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

Year 22 Technical Report (September 2003 - 2004)

Prepared by:
Maryland Department of the Environment

Chesapeake Biological Laboratory · Solomons

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MDE

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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

CWA - Clean Water Act

Cr - Chromium

Cu - Copper

CWA - Clean Water Act

DCAD - Dredging Coordination and Assessment Division

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 Confined Disposal 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.

PROJECT 1: PROJECT MANAGEMENT AND SCIENTIFIC/TECHNICAL COORDINATION
(September 2003 – September 2004)

Hart-Miller Island Exterior Monitoring Program

Prepared for

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The team work of Dr. James Hill of the Maryland Geological Survey and Mr. Andrew Heyes of the University of Maryland was essential in assessing any facility impacts to local sediments or biota surrounding the facility. The Maryland Department of the Environment would like to thank the members of the HMI Citizens' Oversight Committee (COC) for their useful comments and suggestions throughout the project year, as well as their long-term commitment to the HMI project. Maryland Environmental Service (MES) provided helpful comments on the exterior monitoring reports and improved overall report presentation and content.

Lastly, thanks are due to Mr. Robin Grove, former Director of TARSA, and Dr. Rich Eskin, TARSA Director, for their guidance, suggestions and commitment to the Hart-Miller Island Exterior Monitoring Program.

INTRODUCTION

Site Background

Baltimore's strategic location in northern Chesapeake Bay has secured Maryland's place as a stronghold for ship-borne commerce. 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 must provide placement sites for material dredged from these federal maintenance channels. In 1983, Hart-Miller Island Confined Disposal 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 facility connecting the remnants of Hart and Miller Islands and encompassing an open-water area of approximately 1,100 acres. The facility was constructed from sand excavated from the proposed interior of the facility. The eastern or Bay side of the facility was reinforced with filter cloth and rip-rap to protect the facility from wave and storm induced erosion. Completed in 1983, the facility is approximately 29,000 feet long and is divided into North and South Cells by a 4,300 foot interior cross-facility. Placement of dredged material within HMI began with facility 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 2009, at which time it will also be converted into a wildlife refuge. The remnants of Hart and Miller Islands, which lie outside of the facility, serve as a state park and receive heavy recreational use throughout the summer months.

Environmental Monitoring

Background

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

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

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 response to both changes in technology and sampling protocols recommended 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 to 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). This 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 sediments[2]. The sediment toxicity project (Project 4) looks at benthic tissue concentrations for 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.

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

Table 1: Information Provided by Differential 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 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.

PROJECT SUMMARIES

Project I: Project Management and Scientific/Technical Coordination – Maryland Department of the Environment (MDE)

In July 1995, responsibility for Project I was transferred to the Maryland Department of the Environment (MDE) from the Maryland Department of Natural Resources (DNR). As the permitting authority, MDE reviews the overall exterior monitoring program to make sure it meets the general and special conditions of the state's wetlands license. MDE is responsible for ensuring the scientific integrity of the Exterior Monitoring Program, which includes evaluating the sampling protocols and analytical methods used by the Principal Investigators (PIs) for each project. MDE recommends changes to the monitoring that will improve the State's ability to accurately assess the condition of waters surrounding the HMI facility. The Department also coordinates all field sampling among PIs for each project to ensure efficient, timely and representative sample collection.

Project I includes data management and providing HMI data to the public through several media, including written reports and the Internet. HMI monitoring data is now publicly available on the Environmental Protection Agency's STORET Web site (www.epa.gov/storet). Oversight of project budgets, invoicing and deliverable submittal is also a major component of Project I. This includes review of quarterly project status reports to ensure that project goals are met in a timely fashion and within budget.

Project II: Sedimentary Environment – Maryland Geological Survey (MGS)

For Year 22, MGS collected sediment samples from 40 sites on August 29, 2003, and from 43 sites on April 16, 2004. Samples were analyzed for multiple parameters, including: (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).

Concentrations of trace metals surrounding the facility fell into two groups, those exceeding the effects range-low (ERL) and those exceeding the effects range-median (ERM). Cadmium, Cr, Cu, Ni, Pb and Zn were found at some sites with concentrations that exceed the ERL values. At times, Ni and Zn were also found to exceed the ERM.

ERL and ERM values, established by the National Oceanic and Atmospheric Administration (Long, E.R. 1992, Long and others 1995), represent three different biological effects thresholds. Sediment contaminant concentrations below the ERL suggest a minimal effects-range where biological impacts are unlikely to occur. Values above the ERL, but below the ERM, identify a possible effects-range where effects may occasionally occur. Values above the ERM represent a probable effects-range where impacts frequently occur. ERLs and ERMs were developed using mostly Pacific Coast data that were not normalized to sediment grain size.

When the data are normalized, Pb, and to a lesser extent Zn, have samples significantly enriched above baseline. However, based on work done in Baltimore Harbor, the normalized values are well below anticipated biological effects thresholds.

This monitoring year was unique in that the rainfall was near record levels. The high volumes of water input to the Bay would be expected to produced a strong northerly flow from Baltimore Harbor, which supplied metals rich sediment to the HMI zone as seen in the Pb distribution in the region. This is the first time since the start of the monitoring program that Harbor sediment has encroached on the HMI influenced zone. The high rainfall volumes also increased the extent of Back River's influence to HMI.

Overall, HMI operations had minimal influence to the adjacent sedimentary environment during Year 22 monitoring. This is due to the operations in the facility during this period. Material was being accepted at the facility all year, the only period when no material was input was July; thus oxidation of the sediment would be at a minimum in comparison to prior flows. This is reflected in Zn levels in the HMI influenced zone that are lower than Year 21. The primary influences to the sedimentary environment in the area appeared to be from external sources driven by the near record rainfall amounts which altered the hydrodynamic flow to the area.

Project III: Benthic Community Studies – University of Maryland Center for Environmental Science

For HMI Year 22, seventeen stations (11 Nearfield, 3 Reference, and 3 Back River/Hawk Cove stations) were sampled on September 8, 2003 and on April 20, 2004. Three additional stations, the Baseline stations, were added in the Spring sampling only (20 stations total) to document conditions prior to any discharges associated with the South Cell restoration project. 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 benthic macroinvertebrates taxa were found at these twenty benthic community stations during Year 22. *Cyathura polita* and Oligochaete worms of the family Tubificidae were among the numerically dominant taxa on both sampling dates, while *Apocorophium lacustre* and *Mytilopsis leucophaeata* were numerically dominant only in the September 2003 samples, and *Marenzelleria virdis* was numerically dominant only in the April 2004 samples. Polychaete taxa richness, slightly higher in September 2003 than in April 2004, was a result of the complete absence of *Streblospio benedicti* and *Polydora cornuta* in April 2003. Total abundance of all invertebrates (excluding Bryozoa) was higher at most stations in April 2004 than September 2003 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 2003 than in April 2004. The proportion of pollution-sensitive taxa (*M. viridis*, *C. almyra*) was higher in April 2004 than in September 2003. This was primarily due to the high spring recruitment of *M. viridis*. The composition of pollution-indicative taxa (the polychaete worms *H. filiformis, S. benedicti*, *N. succinea*, *P. cornuta*, the oligochaete worms in the family Tubificidae, the amphipod *L. plumulosus*, and the chironomids *Coelotanypus* sp., Chironomus sp., Glyptotendipes sp., and Procladius sp.) changed from September 2003 to April 2004. In September 2003 polychaetes dominanted, while in April 2004 oligochaetes, amphipods, and chironomids dominated.

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI, Weisberg et al. 1997) was calculated for all stations sampled during the September 2003 cruise. Overall, the Benthic Index of Biotic Integrity scores improved or remained the same when compared to Year 21 and were generally similar to the B-IBI scores of the previous 6 years of monitoring at Hart-Miller Island. This year, sixteen stations exceeded the benchmark criteria of 3.0, and only 1 station (MDE-27, Back river station) failed to meet the benchmark.

The addition of the Baseline stations in the spring resulted in significant differences in abundance for the ten most abundant infaunal taxa among the four station types. However, these results do not necessarily indicate any adverse affect from HMI discharges until additional testing can be made in future sampling years.

Project IV: Analytical Services – University of Maryland Center for Environmental Science

For Year 22 of Project 4, 43 stations were sampled for sediments, five stations were analyzed for clams, and seven stations were analyzed for worms. The objective for Year 22 was to analyze sediments, worms and clams for parameters not covered in Project 2 (i.e., ancillary metals and organics). This was the first time since the early years of the HMI project that worms were analyzed for contaminant burdens.

Concentrations of the metals arsenic (As), cadmium (Cd), selenium (Se), and lead (Pb) in sediments were similar to previous years and not substantially different than those found elsewhere in the Bay or marine sediments. Silver (Ag) concentrations were much lower this year than in years past while mercury (Hg) and methyl-mercury (MeHg) are lower than past years, but within the range of expected variance.

The following metals in *Rangia* clams, As, Ag, Se, Cd and Pb, have remained consistent for monitoring years 17 through 22. Concentrations of Hg and MeHg are considerably lower than the previous year's average even though Year 22 sediment concentrations were slightly above the mean. Concentrations of Ag were much higher in clams (almost 2 orders of magnitude) than sediments. Concentrations of Cd were 10 to 50 times higher in clams than sediments. Unlike Ag, Cd values in clams did not decrease despite decreased concentrations in sediments. For worms, concentrations of As, Pb and Hg were much lower than sediment concentrations while levels of Cd, Se, and Ag were similar between both worms and sediments. Worms are likely bioaccumulating Cd, Se, and Ag.

Total polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) in 2003 were lower than but similar to the mean of previous years. PAHs in worms were higher than clams, but both were much lower than sediments. Concentrations of PCBs in worms are slightly higher than clams and similar to sediments. The bioaccumulation factors (BAFs) for PAHs in worms and clams is less than one. For PCBs, BAFs in clams and worms are close to 10 and 100, respectively.

CONCLUSIONS AND RECOMMENDATIONS

Continued monitoring of the HMI facility is recommended to monitor compliance with the state's wetland license. This monitoring will become more important as the facility reaches closure in 2009 and longer-term oxidation patterns in the dredged material produce acidic leachate. Due to tidal currents, inaccuracies in GPS navigational systems, etc., it is also recommended that HMI samples for each project be collected synoptically during a single cruise. This will ensure that the benthic community and tissue samples come from the same parent sample in which sediments are analyzed. THis synoptic sampling scheme will allow for a more accurate assessment of the triad response. Finally, limited laboratory toxicity work should be undertaken to assess any sublethal or chronic effects not captured by tissue analyses alone.

PROJECT 2: SEDIMENTARY ENVIRONMENT
YEAR 22 INTERPRETIVE REPORT
(September 2003 - October 2004)

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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 Confined Disposal 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 August 29, 2003, and from 43 sites on April 16, 2004. 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 22, 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. 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 to a lesser extent 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.

The distribution of Zn and Pb follow the behavioral patterns established from previous monitoring years, showing elevated metals levels in the three zones of activity. The spatial extent and the levels found in the Baltimore Harbor and Back River zones vary according to seasonal climatic changes that influence the hydrodynamic conditions and sediment loading, and activity within those sources. In previous studies the HMI zone was solely influenced by operations in the facility and input from the regional background; this monitoring year was unique, in that the rainfall was near record levels. The high volumes of water input to the Bay would be expected to produced a strongly northerly flow from Baltimore Harbor, which supplied metals rich sediment to the HMI zone as seen in the Pb distribution in the region. This is the first time since the start of the monitoring program that Harbor sediment has encroached on the HMI influenced zone. The high rainfall volumes also increased the extent of the Back River's influence to the area adjacent to HMI.

Overall, HMI operations had minimal influence to the adjacent sedimentary environment during Year 22 monitoring. This is due to the operations in the facility during this period. Material was being accepted at the facility all year, the only period when no material was input was July; thus oxidation of the sediment would be at a minimum based on previous years work.. This is reflected in the Zn levels in the HMI influenced zone that are lower than Year 21. The primary influences to the sedimentary environment in the area appeared to be from external sources driven by the near record rainfall amounts which altered the hydrodynamic flow to the area.

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 facility; low discharge rates increasing the metal loads to the sediment. Currently, the facility is actively accepting material, but as the facility 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 has been converted to an environmental restoration project; water will be circulated through the ponds during certain times of the year to produce either mudflats or a ponded area. The additional sample locations near the discharge point should be maintained to assess this new operation of the facility as part of the on-going monitoring program.

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 facility interior. The physical and geochemical properties of the older, "pristine" sediment used in facility construction differed from 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 contaminants. In addition, oxidation of the sediment placed in the facility during dewatering 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 facility.

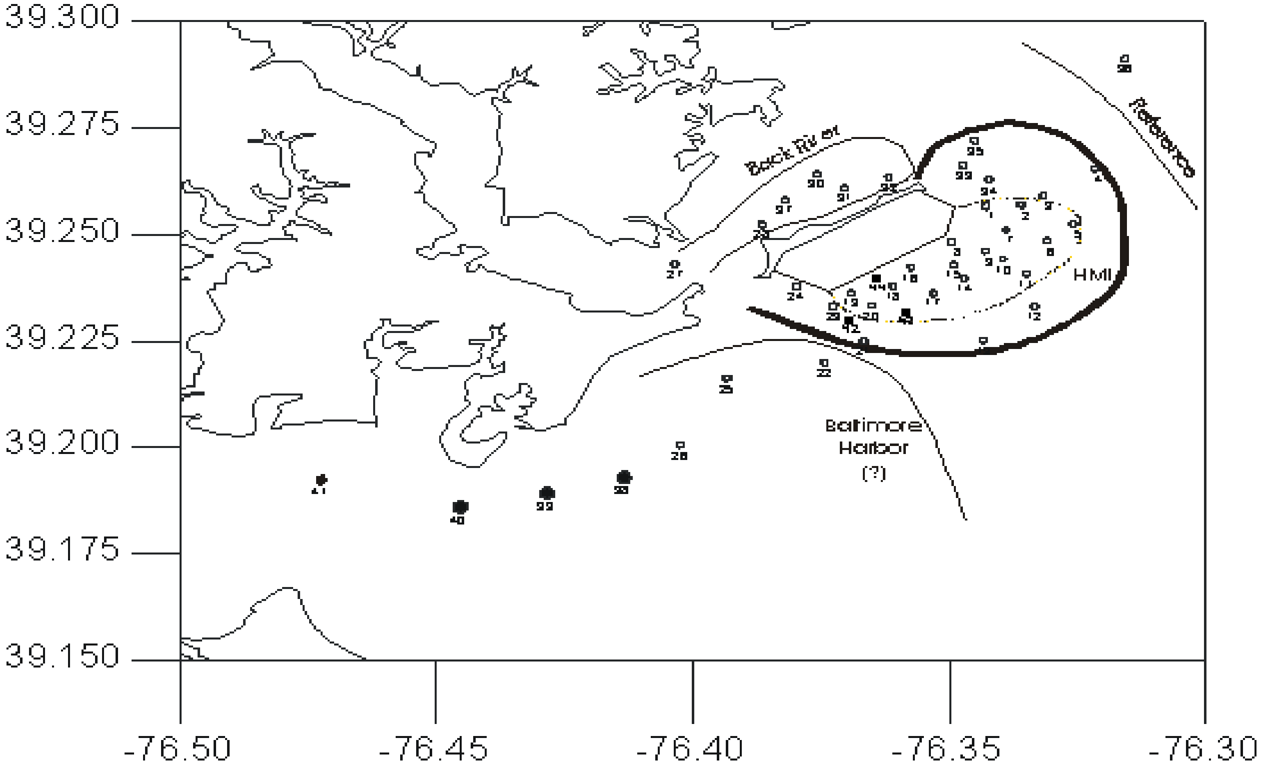


Figure 1: Sampling locations for Year 22. Contours show zones of influence found in previous studies. Solid circles show location of sites added in Year 18 to measure the influence of Baltimore Harbor and the more recent sites added to determine the influence of the conversion of the South Cell to an upland wetlands.

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 facility construction has been well documented in earlier reports (Kerhin et al. 1982a, l982b; Wells and Kerhin 1983; Wells et al. 1984; Wells and Kerhin 1985). This work established a baseline against which changes due to operation of the facility could be measured. The most notable effect of facility 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 facility was thought to be the probable source of the enrichment of Zn accumulating in the sediments. This was confirmed by use of the Upper Bay Model (Wang 1993), a numerical, hydrodynamic model, which was used to predict the dispersion of discharge from the facility, coupled with discharge records from the spillways. From the discharge records it was noted that there is a significant increase in metal loading to the exterior sediments during periods of low discharge (<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 facility.

2. Releases from Spillways #1 and #4 travel in a narrow, highly concentrated band up and down the eastern side of the facility. This explains the location of areas of periodic 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 facility. Conversely, the lower the flow, the less the compression and the greater the dispersion away from the facility.

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

The 3-D hydrodynamic model explains the structure of the plume of material found in the exterior sediments, but it does not explain why the level of Zn in the sediments increases at lower discharges. To account for this behavior, the chemistry of the effluent discharged from the facility was examined, as reported in the *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 facility. The model has two components: (1) loading due to material similar to the sediment in place and (2) loading of enriched material as predicted from a regression line based on discharge data supplied by the 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 facility 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 facility is divided into two zones, (a) the proximal zone, which shows the most consistent enrichment levels through time, and (b) the distal zone, which is affected primarily during extended periods of dewatering and crust management, and;

4. *Baltimore Harbor* – Sites in the southern portion of the area have consistently shown a gradient, indicating that Baltimore Harbor is a source of metals in the area south of HMI. The consistent pattern seen in the monitoring studies is base level values near HMI, which increase towards Baltimore Harbor. This pattern supports the results of a hydrodynamic model analyses performed in conjunction with the 1997 sediment characterization of Baltimore Harbor and Back River (Baker et al., 1998).

Facility 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 facility. Events or operational decisions that affect the quality or quantity of effluent discharged from the facility account for some of the changes in exterior sediment properties observed over time. For this reason, facility operations during the periods preceding each of the Year 22 cruises are summarized below. Information was extracted from *Operations Reports* prepared by MES, covering the periods April 1, 2003 - April 30, 2004; a detailed synopsis of this period and digital discharge records were provided to MGS for this report by MES (pers. com. Carr)

HMI was accepting material throughout the monitoring year; the only month where no material was accepted was July. The amount of sediment placed in the facility was lower than previous years with only approximately 2.5 million cubic yards placed in HMI for the whole period; ~36% prior to the Fall Sampling and the larger portion, ~63%, placed prior to the Spring Sampling. During the monitoring year there were no extended intervals of low discharge (<10 Mgal/day; see Figure 2a). Discharge rates were generally lower only from August 2003 through November 2003. 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 during this study period. Generally, the discharge water had pH values greater than neutral (see Figure 2), with some samples near pH 7 during the mid-May to mid-June period, with a few sporadic samples with lower pH values. Therefore based on previous monitoring years, the external sedimentary environment should not be affected by the facility operations during this period. This is additionally supported in that the effluent was in compliance with the discharge permit for the entire monitoring period.

An interesting feature to note is that the “low pH” values were at their lowest values during the period of highest discharge. This is different behavior than what has been seen in the past; low discharge rates are associated with oxidation of the sediment and acid production, thus producing low pH discharge; high discharge rates are considered a flow through input from high input of water associated with dredge input. Starting in December 2002 through December 2003 the 3rd highest recorded rainfall amounts were recorded in the region. The highest amounts of rainfall corresponded to the high discharge period at the facility, and the atypical association of high discharge with low pH. Thus by inference the low pH levels are due to precipitation. Rain in this region has some of the lowest pH levels in the country (pH~4.4).

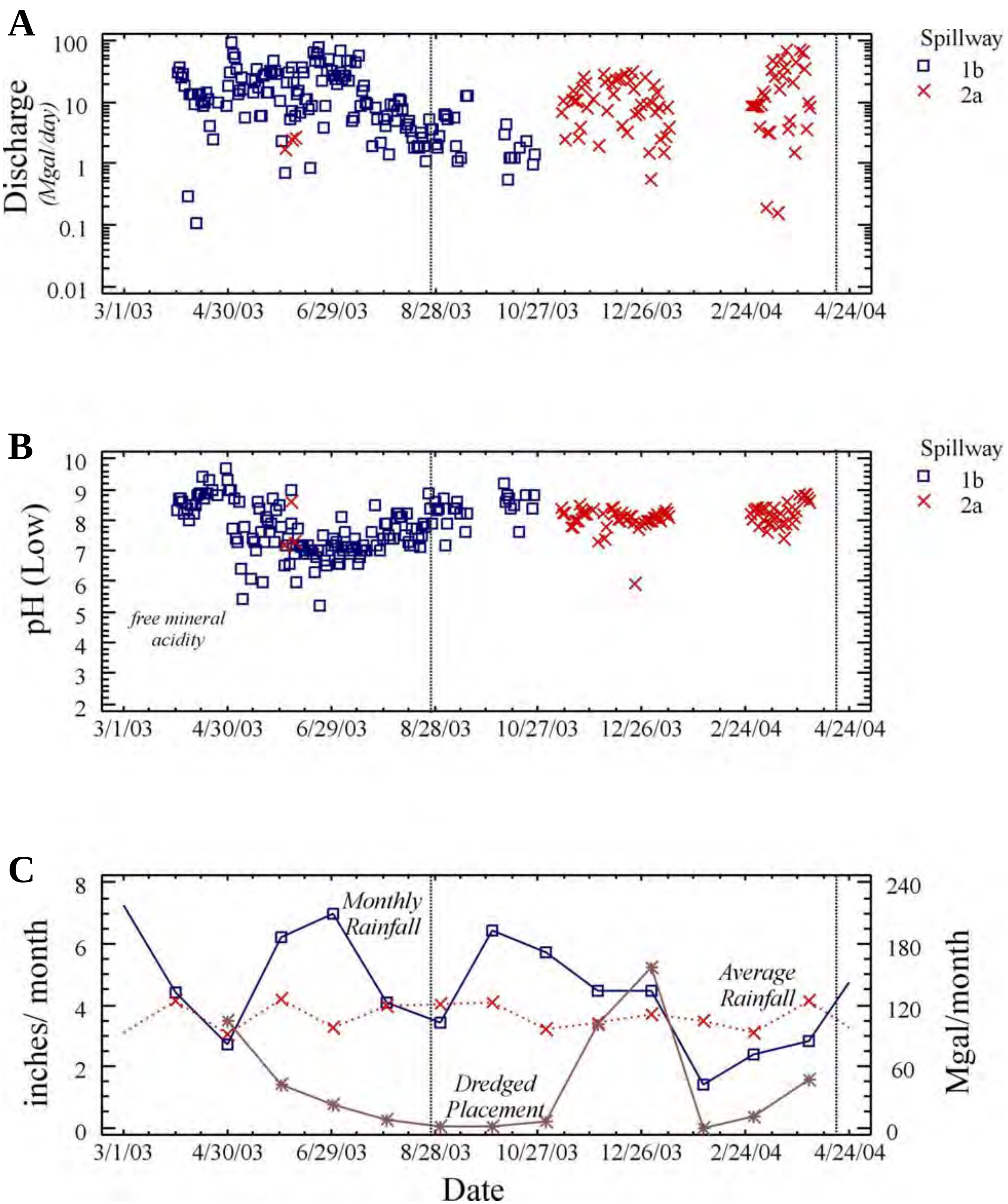


Figure 2: Spillway discharge volume (a), discharge pH (b), and rainfall (c) over the Year 22 project period.

OBJECTIVES

As in the past, the main objectives of the Year 22 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. An objective added in Year 22 was the collection of three additional samples in the vicinity of spillway #3, starting with the spring sampling. This was in order to provide a higher density of samples to assess any changes that may occur due to the addition of a discharge point from the South Cell Environmental Restoration. 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 August 29, 2003, and the second, on April 16, 2004.

Sampling sites (Figure 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 22 sample locations are reported in the companion *Year 22 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, for the first cruise. The second cruise contained three additional sites, MDE-42 through MDE-44, in the vicinity of spillway #3. With the exception of the three sites added during the spring cruise the stations were identical to those sampled during Years 20 and 21.

At 36 stations for the fall cruise and 39 stations for the spring cruise, 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 22 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^{TM} 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

<u>Textural Analyses</u>

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:

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

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 3).

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.

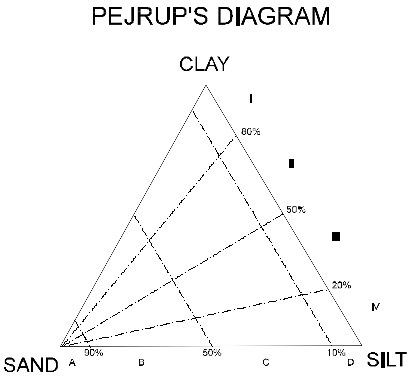


Figure 3: Pejrup's (1988) classification of sediment type.

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 22 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

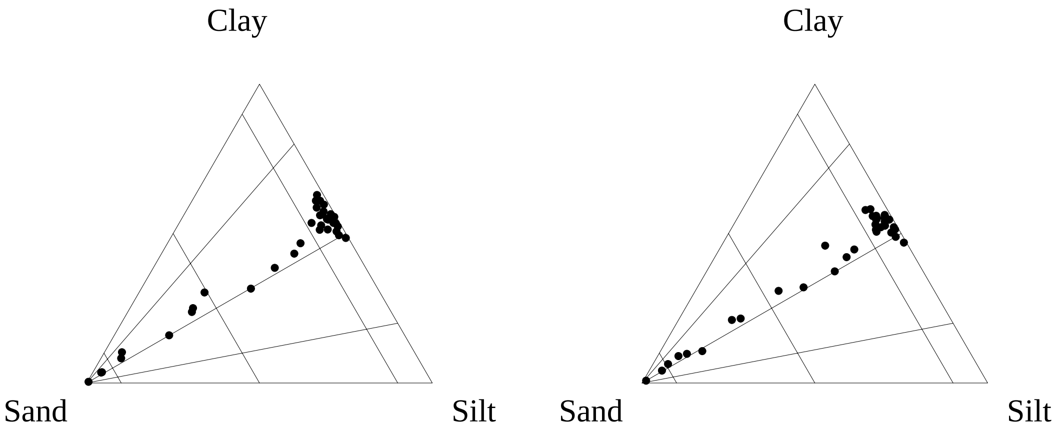
The monitoring effort around HMI is based on the identification of long-term trends in sediment distribution and on the detection of changes in those trends. The sampling scheme, revised in Year 17 and expanded in Year 18, established a new baseline against which any future changes in the sedimentary 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 22 results are discussed with respect to the preceding Year 21 results.

