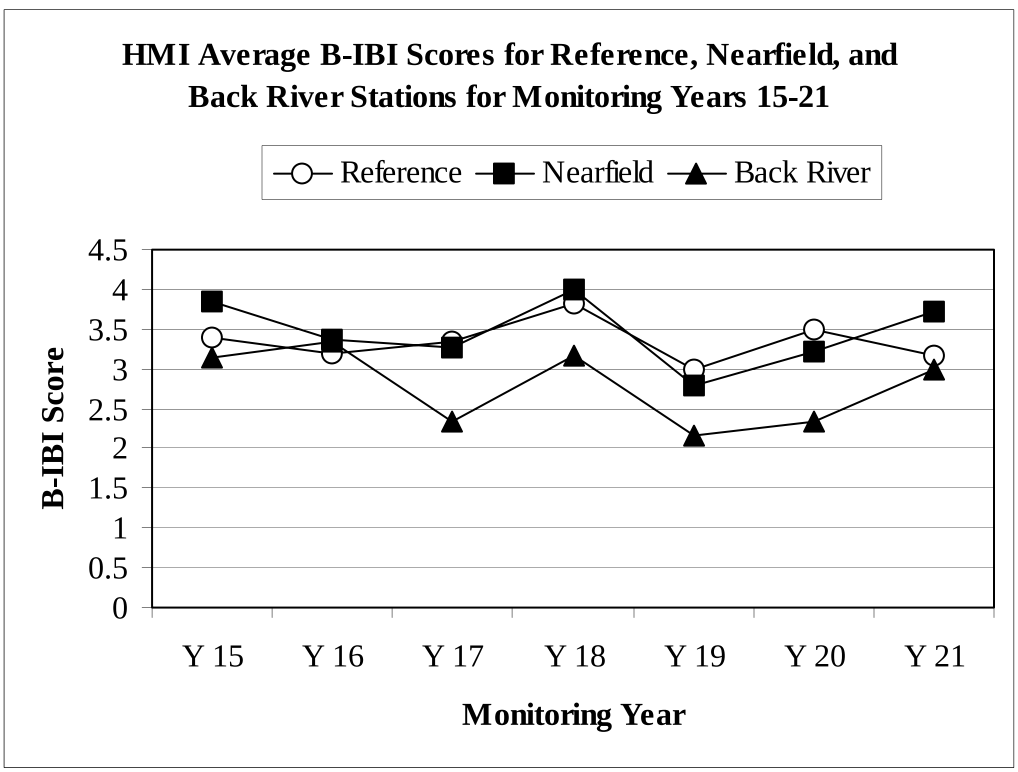

Figure 19: Average B-IBI Scores at HMI for Monitoring Years 15-21.

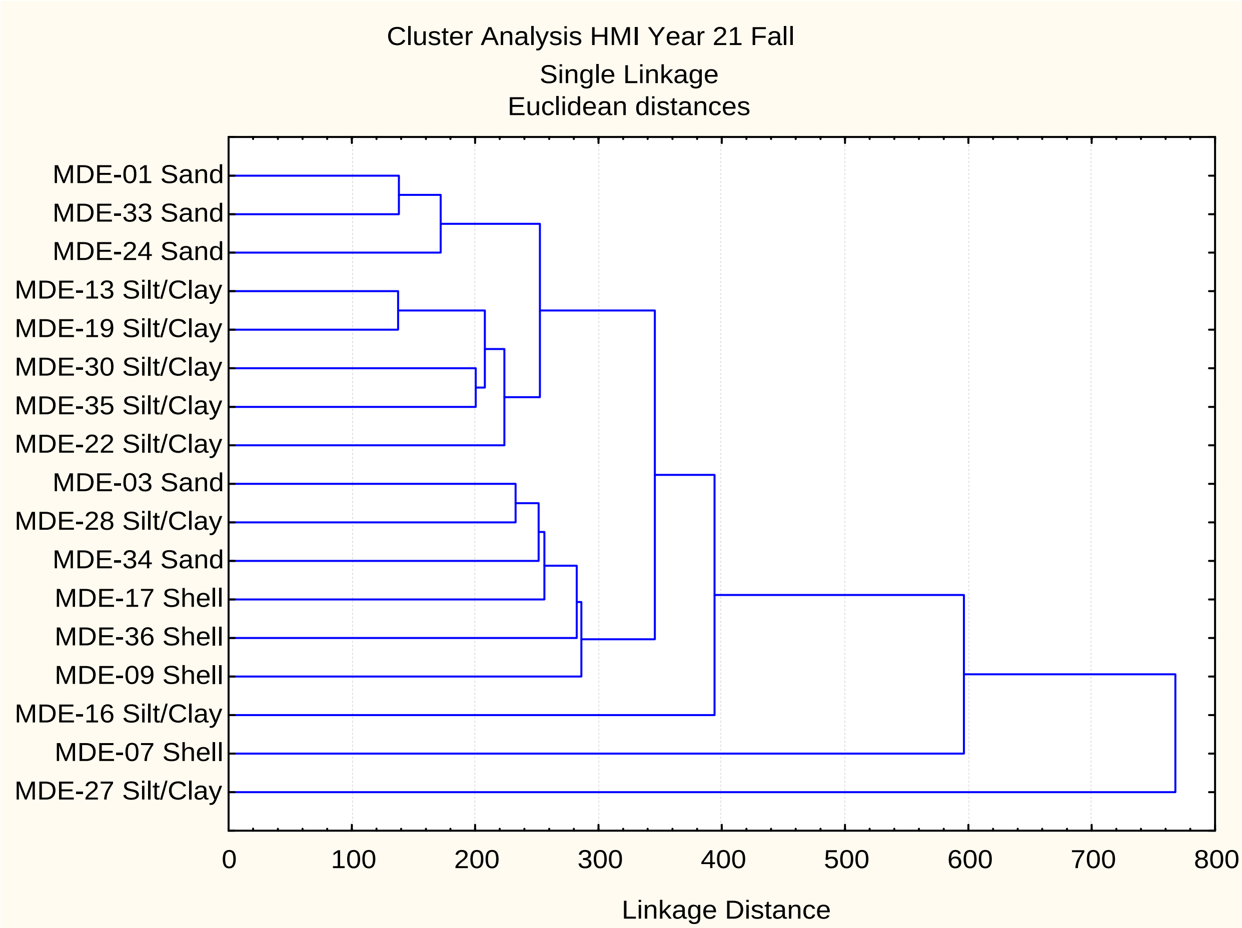

Figure 20: Cluster analysis based on Euclidean distance matrix of infaunal abundances of all HMI stations, year 21 September 2002.

