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

Year 20 Technical Report (September 2001 – 2002)

Prepared by:

Maryland Department of the Environment

Chesapeake Biological Laboratory · Solomons

300th Anniversary Port of Baltimore 1706 Maryland 1706-2006

State of Maryland Department of Natural Resources

MDE

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AAS - Atomic Absorption Spectrometry

Ag - Silver

As - Arsenic

AVS - Acid Volatile Sulfide

BAF - Bioaccumulation Factor

BCF - Bioconcentration Factor

B-IBI - Benthic Index of Biotic Integrity

CBL - Chesapeake Biological Laboratory

Cd - Cadmium

CDF - Confined Disposal Facility

COC - Citizens' Oversight Committee

COMAR - Code of Maryland Regulations

Cr - Chromium

Cu - Copper

CWA - Clean Water Act

ERL - Effects Range Low

ERM - Effects Range Median

Fe - Iron

GC - Gas Chromatography

GFAAS - Graphite Furnace Atomic Absorption Spectrometry

Hg - Mercury

HMI - Hart-Miller Island 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

UMCES - University of Maryland Center for Environmental Science

USACE - U.S. Army Corps of Engineers

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:

$1Kg = 1000g = 2.205lbs.$

$1g = 1000mg = 2.205 \times 10^{-3}lb$

$1mg = 1000\mu g = 2.205 \times 10^{-6}lb$

$1 lb = 16oz = 0.454Kg$

LENGTH:

$1m = 100cm = 3.28ft = 39.370in$

$1cm = 10mm = 0.394in$

$1mm = 1000\mu m = 0.0394in$

$1ft = 12in = 0.348m$

CONCENTRATION:

$1ppm = 1mg/L = 1mg/Kg = 1\mu g/g = 1mL/m^3$

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

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

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

$1oz/gal = 7.489Kg/m^3$

VOLUME:

$1L = 1000mL$

$1mL = 1000\mu L$

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

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

$1acre\text{-}ft = 1233.482m^3$

1 gallon = 3785cc

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

FLOW:

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

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

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

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

$1ft/s = 0.031m/s$

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

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

AREA:

$1m^2 = 10.764ft^2$

$1hectare = 10000m^2 = 2.471acres$

$1ft^2 = 0.093m^2$

$1acre = 4046.856m^2 = 0.405$ hectares

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

CHAPTER 1: PROJECT MANAGEMENT AND SCIENTIFIC/TECHNICAL COORDINATION (PROJECT I) – YEAR 20

Hart-Miller Island Exterior Monitoring Program

September 2001 - September 2002

Prepared for

Maryland Port Administration
Maryland Department of Transportation

By

Matthew C. Rowe
Ecological Assessment Division
Technical and Regulatory Services Administration
Maryland Department of the Environment
1800 Washington Blvd.
Suite 540
Baltimore, MD 21230

ACKNOWLEDGMENTS

The Year 20 Hart-Miller Island (HMI) Exterior Monitoring Program would not have been successful without the help of several Technical and Regulatory Services Administration (TARSA) staff members, including: Mr. George Harman, Chairman; Mr. Matthew Rowe, Project Manager; Mr. Christopher Luckett, Biologist; Miss Caroline Myers, Biologist; and, Mr. Charles Poukish, Division Chief. The dedication and subject matter expertise of these professionals was an invaluable asset in fulfilling this year's monitoring effort.

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 important economic ramifications for the state of Maryland. The Port of Baltimore depends upon annual dredging by the U.S. Army Corps of Engineers (USACE) to maintain the federal approach channels to Baltimore Harbor. The State of Maryland is obligated to provide placement sites for material dredged from these federal maintenance channels. In 1983, 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 dike connecting the remnants of Hart and Miller Islands and encompassing an open-water area of approximately 1,100 acres. The dike was constructed of sandy sediments excavated from the proposed interior of the facility. The eastern or Bay side of the dike was reinforced with filter cloth and rip-rap to protect the dike from wave and storm induced erosion. Completed in 1983, the dike is approximately 29,000 feet long and is divided into North and South Cells by a 4,300 foot interior cross-dike. Placement of dredged material within HMI began with dike completion and continues presently.

The last inflow of dredged material into the South Cell of HMI was completed on October 12th, 1990. The process of converting the 300-acre South Cell into a wildlife refuge is currently underway. The North Cell is projected to reach full capacity by the year 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 dike, serve as a state park and receive heavy recreational use throughout the summer months.

Environmental Monitoring

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

---

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

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

Experimental Design

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

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

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

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

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

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

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

CHAPTER II: SEDIMENTARY ENVIRONMENT (PROJECT 2) – YEAR 20

(September 2001 – September 2002)
Technical Report

Prepared by:

James M. Hill, Ph.D., Principal Investigator,
and Lamere Hennessee

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

Submitted to:

Maryland Department of the Environment
Technical and Regulatory Services
Montgomery Park Business Center
1800 Washington Blvd
Baltimore, MD 21230-1718

ACKNOWLEDGMENTS

For their assistance during the two Year 20 sampling cruises, we would like to thank the Maryland Department of Natural Resources for providing the research vessel *Kerhin*, Captain Rick Younger and First Mate Jake Hollinger, respectively, for piloting the vessel and collecting samples. We would also like to thank our colleagues at the Maryland Geological Survey, Patrick Fangmeyer, Sacha Lanham, Dan Sailsbury, Geoffrey Wikel, and Darlene Wells, for their assistance in the field and lab. Finally, we extend our thanks to Melissa Slatnick and Jennifer Harlan at MES, who provided us with much of the information related to site operation.

EXECUTIVE SUMMARY

The Coastal and Estuarine Geology Program of the Maryland Geological Survey (MGS) has been involved in monitoring the physical and chemical behavior of near-surface sediments around the Hart-Miller Island Dredged Material Containment Facility (HMI) from the initial planning stages of construction of the facility to the present. As part of this year's exterior monitoring program, MGS collected bottom sediment samples from 40 sites on September 13, 2001, and again on April 11, 2002. Survey geologists then analyzed various physical and chemical properties of the samples, 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).

For exterior bottom sediments sampled during Year 20, the pattern of grain size distribution varies slightly from one cruise to the next. The reasons for variation 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.

In terms of metal loadings in the area, some features to note are:

- Most of the samples (74 of 77) are below the detection level for Cd;
- Cd, Cr, Cu, Ni, Pb and Zn are found with concentrations that exceed the Effects Range Low (ERL) values; and
- Zn and Ni have samples that exceed the Effects Range Median (ERM) values.

ERL and ERM are proposed sediment criteria established by the 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 probably have adverse biological effects. These criteria are based on a statistical method of termed preponderance of evidence. The method does not allow for unique basin conditions and does not take into account grain size induced variability in metal concentrations in the sediment. The values are useful as a guide, but are limited in applicability due to regional differences. The grain size normalization procedure utilized in this study is a means of correcting 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, only Zn and Pb are found to be significantly enriched compared to the baseline. However, based on work done in Baltimore Harbor, the normalized values are well below anticipated biological effects thresholds.

Within the context of the life of the facility, Year 20 samples have the lowest metals levels since 1988, falling within baseline levels for all of the measured metals, except Pb which shows slightly elevated levels primarily in the Baltimore Harbor and Back River regions of influence. Levels of metals in the sediment reflect the discharge rates from HMI; generally, low rates of discharge have higher impact to the sediment load of metals. During this monitoring period there were no significant contiguous periods during which discharge rates were below 10 MGD. This is due to two factors; (1) relatively high inflow rates into the dike during the Fall sampling period; and, (2) large periods of no discharge prior to the Spring cruise (Cruise 44 - 81% of the time). Consequently, oxidation of the sediment was minimized; the most acidic daily discharge records showed no periods of free mineral acidity. Without free mineral acidity, leaching is minimized and acid formation rates are low. This accounts for the relatively low observed levels of Zn and Pb in the exterior sediments.

Based on historical data, and the data from Years 18, 19 and this monitoring year, it does not appear that material from the Harbor influences sediments adjacent to the dike in the proximal zone ascribed to HMI . This is supported by both the sedimentation and metals distribution patterns in the area.

Periodic elevated metal levels in sediments around HMI indicate a need for continued monitoring. The pattern of higher levels of metals with lower discharge rates is consistent with previous years' studies. Currently, HMI is actively accepting material, but as the facility reaches capacity and the volume of effluent declines, dewatering of the contained material will lead to sediment oxidation and 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 contaminant load to the Bay. Although these levels are currently much lower than any biological effects threshold, continued monitoring is needed to: (1) detect if the levels increase to a point where action is required; (2) to document the effects that operations have on the exterior environment (for future project design); and, (3) to assess the effectiveness of any amelioration protocol implemented by Maryland Environmental Service (MES) to counteract the effects of exposing contained dredged material to the atmosphere. Close cooperation with Maryland Department of the Environment (MDE) and MES is important in this endeavor. It is also recommended that, to further assess the potential influence of Baltimore Harbor on the HMI exterior sediments, the additional sampling sites be maintained, at least temporarily.

INTRODUCTION

Since 1981, the Maryland Geological Survey (MGS) has monitored the sedimentary environment in the vicinity of Hart-Miller Island Dredged Material Containment Facility (HMI). HMI is a man-made enclosure in northern Chesapeake Bay, named for the two natural islands that form part of its western perimeter (Figure 1). Designed specifically to contain material dredged from Baltimore Harbor and its approach channels, the oblong structure was constructed of sediment dredged from the dike interior. The physical and geochemical properties of the older, "pristine" sediment used in dike construction differed from those of modern sediments accumulating around the island. Likewise, material dredged from shipping channels and deposited inside the facility also differs from recently deposited sediments in the region. Much of the material generated by channel deepening is fine-grained and enriched in trace metals and organic constituents. In addition, oxidation of the sediment placed in the dike during dewatering and crust management produces effluent enriched in metals. These differences in sediment properties and discharge from the facility have allowed the detection of changes attributable to construction and operation of the dike.

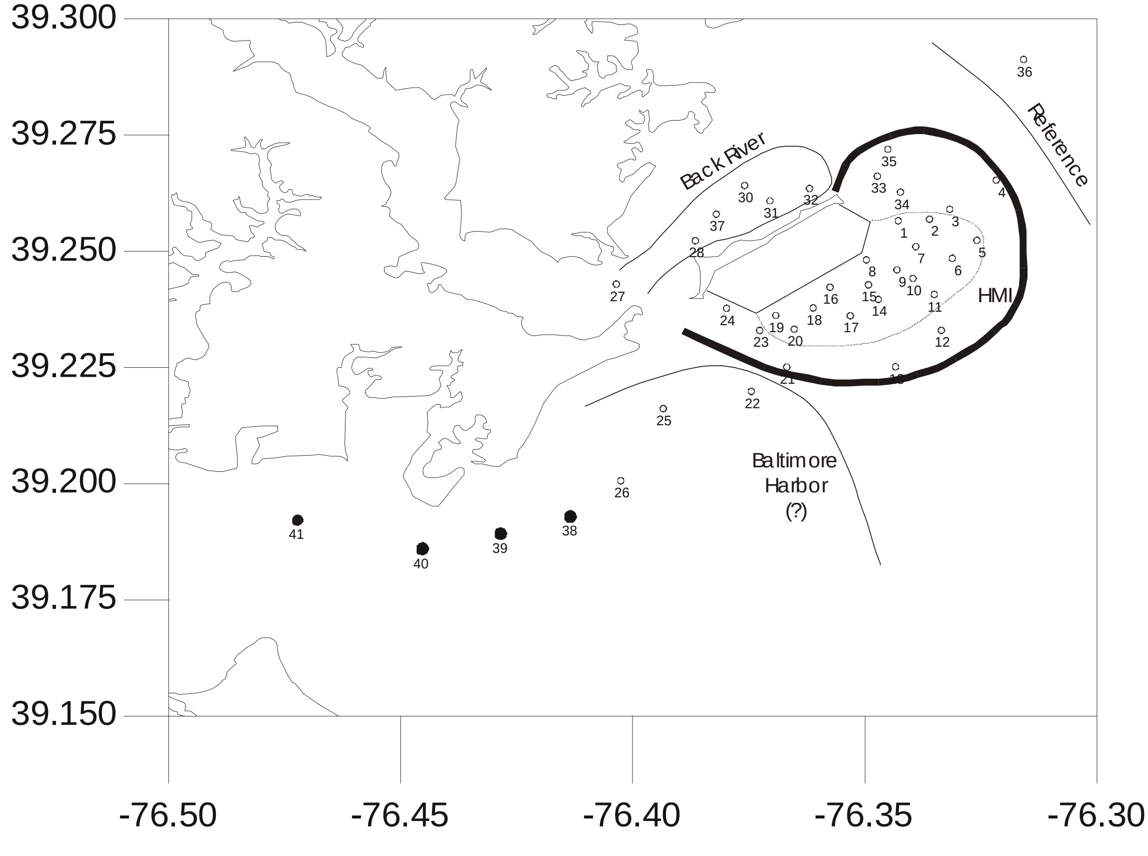


Figure 1: Sampling locations for Year 20. Contours show zones of influence found in previous studies. Solid circles show location of sites added in Year 18.

Previous Work

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

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

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

For a number of years after HMI began operating, no major changes were observed in the surrounding sedimentary environment. Then, in April 1989, more than two years after the first release of effluent from the facility, anomalously high Zn values were detected in samples collected near spillway #1 (Hennessee et al., 1990b). Zinc levels rose from the regional average enrichment factor of 3.2 to 5.5. Enrichment factors are the ratios of concentrations, in this case Zn to Fe, which is in turn normalized to the same ratio in a standard reference material; this number is dimensionless. Effluent discharged during normal operation of the dike was thought to be the probable source of the enrichment of Zn accumulating in the sediments. This was confirmed by use of the Upper Bay Model (Wang 1993), a numerical, hydrodynamic model, which was used to predict the dispersion of discharge from the facility, coupled with discharge records from the spillways. From the discharge records it was noted that there is a significant increase in metal loading to the exterior sediments during periods of low discharge (<10MGD); periods of higher discharge rates corresponded to lower metal levels in the exterior sediments.

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

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

2. Releases from Spillways #1 and #4 travel in a narrow, highly concentrated band up and down the eastern side of the dike. This explains the location of areas of periodically high metal concentrations east and southeast of the facility.

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

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

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

The 3-D hydrodynamic model explains the shape of the plume of material found in the exterior sediments, but it does not explain why the level of Zn in the sediments increases at lower discharges. To account for this behavior, the chemistry of the effluent discharged from the dike was examined, as reported in the *11th Year Technical Report*. As a result of this examination, a model was constructed to predict the general trend in the behavior of Zn as a function of discharge rate from the dike. The model has two components: (1) loading due to material similar to the sediment in place; and, (2) loading of enriched material as predicted from a regression line based on discharge data supplied by the Maryland Environmental Service (MES). The behavior of this model supports the hypothesis of metal contamination during low flow conditions. Sediments discharged from the facility are the source of metals that enrich the exterior sediments. When exposed to the atmosphere, these sediments oxidize in a process analogous to acid mine drainage (i.e., sulfide minerals oxidize to produce sulfuric acid, which leaches acid-soluble metals, nutrients, and organic compounds that are released with the discharged waters). Since the initial detection of Zn, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, in the vicinity of the dike higher than expected levels of Zn have persisted through Year 19, and elevated levels of Pb persist in Year 20. 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 elevated metal levels from previous years' studies. These influences are noted in the figure as:

1. *Reference* - representing the overall blanketing of sediment from the Susquehanna River;

2. *Back River* - Gradients showing the sewage treatment plant as a source carried by the river have varied through time; the sites in this zone encompass the area that has shown the influence from this source. Further documentation of this source was done in the Year 16 report, where samples were collected upstream beyond the sewage treatment plant. These samples clearly showed a continuous gradient from the plant down Back River approaching HMI;

3. *HMI* - The area of influence from the dike is divided into two zones, (a) the proximal zone, which shows the most consistent enrichment levels through time, and (b) the distal zone, which is affected primarily during extended periods of dewatering and crust management; and,

4. *Baltimore Harbor* – A few monitored sites in the southern portion of the area have consistently shown a gradient, suggesting a source of metals south of HMI in the direction of Baltimore Harbor. The pattern frequently seen in the monitoring studies is base level values near HMI which increase towards Baltimore Harbor. Baltimore Harbor, as the source of the material, was further implicated by the results of a hydrodynamic model analyses performed in conjunction with the 1997 sediment characterization of Baltimore Harbor and Back River (Baker et al., 1998). This analysis showed the potential of movement of material from the mouth of the harbor extending northward toward HMI. To assess the effect of Baltimore Harbor on the HMI external sedimentary environment, four sites were added in Year 18 and maintained through Year 20. These sites are indicated by solid circles in Figure 1.

Dike Operations

Certain activities associated with the operation of HMI have a direct impact on the exterior sedimentary environment. Local Bay floor sediments appear to be sensitive, both physically and geochemically, to the release of effluent from the dike. Events or operational decisions that affect the quality or quantity of effluent discharged from the dike account for some of the changes in exterior sediment properties observed over time. For this reason, dike operations during the periods preceding each of the Year 20 cruises are summarized below. Information was extracted from *Operations Reports* prepared by MES, covering the periods April 1, 2001 - April 30, 2002; a detailed synopsis of this period and digital discharge records were provided to MGS for this report by MES.

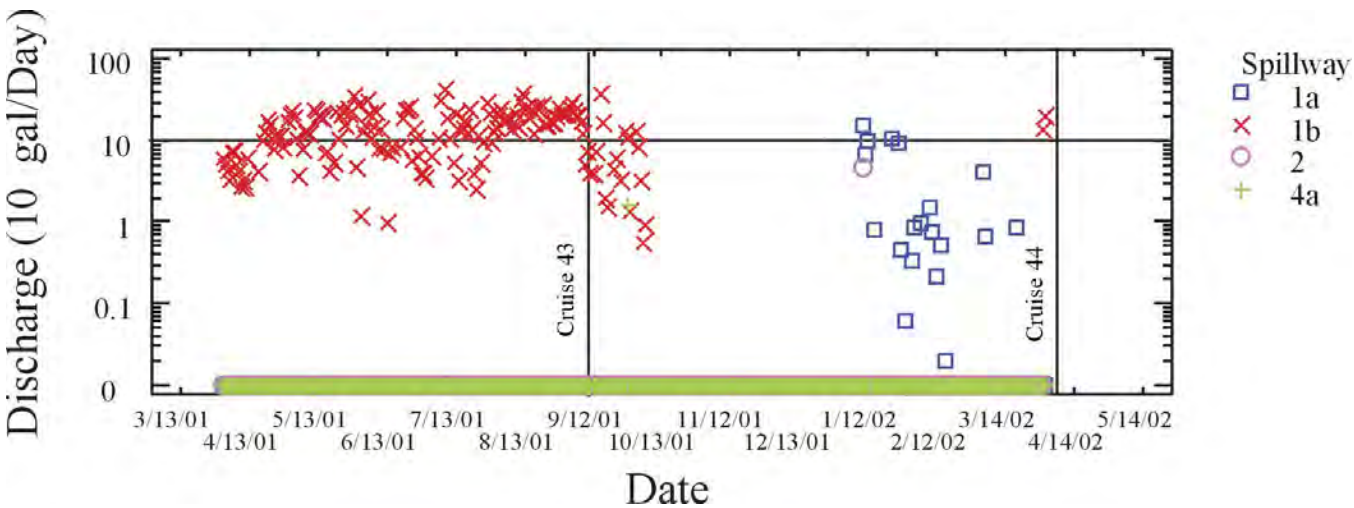


Figure 2: Discharge from HMI during the Year 20 monitoring period. Note that discharge is presented as a logarithmic scale, with days of no discharge set at 0.01 Mgal/day. Vertical lines denote sampling days.

This monitoring year had a bimodal usage. The period prior to the Fall Cruise was a period of high usage of the facility with a total of approximately 1.1 million cubic yards put into HMI from dredging operations to clear the access channel to the Dundalk Marine Terminal. The period before the spring sampling was a period of relatively low usage with a total of approximately 0.3 million cubic yards coming from two operations. Both periods did not produce extended intervals of low discharge (<10 Mgal/day; see Figure 2) that would be expected to effect the external sediments. The conditions that were dominant at the facility prior to the Fall collection study period tended to stabilize the sediment by reducing the potential for oxidation of the sediment by keeping the sediment constantly flooded in a flow through condition. Prior to the Spring sampling, only 26 of 187 days had low flow conditions that might influence the external sediments. It takes a period longer than six months to establish oxidizing conditions which would show a significant effect on the discharge. Consequently, neither of these conditions would be expected to produce low pH discharge and optimal leeching conditions. This expected result is supported by the pH of the water discharged from the facility. The discharge water stayed at values near or greater than neutral see (Figure 3). Therefore based on previous monitoring years, the external sedimentary environment would not be *greatly* affected by the dike operations during this period. This is additionally supported by the fact that the effluent was in compliance with the discharge permit for the entire monitoring period.

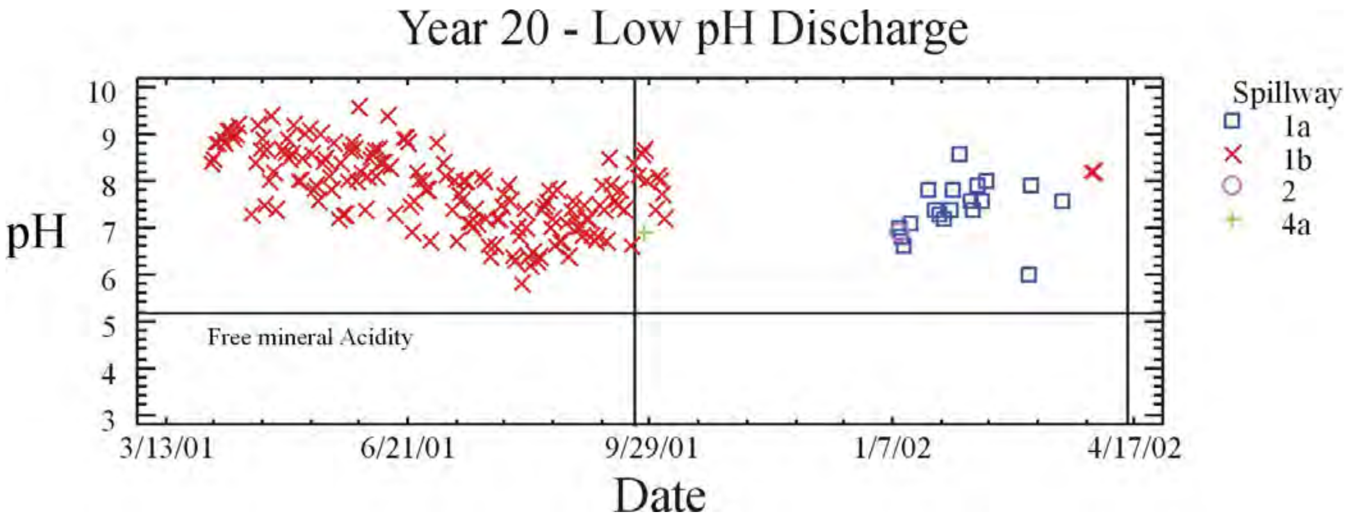


Figure 3: Low pH measured for daily discharge from HMI. Vertical lines denote sampling dates. pH readings below the horizontal line indicates free mineral acidity.