Thirty-eight of the sampling sites visited during Year 22 yielded results that can be compared to those measured during Year 21. 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 4. 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 21-22, for 38 sediment samples common to all four cruises.

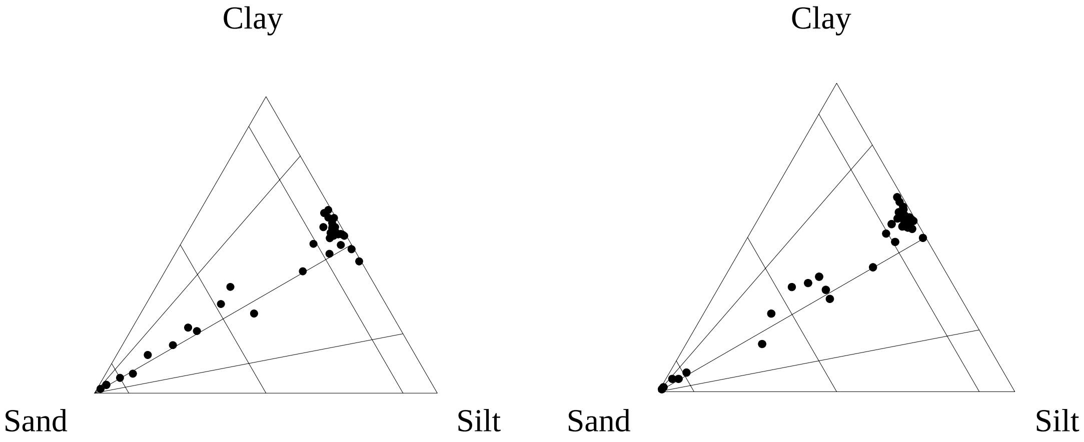
Variable	Sept 2002 Cruise 45	Apr 2003 Cruise 46	Aug 2003 Cruise 47	Apr 2004 Cruise 48
Sand (%)				
Mean	22.34	23.69	24.96	23.10
Median	3.83	5.60	3.88	3.78
Minimum	0.62	0.68	0.54	0.81
Maximum	99.21	98.37	97.54	98.59
Range	98.59	97.69	97.00	97.79
Count	38	38	38	38
Clay:Mud				
Mean	0.56	0.55	0.55	0.57
Median	0.56	0.55	0.56	0.57
Minimum	0.49	0.47	0.45	0.42
Maximum	0.67	0.62	0.62	0.70
Range	0.18	0.15	0.18	0.28
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.



(a) September 2002 (Cruise 45)

(b) April 2003 (Cruise 46)



(c) August 2003 (Cruise 47)

(d) April 2004 (Cruise 48)

Figure 4: Ternary diagrams showing the grain size composition of sediment samples collected in Years 21 and 22 from the 38 sampling sites common to all four cruises: (a) September 2002, (b) April 2003, (c) August 2003, and (d) April 2004.

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. The mean clay:mud was slightly higher for cruise 48, with a value of 0.57, due to the 0.70 clay:mud ratio for sampling site 2 increasing the average. 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 6, 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 facility, the sandiest sediments (>50% sand) are confined to relatively shallow (<15 ft) waters (Fig. 6).

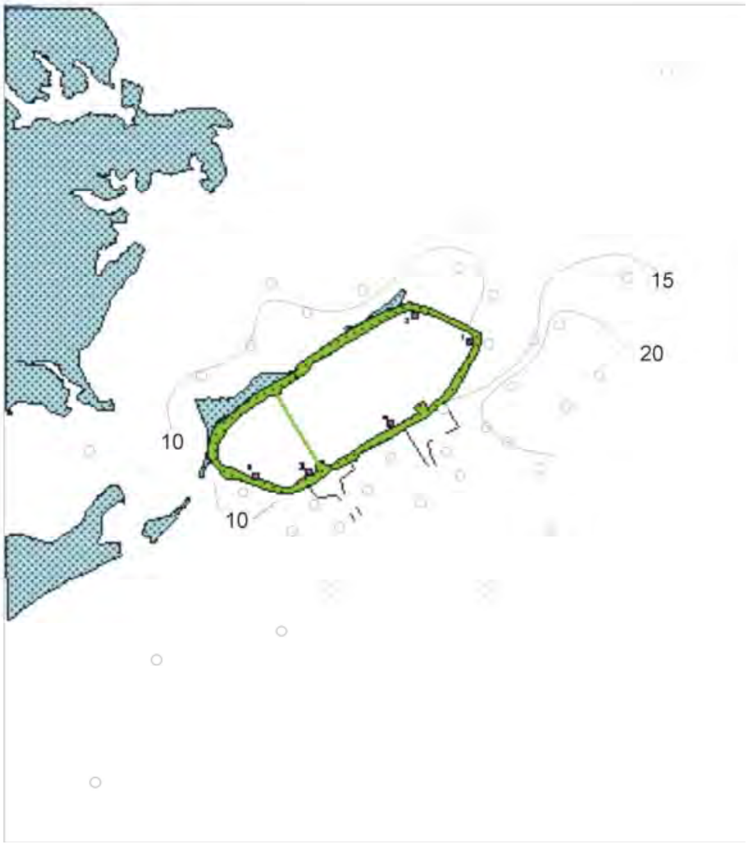


Figure 5 Average water depths, based on Year 17 Monitoring. Contour interval = 5 ft.

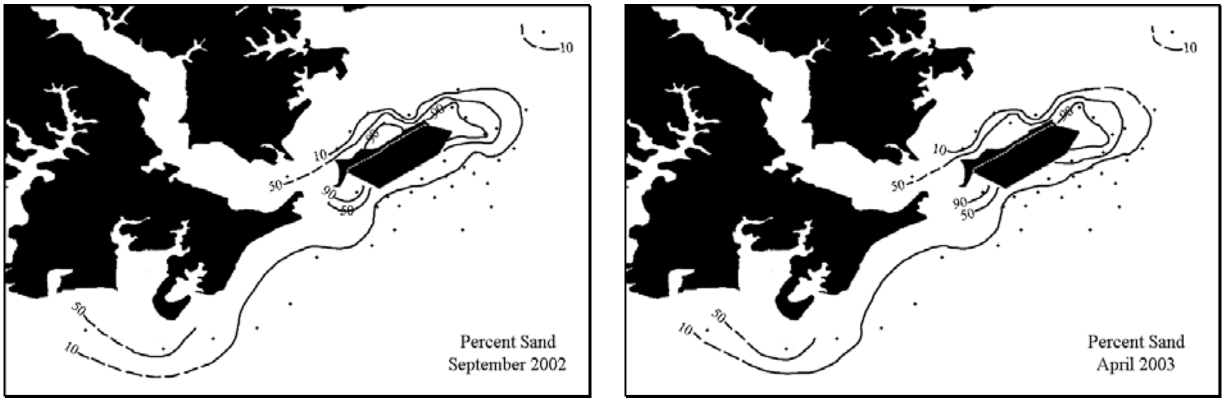
Broadest north and west of the facility, the shoals are the erosional remnants of a larger neck of land. The once continuous landmass has been reduced to a series of islands, including Hart and Miller, extending from the peninsula that now forms the south shore of Back River. However, not all shallow water samples are sandy. In particular, several of the shallow water samples from Hawk Cove (e.g., MDE-30 and MDE-32) contain less than 10% sand. Sand distribution maps for Years 21 and 22 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 22. 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 facility.

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 (Figure 7). MDE-41, at the mouth of Baltimore Harbor, continued to be clay-rich for all four samplings as it had in previous years. There were two 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). In April 2003, four pockets occur with clay:mud ratio values at or above 0.60, including the pocket at MDE-41 (Fig. 7b). 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 became smaller with the decreased clay:mud ratio values at MDE-20 and MDE-31, respectively. 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.

In August 2003, there were two areas that were clay-rich along with the pocket at MDE-41. The one just south of HMI consisted of MDE-18 and MDE-20 and was very similar to that of September 2002 in the same location. The second area was located at MDE-10 to the southeast of HMI, which is also a station that has been clay-rich prior to Year 21. A more noticeable increase in clay-rich area is seen in April 2004. Here, in addition to the MDE-41 site, there was one large area to the south of HMI consisting of seven previously sampled sites as well as one of the sampling sites added in April 2004 (MDE-42). Although it has not been common to see quite as large a pocket of clay-rich samples previously, the contours denote that this entire area has continually had clay:mud values above 0.55, and many of the small pockets previously recorded have been located throughout this area. With the exception of MDE-21, which had a clay:mud ratio of 0.59 in August 2003, all of the stations within the clay-rich area in April 2004 had a clay:mud ratio at or above 0.60 at least once during the previous three samplings going back to September 2002. Therefore, the larger, singular clay-rich pocket in April 2004 is not markedly different from previous results.

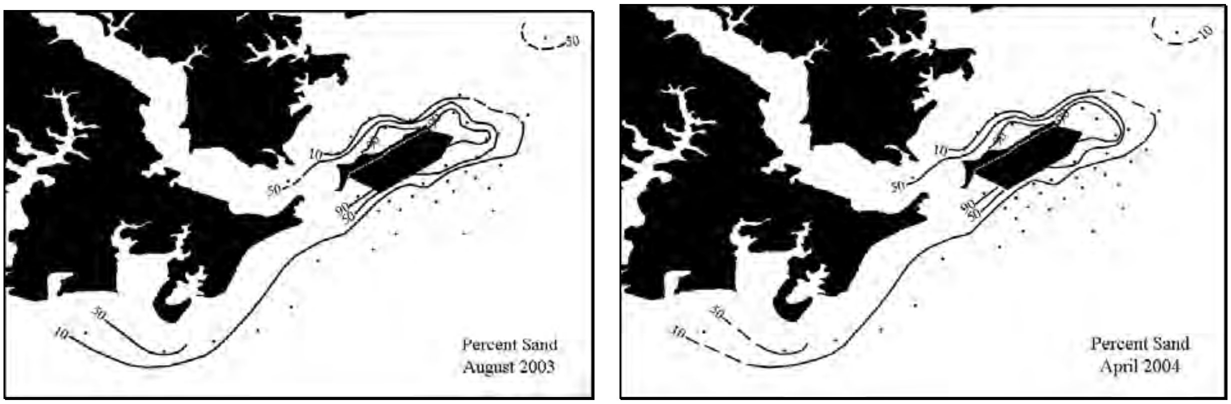
Silt-rich sediments (clay:mud ratio < 0.50) are generally found immediately adjacent to the walls of the facility, commonly in the vicinity of spillways. In September 2002, the fine fraction of only one sample was silt-rich (MDE-12). In April 2003, the fine fraction of three samples was silt rich (MDE-12, MDE-8 adjacent to the wall of the facility to the southeast, and MDE-33 just to the northeast of the facility). At MDE-33, the sand fraction was so great (>98%), that analysis of the fine fraction was problematic. In August 2003, four sites were silt-rich. MDE-8 and MDE-12 continued to be silt-rich along with MDE-19 on the southwest corner of the facility and MDE-27 in Back River. The silt-rich samples in April 2004 consisted of two sites, MDE-8 and MDE-27. The increase in clay:mud ratio at MDE-12 and MDE-19 to above 0.50 in April 2004 correlates with the increase in clay-rich samples also seen in April 2004.

Understanding the specific reasons for these variations in grain size is difficult. They involve the amount, quality, and timing of discharge from particular spillways and the interaction of the effluent with tides and currents in the receiving waters. Those, in turn, are influenced by flow from the Susquehanna River. Based on the similarities between the fine fraction results from Year 21 and those from August 2003, one may conclude that the depositional environment in the vicinity of HMI was unchanged over this period. The increase in the number of clay-rich samples along with the increase in clay:mud ratio values at MDE-12 and MDE-19 to above 0.50 found in April 2004 suggests a higher input of clay-rich sediment following the August 2003 sampling. The exact source of that higher input is unknown. One possible source includes clay-rich sediment eroded from nearby shorelines as a result of Hurricane Isabel, which occurred after the August 2003 sampling. Regardless, no clear trends, affecting many samples from a large area, are evident. The grain size distribution of Year 22 samples is largely consistent with the findings of past monitoring years.



(a) September 2002 (Cruise 45)

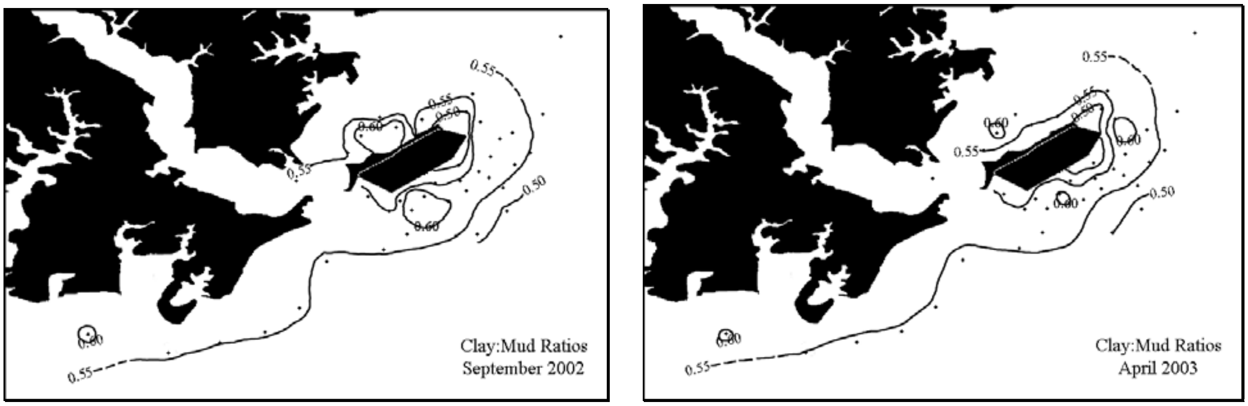
(b) April 2003 (Cruise 46)



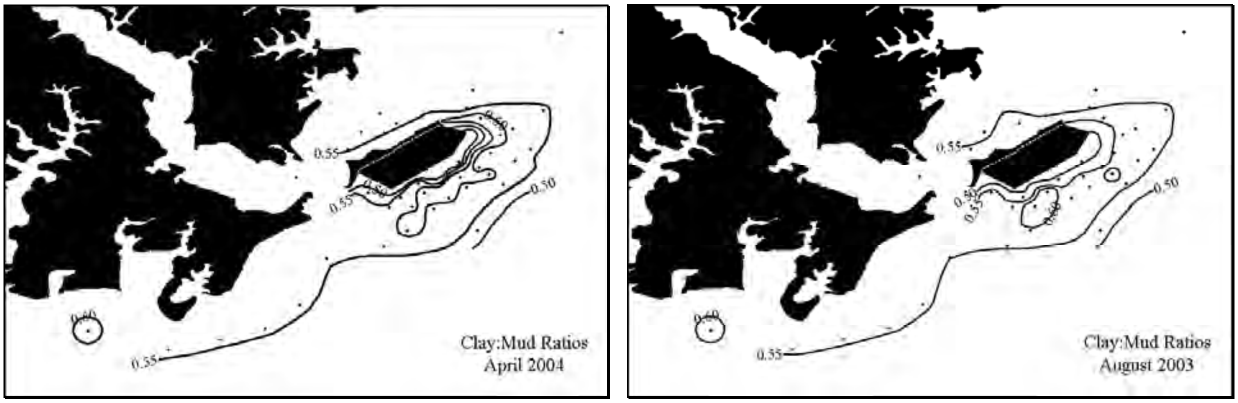
(c) August 2003 (Cruise 47)

(d) April 2004 (Cruise 48)

Figure 6: Sand distribution for Monitoring Years 21 and 22: (a) September 2002, (b) April 2003, (c) August2003, and (d) April 2004. Contour intervals are 10%, 50%, and 90% sand.



(a) September 2002 (Cruise 45) (b) April 2003 (Cruise 46)



(c) August 2003 (Cruise 47) (d) April 2004 (Cruise 48)

Figure 7: Clay:Mud ratios for Monitoring Years 21 and 22. Contour intervals are 0.50, 0.55, and 0.60.

Elemental Analyses

Trace Metals

Interpretive Technique

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 $\pm 2\sigma$ (± 2 standard deviations) are within normal background variability for the region. Samples with a value of ±3σ can be within accepted background variability, but are marginal depending on the trends in the distribution. Any values falling outside this range indicate a significant concentrations above baseline. 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. Ni and Zn exceed also 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 weight-of-evidence. The method does not allow for unique basin geology 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 variability. 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 to a lesser extent 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	Pb	Zn
Count	72	81	81	81	81	81	81	81
Ave.	1.2	102.4	49.3	4.37	2693	83.4	60.8	321
Std.	0.4	52.0	20.0	1.74	1635	35.6	29.1	155
Min.	0.3	8.0	3.0	0.21	253	7.0	5.4	16
Max.	2.3	341.0	90.0	7.97	8600	167.4	133.4	764
ERL	1.3	81.0	34.0	*n/a*	*n/a*	20.9	46.7	150
#>ERL	31.0	61.0	61.0	*n/a*	*n/a*	75.0	57.0	66
ERM	9.5	370.0	270.0	*n/a*	*n/a*	51.6	218.0	410
#>ERM	0.0	0.0	0.0	*n/a*	*n/a*	65.0	0.0	18
	C(%)	**N(%)**	**S(%)**	**P(%)**				
Count	81	81	81	81				
Ave.	2.877	0.197	0.387	0.085				
Std.	1.226	0.076	0.244	0.035				
Min.	0.116	0.011	0.000	0.006				
Max.	6.071	0.303	1.382	0.173				

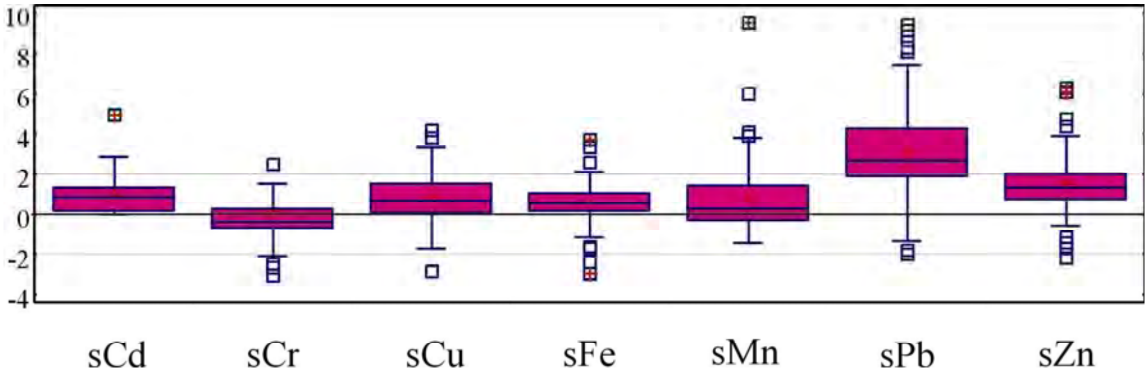


Figure 8: A box and whisker diagram showing the range of the data for both the fall and spring cruise. Cd is not shown due to the concentrations being below the detection limit for all but three samples.

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 8 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. Pb has approximately 3/4 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 spatial extent and magnitude of metals loadings to the exterior sedimentary environment is controlled by three primary factors, including:

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 facility, minimizing atmospheric exposure, and dilutes and buffers any acidic leachate. As a result, higher discharge rates produce metal loadings that are close to background levels.

2.Flow of freshwater into the Bay from the Susquehanna River - The 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 facility;
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 facility. Conversely, the lower the flow, the less the compression and the greater the dispersion away from the facility; and
c. Discharge from the facility has no influence on the circulation gyre. This was determined by simulating point discharges of 0-70 MGD from three different spillways. Changes in discharge rate only modulated the concentration of a hypothetical conservative species released from the facility; the higher the discharge, the higher the concentration in the plume outside the facility.

3. <u>The positions of the primary discharge points from the facility</u> - The spatial 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 facility. 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 9 shows the sigma levels for Pb for Year 21 & 22 monitoring periods in the study area adjacent to HMI; sigma levels for Zn for the same periods are shown in Figure 10. 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 9 & 10 is used to highlight the areas that are significantly elevated above baseline levels. As shown in Figure 1 there are three primary areas of interest that will be referred to: Back River, Baltimore Harbor, and HMI.

Back River - The Back River influence is strongly seen for Pb. Lead is apparently being discharged by Back River during both of the sampling periods with the late summer levels being slightly more elevated than the spring, with both periods having a similar spatial extent. Zinc concentrations were slightly elevated at the mouth of Back River in the late summer, but were within background levels for the spring sampling event. This varied from the previous monitoring year in that higher Pb levels were found in the spring sampling and there was no elevation of Zn in either period.

Baltimore Harbor - Elevated levels of Zn extend into the area south of HMI, but do not reach the area adjacent to the island. The Year 22 levels are comparable for both the late summer and spring sampling events; this is in contrast to Year 21 where there was a large variation, with the fall samples being greater than the spring specifically in the mouth of the Harbor. The spatial extent of Zn in Year 22 is greater than for Year 21, with the elevated levels approaching HMI more closely, but still not reaching the zone of facility influence. Lead levels in Year 22 show an incursion into the HMI zone of influence for the first time. The broadest extent is seen in the late summer sampling, with a significant diminution in the spring

HMI - Zinc levels in Year 22 are consistent with Year 21 where the spring cruise showed the highest elevated levels. 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 concentration is at a level of concern. The late summer cruise has two contiguous sites adjacent to Spillway 1; this contrasts with Year 21 which did not show any station with significantly elevated levels of Zn. On the other hand, elevated Pb for Year 22 was masked by the broader signature from the Harbor. No local signature from the facility could be distinguished for either sampling period.

The distribution of Zn and Pb follow the behavioral patterns established from previous monitoring years, showing elevated metals levels in the three zones of activity. The spatial extent and the levels found in the Baltimore Harbor and Back River zones vary according to seasonal climatic changes that influence the hydrodynamic conditions and sediment loading, and activity within those sources. In previous studies the HMI zone was solely influenced by operations in the facility and input from the regional background; this monitoring year was unique, in that the rainfall was near record levels. The high volumes of water input to the Bay would be expected to produce a strongly northerly flow from Baltimore Harbor, which supplied metals rich sediment to the HMI zone as seen in the Pb distribution in the region. This is the first time since the start of the monitoring program that Harbor sediment has encroached on the HMI influenced zone. The high rainfall volumes also increased the extent of the Back River's influence to the area adjacent to HMI.

In regard to facility operations, this was an active year for placement of material in the facility. 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 through oxidation of sulfides that produce acid leachate. These conditions did not exist in Year 22; material was accepted all year except for one month. The lack of acid formation is supported by the discharge water having pH values greater than neutral, with samples near neutral value during the mid-May to mid-June period and only a few a few sporadic samples with lower pH values.

Overall, HMI operations had minimal influence to the adjacent sedimentary environment in the period. This is reflected in the Zn levels in the HMI influenced zone which are lower than Year 21 (see Figure 11). The primary influences to the sedimentary environment in the area appeared to be from external sources driven by the near record rainfall amounts which altered the hydrodynamic flow to the area.

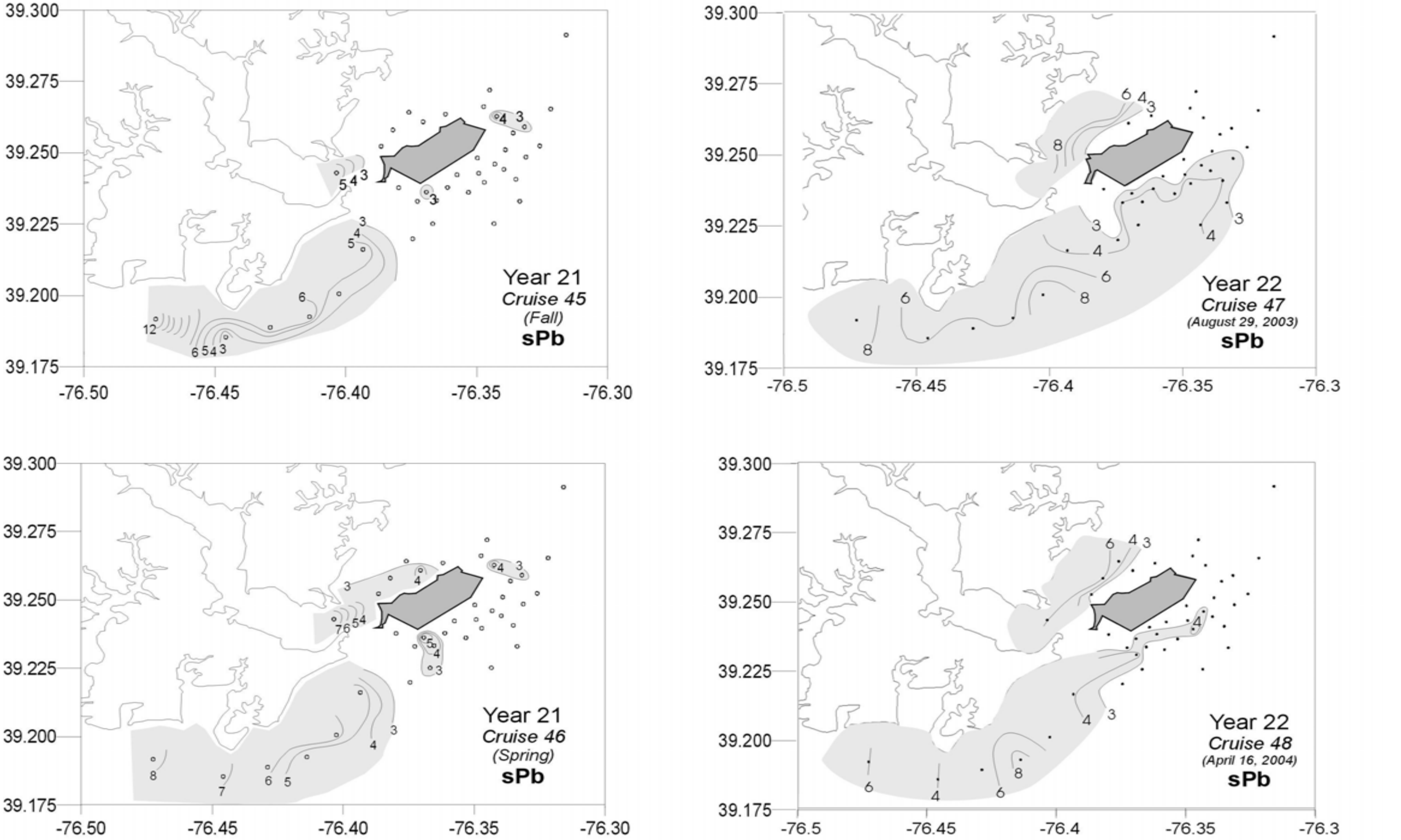


Figure 9: Distribution of Pb in the study area for the Fall and Spring sampling cruises for both Years 21 &22. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional(values less than 3 not shown), >3 = significantly enriched (shaded in figures).