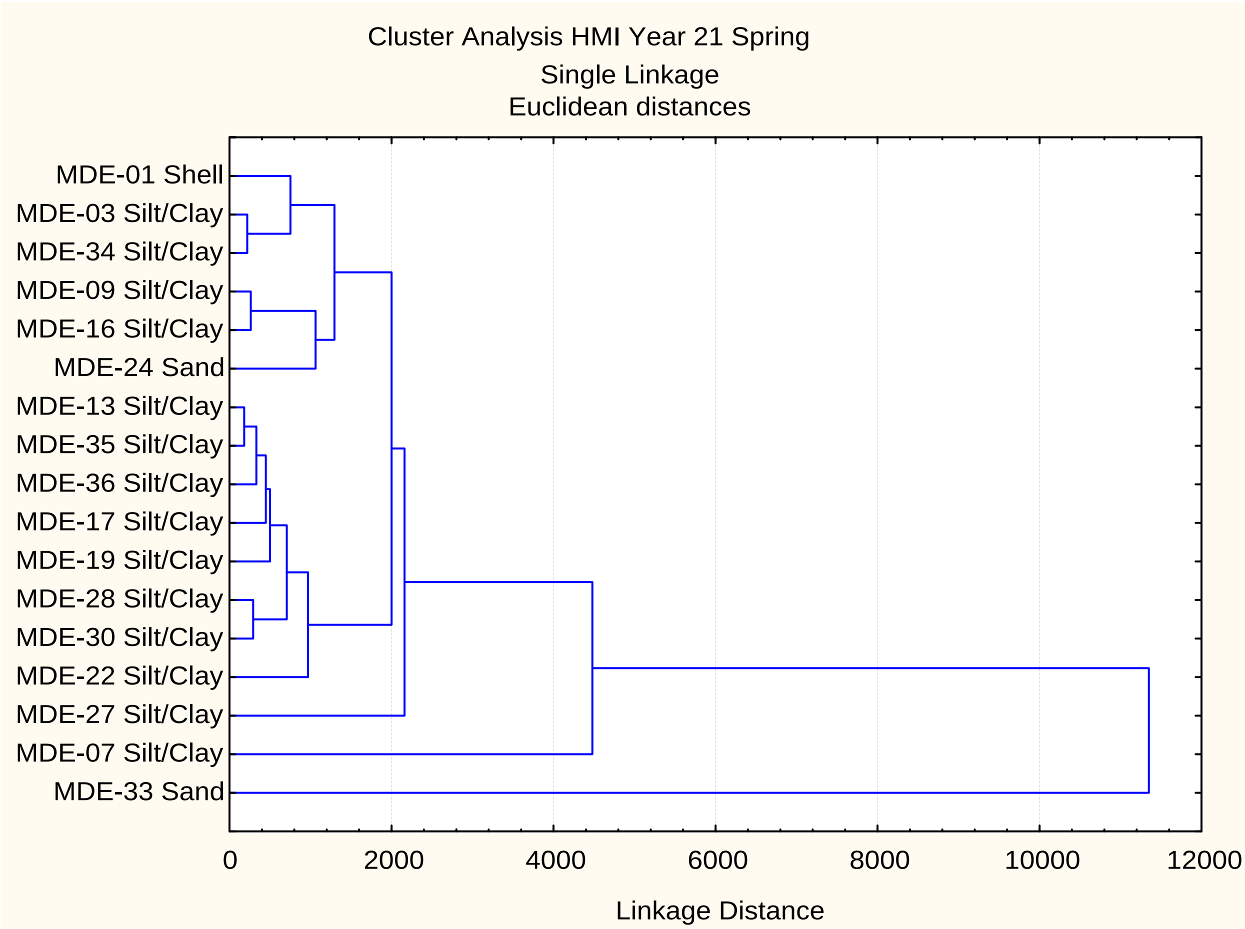

Figure 21: Cluster analysis based on Euclidean distance matrix of infaunal abundances of all HMI stations, year 21 April 2003.

CHAPTER IV: ANALYTICAL SERVICES

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OBJECTIVES

The goals of the project in 2002-2003 were to continue to measure and evaluate the current 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 this data with historical HMI data, will indicate the extent of contamination and any trend in concentrations at this location.

The objective of this study was to provide sensitive, high-quality information on the concentrations of present day trace metals in surface sediments surrounding HMI during the 21st year of exterior monitoring, and to document any seasonal changes. Specific objectives were:

1. In the spring of 2003, collect clams where available and associated sediment for analyses of trace metals, PCB's and PAH's.

2. To determine the concentrations of target trace elements in surface sediments around HMI collected by MGS in September 2002 and Spring 2003, as part of the annual sediment survey. Metal analysis focuses on those metals not measured by MGS, specifically mercury (Hg), monomethylmercury (MMHg), silver (Ag), and arsenic (As), as well as cadmium (Cd) and lead (Pb);

The results of the quality assurance (QA/QC) procedures and the description of the analytical and field protocols are contained in the *Year 21 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 21 Data Report*. Again, the QA/QC objectives were met in this regard.

METHODS AND MATERIALS

Sampling Procedures

Samples were collected using a Ponar grab sampler, from sites designated by the revised sampling plan, developed by the Maryland Department of the Environment in September 2002 and April 2003. Sediment for trace metal and organics analyses were collected using plastic spatulas and glass 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 sediment for PAH and PCB analyses were placed in glass jars. Both sets were kept cooled in an ice chest or refrigerator until they could be processed in the laboratory.

Sediment was sieved for clams. Whole clams where placed in plastic bags with surface water and held on ice. The clams were frozen to allow easy shucking the next day. For organic analysis, composite samples of clams from each site were prepared by removing fresh clams whole from their shells with a stainless steel scalpel. All body fluids were retained in the sample. The scalpel was cleaned with methanol between each sample set to avoid cross contamination between stations. Tissue was placed in a clean glass jar with a Teflon-lined lid and stored in the dark below 0°C. For metals analysis, clams were removed whole from their shells with a Teflon-coated spatula. Most of the water and body fluids were allowed to drain. The spatula was acid rinsed between each site to avoid cross contamination between sites. The clam bodies from each site were homogenized in a plastic blender with a stainless steel blade. Unused samples were returned to their respective bags and stored in the freezer until further analysis.

Analytical Procedures for Metals

Methods used for both metals are similar to those described in detail in Dalal et al. (1999). For metals, 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 60^0C overnight. Upon drying, samples were then reweighed and a dry/wet ratio was calculated.

Sediment and clam tissue were treated the same with regard to analysis. A sub-sample of sediment (5 g wet weight) was placed in acid-cleaned flasks for further digestion, using USEPA Methods (USEPA Methods; Keith 1991). Ten mL of 1:1 HNO_3 was added and the slurry was mixed and covered with a watch glass. The sample was heated to 95^0C and allowed to reflux for 15 minutes without boiling. The samples were cooled, 5 mL of concentrated HNO_3 was added, and then they were allowed to reflux for another 30 minutes. This step was repeated to ensure complete oxidation. The watch glasses were removed and the resulting solution was allowed to evaporate to 5 mL without boiling. When evaporation was complete and the samples cooled, 2 mL of 30% H_2O_2 was added. The flasks were then covered and returned to the hot plate for warming. The samples were heated until effervescence subsided. We continually added 30% H_2O_2 in 1 mL aliquots with warming until the effervescence was minimal. No more than a total of 10 mL of H_2O_2 was added to each sample. Lastly, 5 mL of concentrated HCl and 10 mL of deionized water were added and the samples refluxed for 15 minutes. The samples were then cooled and filtered through Whatman No. 41 filter paper by suction filtration and diluted to 50 mL with deionized water. Sediment homogenates were then analyzed using a Hewlett Packard model 4500 Inductively Coupled Plasma Mass Spectrometer for the other metals and metalloids. These techniques are similar to USEPA Method 1632.

Samples for mercury (1-3 g wet weight) were digested in a solution of 70% sulfuric/30% nitric acid in Teflon vials, heating overnight in an oven at 60^0C (Mason and Lawrence, 1999). The digestate was then diluted to 10 mLs with distilled-deionized water. Prior to analysis, the samples were further oxidized for 30 minutes with 2 mLs of bromine monochloride solution. The excess oxidant was neutralized with 10% hydroxylamine solution and the concentration of mercury in an aliquot of the solution was determined by tin chloride reduction cold vapor atomic fluorescence (CVAFS) detection after gold amalgamation in accordance with protocols outlined in USEPA Method 1631 (Mason et al. 1993).

Samples for methylmercury were distilled after adding a 50% sulfuric acid solution and a 20% potassium chloride solution (Horvat et al. 1993, Bloom 1989). The distillate was reacted with a sodium tetraethylborate solution to convert the nonvolatile MMHg to gaseous MMHg. The volatile adduct was purged from solution and recollected on a graphitic carbon column at room temperature. The MMHg was then thermally desorbed from the column and analyzed by cryogenic gas chromatography with CVAFS. Detection limits for Hg and MMHg were based on three standard deviations of the blank measurement.