OBJECTIVES

As in the past, the main objectives of the Year 20 study were: (1) to measure specific physical and geochemical properties of near-surface sediments around HMI; and, (2) to assess detected changes in the sedimentary environment. Tracking the extent and persistence of the area of historically elevated Zn concentrations was again of particular interest.

METHODS AND MATERIALS

Field Methods

The information presented in this report is based on observations and analyses of surficial sediment samples collected around HMI during two cruises aboard the *R/V Kerhin.* The first cruise took place on September 13, 2001, and the second, on April 11, 2002.

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 20 sample locations are reported in the companion *Year 20 Data Report*.

Using a dip-galvanized Petersen sampler (maximum depth of penetration = 38 cm or 15 inches), crewmembers collected undisturbed samples, or grabs, of surficial sediments at 40 sites, MDE-1 through MDE-28 and MDE-30 through MDE-41. The same 40 stations were occupied during both Year 20 cruises. Stations were identical to those sampled during Years 18 and 19.

At 36 stations, a single grab sample was collected, described lithologically, and split. Triplicate grab samples were collected at the remaining four stations (MDE-2, MDE-7, MDE-9 and MDE-31) and, likewise, described and split. MGS analyzed one split for grain size composition, a suite of trace metals, and carbon/sulfur/nitrogen. The Chesapeake Biological Laboratory (CBL) analyzed the second split for a different suite of trace metals. Field descriptions of samples are included as appendices in the *Year 20 Data Report*.

Using plastic scoops rinsed with deionized water, the crew took sediment sub-samples from below the flocculent layer, usually several centimeters from the top, and away from the sides of the sampler to avoid possible contamination by the sampler itself. MGS's sub-samples were placed in 18-oz Whirl-Pak™ bags and refrigerated. They were maintained at 4^{o}C until they could be processed in the laboratory. CBL's splits were handled in much the same way, except that they included the floc layer and were frozen instead of refrigerated.

Laboratory Procedures

Textural Analyses

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

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

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

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

The relative proportions of sand, silt, and clay were determined using the sedimentological procedures described in Kerhin et al. (1988). The sediment samples were pre-treated with hydrochloric acid and hydrogen peroxide to remove carbonate and organic matter, respectively. Then the samples were wet sieved through a 62-µm mesh to separate the sand from the mud (silt plus clay) fraction. The finer fraction was analyzed using the pipette method to determine the silt and clay components (Blatt et al. 1980). Each fraction was weighed; percent sand, silt, and clay were determined; and the sediments were categorized according to Pejrup's (1988) classification (Figure 4).

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

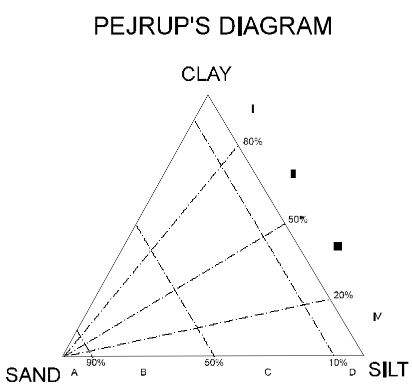


Figure 4: Pejrup's (1988) classification of sediment type.

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

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

Trace Metal Analysis

Sediment solids were analyzed for eight trace metals, including iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb) and cadmium (Cd). In addition to the trace metals, nutrients (nitrogen, phosphorus, carbon and sulfur) were also 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 MGS laboratory followed the steps below in handling and preparing trace metal samples:

1. Samples were homogenized in the Whirl-Pak™ bags in which they were stored and refrigerated (4^{o}C);

2. Approximately 10 g of wet sample were transferred to Teflon evaporating dishes and dried overnight at 105-110^{o}C;

3. Dried samples were hand-ground with an agate mortar and pestle, powdered in a ball mill, and stored in Whirl-Pak™ bags;

4. 0.5000 ± 0.0005 g of dried, ground sample was weighed and transferred to a Teflon digestion vessel;

5. 2.5 ml concentrated nitric acid (HNO_3 :trace metal grade), 7.5 ml concentrated hydrochloric acid (HCl: trace metal grade), and 1 ml ultra-pure water were added to the Teflon vessel;

6. The vessel was capped with a Teflon seal, and the top was hand tightened. Between four and twelve vessels were placed in the microwave carousel;

7. Samples were irradiated using programmed steps appropriate for the number of samples in the carousel. These steps were optimized based on pressure and percent power. The samples were brought to a temperature of 175^{o}C in 5.5 minutes, then maintained between 175-180^{o}C for 9.5 minutes (The pressure during this time peaked at approximately 6 atm for most samples.);

8. Vessels were cooled to room temperature and uncapped. The contents were transferred to a 100 ml volumetric flask, and high purity water was added to bring the

volume to 100 ml. The dissolved samples were transferred to polyethylene bottles and stored for analysis; and,

9. The sample was analyzed.

All surfaces that came into contact with the samples were acid washed (3 days 1:1 HNO_3; 3 days 1:1 HCl), rinsed six times in high purity water (less than 5 mega-ohms), and stored in high-purity water until use.

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 #1646 - Estuarine Sediment; NIST-SRM #2704 - Buffalo River Sediment; National Research Council of Canada #PACS-1 - Marine Sediment) are given in Table 2.

Table 2: Results of MGS's analysis of three standard reference materials, showing the recovery of the certified metals of interest.

Percent Recovery *(n=6)*				
Metal		**NIST 1646**	**Buffalo River**	**PACS**
Fe		80	104	88
Mn		85	81	86
Zn		88	80	84
Cu		83	85	90
Cr		83	85	82
Ni		88	84	87
Cd		Below Detection	*86*	*71*
Pb		83	80	80

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

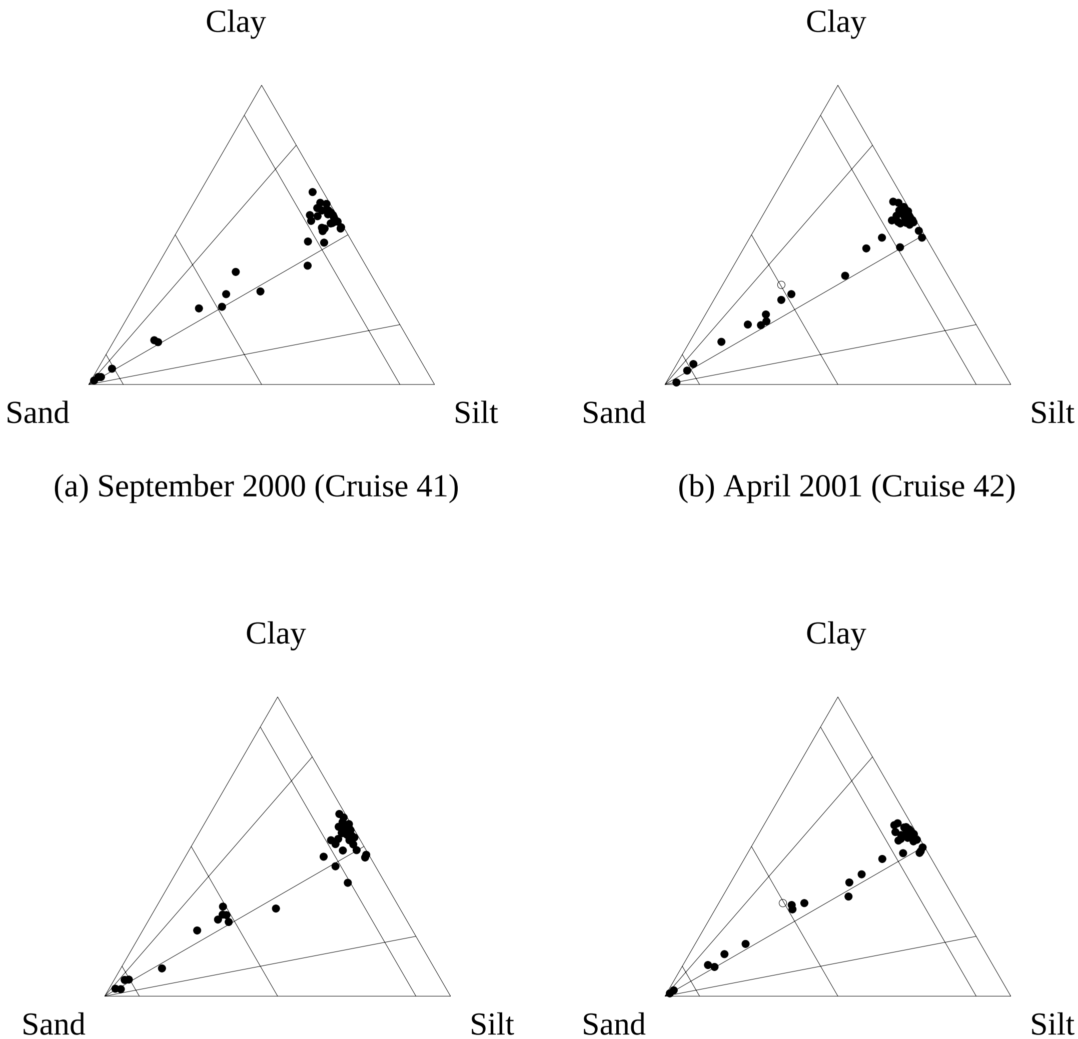
The monitoring effort around HMI is based on the identification of long-term trends in sediment distribution and on the detection of changes in those trends. The sampling scheme, revised in Year 17 and expanded in Year 18, established a new baseline against which any future changes in the sedimentary environment will be measured. Through Year 19, results of all cruises beginning with Year 17 were reported and compared. For this report, Year 20 results are discussed with respect to Year 19.

Thirty-eight of the 40 sampling sites visited during Year 20 yielded results that can be compared to those measured during Year 19. The grain size composition (proportions of sand, silt, and clay) of the 38 samples is depicted as a series of Pejrup's diagrams in Figure 5. Within a diagram, each solid circle represents one sediment sample. Related statistics, by cruise, are presented in Table 3.

Table 3: Summary statistics for Years 19-20, for 38 sediment samples common to all four cruises.

Variable	**Sept 2000 Cruise 41**	**Apr 2001 Cruise 42**	**Sept 2001 Cruise 43**	**Apr 2002 Cruise 44**
		Sand (%)		
Mean	22.62	23.11	24.01	22.28
Median	5.69	4.18	5.14	4.96
Minimum	0.77	0.68	0.64	0.68
Maximum	97.81	96.36	95.33	98.08
Range	97.04	95.68	94.69	97.40
Count	38	38	38	38
		Clay:Mud		
Mean	0.57	0.57	0.54	0.55
Median	0.56	0.57	0.56	0.56
Minimum	0.48	0.50	0.40	0.48
Maximum	0.66	0.66	0.64	0.63
Range	0.18	0.16	0.24	0.15
Count	38	37	38	38

The ternary diagrams show similar distributions of sediment type. 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. 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 2000 (Cruise 41)

(b) April 2001 (Cruise 42)

(c) September 2001 (Cruise 43)

(d) April 2002 (Cruise 44)

Figure 5: Ternary diagrams showing the grain size composition of sediment samples collected in Years 19 and 20 from the 38 sampling sites common to all four cruises: (a) September 2000, (b) April 2001, (c) September 2001, and (d) April 2002.

Based on the summary statistics (Table 3), average grain size composition, reported as % sand and as clay:mud ratios, varied little over the four sampling periods. No clear seasonal trends are evident.

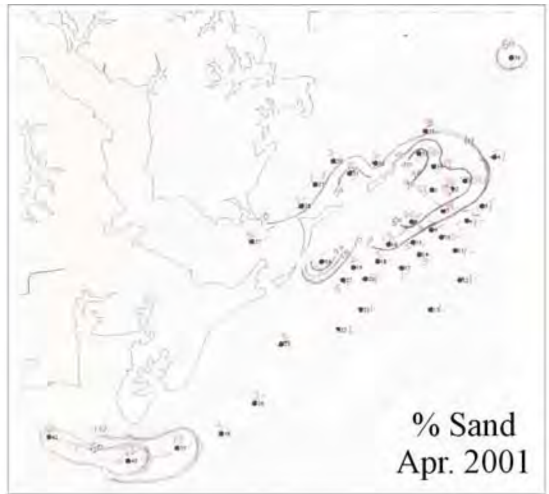
For the two monitoring years, the grain-size distribution of bottom sediments around HMI is depicted in contour maps showing (1) the percentage of sand in bottom sediments and (2) clay:mud ratios. In Figure 5, three contour levels represent 10%, 50%, and 90% sand, coinciding with the parallel lines in Pejrup's diagram. Generally, sand content diminishes with distance from the containment facility. Scattered around the perimeter of the dike, the sandiest sediments (>50% sand) are confined to relatively shallow (<15 ft) waters (Figure 6). Broadest north and west of the facility, the shoals are the erosional remnants of a larger neck of land. The once continuous landmass has been reduced to a series of islands, including Hart and Miller, extending from the peninsula that now forms the south shore of Back River. However, not all shallow water samples are sandy. In particular, several of the shallow water samples from Hawk Cove (e.g., MDE-30 and MDE-32) contain less than 10% sand. Sand distribution maps for Years 19 and 20 are similar in appearance. The most notable difference, at the mouth of Baltimore Harbor, is due to a change in the authors' interpretation of the data. For Year 20, decreasingly sandy bands of sediment were drawn approximately parallel to the shoreline. In general, the distribution of sand around HMI has remained largely unchanged since November 1988, two years after the first release of effluent from the dike.

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 in the diagrams in Figure 9. In September 2001, the most clay-rich sediments occurred as four isolated pockets, three southeast of the dike and one in the mouth of Baltimore Harbor. In April 2002, the clay:mud ratios of only three samples equaled or exceeded 0.60. Two stations (MDE-10 and MDE-41) had been high the previous September. The third, MDE-32 in Hawk Cove, had not. This distribution differs somewhat from Year 19, when clay-rich samples occurred in more extensive lenses southeast of the facility and, in April 2001, in Hawk Cove.

Silt-rich sediments (clay:mud ratio < 0.50) are generally found immediately adjacent to the walls of the dike, commonly in the vicinity of spillways. Silt-rich sediments occurred slightly more frequently in September 2001 (eight sites) than in April 2002 (four sites). The contrast between years was greater. In September 2000, the fine fraction of only two samples was silt-rich (MDE-27 at the mouth of Back River and MDE-16 in the vicinity of spillway #4). In April 2001, only one location, MDE-33, was richer in silt. Here the sand fraction was so great (96%), that analysis of the fine fraction was problematic.

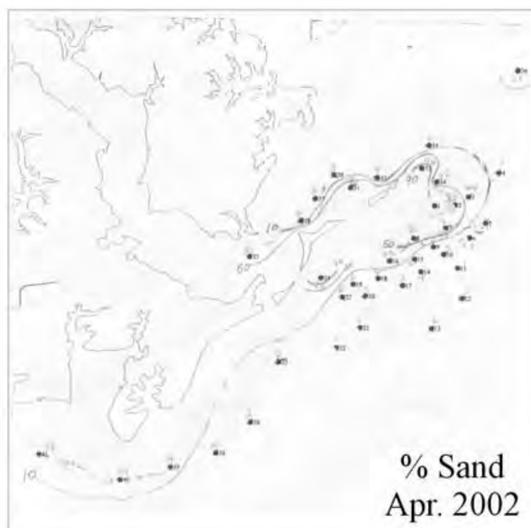
Understanding the reasons for these variations in grain size is difficult. They involve the amount, quality, and timing of discharge from particular spillways and the interaction of the effluent with tides and currents in the receiving waters. Those, in turn, are influenced by flow from the Susquehanna River. Based on the relatively silty nature of the fine fraction in Year 20, one may conclude that the depositional environment in the vicinity of HMI was somewhat more turbulent than during Year 19. The exact cause of that greater turbulence is unknown. Regardless, no clear trends, affecting many samples from a large area, are evident. The grain size distribution of Year 20 samples is largely consistent with the findings of past monitoring years.

(a) September 2000 (Cruise 41)



(b) April 2001 (Cruise 42)

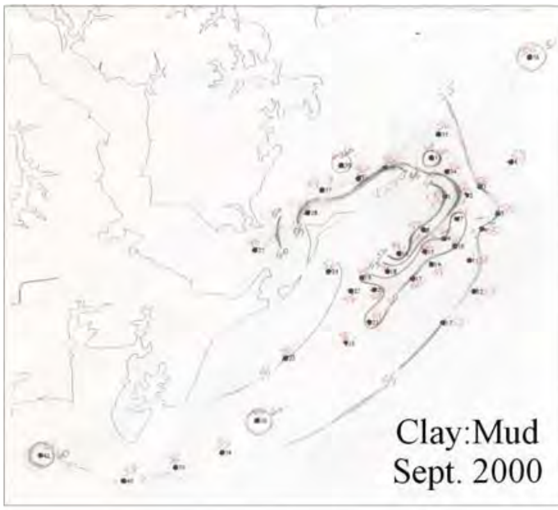
(c) September 2001 (Cruise 43)



(d) April 2002 (Cruise 44)

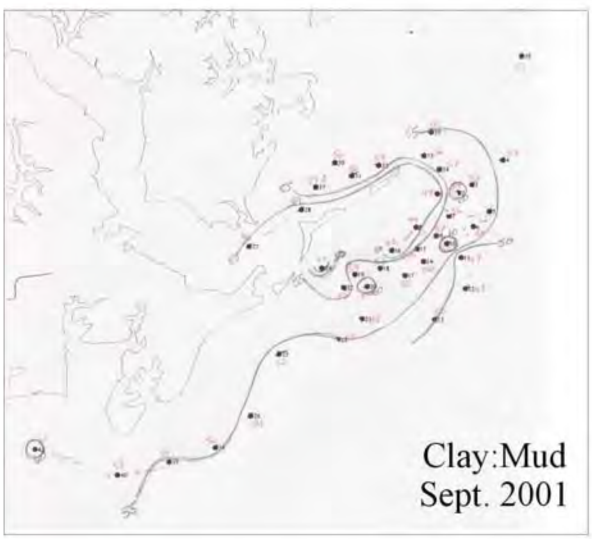
Figure 6: Sand distribution for monitoring years 19 and 20: (a) September 2000, (b) April 2001, (c) September 2001, and (d) April 2002. Contour intervals are 10%, 50% and 90% sand.

Figure 7: Average water depths, based on Year 17 Monitoring. Contour interval = 5 ft.

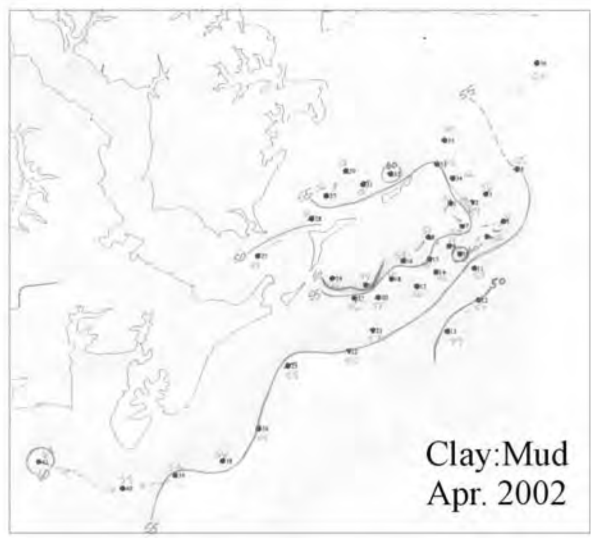


(a) September 2000 (Cruise 41)

(b) April 2001 (Cruise 42)



(c) September 2001 (Cruise 43)



(d) April 2002 (Cruise 44)

Figure 8: Clay:mud ratios for Monitoring Years 19 and 20. Contour interval = 0.10, plus 0.55.

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 = expected concentration of the metal
a, b, and c = the determined coefficients
Sand, Silt, and Clay = the grain size percentages 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 4. 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. 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 4: 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.

	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 4 for the constants in equation 2, and using the measured grain size at the site of interest. These predicted values can then be used to determine variations from the regional norm due to deposition; to exposure of older, more metal-depleted sediments; or to loadings from anthropogenic or other enriched sources.

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

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

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 $\pm 3\sigma$ can be within accepted background variability, but it is marginal depending on the trends in the distribution. Any values falling outside this range indicate a significant perturbation to the environment. The standard deviation (σ) of the baseline data set, the data used to determine the coefficients in Equation 2, is the basis for determining the sigma level of the data. Each metal has a different standard deviation, as reflected in the R^2 values in Table 4 The sigma level for Zn is ~30% (e.g. $1\sigma = 30\%$, $2\sigma = 60\%$, etc.).

General Results

A listing of the summary statistics for the elements analyzed is given in Table 5. Some features to note are:

1. Most of the samples (74 of 77) are below the detection level for Cd (0.60);
2. Cd, Cr, Cu, Ni, Pb, and Zn are found at some sites with concentrations that exceed the Effects Range Low (ERL) values; and
3. Zn and Ni exceed the ERM values at some sites.

ERL and Effects Range Median (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 differences. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, only Pb is 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 5: Summary statistics for elements analyzed. [All concentrations are in ug/g unless otherwise noted].

