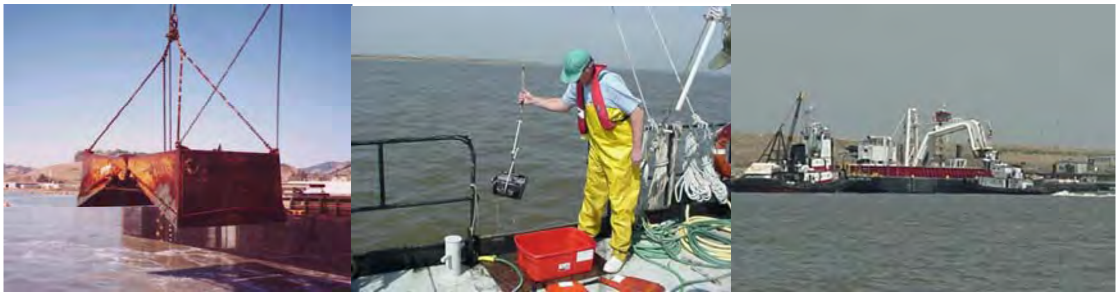
Assessment of Impacts from the Hart-Miller Dredged Material Containment Facility, Maryland.

Year 18 Technical Report (September 1999 – 2000)



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

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CONVERSIONS[1]

WEIGHT:

1Kg = 1000g = 2.205 lbs.
1g = 1000mg = 2.205 x 10^{-3}lbs
1mg = 1000μg = 2.205 x 10^{-6}lbs
1 lb = 16oz = 0.454Kg

LENGTH:

1m = 100cm = 3.281ft = 39.370in
1cm = 10mm = 0.394in
1mm = 1000μm = 0.039in
1ft = 12in = 0.305m

CONCENTRATION:

1ppm = 1mg/L = 1mg/Kg = 1μg/g = 1mL/m^3
1g/cc = 1Kg/L = 8.345 lbs/gallon
1g/m^3 = 1mg/L = 6.243 x 10^{-5}lbs/ft^3
1 lb/gal = 7.481 lbs/ft^3 = 0.120g/cc = 119.826g/L =119.826Kg/m^3
1oz/gal = 7.489Kg/m^3

VOLUME:

1L = 1000mL
1mL = 1000μL
1cc = 10^{-6} m^3
1yd^3 = 27ft^3 = 764.560L = 0.765m^3
1acre-ft = 1233.482m^3
1 gallon = 3785cc
1ft^3 = 0.028m^3 = 28.317L

FLOW:

1m/s = 196.850ft/min = 3.281ft/s
1m^3/s = 35.320ft^3/s
1ft^3/s = 1699.011L/min = 28.317L/s
1ft^2/hr = 2.778 x $10^{-4}$$ft^2$/s = 2.581 x $10^{-5}$$m^2$/s
1ft/s = 0.031m/s
1yd^3/min = 0.450ft^3/s
1yd^3/s = 202gal/s = 764.560L/s

AREA:

1m^2 = 10.764ft^2
1hectare = 10000m^2 = 2.471acres
1ft^2 = 0.093m^2
1acre = 4046.856m^2 = 0.405 hectares

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

LIST OF ACRONYMS

AAS - Atomic Absorption Spectrometry

AVS - Acid Volatile Sulfide

BAF - Bioaccumulation Factor

BCF - Bioconcentration Factor

CBL - Chesapeake Biological Laboratory

COC - Citizens' Oversight Committee

COMAR - Code of Maryland Regulations

CWA - Clean Water Act

DCAD - Dredging Coordination and Assessment Division

DMCF - Dredged Material Containment Facility

EF - Enrichment Factor

ERL - Effects Range Low

ERM - Effects Range Median

GC - Gas Chromatography

GFAAS - Graphite Furnace Atomic Absorption Spectrometry

GPS - Differential Global Positioning System

HMI - Hart -Miller Island Confined Disposal Facility

ICAP- Inductively Coupled Argon Plasma

LBP - Lipid Bioaccumulation Potential

MDE - Maryland Department of the Environment

MGS - Maryland Geological Survey

MLW - Mean Low Water

MPA - Maryland Port Administration

MS - Mass Spectrometry

NIST - National Institute of Standards and Technology

NOAA - National Oceanic and Atmospheric Administration

NRC - National Research Council of Canada

PAH - Polynuclear Aromatic Hydrocarbons

PCB - Polychlorinated Biphenyl

ppb - Parts per billion

ppm - Parts per million

ppt - Parts per thousand

QA - Quality Assurance

QC - Quality Control

SOP - Standard Operating Procedure

SRM - Standard Reference Material

TARSA - Technical and Regulatory Services Administration

TDL - Target Detection Limit

TOC - Total Organic Carbon

TRC - Technical Review Committee

UMCES - University of Maryland Center for Environmental Science

USACE - U.S. Army Corps of Engineers

EPA - United States Environmental Protection Agency

WQC - Water Quality Certification

WQS - Water Quality Standards

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

Hart-Miller Island Exterior Monitoring Program, Year 18
September 1999 – September 2000

Prepared for

Maryland Port Administration
Maryland Department of Transportation

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ACKNOWLEDGMENTS

The Hart-Miller Island (HMI) Exterior Monitoring Program for Year 18 would not have been successful without the help of several Technical and Regulatory Services Administration (TARSA) staff members, including: Mr. George Harman, Chairman, and Ms. Karen Eason, Benthic Ecologist. The Chairman was responsible for making sure that the project work was done efficiently, in a coordinated manner, and met all the technical goals set by the Technical Review Committee for Year 18. The Benthic Ecologist conducted technical review of the data and technical reports and provided insightful comments.

The Maryland Department of the Environment would like to thank all the members of the HMI Exterior Monitoring Program's Technical Review Committee and the HMI Citizens' Oversight Committee for their useful comments and suggestions throughout the project year. Special thanks are in order to the Maryland Port Administration, under the auspices of the Maryland Department of Transportation, for their continued commitment to and financial support of the Exterior Monitoring Program. The efforts and cooperation of the Principal Investigators for each project in the Year 18 monitoring effort are greatly appreciated.

Lastly, thanks to Dr. Robert Summers, Director, Mr. Narendra Panday and Dr. Richard Eskin, of TARSA, for their guidance, suggestions, and commitment to the Hart-Miller Island Exterior Monitoring Program.

INTRODUCTION

With a 64,000 square mile watershed and 2,300 square miles of tidal surface waters, Chesapeake Bay is the nation's largest estuary. Chesapeake Bay is a valuable natural resource and ranks third, behind only the Atlantic and Pacific oceans, among the United States' most productive fisheries. Historically, over half of the nation's catch of blue crabs (*Callinectes sapidus*) and 70-90% of the Atlantic Coast stock of striped bass (*Morone saxatilis*) came from the Chesapeake.

As a highway for shipping, the Bay is also an important center of commerce for the Mid-Atlantic States. Two major ports are found on the Bay: the Hampton Roads Complex near the mouth of the Bay in Virginia and the Port of Baltimore located in the Upper Bay of Maryland. The Hampton Roads complex ranks third in the nation and Baltimore ninth in foreign water-borne commerce. Baltimore is the nation's leading exporter of cars and trucks.

The Port of Baltimore's geographic location, approximately 120 miles north of the mouth of the Bay and 70 miles south of the Chesapeake and Delaware Canal, requires a network of commercial shipping channels. Tributaries contribute vast quantities of sediment to the mainstem Bay, creating a complex of shoals and shallows, which shift with tidal currents, freshwater inflow, and storm events. These dynamic sediment transport processes operating in the Bay watershed require annual maintenance dredging of the approach channels to the port of Baltimore.

Site Background

Finding placement sites for the material dredged from the approach channels to Baltimore Harbor is an ongoing concern. Moreover, sediments dredged from Baltimore's Inner Harbor are contaminated and require placement in specially designed disposal facilities. In 1981, construction of the Hart-Miller Island (HMI) Dredged Material Containment Facility (DMCF) was initiated to provide storage capacity for the Port of Baltimore's dredging projects. A 29,000-foot long dike encircling a 1,140-acre area was constructed along the historical footprints of Hart and Miller Islands located near the mouth of Back River, in Baltimore County, MD. 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. A 4,300-foot long cross-dike was also constructed across the interior of the facility, dividing HMI into an approximately 300-acre South Cell and 800-acre North Cell. A series of five spillways are located on the perimeter dike, with spillways 1, 2 and 4 located in the North Cell and spillways 3 and 5 located in the South Cell. The spillways are designed to release supernatant water from dredged material deposited at HMI.

The dikes were raised from +18 feet above mean low water (MLW) to +28 feet in 1988 in order to provide sufficient capacity for the 50-foot channel-deepening project. The site was filled to capacity in June 1996. Raising the dikes around the North Cell by an additional 16 feet (to +44 feet MLW) increased the placement capacity by 30 million cubic yards, giving the site an additional 12 years of operational life, beginning 10/01/96.

The last inflow of dredged material into the South Cell 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 the dike, serve as a State park and receive heavy recreational use throughout the summer months.

Environmental Monitoring

Revenues to Maryland's economy from Chesapeake Bay's seafood industry rival those from the Port of Baltimore. It was recognized prior to construction that any adverse impacts to the Bay's fishery resources or water quality from HMI could override facility operations. Under Section 404(b&c) of the Clean Water Act (1987), entitled "Permits for Dredged or Fill Material", permits for dredged material disposal can be revoked 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."[4] In accordance with this federal mandate and as a special condition of State Wetlands License 72-127(R), a long-term compliance-monitoring program was implemented in 1981 to assess the effects of HMI on the surrounding environment. Results from monitoring are used to detect changes from baseline environmental conditions in the area surrounding HMI, and, if necessary, to guide decisions regarding operational changes and remedial actions.

The Hart-Miller Island Exterior Monitoring Program has evolved over the past sixteen years, involving different agencies, monitoring components, sampling times and methods. The baseline studies conducted around HMI from 1981-1983 included studies of the water column, currents, submerged aquatic vegetation, fisheries, benthic macroinvertebrates, sediment grain size, sediment geochemistry, and toxicological analyses. Some of these projects were discontinued over the years. The following four projects, which have been consistently monitored from the beginning of the program to the present day, are: (1) Project Management and Scientific/Technical Coordination, (2) Sedimentary Environment, (3) Benthic Community Studies, and (4) Analytical Services. This report covers the 18th consecutive year of monitoring. All sampling stations for Year 18 are depicted in Figure 1.

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[4] From page 250 of the 1987 Clean Water Act published by the Environmental Protection Agency.

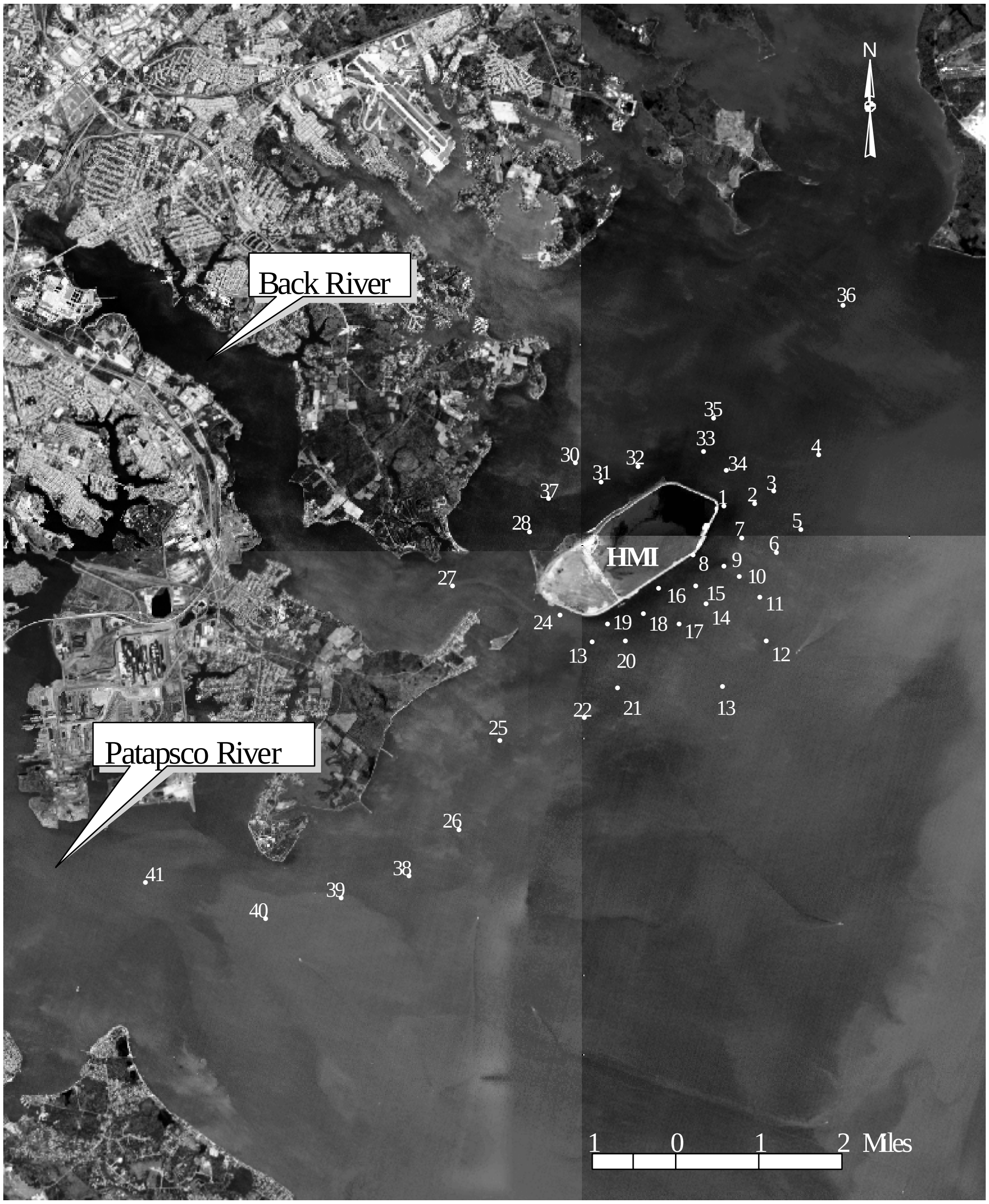

Figure 1: Year 18 Hart-Miller Island Sampling Locations.