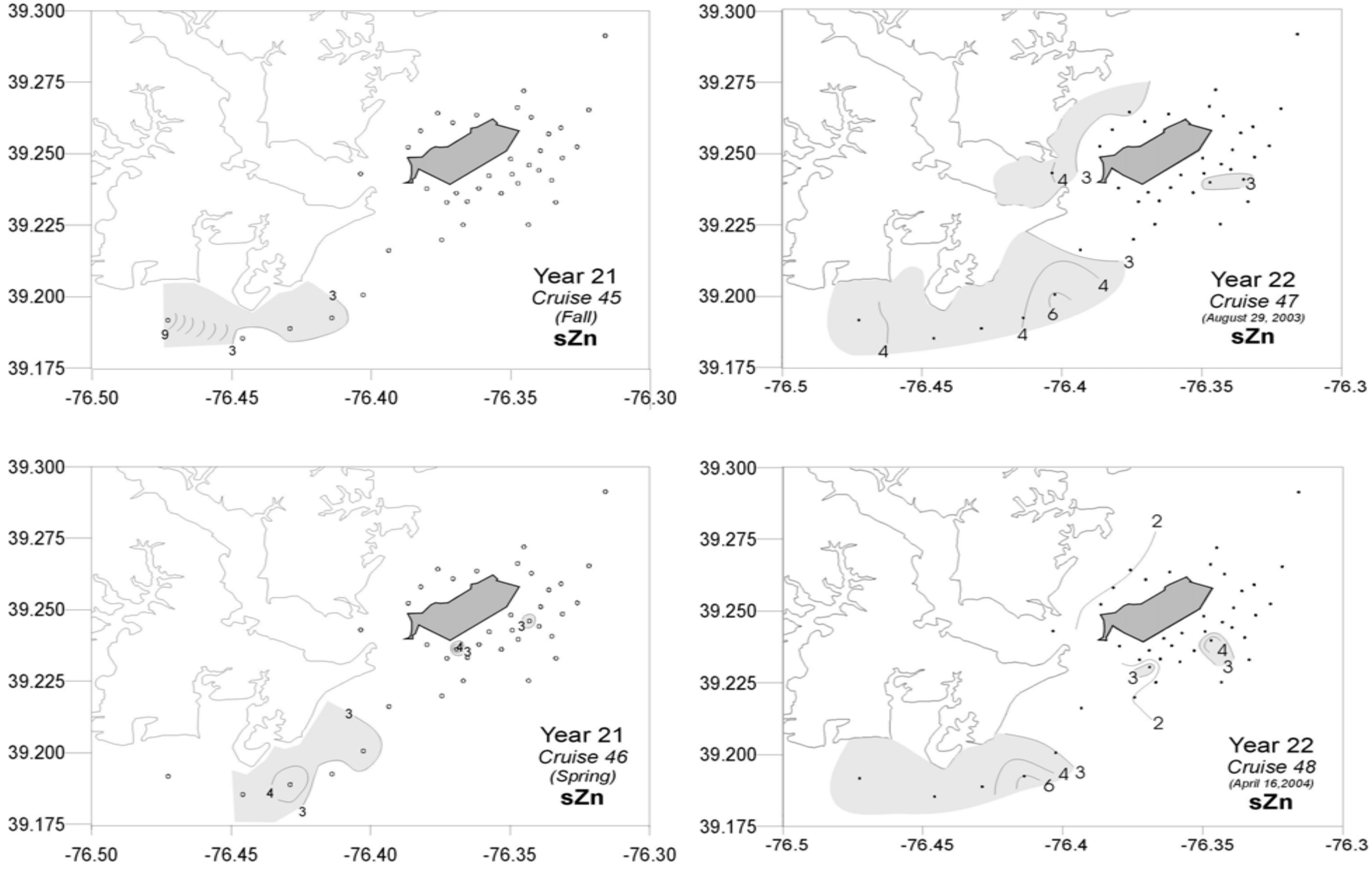


Figure 10: Distribution of Zn in the study area for the Fall and Spring sampling cruises for both Years 21 & 22. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional(values less than 3 not shown), >3 = significantly enriched (shaded in figures).

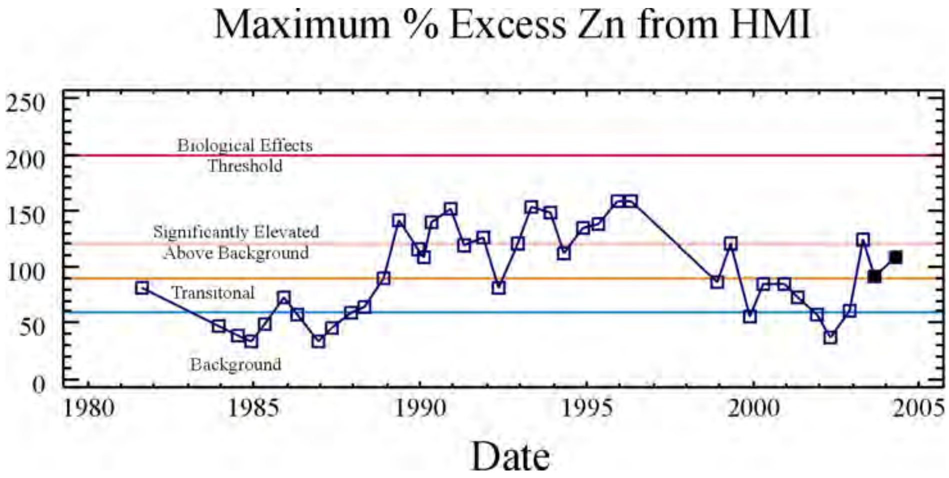


Figure 11: Record of the maximum % Excess Zn for all of the cruises MGS analyzed the sediments.

CONCLUSIONS AND RECOMMENDATIONS

The grain size distribution of the Year 22 sediment samples does not show any clear trends in sedimentation patterns from cruise to cruise. This is due to the complexity of the environmental conditions and source of material to the area. The clay:mud ratios show that the depositional environment was very similar during Year 21 and Year 22. A slight increase in clay content at several stations created a larger area of clay-rich samples in April 2004, which may be due to an increased sediment input from nearby shoreline erosion during Hurricane Isabel coupled with a slightly less turbulent environment during the Spring of 2004. 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 22. 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 2004, there was a increase in the extent of clay-rich sediments in the vicinity of the facility 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 facility. The three stations added in the vicinity of spillway #3 will provide a baseline for future samplings in order assess the operation of the South Cell as upland wetlands with a discharge in the area of this spillway.

With regard to trace metals some features to note are:

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

4. 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 weight-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 to a lesser extent 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.

The distribution of Zn and Pb follow the behavioral patterns established from previous monitoring years, showing elevated metals levels in the three zones of activity. The spatial extent and the levels found in the Baltimore Harbor and Back River zones vary according to seasonal climatic changes that influence the hydrodynamic conditions and sediment loading, and activity within those sources. In previous studies the HMI zone was solely influenced by operations in the facility and input from the regional background; this monitoring year was unique, in that the rainfall was near record levels. The high volumes of water input to the Bay would be expected to produced a strongly northerly flow from Baltimore Harbor, which supplied metals rich sediment to the HMI zone as seen in the Pb distribution in the region. This is the first time since the start of the monitoring program that Harbor sediment has encroached on the HMI influenced zone. The high rainfall volumes also increased the extent of the Back River's influence to the area adjacent to HMI.

Overall, HMI operations had minimal influence to the adjacent sedimentary environment during Year 22 monitoring. This is due to the operations in the facility during this period. Material was being accepted at the facility all year. The only period when no material was input was July; thus oxidation of the sediment would be at a minimum based on previous years work. This is reflected in the Zn levels in the HMI influenced zone that are lower than Year 21. The primary influences to the sedimentary environment in the area appeared to be from external sources driven by the near record rainfall amounts which altered the hydrodynamic flow to the area.

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 facility; low discharge rates increasing the metal loads to the sediment. Currently, the facility is actively accepting material, but as the facility 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 currently much lower than any biological effects threshold, continued monitoring is needed in order to: (1) detect if the levels increase to a point where action is required; (2) 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, the additional Harbor transect sites (MDE 39 through 41) should be maintained,. Further, the South Cell Environmental Restoration project will soon be completed, with a constant flow of water being circulated through upland ponds to produce conditions similar to tidal wetlands. The additional Suoth Cell sample locations (MDE 42 through 44) should be maintained near spillway #3 to assess this new operation of the facility.

PROJECT III: BENTHIC COMMUNITY STUDIES
(September 2003 - September 2004)

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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-second 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 8, 2003. Twenty stations, including 3 additional stations established to collect baseline environmental data for the HMI South Cell Environmental Restoration project (MDE-42, MDE-43, and MDE-44), were sampled on April 20, 2004. 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 benthic macroinvertebrate taxa were found during Year 22 of monitoring. Several of the 43 taxa were clearly dominant. *Cyathura polita* and Oligochaete worms of the family Tubificidae were among the numerically dominant taxa on both sampling dates, while *Apocorophium lacustre* and *Mytilopsis leucophaeata* were numerically dominant only in the September 2003 samples, and *Marenzelleria virdis* was numerically dominant only in the April 2004 samples. Polychaete taxa richness was slightly higher in September 2003 than in April 2004 as a result of the absence of *Streblospio benedicti* and *Polydora cornuta* in April 2003. Total abundance of all invertebrates (excluding Bryozoa) was higher at most stations in April 2004 than September 2003 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 2003 than in April 2004. The proportion of pollution-sensitive taxa (*M. viridis, C. almyra*) was higher in April 2004 than in September 2003. This was primarily due to the high spring recruitment of *M. viridis*. The composition of pollution-indicative taxa (the polychaete worms *H. filiformis, S. benedicti,* N. *succinea*, P. *cornuta* the oligochaete worms in the family Tubificidae, the amphipod L. plumulosus and the chironomids *Coelotanypus* sp., Chironomus sp., Glyptotendipes sp., and Procladius sp.) varied from September 2003 to April 2004. In September 2003 polychaetes dominanted the assemblage, while in April 2004 oligochaetes, amphipods, and chironomids were dominant.

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 2003 cruise. Overall, the Benthic Index of Biotic Integrity scores improved or remained the same when compared to Year 21 and were generally similar to the B-IBI scores of the previous 6 years of monitoring at Hart-Miller

Island. This year, sixteen stations exceeded the benchmark criteria of 3.0, and only 1 station failed to meet the benchmark.

The addition of the South Cell baseline stations in the spring resulted in significant differences among station types for the ten most abundant infaunal taxa. However, these results do not necessarily indicate any adverse effects from HMI discharges near these stations. Additional testing in future sampling years will be needed to clarify the effects on the fauna at these stations.

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 a special condition to the wetland permit for the facility, 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 facility 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 are compared to this baseline, as well as to interseasonal and interannual data. This report represents the twenty-second consecutive year of the benthic macroinvertebrate community monitoring since 1981. In Year 22, the Maryland Department of the Environment was responsible for all aspects of benthic community monitoring.

The goals of the Year 22 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; Llanso 2002), and to compare the results at Nearfield stations to present local reference conditions;

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

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

METHODS AND MATERIALS

For the Year 22 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 8, 2003, and in spring on April 20, 2004. Seventeen benthic stations during the fall and twenty benthic stations during the spring (Table 5; Figure 12) 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 22 benthic community monitoring and Predominant sediment type at each station for September and April.

Station #	Latitude	Longitude	Sediment Type		Maryland 7-Digit Station Designation
			Sept.	April	
Nearfield Stations					
MDE-01	39^o 15.3948	76^o 20.568	Shell	Shell	XIF5505
MDE-03	39^o 15.5436	76^o 19.9026	Silt/clay	Silt/clay	XIG5699
MDE-07	39^o 15.0618	76^o 20.3406	Silt/clay	Silt/clay	XIF5302
MDE-09	39^o 14.7618	76^o 20.5842	Silt/clay	Silt/clay	XIF4806
MDE-16	39^o 14.5368	76^o 21.4494	Silt/clay	Silt/clay	XIF4615
MDE-17	39^o 14.1690	76^o 21.1860	Shell	Silt/clay	XIF4285
MDE-19	39^o 14.1732	76^o 22.1508	Silt/clay	Silt/clay	XIF4221
MDE-24	39^o 14.2650	76^o 22.7862	Sand	Sand	XIF4372
MDE-33	39^o 15.9702	76^o 20.8374	Sand	Sand	XIF6008
MDE-34	39^o 15.7650	76^o 20.5392	Sand	Sand	XIF5805
MDE-35	39^o 16.3182	76^o 20.7024	Silt/clay	Silt/clay	XIF6407
Reference Stations					
MDE-13	39^o 13.5102	76^o 20.6028	Silt/clay	Silt/clay	XIG3506
MDE-22	39^o 13.1934	76^o 22.4658	Silt/clay	Silt/clay	XIF3224
MDE-36	39^o 17.4768	76^o 18.9480	Silt/clay	Silt/clay	XIG7589
Back River/Hawk Cove Stations					
MDE-27	39^o 14.5770	76^o 24.2112	Silt/clay	Silt/clay	XIF4642
MDE-28	39^o 15.3900	76^o 22.7304	Silt/clay	Silt/clay	XIF5232
MDE-30	39^o 15.8502	76^o 22.5528	Silt/clay	Silt/clay	XIF5925
Baseline Monitoring Stations for South Cell					
MDE-42	39^o 23.0390	76^o 36.9050	N/A	Silt/clay	XIF3879
MDE-43	39^o 23.2310	76^o 35.8190	N/A	Silt/clay	XIF3985
MDE-44	39^o 24.0380	76^o 36.3960	N/A	Silt/clay	XIF4482

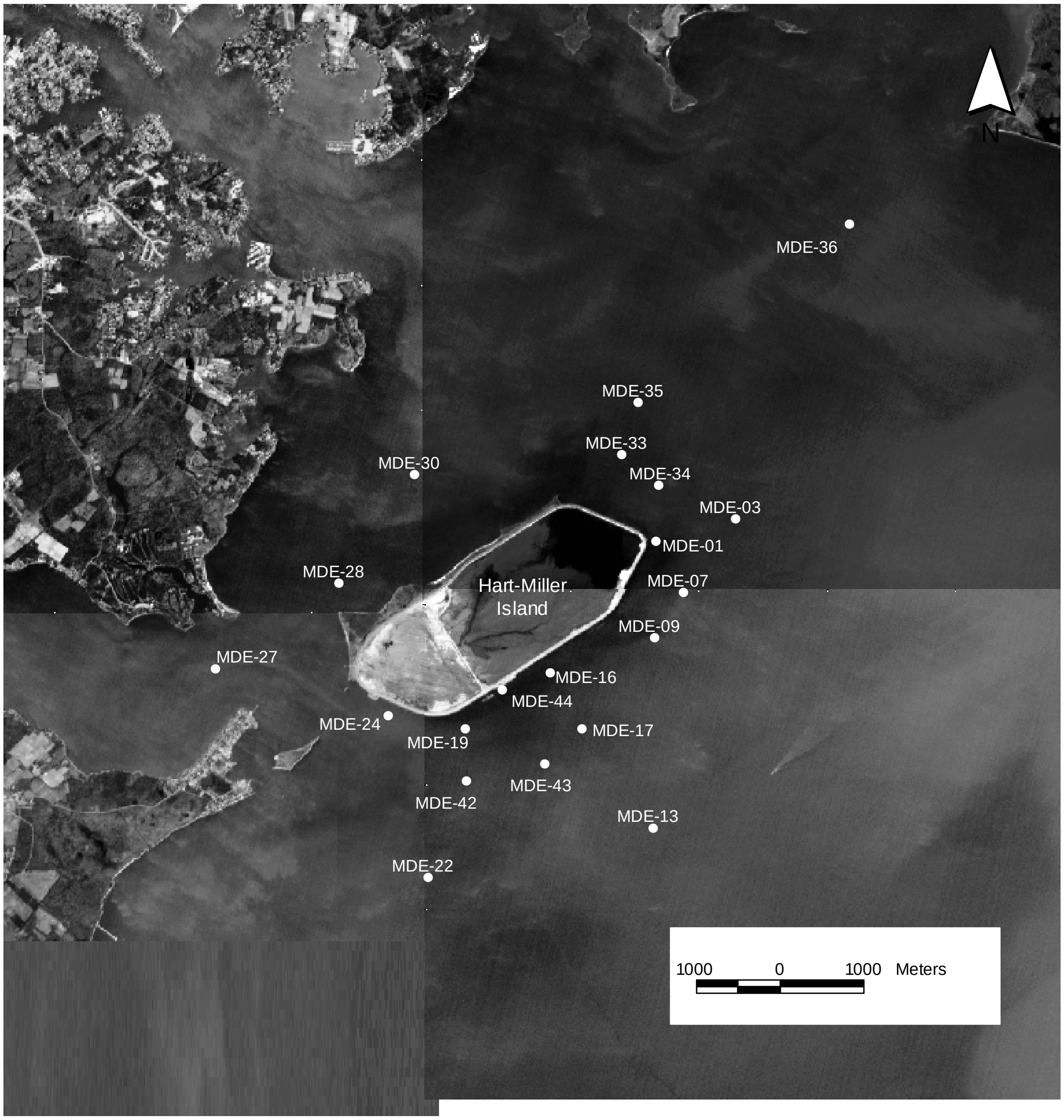

Figure 12: Year 22 Benthic Sampling Stations for the HMI Exterior Monitoring Program. MDE-42, MDE-43, and MDE-44 were only sampled in the spring of Year 22.

All stations sampled during Year 21 of monitoring were again sampled for Year 22. In addition, three new stations were added in April 2004. Stations were classified by location and dominant sediment type (Table 5). There were four location groups (Nearfield stations, Reference stations, Back River/Hawk Cove stations, and South Cell Baseline 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 2003 and April 2004. 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. The secchi depth was measured at all stations during both seasons. Water quality data from all depths are found under Project III of the HMI *Year 22 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 identified using methods similar to Llanso (2002). Where applicable, chironomids 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 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, quality control checks were performed for every sample to ensure greater than or equal to 90% recovery of all organisms. Ten percent of all samples identified were sent to an outside taxonomist for verification.

Nine 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, abundance of carnivores and omnivores, Tanypodinae to Chironomidae abundance ratio, tolerance score, taxa richness, and total abundance of all taxa (excluding Nematoda and Bryozoa). The first seven of these measures were used to calculate the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) for September 2003. The B-IBI is a multi-metric index of biotic integrity used to determine if benthic populations in different areas of the Chesapeake Bay are stressed (Llanso 2002). The B-IBI has not been calibrated for periods outside the summer index period (July 15 through September 30) and, thus, was not used with the April 2004 data. The dominant taxa during each season and the length frequency distributions of the three most common clams (*R. cuneata*, *M. balthica*, and *M. mitchelli*) were also recorded.

Abundance measures were calculated based on the average abundance of each taxon from the three replicate samples collected at each station. Total Abundance was calculated as the average abundance of epifaunal and infaunal organisms per square meter ($\#/m^2$), excluding Bryozoa, which are colonial. Qualitative estimates (i.e., rare, common or abundant) of the number of live bryozoan zooids are included in the *Year 22 Data Report*. Total Infaunal Abundance was calculated as the average abundance of infaunal organisms per square meter ($\#/m^2$). Two different measures of total abundance were calculated because epifaunal organisms are not included in the calculation of the B-IBI (Ranasinghe et al. 1994).

Pollution-Sensitive Taxa Abundance was calculated as the percentage of total infaunal abundance represented by pollution-sensitive taxa (the worm *Marenzelleria viridis* and the isopod *Chiridotea almyra*). Pollution-indicative taxa abundance was calculated as the percentage of total infaunal abundance represented by pollution-indicative taxa (the polychaete worms *H. filiformis, S. benedicti*, N. *succinea*, P. *cornuta* the oligochaete worms in the family Tubificidae, the amphipod L. plumulosus and the chironomids *Coelotanypus* sp., Chironomus sp., Glyptotendipes sp., and Procladius sp.). 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 stations, a single-linkage cluster analysis was performed on an Euclidean distance matrix comprised of station infaunal abundance values. This analysis was performed separately for September 2003 and April 2004 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 2003. The analysis in April 2004 included the three South Cell Baseline stations. 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 no depth stratification. Water quality data for all parameters at all stations are found in the *Year 22 Project III Data Report*. The following discussion will be limited to bottom values as they are the most relevant for benthic macroinvertebrate health. Secchi depths were greater in September 2003 (Table 6, range=0.4m-0.9 m, average=0.6m ± 0.13m) than those in April 2004 (Table 7, range=0.3m-0.5m, average=0.4m ± 0.07m). Station MDE-24 had the lowest Secchi depth (0.4m) in September 2003. All Secchi depths at all stations increased in September 2003, except MDE-01 and MDE-24, which remained at 0.5 and 0.4 m respectively, for both September 2003 and April 2004. It is important to note 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 22, bottom water temperatures did not vary much between stations during both sampling seasons. The September 2003 bottom water temperatures in Year 22 (Table 6, range= 23.75 °C – 24.85 °C, average=24.44°C ± 0.30°C) were greater than those seen at HMI in the previous five monitoring years. Bottom water temperatures were seasonably lower in April 2004 with a range of 12.90°C –15.14 °C and an average of 13.9°C ± 0.68°C. In addition, the April 2004 bottom water temperatures were higher than those recorded in April 2003.

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 2003 (Table 6, range=6.09 ppm-8.60 ppm, average=7.33 ppm ± 0.67 ppm) than those in April 2004 (Table 7, range=10.17 ppm-12.57 ppm, average=11.35 ppm ± 0.55 ppm).

In September 2003, the lowest bottom DO concentration was 6.09 ppm, recorded at station MDE-22. It is important to note that this station had one of the highest temperatures (24.65°C) in September 2003. The low bottom DO concentration at station MDE-22 may have been due to the fact that the solubility of a gas in water decreases as the temperature increases (Smith 1996), i.e., water temperature is highly correlated with DO. The highest bottom DO concentration in September 2003 (8.60 ppm) was recorded at station MDE-30, which had a bottom temperature of (24.34°C).

In April 2004, the lowest bottom DO concentration was 10.17 ppm, recorded at station MDE-27. Since this station also had one of the highest bottom temperatures (15.14°C), it may have had low bottom DO concentrations due to reasons similar to ones stated above. The highest bottom DO concentration (12.57 ppm) was seen at Station MDE-01.

Bottom salinity was greater in September 2003 (Table 6, range=1.11 ppt-3.89 ppt, average=2.57 ppt ± 0.88 ppt) than in April 2004 (Table 7, range=1.01 ppt-2.63 ppt, average=1.66 ppt ± 0.38 ppt). These salinities are much lower than recorded in Year 21. 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 ppt – 5 ppt) and mesohaline (>5ppt – 18 ppt) salinity regimes (Lippson and Lippson 1997).

In Year 22, the highest bottom salinity was seen at Reference station MDE-13 in September 2003 (3.89 ppt) and at Reference station MDE-22 in April 2004 (2.63 ppt). These two stations are least influenced by freshwater discharges due to their location further south in the main bay. In Year 22, the lowest salinity was seen at station MDE-36 in both September 2003 (1.11 ppt) and April 2004 (1.01 ppt). The low bottom salinity at MDE-36 is likely due to its greater proximity to the Susquehanna River discharge.

Table 6: Water quality parameters measured *in situ* at all HMI stations on September 8, 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	1.91	24.29	7.83	7.82	0.5
		Bottom	3.79	1.91	24.24	7.89	7.92	
MDE-03	XIG5699	Surface	0.5	2.38	24.5	7.29	7.64	0.6
		Bottom	5.8	2.44	24.42	7.06	7.75	
MDE-07	XIF5302	Surface	0.5	2.3	24.29	7.39	7.63	0.5
		Bottom	5.72	2.39	24.33	7.36	7.74	
MDE-09	XIF4806	Surface	0.5	2.26	24.2	7.17	7.58	0.7
		Bottom	5.83	2.95	24.48	6.81	7.62	
MDE-16	XIF4615	Surface	0.5	2.6	24.61	7.37	7.55	0.5
		Bottom	4.35	2.99	24.69	6.68	7.43	
MDE-17	XIF4285	Surface	0.5	2.79	24.6	7.44	7.61	0.7
		Bottom	2.9	3.65	24.99	6.52	7.55	
MDE-19	XIF4221	Surface	0.5	2.7	24.54	7.5	7.8	0.5
		Bottom	4.9	3.3	24.85	6.4	7.7	
MDE-24	XIF4372	Surface	0.5	2.2	23.73	8.05	7.97	0.4
		Bottom	2.6	2.1	23.75	8.07	7.98	
MDE-33	XIF6008	Surface	0.5	1.83	24.34	7.72	7.83	0.6
		Bottom	2.66	1.83	24.28	7.68	7.98	
MDE-34	XIF5805	Surface	0.5	1.97	24.27	7.61	7.76	0.6
		Bottom	3.8	1.97	24.24	7.55	7.92	
MDE-35	XIF6407	Surface	0.5	1.84	24.41	7.43	7.76	0.6
		Bottom	3.79	1.87	24.21	7.4	7.92	
Reference Stations								
MDE-13	XIG3506	Surface	0.5	3.05	24.63	8.49	7.99	0.8
		Bottom	5.3	3.89	24.85	7.12	7.54	
MDE-22	XIF3224	Surface	0.5	3	24.34	8.75	8.1	0.9
		Bottom	4.9	4.5	24.65	6.09	7.6	
MDE-36	XIG7589	Surface	0.5	1.09	24.34	7.92	7.91	0.5
		Bottom	3.41	1.11	24.38	7.77	8.02	
Back River/Hawk Cove Stations								
MDE-27	XIF4642	Surface	0.5	2.59	24.8	8.91	8.26	0.5
		Bottom	4.19	2.69	24.58	8.01	8.03	
MDE-28	XIF5232	Surface	0.5	1.97	24.45	9.15	8.33	0.6
		Bottom	2.77	2.22	24.27	7.57	7.88	
MDE-30	XIF5925	Surface	0.5	1.98	24.52	9.12	8.31	0.5
		Bottom	3.41	1.92	24.34	8.6	8.13	

Table 7: Water quality parameters measured *in situ* at all HMI stations on April 20, 2004.