	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Count	3	77	69	77	77	77	75	77
Average	2.84	78.9	31.3	3.02	2742	61.9	46.8	252
Standard deviation	1.98	33.2	12.6	1.11	1706	25.9	19.4	105
Minimum	0.64	3.3	3.6	0.20	295	3.5	3.4	0.0
Maximum	4.47	183	54.4	4.34	7381	106	77.7	441.0
Range	3.83	180	50.8	4.14	7086	103	74.3	441.0
ERL	1.3	81	34	N/A	N/A	20.9	46.7	150
# of Samples >ERL	(2)	(49)	(30)			(68)	(47)	(63)
ERM	9.5	370	270	N/A	N/A	51.6	218	410
# of Samples >ERM	(0)	(0)	(0)			(55)	(0)	(3)

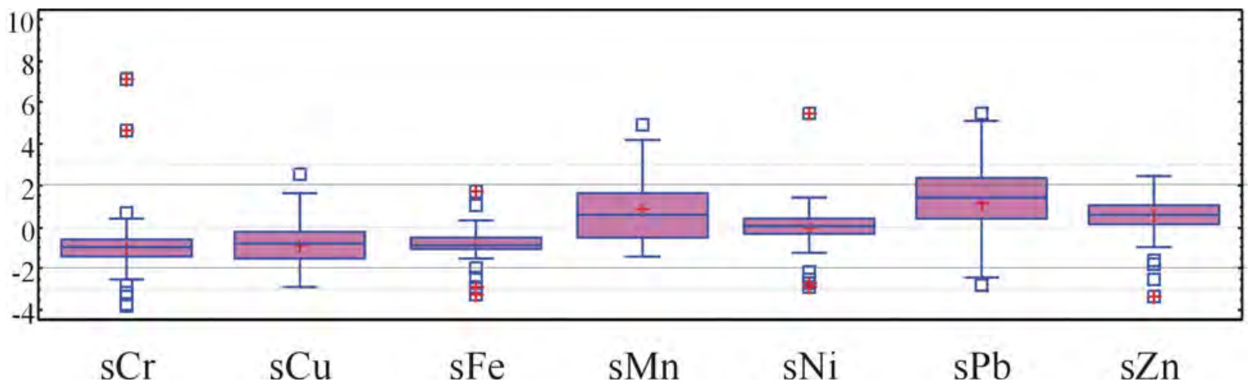


Figure 9: A box and whisker diagram showing the range of the data for both the fall and spring cruise. Cd is not shown due to the concentrations being below the detection limit for all but three samples.

The values presented in Table 5 are the measured concentrations of metals in the sediment, not normalized with respect to grain size variability, as outlined in the preceding *Interpretive Techniques* section. Figure 9 shows the variation of the data from the predicted baseline behavior for each of the elements measured. The values are in units of multiples of standard deviations from the norm; zero values indicate measurements that are identical to the predicted baseline behavior, values within plus or minus two sigma are considered to be within the natural variability of the baseline values. For both sampling cruises, all of the metals except Pb are within the range expected for normal baseline behavior in the area. Lead has approximately half of the samples significantly exceeding the baseline levels. Zinc and Pb will be discussed in the following sections; Zn is included in the discussion due to elevated levels in all previous monitoring years since 1989.

Metal Distributions

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

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

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

3. The positions of the primary discharge points from the dike - The areal distribution of the metals in the sediment also depends on the primary discharge locations to the Bay. The effects of discharge location were determined as part of the hydrodynamic model of the region around HMI. The effects of discharge location are:
   a. Releases from spillways #1 and #4 travel in a narrow, highly concentrated band up and down the eastern side of the dike. This explains the location of the areas of periodic high metal enrichment to the east and southeast of the facility; and

b. Releases from spillway #2 are spread more evenly to the north, east, and west. However, dispersion is not as great as from spillways #1 and #4 because of the lower shearing and straining motions.

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

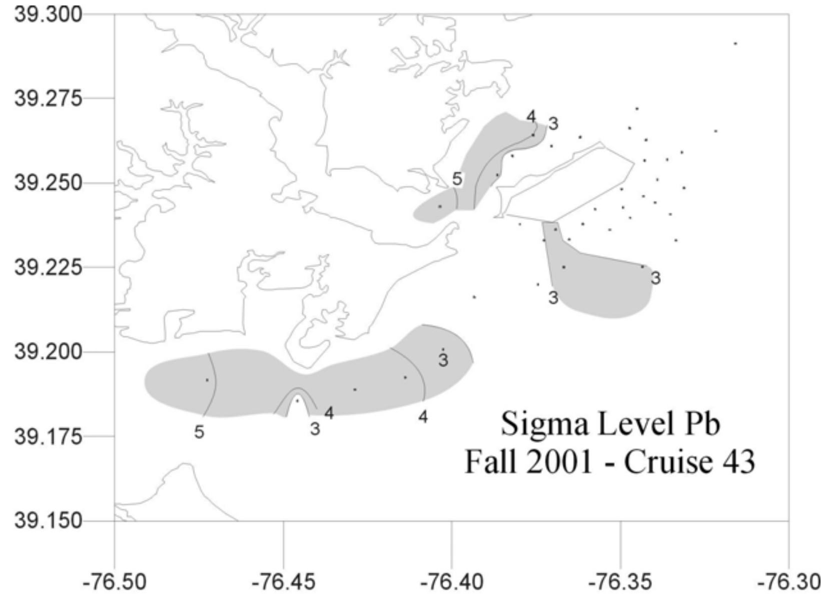
Figure 10 shows the sigma levels for Pb for the Year 20 monitoring period in the study area adjacent to HMI; sigma levels for Zn are not shown because they are all within the range of normal background variability. Sigma levels are the multiple of the standard deviation of the baseline data set. Data 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 Figure 10 is used to highlight the areas that are significantly elevated above baseline levels. There are three primary areas that are highlighted in Figure 10: Back River, Baltimore Harbor, and HMI.

Back River - The Back River influence is strongly seen for Pb. Generally the influence is comparable between the two sampling periods with the Fall period being slightly more elevated than the Spring. This most likely reflects the seasonally lower freshwater input in the Fall. The influence of Back River extends to the southernmost extent of the recreational beach on the Hawk Cove area of HMI.

Baltimore Harbor - Elevated levels of Pb extend into the area south of HMI, but do not reach the area adjacent to the island. The levels are comparable for the two sampling periods, reaching highs of ~5 sigma. Showing a gradational change from higher values in the harbor diminishing to background levels near HMI.

HMI - Only the Fall cruise shows elevated levels near the south cell. These levels are considered transitional, and not necessarily significant. They may be related to sediment off-loading operations or dewatering discharge from the south cell.

Zn distribution patterns show similar trends to Pb, however the Zn levels are less than 2 sigma for all samples and are considered statistically to be within normal background levels. The historical trend for Zn loading is shown in Figure 11. This figure shows the maximum % excess Zn found within the zone historically influenced by HMI for each of the monitoring cruises, with criteria indicating severity of the metals levels. The last two points represent the maxima found during the cruises for Year 20. The Fall cruise is comparable with Year 18 Fall cruise and the Year 20 Spring cruise is comparable to background levels seen in 1988 (Year 8 monitoring). The low metal levels in the exterior sediments during this monitoring year is because there was no significant contiguous periods during which discharge rates were below 10 MGD; the most acidic daily discharge records did not show any periods of free mineral acidity (see Figures 2 and 3). Without the free mineral acidity, leaching is minimized and acid formation rates are low.



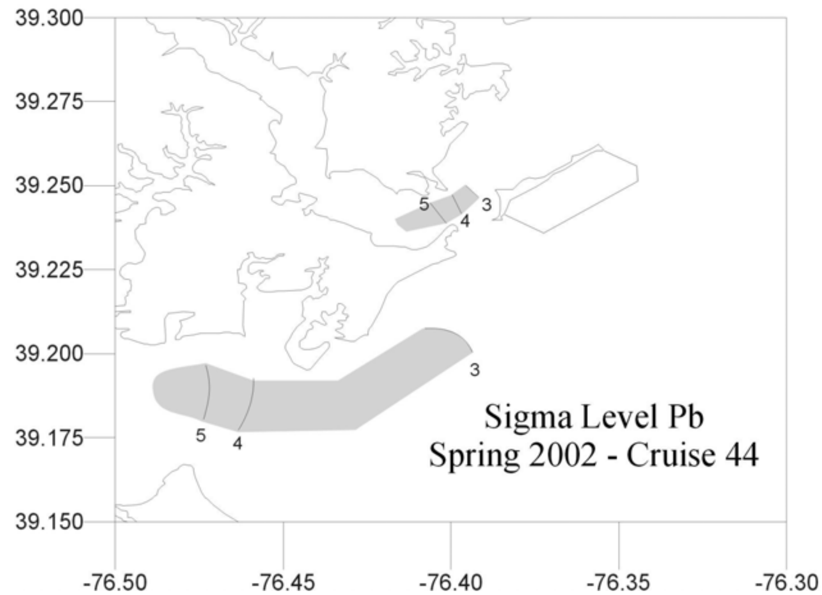


Figure 10: Distribution of Pb in the study area for the Fall and Spring sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional(values less than 3 not shown), >3 = significantly enriched (shaded in figures).

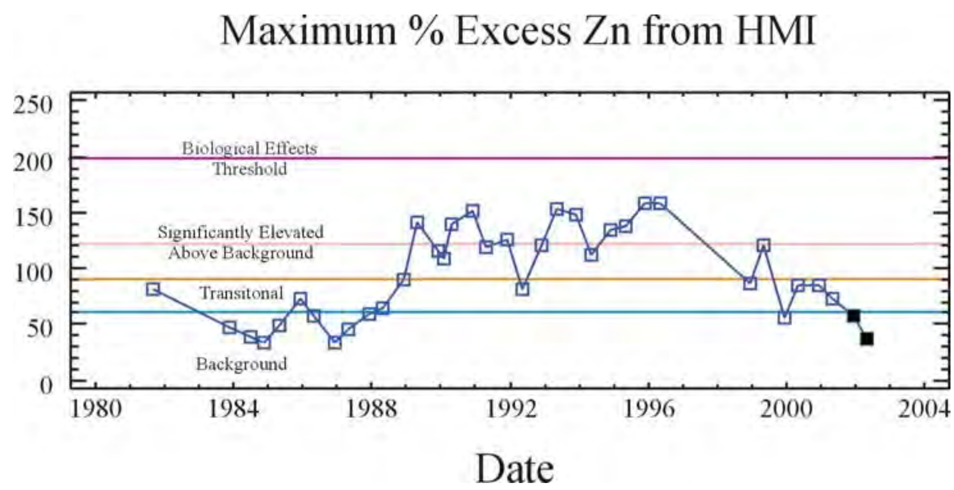


Figure 11: Record of the maximum % Excess Zn for all of the cruises MGS analyzed the sediments.

CONCLUSIONS AND RECOMMENDATIONS

The grain size distribution of Year 20 sediment samples does not show any clear trends in how the pattern alters from cruise to cruise. This is due to the complexity of the environmental conditions and source of material to the area. Based on the relatively silty nature of the fine fraction in Year 20, one may conclude that the depositional environment in the vicinity of HMI was somewhat more turbulent than during Year 19. The exact cause of that greater turbulence is unknown. Regardless, no clear trends, affecting many samples from a large area, are evident. The sediment distribution pattern is generally consistent with the findings of previous monitoring years dating back to 1988 (the second year after the start of release from HMI).

With regard to metal loadings in the area, some features to note are: (1) Most of the samples (74 of 77) are below the detection level for Cd (0.60); (2) Cadmium, Cr, Cu, Ni, Pb and Zn are found with concentrations that exceed the Effects Range Low (ERL) values; and, (3) Zinc and Ni exceed the Effects Range Median (ERM) values. ERLs and ERMs 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 differences. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, only Pb is found to be significantly enriched compared to the baseline; however, based on work done in Baltimore Harbor, the normalized values are well below anticipated biological effects thresholds.

Within the context of the life of the facility, Year 20 monitoring data shows some of the lowest levels of Zn since the onset of the elevated levels in 1989 and are approximately the same as monitoring year (Year 18) . There were no significant contiguous periods during which discharge rates were below 10 MGD and the most acidic daily discharge records did not show any periods of free mineral acidity. Without the free mineral acidity, leaching is minimized and acid formation rates are low. This accounts for the low observed levels of Zn in the exterior sediments.

Based on the historical data, and the data from this report, it does not appear that material from the Harbor influences the sediments adjacent to the dike in the proximal zone ascribed to HMI . This is supported by both the sedimentation and metals distribution patterns in the area.

Persistent elevated metal levels in sediments around HMI indicate a need for continued monitoring, even though the levels were low during this sampling period. The metal levels in the exterior sediments continued to show a consistent response to the operations of the dike (low discharge rates increasing the metal loads to the sediment). Currently, the dike is actively accepting material, but as the dike reaches its capacity the volume of effluent is expected to decline. Dewatering of this contained material and exposure to the air is likely to result in the mobilization of metals that may lead to higher metal levels in the effluent. 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: (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, (3) to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of exposing contained dredged material to the atmosphere. It is further recommended the Baltimore Harbor transect sites be maintained in order to assess the potential influence of Baltimore Harbor on the HMI exterior sediments.

REFERENCES

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

CHAPTER III: BENTHIC COMMUNITY STUDIES (PROJECT 3) - YEAR 20

(September 2001 – September 2002)

Prepared by:

Caroline Myers, Co-Principal Investigator
Sean Sipple, Co-Principal Investigator
Matthew Rowe, Co-Principal Investigator
Chris Luckett, Taxonomist
Nicolas Kaltenbach, Research Assistant
Chelsea Reid, Research Assistant
Jeff Carter, Research Assistant

Maryland Department of the Environment
Technical and Regulatory Services Administration
Environmental Assessment Division

Prepared for:

Maryland Port Administration
2310 Broening Highway
Baltimore, MD 21224

ABSTRACT

The benthic macroinvertebrate community in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI) was studied for the twentieth 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 and Baltimore Harbor). Water quality parameters, including dissolved oxygen concentrations, salinity, temperature, pH, conductivity and secchi depth were measured *in situ.*

Twenty-one stations (11 Nearfield, 3 Reference, 3 Back River/Hawk Cove stations and 4 Harbor Stations) were sampled on September 25, 2001, and again on April 12, 2002. The Baltimore Harbor stations, located near the mouth of the Patapsco River, were sampled this year to determine if the legacy of contamination from Baltimore's Inner Harbor could be affecting benthic communities surrounding Hart-Miller Island. 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-meter intervals thereafter to develop vertical water quality profiles.

A total of 41 benthic macroinvertebrate taxa were found at these twenty-one benthic community stations during Year 20 of monitoring. Of these 41 taxa, three taxa, *Leptocheirus plumulosus, Macoma balthica,* and oligochaete worms in the family Tubificidae, were clearly dominant. The total abundance was higher at most stations in April 2002 than September 2001 due to high seasonal recruitment, especially of the polychaete worm *Marenzelleria viridis.*

Species diversity was examined using the Shannon-Wiener diversity index. Diversity ranged from 1.86-3.27 in September 2001 and from 2.11-3.50 in April 2002. The proportion of pollution-sensitive taxa (*Cyathura polita*, *Rangia cuneata*, *M. viridis*, *Glycinde solitaria*, *M. balthica,* and *Mya arenaria*) was generally higher in September 2001 than in April 2002. This was primarily due to the low spring recruitment of *M. viridis*. The proportion of pollution-indicative taxa (the polychaete worms *Eteone heteropoda*, *Streblospio benedicti*, the oligochaete worms in the family Tubificidae, and the clam *Mulinia lateralis*) was generally also higher in September 2001 than in April 2002. This was primarily due to the large numbers of *S. benedicti* and worms in the Tubificidae family that were found in September 2001.

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI, Weisberg et al. 1997), a multimetric index of biotic condition that evaluates summer populations (July 15th through September 30th) of benthic macroinvertebrates, was calculated for all stations sampled during the September 2001 cruise. Overall, there was an increase in B-IBI scores when compared to last year. This year, sixteen of the twenty-one stations exceeded or met the Restoration Goal of 3.0 and only five failed to meet it. In Year 19, thirteen stations failed to meet the B-IBI score of 3.0. The average B-IBI scores for all stations in September 2001 met or exceeded 3.0, except for the Back River stations (average B-IBI score of 2.3).

Statistical analyses found no significant differences between the ten most abundant infaunal taxa at Nearfield, Reference, Back River/Hawk Cove, and Harbor 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 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 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 wetlands license issued for HMI, an exterior monitoring program was required to assess any environmental impacts associated with HMI. Various agencies have worked together since the inception of this program to monitor for environmental impacts resulting from dike construction and dredged material management activities. Studies were completed prior to and during the early construction period to determine baseline environmental conditions in the HMI vicinity. The results of post-construction monitoring are compared to this baseline, as well as to interseasonal and interannual results. This report represents the twentieth consecutive year of the benthic macroinvertebrate community monitoring since 1981. In Year 20, the Maryland Department of the Environment was responsible for all aspects of benthic community monitoring.

The goals of the Year 20 benthic community monitoring were:

- To monitor the benthic community condition as required under the wetlands license;

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

- To monitor other potential sources of contamination to the HMI region by sampling transects along the mouth of Back River and leading into the Baltimore Harbor/Patapsco 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 20 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 in early fall (September 25, 2001) and in spring (April 12, 2002) with assistance from the Maryland Department of Natural Resources. Twenty-one benthic stations (Table 6; Figure 12) in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI) were included in the study. All stations sampled during Year 19 of monitoring were again sampled for Year 20. Stations can be classified as one of four types based on location: Nearfield, Reference, Back River/Hawk Cove Transect, or Baltimore Harbor Transect stations and can also be classified based on dominant sediment type: silt/clay, shell, or sand. (Table 6).

Table 6: Target Locations (latitudes and longitudes in degrees, decimal minutes), and 7-digit codes of stations used for Year 20 benthic community monitoring.

Station #	Latitude	Longitude	Sediment Type	Maryland 7-Digit Station Designation
Nearfield Stations				
MDE-01	39° 15.3948	76° 20.568	Shell	XIF5505
MDE-03	39° 15.5436	76° 19.9026	Sand	XIG5699
MDE-07	39° 15.0618	76° 20.3406	Silt/clay	XIF5302
MDE-09	39° 14.7618	76° 20.5842	Silt/clay	XIF4806
MDE-16	39° 14.5368	76° 21.4494	Silt/clay	XIF4615
MDE-17	39° 14.1690	76° 21.1860	Silt/clay	XIF4285
MDE-19	39° 14.1732	76° 22.1508	Silt/clay	XIF4221
MDE-24	39° 14.2650	76° 22.7862	Sand	XIF4372
MDE-33	39° 15.9702	76° 20.8374	Sand	XIF6008
MDE-34	39° 15.7650	76° 20.5392	Sand	XIF5805
MDE-35	39° 16.3182	76° 20.7024	Silt/clay	XIF6407
Reference Stations				
MDE-13	39° 13.5102	76° 20.6028	Shell	XIG3506
MDE-22	39° 13.1934	76° 22.4658	Silt/clay	XIF3224
MDE-36	39° 17.4768	76° 18.9480	Silt/clay	XIG7589
Back River/Hawk Cove Stations				
MDE-27	39° 14.5770	76° 24.2112	Silt/clay	XIF4642
MDE-28	39° 15.3900	76° 22.7304	Silt/clay	XIF5232
MDE-30	39° 15.8502	76° 22.5528	Silt/clay	XIF5925
Harbor Stations				
MDE- 38	39° 11.5500	76° 24.8298	Silt/clay	XIF1652
MDE- 39	39° 11.3298	76° 25.7298	Silt/clay	XIF1343
MDE- 40	39° 11.1252	76° 26.7498	Sand	XIF1133
MDE- 41	39° 11.1501	76° 28.3590	Silt/clay	XIF1517

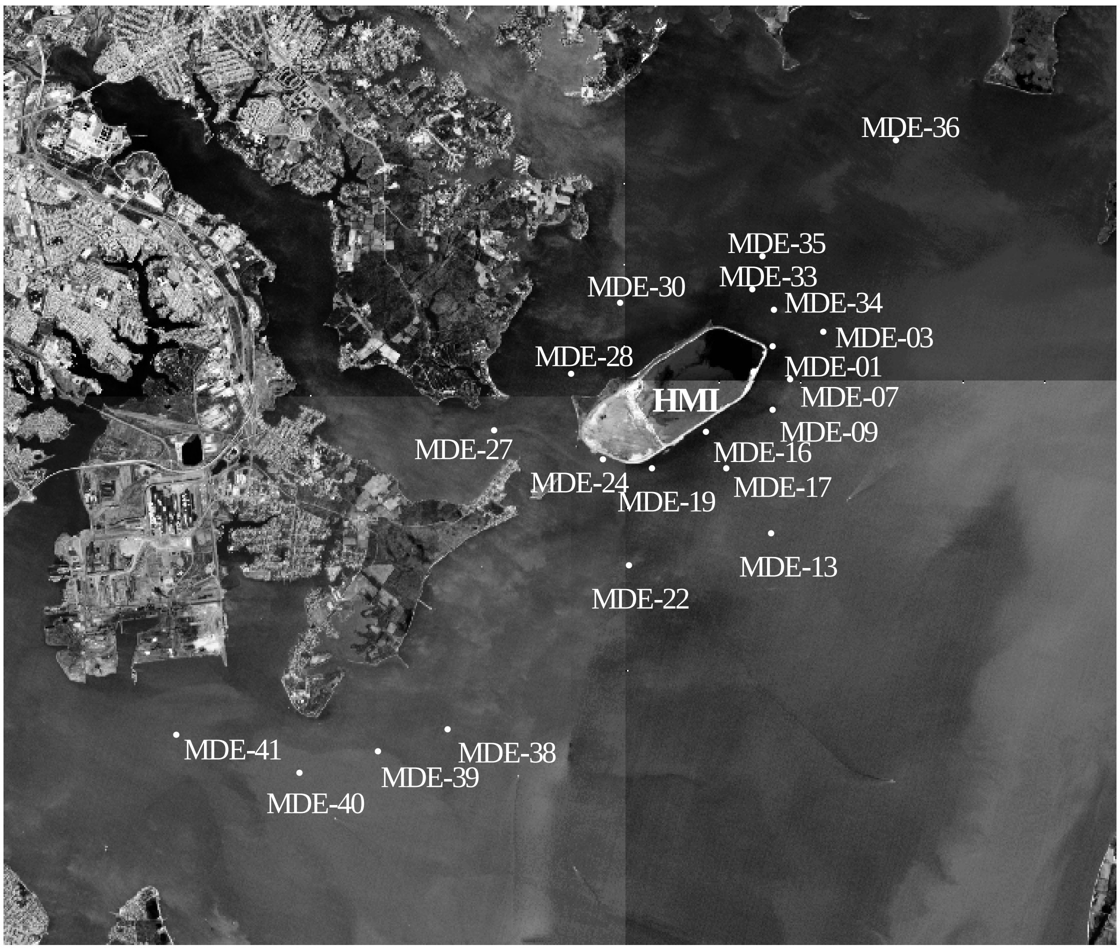


Figure 12: Year 20 Benthic Sampling Stations for the HMI Exterior Monitoring Program.