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 perdueterated polyaromatic hydrocarbon (PAH) cocktail (d_8-napthalene, d_{10}-fluorene, d_{10}-fluoranthene, d_{12}-perylene) and a noncommercial polychlorinated biphenyl (PCB) solution (IUPAC #'s 14, 65, 166) are added as surrogates to each sample to track extraction efficiency. The mixture is then extracted in a Soxhlet apparatus with 250 mL of dichloromethane (DCM) for 24 hours. The extracts are then concentrated to 2 mL using a vacuum rotary evaporator and transferred into hexane. Each sample is transferred to a 4 ml Waters autosampler vial with sample and rinses amounting to approximately 4 mL. Gravimetric lipid analysis is performed on each sample with subsampled fractions determined gravimetrically (Kucklick et al. 1996). Samples are again concentrated in similar fashion as above, then solvent exchanged to hexane. To remove lipids the extracts are then eluted with 25 mL petroleum ether over 4 g deactivated Alumina [6% (w/w) water]. After concentrating, the extracts are spiked with a perdueterated 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 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 are analyzed by gas chromatography using a J&W Scientific DB-5 capillary column (60m x 0.32mm, 0.25µm film thickness) coupled with an electron capture detector. Individual PCB congeners are identified and quantified using the method of Mullins et al. (1985) using the noncommercial PCB congeners IUPAC 30 and 204 as internal standards. After quantification of PCB congeners, the two Florisil fractions from each sample are recombined and pesticides are quantified by gas chromatography (30 m DB-5 column) with negative chemical ionization mass spectrometric (NCI-MS) detection. Chemical ionization with methane reagent gas is used. Pesticides are identified by their chromatographic retention times and confirmed by the relative abundance of negative fragments (confirmation ions) relative to the quantification fragment. Five-point calibration curves are used for each pesticide analyzed. Polychlorinated biphenyl congener 204 is used as the internal standard for the pesticide quantification.

RESULTS AND DISCUSSION

Metals in the sediment

Concentrations of arsenic, selenium, cadmium and lead in 2002-2003 are similar to previous years (Figures 22 and 23). However, silver concentrations are much lower than in past years throughout the region (Figure 24). Silver contamination is often associated with general urban pollution, having origins in sewage treatment plants. Elevated concentrations in 1999 and 2000 may have been associated with anomalous discharges from the city of Baltimore. Silver is strongly associated with organic matter (r^2 0.71) and could easily have been redistributed down the Bay.

Concentrations of mercury (T-Hg) and methylmercury (MeHg) in sediment are lower than the average of previous years but are within the error bars (Figure 25). Concentrations of methylmercury are responding to other factors that are affecting microbial activity such as carbon supply and the presence of sulfide in the porewater, which controls the bioavailability of mercury (Benoit et al. 2003).

Concentrations of T-Hg in the main stem of the Chesapeake Bay range from 250 to 0.2 ng g^{-1} dry weight and concentrations of MeHg range from 0.01 to 2.2 ng g^{-1} dry weight (Figure 26) (Heyes et al. submitted). Concentrations of both T-Hg and MeHg are highest in the upper bay, with T-Hg concentrations on the order of 130 ng g^{-1} and MeHg concentrations 1 ng g^{-1}. Concentrations of T-Hg around HMI have averaged 200 ng g^{-1} and MeHg concentrations have averaged 1 ng g^{-1}over the study years (Figure 25).

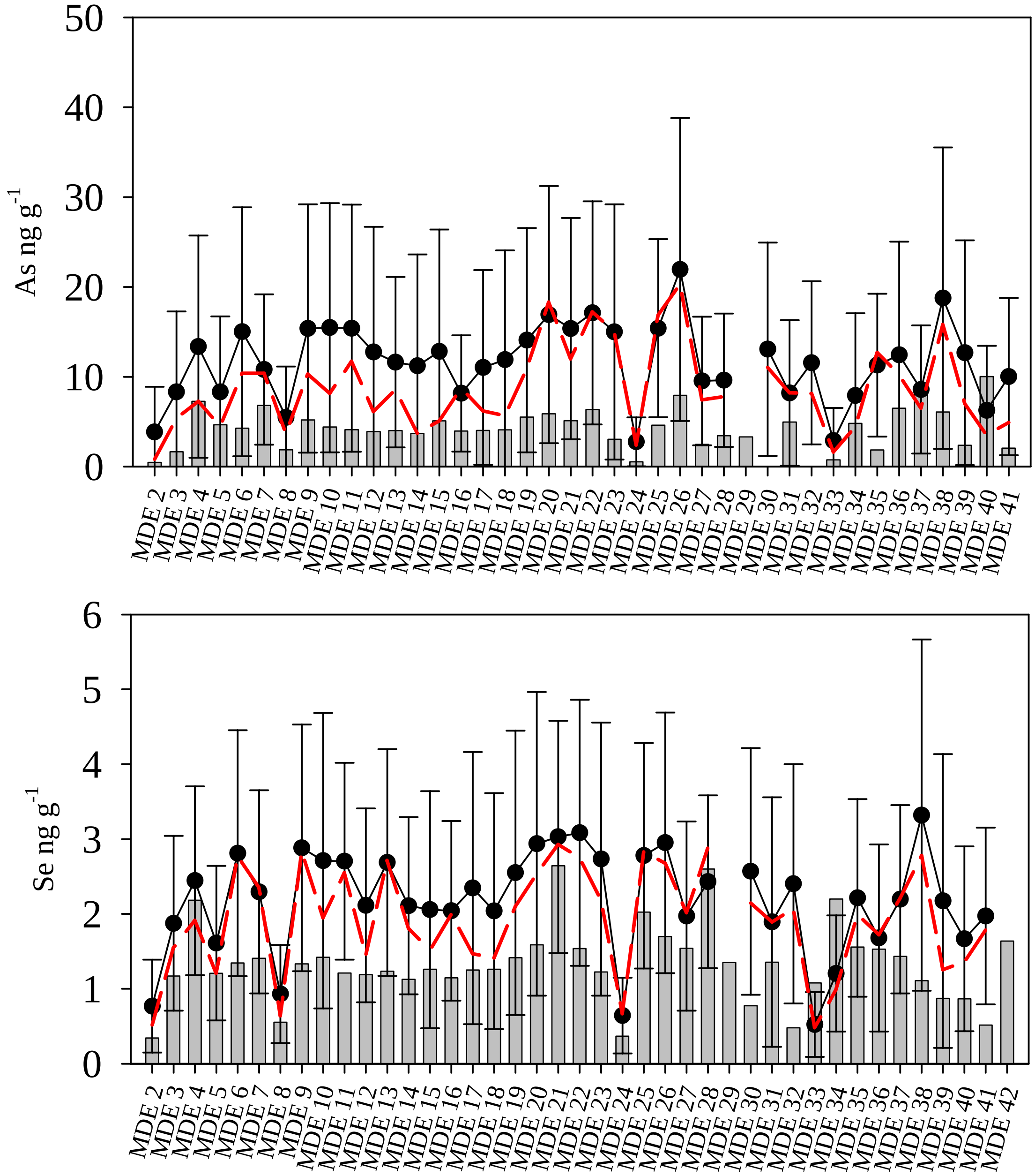

Figure 22: Arsenic (Ag) and selenium (Se) concentrations in 2002 sediment (bars) and the 1998-2001 mean (circles) with standard deviation (error bars) and the 1998-2001 median (dashed line).