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	1.36	14.66	12.13	8.76	0.5
		Bottom	3.63	1.40	14.68	12.57	8.80	
MDE-03	XIG5699	Surface	0.5	1.42	14.51	11.09	8.25	0.5
		Bottom	5.64	1.38	13.73	11.63	8.08	
MDE-07	XIF5302	Surface	0.5	1.49	14.05	11.61	8.13	0.4
		Bottom	5.84	1.49	13.67	11.56	8.07	
MDE-09	XIF4806	Surface	0.5	1.62	13.85	11.23	8.09	0.4
		Bottom	5.72	1.61	13.53	11.61	8.08	
MDE-16	XIF4615	Surface	0.5	1.79	14.23	10.81	8.30	0.35
		Bottom	4.62	1.76	13.83	11.56	8.24	
MDE-17	XIF4285	Surface	0.5	1.76	13.72	10.66	8.11	0.35
		Bottom	5.14	1.80	13.17	10.83	7.97	
MDE-19	XIF4221	Surface	0.5	1.86	14.05	11.04	8.24	0.4
		Bottom	4.87	1.89	13.81	11.95	8.15	
MDE-24	XIF4372	Surface	0.5	1.64	14.47	11.16	8.48	0.4
		Bottom	2.17	1.92	14.25	10.97	8.28	
MDE-33	XIF6008	Surface	0.5	1.27	14.61	11.47	8.51	0.45
		Bottom	2.59	1.28	14.46	11.63	8.55	
MDE-34	XIF5805	Surface	0.5	1.28	14.68	12.33	8.67	0.5
		Bottom	3.66	1.28	14.66	12.26	8.68	
MDE-35	XIF6407	Surface	0.5	1.14	15.02	11.46	8.43	0.45
		Bottom	3.79	1.27	13.96	11.48	8.17	
Reference Stations								
MDE-13	XIG3506	Surface	0.5	2.07	13.05	11.42	7.85	0.3
		Bottom	5.11	2.09	12.90	10.78	7.87	
MDE-22	XIF3224	Surface	0.5	1.66	13.55	10.87	8.06	0.45
		Bottom	5.5	2.63	13.10	11.20	7.85	
MDE-36	XIG7589	Surface	0.5	0.70	15.38	11.02	8.38	0.45
		Bottom	3.44	1.01	13.48	11.10	8.21	
Back River/Hawk Cove Stations								
MDE-27	XIF4642	Surface	0.5	1.65	16.34	11.09	8.91	0.40
		Bottom	4.17	1.89	15.14	10.17	8.65	
MDE-28	XIF5232	Surface	0.5	1.18	15.49	11.71	8.96	0.5
		Bottom	2.54	1.33	14.99	11.34	8.89	
MDE-30	XIF5925	Surface	0.5	1.17	16.61	11.63	9.14	0.45
		Bottom	3.24	1.34	14.52	10.87	8.53	
South Cell Monitoring Stations								
MDE-42	XIF3879	Surface	0.5	1.68	13.98	10.62	8.28	0.5
		Bottom	5.1	1.89	13.17	10.98	7.89	
MDE-43	XIF3985	Surface	0.5	1.72	13.88	11.25	8.17	0.5
		Bottom	5.13	2.00	13.01	10.98	7.86	
MDE-44	XIF4482	Surface	0.5	1.72	14.38	10.61	8.41	0.3
		Bottom	5.32	1.87	14.15	11.52	8.32	

Benthic Macroinvertebrate Community

Taxa Richness and Dominance

A total of 45 taxa were found over the two seasons of sampling during Year 22 of benthic community monitoring in the vicinity of Hart- Miller Island. This is similar to the previous three years where Year 21 had a total of 43 taxa, Year 20 had a total of 41 taxa, and Year 19 had a total of 42 taxa. In terms of station type, six taxa were found only at Silt/Clay stations. These six taxa were: *Macoma mitchelli, Chironomus riparius, Glyptotendipes* sp., an undetermined species from the phylum *Playthelminthes* , *Hypaniola grayi,* and *Amphicteis floridus.* In addition, following three taxa were only found at Shell stations: *Harnichia sp., Hydrobia sp., and Piscicolidae*. *Parahaustorius sp.* was only found at Sand stations. In terms of station type, eleven taxa were only found at Nearfield stations. These eleven taxa were: *Polydora cornuta, B. subalbidus, G. bosci, M. arenaria, Chiridotea almyra, Cricotopus sp., Parahaustorius sp.,* Rheotanytarsus sp., undetermined species from the classes Copepoda and Hydrozoa, and undetermined species from the family Piscicolidae. In addition, *Hydrobia sp.* and Harnishia sp. were only found at reference stations. *Amphicteis floridus* , *Hypaniola grayi* , undetermined species from the phyla *Playthelminthes and Arthropoda* were 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 Mollusca (shellfish having two separate shells joined by a muscular hinge). Twenty species of Arthropoda were found in the course of the study. This is the same number of species that was found in Year 21. The most common types of arthropods were the amphipods (such as *Leptocheirus plumulosus*) and the isopods (such as *C. polita*). Six species of annelid worms in the class Polychaeta were found. This is lower than the seven species of polychaetes found in Year 21. Polychaete Taxa Richness was the same (5 species) in September 2003 as in April 2004. *G. solitaria*, and *E. heteropoda* which were found in Year 21, were completely absent in Year 22. This may have been due to the lower salinities in the upper bay during the Year 22 sampling period. Six species of bivalve mollusks were found. Bivalve mollusk taxa richness in Year 22 (6) was slightly less than that of year 21 (7). However, bivalve mollusk average abundances were much lower in April 2004 than in September 2003 (Tables 8 & 9). This may have 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 22 late summer, September 2003 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	10.91765	185.6	21.6	0	2.56	12.218182	0	17.067
Carinoma tremophoros	9.411765	160	8.8	8	11.52	9.8909091	14.933	2.1333
Bivalvia	3.764706	64	2.4	6.4	3.84	2.9090909	8.5333	2.1333
Macoma sp.	2.635294	44.8	3.2	1.6	2.56	1.7454545	8.5333	0
Macoma balthica	14.30588	243.2	24	8	3.84	8.1454545	49.067	2.1333
Macoma mitchelli	2.635294	44.8	5.6	0	0	0	10.667	4.2667
Rangia cuneata	461.5529	7846.4	350.4	555.2	564.48	527.70909	514.13	166.4
Ischadium recurvum	17.31765	294.4	2.4	49.6	15.36	26.763636	0	0
Mytilopsis leucophaeata	638.4941	10854.4	15.2	2425.6	206.08	976.87273	29.867	6.4
Heteromastus filiformis	6.776471	115.2	7.2	8	5.12	4.6545455	21.333	0
Spionidae	0.752941	12.8	0	1.6	1.28	1.1636364	0	0
Marenzelleria viridis	173.5529	2950.4	60.8	144	377.6	231.56364	74.667	59.733
Streblospio benedicti	102.4	1740.8	114.4	43.2	130.56	78.545455	34.133	258.13
Polydora cornuta	5.270588	89.6	0	19.2	2.56	8.1454545	0	0
Neanthes succinea	13.55294	230.4	9.6	24	11.52	16.872727	12.8	2.1333
Tubificidae	1008.188	17139.2	1580.8	782.4	272.64	489.89091	104.53	3812.3
Crustacea	0.752941	12.8	0.8	1.6	0	0.5818182	2.1333	0
Amphipoda	131.0118	2227.2	161.6	148.8	67.84	104.14545	170.67	189.87
Gammaridea	0.752941	12.8	0	3.2	0	1.1636364	0	0
Ameroculodes spp. complex	54.21176	921.6	36	46.4	89.6	62.836364	66.133	10.667
Leptocherius plumulosus	278.2118	4729.6	450.4	124.8	125.44	198.98182	328.53	518.4
Gammarus sp.	9.035294	153.6	3.2	14.4	14.08	11.636364	2.1333	6.4
Melitidae	0.376471	6.4	0.8	0	0	0	0	2.1333
Meltia nitida	99.38824	1689.6	159.2	89.6	11.52	83.781818	64	192
Corophiidae	43.67059	742.4	0	164.8	16.64	67.490909	0	0
Apocorophium lacustre	575.2471	9779.2	11.2	1942.4	384	886.69091	0	8.5333
Isopoda	1.882353	32	1.6	4.8	0	1.1636364	6.4	0
Cyathura poltia	350.4941	5958.4	301.6	468.8	334.08	402.03636	337.07	174.93
Edotia triloba	57.22353	972.8	26.4	70.4	96	70.981818	2.1333	61.867
Chirodotea almyra	4.894118	83.2	0	0	16.64	7.5636364	0	0
Balanus improvisus	30.49412	518.4	13.6	49.6	42.24	37.818182	34.133	0

Table 8: Continued.

Taxon	Average Abundance, All stations	Total Abundance, All stations	Substrate			Station Type		
			Silt/Clay	Shell	Sand	Nearfield	Ref.	Back River
Balanus subalbidus	3.0	51.2	0	3.2	7.7	4.6545455	0	0
Xanthidae	1.9	32	0	4.8	2.6	2.9090909	0	0
Rhithropanopeus harrissi	20.0	339.2	1.6	51.2	24.3	30.254545	2.1	0
Membranipora sp.	+	+	+	+	+	+	+	0
Chironomidae	2.6	44.8	2.4	3.2	2.6	1.1636364	4.3	6.4
Chiromoninae	0.4	6.4	0.8	0	0	0	0	2.1
Tanypodinae	0	0	0	0	0	0	0	0
Coelotanypus sp.	80.94	1376	140.8	56	5.1	15.127273	68.3	334.9
Chironomus	0.8	12.8	1.6	0	0	0	0	4.3
Chironomus riparius	0.4	6.4	0.8	0	0	0	0	2.1
Cryptochironomus sp.	5.3	89.6	8	1.6	3.8	3.4909091	0	17.1
Coelotanypodini	0	0	0	0	0	0	0	0
Procladius sp.	0.8	12.8	0	1.6	1.3	1.1636364	0	0
Procladius (Holotanypus) sp.	6.0	102.4	2.4	12.8	6.4	5.8181818	8.5	4.3
Glyptotendipes sp.	0.4	6.4	0.8	0	0	0	0	2.1
Tanytarsini	0.4	6.4	0	0	1.28	0.5818182	0	0
Harnischia	0.4	6.4	0	1.6	0	0	2.1	0
Hydrozoa	16.2	275.2	0.8	0	53.8	25.018182	0	0
Gobiosoma bosci	1.1	19.2	0	1.6	2.	1.7454545	0	0
Arthropoda	0.4	6.4	0.8	0	0	0	0	2.1
Hydrobia sp.	1.5	25.6	0	6.4	0	0	8.5	0

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

Table 9: Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 22 Spring sampling, April 2004, by substrate and station type.

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Substrate			Station Type			
			Silt/Clay	Shell	Sand	Near-field	Back River	Ref.	S. Cell Baseline
Nemata	34.2	684.8	39.5	6.4	3.2	34.3	100.3	0	2.1
Carinoma tremophoros	8.3	166.4	9.4	6.4	0	5.8	8.5	8.5	17.0
Bivalvia	14.7	294.4	15.1	0	19.2	9.3	44.8	6.4	12.8
Macoma sp	0.3	6.4	0.4	0	0	0	0	2.1	0
Macoma balthica	25.9	518.4	30.5	0	0	4.0	0	123.7	34.1
Macoma mitchelli	0.00	0	0	0	0	0	0	0	0
Rangia cuneata	170.2	3404.8	139.7	64	483.2	207.7	142.9	177.1	53.3
Mulinia lateralis	0.00	0	0	0	0	0	0	0	0
Ischadium recurvum	5.8	115.2	2.6	57.6	6.4	9.9	0	0	2.1
Mytilopsis leucophaeata	61.4	1228.8	49.7	371.2	6.4	111.1	0	2.1	0
Capitellidae	0.00	0	0	0	0	0	0	0	0
Heteromastus filiformis	4.8	96	4.9	12.8	0	2.3	0	19.2	4.3
Spionidae	25.9	518.4	22.2	0	70.4	30.3	10.7	23.5	27.7
Marenzellaria viridis	2948.8	58976	2991.1	2758.4	2684.8	3964.5	305.1	2429.9	2387.2
Streblospio benedicti	0	0	0	0	0	0	0	0	0
Nereididae	0.6	12.8	0.8	0	0	0	0	4.3	0
Neanthes succinea	1.6	32	1.9	0	0	1.2	4.3	0	2.1
Tubificidae	811.2	16224	920.5	537.6	19.2	359.6	2988.8	473.6	627.2
Tubificidae w/o capillary setae	0	0	0	0	0	0	0	0	0
Tubificoides sp.	1297.6	25952	1469.4	857.6	57.6	720.9	4177.1	974.9	855.5
Amphipoda	110.1	2201.6	94.9	467.2	60.8	104.7	166.4	68.3	115.2
Gammaridea	1.3	25.6	1.5	0	0	0	2.1	0	6.4
Ameroculodes spp complex	21.1	422.4	18.5	0	54.4	25.6	4.3	19.2	23.5
Leptocheirus plumulosus	295.0	5900.8	319.6	0	233.6	179.8	586.7	373.3	347.7
Gammarus sp	32.6	652.8	31.2	38.4	41.6	22.1	0	55.5	81.1
Melitadae	1.6	32	1.9	0	0	2.9	0	0	0
Melita nitida	64.0	1280	63.3	153.6	25.6	60.5	81.1	76.8	46.9
Corophiidae	23.4	467.2	2.6	416	3.2	40.7	4.3	2.1	0
Apocorophium sp.	0.6	12.8	0.8	0	0	0	0	0	4.3
Apocorophium lacustre	137.6	2752	59.5	1593.6	73.6	209.5	44.8	57.6	46.9
Isopoda	0	0	0	0	0	0	0	0	0
Cyathura polita	440.0	8800	468.7	460.8	185.6	532.4	110.9	437.3	433.1

Table 9: Continued

TAXON	Average Abundance, All Stations	Total Abundance, All Stations	Substrate			Station			
			Silt/Clay	Shell	Sand	Nearfield	Back River	Ref.	S. Cell Baseline
Edotea triloba	32.64	652.8	33.9	0	38.4	34.3	27.733	40.5	23.5
Chiridotea almyra	3.20	64	1.5	0	19.2	5.8	0	0	0
Cirripedia	0.64	12.8	0.8	0	0	1.2	0	0	0
Balanus sp	0.32	6.4	0	6.4	0	0.6	0	0	0
Balanus improvisus	19.52	390.4	1.1	371.2	0	35.5	0	0	0
Balanus subalbidus	14.72	294.4	0	294.4	0	26.8	0	0	0
Xanthidae	0.32	6.4	0.4	0	0	0.6	0	0	0
Rhithropanopeus harrisii	35.20	704	17.7	403.2	0	63.4	0	0	2.1
Membranipora sp	0.00	0	0	0	0	0	0	0	0
Chironomidae	15.68	313.6	13.6	83.2	0	9.9	29.867	36.3	2.1
Tanypodinae	0.00	0	0	0	0	0	0	0	0
Orthocladiinae	0.64	12.8	0	0	6.4	1.2	0	0	0
Coelotanypus sp.	51.84	1036.8	59.5	25.6	0	13.4	46.933	243.2	6.4
Coelotanypodini	0.00	0	0	0	0	0	0	0	0
Procladius sp.	3.52	70.4	4.1	0	0	0	19.2	2.1	2.1
Procladius(Holotanypus) sp.	19.52	390.4	23.0	0	0	9.9	53.333	34.1	6.4
Chironomidae	0.64	12.8	0.8	0	0	0	0	4.3	0
Cryptochironomus sp.	1.28	25.6	1.1	6.4	0	1.2	4.2667	0	0
Cricotopus sp.	5.76	115.2	0.8	102.4	0	10.5	0	0	0
Rehotanytarsus sp.	4.48	89.6	0.4	83.2	0	8.1	0	0	0
Mya arenaria	5.76	115.2	0.8	102.4	0	10.5	0	0	0
Copepoda	4.48	89.6	0.4	83.2	0	8.1	0	0	0
Hydrozoa	2.56	51.2	1.1	25.6	3.2	4.7	0	0	0
Parahaustarius sp.	0.64	12.8	0	0	6.4	1.2	0	0	0
Amphicteis floridus	0.32	6.4	0.4	0	0	0	0	2.1	0
Platyhelminthes	0.32	6.4	0.4	0	0	0	0	2.1	0
Hypaniola grayi	0.32	6.4	0.4	0	0	0	0	2.1	0
Piscicolidae	0.64	12.8	0	12.8	0	1.2	0	0	0

Of the 45 taxa found in Year 22, twenty-four are considered truly infaunal, twelve are considered epifaunal, and the remaining nine are considered too general to classify as either infaunal or epifaunal (see Ranasinghe et al. 1994). The most common infaunal species found during Year 22 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 was the bivalve *M. leucophaeata*. The population size of *M. Leucophaeata* was unusually high throughout the upper bay in 2003/2004. 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-03 and Back River/Hawk Cove Station MDE-27 had the highest number of taxa in the September 2003 (23 taxa), followed by the Nearfield stations MDE-01 and MDE-07 (22 taxa) (Table 10). The stations with the fewest taxa in September 2003 were Back River/Hawk Cove Station MDE-30 (10 taxa), Nearfield station MDE-19 (11 taxa), and Back River/Hawk Cove Station MDE-28 (14 taxa) (Table 10). Overall, average taxa richness was highest at the Nearfield stations but did not vary greatly between station types (average taxa richness: Nearfield=19 taxa, Reference=16 taxa, Back River/Hawk Cove=16 taxa).

Table 10: Summary of metrics for each HMI benthic station surveyed during the Year 22 late summer sampling cruise, September 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	Tolerance Score	% Carnivore/ Omnivore	Tanypodinae: Chironomidae	B-IBI
Nearfield Stations											
MDE-01	819.2	1222.4	22	12	2.99	10.9	37.5	6.13	19.9	100	3.57
MDE-03	2611.2	2790.4	23	15	2.77	24.3	28.4	6.22	25.9	85.7	3.86
MDE-07	2771.2	3916.8	22	12	1.98	5.31	71.8	6.00	10.1	0	3.86
MDE-09	2892.8	20979.2	21	14	2.57	1.77	24.3	6.16	4.28	87.5	3.57
MDE-16	3481.6	2515.2	19	12	2.50	4.41	18.9	6.00	21.4	100	3.86
MDE-17	3193.6	2451.2	18	12	2.60	6.01	26.1	6.01	20.4	100	3.86
MDE-19	1856	1241.6	11	8	2.27	0	17.6	6.01	31.4	100	3.86
MDE-24	2912	2547.2	21	15	2.99	7.03	31.9	6.05	12.8	66.7	3.57
MDE-33	2259.2	4019.2	19	12	2.36	3.83	7.08	6.01	6.37	0	4.14
MDE-34	4243.2	3961.6	20	10	2.58	17.2	15.7	6.00	10.7	33.3	3.57
MDE-35	2963.2	2809.6	15	12	2.48	3.89	57.2	6.22	14.6	87.5	3.29
Reference Stations											
MDE-13	2073.6	1606.4	16	11	2.77	0	17.3	6.05	23.5	100	3.86
MDE-22	2956.8	2304	15	13	2.96	1.30	20.8	6.00	19.4	100	3.86
MDE-36	2560	2022.4	16	12	2.99	7.25	29.7	6.14	25.6	91.7	3.86
Back River/Hawk Cove Stations											
MDE-27	14803.2	14796.8	23	18	1.30	0.346	88.9	6.34	3.50	78	2.14
MDE-28	2022.4	1664	14	9	2.79	3.80	48.4	6.19	42.7	97.5	3.86
MDE-30	1337.6	1107.2	10	7	2.67	3.83	49.8	6.19	38.7	93.3	3.86

In April 2004 the Nearfield station MDE-01 had the highest number of taxa (23 taxa), followed closely by the Nearfield station MDE-09 (21 taxa) and Nearfield station MDE-03 (18 taxa) (Table 11). The Back River/Hawk Cove station MDE-30 had the lowest number of taxa (11 taxa), followed by Nearfield station MDE-13 (12 taxa; see Table 11). Overall, the average taxa richness was highest at the Nearfield stations, but did not vary greatly between station types (average taxa richness: Nearfield=16 taxa, Reference=14 taxa, Back River/Hawk Cove=13 taxa, Baseline Monitoring Stations=14).

Table 11: Summary of metrics for each HMI benthic station surveyed during the Year 22 spring sampling cruise, April 2004. 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	5523.2	9388.8	23	12	2.96	49.9	26.0
MDE-03	5638.4	5856	18	10	1.72	67.7	18.7
MDE-07	8844.8	8992	16	11	1.71	64.8	25.8
MDE-09	10432	11500.8	21	13	1.60	69.0	19.0
MDE-16	8000	8275.2	15	10	1.28	78.6	10.3
MDE-17	6476.8	6694.4	16	9	1.30	76.2	7.11
MDE-19	2457.6	2636.8	14	10	2.15	49.7	33.1
MDE-24	5484.8	5766.4	14	8	1.08	84.4	5.95
MDE-33	2348.8	2432	12	9	2.35	33.2	12.5
MDE-34	10432	10809.6	17	10	1.95	53.3	30.2
MDE-35	2796.8	3001.6	13	9	2.74	27.2	54.7
Reference Stations							
MDE-13	7552	7776	15	12	1.72	71.3	14.3
MDE-22	5881.6	6009.6	13	9	2.50	11.1	72.7
MDE-36	2508.8	2739.2	13	10	2.43	50.0	21.0
Back River/Hawk Cove Stations							
MDE-27	21964.8	22195.2	13	10	1.39	1.69	97.4
MDE-28	3052.8	3494.4	14	8	2.90	11.7	61.6
MDE-30	1350.4	1433.6	11	9	2.79	13.7	62.1
Baseline Monitoring Stations for South Cell							
MDE-42	4115.2	4236.8	14	10	2.54	21.0	66.7
MDE-43	5376	5555.2	13	8	2.18	55.5	26.9
MDE-44	5580.8	5670.4	14	11	1.98	59.4	24.4

Since the first benthic survey studies of the Hart-Miller Island area in 1981, a small number of taxa have been dominant; Year 22 was no exception. During both seasons, 4 taxa were clearly dominant: 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 2003 and April 2004 are provided in Tables 12 thru 15.

Table 12: Average number of individuals collected per square meter at each station during the HMI Year 22 late summer sampling, September 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	6.4	51.2	6.4	0	19.2	12.8	12.8	6.4	12.8
Bivalvia	0	0	0	0	12.8	0	12.8	0	0
Macoma sp	0	12.8	0	0	0	0	6.4	0	25.6
Macoma balthica	0	6.4	25.6	0	44.8	0	6.4	12.8	102.4
Macoma mitchelli	0	0	0	0	0	0	0	0	32
Rangia cuneata	160	384	236.8	819.2	416	934.4	601.6	339.2	563.2
Ischadium recurvum	12.8	38.4	89.6	108.8	0	19.2	0	0	0
Mytilopsis leucophaeata	70.4	121.6	467.2	9190.4	51.2	19.2	38.4	0	32
Heteromastus filiformis	6.4	0	12.8	0	19.2	6.4	0	0	25.6
Spionidae	0	0	0	6.4	0	0	0	0	0
Marenzellaria viridis	89.6	633.6	147.2	51.2	0	153.6	192	0	38.4
Streblospio benedicti	70.4	166.4	128	12.8	6.4	32	19.2	0	83.2
Polydora cornuta	0	0	25.6	44.8	0	0	6.4	0	0
Neanthes succinea	32	6.4	83.2	6.4	38.4	12.8	6.4	19.2	0
Tubificidae	108.8	505.6	1728	505.6	32	435.2	678.4	25.6	64
Crustacea	0	0	6.4	0	0	0	0	0	6.4
Amphipoda	12.8	25.6	44.8	345.6	179.2	108.8	70.4	115.2	198.4
Gammaridea	0	0	0	0	0	0	12.8	0	0
Ameroculodes spp complex	38.4	121.6	0	64	76.8	38.4	96	0	96
Leptocheirus plumulosus	83.2	25.6	12.8	89.6	256	166.4	96	268.8	428.8
Gammarus sp.	6.4	6.4	12.8	44.8	0	0	0	0	6.4
Melitadae	0	0	0	0	0	0	0	0	0
Melita nitida	32	0	38.4	262.4	25.6	32	57.6	83.2	166.4
Corophiidae	0	0	19.2	640	0	0	0	0	0
Apocorophium lacustre	76.8	0	179.2	7590.4	0	0	0	6.4	0
Isopoda	0	0	0	12.8	12.8	0	0	0	0
Cyathura polita	198.4	620.8	307.2	838.4	313.6	505.6	454.4	352	422.4
Edotia triloba	19.2	19.2	38.4	230.4	0	25.6	6.4	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
Chiridotea almyra	0	0	0	0	0	0	0	0	0
Balanus improvisus	102.4	6.4	185.6	0	102.4	0	12.8	6.4	0
Balanus subalbidus	32	0	12.8	0	0	0	0	0	0
Xanthidae	0	6.4	12.8	0	0	0	6.4	0	0
Rhithropanopeus harrisii	57.6	6.4	102.4	57.6	6.4	6.4	44.8	0	0
Membranipora sp.	+	+	+	0	0	+	+	0	0
Chironomidae	0	0	0	0	0	0	0	0	0
Chironominae	0	0	0	0	0	0	0	0	0
Tanypodinae	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	12.8	0	6.4	0	6.4	25.6	12.8	12.8
Crironomus	0	0	0	0	0	0	0	0	0
Chironomus riparius	0	0	0	0	0	0	0	0	0
Cryptochironomus sp.	0	6.4	0	6.4	0	0	0	0	0
Coelotanypodini	0	0	0	0	0	0	0	0	0
Procladius sp.	0	6.4	0	6.4	0	0	0	0	0
Procladius (Holotanypus) sp.	6.4	19.2	0	32	6.4	0	0	0	0
Glyptotendipes sp.	0	0	0	0	0	0	0	0	0
Tanytarsini	0	0	0	0	0	0	0	0	0
Harnischia	0	0	0	0	0	0	0	0	0
Hydrozoa	0	25.6	0	0	0	6.4	0	0	0
Gobiosoma bosci	6.4	6.4	0	6.4	0	0	0	0	0
Unknown sp. 2	0	0	0	0	6.4	0	0	0	0
Polydora sp. 1	0	0	0	0	0	6.4	0	0	0
Unknown taxa 1	0	0	0	0	0	0	0	0	0
Arthropoda	0	0	0	0	0	0	0	0	0
Unknown sp. 1	0	0	0	0	0	0	0	0	0
Hydrobia sp.	0	0	0	0	0	0	0	0	0