In Year 18, station MDE-41 was the only Baltimore Harbor station sampled. Three additional stations (MDE-38, MDE-39, and MDE-40) were added in Year 19 to form a transect from the Baltimore Harbor area to HMI. This transect was sampled in conjunction with sediment and benthic tissue analysis studies as part of a comprehensive study to assess the Harbor's influence on environmental conditions in the HMI vicinity. The inclusion of these stations will also provide a linkage to the 1996 Baltimore Harbor benthic community structure study (Brown et al 1998). 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 2001 and April 2002. Water quality parameters were measured at approximately 0.5 m (1.6 feet) below the surface, 1.0 m (3.3 feet) above the bottom, and at 1.0 m intervals from bottom to surface in order to develop a vertical water quality profile at each station. The secchi depth was measured at all stations during both seasons. Water quality data from all depths are found under Project III of the *Year 20 Data Report* (MDE year 20 in review).

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 benthic grab samples were collected at all stations except for MDE-1, MDE-19, MDE-22, MDE-24, and MDE-41 where 6 replicate benthic grabs were taken to be used in a sub-sampling experiment. The data from these extra replicates is not presented in this report. A visual field estimate of the substrate composition [percent contributions of detritus, gravel, shell, sand, and silt/clay (mud)] was made at each station (MDE year 20 in review). Samples were then rinsed through a 0.5-mm sieve on board the vessel and preserved in a solution of 10% formalin and bay water, with rose bengal dye added to stain the benthic organisms.

In the laboratory, each benthic macroinvertebrate sample was placed into a 0.5-mm sieve and rinsed to remove the field preservative and sediment. Organisms were sorted from the remaining debris, separated into vials by major taxonomic groups, and preserved in 70% ethanol. Large organisms were identified to the lowest practical taxon using a stereo dissecting microscope. Members of the insect family Chironomidae were mounted on slides and identified to the lowest practical taxon using a binocular compound microscope. In cases where an animal was fragmented, only the head portion, if fully intact and identifiable, was counted as an individual organism. All other body fragments were discarded. Individuals of the most common clam species (*Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli*) were measured to the nearest millimeter.

Six main measures of benthic community condition were examined, including: total infaunal abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance of pollution-sensitive infaunal taxa, the Shannon-Wiener diversity index, taxa richness and total abundance of all taxa (excluding Nematoda and Bryozoa). The first four of these measures were used to calculate the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) for September 2001. The B-IBI is a multi-metric index of biotic integrity used to determine if benthic populations in different areas of the Chesapeake Bay are stressed

(Weisberg et al. 1997). The B-IBI has not been calibrated for periods outside the summer index period (July 15 through September 30) and, thus, was not used with the April 2002 data. In addition to the above metrics, we examined the numerically dominant taxa during each season and the length frequency distributions of the three most common clams (*R. cuneata*, *M. balthica*, and *M. mitchelli*) was calculated.

Abundance measures were calculated based on the average abundance of each taxon from the three replicate samples collected at each station. Total Abundance was calculated as the average abundance of epifaunal and infaunal organisms per meter squared (#/m^2), excluding Bryozoa, which are colonial. Qualitative estimates (i.e., rare, common or abundant) of the number of live bryozoan zooids are included in the *Year 20 Data Report* (MDE year 20 in review). Total Infaunal Abundance was calculated as the average abundance of infaunal organisms per meter squared (#/m^2). Two different measures of total abundance were calculated because epifaunal organisms are not included in the calculation of the B-IBI (Ranasinghe et al. 1994).

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

The Shannon-Wiener Diversity Index (H') was calculated for each station after data conversion to base 2 logarithms (Pielou 1966). Taxa richness (number of taxa) was calculated for each station as the total number of taxa (infaunal and epifaunal) found in all three replicates. Infaunal taxa richness was calculated as the number of infaunal taxa found in all three replicates. The abundance of the three most common taxa at Reference and Nearfield stations was also examined.

To evaluate the numerical similarity of the infaunal abundances among the 21 stations, a single-linkage cluster analysis was performed on a Euclidean distance matrix comprised of station infaunal abundance values. Friedman’s nonparametric test was used to analyze the differences of the 10 most abundant infaunal species among the Nearfield, Reference, Back River/Hawk Cove and Harbor stations for both September 2001 and April 2002. The statistical analyses were performed using Statistica, Version 6.0.

RESULTS AND DISCUSSION

Water Quality

Secchi depth, salinity, temperature, dissolved oxygen, conductivity, and pH were measured *in situ* at all stations for both sampling events. This report will address the first four of these parameters only. Water quality data for all parameters at all stations are found in the *Year 20 Project III Data Report*. Variations in water quality values throughout the water column were generally small, indicating that no vertical stratification occurred. Because the water column was not vertically stratified, and because water quality conditions at the bottom depths are the most relevant to benthic community health, the following discussion focuses on seasonal variation within the bottom waters only.

Secchi depths were greater in September 2001 (Table 7, range=0.6m-1.4m, average=0.9m ± 0.2m) than those in April 2002 (Table 8, range=0.4m-0.8m, average=0.6m ± 0.15m). Station MDE-39 had the lowest Secchi depth (0.6m) in September 2001. Secchi depths at all stations were greater in September 2001 except MDE-39, which went from 0.6m in September 2001 to 0.8m in April 2002 . It should be kept in mind that secchi depth measurements provide a snapshot of the conditions prevalent at the time of sampling and do not necessarily reflect the dominant water clarity conditions for the entire season.

Bottom salinity was greater in September 2001 (Table 7, range=8.3 ppt-12.5 ppt, average=10.4 ppt ± 1.25 ppt) than in April 2002 (Table 8, range=3.8 ppt-10.0 ppt, average=5.3 ppt ± 1.8 ppt). This 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).

The stations with the highest bottom salinity for Year 20 were similar to those on Year 19. In Year 20, the highest bottom salinity was seen at station MDE-40 in September 2001 (12.5 ppt) and station MDE-41 in April 2002 (10.1 ppt). These are Harbor transect stations, which are the southern most sampling stations and closer to tidal influence.

The stations with the lowest bottom salinity for Year 20 were similar to those in Year 19. In Year 20, the lowest salinity was seen at stations MDE-30 and MDE-33 in September 2001 (8.3 ppt) and station MDE-28 in April 2002 (3.8 ppt). These stations are Back River stations, which receive frequent freshwater input.

In Year 20, bottom water temperatures did not vary much between stations during both sampling seasons. The September 2001 bottom water temperatures (Table 7, range= 22.5 °C – 23.4 °C, average=23.0°C ± 0.25°C) were greater than those seen at HMI in the previous three monitoring years. Bottom water temperatures were seasonably lower in April 2002 with a range of 11.3°C -13.4 °C and an average of 12.3°C ± 0.5°C. The April 2002 bottom water temperatures were lower than those recorded in April 2001.

Average 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 2001 (Table 7, range=4.6 ppm-8.3 ppm, average=6.8 ppm ± 0.9 ppm) than those in April 2002 (Table 8, range=8.7 ppm-12.5 ppm, average=11.5 ppm ± 0.8 ppm).

In September 2001, the lowest bottom DO concentration was 4.6 ppm, recorded at station MDE-40. It is important to note that this station also had the highest temperature (23.4°C) in September 2001. The low bottom DO concentration at station MDE-40 may have been due to the fact that the solubility of a gas in water decreases as the temperature increases (Smith 1996). The highest bottom DO concentration in September 2001 (8.3 ppm) was recorded at station MDE-33, which had one of the lowest temperatures recorded (22.6°C). Similarly, since cold water holds more oxygen, station MDE-33 may have held a high bottom DO concentration compared to other stations with warmer bottom temperatures. In April 2002, the lowest bottom DO concentration was 8.7 ppm, recorded at station MDE-41. The highest bottom DO concentration (12.5 ppm) was seen at Station MDE-03, with no appreciable difference in temperature.

Table 7: Water quality parameters measured *in situ* at all HMI stations on September 25, 2001.

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	0.6	8.5	22.8	6.8	7.2	0.9
		Bottom	3.9	10.0	23.0	6.6	7.2	
MDE-03	XIG5699	Surface	0.5	8.5	22.6	7.5	7.3	0.8
		Bottom	5.5	10.2	23.2	6.7	7.3	
MDE-07	XIF5302	Surface	0.5	8.4	22.6	7.3	7.2	1.0
		Bottom	5.7	10.6	23.1	6.4	7.2	
MDE-09	XIF4806	Surface	0.5	8.5	22.6	7.3	7.2	0.9
		Bottom	5.6	10.3	23.0	7.7	7.3	
MDE-16	XIF4615	Surface	0.5	9.6	22.7	7.0	7.3	0.8
		Bottom	4.4	10.8	23.2	5.8	7.2	
MDE-17	XIF4285	Surface	0.5	9.1	22.7	7.2	7.3	0.8
		Bottom	5.0	10.6	23.2	7.0	7.3	
MDE-19	XIF4221	Surface	0.5	10.3	22.9	6.9	7.3	0.8
		Bottom	4.8	11.3	23.2	7.5	7.4	
MDE-24	XIF4372	Surface	0.5	8.7	22.7	6.9	7.1	1.0
		Bottom	2.5	11.1	23.4	6.6	7.2	
MDE-33	XIF6008	Surface	0.5	8.3	22.7	7.4	7.2	0.8
		Bottom	2.2	8.3	22.6	8.3	7.4	
MDE-34	XIF5805	Surface	0.5	8.4	22.8	7.2	7.2	1.0
		Bottom	3.3	9.9	23.0	7.2	7.1	
MDE-35	XIF6407	Surface	0.5	8.1	22.7	7.6	7.3	0.8
		Bottom	3.7	9.4	23.0	7.9	7.2	
Reference Stations								
MDE-13	XIG3506	Surface	0.5	9.3	22.6	7.3	7.3	0.8
		Bottom	4.9	10.3	22.8	7.1	7.4	
MDE-22	XIF3224	Surface	0.5	9.6	22.8	6.8	7.2	1.0
		Bottom	5.3	11.3	23.2	6.9	7.4	
MDE-36	XIG7589	Surface	0.5	8.2	22.5	7.3	7.2	0.8
		Bottom	3.3	8.8	22.7	6.7	7.2	
Back River/Hawk Cove Stations								
MDE-27	XIF4642	Surface	0.5	8.2	22.8	6.5	7.0	1.0
		Bottom	3.7	9.6	22.5	7.1	7.0	
MDE-28	XIF5232	Surface	0.5	8.4	22.6	7.1	6.9	1.4
		Bottom	2.5	8.5	22.8	7.8	7.2	
MDE-30	XIF5925	Surface	0.5	8.3	22.8	7.7	7.3	1.0
		Bottom	3.2	8.3	22.8	8.0	7.3	
Harbor Stations								
MDE-38	XIF1652	Surface	0.5	12.0	23.2	6.4	7.5	0.8
		Bottom	4.7	12.0	23.2	6.4	7.5	

Table 7: Continued.

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt; ‰)	Temp. (C)	Dissolved Oxygen (mg/l)	pH	Secchi Depth (m)
MDE-39	XIF1343	Surface	0.4	11.7	23.0	6.5	7.5	0.6
		Bottom	4.5	11.9	23.0	6.3	7.4	
MDE-40	XIF1133	Surface	0.5	11.6	23.0	6.4	7.5	1.0
		Bottom	4.5	12.5	23.4	4.6	7.3	
MDE-41	XIF1517	Surface	0.5	11.0	23.2	6.3	7.6	1.2
		Bottom	6.3	12.3	23.3	5.3	7.3	

Table 8: Water quality parameters measured *in situ* at all HMI stations on April 12, 2002.

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt)	Temp. (C)	Dissolved Oxygen (mg/l)	pH	Secchi Depth (m)
Nearfield Stations								
MDE-01	XIF5505	Surface	0.5	4.0	12.5	12.0	8.7	0.4
		Bottom	3.5	4.0	12.5	11.7	8.6	
MDE-03	XIG5699	Surface	0.5	4.2	12.5	11.8	8.4	0.4
		Bottom	5.0	4.4	12.4	12.5	8.4	
MDE-07	XIF5302	Surface	0.5	4.1	12.6	8.5	8.5	0.4
		Bottom	5.5	4.6	12.1	11.8	8.3	
MDE-09	XIF4806	Surface	0.5	4.4	12.3	11.3	8.4	0.6
		Bottom	5.5	5.0	11.9	12.1	8.2	
MDE-16	XIF4615	Surface	0.5	4.5	12.4	10.9	8.4	0.4
		Bottom	3.5	5.2	11.9	11.7	8.2	
MDE-17	XIF4285	Surface	0.5	4.9	11.9	11.5	8.4	0.7
		Bottom	4.5	5.4	11.8	11.6	8.2	
MDE-19	XIF4221	Surface	0.5	4.7	12.3	10.9	8.4	0.7
		Bottom	4.5	5.1	12.1	10.6	8.2	
MDE-24	XIF4372	Surface	0.5	4.3	12.5	11.2	8.6	0.7
		Bottom	2.0	4.3	12.5	11.1	8.5	
MDE-33	XIF6008	Surface	0.5	3.8	12.9	11.7	8.7	0.4
		Bottom	1.5	3.8	12.8	11.6	8.6	
MDE-34	XIF5805	Surface	0.5	3.9	12.7	11.8	8.6	0.6
		Bottom	3.0	3.9	12.6	11.7	8.6	
MDE-35	XIF6407	Surface	0.5	3.8	12.4	11.6	8.4	0.6
		Bottom	3.0	3.9	12.5	12.0	8.5	

Table 8: Continued

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt)	Temp. (C)	Dissolved Oxygen (mg/l)	pH	Secchi Depth (m)
Reference Stations								
MDE-13	XIG3506	Surface	0.5	5.6	11.6	11.2	8.2	0.6
		Bottom	4.5	5.8	11.9	11.7	8.2	
MDE-22	XIF3224	Surface	0.5	4.9	12.2	11.4	8.4	0.6
		Bottom	5.5	5.8	12.0	11.9	8.3	
MDE-36	XIG7589	Surface	0.5	3.7	12.5	11.6	8.3	0.7
		Bottom	2.5	4.0	12.1	11.3	8.0	
Back River/Hawk Cove Stations								
MDE-27	XIF4642	Surface	0.5	4.1	13.6	12.1	9.0	0.4
		Bottom	3.5	4.3	13.2	12.4	8.7	
MDE-28	XIF5232	Surface	0.5	3.9	12.9	11.7	8.9	0.4
		Bottom	2.0	3.8	12.8	11.5	8.8	
MDE-30	XIF5925	Surface	0.5	3.9	13.5	12.1	9.0	0.5
		Bottom	2.5	3.9	13.4	11.9	9.0	
Harbor Stations								
MDE-38	XIF1652	Surface	0.5	6.7	11.9	11.7	8.4	0.8
		Bottom	4.5	7.7	11.8	10.4	8.0	
MDE-39	XIF1343	Surface	0.5	5.6	12.2	11.9	8.5	0.8
		Bottom	4.5	8.1	12.0	10.6	8.3	
MDE-40	XIF1133	Surface	0.5	5.6	12.6	11.9	8.5	0.8
		Bottom	4.0	8.3	12.0	10.7	8.2	
MDE-41	XIF1501	Surface	0.5	5.6	12.4	11.8	8.5	0.7
		Bottom	5.5	10.1	11.3	8.7	7.8	

Benthic Macroinvertebrate Community

Taxa Richness and Dominance

A total of 41 taxa were found over the two seasons sampled during Year 20. This is similar to Years 18 and 19 with 41 and 42 taxa, respectively. Five taxa (*Paraprionospio pinnata*, *Glycinde solitaria*, an undetermined species of the family Xanthidae, an undetermined species from the class Hydrozoa, and *Pectinaria gouldi*) were only present in the Harbor transect stations. The most common taxa were members of the phyla Arthropoda (joint-legged organisms), Annelida (segmented worms), and bivalve mollusks (shellfish having two separate shells joined by a muscular hinge). Ten species of annelid worms in the class polychaeta were found in the course of the study. This is higher than the eight species of polychaetes found in Year 19. Fifteen species of arthropods were found. This is lower than the eighteen species of arthropods found in Year 19. The most common types of arthropods were the amphipods (such as *Leptocheirus plumulosus*), followed by isopods (such as *Cyathura polita*). Of the 41 taxa found in Year 20, twenty-four are considered truly infaunal, fifteen are considered epifaunal, and the remaining two are considered too general to classify as either infaunal or epifaunal (see Ranasinghe et al. 1994). The most common infaunal species found during Year 20 were the amphipod *L. plumlosus* and worms from the family Tubificidae. Of the epifaunal taxa, the most common species were the barnacle *Balanus improvisus* and an undetermined species in the class Anthozoa. Epifaunal taxa, such as the barnacles (*B. improvisus* and *Balanus subalbidus*), bryozoans, and mud crabs (*Rhithropanopeus harrisii*), were found more often at stations where the substrate (sediment) contained a large amount of sand (Tables 9 and 10).

Table 9: Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 20 September 2001 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	Harbor
Nematoda	2.1	44.8	3.4	0.0	0.0	1.2	0.0	10.7	0.0
Nemertea	0.3	6.4	0.0	1.6	0.0	0.6	0.0	0.0	0.0
Carinoma tremophoros	115.8	2432.0	117.2	185.6	41.6	119.9	140.8	181.3	36.8
Bivalvia	36.6	768.0	39.9	36.8	25.6	23.3	61.9	6.4	76.8
Macoma sp.	24.7	518.4	26.1	28.8	16.0	23.3	21.3	21.3	33.6
Macoma balthica	242.0	5081.6	319.5	212.8	19.2	131.5	362.7	328.5	390.4
Macoma mitchelli	21.0	441.6	24.1	6.4	25.6	21.5	25.6	36.3	4.8
Rangia cuneata	219.4	4608.0	209.7	275.2	195.2	266.5	61.9	462.9	25.6
Mulinia lateralis	2.4	51.2	3.9	0.0	0.0	0.0	2.1	0.0	11.2
Ischadium recurvum	7.0	147.2	3.9	11.2	12.8	5.8	0.0	0.0	20.8
Mytilopsis leucophaeata	4.3	89.6	2.5	6.4	8.0	4.1	0.0	2.1	9.6
Capitellidae	0.3	6.4	0.5	0.0	0.0	0.0	0.0	2.1	0.0
Heteromastus filiformis	47.2	992.0	54.6	36.8	33.6	36.1	59.7	10.7	96.0
Marenzellaria viridis	29.3	614.4	13.8	11.2	97.6	45.4	17.1	17.1	3.2
Streblospio benedicti	213.3	4480.0	193.0	272.0	220.8	206.5	183.5	296.5	192.0
Paraprionospio pinnata	0.3	6.4	0.5	0.0	0.0	0.0	0.0	0.0	1.6
Polydora cornuta	3.0	64.0	4.9	0.0	0.0	1.2	2.1	6.4	6.4
Nereididae	22.9	480.0	11.8	20.8	60.8	12.8	2.1	10.7	75.2
Neanthes succinea	100.3	2105.6	78.3	126.4	145.6	66.9	32.0	10.7	310.4
Glycinde solitaria	26.5	556.8	23.6	0.0	62.4	0.0	0.0	0.0	139.2
Eteone heteropoda	8.8	185.6	10.3	3.2	9.6	3.5	2.1	32.0	11.2
Tubificidae	434.6	9126.4	583.4	200.0	185.6	158.3	241.1	1572.3	486.4
Amphipoda	45.1	947.2	64.5	22.4	4.8	9.9	151.5	21.3	80.0
Gammaridea	7.6	160.0	11.8	1.6	0.0	2.3	0.0	0.0	33.6
Ameroculodes spp. complex	21.6	454.4	20.7	8.0	38.4	22.7	32.0	34.1	1.6
Leptocheirus plumulosus	596.4	12524.8	913.2	91.2	72.0	107.1	945.1	450.1	1790.4

Table 9: continued

Taxon	Average Abundance, All stations	Total Abundance, All stations	Substrate			Station Type			
			Silt/Clay	Shell	Sand	Near-field	Ref.	Back River	Harbor
Gammarus sp	1.2	25.6	0.0	0.0	6.4	2.3	0.0	0.0	0.0
Melitadae	0.3	6.4	0.5	0.0	0.0	0.0	2.1	0.0	0.0
Melita nitida	18.9	396.8	27.6	9.6	0.0	9.3	40.5	12.8	33.6
Corophiidae	0.3	6.4	0.5	0.0	0.0	0.0	0.0	2.1	0.0
Apocorophium sp.	0.3	6.4	0.5	0.0	0.0	0.0	0.0	2.1	0.0
Apocorophium lacustre	0.6	12.8	1.0	0.0	0.0	0.0	0.0	4.3	0.0
Cyathura polita	230.1	4832.0	226.5	308.8	163.2	244.9	292.3	381.9	28.8
Edotia triloba	18.9	396.8	9.8	1.6	65.6	25.6	10.7	25.6	1.6
Chirodotea almyra	0.6	12.8	0.5	0.0	1.6	0.6	0.0	2.1	0.0
Balanus sp.	0.3	6.4	0.0	0.0	1.6	0.0	0.0	0.0	1.6
Balanus improvisus	26.2	550.4	8.9	33.6	75.2	36.7	0.0	0.0	36.8
Xanthidae	0.3	6.4	0.5	0.0	0.0	0.0	0.0	0.0	1.6
Rhithropanopeus harrisii	18.9	396.8	13.3	38.4	17.6	25.6	2.1	2.1	25.6
Membranipora sp.	+	+	0.0	+	0.0	0.0	+	0.0	0.0
Tanypodinae	0.3	6.4	0.5	0.0	0.0	0.0	2.1	0.0	0.0
Coelotanypodini	12.8	268.8	20.7	0.0	0.0	0.6	4.3	83.2	0.0
Anthozoa	49.1	1030.4	46.8	0.0	105.6	0.0	0.0	0.0	257.6
Mysidacea	1.5	32.0	2.5	0.0	0.0	0.0	2.1	0.0	6.4
Hobsonia florida	0.6	12.8	0.5	0.0	1.6	0.6	2.1	0.0	0.0
Gobiosoma bosci	0.6	12.8	1.0	0.0	0.0	0.6	0.0	0.0	1.6
Mya arenaria	0.3	6.4	0.5	0.0	0.0	0.0	0.0	0.0	1.6
Piscicola sp.	0.3	6.4	0.5	0.0	0.0	0.0	0.0	0.0	1.6

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

Table 10: Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 20 April 2002 sampling by substrate and station type.