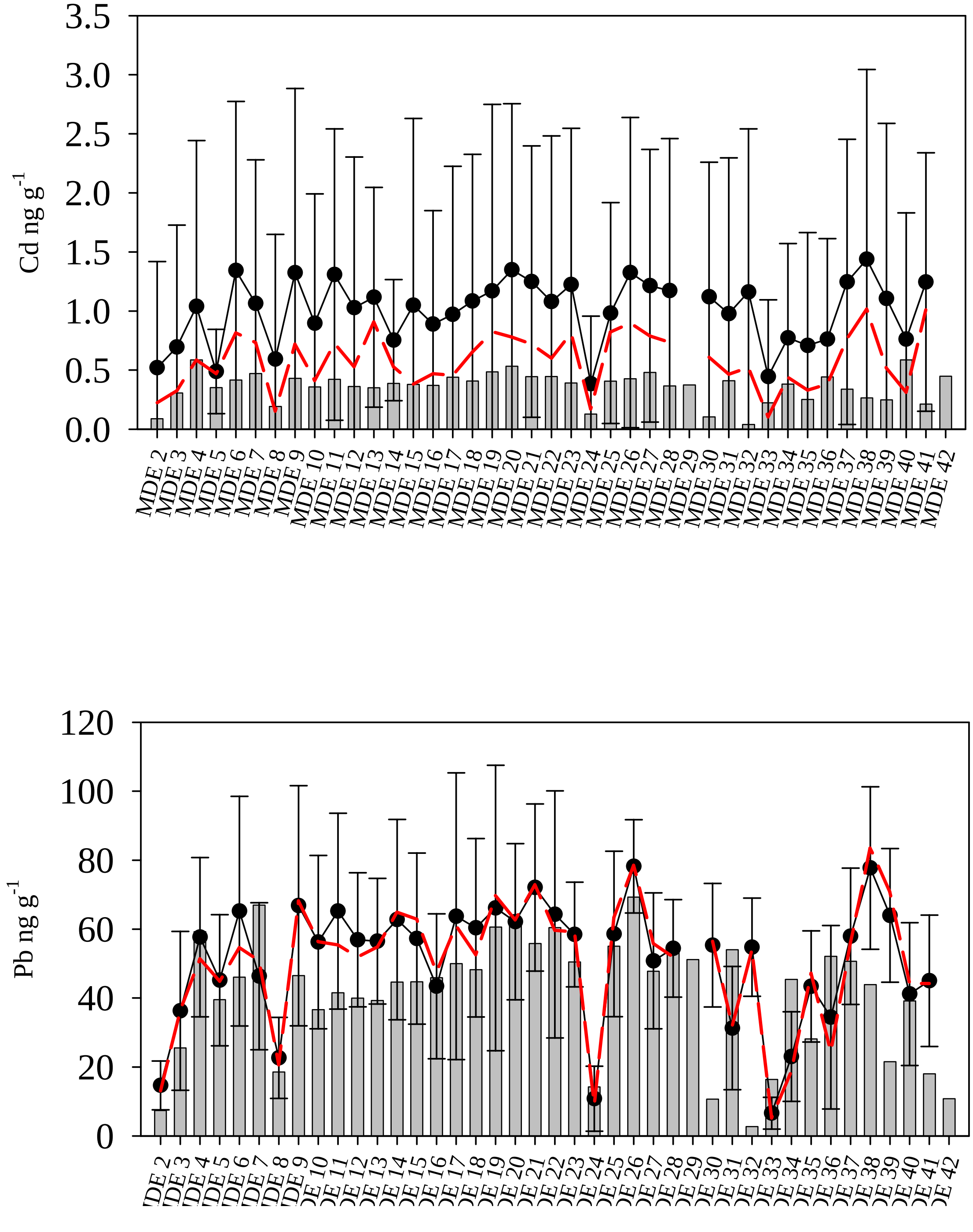

Figure 23: Cadmium (Cd) and lead (Pb) concentrations in 2002 sediment (bars) and the 1998-2001 mean (circles) with standard deviation (error bars) and the 1998-2001 median (dashed line).

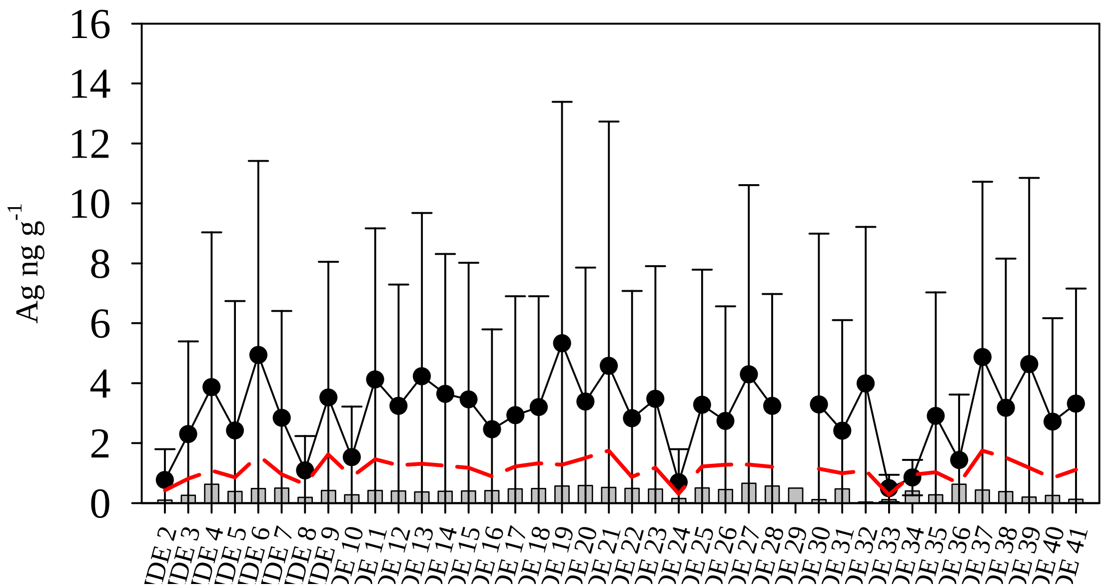

Figure 24: Silver (Ag) concentrations in 2002 sediment (bars) and the 1998-2001 mean (circles) with standard deviation (error bars) and the 1998-2001 median (dashed line).