Project II – IV Summaries

Project II: Sedimentary Environment – Maryland Geological Survey (MGS)/Department of Natural Resources

MGS conducted two monitoring cruises for Year 18, one on September 9th, 1999 and one on April 27th, 2000. Sediment samples were collected from 40 stations surrounding the facility, four of which (MDE-38, MDE-39, MDE-40, and MDE-41) were new Baltimore Harbor transect stations established to detect any contamination gradients leading from the Patapsco River to HMI.

Year 18 Sediments were analyzed for total elemental concentrations of the following substances: cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), phosphorus (P), nitrogen (N), carbon (C) and sulfur (S). Sediment metal concentrations were normalized to sediment grain-size and compared to baseline sediment metal concentrations surrounding the facility while nutrients were compared to Redfield's ratio.

Due to the seasonal variability in hydrodynamic conditions surrounding the facility, no clear trends in sediment grain-size composition or distribution were observed between cruises. As a general rule, however, the distribution of sand at the longer-term sampling sites surrounding the facility has remained unchanged since 1988 while the clay:mud ratios exhibit interseasonal and interannual variability. The clay:mud ratios at the new Harbor transect stations were highly variable between sampling events compared to the more stable clay:mud ratios closer in to the dike. This pattern suggested that the Harbor transect stations are in a different depositional environment than that surrounding HMI and that Harbor sediments have little influence on the nearfield HMI sampling stations.

Metal concentrations surrounding the facility were some of the lowest seen since elevated levels were first reported in 1989. The higher volumes of discharge from the facility and absence of free mineral acidity prohibited oxidation of the contained dredged material and limited the production of acidic conditions. Most of the samples analyzed for cadmium were below analytical detection limits. Chromium, lead, copper, zinc and nickel were found to be above effects range-low (Long et al. 1995) values, and values for zinc and nickel were above effects range median (Long et al. 1995) concentrations. When normalized to sediment grain-size, however, only zinc and lead appear to be significantly enriched above baseline concentrations measured around the facility. Lead has only been measured since Year 15, so the trends for lead are not as clearly established.

Nutrient levels in sediments surrounding the facility do not appear to be enriched above upper Chesapeake Bay background levels. This does not guarantee that the facility is not a source of nutrients to the upper Bay, but only that elevated nutrient concentrations are not accumulating in the sediments surrounding the island. It is possible nutrients contained in effluent discharge from the facility are transported in an aqueous phase and do not accumulate in nearfield HMI sediments.

Project III: Benthic Community Studies – Maryland Department of the Environment/Environmental Assessment Division (MDE/EAD)

For the second consecutive year, MDE/EAD was responsible for describing the benthic community surrounding HMI. In addition to the same 17 stations sampled last year, the new Harbor station MDE-41 was sampled this year to complement the Harbor transect stations sampled in Projects II and IV. Sampling was conducted during two different seasons, the late summer (September 9, 1999) and spring (August 27th and 28th).

During Year 18, a total of forty-one taxa were found in the vicinity of Hart-Miller Island over two seasons of benthic community monitoring. This is somewhat higher than the number of taxa that had been found in Years 12 through 17 (30, 30, 31, 26, 29, and 32 taxa, respectively), and most likely due in part to the addition of Harbor Station MDE-41. Of the forty-one taxa found in Year 18, twenty-seven are considered truly infaunal; the other fourteen, epifaunal (see Ranasinghe et al. 1994). The most common taxa were members of the phyla Annelida (segmented worms) and Bivalvia (molluscs having two separate shells joined by a muscular hinge). Ten species of annelid worms in the class Polychaeta were found during the study. Eleven species of arthropods were found. The most common arthropods were the isopods (such as *Cyathura polita*) and amphipods (such as *Leptocheirus plumulosus*). Epifaunal taxa, such as barnacles, bryozoans, and mud crabs were found more often at stations where the substrate (sediment) contained a large amount of shell. The major differences in the dominant or most abundant species among stations were most likely a result of differences in bottom-type (e.g., silt/clay, shell or sand). As in years past, a small number of species were the dominant members of the benthic community.

The benthic index of biotic integrity (B-IBI) was used for the fourth consecutive year. The B-IBI was developed as a benchmark to determine whether any given benthic sample taken from different salinity regimes in 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 equal to or greater than 3.0 represents a benthic community that is not considered to be stressed by *in situ* environmental conditions. All Year 18 samples collected during the late summer sampling (September 9, 1999) were compared to this benchmark.

Fifteen of the eighteen benthic stations, including all of the Reference stations, exceeded a B-IBI score of 3, which indicates minimal environmental stress at these stations. Two other stations, Back River/Hawk Cove stations MDE-27 and MDE-28, exactly met the standard with a score of 3.0. Nearfield station MDE-1, which lies very close to spillway one and exhibited a highly variable interseasonal substrate composition, was the only station that had a B-IBI score of less than 3.0.

In general, however, there were no apparent discrepancies between the B-IBI scores of the HMI Nearfield or Reference stations. The results of the benthic community sampling for Year 18 are consistent with past monitoring years and show no adverse impacts associated with the Hart-Miller Island Dredged Material Containment facility.

Project IV: Analysis of Contaminants in Sediment Samples Collected Near Hart-Miller Island - University of Maryland Center for Environmental Science/Chesapeake Biological Laboratory (UMCES/CBL)

UMCES/CBL has been involved in the monitoring of contaminants around the Hart-Miller Island facility since Year 15. Sediment samples for the Year 18 monitoring effort were collected in tandem with samples collected by MGS. UMCES/CBL analyzed sediments for the presence of arsenic (As), silver (Ag), mercury (Hg) and methyl mercury (MeHg). Cadmium (Cd) and lead (Pb) were also measured by UMCES/CBL and serve as a point of comparison between values for Cd and Pb measured by MGS. Sediment metal concentrations were normalized to the organic carbon (OC) content of the sediments.

The metal concentrations in sediments analyzed for Year 18 showed both interannual and interseasonal variability, particularly for As, although no apparent trends in concentrations could be determined. Most of the variability in concentrations could be explained by seasonal and annual variations in sediment OC content. Sediment concentrations of Pb, Cd, and Hg did exceed the Effects Range-Low values derived by Long et al. 1995, but none exceeded the Effects Range-Median. Overall, contaminant concentrations surrounding HMI appear to be consistent with values in the upper Bay region in general, and are significantly lower than concentrations in either the Patapsco River/Baltimore Harbor or Back River.

The Harbor samples taken along a transect leading into the Patapsco River did not show any gradients in contamination from the Harbor to HMI. An analysis of sediment OC content further revealed that there was little change in OC along the Harbor transect so that any effect of OC content on sediment metals concentrations is minimal. This was in contrast to the Back River trend discovered in Year 16 that revealed a strong contamination gradient leading from Back River to the HMI region (Hawk Cove area). The Harbor samples suggest, however, that no such trend is apparent in the Patapsco River.

CONCLUSIONS AND RECOMMENDATIONS

Since dredged material inputs, weather conditions and consequent site management varies on an annual basis, continued monitoring of the exterior environment surrounding HMI is recommended. In addition, it is also recommended that the Baltimore Harbor transect continue to be sampled in order to determine any gradients in contamination leading from Baltimore Harbor to the Hart-Miller Island vicinity. One final recommendation is that a comprehensive, statistically rigorous review of all HMI data be undertaken at some point in the future to establish historical trends.

CHAPTER 2: THE SEDIMENTARY ENVIRONMENT (PROJECT 2)

Hart-Miller Island Exterior Monitoring Program, Year 18

September 1999 – September 2000

Prepared for

Maryland Port Administration
Maryland Department of Transportation

Prepared by

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EXECUTIVE SUMMARY

The Coastal and Estuarine Geology Program of the Maryland Geological Survey (MGS) has been involved in monitoring the physical and chemical behavior of near-surface sediments around the Hart-Miller Island (HMI) Dredged Material Containment Facility (DMCF) from the onset of the 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 8, 1999, and again on April 27, 2000. Survey geologists then analyzed various physical and chemical properties of the samples: (1) water content, (2) grain size (relative proportions of sand, silt, and clay), and (3) total elemental concentrations of iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), cadmium (Cd), lead (Pb), phosphorous (P), carbon (C), nitrogen (N), and sulfur (S).

The grain size distribution of Year 18 sediment samples does not show any clear trends from cruise to cruise. This is due to the complexity of environmental conditions and source of material to the area. However, the general sediment distribution pattern is consistent with the findings of previous monitoring years dating back to 1988 (the second year after the start of release from HMI). The main reason for adding the Baltimore Harbor samples was to determine if the Harbor was a possible source of the trace metals often concentrated in sediments deposited between spillways #3 and #4. The clay:mud distributions seem to argue against that possibility. In September 1999, the most clay-rich sediments formed discontinuous lenses, interrupted by slightly less clay-rich samples. Presumably, trace metals derived from Baltimore Harbor are more likely to settle with clay-rich sediments at the mouth of the Harbor; whereas, those derived from the containment facility are deposited in the vicinity of the dike. In April 2000, the persistence of clay-rich sites in the vicinity of the dike coupled with the disappearance of clay-rich sediments at the Harbor mouth seem to indicate two distinct depositional environments.

Discharge from HMI apparently does not leave a C, N or P signature in the exterior sediments. This is based on the use of Redfield's Ratio, data from the main stem of the Bay and the distribution pattern of these elements around the facility. However, this does not mean that there may not be significant discharge of nutrients into the Bay from HMI. Nutrients discharged in a dissolved or suspended phase that does not settle quickly in the area adjacent to the facility would not be detected in the exterior monitoring of the sediment. The nutrient levels found in the samples that extend into Baltimore Harbor do not show any appreciable difference from the sediments adjacent to HMI.

With regard to metal loadings in the area, some features to note are:

1. Most of the samples (62 of 80) are below the detection level for Cd (0.10);
2. Cr, Cu, Ni, Pb and Zn are found with concentrations that exceed the Effects Range

Low (ERL) values; and
3. Zn and Ni exceed the ERM values.

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 termed "preponderance of evidence". The method does not allow for unique basin conditions and does not take into account grain size induced variability in sediment metal concentrations. 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 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, the fall cruise shows the lowest level of Zn since the onset of the elevated levels in 1989. The spring cruise levels are only slightly elevated from the Fall, and are approximately the same as the Fall of the preceding monitoring year (Year 17). There were no significant periods during which discharge rates were below 10 MGD; 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 are much lower during this sampling period. Currently, the facility is actively accepting material, but as the dike reaches its capacity and the volume of effluent is expected to decline, dewatering of the contained material may lead to higher metal levels in the effluent. Exposure of dredged material to the air is likely to result in the mobilization of metals associated with those sediments, an effect analogous to acid mine drainage. Metals released in the effluent, particularly at low discharge rates, are deposited on the surrounding Bay floor and are increasing the long-term sediment load in the Bay. Although these levels are much lower than any biological effects threshold, continued monitoring is needed in order to: detect if the levels increase to a point where action is required, document the effect that operations has on the exterior environment (for future project design), and to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of exposing contained dredged material to the atmosphere. Close cooperation with MES is important in this endeavor.

It is further recommended, in order to better assess the potential influence of Baltimore Harbor on the HMI exterior sediments, that 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 2). 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 dredge material during the dewatering and crust management phase produces effluent enriched in metals. These differences in sediment properties and discharge from the facility have allowed the detection of changes attributable to construction and operation of the dike.