Taxon	Average Abundance All	Total Abundance All	Substrate			Station Type			
			Silt/Clay	Shell	Sand	Near-field	Ref.	Back River	Harbor
Nematoda	0.9	19.2	1.2	0.0	0.0	0.5	0.0	4.3	0.0
Carinoma tremophoros	65.2	1369.6	70.4	46.9	51.2	68.6	98.1	74.7	32.0
Bivalvia	147.8	3104.0	163.6	96.0	99.2	109.7	145.1	46.9	289.6
Macoma sp.	117.0	2457.6	132.8	83.2	41.6	173.7	273.1	61.9	88.0
Macoma balthica	354.7	7449.6	379.2	311.5	224.0	271.1	616.5	334.9	208.0
Macoma mitchelli	57.9	1216.0	62.4	34.1	57.6	94.6	179.2	34.1	25.6
Rangia cuneata	191.1	4012.8	199.2	172.8	153.6	169.6	100.3	371.2	0.0
Mulinia lateralis	17.7	371.2	22.8	2.1	0.0	17.4	0.0	0.0	88.0
Ischadium recurvum	14.3	300.8	5.2	68.3	6.4	18.7	0.0	0.0	16.0
Mytilopsis leucophaeata	3.7	76.8	1.2	12.8	9.6	2.7	2.1	4.3	0.0
Capitellidae	26.2	550.4	25.6	14.9	48.0	20.6	46.9	0.0	19.2
Heteromastus filiformis	0.0	0.0	0.0	0.0	0.0	15.1	0.0	0.0	0.0
Marenzellaria viridis	100.6	2112.0	114.8	34.1	86.4	34.7	253.9	8.5	190.4
Streblospio benedicti	0.0	0.0	0.0	0.0	0.0	35.7	0.0	0.0	0.0
Polydora cornuta	330.7	6944.0	115.6	578.1	1680.0	284.8	181.3	213.3	16.0
Nereidae	251.4	5280.0	270.8	202.7	169.6	96.5	102.4	514.1	473.6
Neanthes succinea	0.0	0.0	0.0	0.0	0.0	67.2	0.0	0.0	0.0
Glycinde solitaria	50.9	1068.8	7.2	317.9	0.0	72.2	0.0	34.1	3.2
Eteone heteropoda	18.6	390.4	17.6	27.7	12.8	50.7	2.1	0.0	68.8
Tubificidae	128.9	2707.2	124.8	219.7	25.6	75.9	27.7	38.4	355.2
Amphipoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gammaridea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ameroculodes spp. complex	31.1	652.8	40.8	0.0	0.0	0.0	0.0	0.0	163.2
Leptocheirus plumulosus	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0
Gammaridae	45.7	960.0	51.2	8.5	57.6	25.1	55.5	36.3	83.2
Gammarus sp	0.0	0.0	0.0	0.0	0.0	126.2	0.0	0.0	0.0
Melitadae	328.5	6899.2	350.0	401.1	48.0	242.7	362.7	283.7	379.2
Melita nitida	0.0	0.0	0.0	0.0	0.0	10.1	0.0	0.0	0.0
Apocorophium sp.	69.8	1465.6	85.6	19.2	19.2	37.5	113.1	27.7	123.2
Apocorophium lacustre	0.3	6.4	0.4	0.0	0.0	1.8	0.0	0.0	0.0
Isopoda	20.4	428.8	11.6	17.1	96.0	158.6	19.2	4.3	8.0
Cyathura polita	1115.1	23417.6	1336.0	298.7	572.8	410.1	1243.7	394.7	3080.0
Edotea triloba	3.0	64.0	4.0	0.0	0.0	0.9	0.0	21.3	0.0
Chiridotea almyra	30.8	646.4	24.0	42.7	67.2	21.9	42.7	38.4	1.6
Cirripedia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Balanus sp.	2.7	57.6	3.6	0.0	0.0	16.9	0.0	4.3	11.2
Balanus improvisus	46.6	979.2	50.0	55.5	6.4	31.1	108.8	8.5	48.0
Balanus subalbidus	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0
Xanthidae	3.0	64.0	0.8	4.3	19.2	9.1	2.1	0.0	0.0

Table 10: Continued.

Taxon	Average Abundance All	Total Abundance All	Substrate			Station Type			
			Silt/Clay	Shell	Sand	Near-field	Ref.	Back River	Harbor
Rhithropanopeus harrisii	14.9	313.6	7.6	59.7	6.4	15.5	10.7	2.1	12.8
Membranipora sp.	+	+	+	+	+	+	+	0.0	+
Tanypodinae	0.3	6.4	0.4	0.0	0.0	0.9	0.0	2.1	0.0
Chirnomidae	0.9	19.2	0.8	2.1	0.0	0.9	0.0	2.1	0.0
Coelotanypodini	6.4	134.4	8.4	0.0	0.0	0.0	8.5	36.3	0.0
Procladiini	0.9	19.2	1.2	0.0	0.0	0.0	6.4	0.0	0.0
Anthozoa	71.9	1510.4	94.4	0.0	0.0	0.0	196.3	0.0	230.4
Hydrozoa	0.6	12.8	0.8	0.0	0.0	0.0	0.0	0.0	3.2
Mysidacea	1.2	25.6	1.2	2.1	0.0	1.4	0.0	0.0	1.6
Hobsonia florida	0.3	6.4	0.4	0.0	0.0	0.0	0.0	2.1	0.0
Mya arenaria	3.7	76.8	1.6	8.5	12.8	5.5	0.0	0.0	0.0
Copepoda	32.0	672.0	22.4	17.1	131.2	31.1	27.7	0.0	1.6
Platyhelminthes	0.3	6.4	0.0	0.0	3.2	0.5	0.0	0.0	0.0
Pectinaria gouldi	0.6	12.8	0.8	0.0	0.0	0.0	0.0	0.0	3.2

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

Harbor station MDE-41 had the greatest number of taxa in September 2001 (18), followed by the Back River stations MDE-27 and MDE-28, the Reference station MDE-36, the Nearfield station MDE-16, and the Harbor station MDE-38 (17 each, see Table 11). The stations with the fewest taxa in September 2001 of Year 20 were Back River/Hawk Cove station MDE-30 (11) and Nearfield station MDE-19 (11 taxa - see Table 11). Overall, average taxa richness was highest at the Harbor stations but did not vary greatly between stations types (Nearfield=14.90 taxa, Reference=15.33 taxa, Back River/Hawk Cove=15.0 taxa, Harbor=16.0 taxa).

In April 2002, Nearfield station MDE-34 had the greatest number of taxa (24), followed closely by the Nearfield stations MDE-03, MDE-09, MDE-24, and the Harbor station MDE-40 (21 each - Table 12). The number of taxa was higher at most stations in April 2002 than in September 2002 and may be due to seasonal recruitment. The Nearfield station MDE-35 and the Back River station MDE-30 both had the lowest number of taxa (14 each, see Table 12). Overall, the average taxa richness was highest at the Nearfield stations, and did not vary greatly between station types (Nearfield=19.09 taxa, Reference=17.33 taxa, Back River=16.00 taxa, Harbor=18.75 taxa).

Since the first benthic survey studies of the Hart-Miller Island area in 1981, a small number of taxa have been dominant; Year 20 was no exception. During both seasons, 3 taxa were clearly dominant. In September 2001, these taxa were the amphipod *L. plumulosus*, oligochaete worms of the family Tubificidae, and the bivalve mollusk *Macoma balthica*. The average abundance of each taxon (individuals per meter squared) found at each station during September 2001 is provided in Tables 13 and 14.

In April 2002, *L. plumulosus* and *M. balthica* continued to numerically dominate the benthic macroinvertebrate community, while the polychaete *Marenzelleria viridis* replaced worms in the family Tubificidae. This is similar to Year 19, where heavy seasonal recruitment of *M. viridis* replaced *Streblospio benedicti* as dominant species. The average abundance of each taxon (individuals per meter squared) found at each station during April 2002 is provided in Tables 15 and 16.

Table 11: Summary of metrics for each HMI benthic station surveyed during the Year 20 September 2001 sampling cruise. Total Infaunal Abundance and Total Abundance (individuals per square meter), excluding Polycladida, Nematoda, and Bryozoa.

Station	Total Infauna	Total All (excluding Polycladida, Nematoda, & bryozoans)	All Taxa	Infaunal Taxa	Shannon-Wiener	PSTA	PITA	B-IBI
Nearfield Stations								
MDE-01	1132.8	1318.4	16	12	2.89	63.3	19.2	3.5
MDE-03	1817.6	1958.4	14	11	3.09	28.9	40.5	3.0
MDE-07	2246.4	2336.0	16	13	3.21	48.7	24.8	3.5
MDE-09	1708.8	1804.8	13	11	2.91	60.7	16.1	4.0
MDE-16	1484.8	1670.4	17	13	3.23	47.4	23.7	3.0
MDE-17	1734.4	1849.6	14	11	2.97	65.3	4.8	4.5
MDE-19	774.4	800.0	11	10	3.01	39.7	22.3	2.5
MDE-24	1395.2	1651.2	16	14	3.27	54.1	20.6	3.0
MDE-33	940.8	1024.0	15	13	2.97	44.2	22.4	3.0
MDE-34	1440.0	1657.6	16	11	2.94	33.3	36.4	2.5
MDE-35	1632.0	1708.8	16	14	2.80	24.7	39.6	3.0
Reference Stations								
MDE-13	1657.6	1779.2	16	12	2.99	31.3	5.8	4.0
MDE-22	3635.2	3788.8	13	12	2.58	36.8	7.0	3.5
MDE-36	2323.2	2412.8	17	16	2.98	14.9	35.3	3.0
Back River/Hawk Cove Stations								
MDE-27	8710.4	8800.0	17	14	2.44	20.9	56.9	1.5
MDE-28	2272.0	2342.4	17	14	2.44	63.4	27.3	3.0
MDE-30	908.8	921.6	11	10	2.94	33.8	42.3	2.5
Harbor Stations								
MDE-38	5254.4	5574.4	17	15	1.92	11.3	7.4	3.0
MDE-39	5331.2	5574.4	14	12	1.86	11.3	11.9	2.5
MDE-40	2131.2	2854.4	15	9	2.67	12.3	44.1	3.0
MDE-41	2182.4	2924.8	18	13	2.82	41.1	38.4	3.5

Table 12: Summary of metrics for each HMI benthic station surveyed during the Year 20 April 2002 sampling cruise. Total Infaunal Abundance and Total Abundance (individuals per square meter), excluding Polycladida, Nematoda, and Bryozoa.

Station	Total Infauna	Total All (excluding Polycladida, Nematoda, & bryozoans)	All Taxa	Infaunal Taxa	Shannon-Wiener	PSTA	PITA
Nearfield Stations							
MDE-01	2118.4	6182.4	18	10	2.18	3.9	36.0
MDE-03	2617.6	2803.2	21	12	3.40	45.5	24.7
MDE-07	3123.2	3315.2	19	15	3.03	32.4	24.0
MDE-09	3008.0	3212.8	21	15	3.32	47.0	10.6
MDE-16	3865.6	4313.6	17	13	3.39	46.2	25.0
MDE-17	3200.0	3488.0	18	14	3.16	45.0	12.8
MDE-19	876.8	1132.8	18	13	3.50	43.1	16.8
MDE-24	3289.6	3488.0	21	15	3.21	50.4	9.7
MDE-33	3859.2	4320.0	19	15	2.31	70.3	6.1
MDE-34	4435.2	4876.8	24	18	3.25	57.9	9.8
MDE-35	2636.8	2860.8	14	12	2.83	20.6	13.8
Reference Stations							
MDE-13	1792.0	2041.6	17	13	2.91	33.9	3.2
MDE-22	6694.4	7609.6	17	13	3.24	31.1	18.7
MDE-36	3852.8	4224.0	19	16	2.83	30.4	7.0
Back River/Hawk Cove Stations							
MDE-27	2841.6	2912.0	15	13	3.00	51.8	17.8
MDE-28	4108.8	4230.4	19	16	3.17	33.8	44.7
MDE-30	1216.0	1273.6	14	12	3.16	38.4	22.1
Harbor Stations							
MDE-38	5907.2	6368.0	16	13	2.11	5.7	16.4
MDE-39	5228.8	5472.0	18	13	2.46	7.1	16.2
MDE-40	4256.0	5049.6	21	14	2.87	8.6	25.0
MDE-41	6355.2	7417.6	20	13	2.19	9.2	19.2

Table 13: Average number of Individuals collected per square meter at each station during the HMI Year 20 late summer sampling, September 2001, 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
Nemertea	0	0	6.4	0	0	0	0	0	0
Carinoma tremophoros	64	230.4	211.2	192	185.6	134.4	140.8	108.8	179.2
Bivalvia	12.8	44.8	25.6	6.4	57.6	19.2	44.8	12.8	89.6
Macoma sp	0	19.2	51.2	38.4	19.2	6.4	44.8	57.6	25.6
Macoma balthica	19.2	76.8	288	243.2	224	204.8	473.6	38.4	812.8
Macoma mitchelli	0	12.8	6.4	32	19.2	12.8	6.4	0	32
Rangia cuneata	179.2	185.6	352	563.2	25.6	281.6	243.2	19.2	64
Mulinia lateralis	0	0	0	0	6.4	0	0	0	0
Ischadium recurvum	12.8	12.8	12.8	0	0	0	19.2	0	0
Mytilopsis leucophaeata	0	12.8	0	0	0	0	0	0	0
Heteromastus filiformis	6.4	44.8	44.8	64	89.6	57.6	32	32	51.2
Marenzellaria viridis	224	25.6	6.4	0	12.8	12.8	12.8	38.4	12.8
Streblospio benedicti	166.4	492.8	249.6	89.6	32	179.2	38.4	153.6	51.2
Polydora cornuta	0	0	0	0	0	6.4	0	0	0
Nereidae	0	12.8	12.8	6.4	6.4	38.4	6.4	0	0
Neanthes succinea	6.4	172.8	121.6	32	44.8	153.6	51.2	0	32
Eteone heteropoda	0	0	6.4	0	0	0	0	0	0
Tubificidae	51.2	243.2	300.8	185.6	57.6	172.8	44.8	19.2	204.8
Amphipoda	0	6.4	6.4	0	134.4	6.4	76.8	0	179.2
Gammaridea	0	0	6.4	19.2	0	0	0	0	0
Ameroculodes spp complex	38.4	0	19.2	6.4	0	6.4	0	25.6	32
Leptocheirus plumulosus	76.8	57.6	121.6	25.6	544	6.4	160	70.4	1510.4
Melita nitida	0	0	0	0	19.2	0	25.6	0	64
Cyathura polita	294.4	236.8	448	230.4	256	204.8	403.2	211.2	448
Edotia triloba	6.4	0	0	0	32	6.4	0	12.8	0
Chiridotea almyra	6.4	0	0	0	0	0	0	0	0
Balanus improvisus	153.6	0	12.8	38.4	0	76.8	0	0	0
Rhithropanopeus harrisii	0	70.4	25.6	32	6.4	76.8	25.6	0	0
Membranipora sp	+	+	+	+	+	+	+	+	+
Mysidacea	0	0	0	0	6.4	0	0	0	0
Gobiosoma bosci	0	0	0	0	0	6.4	0	0	0

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

Table 14: Average number of Individuals collected per square meter during the HMI Year 20 early fall sampling, September 2001, stations MDE-24 to MDE-41.

Taxon	Station											
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36	MDE-38	MDE-39	MDE-40	MDE-41
Nematoda	0	19.2	12.8	0	0	0	12.8	0	0	0	0	0
Carinoma tremophoros	51.2	377.6	108.8	57.6	12.8	160	12.8	57.6	25.6	19.2	38	64
Bivalvia	0	0	19.2	0	57.6	32	0	38.4	224	38.4	32	12.8
Macoma sp	0	19.2	6.4	38.4	38.4	0	0	19.2	32	6.4	26	70.4
Macoma balthica	38.4	953.6	19.2	12.8	6.4	12.8	44.8	51.2	480	480	13	588.8
Macoma mitchelli	44.8	102.4	6.4	0	57.6	0	64	25.6	0	6.4	0	12.8
Rangia cuneata	294.4	192	1120	76.8	307.2	320	185.6	96	12.8	38.4	0	51.2
Mulinia lateralis	0	0	0	0	0	0	0	0	19.2	25.6	0	0
Ischadium recurvum	0	0	0	0	6.4	0	0	0	0	0	32	51.2
Mytilopsis leucophaeata	0	0	6.4	0	19.2	12.8	0	0	0	0	13	25.6
Capitellidae	0	6.4	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	19.2	25.6	6.4	0	38.4	25.6	32	38.4	217.6	76.8	70	19.2
Marenzellaria viridis	115.2	0	51.2	0	51.2	0	12.8	25.6	12.8	0	0	0
Streblospio benedicti	211.2	332.8	281.6	275.2	198.4	307.2	185.6	467	128	250	307	83.2
Paraprionospio pinnata	0	0	0	0	0	0	0	0	6.4	0	0	0
Polydora cornuta	0	0	6.4	12.8	0	0	6.4	6.4	0	0	0	25.6
Nereidae	6.4	32	0	0	6.4	51.2	0	0	6.4	25.6	230	38.4
Neanthes succinea	12.8	6.4	6.4	19.2	25.6	160	0	19.2	198.4	352	538	153.6
Glycinde solitaria	0	0	0	0	0	0	0	0	19.2	38.4	250	249.6
Eteone heteropoda	19.2	96	0	0	0	6.4	6.4	6.4	6.4	0	19	19.2
Tubificidae	57.6	4410	262.4	51.2	12.8	211.2	448	333	230.4	358	614	736
Amphipoda	12.8	44.8	0	19.2	0	0	0	141	249.6	44.8	6.4	19.2
Gammaridea	0	0	0	0	0	0	0	0	0	134	0	0
Ameroculodes spp complex	108.8	44.8	57.6	0	6.4	12.8	25.6	64	6.4	0	0	0
Leptocheirus plumulosus	70.4	1267	12.8	70.4	121.6	25.6	441.6	781	3533	3565	19	44.8
Gammarus sp	25.6	0	0	0	0	0	0	0	0	0	0	0
Melitadae	0	0	0	0	0	0	0	6.4	0	0	0	0
Melita nitida	0	25.6	0	12.8	0	12.8	64	38.4	70.4	64	0	0
Corophiidae	0	6.4	0	0	0	0	0	0	0	0	0	0
Apocorophium sp	0	6.4	0	0	0	0	0	0	0	0	0	0
Apocorophium lacustre	0	12.8	0	0	0	0	0	0	0	0	0	0
Cyathura polita	307.2	678.4	249.6	217.6	51.2	147.2	160	173	70.4	44.8	0	0
Edotia triloba	249.6	38.4	38.4	0	0	6.4	0	0	0	0	6.4	0
Chiridotea almyra	0	6.4	0	0	0	0	0	0	0	0	0	0
Balanus sp	0	0	0	0	0	0	0	0	0	0	6.4	0
Balanus improvisus	0	0	0	0	0	121.6	0	0	0	0	147	0

Table 14: Continued

	Station											
Taxon	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36	MDE-38	MDE-39	MDE-40	MDE-41
Xanthidae	0	0	0	0	0	0	0	0	0	0	0	6.4
Rhithropanopeus harrisii	6.4	0	6.4	0	0	32	12.8	0	0	0	64	38.4
Membranipora sp	0	0	0	0	+	+	0	+	0	0	+	+
Tanypdinae	0	0	0	0	0	0	0	6.4	0	0	0	0
Coelotanypodini	0	115.2	76.8	57.6	0	0	6.4	12.8	0	0	0	0
Anthozoa	0	0	0	0	0	0	0	0	0	6.4	422	601.6
Mysidacea	0	0	0	0	0	0	0	0	25.6	0	0	0
Hobsonia florida	0	0	0	0	6.4	0	0	6.4	0	0	0	0
Gobiosoma bosci	0	0	0	0	0	0	0	0	0	0	0	6.4
Mya arenaria	0	0	0	0	0	0	0	0	0	0	0	6.4
Piscicola sp.	0	0	0	0	0	0	0	0	0	6.4	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 20 spring sampling, April 2002, stations MDE-1 to MDE-22.

Taxon	Station								
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19	MDE-22
Nematoda	0	0	0	0	0	0	0	0	0
Carinoma tremophoros	0	70.4	76.8	51.2	57.6	166.4	102.4	32	179.2
Bivalvia	6.4	51.2	64	147.2	96	262.4	153.6	121.6	121.6
Macoma sp	6.4	51.2	70.4	236.8	38.4	243.2	32	38.4	454.4
Macoma balthica	38.4	358.4	544	396.8	198.4	595.2	633.6	57.6	1292.8
Macoma mitchelli	0	51.2	44.8	25.6	38.4	83.2	38.4	32	345.6
Rangia cuneata	6.4	268.8	89.6	544	70.4	633.6	313.6	89.6	76.8
Mulinia lateralis	0	0	0	12.8	0	0	0	0	0
Ischadium recurvum	198.4	6.4	6.4	12.8	0	0	0	0	0
Mytilopsis leucophaeata	19.2	19.2	0	0	0	0	0	0	0
Capitellidae	25.6	19.2	6.4	0	6.4	38.4	121.6	12.8	121.6
Heteromastus filiformis	6.4	51.2	70.4	83.2	115.2	83.2	32	19.2	627.2
Marenzellaria viridis	38.4	204.8	160	96	12.8	128	51.2	32	76.8
Streblospio benedicti	179.2	172.8	185.6	89.6	6.4	96	89.6	0	256
Polydora cornuta	940.8	0	0	0	0	0	0	0	0
Nereidae	51.2	6.4	0	0	6.4	0	0	0	0
Neanthes succinea	211.2	243.2	25.6	134.4	51.2	64	102.4	51.2	6.4
Glycinde solitaria	0	0	0	0	0	0	0	0	0
Eteone heteropoda	0	12.8	51.2	6.4	19.2	83.2	25.6	6.4	140.8
Tubificidae	582.4	460.8	512	211.2	32	787.2	294.4	140.8	857.6
Amphipoda	12.8	19.2	25.6	83.2	89.6	115.2	70.4	38.4	89.6
Gammaridea	0	0	0	0	0	0	6.4	0	0
Ameroculodes spp complex	0	0	6.4	12.8	19.2	12.8	6.4	44.8	6.4
Leptocheirus plumulosus	12.8	268.8	1017.6	646.4	704	307.2	844.8	76.8	1529.6
Gammaridae	0	0	0	0	0	0	0	0	0
Gammarus sp	0	0	12.8	0	0	0	0	6.4	0
Melitadae	0	0	0	0	0	0	0	0	0
Melita nitida	134.4	12.8	83.2	6.4	115.2	0	70.4	19.2	108.8
Apocorophium sp	12.8	0	0	0	6.4	0	0	6.4	0
Apocorophium lacustre	102.4	0	0	0	0	0	0	0	0
Cyathura polita	0	358.4	217.6	358.4	326.4	428.8	435.2	198.4	633.6
Edotia triloba	0	6.4	0	6.4	0	19.2	12.8	0	0
Balanus sp	12.8	0	0	0	6.4	0	6.4	0	0
Balanus improvisus	3379.2	19.2	32	6.4	0	6.4	19.2	12.8	0
Balanus subalbidus	57.6	6.4	6.4	0	6.4	0	0	0	0
Rhithropanopeus harrisii	134.4	38.4	0	12.8	19.2	6.4	0	12.8	12.8

Table 15: Continued.