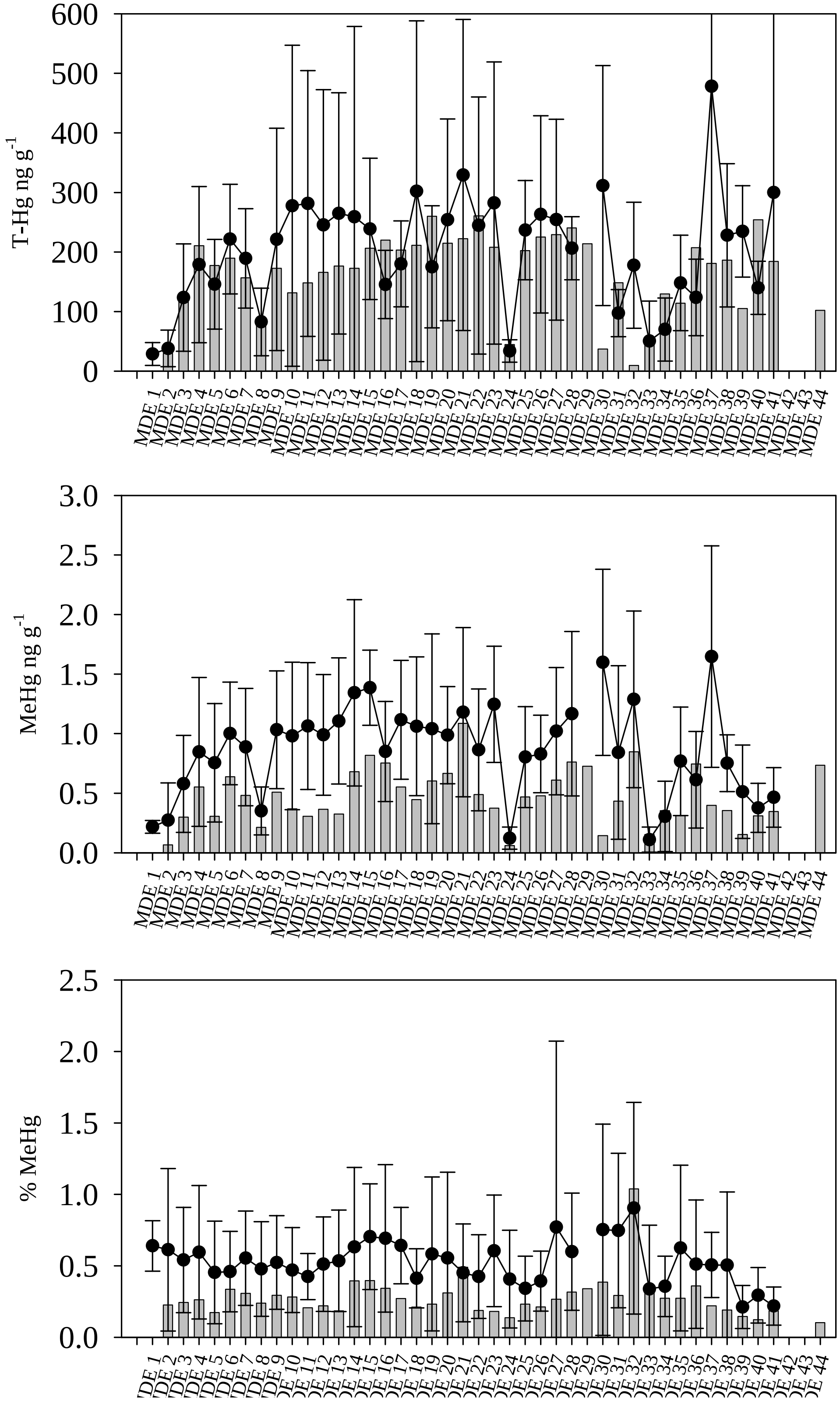

Figure 25: Mercury (Hg) and methylmercury (MeHg) concentrations, and percent Hg as MeHg, in 2001 sediment (bars) and the 1998-2000 mean (circles) with standard deviation (error bars).

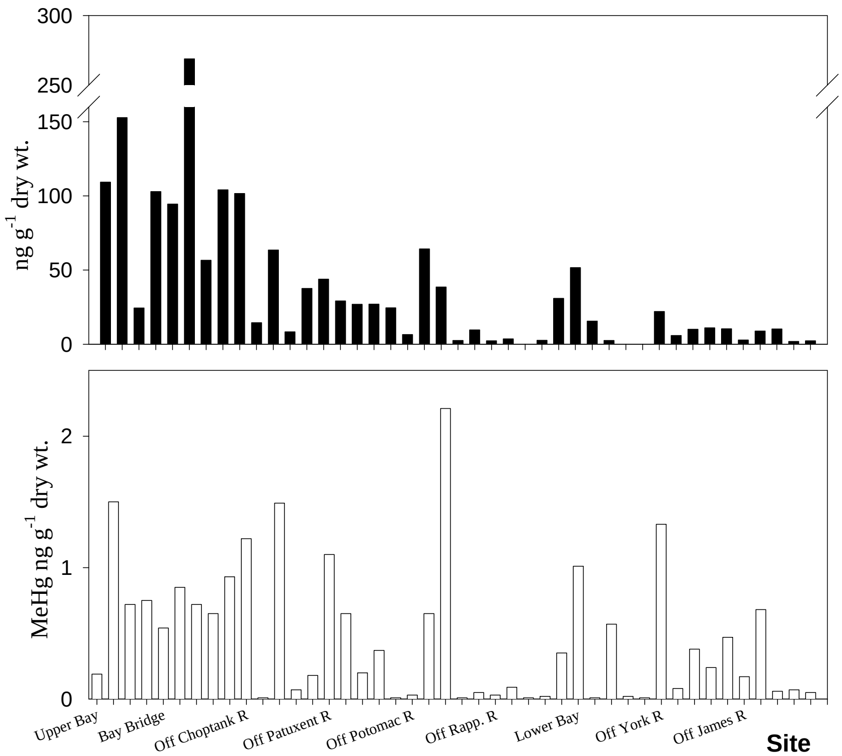

Figure 26: Total mercury and methylmercury concentrations in sediments of the Chesapeake Bay.

Metals in Clams

Concentrations of the metals As, Se, Ag, Cd, and Pb in clams have remained consistent between years 17 and 21 (Figure 27). Most metal concentrations are low and not very variable among the sites. Concentrations of As, Se and Pb in the biota are not any higher than the sediment indicating little if any bioaccumulation of these metals from the sediment has occurred. Concentrations of silver are much higher in the clams, often by two orders of magnitude, indicating substantial bioaccumulation. Ag has many sources in the watershed and primarily transported bound to organic matter. Clams being filter feeders, are effective in accumulating Ag. The concentration of Ag in sediment decreased at all sites around HMI in 2002 and this was reflected in the clams. Concentrations of Cd are 10 to 50 times higher in clams than in the sediment. Bioaccumulation of Cd is common in clams and as in the case of Ag. Unlike Ag, Cd concentrations in clams did not decrease despite a decrease in the sediment concentration of Cd.

The concentration of mercury in clams is consistent from year to year and there is little variability among the sites. Methylmercury concentrations in clams have also been consistent over the study, however the percent of Hg as MeHg was lower in year 21 than the other study years. Concentrations of methylmercury in sediment were also lower at all of the sites in 2002, indicating that net ecosystem methylation was lower and this is reflected in the clams.

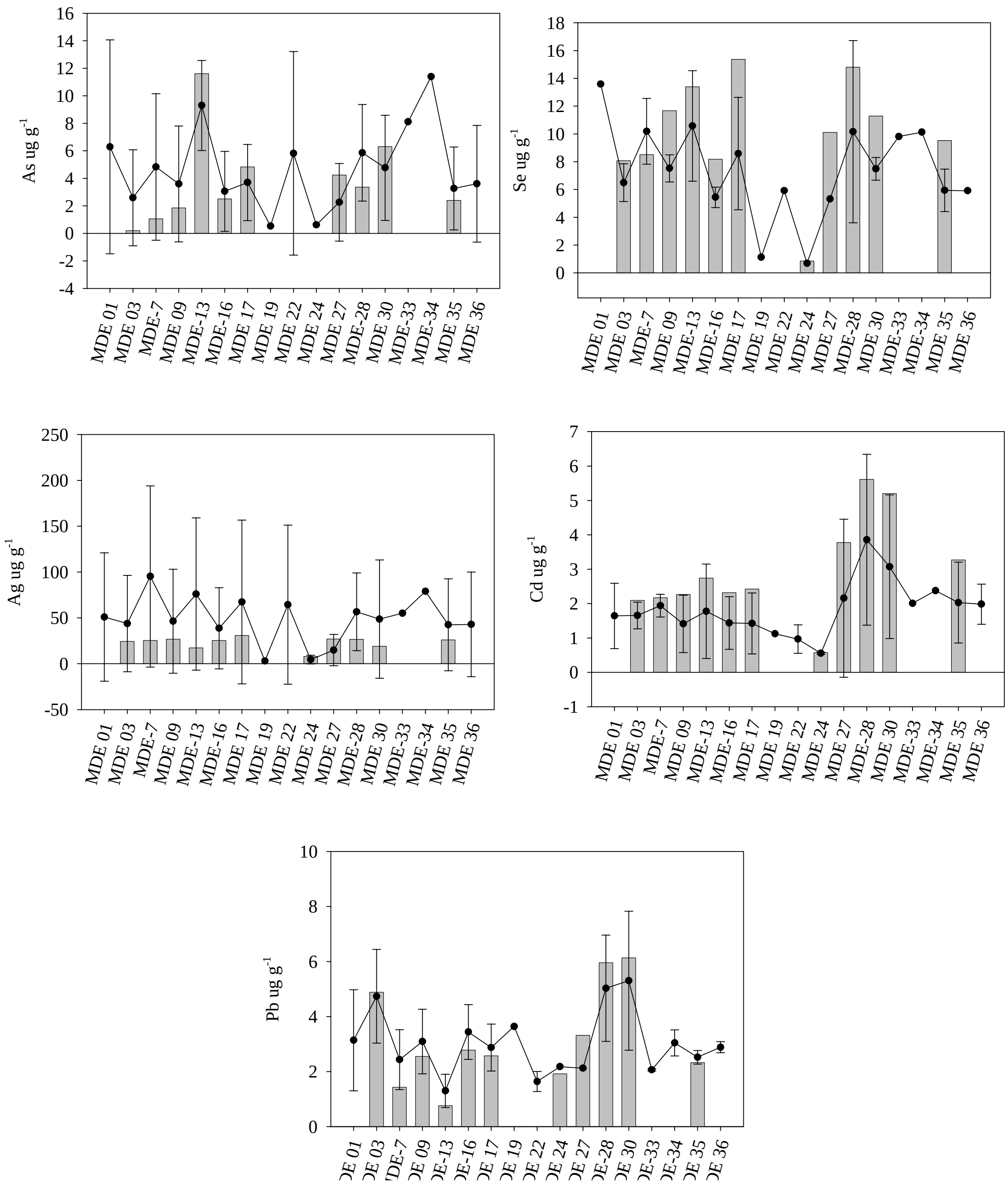

Figure 27: Concentrations of arsenic (As), selenium (Se), silver (Ag), cadmium (Cd) and lead (Pb) in 2001 clams (bars) and the 1998-2000 mean (circles) with standard deviation (error bars).