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

Table 13: Average number of individuals collected per square meter at each station during the HMI Year 22 late summer sampling, September 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	12.8	38.4	12.8	0	0	0	121.6	0
Carinoma tremophoros	0	6.4	0	0	0	0	12.8	12.8
Bivalvia	0	6.4	0	0	0	19.2	0	12.8
Macoma sp	0	0	0	0	0	0	0	0
Macoma balthica	12.8	6.4	0	0	0	0	25.6	0
Macoma mitchelli	0	12.8	0	0	0	0	0	0
Rangia cuneata	582.4	313.6	172.8	12.8	806.4	889.6	51.2	563.2
Ischadium recurvum	0	0	0	0	12.8	12.8	0	0
Mytilopsis leucophaeata	0	19.2	0	0	576	262.4	0	6.4
Heteromastus filiformis	12.8	0	0	0	0	6.4	6.4	19.2
Spionidae	0	0	0	0	0	6.4	0	0
Marenzellaria viridis	134.4	51.2	76.8	51.2	300.8	729.6	115.2	185.6
Streblospio benedicti	313.6	742.4	32	0	19.2	83.2	19.2	12.8
Polydora cornuta	0	0	0	0	0	12.8	0	0
Neanthes succinea	6.4	6.4	0	0	12.8	0	0	0
Tubificidae	249.6	11059.2	198.4	179.2	19.2	480	652.8	217.6
Crustacea	0	0	0	0	0	0	0	0
Amphipoda	32	230.4	185.6	153.6	198.4	70.4	121.6	134.4
Gammaridea	0	0	0	0	0	0	0	0
Ameroculodes spp complex	128	19.2	0	12.8	38.4	121.6	44.8	25.6
Leptocheirus plumulosus	332.8	1088	249.6	217.6	108.8	76.8	928	300.8
Gammarus sp.	6.4	19.2	0	0	51.2	0	0	0
Melitadae	0	6.4	0	0	0	0	0	0
Melita nitida	12.8	512	25.6	38.4	0	12.8	390.4	0
Corophiidae	0	0	0	0	57.6	25.6	0	0
Apocorophium lacustre	19.2	12.8	6.4	6.4	1529.6	294.4	57.6	0
Isopoda	0	0	0	0	0	0	0	6.4
Cyathura polita	230.4	185.6	198.4	140.8	217.6	403.2	294.4	275.2
Edotia triloba	160	185.6	0	0	12.8	268.8	0	6.4
Chiridotea almyra	70.4	0	0	0	12.8	0	0	0
Balanus improvisus	0	0	0	0	6.4	96	0	0
Balanus subalbidus	0	0	0	0	0	6.4	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	6.4	0	0
Rhithropanopeus harrisii	0	0	0	0	6.4	51.2	0	0
Membranipora sp.	0	0	0	0	0	+	0	+
Chironomidae	0	0	0	19.2	0	12.8	0	12.8
Chironominae	0	0	6.4	0	0	0	0	0
Tanypodinae	0	0	0	0	0	0	0	0
Coelotanypus sp.	6.4	243.2	492.8	268.8	0	6.4	89.6	192
Crironomus	0	12.8	0	0	0	0	0	0
Chironomus riparius	0	6.4	0	0	0	0	0	0
Cryptochironomus sp.	6.4	44.8	6.4	0	6.4	0	12.8	0
Coelotanypodini	0	0	0	0	0	0	0	0
Procladius sp.	0	0	0	0	0	0	0	0
Procladius (Holotanypus) sp.	6.4	6.4	6.4	0	0	0	0	19.2
Glyptotendipes sp.	0	6.4	0	0	0	0	0	0
Tanytarsini	0	0	0	0	6.4	0	0	0
Harnischia	0	0	0	0	0	0	0	6.4
Hydrozoa	217.6	0	0	0	19.2	6.4	0	0
Gobiosoma bosci	0	0	0	0	0	0	0	0
Unknown sp. 2	0	0	0	0	0	0	0	0
Polydora sp. 1	0	0	0	0	0	0	0	0
Unknown taxa 1	6.4	0	0	0	0	0	0	0
Arthropoda	0	0	6.4	0	0	0	0	0
Unknown sp. 1	0	0	0	6.4	0	0	0	0
Hydrobia sp.	0	0	0	0	0	0	0	25.6

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

Table 14: Average number of individuals collected per square meter at each station during the HMI Year 22 spring sampling, April 2004, 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	6.4	0	0	0	0	0	0	6.4	0
Carinoma tremophoros	6.4	25.6	12.8	6.4	25.6	6.4	0	6.4	0
Bivalvia	0	12.8	0	0	0	0	6.4	0	6.4
Macoma sp	0	0	0	0	0	0	0	0	6.4
Macoma balthica	0	0	6.4	12.8	32	0	0	12.8	339.2
Macoma mitchelli	0	0	0	0	0	0	0	0	0
Rangia cuneata	64	185.6	108.8	134.4	64	243.2	121.6	19.2	38.4
Mulinia lateralis	0	0	0	0	0	0	0	0	0
Ischadium recurvum	57.6	12.8	0	25.6	0	0	0	0	0
Mytilopsis leucophaeata	371.2	19.2	6.4	748.8	0	0	25.6	0	6.4
Capitellidae	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	12.8	0	0	12.8	25.6	0	0	0	12.8
Spionidae	0	25.6	6.4	96	51.2	0	19.2	0	12.8
Marenzellaria viridis	2758.4	3814.4	5728	7200	5382.4	6284.8	4934.4	1222.4	652.8
Streblospio benedicti	0	0	0	0	0	0	0	0	0
Nereididae	0	0	0	0	12.8	0	0	0	0
Neanthes succinea	0	0	0	0	0	0	12.8	0	0
Tubificidae	537.6	531.2	633.6	710.4	288	262.4	96	108.8	1113.6
Tubificidae w/ out capilary setae	0	0	0	0	0	0	0	0	0
Tubificoides sp.	857.6	448	1491.2	1216	518.4	486.4	288	140.8	2348.8
Amphipoda	467.2	44.8	115.2	57.6	102.4	76.8	38.4	89.6	57.6
Gammaridea	0	0	0	0	0	0	0	0	0
Ameroculodes spp complex	0	12.8	32	32	51.2	19.2	25.6	12.8	0
Leptocheirus plumulosus	0	44.8	153.6	12.8	230.4	64	57.6	550.4	729.6
Gammarus sp	38.4	19.2	19.2	0	166.4	19.2	19.2	0	0
Melitadae	0	0	0	0	0	32	0	0	0
Melita nitida	153.6	19.2	12.8	64	128	70.4	38.4	160	89.6
Corophiidae	416	0	0	6.4	6.4	6.4	0	0	0
Apocorophium sp.	0	0	0	0	0	0	0	0	0
Apocorophium lacustre	1593.6	70.4	51.2	102.4	102.4	96	70.4	19.2	12.8
Isopoda	0	0	0	0	0	0	0	0	0
Cyathura polita	460.8	454.4	524.8	889.6	582.4	524.8	857.6	281.6	499.2
Edotea triloba	0	19.2	57.6	25.6	6.4	19.2	12.8	6.4	12.8
Chiridotea almyra	0	0	0	0	0	0	0	0	0
Cirripedia	0	0	0	0	0	0	12.8	0	0
Balanus sp	6.4	0	0	0	0	0	0	0	0
Balanus improvisus	371.2	6.4	0	6.4	0	0	6.4	0	0
Balanus subalbidus	294.4	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
Xanthidae	0	0	6.4	0	0	0	0	0	0
Rhithropanopeus harrisii	403.2	44.8	25.6	83.2	0	38.4	32	0	0
Membranipora sp	0	0	0	0	0	0	0	0	0
Chironomidae	83.2	0	0	12.8	6.4	6.4	6.4	0	0
Tanypodinae	0	0	0	0	0	0	0	0	0
Orthocladiinae	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	25.6	6.4	0	6.4	19.2	6.4	6.4	6.4	44.8
Coelotanypodini	0	0	0	0	0	0	0	0	0
Procladius sp.	0	0	0	0	0	0	0	0	6.4
Procladius(Holotanypus) sp.	0	25.6	6.4	19.2	0	6.4	0	6.4	19.2
Chironominae	0	0	0	0	0	0	0	0	0
Cryptochironomus sp.	6.4	0	6.4	0	0	0	0	0	0
Cricotopus sp.	102.4	0	0	12.8	0	0	0	0	0
Rehotanytarsus sp.	83.2	0	0	0	0	0	0	0	0
Mya arenaria	102.4	0	0	12.8	0	0	0	0	0
Copepoda	83.2	0	0	0	0	0	0	0	0
Callineates sapidus	0	0	0	0	0	0	0	0	0
Unknown balanus sp. 1	0	0	0	0	0	0	0	0	0
Cladocera	0	0	0	0	0	0	0	0	0
Morone americana	0	0	0	0	0	0	0	0	0
Anguilla rostrata	0	0	0	0	0	0	0	0	0
Unknown Spionidae sp. 3	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
Unknown sp. 1	0	38.4	0	0	0	0	0	0	0
Hydrozoa	25.6	0	0	0	0	12.8	6.4	0	0
Parahaustarius sp.	0	0	0	0	0	0	0	0	0
Amphicteis floridus	0	0	0	0	0	0	0	0	0
Platyhelminthes	0	0	0	0	0	0	0	0	0
Hypaniola grayi	0	0	0	0	0	0	0	0	0
Piscicolidae	12.8	0	0	0	0	0	0	0	0

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

Table 15: Average number of individuals collected per square meter at each station during the HMI Year 22 spring sampling, April 2004, stations MDE-24 to MDE-44.

Taxon	Station										
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36	MDE-42	MDE-43	MDE-44
Nemata	6.4	179.2	121.6	0	0	6.4	352	0	6.4	0	0
Carinoma tremophoros	0	12.8	0	12.8	0	0	0	0	6.4	0	44.8
Bivalvia	19.2	57.6	76.8	0	19.2	0	44.8	12.8	0	6.4	32
Macoma sp	0	0	0	0	0	0	0	0	0	0	0
Macoma balthica	0	0	0	0	0	0	12.8	0	64	32	6.4
Macoma mitchelli	0	0	0	0	0	0	0	0	0	0	0
Rangia cuneata	89.6	51.2	371.2	6.4	876.8	211.2	230.4	428.8	12.8	70.4	76.8
Mulinia lateralis	0	0	0	0	0	0	0	0	0	0	0
Ischadium recurvum	0	0	0	0	12.8	0	0	0	0	6.4	0
Mytilopsis leucophaeata	0	0	0	0	12.8	38.4	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	0	0	0	0	0	0	0	19.2	0	12.8	0
Spionidae	140.8	0	0	32	0	32	12.8	6.4	38.4	38.4	6.4
Marenzellaria viridis	4601.6	371.2	358.4	185.6	768	5536	761.6	1254.4	864	2982.4	3315.2
Streblospio benedicti	0	0	0	0	0	0	0	0	0	0	0
Nereididae	0	0	0	0	0	0	0	0	0	0	0
Neanthes succinea	0	0	0	12.8	0	0	0	0	0	0	6.4
Tubificidae	19.2	8825.6	134.4	6.4	19.2	870.4	166.4	19.2	665.6	768	448
Tubificidae w/o cap. setae	0	0	0	0	0	0	0	0	0	0	0
Tubificoides sp.	25.6	11795.2	620.8	115.2	89.6	2227.2	659.2	57.6	1388.8	473.6	704
Amphipoda	25.6	70.4	262.4	166.4	96	83.2	57.6	44.8	121.6	172.8	51.2
Gammaridea	0	0	0	6.4	0	0	0	0	0	19.2	0
Ameroculodes spp Complex	32	12.8	0	0	76.8	19.2	19.2	6.4	12.8	0	57.6
Leptocheirus plumulosus	281.6	601.6	710.4	448	185.6	51.2	576	160	652.8	192	198.4
Gammarus sp	76.8	0	0	0	6.4	44.8	0	0	0	230.4	12.8
Melitadae	0	0	0	0	0	0	0	0	0	0	0
Melita nitida	51.2	179.2	32	32	0	19.2	76.8	12.8	89.6	44.8	6.4
Corophiidae	0	0	12.8	0	6.4	12.8	0	0	0	0	0
Apocorophium sp.	0	0	0	0	0	0	0	0	0	12.8	0
Apocorophium lacustre	115.2	0	102.4	32	32	96	57.6	57.6	25.6	76.8	38.4
Isopoda	0	0	0	0	0	0	0	0	0	0	0
Cyathura polita	166.4	51.2	172.8	108.8	204.8	1318.4	172.8	230.4	249.6	403.2	646.4
Edotea triloba	76.8	0	121.6	0	0	134.4	25.6	64	12.8	0	57.6
Chiridotea almyra	25.6	0	0	0	12.8	25.6	0	0	0	0	0
Cirripedia	0	0	0	0	0	0	0	0	0	0	0
Balanus sp	0	0	0	0	0	0	0	0	0	0	0
Balanus improvisus	0	0	0	0	0	0	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**	**MDE-42**	**MDE-43**	**MDE-44**
Balanus subalbidus	0	0	0	0	0	0	0	0	0	0	0
Xanthidae	0	0	0	0	0	0	0	0	0	0	0
Rhithropanopeus Harrisii	0	0	0	0	0	70.4	0	0	0	6.4	0
Membranipora sp	0	0	0	0	0	0	0	0	0	0	0
Chironomidae	0	0	83.2	25.6	0	0	0	83.2	0	6.4	0
Tanypodinae	0	0	0	0	0	0	0	0	0	0	0
Orthocladiinae	0	0	0	0	12.8	0	0	0	0	0	0
Coelotanypus sp.	0	134.4	371.2	224	0	6.4	83.2	76.8	19.2	0	0
Coelotanypodini	0	0	0	0	0	0	0	0	0	0	0
Procladius sp.	0	0	0	6.4	0	0	0	51.2	0	0	6.4
Procladius(Holotanypus) sp.	0	32	44.8	25.6	0	0	44.8	140.8	19.2	0	0
Chironominae	0	6.4	6.4	0	0	0	0	0	0	0	0
Cryptochironomus sp.	0	0	0	0	0	0	0	12.8	0	0	0
Cricotopus sp.	0	0	0	0	0	0	0	0	0	0	0
Rehotanytarsus sp.	0	0	0	0	0	6.4	0	0	0	0	0
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0
Copepoda	0	0	0	0	0	6.4	0	0	0	0	0
Callineates sapidus	0	0	0	0	0	0	0	0	0	0	0
Unknown balanus sp. 1	0	0	0	0	0	0	0	0	0	0	0
Cladocera	0	0	0	0	0	0	0	0	0	0	0
Morone americana	0	0	0	0	0	0	0	0	0	0	0
Anguilla rostrata	0	0	0	0	0	0	0	0	0	0	0
Unknown Spionidae sp. 3	0	0	0	0	0	0	0	0	0	0	0
Hemiptera	0	0	0	0	0	0	0	0	0	0	0
Ostracoda	0	0	0	0	0	0	0	0	0	0	0
Diptera	0	0	0	0	0	0	0	0	0	0	0
Unknown sp. 1	0	0	0	0	0	0	0	0	0	0	0
Hydrozoa	6.4	0	0	0	0	0	0	0	0	0	0
Parahaustarius sp.	12.8	0	0	0	0	0	0	0	0	0	0
Amphicteis floridus	0	6.4	0	0	0	0	0	0	0	0	0
Platyhelminthes	0	0	6.4	0	0	0	0	0	0	0	0
Hypaniola grayi	0	0	6.4	0	0	0	0	0	0	0	0
Piscicolidae	0	0	0	0	0	0	0	0	0	0	0

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

Taxa Abundance

Total abundance was higher in the spring (April 2004) than in the late summer (September 2003) due to seasonal recruitment in April 2004 (see Figure 13). In September 2003, total abundance in the vicinity of HMI ranged from 6.4 to 17139.2 organisms per square meter (individuals/m^2) and averaged 1314.56 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 2003 abundance was found at the Back River/Hawk Cove station MDE-27, due primarily to large numbers of the bivalve *Rangia cuneata* and members of the oligochaete family Tubificidae. The lowest abundance in September 2003 was found at the Back River/Hawk Cove station MDE-30 (Table 10). Average total abundance was very similar between Reference stations and Nearfield stations in September 2003 (2530.1 individuals/m^2 and 2727.7individuals/m^2 respectively), while total abundance was highest at the Back River/Hawk Cove stations (6054.4 individuals/m^2).

In April 2004, total abundance ranged from 6.4 to 58,976 organisms per meter squared and averaged 1933.07 individuals/m^2. The station with the highest abundance was the Back River/ Hawk Cove station MDE-27, 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 South Cell stations (5024 individuals/m^2) and highest at the Back River/Hawk Cove stations (8789.3 individuals/m^2), with the Reference (5314.1 individuals/m^2), with Nearfield stations (6221.4 individuals/m^2) stations falling in between.

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 22, total infaunal abundance was similar to total abundance, accounting for ≥75% of all organisms at most stations during both seasons. The only exceptions were Nearfield stations MDE-01 (67%), MDE-7 (71%), MDE-9 (14%), MDE-33 (45%), and MDE-34 (73%) in September 2003, and Nearfield station MDE-1 (59%) in April 2004. Epi-faunal taxa dominated abundance at Nearfield stations MDE-9 and MDE-33 in September 2003.

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 highest in the summer, when recruitment decreases and predation increases 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 22 are presented in Tables 10 and 11. On average, diversity was moderately higher in September 2003 than in April 2004. These results are different from Year 21, where diversity values were markedly different between seasons.

The Shannon-Wiener diversity Index (SWDI) values in Year 22 averaged 2.56 ± 0.43 in September 2003 and 2.1 ± 0.58 in April 2004. The lowest diversity value in September 2003 occurred at Back River/Hawk Cove station MDE-27 (1.30). This was due to the predominance of the oligochaete worms of the family Tubificidae, which accounted for 79% of total infaunal abundance at this station. The highest September 2003 diversity value (2.99) occurred at Nearfield stations MDE-24, and MDE-1, and at Reference station MDE-36. This is similar to September 2002, where the highest diversity value also occurred at Nearfield station MDE-24. The lowest diversity value in April 2004 occurred at Nearfield station MDE-24 (1.08); this was due to the large percentage of the polychaete worm *M. viridis,* which accounted for 84% of total infaunal abundance at this station. The highest April 2004 diversity value occurred at Nearfield station MDE-1 (2.96).

For the most part, Nearfield stations had diversity values similar to Reference stations in September 2003. However, in April 2004, diversity did not very much among station types, due to the recruitment of *M. viridis*.

Pollution Sensitive Taxa Abundance

There were two taxa found during Year 22 benthic monitoring that are designated as "pollution-sensitive" according to Alden et al. (2002). These were the polychaete worm *M. viridis* and the isopod crustacean *C. almyra.* The calculation of the PSTA was a ratio of the relative abundance to total infaunal abundance. In Year 22 the oligohaline salinity regime resulted in a change of the PSTA taxa from Year 21, when low mesohaline conditions prevailed.

In September 2003, pollution-sensitive taxa abundance (PSTA) ranged from 0% at MDE-13 and MDE-19 (Nearfield stations) to 24.3% at MDE-3 (Nearfield station) (Table 10 and Figure 15). The average PSTA for September 2003 was 6.5%. In September 2003, the average lowest PSTA was 2.7% at the Back River/Hawk Cove stations followed by the Reference stations at 2.8%. The highest average PSTA occurred at the Nearfield stations with an average PSTA of 11%.

In April 2004, the lowest PSTA was 11.7% at MDE-28 (Back River/Hawk Cove station) and the highest was 84.4% at MDE-24 (Nearfield station) (Table 11 and Figure 15). The average PSTA in April 2003 was 47.5%. The Nearfield stations had the highest PSTA at 59.5%, followed by the South Cell baseline stations at 45.3% and the Reference stations at 44.1%; the Back River/Hawk Cove stations had the lowest PSTA of 9.1%. Historically, the PSTAs in April are usually higher than September, and in year 22 this was true for all stations sampled.

Pollution Indicative Taxa Abundance

Ten taxa found during Year 22 benthic monitoring were designated as “pollution-indicative” according to Alden et al. (2002). These were the Chironomids *Coelotanypus* sp., *Chironomus* sp., Glyptotendipes sp., *Procladius* sp., *Tanypus* sp., the polychaete worms *S. benedicti, H. filiformis, N. succinea, P. cornuta,* the Arthropod *L. plumulosus,* and the oligochaete worms of the family Tubificidae. Relative abundance of these taxa was calculated as a proportion of total infaunal abundance. As with the PSTA, the PITA changed due to the change in salinity regime; however, there were no major changes compared to Year 21.

In September 2003, the relative abundance of pollution-indicative taxa (PITA) ranged from 7.1% at MDE-33 (Nearfield station) to 71.8% at MDE-7 (Nearfield station) (Table 10, Figure 16). The average PITA for September 2003 was 34.8%. In September 2003, the Nearfield stations had an average PITA of 30.6%, the Reference stations had an average of 22.6 %, and the Back River/Hawk Cove stations had average PITA of 62.4%.

In April 2004, the PITA averaged 22.1% for Nearfield stations, 36.0% for Reference stations, 73.7% for Back River/Hawk Cove stations, and 39.4% at South Cell baseline monitoring stations. In April 2004 the PITA ranged from 6.0% at MDE-24 (Nearfield station), to 97.4% at MDE-27 (Back River/Hawk Cove station) (Table 11, Figure 16). The average PITA was 34.5%.

Clam Length Frequency Distribution

In September 2003, the greatest average abundance of *R. cuneata* occurred at the Nearfield stations, followed by the Reference stations, and then the Back River/Hawk Cove stations. The greatest abundance of *R. cuneata* was found in the 1-5 mm size class. In April 2004, the greatest average abundance of *R. cuneata* occurred at the Nearfield stations, followed by the Reference and Back River/Hawk Cove stations, with lowest abundance occurring at the South Cell baseline monitoring stations. The greatest abundance of *R. cuneata* was found in the 1 mm size class.

The greatest average abundance of *M. mitchelli* in September 2003 was found at the Reference stations, followed by the Nearfield and then the Back River/Hawk Cove stations, which had the same average abundance. The strongest recruitment for all station types was in the 13-14 mm size class range. No M. mitchelli were collected in April 2004. This indicates recruitment of this species was likely minimal in the Spring of 2004.

In September 2003 *M. balthica* had the greatest average abundance at the Reference stations, followed by the Nearfield and then the Back River/Hawk Cove stations. The greatest abundance of *M. balthica* was found in the in the 19-20 mm size class. In April 2004, *M. balthica* had the greatest average abundance the Reference stations, followed by the South Cell and Nearfield stations, with lowest abundance occurring at the Back River/Hawk

Cove stations. For all the stations in April 2004 *M. balthica* had its greatest abundance in the 20-21 mm size class. All size class data for clams is available in the *Year 22 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 2003 data only (see Methods and Materials). Six metrics were used to calculate the B-IBI for these stations under the oligohaline classification (0.5 – 5.0 ppt). These metrics were total infaunal abundance, tolerance score, Tanypodinae to Chironomidae abundance ratio, abundance of carnivores and omnivores, 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 stations studied during the Year 22 late summer sampling were compared to this benchmark.

Overall, the Benthic Index of Biotic Integrity (B-IBI) scores improved or remained the same when compared to Year 21 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 10 stations and decreased at 7 stations. Sixteen of the seventeen stations exceeded the benchmark criteria of 3.0, only MDE-27 (B-IBI = 2.5) failed to meet this benchmark. (Table 10, Figure 17). In Year 21, 15 stations met the benchmark and 2 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 also failed to meet the benchmark in Year 20.

The highest B-IBI scores were at the Reference stations, which had an average B-IBI score of 3.9, followed by the Nearfield stations that had an average score of 3.7. The Back River/Hawk Cove stations had the lowest average B-IBI score of 3.3. 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 7 years, the average B-IBI scores of the Back River/Hawk Cove stations have been lower than the average Nearfield and Reference stations scores (Figure 18).

Statistical Analysis

Cluster analysis was 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 19 and 20, the stations with faunal similarity (based on a Euclidean distance matrix comprised of station infaunal abundance values for all 17 stations in the fall and all 20 stations in the spring) 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 sediment type (Pfitzenmeyer, 1985; Duguay et al, 1999). Thus, any unusual grouping of stations tends to suggest changes are occurring due to factors other than sediment 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 2003 is presented in Figure 19, indicating no clear-cut pattern of faunal response to sediment type. 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 most striking result of the Fall Cluster Analysis was the uniqueness of the last three stations to join the dendrogram: MDE-35, a Nearfield Silt/Clay station, MDE-7, a Nearfield Shell station, and MDE-27, a Back River Silt/Clay station. As in previous years for which a cluster analysis was performed, Back River/Hawk Cove station MDE-27 had the most aberrant fauna of all the stations.

The cluster analysis for April 2004 is presented in Figure 20. In this dendrogram there are two distinct groupings of stations, one moderately aberrant station (MDE-1), and one extremely aberrant station (MDE-27). One grouping consisted of ten stations, nine that had Silt/Clay sediment. There were seven Nearfield stations in this group: MDE-3, MDE-17, MDE-24, MDE-16, MDE-7, MDE-34, and MDE-9. The three remaining stations were two South Cell baseline (MDE-43 and MDE-44) and one Reference station (MDE-13). The second distinct grouping consists of eight stations, seven that had Silt/Clay sediment. There were three Nearfield stations in this group: MDE-19, MDE-33, and MDE-35. The two remaining Reference stations were also in this group (MDE-36 and MDE-22). The remaining three stations in this group were Back River stations (MDE-28 and MDE-30) and Baseline station MDE-42. The faunal relationship to sediment type was not evident in this dendrogram, because all but three of the stations in April 2004 were Silt/Clay. Overall, the Nearfield, Reference, and Baseline stations were well mixed throughout the dendrogram and show no distinct grouping by station type as has been shown in previous monitoring years. The Back River/ Hawk Cove stations were absent from the ten-station grouping. The cluster analyses for September and April indicated one unusually isolated station (MDE-27), which suggests that the area is strongly affected by the localized conditions existing in Back River, and is not a result of any influence from the Hart Miller Island outfall.