Taxon	Station								
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19	MDE-22
Membranipora sp	+	+	+	+	+	+	+	+	0
Chironomidae	6.4	0	6.4	0	0	0	0	0	0
Anthozoa	0	0	0	0	0	0	0	0	588.8
Mysidacea	0	6.4	0	12.8	0	0	0	0	0
Mya arenaria	0	0	0	19.2	0	0	6.4	0	0
Copepoda	6.4	19.2	0	0	0	153.6	19.2	83.2	83.2

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

Table 16: Average number of Individuals collected per square meter at each station during the HMI Year 20 spring sampling, April 2002, stations MDE-24 to MDE-41.

Taxon	Station											
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36	MDE-38	MDE-39	MDE-40	MDE-41
Nematoda	0	0	12.8	0	0	0	6.4	0	0	0	0	0
Carinoma tremophoros	70.4	83.2	115.2	25.6	32	70.4	51.2	57.6	57.6	51.2	12.8	6.4
Bivalvia	0	25.6	83.2	32	198.4	230.4	134.4	217.6	275.2	140.8	128	614.4
Macoma sp	76.8	32	108.8	44.8	6.4	192	147.2	326.4	64	83.2	166.4	38.4
Macoma balthica	358.4	800	153.6	51.2	89.6	537.6	153.6	358.4	236.8	288	38.4	268.8
Macoma mitchelli	57.6	19.2	83.2	0	57.6	51.2	32	153.6	25.6	0	12.8	64
Rangia cuneata	70.4	166.4	889.6	57.6	236.8	243.2	102.4	153.6	0	0	0	0
Mulinia lateralis	0	0	0	0	0	6.4	0	0	147.2	160	12.8	32
Ischadium recurvum	0	0	0	0	12.8	0	0	0	0	0	57.6	6.4
Mytilopsis leucophaeata	0	0	12.8	0	19.2	0	0	6.4	0	0	0	0
Capitellidae	51.2	0	0	0	44.8	0	12.8	12.8	0	57.6	0	19.2
Heteromastus filiformis	96	19.2	0	6.4	76.8	44.8	0	19.2	211.2	339.2	76.8	134.4
Marenzellaria viridis	1024	147.2	268.8	224	2336	1491	134.4	454.4	0	12.8	44.8	6.4
Streblospio benedicti	153.6	83.2	1299	160	185.6	256	128	44.8	550.4	288	428.8	627.2
Polydora cornuta	0	0	102.4	0	0	12.8	0	0	0	0	12.8	0
Nereidae	12.8	0	0	0	12.8	25.6	0	0	0	25.6	224	25.6
Neanthes succinea	25.6	76.8	12.8	25.6	25.6	204.8	0	25.6	217.6	345.6	563.2	294.4
Glycinde solitaria	0	0	0	0	0	0	0	0	32	32	281.6	307.2
Eteone heteropoda	115.2	44.8	44.8	19.2	0	12.8	38.4	6.4	83.2	102.4	102.4	44.8
Tubificidae	51.2	377.6	428.8	44.8	51.2	160	198.4	192	185.6	294.4	518.4	518.4
Amphipoda	12.8	6.4	38.4	38.4	25.6	25.6	121.6	160	185.6	121.6	76.8	108.8
Gammaridea	0	0	0	0	0	0	0	0	0	0	0	0
Ameroculodes spp complex	140.8	0	12.8	0	51.2	51.2	0	32	25.6	0	6.4	0
Leptocheirus plumulosus	704	601.6	243.2	339.2	441.6	614.4	1248	1498	3814	2982	1677	3846
Gammaridae	0	19.2	44.8	0	0	0	0	0	0	0	0	0
Gammarus sp	44.8	6.4	108.8	0	89.6	128	115.2	128	0	6.4	0	0
Melitadae	0	12.8	0	0	0	0	0	0	12.8	25.6	6.4	0
Melita nitida	12.8	12.8	0	12.8	0	19.2	76.8	102.4	140.8	32	12.8	6.4
Apocorophium sp	6.4	0	0	0	32	0	0	0	0	0	0	0
Apocorophium lacustre	25.6	0	0	6.4	44.8	19.2	0	0	12.8	12.8	6.4	6.4
Isopoda	0	0	0	0	6.4	0	0	0	0	0	0	0
Cyathura polita	204.8	358.4	76.8	134.4	25.6	268.8	153.6	204.8	70.4	38.4	0	0
Edotea triloba	19.2	19.2	19.2	0	0	96	0	25.6	19.2	6.4	6.4	0
Chiridotea almyra	19.2	0	0	0	38.4	12.8	0	0	0	0	0	0
Cirripedia	6.4	0	0	0	0	0	0	0	0	0	0	0
Balanus sp	0	0	0	0	0	0	0	0	0	0	0	0
Balanus improvisus	0	0	0	0	0	44.8	0	0	0	0	25.6	0

Table 16: Continued.

Taxon	Station											
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36	MDE-38	MDE-39	MDE-40	MDE-41
Balanus subalbidus	0	0	0	0	0	0	0	0	0	0	0	0
Xanthidae	0	0	0	0	0	0	0	0	0	0	0	6.4
Rhithropanopeus harrisii	6.4	0	6.4	0	6.4	6.4	0	0	0	0	25.6	25.6
Membranipora sp	+	0	0	0	+	+	+	0	0	0	+	+
Tanypdinae	0	0	0	6.4	0	0	0	0	0	0	0	0
Chironomidae	0	0	6.4	0	0	0	0	0	0	0	0	0
Coelotanypodini	0	0	64	44.8	0	0	0	25.6	0	0	0	0
Procladiini	0	0	0	0	0	0	0	19.2	0	0	0	0
Anthozoa	0	0	0	0	0	0	0	0	0	12.8	524.8	384
Hydrozoa	0	0	0	0	0	0	0	0	0	12.8	0	0
Mysidacea	0	0	0	0	0	0	0	0	0	0	0	6.4
Hobsonia florida	0	0	6.4	0	0	0	0	0	0	0	0	0
Mya arenaria	0	0	0	0	25.6	25.6	0	0	0	0	0	0
Copepoda	115.2	0	0	0	147.2	25.6	12.8	0	0	0	0	6.4
Platyhelminthes	6.4	0	0	0	0	0	0	0	0	0	0	0
Pectinaria gouldi	0	0	0	0	0	0	0	0	0	0	0	12.8

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

Taxa Abundance

Total abundance was higher in the spring (April 2002) than in the late summer (September 2001) due to seasonal recruitment. In September 2001 total abundance in the vicinity of HMI ranged from 800 to 8800 organisms per square meter (individuals/m^2) and averaged 2607 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 2001 abundance was found at the Back River/Hawk Cove station MDE-27, due primarily to large numbers of the amphipod *Leptocheirus plumulosus* and members of the oligochaete family Tubificidae. The lowest abundance in September 2001 was found at the Nearfield station MDE-19 (Table 11, Figure 13). Average total abundance was moderately similar between Reference and Nearfield stations in the September 2001 (1616.3 individuals/m^2 and 2660.3 individuals/m^2, respectively); however, total abundance was much higher at the Harbor Stations (4232.0 individuals/m^2) and Back River/Hawk Cove stations (4021.3 individuals/m^2).

In April 2002, total abundance ranged from 1132.8 to 7609.6 organisms per meter squared and averaged 4122.5 individuals/m^2. The station with the highest abundance was the Reference station MDE-22, due to very high numbers of the bivalve *Macoma balthica* and *L. plumulosus*. The lowest spring abundance occurred at the Nearfield station MDE-19 (Table 12, Figure 13). This was due in part to the near absence of the polychaete worm *Marenzelleria viridis*, which generally occurred in high numbers at other stations (Table 12, Figure 13). The average total abundance was lowest at the Back River/Hawk Cove stations (2805.3 individuals/m^2) and highest at the Harbor stations (6076.8 individuals/m^2), with the Nearfield and Reference stations falling in between (3634.0 individuals/m^{2}and 4625.1individuals/m^2, respectively).

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 20, total infaunal abundance was similar to total abundance, accounting for ≥75% of all organisms at most stations during both seasons. The only exception was at Nearfield station MDE-01, where 65.7% of total abundance was epifaunal.

Species Diversity

Species diversity was examined using the Shannon-Wiener diversity index, which measures diversity on a numerical scale from 1 to 4. A lower score indicates an unbalanced community dominated by only one or two species whereas a higher score suggests a balanced, diverse benthic community. Pfitzenmeyer et al. (1982) suggested that diversity, as measured by the Shannon-Wiener Diversity Index (SWDI), would be higher in the summer than the spring, when recruitment decreased and predation increased thus reducing the numbers of the dominant taxa. Diversity has often been lowest at most stations in spring (April or May) due to an influx of juveniles, especially of the dominant species (Duguay et al. 1998, Duguay et al. 1995a, Duguay et al. 1995b, Duguay 1992, Duguay 1990, Pfitzenmeyer and Tenore 1987). Diversity values for Year 20 are presented in Tables 11 & 12. In this monitoring year, diversity values were not distinctly higher in one season versus the other. Diversity was higher in September than in April at five of the twenty-one stations, lower in September than in April at another thirteen stations, and similar (≤ 0.10 difference) between the two seasons at the remaining three stations (Figure 14). These results are similar to Year 19, when eight out of twenty-one stations had higher diversity values in the September 2000 than in April 2001, nine stations were lower in September 2000 than in April 2001, and two were similar between the two seasons.

The Shannon-Weiner diversity Index (SWDI) values in Year 20 averaged 2.78 ± 0.42 in September 2001 and 3.01 ± 0.39 in April 2002. The lowest diversity value in September 2001 occurred at Harbor station MDE-39 (1.86). This was due to the predominance of the amphipod *Leptocheirus plumulosus*, which accounted for 66.9% of total infaunal abundance at this station. The highest September 2000 diversity value occurred at Nearfield station MDE-24 (3.27). The lowest diversity value in April 2002 occurred at Harbor station MDE-38 (2.11), due to the large percentage of the amphipod *L. plumulosus*, which accounted for 64.6% of total infaunal abundance at this station. The highest April 2002 diversity value occurred at Nearfield station MDE-19 (3.50).

For the most part, Nearfield stations had diversity values similar to Reference stations in both seasons, with the exception of Nearfield station MDE-01, which had the second lowest diversity value for April 2002 (2.18). This low diversity was due to a high percentage of *Balanus improvisus*, which accounted for 54.7% of the total abundance of organisms. This station typically has a high percentage of shell, which provides a good substrate for barnacles to attach such as *B. improvisus*.

Pollution Sensitive Taxa Abundance

There were six taxa found during Year 20 benthic monitoring that were designated as "pollution-sensitive" according to Weisberg et al. (1997). These were the clams *Rangia cuneata, Macoma balthica* and *Mya arenaria;* the polychaete worms *Marenzelleria viridis* and *Glycinde solitaria;* and the isopod crustacean *Cyathura polita.* Relative abundance of these taxa was calculated as a proportion of total infaunal abundance. In September 2001, the average pollution-sensitive taxa abundance (PSTA) ranged from 11.3% at MDE-38, a Harbor station to 65.3% at MDE-17 a nearfield station (Table 11). The average PSTA for September 2001 was 37.5%. In April 2002, the lowest average PSTA was 3.9% at MDE-1 and the highest was 70.4% at MDE-33, both of which were Nearfield stations (Table 12). The average PSTA in April 2002 was 33.9%.

In September 2001, the lowest average PSTA was 19.0% at the Harbor stations followed by the Reference stations at 27.6% and Back River stations at 39.4%. The highest average PSTA occurred at the Nearfield stations with an average PSTA of 46.4%. In April 2002, the average PSTA of the Reference stations, Back River, Nearfield, and Baltimore Harbor stations was 31.8%, 41.3%, 42.0%, and 7.7%, respectively. Historically, the PSTA's in April are higher than September, however this was true of only the Back River and Reference stations (Figure 15). This may be due to low seasonal recruitment of the polychaete worm *M. viridis*.

Pollution Indicative Taxa Abundance

Four taxa found during Year 20 benthic monitoring were designated as "pollution-indicative" according to Weisberg et al. (1997). These were the clam *Mulinia lateralis*, and the polychaete worms *Streblospio benedicti* and *Eteone heteropoda*. In addition, oligochaete worms of the family Tubificidae were classified as pollution-indicative because past studies have shown *Limnodrillus hoffmeisteri*, which is considered pollution-indicative, to be common in the vicinity of HMI. Relative abundance of these taxa was calculated as a proportion of total infaunal abundance. In September 2001, the relative abundance of pollution-indicative taxa (PITA) ranged from 4.8% at MDE-17, a Nearfield station and 55.5% at MDE-27 a Back River station (Table 11, Figure 16). The average PITA for September 2001 was 25.5%. In April 2002 the PITA ranged from 3.2% at MDE-13 a Reference station, to 43.1% at MDE-28 a Back River station (Table 12, Figure 16). The average PITA was 17.8%.

In September 2001, the Reference stations had an average PITA of 15.8%, the Nearfield stations had an average of 24.6% and Harbor stations and Back River stations had average PITA's of 25.5% and 42.2% respectively. In April 2002, the PITA averaged 9.4% for Reference stations, 17.2% for Nearfield stations, 19.2% for Harbor stations and 28.2% for Back River stations.

Clam Length Frequency Distribution

In September 2001, *Rangia cuneata* had the greatest abundance at the Back River stations, followed by Nearfield, Reference and Harbor stations (Table 9). The greatest abundance of *R. cuneata* was found in the 16-20 mm size class. In April 2002, the greatest average abundance of *R. cuneata* occurred at the Back River stations followed by Nearfield and Reference stations in the 21-25 mm size class. There were no *R. cuneata* present in the Harbor stations in April 2002 (Table 10).

The greatest average abundance of *Macoma mitchelli* in September 2001 occurred at the Back River stations, followed by Nearfield, Reference and Harbor stations (Table 9). The greatest abundance of *M. mitchelli* for all stations was found in the 19-20 mm size class. In April 2002, the greatest average abundances for *M. mitchelli* were found at the Reference stations followed by the Nearfield, Back River and Harbor stations and had the strongest recruitment for all station types in the 1-2 mm size class. The greatest average abundance in September 2001 for *Macoma balthica* occurred at the Harbor stations followed by Reference, Back River and Nearfield stations (Table 9). For all stations the greatest recruitment of *M. balthica* was in the 15-16 mm size class. In April 2002, *M. balthica* had the greatest average abundances at the Reference stations followed by Nearfield, Back River and Harbor stations (Table 10). For all stations in April 2002, *M. balthica* had its greatest abundance in the 7-8 mm size class. All size class data for clams is available in the *Year 20 Data Report*.

Benthic Index of Biotic Integrity (B-IBI)

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) was calculated for all stations based on September 2001 data only (see Methods and Materials). Four metrics were used to calculate the B-IBI for these stations under the low mesohaline classification (> 5-12 ppt). These metrics were total infaunal abundance, the Shannon-Wiener diversity index, relative abundance of pollution-sensitive taxa, and relative abundance of pollution-indicative taxa [Note: the relative abundance of pollution-sensitive taxa was included as an accepted substitution for biomass-based metrics (Weisberg et al 1997)]. The B-IBI was developed as a benchmark to determine whether any given benthic sample taken from the Bay either approximates (B-IBI score = 5), deviates slightly (B-IBI score = 3), or deviates greatly (B-IBI score = 1) from conditions at the best Reference sites (Weisberg et al., 1997). A B-IBI score greater than or equal to 3.0 represents a benthic community that is not considered stressed by *in situ* environmental conditions. The twenty-one benthic stations studied during Year 20 were compared to this benchmark.

Overall, the Benthic Index of Biotic Integrity (B-IBI) scores improved or remained the same when compared to Year 19. The B-IBI scores increased at 13 stations, decreased at 4 stations and remained the same at 4 stations. Seven stations exceeded the benchmark criteria of 3.0, nine stations met it and only 5 stations failed to meet the benchmark (Table 11, Figure 17). The stations that failed to meet the benchmark were MDE-27, MDE-30, (Back River stations), MDE-34, MDE-19 (Nearfield stations), and MDE-39 (Harbor station).

In Year 19, thirteen stations failed to meet the benchmark score of 3.0. Of the stations that failed the B-IBI, all of them except MDE-30 had failed in the previous year and MDE-19 and MDE-27's B-IBI scores actually increased from Year 19. Stations MDE-34 and MDE-39 had the same score as Year 19 and MDE-30 was the only station that had a lower score that failed when compared to the previous year.

The highest B-IBI scores were found at the reference stations which had an average B-IBI score of 3.5, followed by the Nearfield and Harbor stations with average B-IBI scores of 3.2 and 3.0, respectively. The lowest average B-IBI score was found at the Back River stations, which had an average score of 2.3. 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. Overall, this year's B-IBI scores are generally similar to the B-IBI scores of the previous 5 years of monitoring at Hart-Miller Island (Figure 17).

Statistical Analysis

Cluster analysis was employed again in this year's study to examine relationships among the different groups of stations based upon the 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 21 stations), are linked by vertical connections in the dendrograms. Essentially, each station was considered to be a cluster of its own and at each step (amalgamated distances) the clusters with the shortest distance between them were combined (amalgamated) and treated as one cluster. Cluster analysis in past studies at HMI has clearly indicated a faunal response to substrate type (Pfitzenmeyer, 1985; Duguay et al, 1999). Thus, any unusual grouping of stations suggests changes are occurring due to factors other than substrate type and further examination of these stations may be warranted. Experience and familiarity with the area under study can usually help to explain faunal differences. However, when they cannot be explained other factors must be considered.

The dendrogram of the cluster analysis for September 2001 is presented in Figure 19. The first stations to join the dendrogram are MDE-1 and MDE-24, which are both Nearfield, sand stations. Station MDE-19, a Nearfield silt/clay station and MDE-30, a Back River silt/clay station, are the next stations to join the dendrogram. Stations MDE-13, MDE-35, MDE-36, and MDE-28 form a grouping of silt/clay stations. The Harbor stations MDE-40 (sand) and MDE-41 (silt/clay) are closely linked to the Harbor stations MDE-38 and MDE-39, which are both silt/clay stations. Overall, the Nearfield, Reference, Back River/Hawk Cove, and Harbor stations are well distributed throughout the dendrogram and show no distinct clustering by sediment or station type. As in previous years for which cluster analysis was performed, Back River/Hawk Cove station MDE-27 was one of the last to join the dendrogram.

The cluster analysis for April 2002 is presented in Figure 20. The first stations to join the dendrogram were Nearfield, shell stations MDE-1 and MDE-3, followed by a grouping of silt/clay stations (MDE-7, MDE-9. MDE-17, MDE-27, MDE-35, MDE-36, MDE-13, MDE-19, MDE-30, MDE-16, and MDE-40). A sand station (MDE-24) and shell station (MDE-34) were next to join the cluster followed by MDE-33, another sand station. The last 5 stations to join the dendrogram were all silt/clay stations (MDE-22, MDE-28, MDE-38, MDE-41 and MDE-39). Overall, the groupings that formed during April 2002 indicate a faunal response to sediment type. Faunal response to sediment type has also been observed in previous monitoring years. This analysis showed no unusually isolated stations, which suggesting that the area is not being adversely affected.

Friedman's nonparametric test was used to determine if a significant difference could be detected among sampling stations using the average abundance of the 10 most abundant infaunal species. The test indicated there were no significant ($P < 0.05$) differences in the 10 most abundant infaunal species between Nearfield, Reference, Back River/Hawk Cove and Harbor stations for September 2001 or April 2002 (Tables 17 and 18).

Table 17: Friedman Analysis of Variance for September 2001's 10 most abundant species among; Back River/Hawk Cove, Nearfield, Reference and Harbor stations. ANOVA Chi Sqr. (N = 30, df = 3) = 2.07, P < 0.558; Average rank = -.0107

Station Type	Average Rank	Sum of Ranks	Mean	Std. Dev.
Reference	2.42	72.5	158.51	135.07
Back River	2.73	82.0	242.77	320.32
Nearfield	2.28	68.5	371.84	834.25
Harbor	2.57	77.0	418.56	872.16

Table 18: Friedman Analysis of Variance for April, 2002's 10 most abundant species among; Back River/Hawk Cove, Nearfield, Reference and Harbor stations. ANOVA Chi Sqr. (N = 30, df = 3) = 4.27; Average Rank = -0.015, P < 0.233

Station Type	Average Rank	Sum of Ranks	Mean	Std. Dev
Nearfield	2.28	68.50	163.63	166.60
Reference	2.48	74.50	318.72	442.79
Back River	2.33	70.00	225.92	305.99
Harbor	2.90	87.00	485.12	860.44

CONCLUSIONS AND RECOMMENDATIONS

The benthic macroinvertebrate community for Year 20, as measured by the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI), improved compared to the previous year (Year 19). The B-IBI scores increased at 13 stations, decreased at 4 stations and remained the same at 4 stations. Seven stations exceeded the benchmark criteria of 3.0, nine stations met it and only 5 stations failed to meet the benchmark. In Year 19, thirteen stations failed to meet the benchmark score of 3.0. The B-IBI scores of Fall 2001 were similar to scores seen over the past 5 monitoring years. Statistical analyses confirmed that there were no significant infaunal differences among Reference, Nearfield, Back River, and Harbor stations. The cluster analysis for April 2002 indicated that infaunal differences could be explained by dominant substrate at each station.