Previous Work

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

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

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

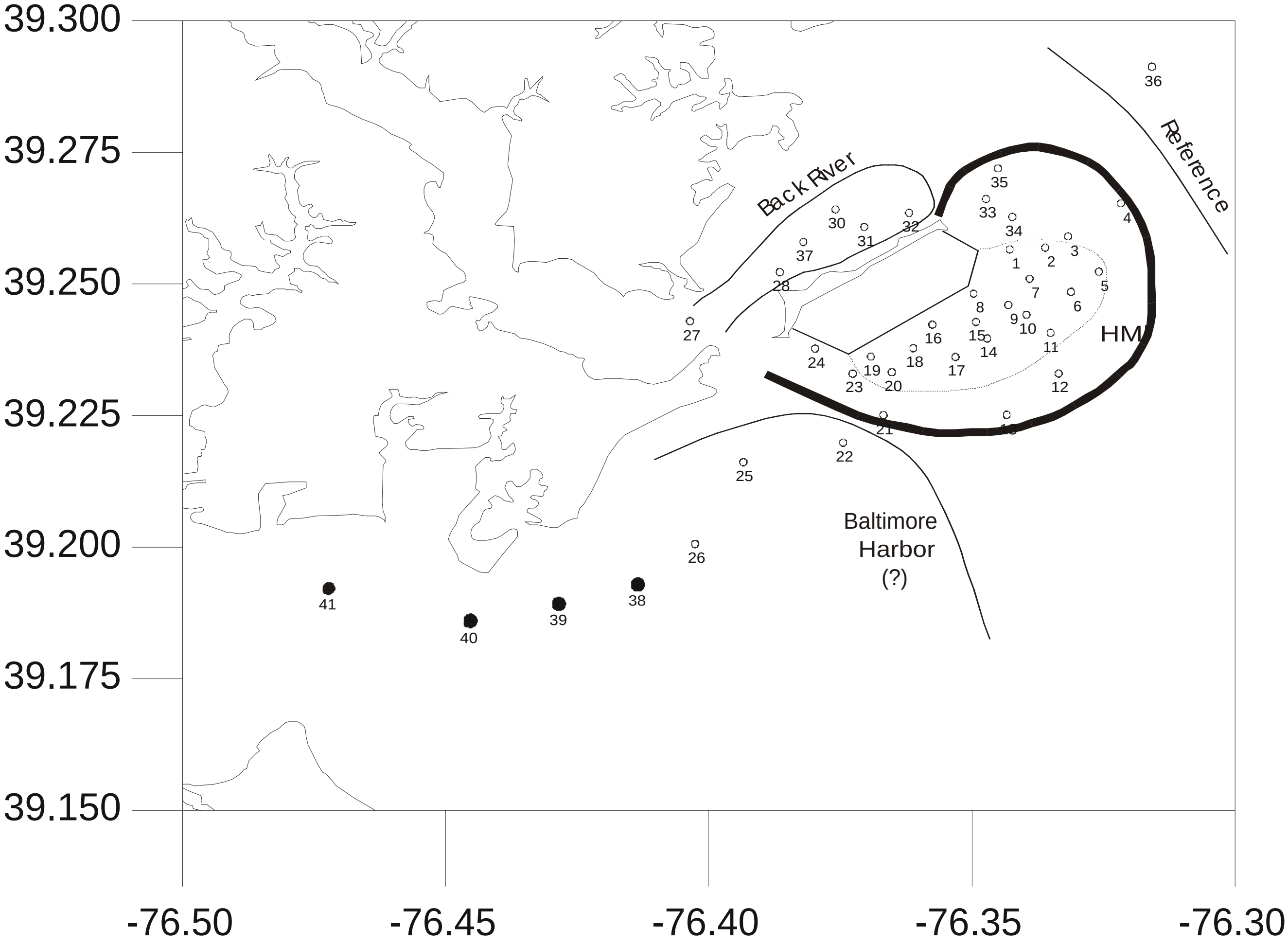


Figure 2: Year 18 sampling stations for the Hart-Miller Island exterior monitoring program. [Contours show zones of influence found in previous studies. Solid circles show location of sites added this year].

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

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

1. A circulation gyre exists east of HMI. The gyre circulates water in a clockwise pattern, compressing the discharge from the facility against the eastern and southeastern perimeter of the dike.
2. Releases from Spillways #1 and #4 travel in a narrow, highly concentrated band up and down the eastern side of the dike. This explains the location of the areas ofperiodic high metal concentrations to the east and southeast of the facility. Releases from Spillway #2 are spread more evenly to the north, east, and west. However, dispersion is not as great as from Spillways #1 and #4 because of the lower shearing and straining motions away from the influence of the gyre.
3. The circulation gyre is modulated by fresh water flow from the Susquehanna River. The higher the flow from the Susquehanna, the stronger the circulation pattern and, the greater the compression against the dike. Conversely, the lower the flow, the less the compression and the greater the dispersion away from the dike.
4. Discharge from the HMI spillways has no influence on the circulation gyre. This was determined by simulating point discharges of 0-70 million gallons/day (MGD) from three different spillways. Changes in discharge rate only modulated the concentration of a hypothetical conservative species released from the dike; the higher the discharge, the higher the concentration in the plume outside the dike.

The 3-D hydrodynamic model explains the structure of the plume of material found in the exterior sediments, but it does not explain why the level of Zn in the sediments increases at lower discharges. To account for this behavior, the chemistry of the effluent discharged from the dike was examined, as reported in the *11th Year Interpretive Report*. As a result of this examination, a model was constructed that predicts 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, higher than expected Zn levels persisted through

Year 18 in the vicinity of the dike.

Figure 2, in addition to showing the sampling sites for Year 18, shows zones which indicate influence of sources of material to the exterior sedimentary environment based onelevated metal levels from previous years' studies. These influences are noted in the figure as:

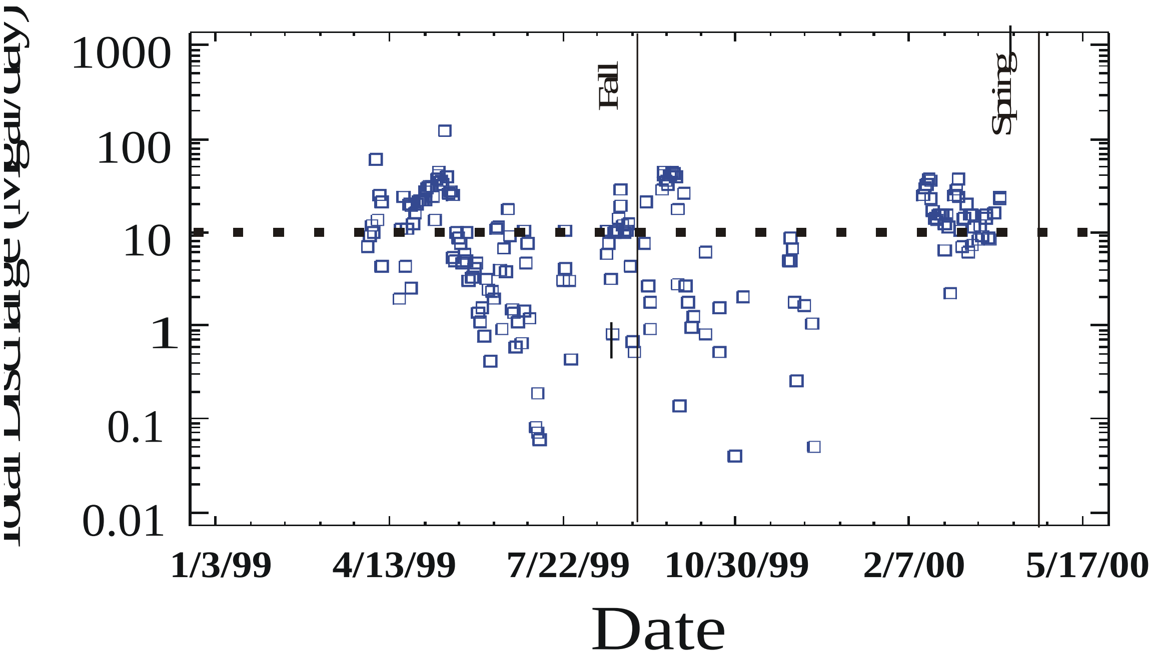


Figure 3: Total discharge from the spillways at HMI. [The cruise dates are denoted by vertical lines, and the 10Mgal/day discharge shown as a horizontal line. Discharge occurred from the northern cell during this period].

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 which have 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, the proximal zone which shows the most consistent enrichment levels through time, and the distal zone which is effected primarily during extended periods of dewatering and crust management, and;

4. *Baltimore Harbor* - There are a handful of sites in the southern portion of the area studied in the exterior monitoring program which have consistently shown a gradient suggesting that

there is 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 that 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. However to date, there have been no samples collected between HMI and the harbor which would confirm this trend. Four sites have been added in the Year 18 study to assess the role of Baltimore harbor to the HMI external sedimentary environment. These are indicated by the solid circles in Figure 2.

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 18 cruises are summarized below. Information was extracted from *Operations Reports* prepared by MES, covering the periods April 1, 1999 - April 30, 2000; a detailed synopsis of this period and digital discharge records were provided to MGS for this report by MES (pers. com. Hubbles).

This monitoring year was a period of high usage of the facility. Prior to the fall sampling cruise a total of approximately 1.6 million cubic yards were put into HMI from eight separate dredging operations. The period before the spring sampling was similar, with a total of approximately 1.8 million cubic yards from 7 operations. This relatively high level of usage produced relatively high outflow (>10Mgal/day) at the spillways; there were no extended periods of low discharge. The conditions that were dominant at the facility during the study period tend to stabilize the sediment by preventing oxidation of the sediment. This is in contrast to periods when the sediments are exposed to the atmosphere, as during dewatering and crust management operations. Consequently during this monitoring year, acid formation and the accompanying leaching would not be expected to occur. 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 4); the relatively lower pH occurred during periods of low flow, as expected, but all measurements indicated no free mineral acidity. 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.

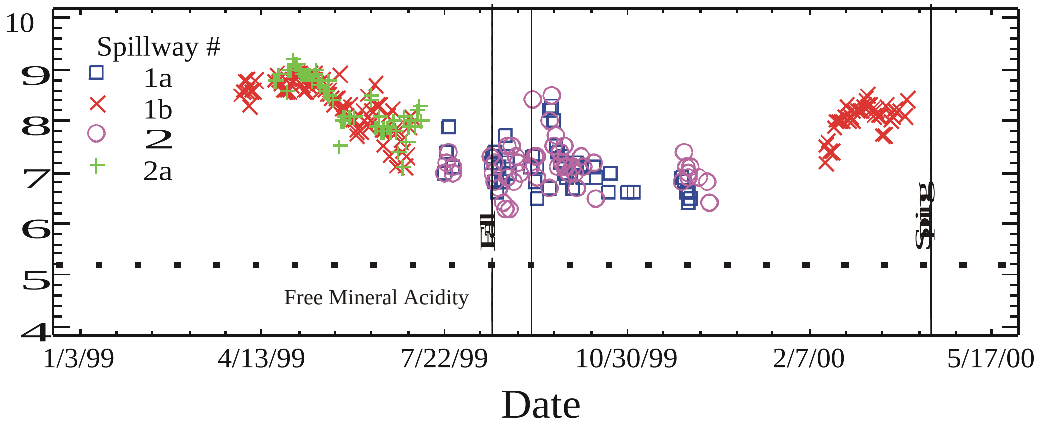


Figure 4: Daily low pH readings from HMI discharge. [Discharge only occurred from North Cell spillways during this monitoring year. Vertical lines denote sampling cruise dates. pH readings below the horizontal line indicates free mineral acidity].

Objectives

As in the past, the main objectives of the Year 18 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 having historically elevated Zn concentrations was again of particular interest. New to this year, an assessment of the influence of Baltimore Harbor to the region was performed by adding new sites to link the HMI study area to the harbor.

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 Thomas C. Hopkins, Jr.* The first cruise took place on September 8, 1999, and the second, on April 26, 2000.

Sampling sites (Fig. 2) were located in the field by means of a Garmin differential global positioning system (GPS). According to the manufacturer's specifications, the repeatability of the navigation system -- the ability to return to a location at which a navigation fix has previously been obtained -- is better than 10 m (33 ft); the actual accuracy is an estimated 3-5 m (10-16 ft) (Evans, W., pers. comm.). The target and actual coordinates (latitude and longitude -- North American Datum of 1983) of Year 18 sample locations are reported in the companion Year 18 Data Report.

The same 40 stations were occupied during both Year 18 cruises. Except for one modification and four additions, stations were identical to those sampled during Year 17. Site MDE-29 was discontinued because of interference due to construction of a beach protection structure. The site was moved slightly away from the beach and numbered MDE-37. Four stations (MDE-38, MDE-39, MDE-40, and MDE-41) were added to better understand the influence of Baltimore Harbor on the plume of high trace metal concentrations often found in sediments southeast of HMI. Those sites were selected based on the following criteria:

1. Avoid historical dredge disposal sites and shipping channels;
2. Avoid sands; and,
3. Lie within historic depositional areas, based on bathymetric comparisons.

Furthermore, MDE-41 had been included in 1994 and 1996 studies of Baltimore Harbor (site BSM #10), so comparison data existed for that site.

During the September 1999 cruise, undisturbed samples of the upper 20 cm (8 inches) of the sediments were obtained with a Van Veen sampler. The same sampler was used to collect sediments at the first seven stations revisited during the second cruise. However, after losing the Van Veen overboard, the crew switched to a 9-inch Ponar Dredge and used it to collect the remaining samples. At 36 stations, one grab sample was collected and split for MGS's textural and trace metal analyses. With the research vessel anchored, triplicate grab samples were collected at four stations (MDE-2, MDE-7, MDE-9 and MDE-31). At all stations, samples were also collected for the Chesapeake Biological Laboratory (CBL), which analyzes a second suite of trace metals. Upon collection, each sediment sample was described lithologically and subsampled. Field descriptions of samples are included in the Year 18 Data Report.