Friedman’s nonparametric test was used to determine if a significant difference could be detected among the three station types (Nearfield, Back River, and Reference) in the fall sampling, and the four station types (Nearfield, Back River, Reference, and South Cell Baseline) in the spring sampling, for the average abundance of the 10 most abundant infaunal species. The test indicated that there were no significant differences in the 10 most abundant infaunal species between Nearfield, Reference and Back River/Hawk Cove for September 2003 data (9< 0.67); however, for the April 2004 data the Friedman’s test results indicated that there were significant differences (p< 0.19) between the station types for the 10 most abundant infaunal species (Tables 16 and 17). These results for the spring may have been due to the addition of the three Baseline stations. Since these three stations are influenced by HMI’s South Cell, it will be important to see if this pattern continues in subsequent sampling years. The Baseline stations, particularly MDE-44 may be affected by the boat loading and unloading activities occurring at the nearby HMI dock. Therefore, the significant infaunal differences at the Baseline stations may not be due to adverse effects from the HMI outfall discharges, but only an artifact of these boat activities.

Table 16: Friedman Analysis of Variance for September 2003’s 10 most abundant species among; Back River/Hawk Cove, Nearfield, and Reference stations. ANOVA Chi Sqr. (N = 10, df = 2) = 0.80, P < 0.67.

Station Type	Average Rank	Sum of Ranks	Mean	Std. Dev.
Nearfield	2.20	22.00	203.17	203.10
Reference	2.00	20.00	158.93	170.80
Back River	1.80	18.00	533.97	1163.88

Table 17: Friedman Analysis of Variance for April, 2004’s 10 most abundant species among; Back River/Hawk Cove, Nearfield, Reference stations, and Baseline Monitoring Stations. ANOVA Chi Sqr. (N = 10, df = 3) = 4.76, P < 0.19.

Station Type	Average rank	Sum of ranks	Mean	Std. Dev
Nearfield	2.70	27.00	635.93	1189.83
Reference	2.90	29.00	504.96	738.06
Back River	2.65	26.50	868.05	1467.55
South Cell Baseline	1.75	17.50	480.43	732.70

CONCLUSIONS AND RECOMMENDATIONS

The condition of the benthic macroinvertebrate community for Year 22, 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 21 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 10 stations and decreased at 7 stations. Sixteen of the seventeen stations exceeded the benchmark criteria of 3.0, one station failed to meet the benchmark. In general the statistical analyses indicated that there were no significant differences in infauna among the Reference, Nearfield, and Back River/Hawk Cove stations. However, the addition of the three South Cell Baseline stations may have yielded the significant results for the spring Friedman's test. It will be important to continue to monitor the Baseline stations because they may indicate effects of the South Cell restoration activities on the benthos. The cluster analyses indicated some distinct clustering of stations, but no pattern for sediment type or station type was evident. 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 to 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 to be certain that changes in site management do not have adverse effects on the surrounding biological community.

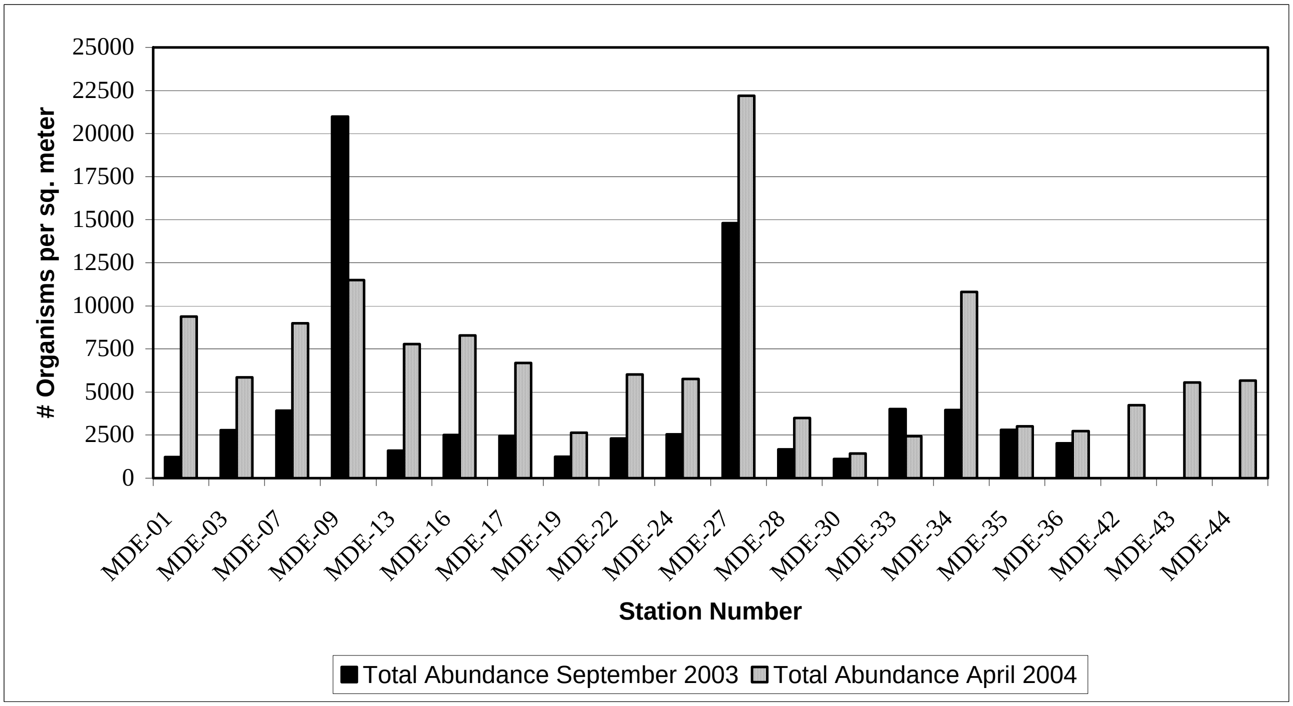

Figure 13: Total average abundance of infauna and epifauna taxa collected at each HMI station in year 22, September 2003 and April 2004.

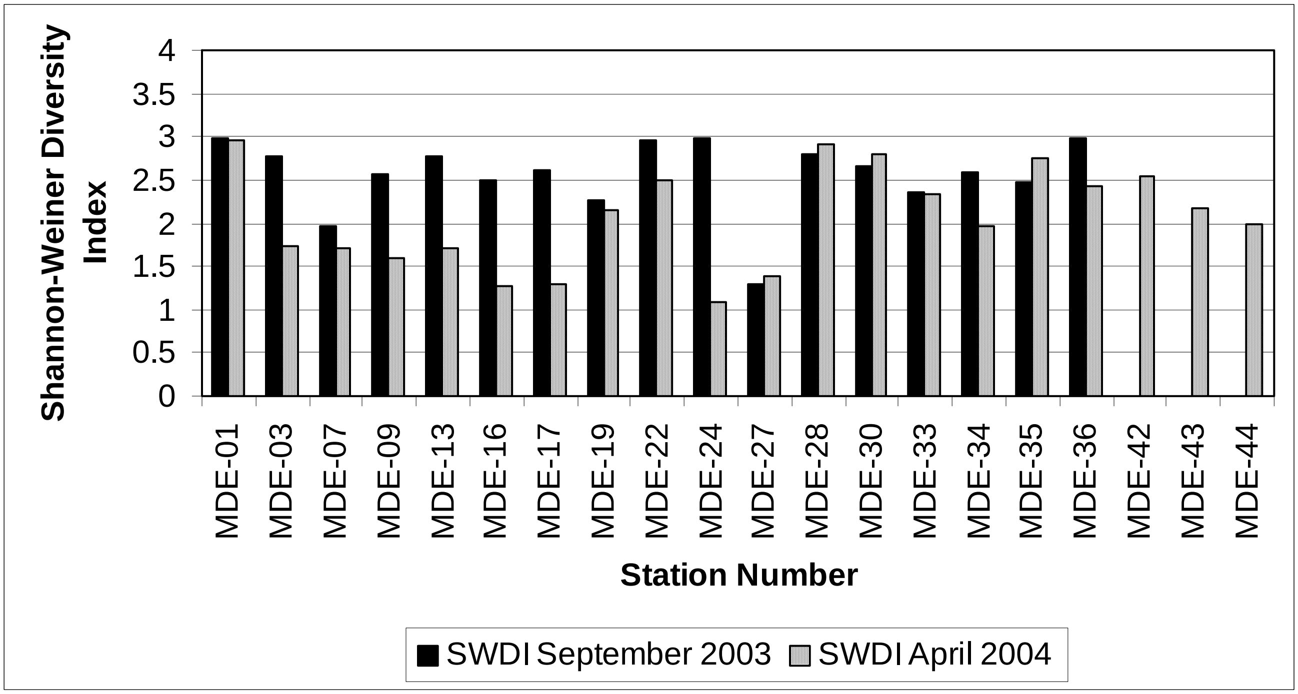

Figure 14: Shannon-Weiner Diversity Index (SWDI), HMI year 22, September 2003 and April 2004.

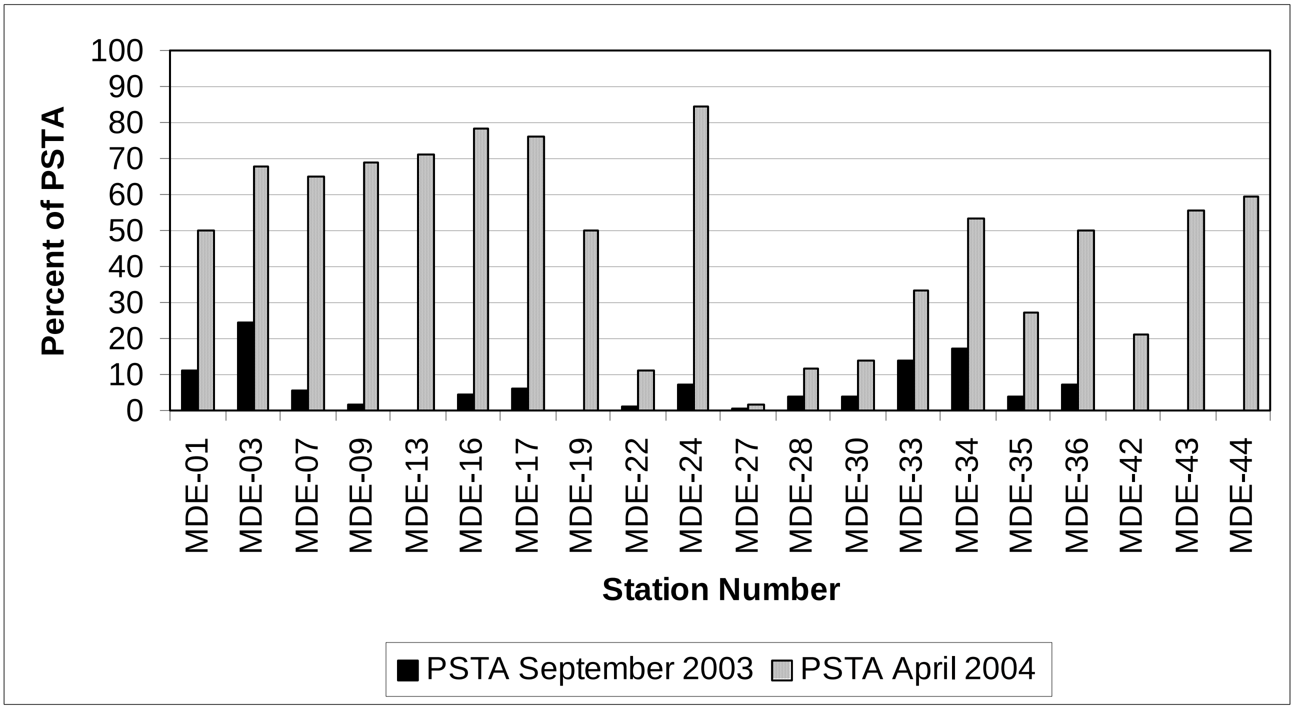

Figure 15: Percent abundance comprised of pollution sensitive taxa abundance (PSTA), HMI year 22 September 2003 and April 2004.

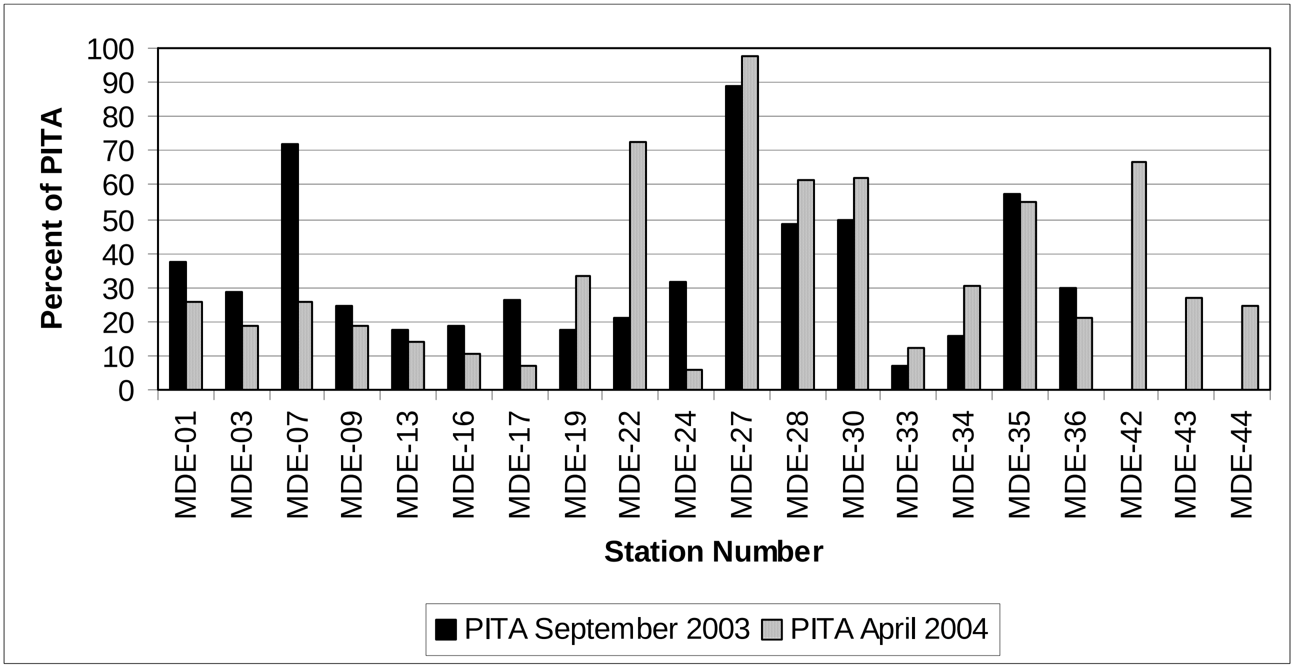

Figure 16: Percent abundance comprised of pollution indicative species (PITA), HMI year 22 September 2003 and April 2004.

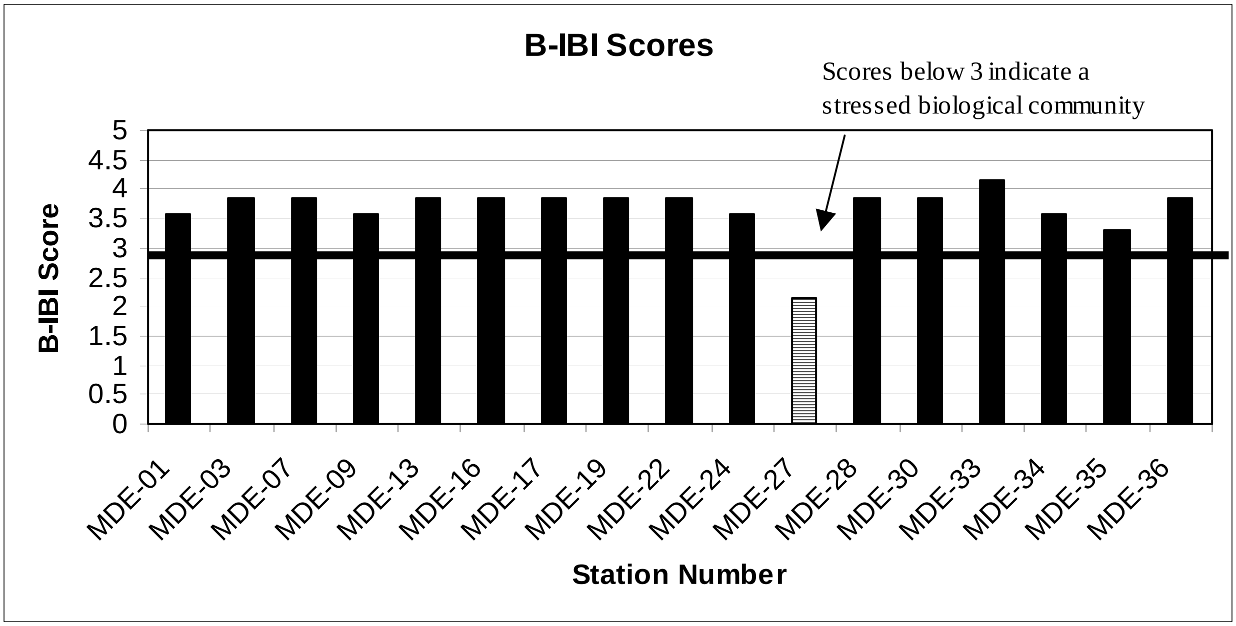

Figure 17: B-IBI Scores for all stations in September 2003.

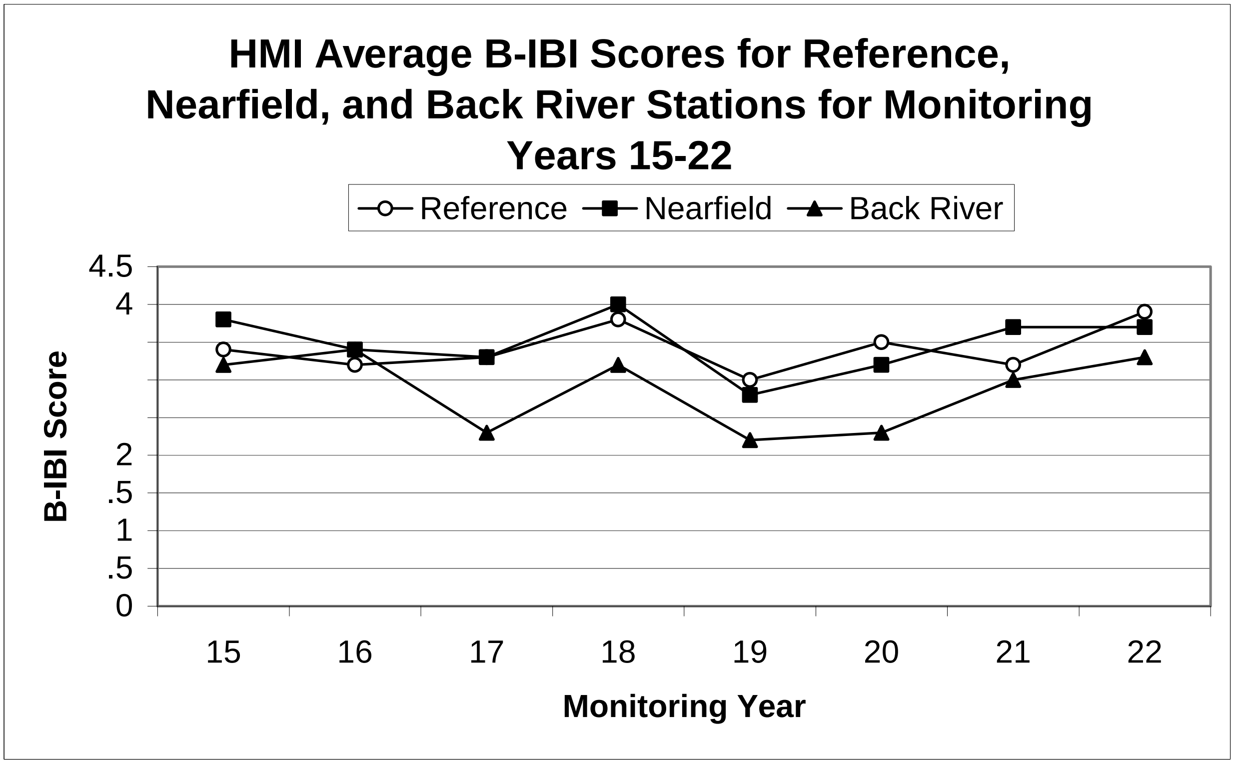

Figure 18: Average B-IBI Scores at HMI for Monitoring Years 15-22.

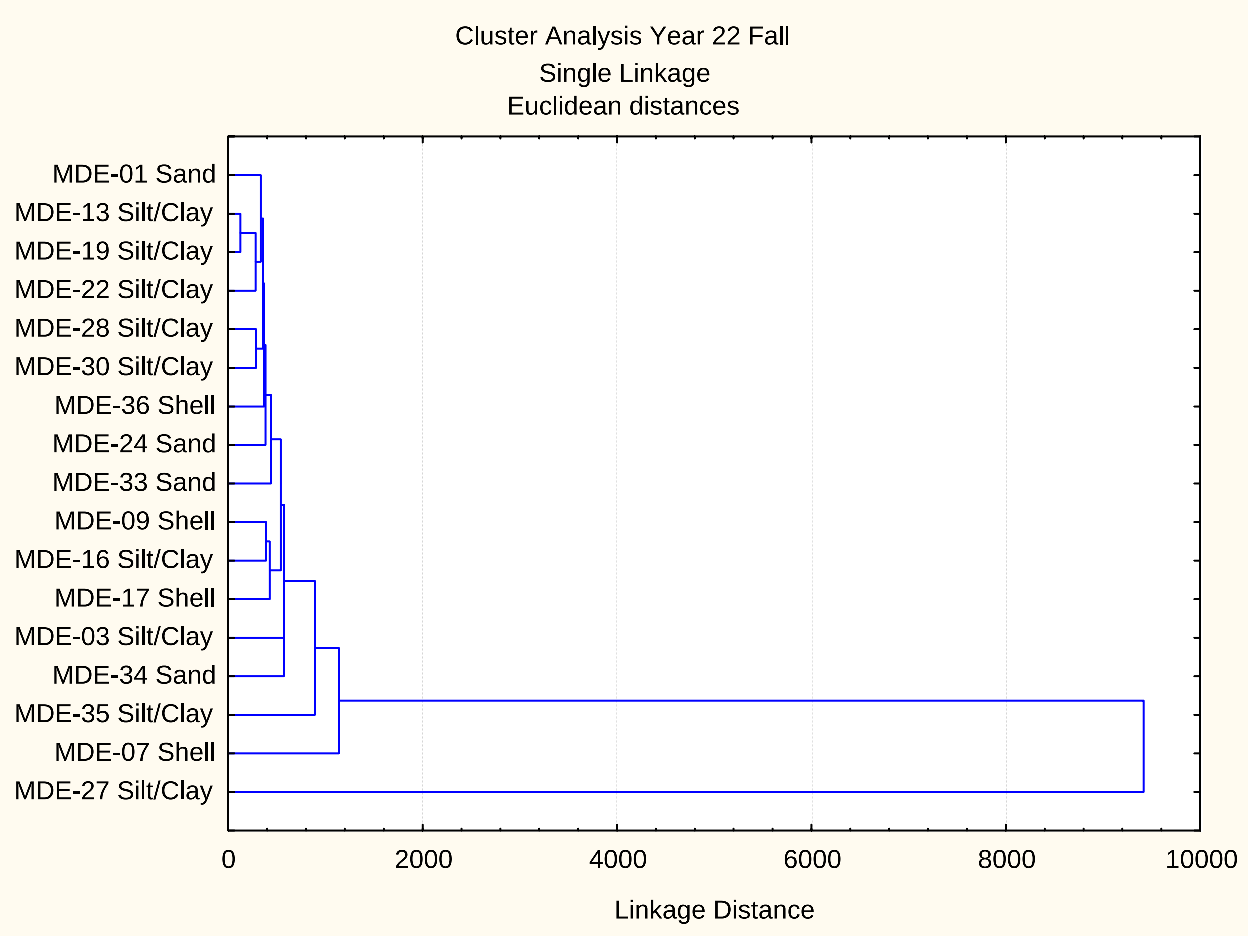

Figure 19: Cluster analysis based on Euclidean distance matrix of infaunal abundances of all HMI stations, year 22 September 2003.

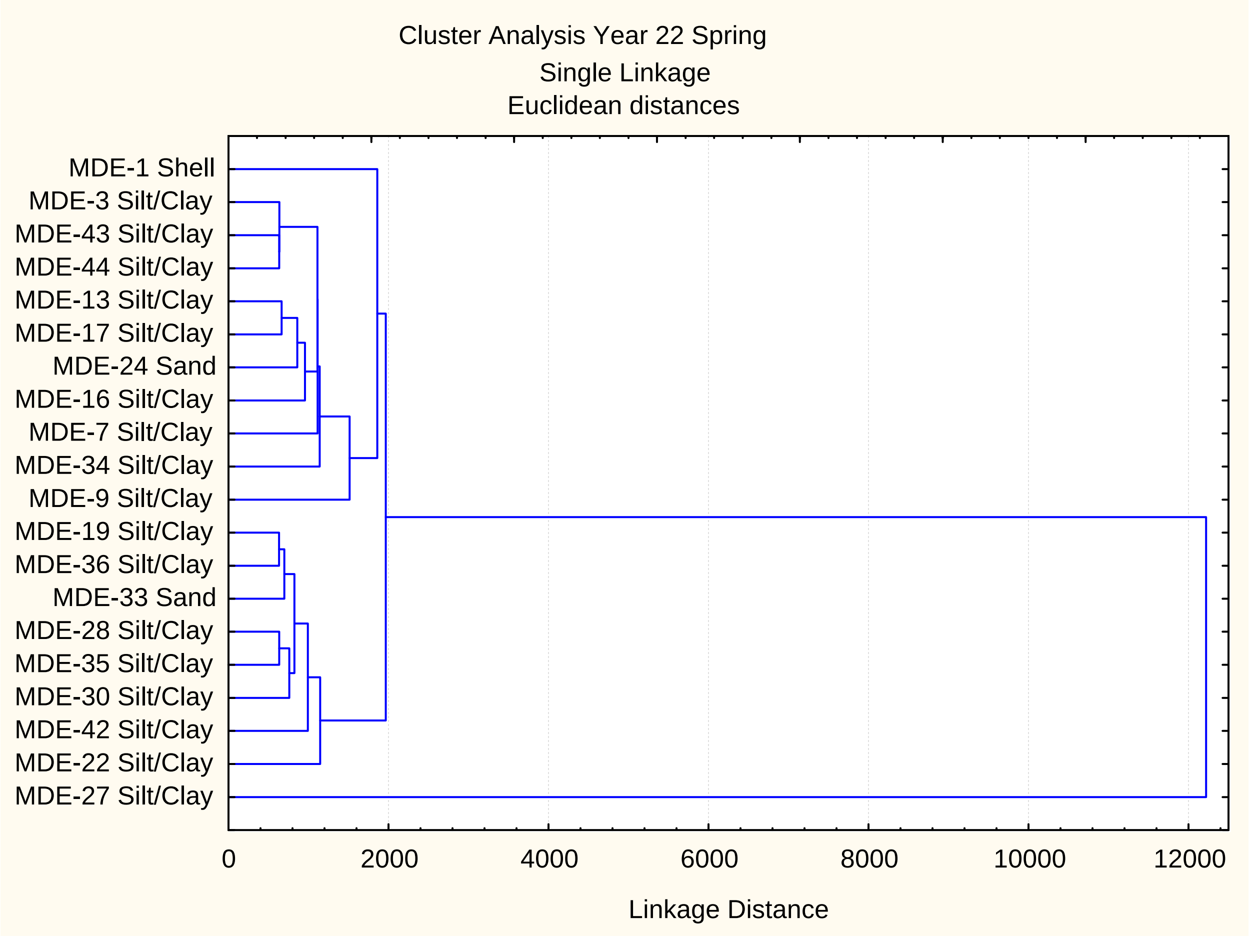

Figure 20: Cluster analysis based on Euclidean distance matrix of infaunal abundances of all HMI stations, year 22 April 2004.