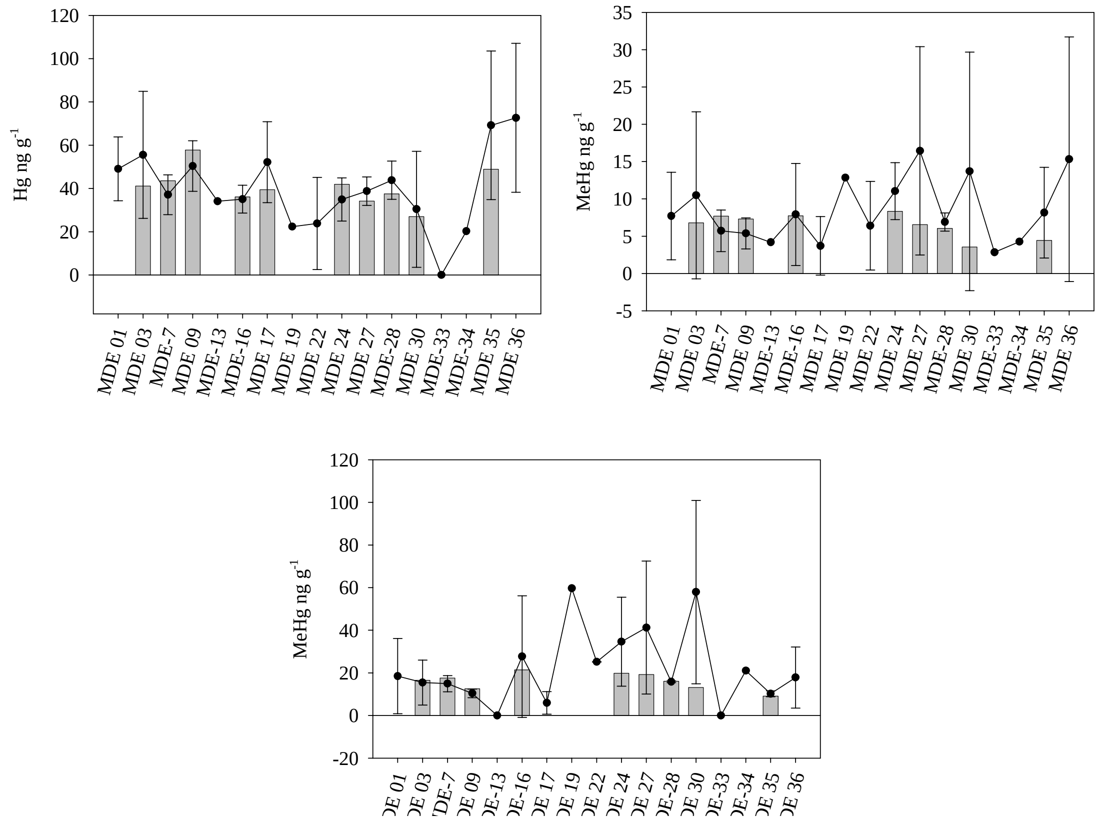

Figure 28: Mercury (Hg) and methylmercury (MeHg) concentrations and percent Hg and MeHg in 2002 clams (bars) and the 1998-2001 mean (circles) with standard deviation (error bars).

Organics in Sediment

With three years of data on PAH and PCB concentrations in sediment, we can now begin to investigate the temporal variability in these substances. All 95 PCB congeners and 38 PAH compounds tested are presented in the appendices 3 and 5 of the data report. For this report we have shown examples of three PAH and PCB congener groups to illustrate spatial and temporal variations in the concentrations of these compounds (Figures 29 and 30).

The concentration of the PAH's are at least as variable within sites as among sites and the control sites have concentrations that are within a factor of two of the concentrations at any other site within the same year. This data implies that the concentrations of PAH's in sediments is responding to regional variations and not a point source such as HMI. This has been illustrated with the use of three PAH compounds, napthalene, flouranthene and benzo(g,h,i)perylene (Figure 8). Samples collected in 2002 are similar to other years. In fact there has been little variation over the course of the study.

The concentrations of PCB's have also remained low and consistent around HMI. We have illustrated the point using three PCB congener assemblages, congener17, the 66- 95 congener assemblage, and the 163-138 assemblage (Figure 30). These congeners represent a significant proportion of the total PCB load in sediments, and for the most part, these congeners reflect the behavior of the total PCB pool. At the sites MDE-3 and MDE-13, the PCB congener 17 occurred in a substantial higher concentration in 2002 than at the other sites. Such spikes in the concentrations of single PCB congeners indicates is difficult to explain, owing to the varied sources of the compounds. However, the spike in the concentration of this one PCB did not influence the total PCB load for the year. In fact the total PCB concentrations in year 21 was the lower than the average. This underlines the need to assess the total PCB load of the sediment.