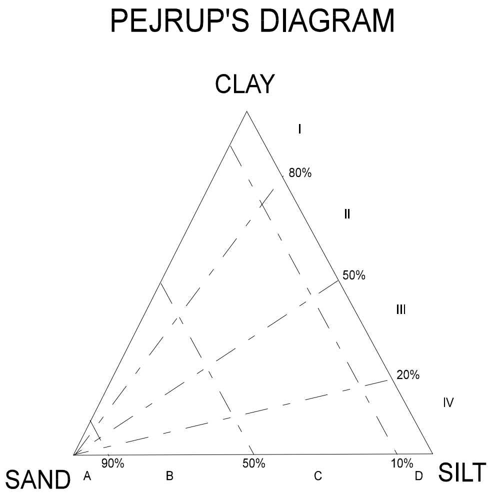


Figure 5: Pejrup's (1988) classification of sediment type.

Using plastic scoops rinsed with deionized water, the crew took sediment sub-samples from below the flocculent layer, usually several centimeters from the top, and away from the sides of the sampler to avoid possible contamination by the sampler itself. MGS's sub-samples were placed in 18-oz Whirl-Pak^{TM} bags, stored on-board in an ice chest, then transferred to a refrigerator, where they were maintained at 4^{o}C until they could be processed in the laboratory. CBL's sub-samples were placed in containers supplied by CBL and also stored on-board in an ice chest.

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:

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

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-um 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 5).

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

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

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

Trace Metal Analysis

Sediment solids were analyzed for eight trace metals, including iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb) and cadmium (Cd). In addition to the trace metals, total phosphorus (P) was analyzed. Samples were digested using a microwave digestion technique followed by analysis on an Inductively Coupled Argon Plasma Spectrometer (ICAP). The digestion method was modified from USEPA Method #3051 in order to achieve total recovery of the elements analyzed. The 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^oC);
2. Approximately 10 g of wet sample were transferred to Teflon evaporating dishes and dried overnight at $105\text{-}110^oC$;
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^oC in 5.5 minutes, then maintained between 175-180^oC 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 1. The microwave/ICAP method has recoveries (accuracies) within ±5% for all of the metals analyzed, except Mn. Although poorer, the recoveries for Mn are good. The poorer recoveries for Ni and Mn are due to the concentrations of these elements being near detection limits. The SRM's have unrealistically low concentrations compared to the samples around HMI.

Table 1: Results of Maryland Geological Survey’s analysis of three standard reference materials, showing the recovery of the certified metals of interest.

		Percent	Recovery	*(n=15)*
Metal		NIST 1646	Buffalo River	PACS
Fe		93±4	99±2	92±3
Mn		93±6	83±4	79±5
Zn		100±1	90±1	101±2
Cu		99±5	96±4	101±2
Cr		96±4	115±5	101±4
Ni		93±9	105±9	89±8
Cd		98±9	*Below Detection*	*Below Detection*
Pb		92±3	87±4	100±5

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 depends on the identification of long-term trends in sediment distribution and the detection of changes in those trends. The sampling scheme, revised in Year 17, established a new baseline against which future changes in the sedimentary environment could be measured. Where appropriate, then, Year 18 results are discussed with respect to Year 17. Thirty-two of the 40 sampling sites visited during Year 18 yielded results that can be compared to those acquired the previous year. (The four new Year 18 samples and the one relocated sample were excluded, along with three samples for which Year 17 data were unavailable.) The grain size composition (proportions of sand, silt, and clay) of the 32 sediment samples collected during Years 17 and 18 is depicted as Pejrup's diagrams in Figure 6. Within a diagram, each solid circle represents one sediment sample. Related statistics, by cruise, are presented in Table 2.

Table 2: Summary statistics for Years 17 and 18, for 32 common sediment samples.

Variable	September 1998 (Cruise 37)	April 1999 (Cruise 38)	September 1999 (Cruise 39)	April 2000 (Cruise 40)
Sand content (%)				
Mean	23.82	21.09	21.47	23.99
Median	3.59	5.52	3.68	5.42
Minimum	0.77	0.71	0.59	1.27
Maximum	96.94	97.73	91.25	100.00
Range	96.17	97.02	90.66	98.73
Clay:mud ratio				
Mean	0.56	0.54	0.57	0.52
Median	0.57	0.56	0.57	0.53
Minimum	0.48	0.36	0.47	0.25
Maximum	0.63	0.66	0.68	0.64
Range	0.15	0.30	0.21	0.39
Number of samples	32	32	32	32

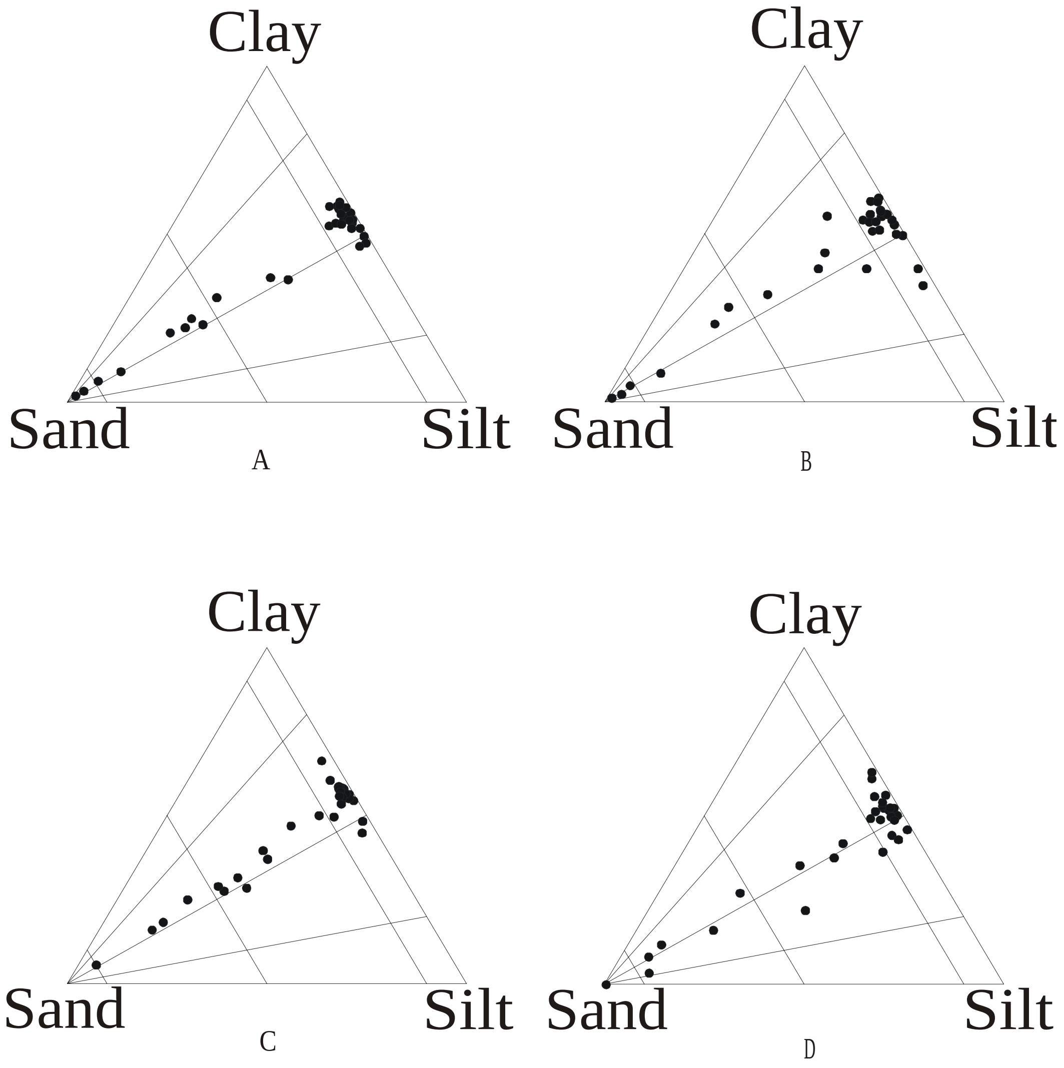


Figure 6: Ternary diagrams showing the grain size composition of sediment samples collected in Years 17 and 18 from the 32 sampling sites common to all four cruises: (a) September 1998, (b) April 1999, (c) September 1999, and (d) April 2000.

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; about 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.

Although the four diagrams are similar, they are not identical. The most notable difference is that more samples fall further below the 0.50 line in the spring than in the fall. Clay:mud ratios vary over a broader range in April than they do in September, as reflected in the summary statistics shown in Table 2. The range of ratios in September 1998 and September 1999 was 0.15 and 0.21, respectively, compared to 0.30 and 0.39 the following spring. Based on the clay:mud minima, it appears that, in the spring, certain localities are somewhat more turbulent (more silt-rich) than they had been the previous fall. The greater turbulence may be associated with the influx of water into the Bay during the spring freshet.

For Years 17 and 18, 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 8, 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 HMI. Scattered around the perimeter of the dike, the sandiest sediments (>50% sand), are confined to relatively shallow (<15 ft) waters (Figure 7). Broadest north and west of the facility, the shoals are the erosional remains 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 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.

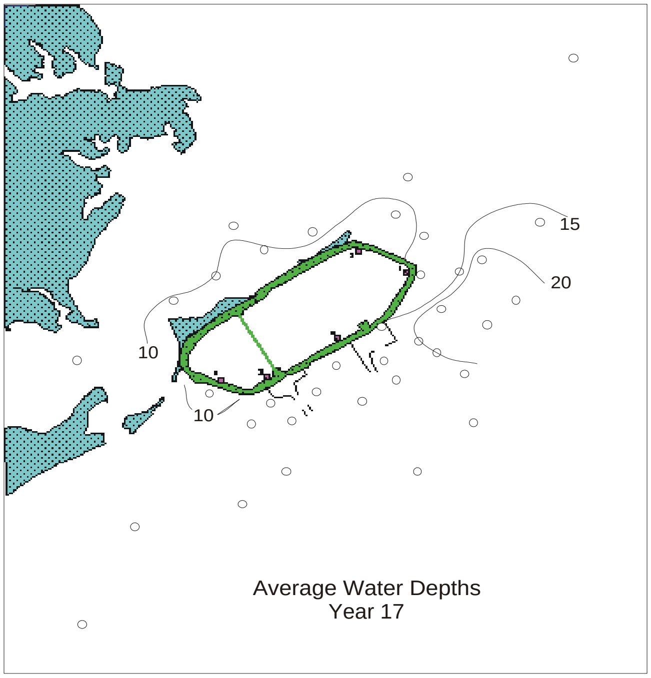


Figure 7: Average water depths.

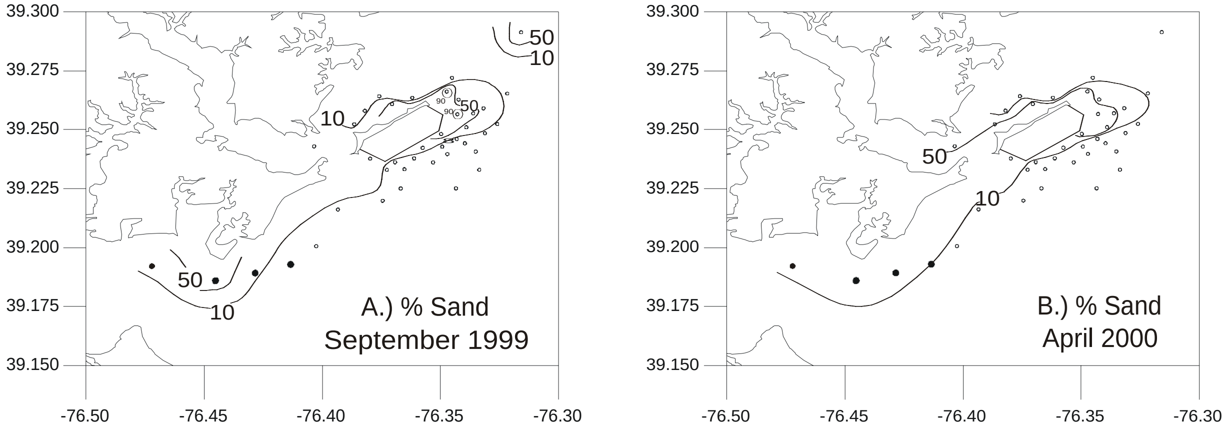


Figure 8: Distribution of percent sand for both Year 18 sampling cruises.

Sand distribution maps for Years 17 and 18 are similar in appearance. In fact, in reviewing the results of earlier monitoring years, the distribution of sand around HMI has remained largely unchanged since November 1988, two years following the first release of effluent from the dike. Over time, clay:mud ratios have tended to be more variable in their distribution. Year 18 was no exception (Figure 9). In September 1999, the fine fraction of the sediment was coarsest, or siltiest, (clay:mud ratio < 0.50) in three areas -- one adjacent to spillway #4 (station MDE-8), one at the mouth of Back River (station MDE-27), and the third near the eastern extent of the study area (station MDE-12). Beyond those three areas, the muddy fraction of sediments deposited around the dike is clay-rich. Within the established study area, clay:mud ratios are highest in a lens of sediments southeast of the dike between spillways #3 and #4, and in several small, scattered pockets around the dike – MDE-37 in Hawk Cove, MDE-2, northeast of spillway #1, and MDE-21, south of HMI. The most clay-rich sediments (clay:mud ratio > 0.60) are found in the mouth of Baltimore Harbor, in a lens of sediment encompassing the new sampling locations.