CHAPTER 4: ANALYTICAL SERVICES (PROJECT IV)
(September 2003 – September 2004)

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OBJECTIVES

The goals of the project in 2003-2004 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 these 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 22nd year of exterior monitoring, and to document any seasonal changes. Specific objectives were:

1. In the fall of 2003 and spring of 2004, collect clams and worms where available and associated sediment for analyses of trace metals, PCB's and PAH's; and,

2. To determine the concentrations of target trace elements in surface sediments around HMI collected by MGS in September 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 22 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 22 Data Report*.

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 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^oC. 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. 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 metals are similar to those described in detail in Dalal et al. (1999). 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.

Worm samples were digested by a microwave digestion technique (Sheppard et al. 1994). Approximately 1 gram of worm tissue was placed in a quartz digestion cell with 2 ml of concentrated ultra pure nitric acid. The quartz vessels were sealed and digested at 140^oC at 580 kPa. The samples were then diluted to approximately 15 ml with ultra pure water. Samples where further diluted and analyzed by ICP-MS for select trace metals.

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, clam and worm 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 Sediment

Concentrations of As, Se, Cd and Pb in the sediment collected around HMI in Year 22 (2003-2004) are similar to previous years (Figure 21 and 22) and not substantially different than the concentrations found elsewhere in the Chesapeake Bay or in marine sediments. Typical As concentrations in Chesapeake Bay sediment are 20 ug g^{-1} dry weight, which are similar to the mean HMI concentration. Concentrations of Cd in marine sediments range from 0.03 to 1 ug g^{-1} dry weight, which are similar to the 2003 concentrations (Figure 22). Concentrations of Pb in Chesapeake Bay sediment recorded by Di Giulio and Scanlon (1985) ranged from 1-134 ug g^{-1} dry weight. Concentrations around HMI in 2003 were all less than 60 ug g^{-1} dry weight, placing them well within the historical range. Silver concentrations were much lower throughout the region in 2003 than in past years (Figure 23). Silver contamination is often associated with general urban pollution, having origins in sewage treatment plants (Purcell and Peters, 1998). Concentrations of Ag in sediment observed in 1999 and 2000 remain anomalous relative to other years.

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 24). Concentrations of T-Hg in the main stem of the Chesapeake Bay range from 0.2 to 250 ng g^{-1} dry weight and concentrations of MeHg range from 0.01 to 2.2 ng g^{-1} dry weight (Figure 24) (Heyes et al. in Press). 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 24).

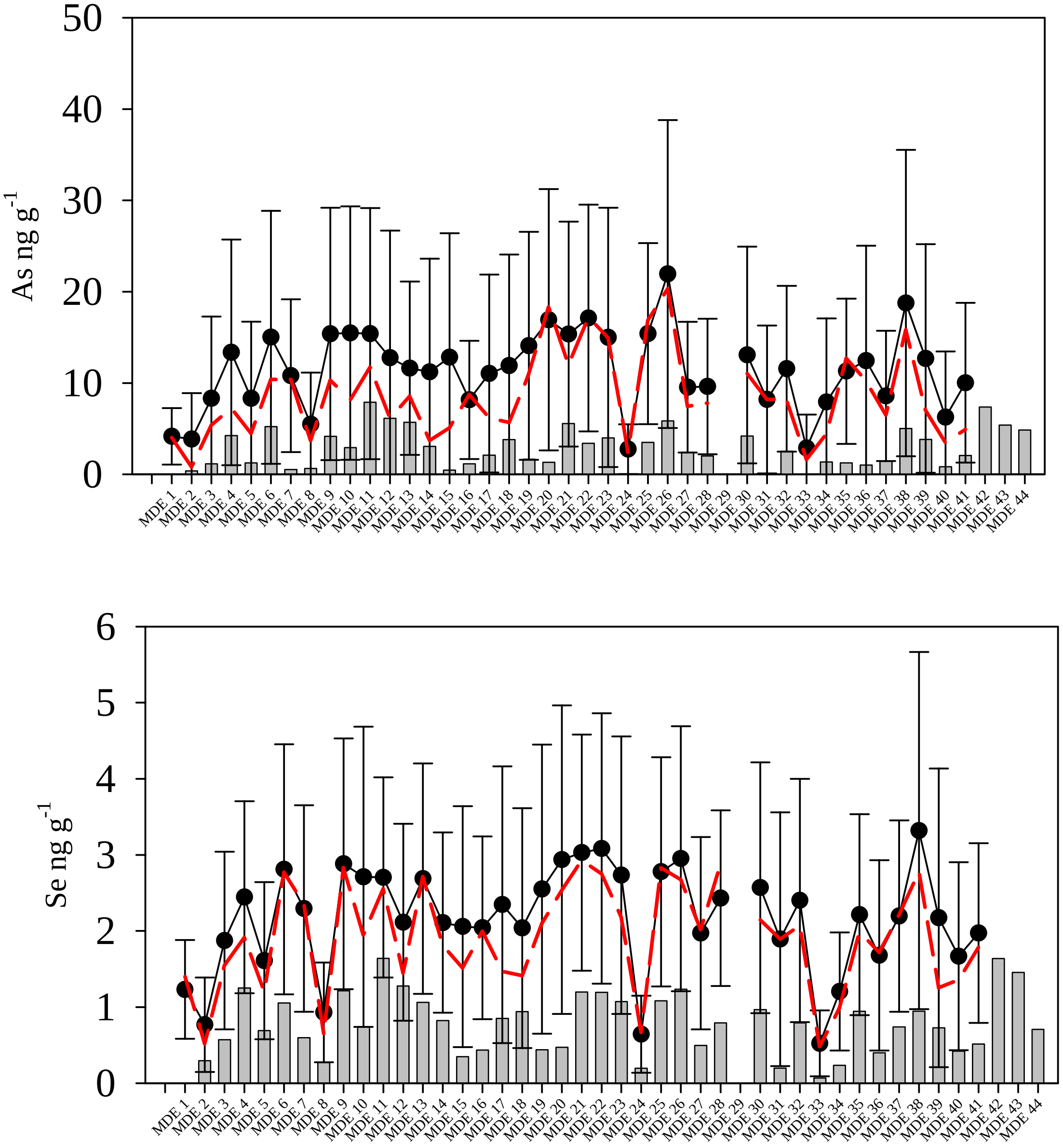

Figure 21: Arsenic (As) and selenium (Se) concentrations in sediment, expressed in dry weight, from 2003 (bars) and the 1998-2002 mean (circles) with standard deviation (error bars) and the 1998-2002 median (dashed line).

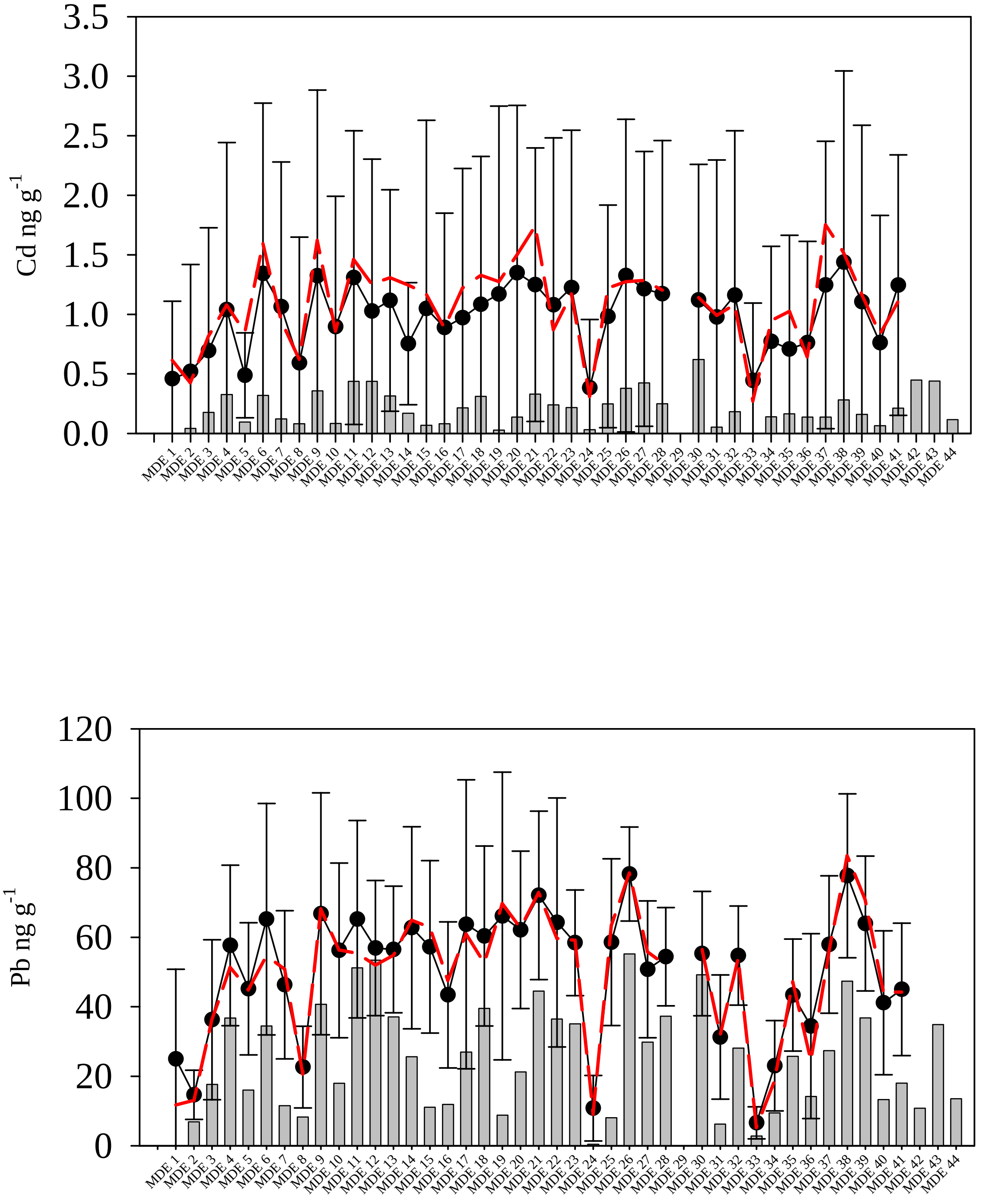

Figure 22: Cadmium (Cd) and lead (Pb) concentrations in sediment, expressed as dry weight, from 2003 (bars) and the 1998-2002 mean (circles) with standard deviation (error bars) and the 1998-2002 median (dashed line).

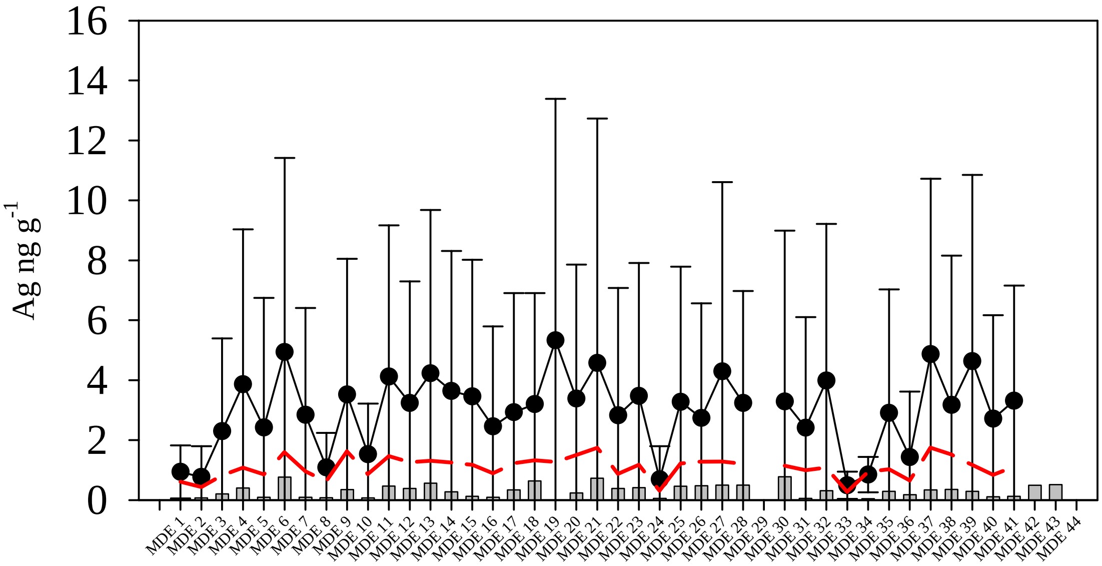

Figure 23: Silver (Ag) concentrations in sediment from 2003 (bars), expressed as dry wt, and the 1998-2002 mean (circles) with standard deviation (error bars) and the 1998-2002 median (dashed line).

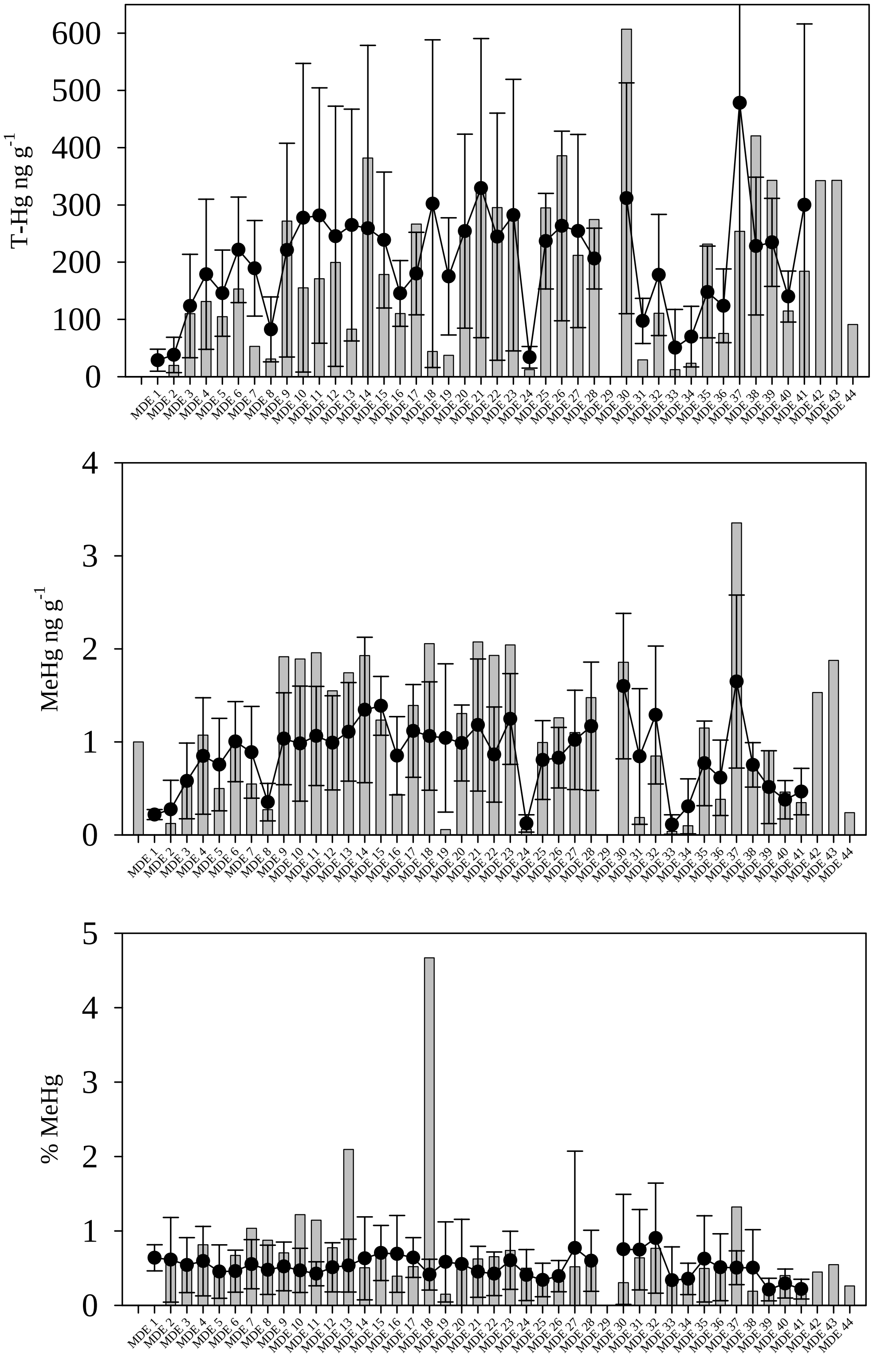

Figure 24: Mercury (Hg) and methylmercury (MeHg) concentrations, expressed as dry weight, and percent Hg as MeHg, in 2003 sediment (bars) and the 1998-2002 mean (circles) with standard deviation (error bars).

Metals in Clams

Concentrations of the metals As, Se, Ag, Cd, and Pb in the clam *Rangia* have remained consistent between years 17 and 22 (Figure 25). The concentrations of both T-Hg and MeHg in clams collected in year 22 are considerably lower than the average of the previous years (figure 26). This is despite T-Hg and MeHg concentrations in sediment being normal to slightly above the mean of the previous years. Most metal concentrations were low and varied little among the sites. Concentrations of As, Se and Pb in the biota were not any higher than the sediment concentrations on a per gram wet weight basis (Figure 27). This suggests little if any bioaccumulation of these metals from the sediment has occurred. Concentrations of Ag are much higher in the clams, often by two orders of magnitude, indicating substantial bioaccumulation, which will be discussed later. Silver has many sources in the watershed and is 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 2003 and this was also reflected in the lower concentrations in clams. Concentrations of Cd are 10 to 50 times higher in clams than in the sediment. Bioaccumulation of Cd is common in clams, which accumulate Cd from both the dissolved phase and particles. Particles, be they derived from the local sediment or transported from elsewhere in the Bay are most likely source of Cd (Griscom et al. 2002). Unlike Ag, Cd concentrations in clams did not decrease despite lower than average Cd concentrations in sediment. Concentrations of Hg and MeHg are higher in sediment than clams on a per gram wet weight basis (Figure 27).

Metals in Worms

Metal concentrations were measured in the polychaetes (worms) *nereis* and *M. viridis* that were obtained from 5 and 3 sites, respectively. The concentrations of metals in worms were similar among the sites, with a few anomalies. Concentrations of As, Pb and Hg were much lower in worms than sediment when compared on a wet weight basis (Figure 27) but concentrations of Cd, Ag and Se where similar. The worms are likely bioaccumulating Cd, Ag and Se. The concentrations of metals observed in *nereis* around HMI are similar to what has been observed in other estuaries. Arsenic concentrations are typically less than 10 ug g^{-1} and Se concentrations are between 1 and 10 ug g^{-1} (Wang et al. 1999 and Baeyens et al. 2005). Concentrations of Cd and Ag are more variable in worms, often exceeding 10 ug g^{-1}. No useful data has been found with which to compare the Hg or Pb data from HMI.

In comparing the three sites (HMI 3, 9 and 17) where we were able to collect clams and worms, there is no consistent pattern of response between worms and clams and any single metal. For example the clams at HMI 9 have very high concentrations of Ag compared to the worms, but this is not the case at the other two sites.

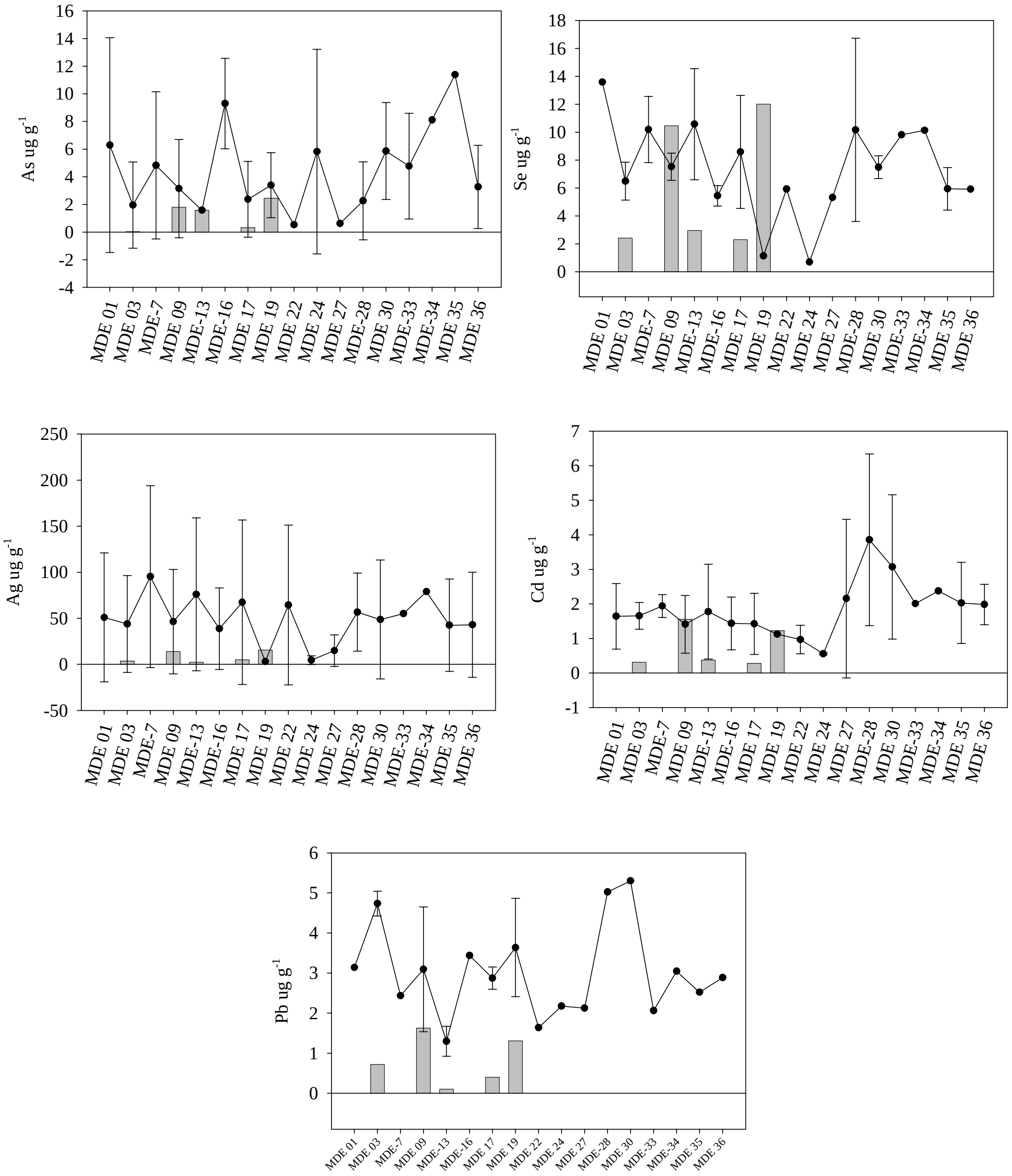

Figure 25: Concentrations of arsenic (As), selenium (Se), silver (Ag), cadmium (Cd) and lead (Pb) in the clams, expressed as dry weight, collected in 2003 (bars) and the 1998-2002 mean (circles) with standard deviation (error bars).

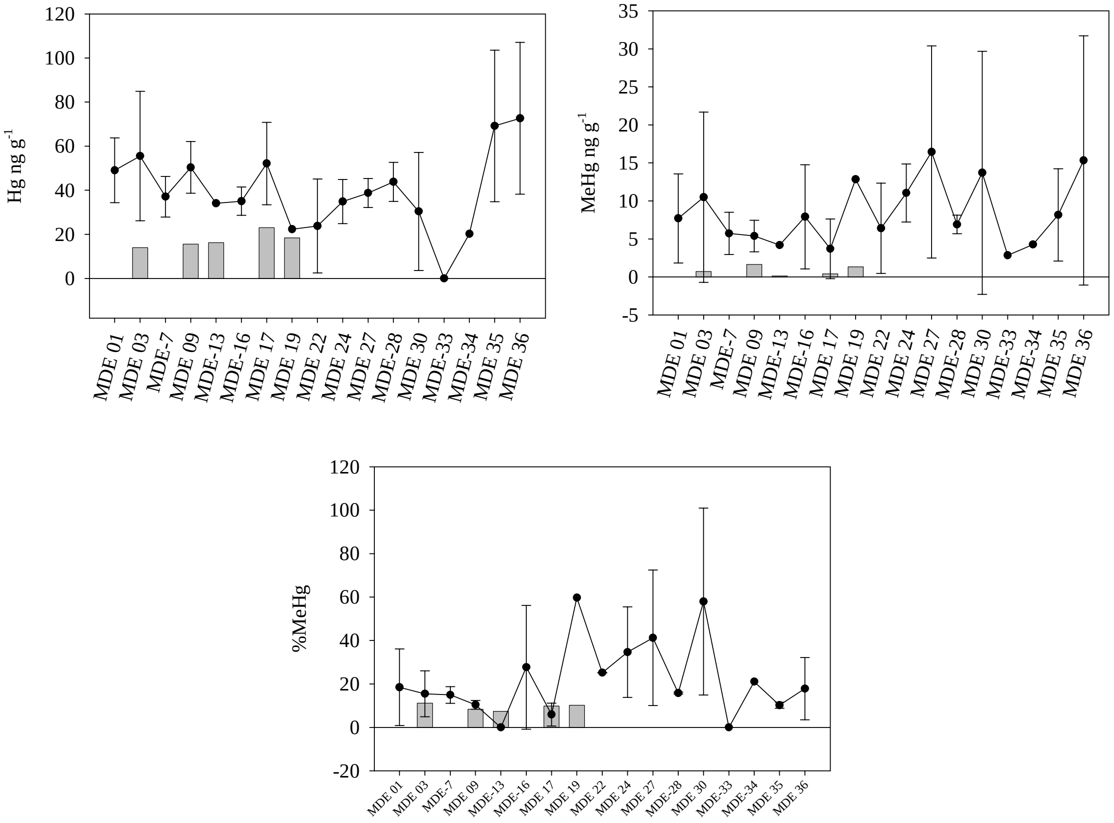

Figure 26: Mercury (Hg) and methylmercury (MeHg) concentrations, expressed on a dry weight basis, and percent Hg and MeHg in clams, collected in 2003 (bars) and the 1998-2002 mean (circles) with standard deviation (error bars).