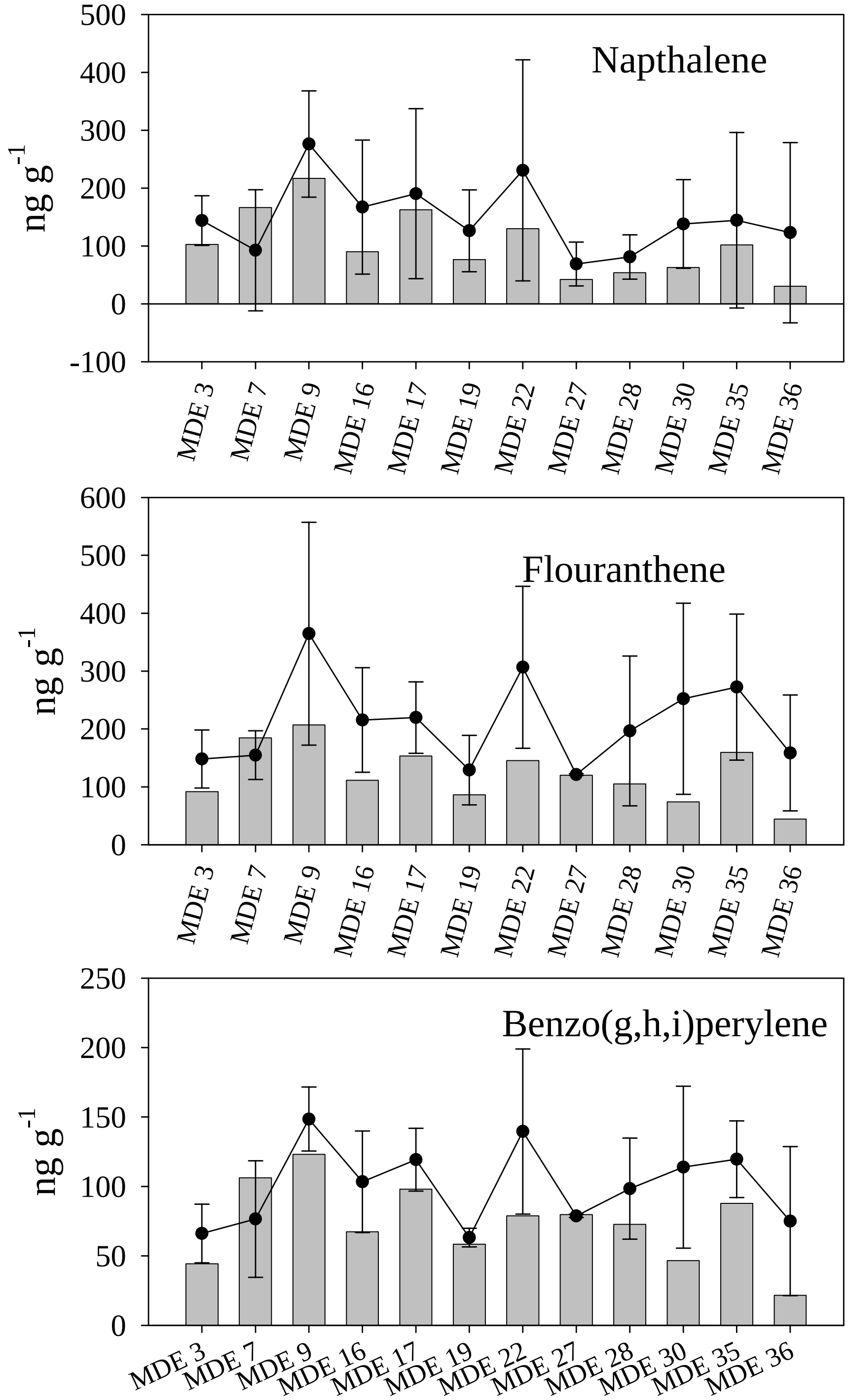

Figure 29: Concentrations of example PAH's in sediments collected around HMI in 2002. The bars are from 2002 where as the lines represent the mean and standard deviation of concentrations observed over the entire study period.

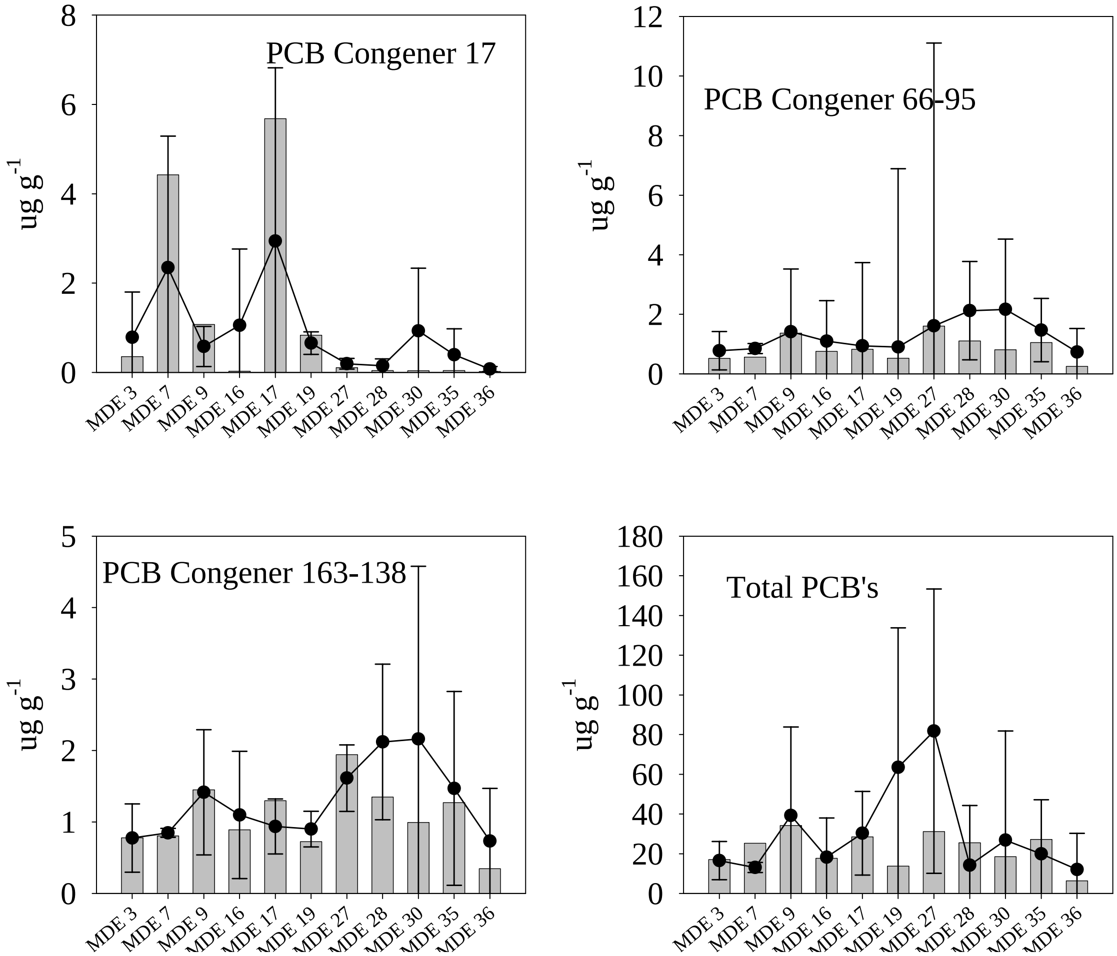

Figure 30: Concentrations of three PCB congeners and the total PCB concentration in sediments around HMI. The bars are from 2002 where as the lines represent the mean and standard deviation of concentrations observed over the entire study period.

PAH's and PCB's in Clams

The concentrations of 28 PAH's and 84 PCB congeners or combinations where measured in 2002 are listed in Appendix 2 and 4 of the data report. The concentrations of PAH's have remained low over the study period and are at there lowest in year 21. A large number of PAH's, such as benzo(b)fluorant, where below the level of detection at all locations (Figure 31). The levels of PAH detection have not changed significantly between years, therefore these natural variation must reflect changes in the concentrations in the clam population. In the case of PCB's, concentrations in clams at individual sites have varied significantly over the study. Some PCB congeners, such as the 77,110 combined congener, where much lower in 2002 than in other years (Figure 32). The net effect is the total amount of PCB's in clams is only slightly lower in 2002, but hardly outside the variation observed to date.