In April 2000, the clay:mud distribution changed somewhat. Silt-rich sediments were retrieved adjacent to the dike, near spillways #2, #3, and #4, and at the mouth of Back River (stations MDE-27 and MDE-28). The pocket of silty sediment at the eastern extent of the study area expanded in the spring to include MDE-13. Likewise, sediments were coarser at reference station MDE-36 to the north. The most marked change was in Baltimore Harbor sediments. Samples that had been clay-rich in the fall were decidedly silt-rich in the spring (stations MDE-40 and MDE-41). Except for Baltimore Harbor samples, clay-rich areas (>0.50) tended to persist through the spring, though the highest ratios (>0.60) diminished in extent.

Understanding the reasons for these variations in grain size distribution 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. Alternatively, sediment composition in these areas may vary locally. In that case, if the research vessel occupies a slightly different position from one cruise to the next, grain size will vary solely as a function of boat location. Whatever the cause of the variation, no clear trends, affecting many samples from a large area, are evident. For the established stations, the grain size distribution of Year 18 sediment samples is largely consistent with the findings of previous monitoring years.

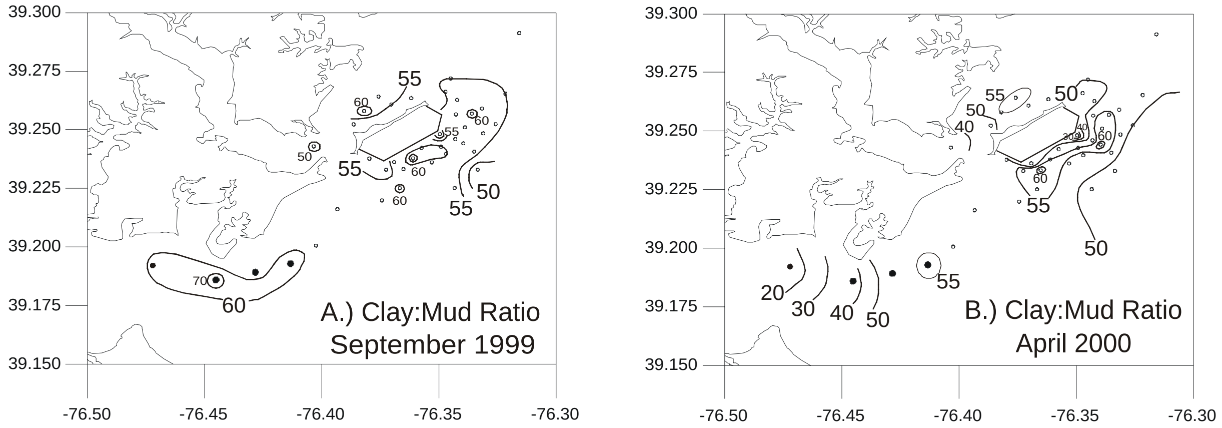


Figure 9: Distribution of clay:mud ratios for both Year 18 sampling cruises.

The main reason for adding the Baltimore Harbor samples was to determine if the Harbor was a possible source of the trace metals often concentrated in sediments deposited between spillways #3 and #4. The clay:mud distributions seem to argue against that possibility. In September 1999, the most clay-rich sediments formed discontinuous lenses, interrupted by slightly less clay-rich samples. Presumably, trace metals derived from Baltimore Harbor are more likely to settle with clay-rich sediments at the mouth of the Harbor; whereas, those derived from the containment facility are deposited in the vicinity of the dike. In April 2000, the persistence of clay-rich sites in the vicinity of the dike coupled with the disappearance of clay-rich sediments at the Harbor mouth seem to indicate two distinct depositional environments.

Elemental Analyses

Nutrients: Carbon, Nitrogen, and Phosphorus

There is a concern that HMI is a source of nutrients to the upper Bay. As a result, it would be expected that any particulate matter enriched in nutrients and that are discharged from the facility may influence the external sedimentary environment, as has been seen in previous years in relation to metals loading. Table 5 lists the gross statistics for the concentrations of total C, N, and P found in the external sediments. These values are in the concentration ranges of these elements found in the northern Bay. In order to assess, whether there is any enrichment due to localized sources such as HMI, it must be first determined if there is any enrichment and secondly does the distribution pattern of the enrichment suggest a localized source. Table 3 is a list of the ratios of the three nutrients to one another measured from this study; the Redfield ratio (Redfield et al. 1966) is given for comparison. Redfield's ratio is the ratio of nutrients found in plankton (C:N:P = 106:16:1); it is commonly used as a reference to gauge diagenetic reactions, and the input of organic material from of different sources.

Within the northern Bay, the two sources of carbon are plankton and terrigenous material (Hennessee et al. 1986; Cornwell et al. 1995). The plankton behave in accord with Redfield's ratio while the terrigenous (non-reactive) carbon, derived from coal and plant litter, is virtually devoid of N and P. The N/C ratio indicates that carbon is enriched with 2.6 times above what would be expected, through the addition of non-reactive carbon. Based on the P/N ratio, P is enriched by a factor of three over the amount predicted by Redfield's ratio; this enrichment is identical to what would be found if the carbon is adjusted in the P/C to reflect the 2.6 enrichment. These enrichments are typical of what is found in the northern Bay (Hennessee et al. 1986, Cornwell et al. 1995, Berner 1981). In addition, when the data are plotted on a map of the area, the distributions show a relatively uniform pattern, as would be expected from the low RSD. Discharge from HMI does not leave a C, N or P signature in the exterior sediments.

Table 3: Nutrient ratios found in the study area for Yr 17 as compared to Redfield's ratio.

	N/C	**P/C**	**P/N**
Redfield's	0.176	0.024	0.138
HMI (this study)	0.065	0.027	0.412
Standard Dev.	0.016	0.008	0.067
Relative Stand. Dev. (RSD)	25%	30%	16%

This does not mean that there may not be significant discharge of nutrients into the Bay, only that the nutrients discharged are in a dissolved or suspended phase that does not settle quickly in the area adjacent to the facility. These results are nearly identical to the results from the Year 17 report. In addition, the data from the samples that extend into Baltimore harbor do not vary significantly from the behavior exhibited proximal to the facility.

Trace Metals

Interpretive Technique

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

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

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

A least squares fit of the data was obtained by using a Marquardt (1963) type algorithm. The results of this analysis are presented in Table 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. This can be done by substituting the least squares coefficients from Table 4 for the determined coefficients in equation 2. 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 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 (62 of 80) are below the detection level for Cd (0.10);
2. Cr, Cu, Ni, Pb and Zn are found with concentrations that exceed the Effects Range Low (ERL) values; and
3. Zn and Ni exceed the ERM values.

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

Table 5: Summary statistics for elements analyzed. [All concentrations are in ug/g unless otherwise noted].

Element	***Cd***	***Cr***	***Cu***	***Fe(%)***	***Mn***	***Ni***	***Pb***	***Zn***
Count	18	80	80	80	80	80	80	80
Average	0.449	94	40.0	0.26	2396	62.4	51.3	283
Standard deviation	0.173	46.3	15.3	1.19	1223	27.3	22.5	120
Minimum	bdl	5.19	1.18	0.19	311	6.9	0.037	bdl
Maximum	0.79	346	67.5	5.16	5622	105	109	613
Range	0.79	341	66.3	4.93	5311	98	109	613
ERL	1.3	81	34	N/A	N/A	20.9	46.7	150
# of Samples >ERL	(0)	(59)	(34)	N/A	N/A	(70)	(48)	(66)
ERM	9.5	370	270	N/A	N/A	51.6	218	410
# of Samples >ERM	(0)	(0)	(0)	N/A	N/A	(57)	(0)	(11)

Element	***Carbon (%)***	***Nitrogen (%)***	***Phosphorus***
Count	80	80	80
Average	3.39	0.208	832
Standard deviation	1.24	0.069	283
Minimum	0.08	0.0095	52
Maximum	6.29	0.320	1339
Range	6.21	0.311	1287

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 10 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 Zn and Pb, are within the range expected for normal baseline behavior in the area. Pb has approximately half of the samples significantly exceeding the baseline levels; while Zn has approximately one quarter of the sites greater than background. Both Zn and Pb will be discussed in the following sections.

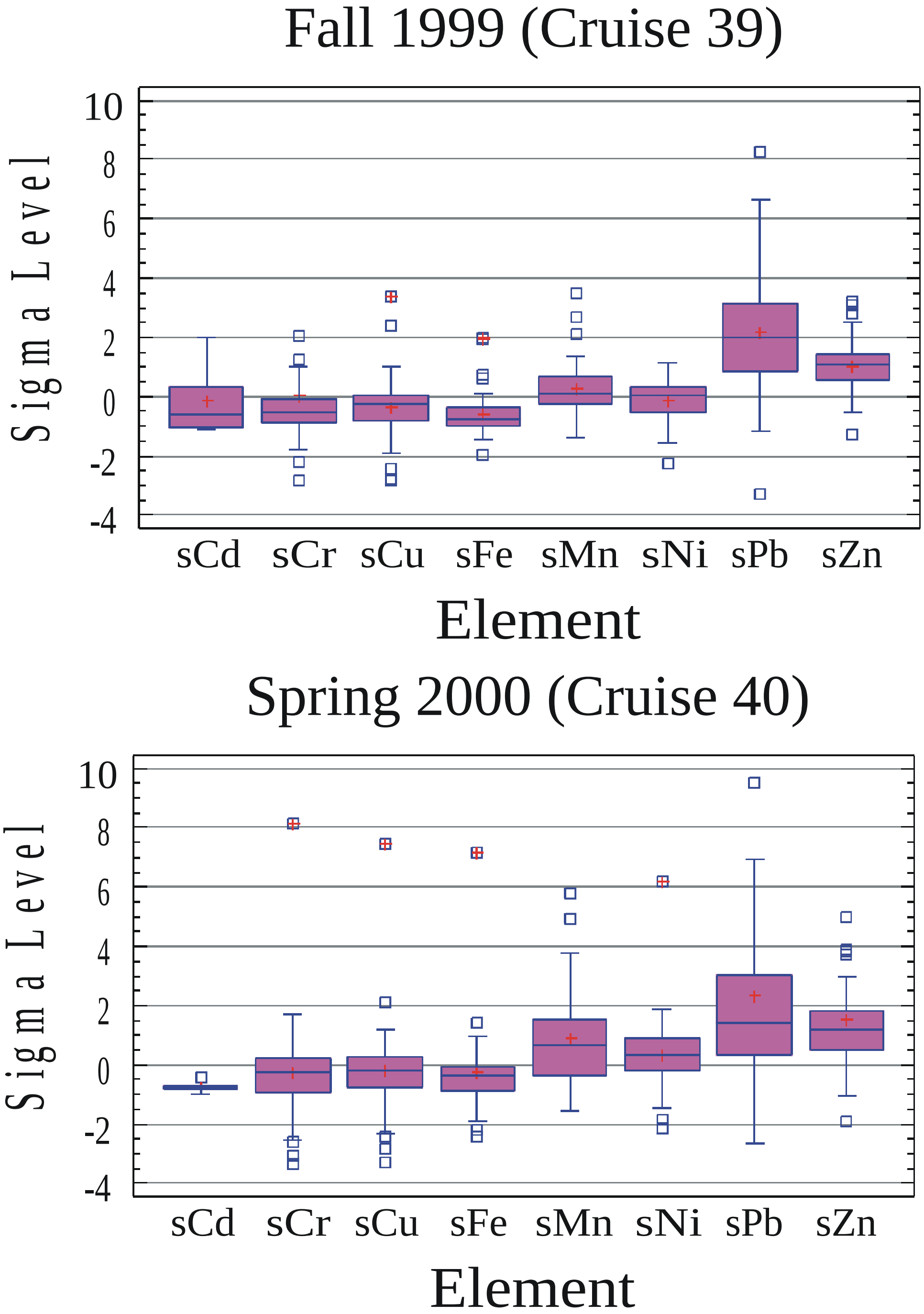


Figure 10: Box and whisker diagrams for Sigma Levels measured for all metals during Year 18 cruises.

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 11 shows the sigma levels for Zn in the study area adjacent to HMI for Fall 1999 and Spring 2000: Figure 12 shows the sigma levels for Pb for the same period. 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 zone in which the exterior sediments have been consistently elevated with Zn, due to the operations of the dike are outlined in Figure 2; the zone closest to the eastern side of the dike has been the most significantly influenced by the dike. For Year 18, the levels of metal elevation in the area influenced by HMI are some of the lowest since elevated levels were first noted in 1989. The levels were lower than those measured for the Year 17 monitoring, which was also low. This is true for both Zn and Pb; however, Pb has only been analyzed since Year 15, so the longer term trend is not as well established. The historical trend for Zn is shown in Figure 13 which is a plot of the maximum % Zn in the zone influenced by HMI (the data from this report are the solid squares in the figure) as a function of time. The data from this report for the HMI influenced area fall into normal baseline (Fall 1999) and transitional conditions (Spring 2000). Neither sampling cruise has levels in this area significantly elevated above background. On the other hand, the areas influenced by Baltimore Harbor and Back River are significantly elevated above baseline levels.