The Hart-Miller Island Dredged Material Containment Facility will continue to operate at least until the year 2009. To date, there have been no measurable impacts from HMI on the benthic community in the adjacent area. However, a comprehensive analysis of all the historical HMI data for all projects needs to be undertaken before any final conclusions about HMI's impact on the surrounding community can be made. It is further recommended that benthic community monitoring continue throughout the operational life-time of HMI as well as the post-operational periods in order to be certain that changes in site management and dredged material inputs do not have adverse effects on the surrounding biological community.

REFERENCES

Brown, S.S., R.R. Hebert, and C.T.Morris. 1998. Macrobenthic Community Structure in Baltimore Harbor: Analysis of Samples from 40 Stations. University of Maryland, Center for Environmental Science, Ref. No [UMCEES] CBL 98-101. July 8, 1998. *Submitted to* Mr. Nauth Panday, Technical and Regulatory Services Adminstration, Maryland Department of the Environment.

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

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

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

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

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

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

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

Maryland Department of the Environment. *in review*. Assessment of the Environmental Impacts of the Hart-Miller Island Dredged Material Containment Facility Dredged material containment facility, Maryland. Year 20 Exterior Monitoring Data Report, September 2001-April 2002. *Prepared by* Dredging Coordination and Assessment Division of Maryland Department of the Environment *for* Maryland Port Administration.

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

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

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

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

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

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

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

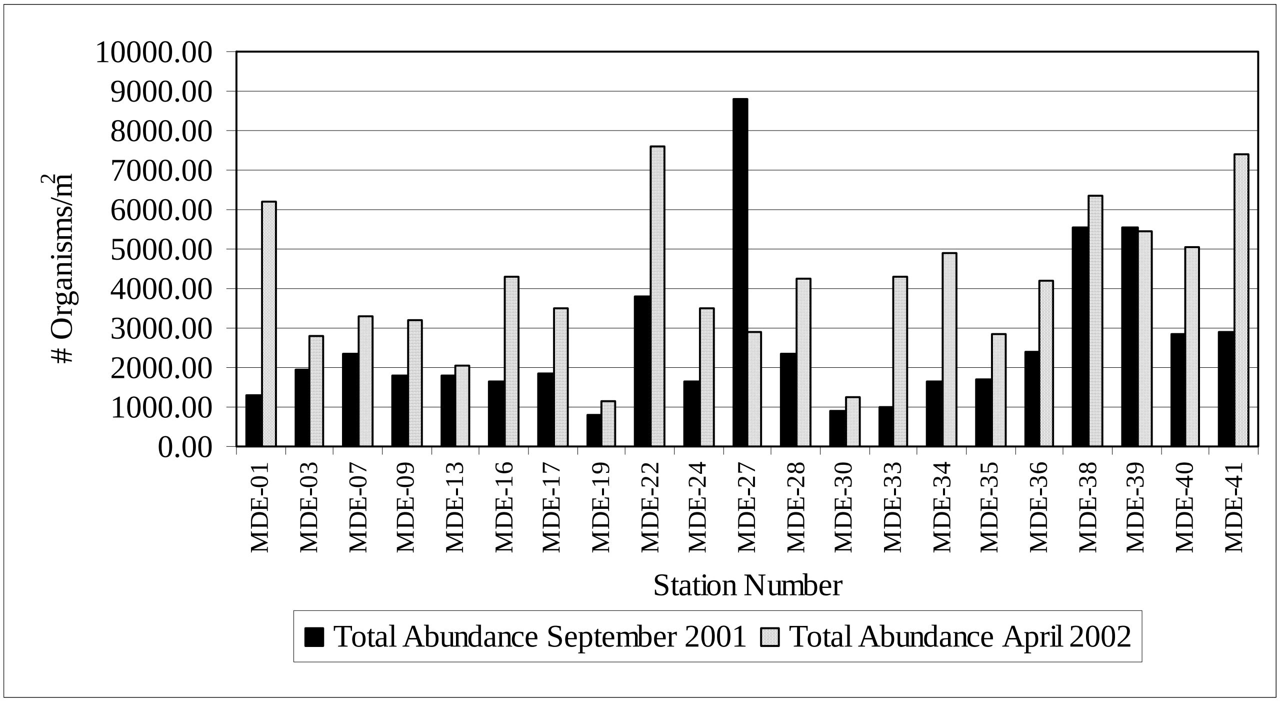


Figure 13: Total average abundance of infauna and epifauna taxa collected at each HMI station in Year 20, September 2001 and April 2002.

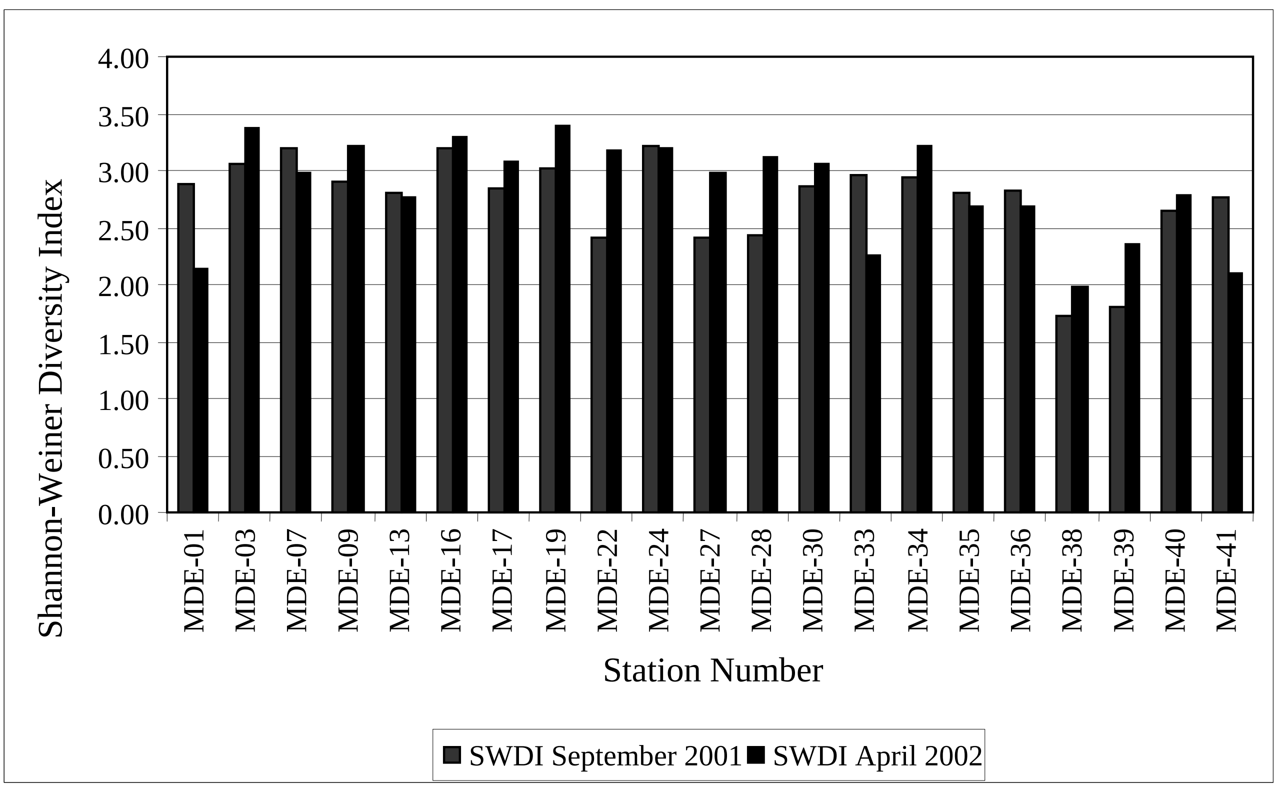


Figure 14: Shannon-Weiner Diversity Index (SWDI), HMI year 20, September 2001 and April 2002.

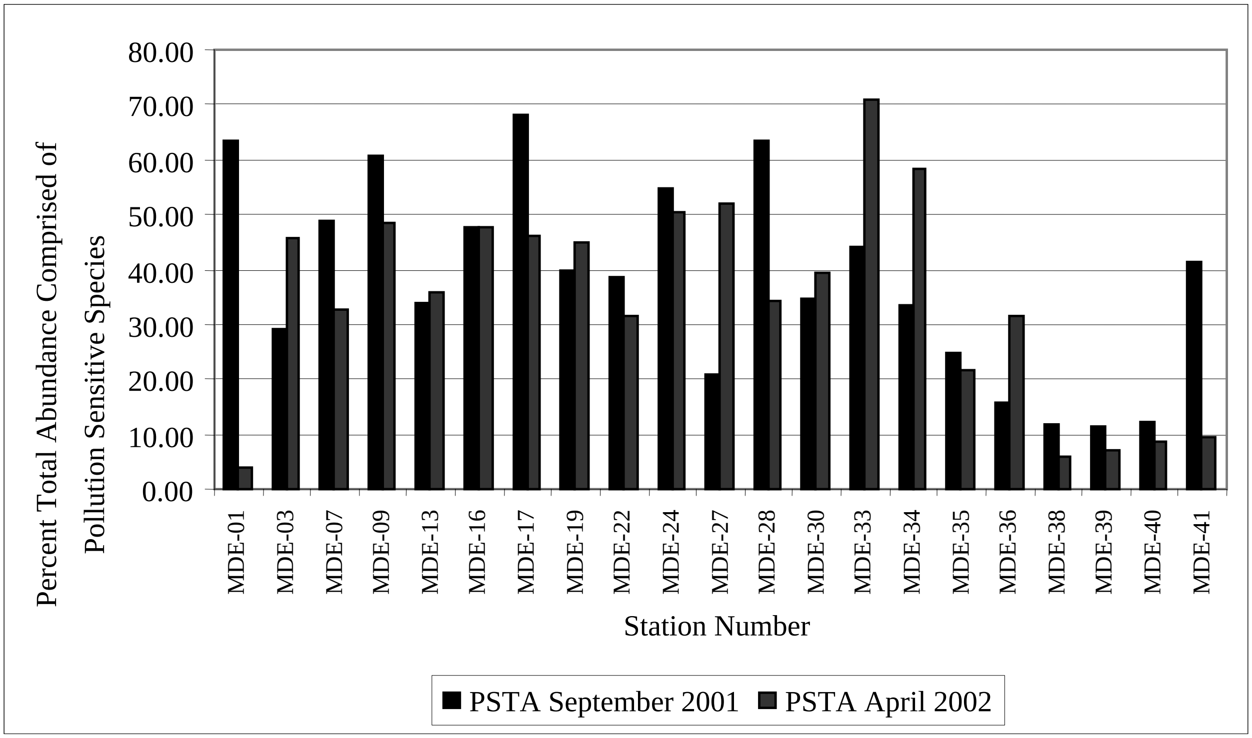


Figure 15: Percent abundance comprised of pollution sensitive taxa abundance (PSTA), HMI year 20 September 2001 and April 2002.

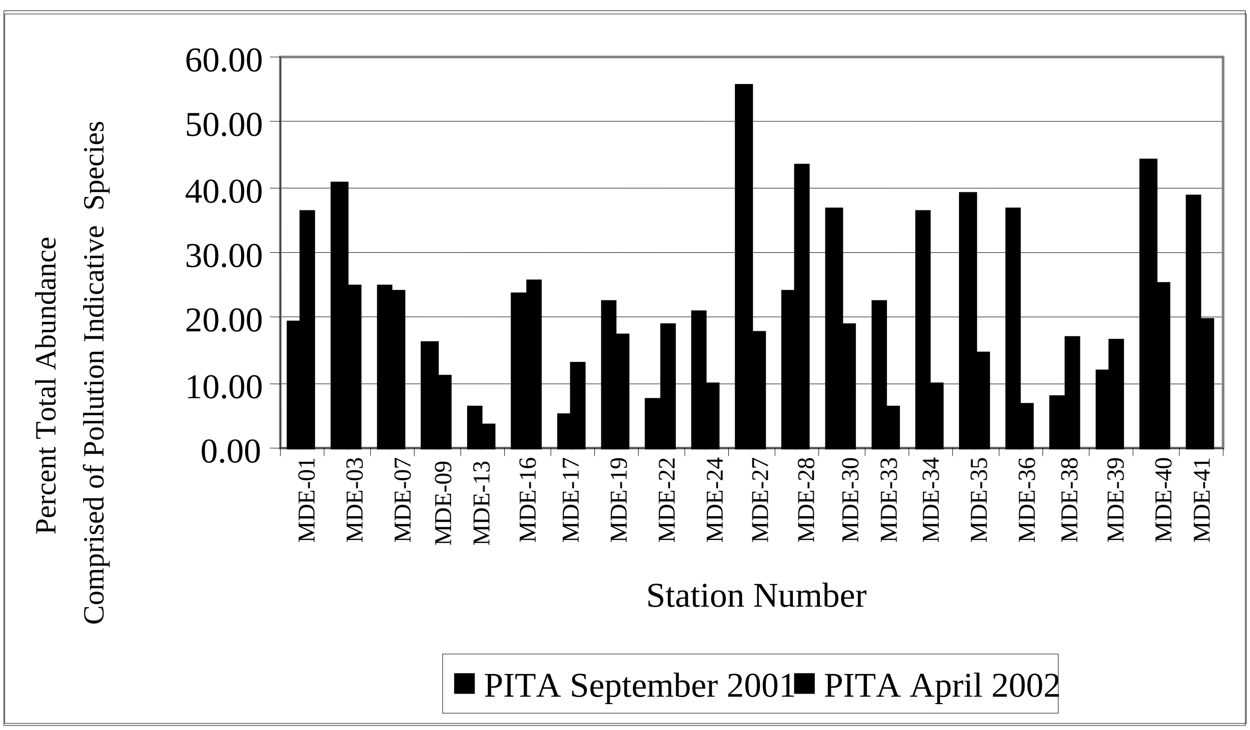


Figure 16: Percent abundance comprised of pollution indicative species (PITA), HMI year 20 September 2001 and April 2002.

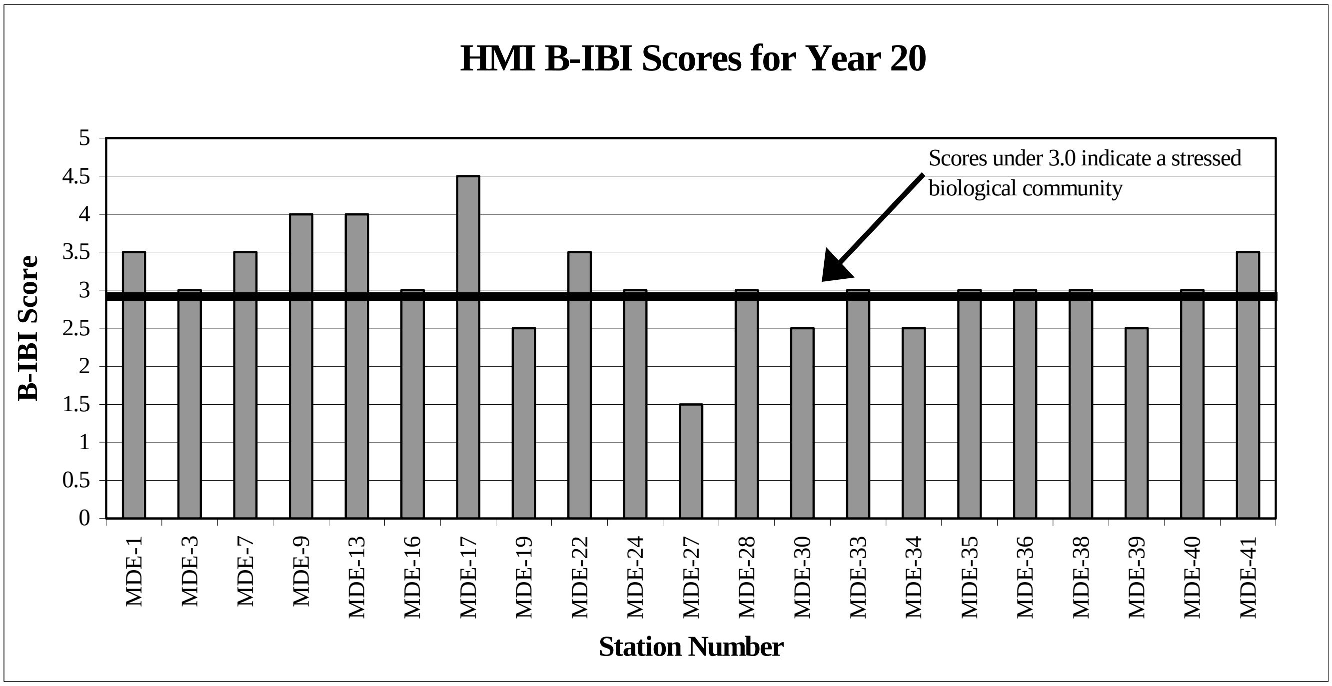


Figure 17: B-IBI Scores for all stations in September 2001 .

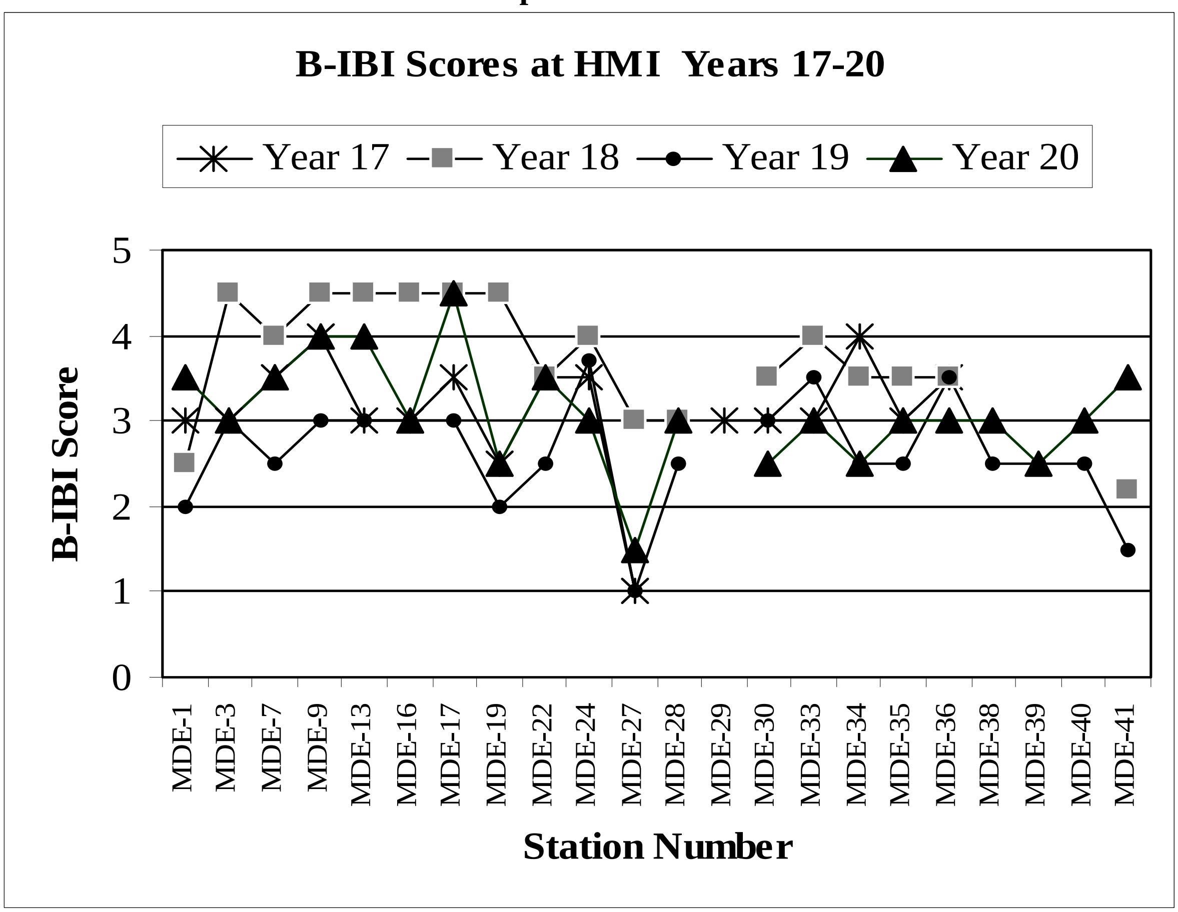


Figure 18: B-IBI Scores at HMI for Monitoring Years 17, 18, 19 and 20.

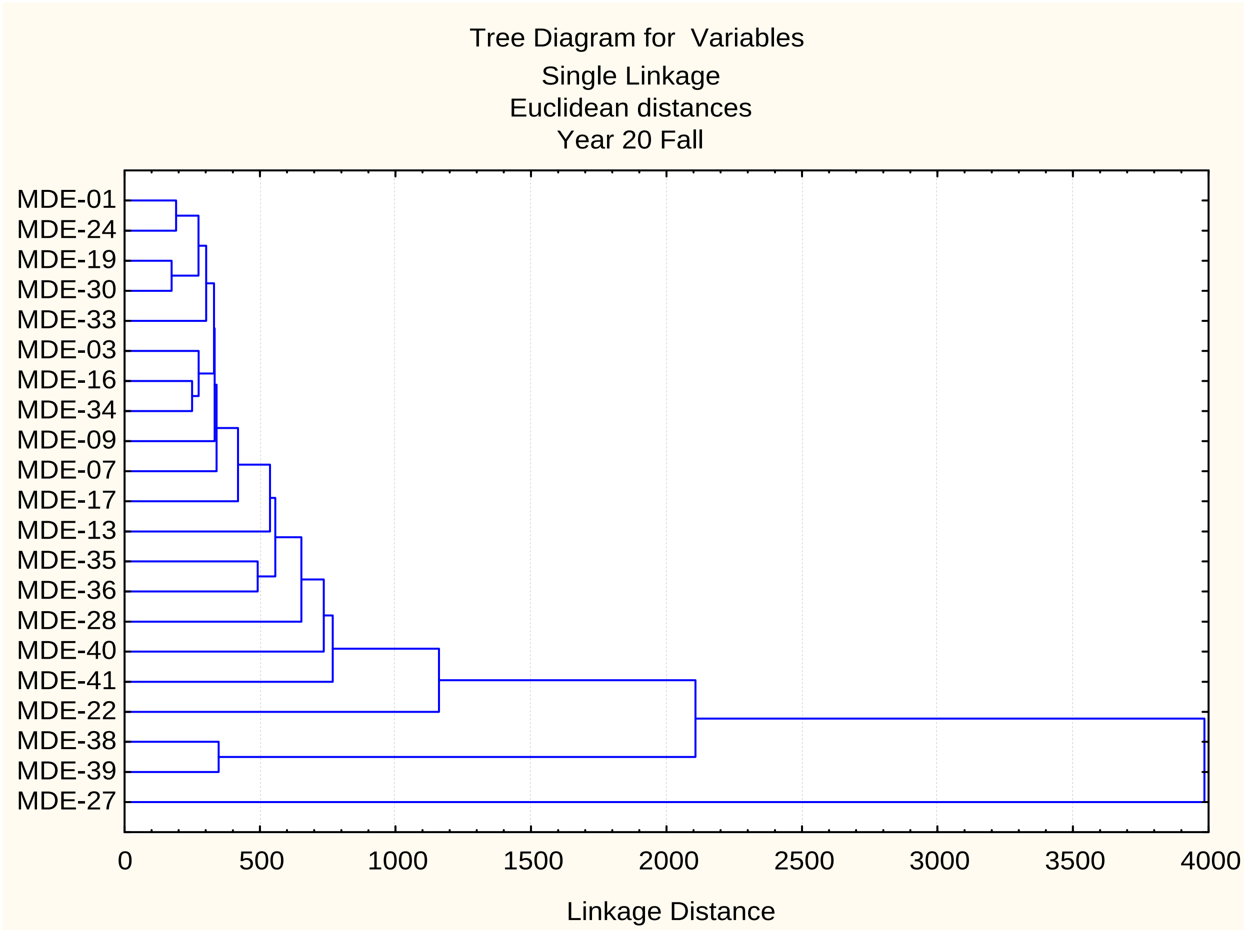


Figure 19: Cluster analysis based on Euclidean distance matrix of infaunal abundances of all HMI stations, year 20 September 2001.