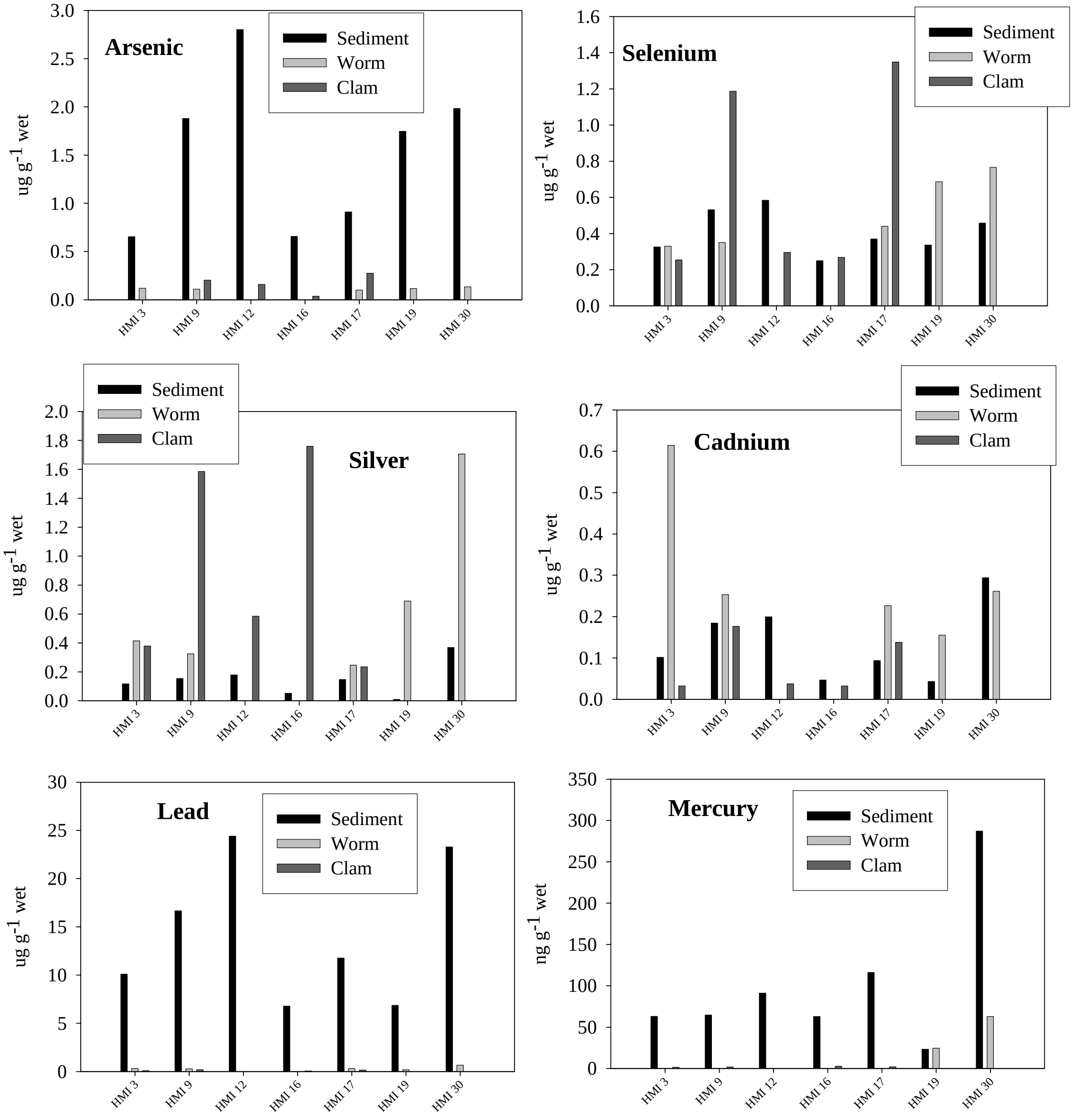

Figure 27: Metal concentrations in sediment, clams and worms, expressed in per gram wet weight, at sites around HMI in 2003.

Metal Bioaccumulation Factors

Difference in the proportions of water between sediments and the organisms means that an evaluation of bioaccumulation factors (BAF) must be done on a dry weight basis. The wet/dry ratios for clams and worms are on the order of 10 and 20 respectively whereas the ratio for sediments is closer to 2. The BAF's for trace metals are summarized in Figure 28. The BAF for As is around 1 for both clams and worms, indicating bioaccumulation does not occur. The BAF for Pb is less than 1, indicating exclusion of Pb by the organism. The BAF's for Hg and MeHg range from less than 1 to 10. Thus for Hg and As, bioaccumulation is minimal. The BAF for Se and Cd in clams is approximately 10, where as the BAF for Se and Cd in worms range from 10 to 100 indicating significant enrichment. The most significant enrichment observed was with Ag, which has been observed elsewhere (Hoo et al. 2004). The trend in BAF's is consistent with those of previous years, the exception being Ag. The high BAF's observed in 2003 are likely the result of the low Ag concentrations observed in sediment, as the Ag concentrations in clams are typical of all years except 1999 and 2000. There is substantial debate in the literature regarding the source and bioavailability of silver. The surface water, deposited particles, porewater and deeper sediment have all been identified as potential sources. Freshly deposited particles appear to be the most likely source, which is the food of choice for both clams and worms. Of all the metals Ag appears most variable but it is also the metal most likely to have a pulsed urban source.

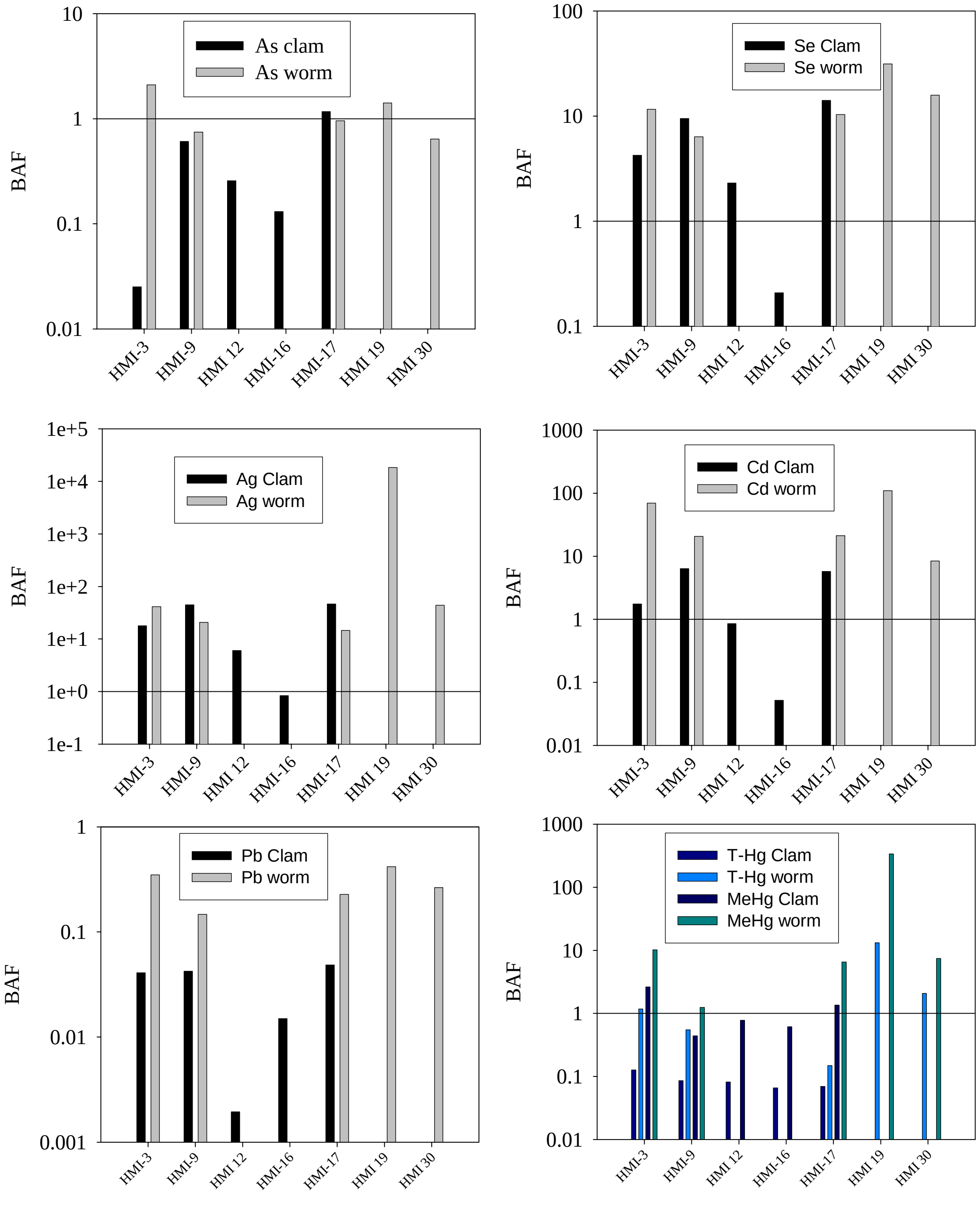

Figure 28: Bioaccumulation factors BAF's in clams and worms from 2003-04.

PCB and PAH's in Sediment

Concentrations of all the 95 PCB congeners and 38 PAH compounds measured in the sediment collected around HMI are presented in the Year 22 data report. This report is focused on comparing the total PCB and PAH concentrations measured in 2003 with those of previous years (Figures 29 and 30). The total PCB concentrations in 2003 are lower than the mean of previous years, although they are within the range of the variability observed in previous years. The total PAH concentrations fall very close to the mean concentrations observed since 1998.

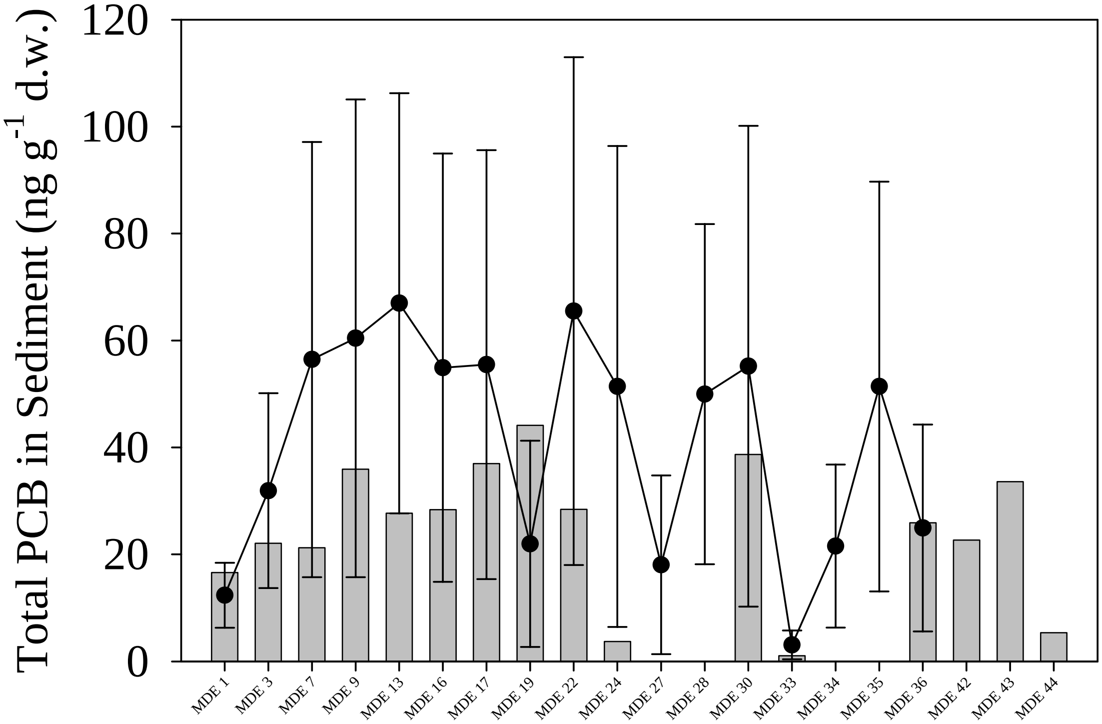

Figure 29: Total PCB concentrations in sediments collected around HMI in 2003. The bars are from 2003 where as the lines represent the mean and standard deviation of concentrations observed over the entire study period 1998-2002.

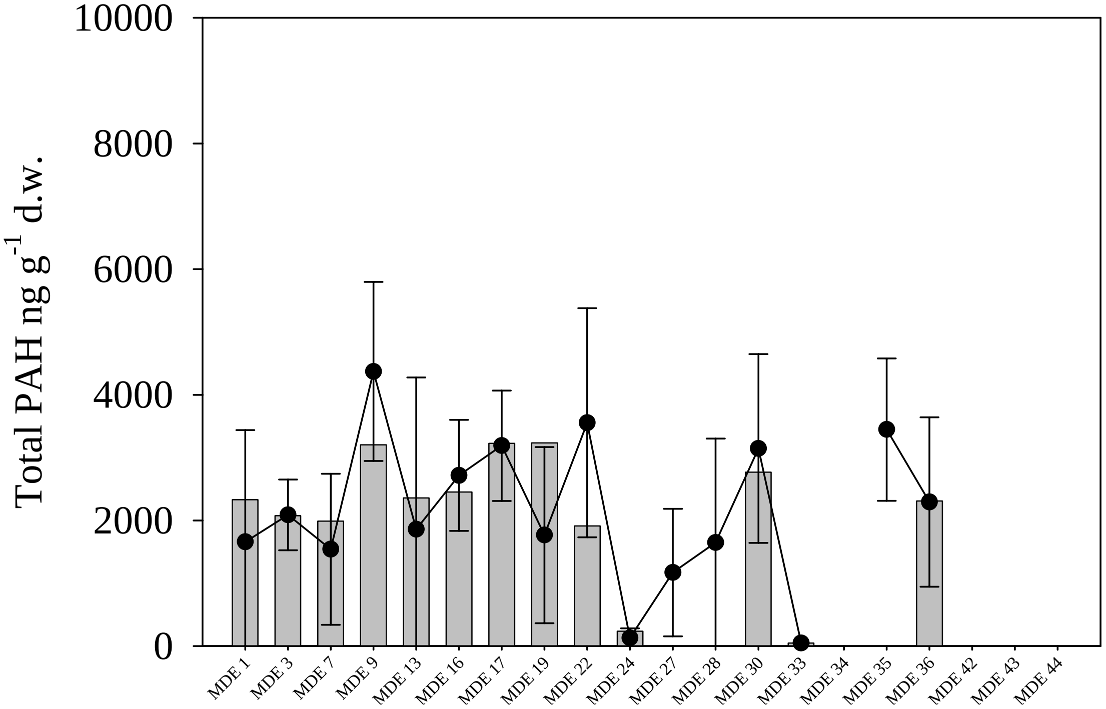

Figure 30: Concentrations of PAH congeners and the total PCB concentration in sediments around HMI. The bars are from 2002 where as the lines represent the mean and standard deviation of concentrations observed over the entire study period.

PAH's and PCB's in Clams and Worms

The concentrations of 28 PAH's and 84 PCB congeners or combinations where measured in 2002 are listed in appendices of the data report. Total PAH and PCB concentrations measured in 2003 were lower than but similar to the mean of the previous years (Figure 31 and 32). Only five sites were investigated in year 22, and the worms *nereis* and *m viridis* were also tested from 5 sites.

Concentrations of PAH's in worms (40-100 ug g^{-1}) are higher than clams (5-10 ug g^{-1}) on a wet weight basis, but both worms and clams are much lower than the concentrations in the sediment (1000-2000 ug g^{-1}) (Figure 33). Concentrations of PCB's in worms (10-100 ug g^{-1}) are slightly higher than clams (5-40 ug g^{-1}) on a wet weight basis, and similar to sediment (5-60 ug g^{-1}).

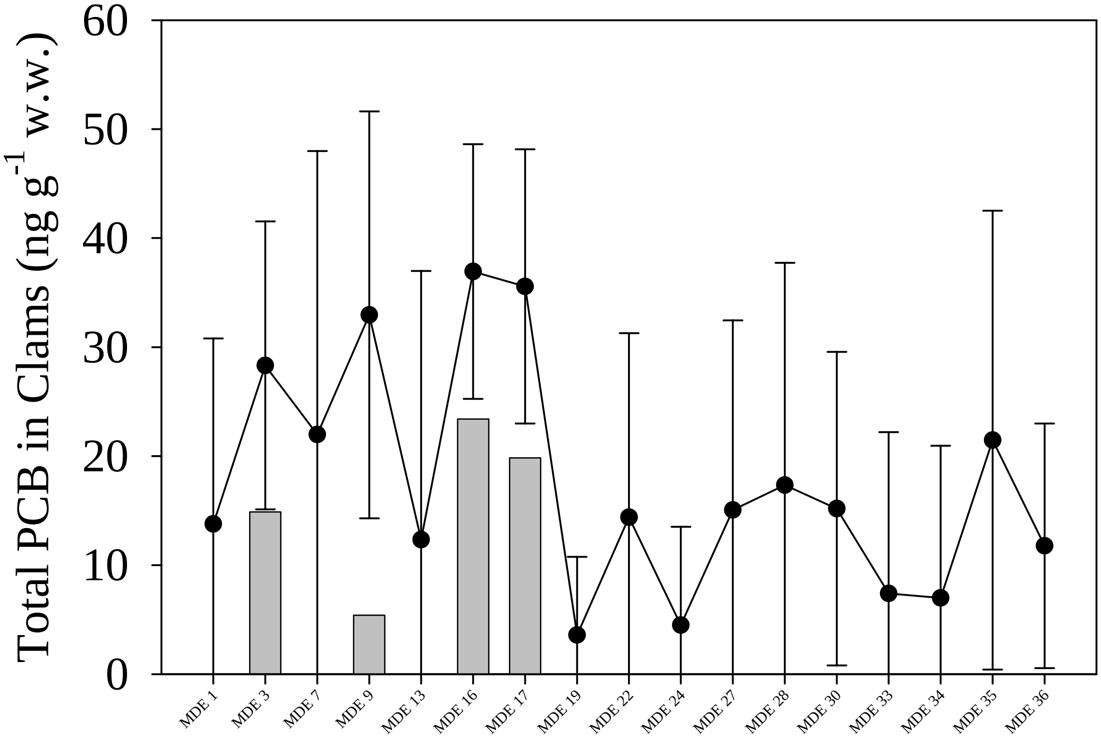

Figure 31: Total PCB concentrations (ng g^{-1} wet weight) in clams collected around the HMI. The bars are from 2003 and the lines represent the mean and standard deviation of concentrations observed over the entire study period.

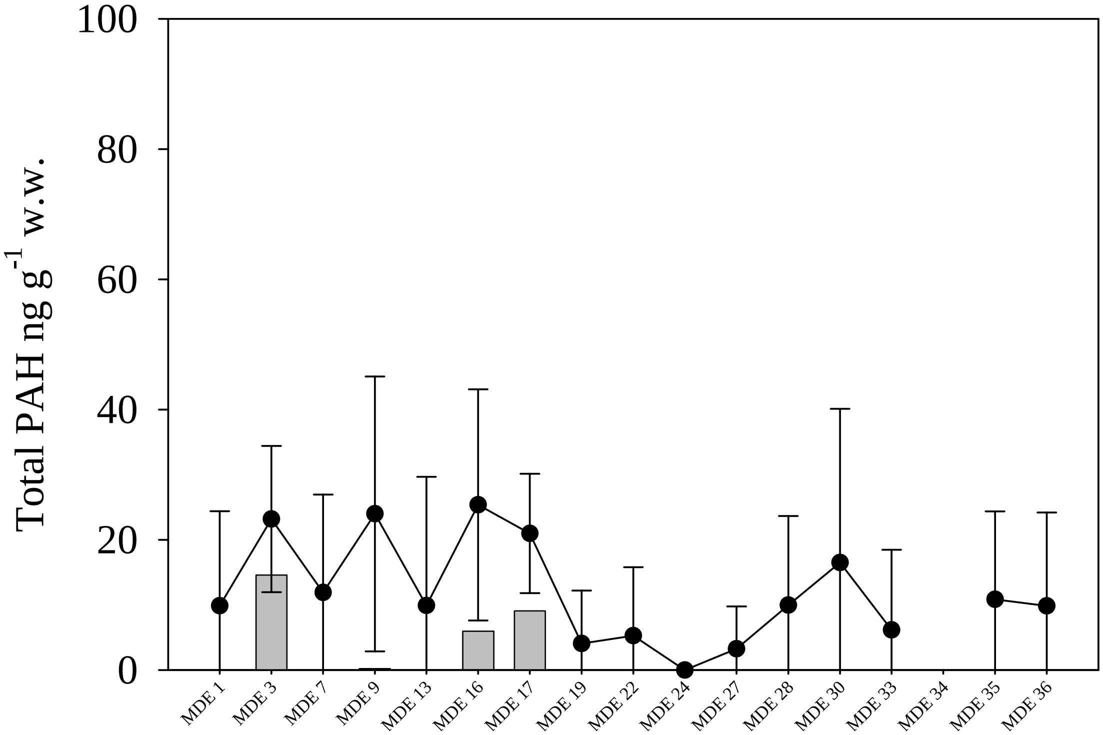

Figure 32: Total PAH concentrations (ng g^{-1} wet weight) in clams collected around the HMI. The bars are from 2003 and the lines represent the mean and standard deviation of concentrations observed over the entire study period.

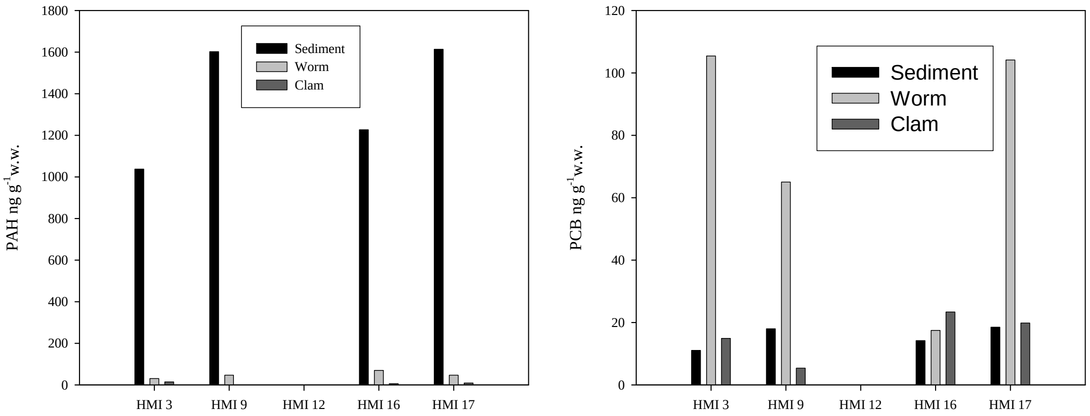

Figure 33: PAH and PCB concentrations (ng g^{-1} wet weight) in sediment, worms and clams from sites around HMI.

Bioaccumulation of PAH's and PCB into clams and worms

The concentrations of PAH's in sediments are much larger than the concentrations in either worms or clams (Figure 33). The BAF's calculated for both worms and clams are less than 1, and thus do not bioaccumulate PAH's (Figure 34). This finding is consistent with previous years finding with regard to clams. On the other hand, PCB concentrations in clams are comparable to sediment on a wet weight basis, but are much higher in worms (Figure 33). The BAF's for PCB's in clams is slightly less than 10 on average, which is consistent with previous years. The BAF for PCB's in worms is an order of magnitude higher, approaching 100. Incorporation of PCB's into worms is both highly efficient and rapid leading to such high accumulation factors (Ahrens et al. 2001).

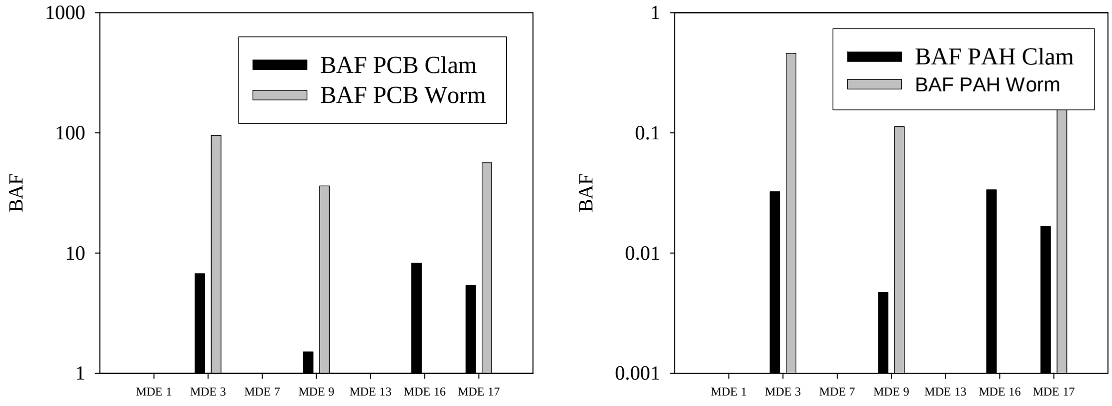

Figure 34: Bioaccumulation factors (BAF) for PCB's and PAH's in worms.

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.

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

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.

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.

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.

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.

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.

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.

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.

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: 7thAnnual 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

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.

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

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.

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.

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

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.

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.

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

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

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

Maryland Department of the Environment. 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.

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.

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.

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.

Purcell, T.W. and Peters, J.J. 1998. Sources of silver in the environment. Environ. Toxic. Chem. 17:539-546.

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.

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

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.

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.

Smith, R.L. 1996. Ecology and Field Biology, Fifth Edition. HarperCollins College Publications.

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.

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.

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.

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 Facility 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.

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.