The shading in Figures 11 and 12 are used to highlight the areas that are significantly elevated above baseline levels. There are three primary areas that are highlighted during this monitoring period: Back River, Baltimore Harbor, and HMI. The Back River influence is stronger for Pb than Zn. Zn elevation is similar for both of the sampling cruises with the extent of the influence confined within the river, and the levels just within what would be considered a significant elevation. Pb on the other hand, had much higher levels of significant elevation, 10 compared to 3, and the extent of the enriched area covered the entire region of the Back River influenced zone (see Figure 12).

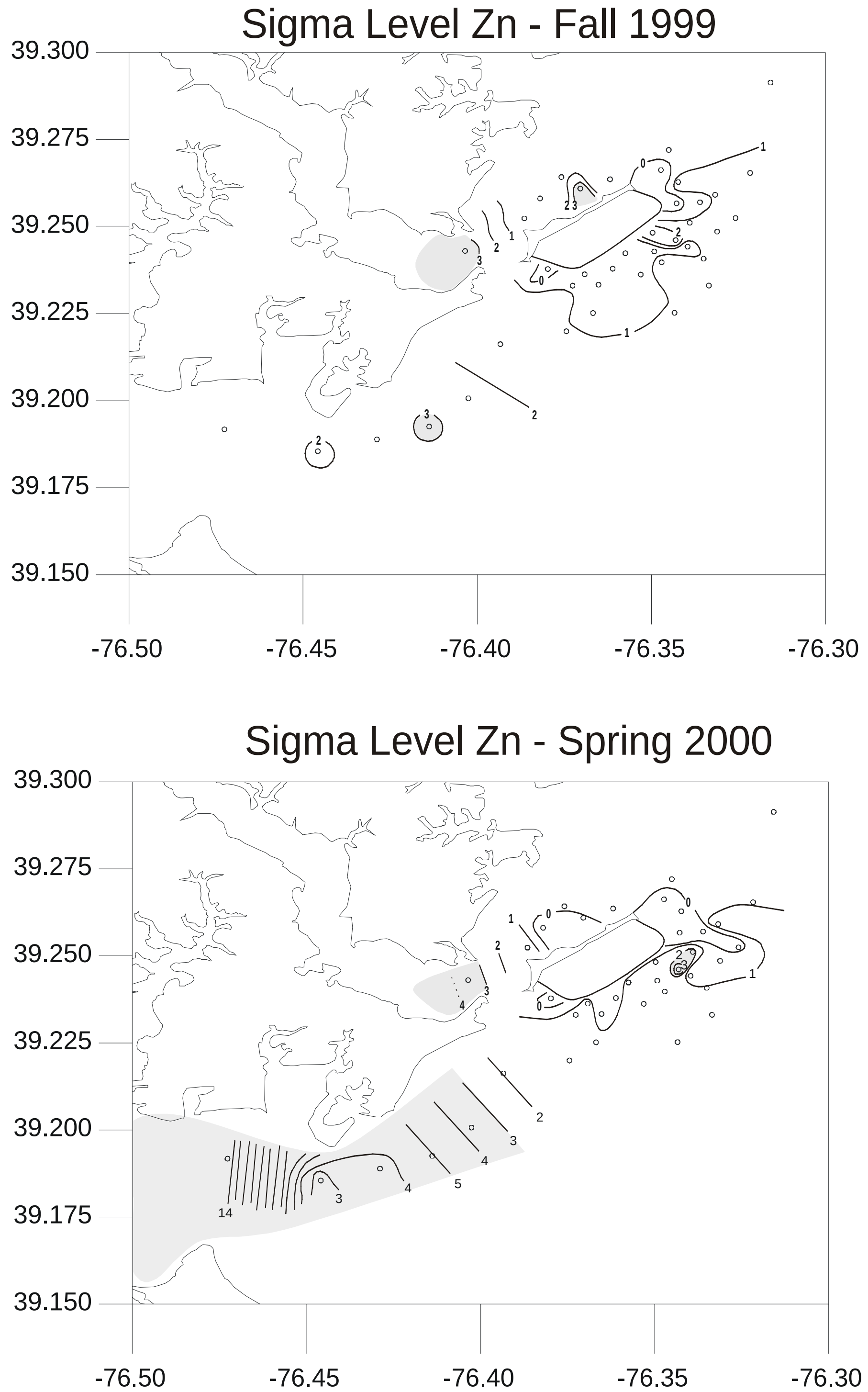
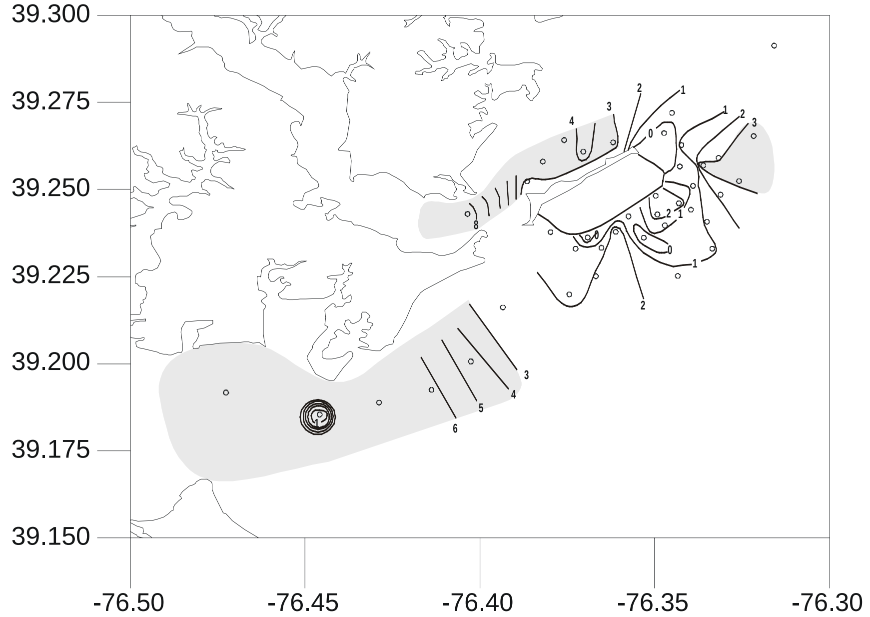
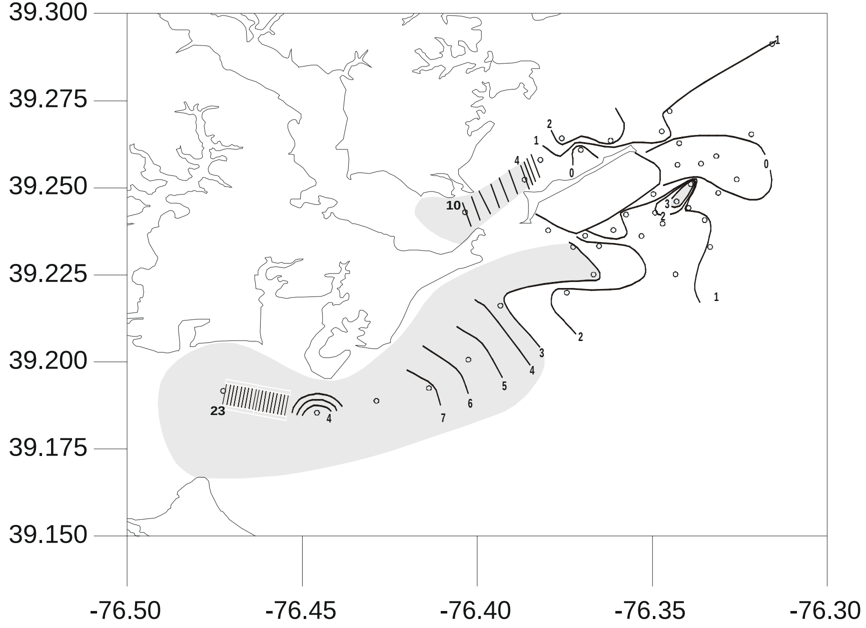


Figure 11: Distribution of Zn in the study area for the Fall and Spring sampling cruises. [Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional, >3 = significantly enriched].



Sigma Level Pb - Fall 1999



Sigma level Pb - Spring 2000

Figure 12: 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, >3 = significantly enriched].

The area influenced by Baltimore Harbor is more clearly defined this monitoring year than in previous years due to the additional four sampling sites. In previous years Station 26 was the southernmost station. Station 26, 25, and 22 defined the area that consistently suggested input from a southern source, but without adequate additional stations it was not possible to infer anything further. With the additional samples, the concentration gradients for both Zn and Pb indicate that the Harbor is the source of the elevated levels that are found south of HMI. It is important to note, when looking at the distributions in Figures 11 and 12 the high levels in the fall for Station 41 (the station farthest within the harbor) are most likely an over estimate. The station has highly variable sedimentary characteristics, and the gravel and clinker content made it difficult to get a reliable grain size determination; this in turn would affect the grain size normalization procedure. Taking this into account, Pb has a relatively consistent metal distribution for both the fall and spring sampling periods, both with regard to the levels found and the spatial extent of the elevation. Zn in contrast varies seasonally, with higher levels and greater spatial extent in the spring as compared to the fall. Both of the areas with elevated metals levels are within the historical zone where elevated levels have been seen south of HMI, and had been tentatively designated as influenced by Baltimore Harbor. 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 influence.

The HMI influence to the exterior sediments, for Pb and Zn, is only evident in the samples collected in the spring. Stations adjacent to Spillway 1 show significant elevation, but barely; the minimal influence of HMI can be attributed to facility operations. The low levels are put into historical perspective in Figure 13. This figure shows the maximum % excess Zn found within the zone historically influenced by HMI for each of the monitoring cruises. The last two points represent the maxima found during the cruises for Year 18. The Fall cruise shows the lowest value of % Excess Zn since the onset of the elevated levels in 1989, and the Spring cruise levels are only slightly elevated from the Fall, and are approximately the same as the Fall of the preceding monitoring year (Year 17). There were no significant 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 3 & 4). 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.

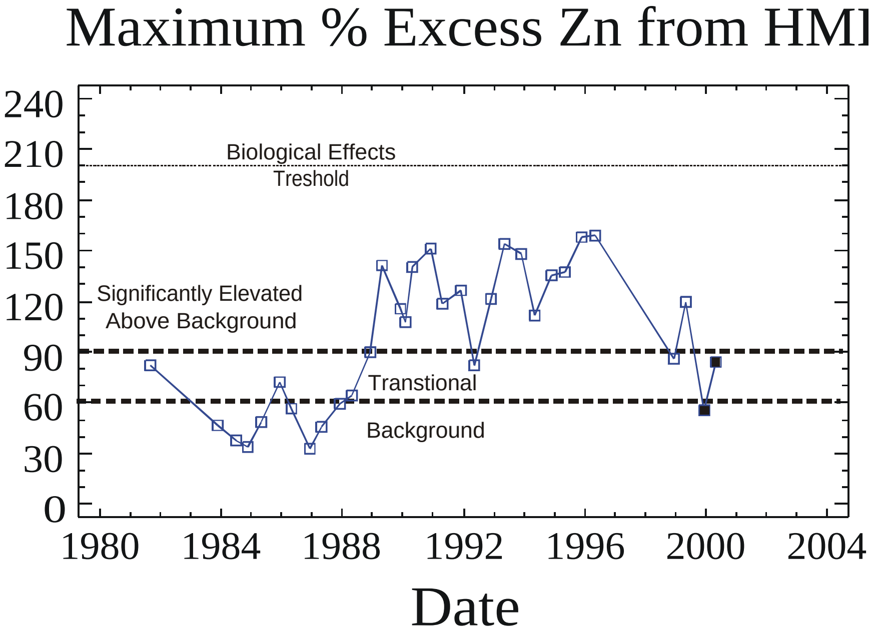


Figure 13: Maximum % excess Zn measured for all cruises monitored by Maryland Geological Survey.

CONCLUSIONS AND RECOMMENDATIONS

The grain size distribution of Year 18 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. However, the general sediment distribution pattern is consistent with the findings of previous monitoring years dating back to 1988 (the second year after the start of release from HMI). The main reason for adding the Baltimore Harbor samples was to determine if the Harbor was a possible source of the trace metals often concentrated in sediments deposited between spillways #3 and #4. The clay:mud distributions seem to argue against that possibility. In September 1999, the most clay-rich sediments formed discontinuous lenses, interrupted by slightly less clay-rich samples. Presumably, trace metals derived from Baltimore Harbor are more likely to settle with clay-rich sediments at the mouth of the Harbor; whereas, those derived from the containment facility are deposited in the vicinity of the dike. In April 2000, the persistence of clay-rich sites in the vicinity of the dike coupled with the disappearance of clay-rich sediments at the Harbor mouth seem to indicate two distinct depositional environments.

Discharge from HMI apparently does not leave a C, N or P signature in the exterior sediments. This is based on the use of Redfield's Ratio, data from the main stem of the Bay and the distribution pattern of these elements around the facility. However, this does not mean that there may not be significant discharge of nutrients into the Bay from HMI. Nutrients discharged in a dissolved or suspended phase that does not settle quickly in the area adjacent to the facility would not be detected in the exterior monitoring of the sediment. The nutrient levels found in the samples that extend into Baltimore Harbor do not show any appreciable difference from the sediments adjacent to HMI.