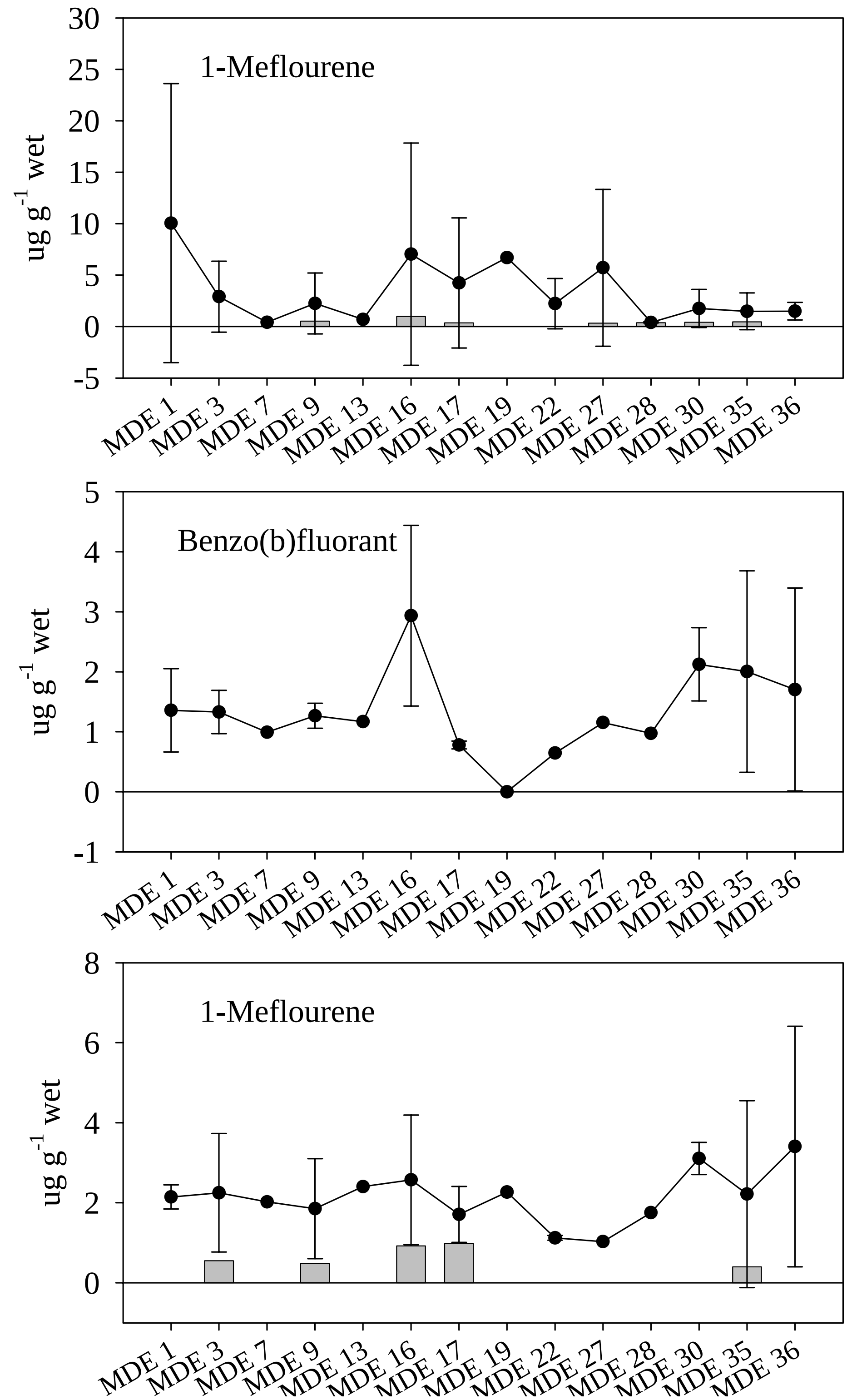

Figure 31: Examples of PAH concentrations in clams collected around the HMI. The bars are from 2002 where as the lines represent the mean and standard deviation of concentrations observed over the entire study period.

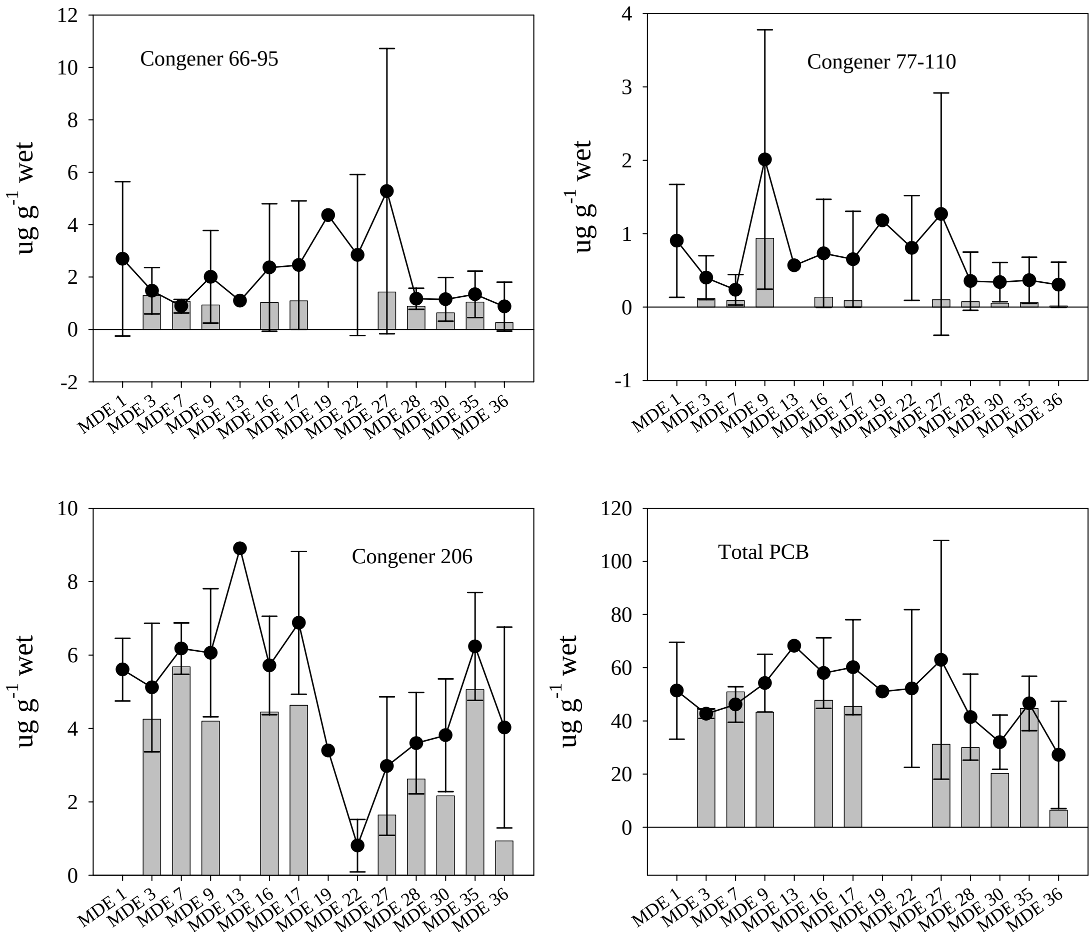

Figure 32: Concentrations of three example PCB congener assemblages and total PCB's in clams collected in the vicinity of HMI. The bars are concentrations from 2002 and the lines are the means and standard deviation for the entire study period.

REFERENCES

Ahrens, M.J., Hertz, J. Lamoureux, E.M., Lopez, G.R., McElroy A.E., Brownawell, B.J. 2001. The role of digestive surfactants in determining bioavailability of sediment-bound hydrophobic organic contaminants to 2 deposit feeding polychaetes. Marine Ecol. Prog. Series. 212:145-157.

Baeyens, W., Leermakers, M., De Gieter, M., Nguyen, H.L., Parmentier, K. Panutrakul, S and Elskens, M. 2005. Overview of trace metal contaminants in the Scheldt estuary and effect of regulatory measures. Hydrobiologia 540:141-154.

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

Di Giulio R.T. and Scanlon, P.F. 1985. Heavy metals in aquatic plants, clams and sediments from the Chesapeake Bay, USA. Implications for waterfowl. Sci. Total Environ. 41:259-274.

Griscom, S.B, Fisher, N.F., Luoma, S.N. 2002. Kinetic modeling of Ag, Cd, and Co bioaccumulation in the clam Macoma blthica: quantifying dietary and dissolved sources. Marine Ecol. Prog. Ser. 240:127-141.

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

Horvat, M.; N.S. Bloom, and L. Liang. 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.

Keith, L.H. (Editor). 1991. Compilation of EPA's Sampling and Analysis Methods. Lewis Publ., Boca Raton.

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, Marylabd, 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.

Purcell, T.W. and Peters, J.J. 1998. Sources of silver in the environment. Environ. Toxic. Chem.

17:539-546.

Sheppard, B.S., Heitkemper, D.T., and Gaston, C.M. 1994. Microwave digestion for the determination of Arsenic, Cadmium, and lead in seafood products by inductively coupled plasma atomic emission and meass spectrometry. Analyst. 119:1683-1686.

Wang, W.X., Stupakoff, I and Fisher, N.S. Bioavailability of dissolved and sediment-bound metals to a marine deposit-feeding polychaete. Marine Ecology Prog. Series. 178:281-293.

Yoo, H., Lee, J.S., Lee, B.G., Lee, I.T., Schlekat C.E. Koh, C.H., Luoma, S.N. 2004. Uptake pathway for Ag bioaccumulation in three benthic invertebrates exposed to contaminated sediments. Marine Ecology Progress Series 270:141-152.