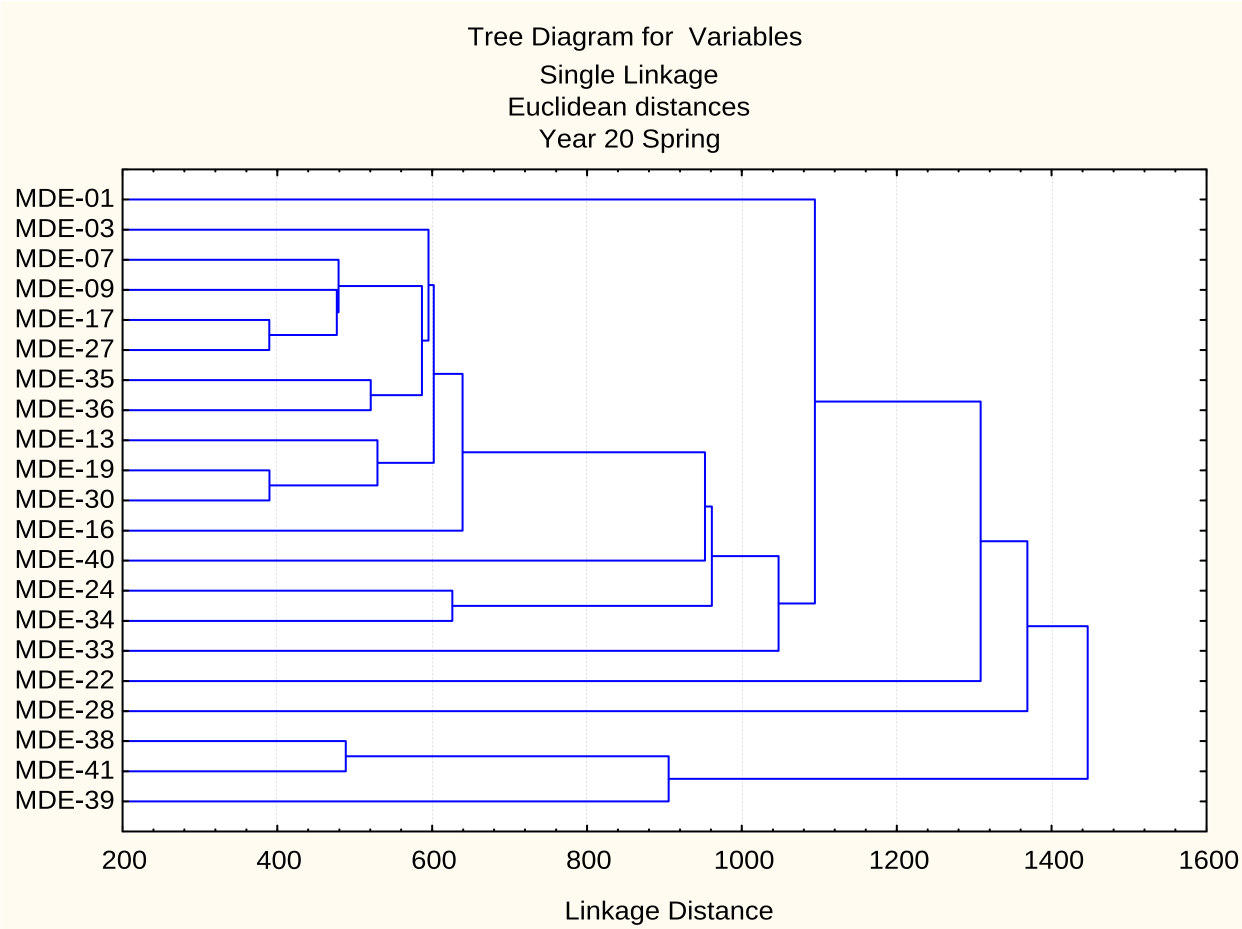


Figure 20: Cluster analysis based on Euclidean distance matrix of infaunal abundances of all HMI stations, year 20 April 2002.

PROJECT IV: ANALYTICAL SERVICES (PROJECT 4) – YEAR 20

(September 2001 – September 2002)

Technical Report

Prepared By:

R. Mason, Principal Investigator
J. Baker, Principal Investigator
Andrew Heyes, Associate Research Scientist
Debby Heyes, Faculty Research Assistant

Coastal Chemistry Laboratory
Chesapeake Biological Laboratory
Center for Environmental Sciences
University of Maryland System
P.O. Box 38, 1 Williams Street
Solomons, Maryland 20688

Submitted to:

Maryland Department of the Environment
Technical and Regulatory Services
Montgomery Park Business Center
1800 Washington Blvd
Baltimore, MD 21230-1718

OBJECTIVES

The goals of the project in 2001 are 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. Another objective of this study is to supplement the metals monitoring conducted by Maryland Geological Survey to include analysis of mercury, arsenic, silver, lead, cadmium, and selenium.

The results of the quality assurance (QA/QC) procedures and the description of the analytical and field protocols are contained in the *Year 20 Data* Report. Comparisons of duplicate analyses and comparison of measured values to certified values for the analyzed Standard Reference Materials are also discussed in the *Year 20 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.

METHODS AND MATERIALS

Sampling Procedures

Samples were collected from sites designated by the revised sampling plan, developed by the Maryland Department of the Environment in September 2000. Trace metal samples were collected using plastic spatulas integrating the top several centimeters and avoiding the sides of the sampler to minimize the possibility of contamination. Sediments were placed in plastic sampling cups and were kept cooled in an ice chest until they could be processed in the laboratory.

Analytical Procedures for Metals

The analytical methods used in this study are similar to those described in detail in Dalal et al. (1999). For metals, a subsample of each trace metal sample (sediments) was used for dry weight determination. Weighed samples were placed in a VWR Scientific Forced Air Oven at 60^0C overnight. Upon drying, samples were then reweighed and a dry/wet ratio was calculated.

Another subsample of sediment (5 g wet weight) was placed in acid-cleaned flasks for further digestion, using USEPA Methods (USEPA Methods; Keith 1991). Ten mL of 1:1 HNO_3 was added and the slurry was mixed and covered with a watch glass. The sample was heated to 95^0C and allowed to reflux for 15 minutes without boiling. The samples were cooled, 5 mL of concentrated HNO_3 was added, and then they were allowed to reflux for another 30 minutes. This step was repeated to ensure complete oxidation. The watch glasses were removed and the resulting solution was allowed to evaporate to 5 mL without boiling. When evaporation was complete and the samples cooled, 2 mL of 30% H_2O_2 was added.

The flasks were then covered and returned to the hot plate for warming. The samples were heated until effervescence subsided. We continually added 30% H_2O_2 in 1 mL aliquots with warming until the effervescence was minimal. No more than a total of 10 mL of H_2O_2 was added to each sample. Lastly, 5 mL of concentrated HCl and 10 mL of deionized water were added and the samples refluxed for 15 minutes. The samples were then cooled and filtered through Whatman No. 41 filter paper by suction filtration and diluted to 50 mL with deionized water. Sediment homogenates were then analyzed using a Hewlett Packard model 4500 Inductively Coupled Plasma Mass Spectrometer for the other metals and metalloids. These techniques are similar to USEPA Method 1632.

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

Samples for methylmercury were distilled after adding a 50% sulfuric acid solution and a 20% potassium chloride solution (Horvat et al. 1993, Bloom 1989). The distillate was reacted with a sodium tetraethylborate solution to convert the nonvolatile MMHg to gaseous MMHg. The volatile adduct was purged from solution and recollected on Tenex® 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.

RESULTS AND DISCUSSION

Mercury, Cd, and Ag concentrations in sediments for the Year 20 fall sampling are compared to those of all stations in the past 4 years (Figures 21 through 23). Overall, for Hg and Cd, there is little difference in the average concentrations over the years. For Ag, there is much more variability in the data, and this reflects the greater difficulty of measuring Ag in sediments compared to the other metals. Measured Ag concentrations are higher in 2000 and 2001 when compared to 1998 and 1999. However, when compared to 1996 and 1997, the difference is greatly diminished (Figure 24). Furthermore, the error bars overlap and thus the trend is not statistically significant. Looking at the individual sites, there appears to be little in the way of a spatial trend. The highest Ag concentrations tend to be in the Back River and Harbor mouth but concentrations tend to rise and fall in the entire region. As Ag is a good indicator of sewage discharge and urban inputs, due to its use widely in the photographic industry, the large temporal variations may indicate changes in sewage discharge conditions and activities. Silver associates with organic matter and can be widely dispersed. More analysis and sampling would be needed to further assess this trend. For As, Se and Pb, concentrations at some stations vary little whereas other stations show large variability between years. Concentrations remain stable although As concentrations have been slightly higher in 2000 and 2001 and it is too early to describe this as a trend (Figure 25).

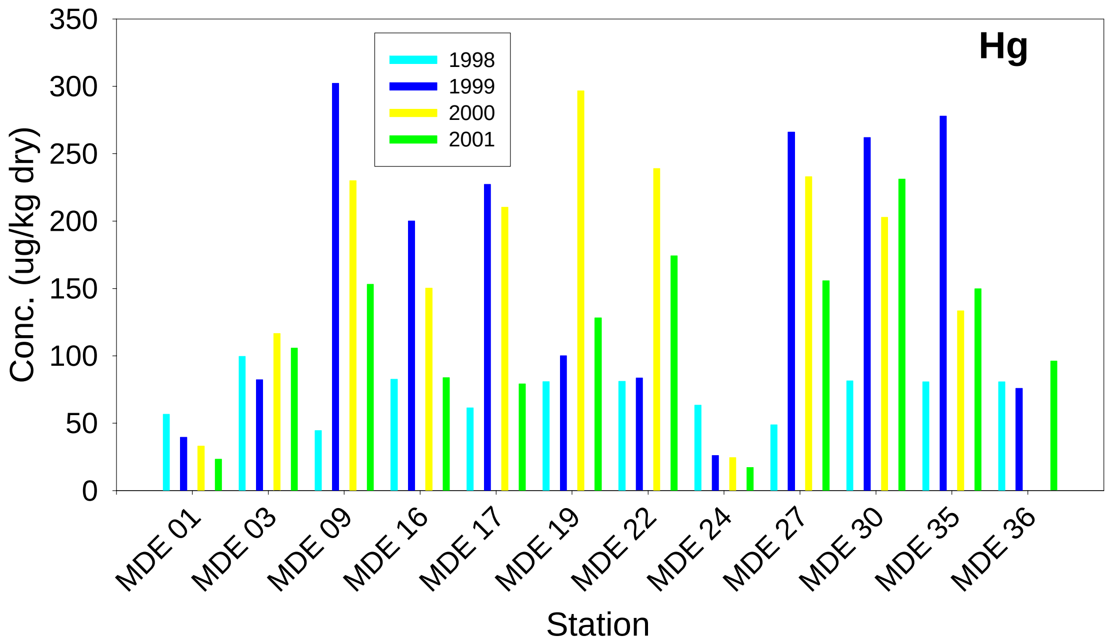


Figure 21: Mercury concentrations in sediment between 1998 and 2001.

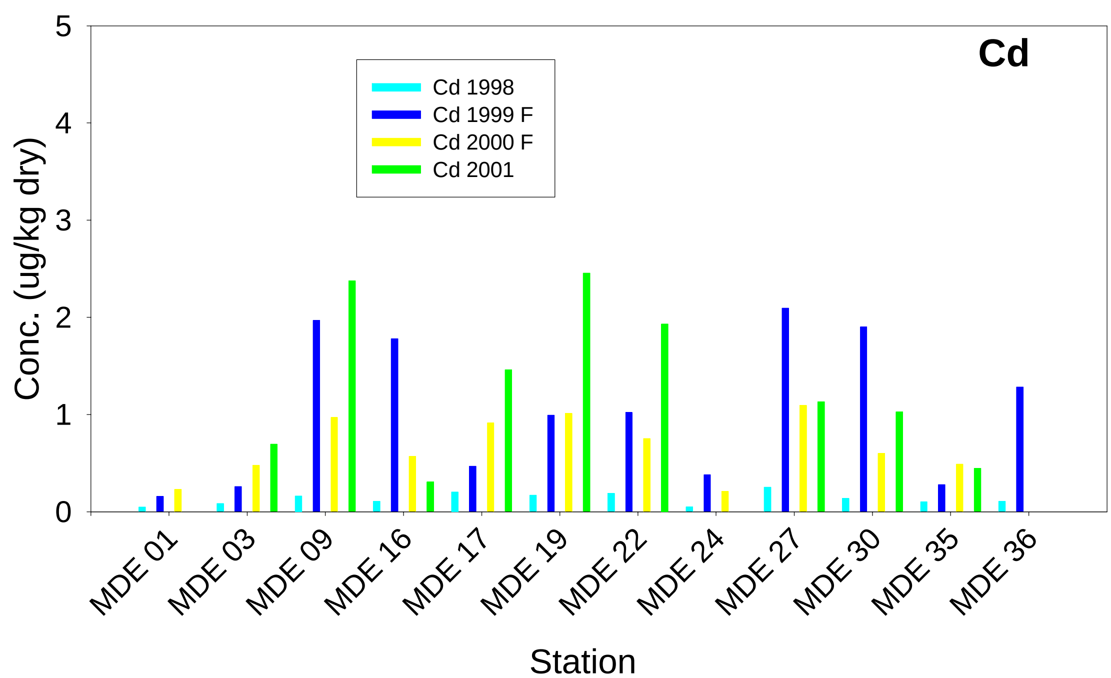


Figure 22: Cadmium concentrations in sediment from 1998 to 2001.

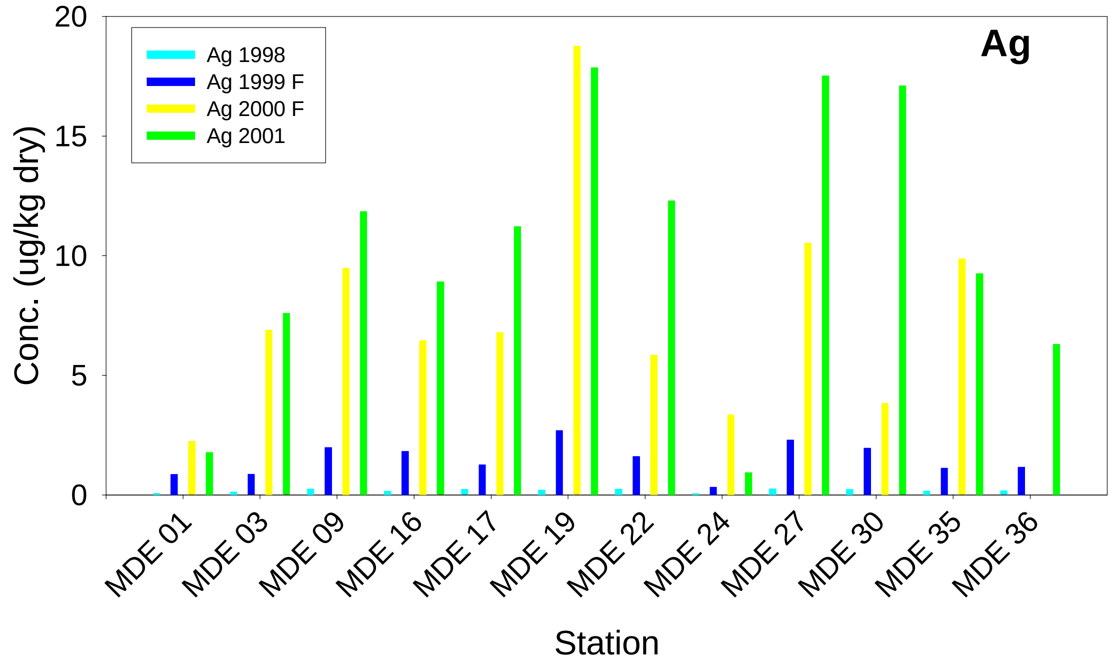


Figure 23: Silver concentrations in sediment between 1998 and 2001.

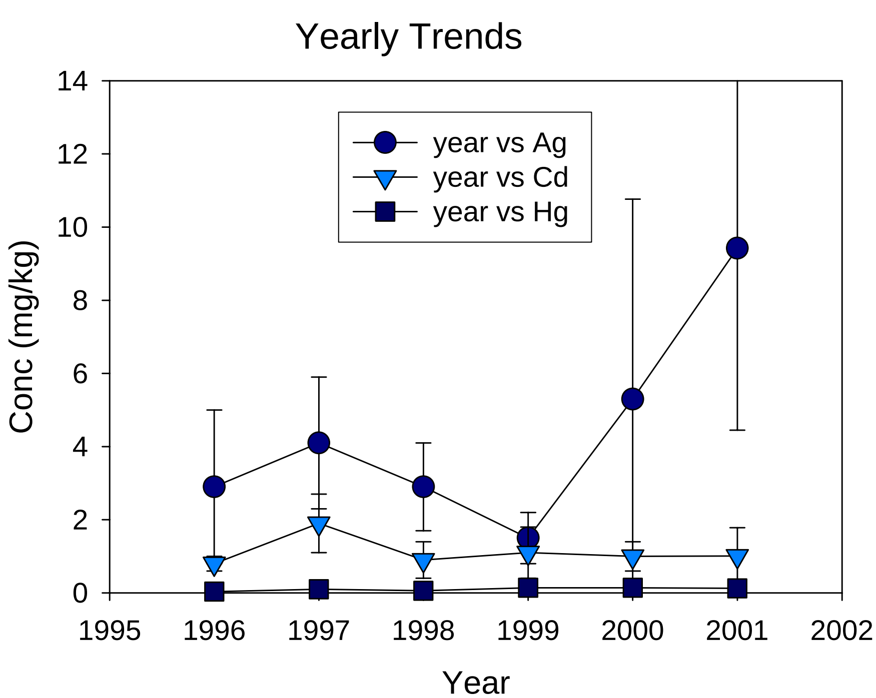


Figure 24: Trend in silver, cadmium, and mercury 1996-2001.

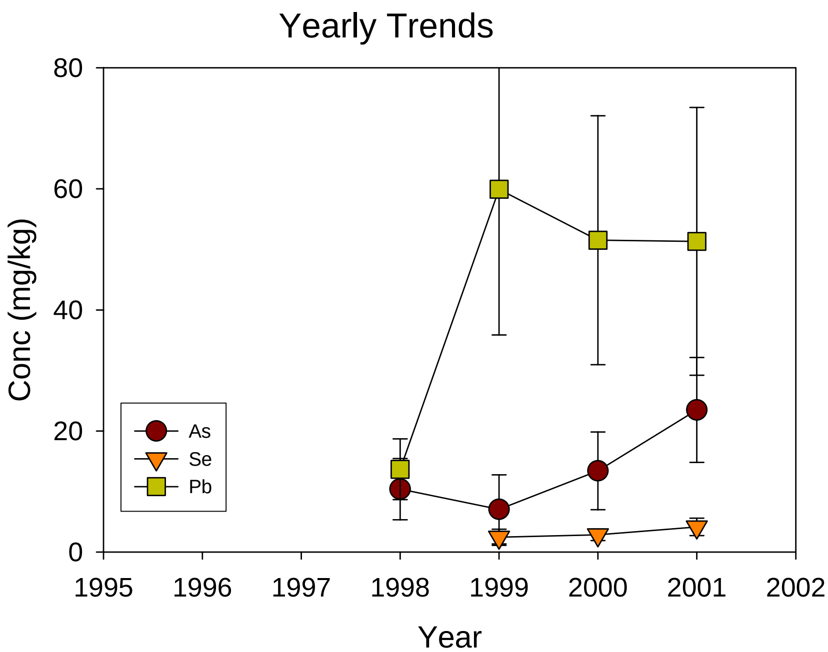


Figure 25: Arsenic, selenium, and lead concentrations 1996-2001.

REFERENCES

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

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

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

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

Mason, R.P., 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. *Limnology and Oceanogr*aphy 38: 1227-1241.

Mason, R.P. and A.L. Lawrence. 1999. Concentration, distribution, and bioavailability of mercury and methylmercury in sediment of Baltimore Harbor and Chesapeake Bay, Maryland, USA. Environ. Toxicol. Chem. 18(11):2438-2447.

United States Environmental Protection Agency. 1995. Method 1631. Mercury in water by oxidation, purge and trap and cold vapor atomic fluorescence spectrometry. EPA 821-R-95-027 Draft.

United States Environmental Protection Agency. 1996. CD-ROM Compilation of Analytical Methods. Method 7131. Analysis of Metal Samples by Furnace Atomic Adsorption (GFAA); Method 1639. Measurement of Metals by Temperature Stabilized GFAA; Methods 600 Series; 7000 Series; Method 1632. Analysis of Arsenic by Hydride Generation GFAA.