With regard to metal loadings in the area, some features to note are:

1. Most of the samples (62 of 80) are below the detection level for Cd (0.10);
2. Cr, Cu, Ni, Pb and Zn are found with concentrations that exceed the Effects Range Low (ERL) values; and,
3. Zn and Ni exceed the ERM values.

ERL and Effects Range Medium (ERM) are proposed criteria put forward by National Oceanic and Atmospheric Administration (NOAA - Long et al. 1995) to gauge the potential for deleterious biological effects. Sediments with concentrations below the ERL are considered baseline concentrations with no expected adverse effects. Concentrations between the ERL and ERM may have adverse impacts to benthic organisms, while values greater than the ERM have probable adverse biological effects. These criteria are based on a statistical method termed "preponderance of evidence". The method does not allow for unique basin conditions and does not take into account grain size induced variability in metal concentrations in the sediment. The values are useful as a guide, but are limited in applicability due to regional difference. The grain size normalization procedure outlined in the previous section is a means to correct the inadequacies 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 significantly enriched when 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, the Fall cruise shows the lowest level of Zn since the onset of the elevated levels in 1989, and the Spring cruise levels are only slightly elevated from the Fall, and are approximately the same as the Fall of the preceding monitoring year (Year 17). There were no significant periods during which discharge rates were below 10 MGD; 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 are much lower during this sampling period. Currently, the facility is actively accepting material, but as it reaches capacity and the volume of effluent is expected to decline, dewatering of the contained material may lead to higher metal levels in the effluent. Exposure of dredged material to the air is likely to result in the mobilization of metals associated with those sediments, an effect analogous to acid mine drainage. Metals released in the effluent, particularly at low discharge rates, are deposited on the surrounding Bay floor and are increasing the long term sediment load in the Bay. Although these levels are much lower than any biological effects threshold, continued monitoring is needed in order to; detect if the levels increase to a point where action is required, document the effect that operations have on the exterior environment (for future project design), and to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of exposing contained dredged material to the atmosphere. Close cooperation with MES is important in this endeavor.

It is further recommended, in order to assess the potential influence of Baltimore Harbor on the HMI exterior sediments better, the additional sampling sites be maintained, at least temporarily.

CHAPTER 3: BENTHIC COMMUNITY STUDIES (Project 3)

Year 18 (September 1999 – September 2000)

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ABSTRACT

The benthic macroinvertebrate community in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI) was studied for the eighteenth 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.*

Eighteen stations (11 nearfield, 3 reference, 3 Back River/Hawk Cove stations and 1 Harbor Station) were sampled on September 9, 1999, and again on April 27 and 28, 2000. The Baltimore Harbor station, located near the mouth of the Patapsco River, was sampled this year to determine if the legacy of contamination from Baltimore's Inner Harbor could be affecting benthic communities as far away as 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, a Yellow Springs Instruments (YSI) multi-parameter water quality meter, and/or a Global Water WQ700 turbidimeter at one-meter intervals from the bottom of the water column to develop vertical profiles. Sediment samples were collected at each station for grain-size analysis.

A total of 41 taxa of benthic macroinvertebrates were found at these eighteen benthic community stations during Year 18 of monitoring. Of these 41 taxa, five taxa (the clam *Rangia cuneata*, the polychaete worms *Streblospio benedicti* and *Neanthes succinea*, oligochaete worms in the family Tubificidae, and the isopod crustacean *Cyathura polita*) were found at most stations during both seasons. At most stations, total abundance was higher in the spring rather than in late summer due to high seasonal recruitment, especially of the polychaete worm *Marenzelleria viridis* and the amphipod crustacean *Leptocheirus plumulosus*.

Diversity was examined using the Shannon-Wiener diversity index. Diversity values ranged from 1.55 to 3.17 in late summer and from 1.07 to 2.87 in the spring. Diversity was greatly influenced by the abundance of a few taxa; particularly the clam *Rangia cuneata*, the polychaete worm *Marenzelleria viridis*, and the amphipod *Leptocheirus plumulosus*, which together accounted for over 50% of the individuals at each station in the spring. The proportion of pollution-sensitive taxa (*Cyathura polita*, *Rangia cuneata*, *Marenzelleria viridis*, *Glycinde solitaria* and *Macoma balthica*) was generally higher in April 2000 than in September 1999. This was primarily due to spring recruitment of *M. viridis*. The proportion of pollution-indicative taxa (the polychaete worms *Eteone heteropoda, Streblospio benedicti*, and *Paraprionospio pinnata*, oligochaete worms in the family Tubificidae, the clam *Mulinia lateralis*, and midge larvae in the family Chironomidae) was higher at all stations in September than in May. This was primarily due to the large numbers of *S. benedicti* found in September.

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI, Weisberg et al.

1997), a multimetric index of biotic condition that evaluates summer populations (during the July 15th to September 30th timeframe) of benthic macroinvertebrates, was calculated for all of the stations that were sampled during the September 1999 cruise. Sixteen benthic stations, including all three reference stations, met or exceeded the Restoration Goal of a B-IBI score of 3.0. Only two stations, MDE-1 and the new Harbor station MDE-41, had a B-IBI score less than three, indicating a stressed or impacted benthic macroinvertebrate community.

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 placement sites for placement of dredged material. In 1981, the Hart-Miller Island Dredged Material Containment Facility (HMI) was constructed to accommodate the dredged material management needs for the Port of Baltimore and specifically the need to manage contaminated sediments dredged from Baltimore's Inner Harbor. HMI is a 1,140-acre artificial island surrounded by a 29,000-foot long dike constructed along the historical footprints of Hart and Miller Islands at the mouth of Back River. A series of five spillways are located around the perimeter of the facility to discharge excess water released from on-site dredged material disposal operations.

As part of the environmental permitting process for dredged material containment facilities, an exterior monitoring program was developed to assess any environmental impacts associated with HMI. Various agencies have worked together since the inception of this program to monitor for environmental impacts associated with dike construction and dredged material management activities. Studies were completed prior to and during the early construction period to determine baseline environmental conditions in the HMI vicinity. The results of post-construction monitoring have then been compared to this baseline as well as to interseasonal and interannual data. This report represents the eighteenth consecutive year of the benthic macroinvertebrate community monitoring since 1981. In Year 18, the Maryland Department of the Environment was responsible for all aspects of benthic community monitoring.

The goals of the Year 18 benthic community monitoring were:

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

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

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

METHODS AND MATERIALS

For the Year 18 benthic community studies, staff from the Maryland Department of the Environment's Biological Assessment Section and Field Office Program collected benthic macroinvertebrate samples and measured several *in situ* habitat quality parameters. Field sampling cruises were conducted on September 9, 1999, and on April 27 and 28, 2000. Eighteen benthic stations (Figure 14; Table 6) in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI) were included in the study. The Hawk Cove/Back River station MDE-29 was dropped this year due to its proximity to the breakwaters being constructed along the recreational beach between Hart and Miller islands. The Maryland Geological Survey Hawk Cove/Back River station MDE-28 was sampled to compensate for the loss of station MDE-29. An additional station MDE-41 near the mouth of the Patapsco River (entrance to Baltimore Harbor) was also sampled to examine the potential for adverse environmental effects to the HMI benthic community from Baltimore Harbor. 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 1999 and April 2000. 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. In September, turbidity was measured at stations MDE-22, MDE-24, and MDE-41 using a Yellow Springs Instruments (YSI) unit. Turbidity was not measured at other stations due to problems with the YSI unit. During the spring cruise, turbidity was measured at all stations using a Global Waters Turbidimeter. Secchi depth was measured at all stations during both seasons. Water quality data from all depths are found under Project III of the *Year 18 Data Report*.

All benthic samples were collected using a Ponar grab sampler, which collects approximately 0.05 m^2 (0.56 ft^2) of bottom substrate. Three replicate benthic grab samples were collected at each station. Some replicates, particularly at sand and shell stations, consisted of multiple grabs to account for small sample sizes. Samples were 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

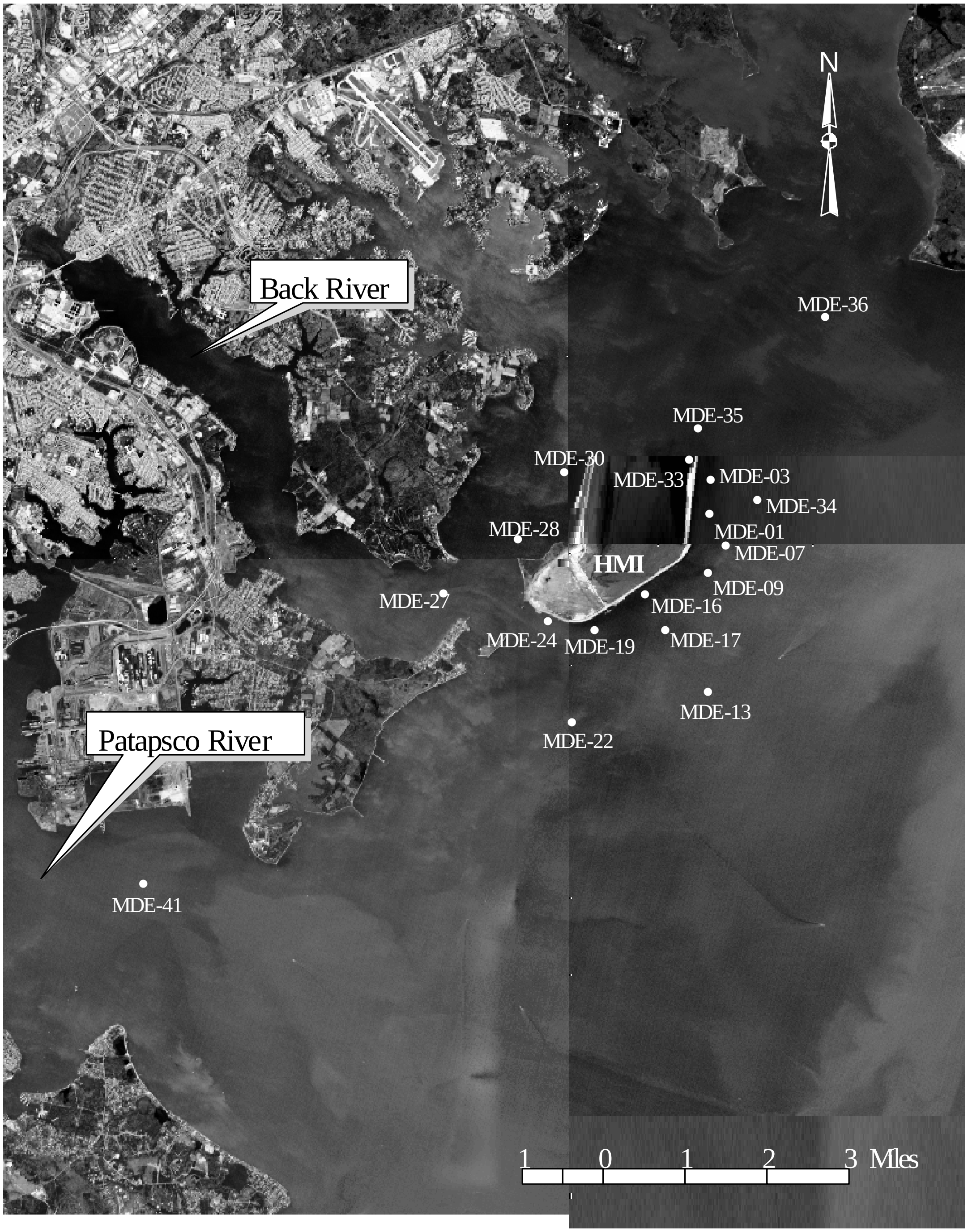


Figure 14: Year 18 Benthic Community Sampling Stations.

Table 6: Locations (latitudes and longitudes in degrees, decimal minutes), major sediment type, and 7-digit codes of stations used for Year 18 benthic community monitoring.

Station #	Latitude	Longitude	Predominant Sediment Type	Maryland 7-Digit Station Designation
Nearfield Stations				
MDE-1	39^{o} 15.3948	76^{o} 20.5680	Shell	XIF5505
MDE-3	39^{o} 15.5436	76^{o} 19.9026	Shell	XIG5699
MDE-7	39^{o} 15.0618	76^{o} 20.3406	Silt/clay	XIF5302
MDE-9	39^{o} 14.7618	76^{o} 20.5842	Silt/clay	XIF4806
MDE-16	39^{o} 14.5368	76^{o} 21.4494	Shell	XIF4615
MDE-17	39^{o} 14.1690	76^{o} 21.1860	Silt/clay	XIF4285
MDE-19	39^{o} 14.1732	76^{o} 22.1508	Shell	XIF4221
MDE-24	39^{o} 14.2650	76^{o} 22.7862	Sand	XIF4372
MDE-33	39^{o} 15.9702	76^{o} 20.8374	Sand	XIF6008
MDE-34	39^{o} 15.7650	76^{o} 20.5392	Sand	XIF5805
MDE-35	39^{o} 16.3182	76^{o} 20.7024	Silt/clay	XIF6407
Reference				
MDE-13	39^{o} 13.5102	76^{o} 20.6028	Shell	XIG3506
MDE-22	39^{o} 13.1934	76^{o} 22.4658	Silt/clay	XIF3224
MDE-36	39^{o} 17.4768	76^{o} 18.9480	Silt/clay	XIG7589
Back River/Hawk Cove				
MDE-27	39^{o} 14.5770	76^{o} 24.2112	Silt/clay	XIF4642
MDE-28	39^{o} 15.3900	76^{o} 22.7304	Silt/clay	XIF5427
MDE-30	39^{o} 15.8502	76^{o} 22.5528	Shell	XIF5925
Patapsco River/Baltimore Harbor				
MDE-41	39^{o} 11.5020	76^{o} 28.3578	Sand	XIF1517

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 genus using a binocular compound microscope. In cases where an animal was fragmented, only the head portion, if fully intact and identifiable, was counted as an individual organism. All other body fragments were discarded. Individuals of the most common clam species (*Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli*) were measured to the nearest millimeter. All identifiable clams were enumerated.

At each station, subjective estimates (nearest 5%) of the percent contributions of detritus, gravel, shell, sand, and silt/clay (mud) were made in the field. In addition, approximately 200 to 400 grams of sediment were taken from a fourth grab sample collected at each benthic station. These sediment samples were taken to the laboratory, where a representative subsample (approximately 50 grams) of each was used to determine water content and grain size distribution. These sediment subsamples were weighed, wet sieved and dried in an oven according to MDE's Standard Operating Procedures for sediment analysis (MDE 1999). Total dry weight was determined by summing the dry weights of the various size fractions. Shell or shell fragments in a sample are included with the sand and gravel fractions according to the sieve upon which they are retained. Each fraction was expressed as a percentage of the total dry weight. Water content was expressed as a percentage of the wet sediment weight.

Seven main measures of benthic community condition were examined, including: total infaunal abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance of pollution-sensitive infaunal taxa, the Shannon-Wiener diversity index, abundance of carnivores and omnivores (for Harbor station MDE-41 only), and taxa richness and total abundance of all taxa (excluding Bryozoa). The first five of these measures were used to calculate the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI; Weisberg et al. 1997) for September 1999 only. The B-IBI only evaluates samples collected from July 15th through September 30th. Other parameters examined for this project included the numerically dominant taxa during each season and as well as the length frequency distributions of the three most common clams (*Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli*).

Abundance measures were calculated based on the average abundance of each taxon in the three replicate samples collected at each station. Total Abundance was calculated as the total number of organisms per square meter ($\#/m^2$), excluding Bryozoa, which are colonial. Total Infaunal Abundance was calculated as the total number of infaunal organisms per square meter ($\#/m^2$). Taxa that were designated as "epifaunal" for the calculation of the B-IBI (see Ranasinghe et al. 1994) were excluded from the total infaunal abundance. Some excluded taxa were the mussel *Mytilopsis leucophaeata*, the amphipods *Melita nitida* and *Apocorophium lacustre*, the crab *Rhithropanopeus harrisii*, the barnacles *Balanus improvisus* and *Balanus subalbidus*, and the isopod *Edotea triloba*. Members of the phylum Bryozoa (bryozoans) were excluded because they are not only epifaunal, but also colonial. Qualitative estimates of the number of live bryozoan zooids are included in the *Year 18 Data Report*.

Pollution-Sensitive Taxa Abundance was calculated as the percentage of total infaunal abundance represented by pollution-sensitive taxa (the clams *Macoma balthica* and *Rangia cuneata*, 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 midge *Coelotanypus* sp., the clam *Mulinia lateralis*, and the polychaete worms *Streblospio benedicti, Paraprionospo pinnata* and *Eteone heteropoda*). Taxa were designated as pollution-indicative or pollution-sensitive according to Weisberg et al. (1997). The Shannon-Wiener Diversity Index (H') was estimated using the machine formula provided in Weber (1973). Taxa richness (number of taxa) was calculated for each station as the total number of taxa found in all three replicates. Infaunal taxa richness was calculated as the number of infaunal taxa found in all three replicates. The abundance of the three most common taxa at reference and monitoring stations was also examined. This measure included epifaunal taxa other than bryozoans.

Scientific names of several organisms collected over the years as part of the Hart-Miller Island Exterior Monitoring Program have changed. Table 7 lists the old and new names of these organisms. It also lists common names of these and other organisms that have been found routinely at HMI.

Table 7: Synonyms and common names of organisms found in the sediments around Hart-Miller Island Dredged Material Containment Facility. The list includes only those organisms whose scientific names have changed since the beginning of the HMI Exterior Monitoring Program in 1981, or for which common names are available.

Old Name	New Name	Common Name
Nereis succinea	*Neanthes succinea*	Clam worm
Polydora ligni	*Polydora cornuta*	Whip mud worm
Scolecolepides viridis	*Marenzelleria viridis*	Red-gilled mud worm
Congeria leucophaeta	*Mytilopsis leucophaeata*	Dark falsemussel
Macoma balthica		Baltic macoma clam
Macoma mitchelli		Mitchell's macoma clam
Rangia cuneata		Brackish water clam
Balanus improvisus		Bay barnacle
Cyathura polita		Slender isopod
Edotea triloba		Mounded-back isopod
Leptocheirus plumulosus		Common burrower amphipod
Corophium lacustre	*Apocorophium lacustre*	Slender tube-builder amphipod
Gammarus species		scuds
Monoculodes edwardsi	*Ameroculodes* spp. complex	Red-eyed amphipod
Rhithropanopeus harrisii		White-fingered mud crab
Membranipora sp.		Coffin-box bryozoan
Haliplanella luciae		Striped anemone

RESULTS AND DISCUSSION

Seasonal Water Quality Parameters for Year 18

Salinity, temperature, dissolved oxygen, conductivity, Secchi depth and pH were measured *in situ* at all stations during both sampling events. Turbidity was measured at all stations during the spring, but only at a few stations (MDE-22, MDE-24 and MDE-41) during the late summer due to technical problems with the sampling equipment. Water quality data for all depths at all stations during both the late summer (September 1999) and spring (April 2000) cruises are found in the *Year 18 Data Report*. Since water quality conditions at bottom depths are the ones most relevant to the benthic community, the following discussion focuses on water quality parameters measured nearest to the Bay floor.

The variation seen in bottom salinities between September 1999 and April 2000 was typical of seasonal variations in the northern region of Chesapeake Bay. Bottom salinities in September 1999 generally fell within the low mesohaline category (5.0 to 12.0 parts per thousand, Weisberg et al., 1997) and ranged from 8.1 to 12.6 ‰ (Table 8, average = 9.4 ‰ ± 1.1 ‰). The exception was the Harbor station MDE-41, which fell into the high mesohaline range (12 - 18 parts per thousand (‰),Weisberg et al., 1997). The Year 18 late summer salinity range was considerably higher than the salinity range during the corresponding season in Year 17 (average = 7.6 ‰ ± 0.7 ‰, range = 6.0 - 8.7 ‰). This was likely due to a severe drought in Maryland during the summer of 1999 (Figure 15), which reduced the flow of freshwater from the Susquehanna River to the upper Chesapeake Bay. In September 1999, the lowest bottom salinity (8.1 ‰) was found at Back River /Hawk Cove station MDE-30, whereas last year's lowest salinity (6.0 ‰) was found at reference station MDE-36. Both of these are northerly stations more influenced by freshwater flows from the Back and Susquehanna Rivers, respectively. The highest bottom salinity (12.6 ‰) was found at Harbor station (MDE-41), the new southernmost station that is furthest from the freshwater influence of the Susquehanna River. The highest bottom salinity measured in Year 17 during the late summer was 8.7 ‰ at reference station MDE-13, also a southerly station.

Year 18 surface and bottom salinities for September showed more vertical stratification this year than last. Nearfield stations MDE-3, MDE-7, MDE-9, MDE-35, reference station MDE-36 and Harbor station MDE-41 all had bottom salinities which were nine-tenths or more parts per thousand greater than their surface values (1.4 ‰, 1.0‰, 1.3 ‰, 1.2 ‰, 0.9 ‰ and 2.4 ‰, respectively). Last year, surface and bottom

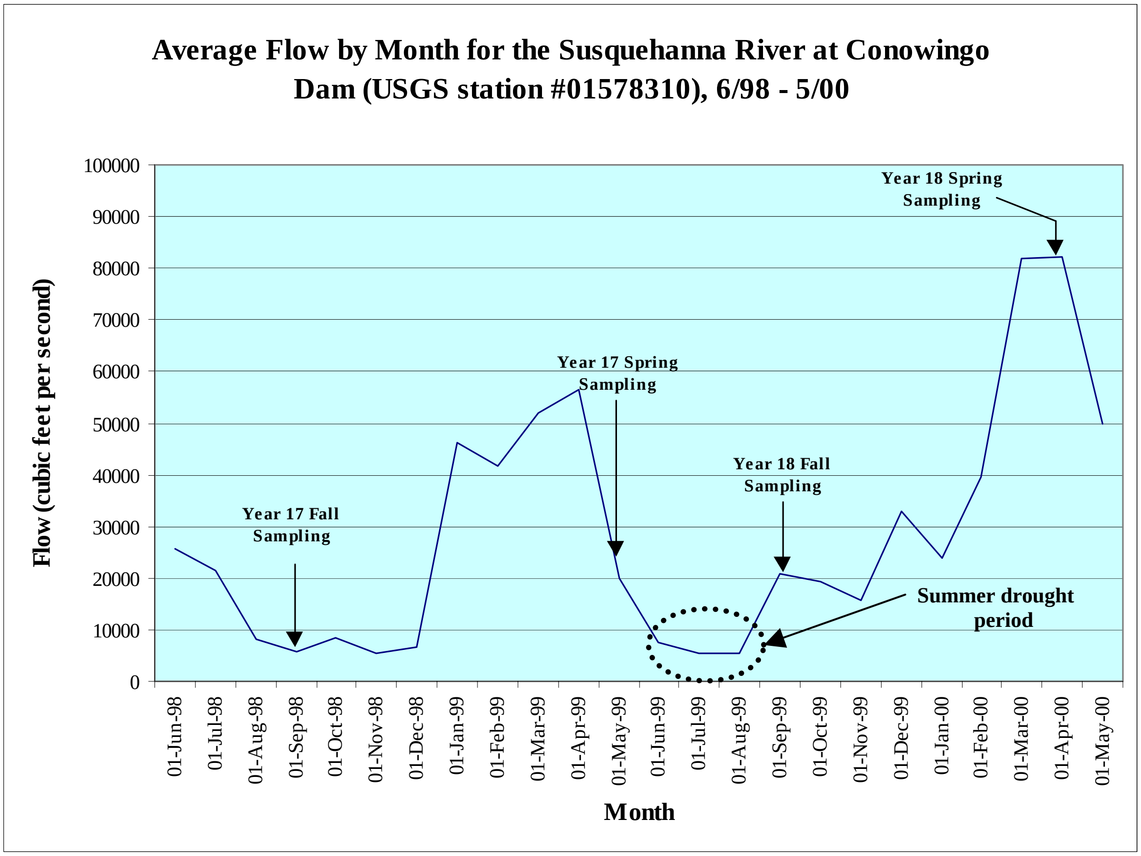


Figure 15: Average flow of the Susquehanna River at Conowingo Dam over the last two sampling periods.

salinities at each station during late summer never differed by more than 0.2 ‰, with the exception of MDE-27 (surface = 5.8 ‰, bottom = 7.7 ‰). Drought conditions, which both increase the northern extent of the salt-water wedge and minimize vertical mixing of the water column, could have contributed to the greater variability between surface and bottom salinities in September.

In April 2000, bottom salinities ranged from 0.3 ‰ to 6.3 ‰ (Table 9, average = 1.2 ‰ ± 1.3 ‰), straddling the tidal freshwater [0.0 - 0.5 ‰ (Weisberg et al., 1997)], oligohaline [0.5 - 5 ‰ (Weisberg et al., 1997)] and mesohaline regimes. The highest bottom salinity this year was found at the new southernmost Harbor station MDE-41 (6.2 ‰). Excluding this new station (MDE-41), the next highest bottom salinity this year occurred at station MDE-22 with a value of 1.8 ‰ as compared to last spring's highest value of 7.0 ‰ found at the same station. The lowest bottom salinity (0.3 ‰) was found at reference station MDE-36, the northernmost of all HMI sampling stations. Last year's lowest values were found at Back River/Hawk Cove stations MDE-29 and MDE-30 (3.4 ‰ and 3.2 ‰, respectively). Both of these stations are northwest of HMI and within the path of freshwater influx from the Back River. Differences between surface and bottom salinities in April 2000, with the exception of Harbor station MDE-41 (difference of 3.7 ‰), ranged from 0-0.2 ‰ compared to last year's range of difference (0 ‰-2.4 ‰).

Bottom water temperatures in September 1999 were warm with an average of 25.2 ºC ± 0.6 ºC (Table 8, range = 24.4 ºC - 26.2 ºC) compared to last year's average bottom temperature of 23.9 ºC ± 1.0 ºC (range = 22.8 ºC - 27.7 ºC). The difference between the surface and bottom temperatures at any station during September fell between 0 ºC - 1.7 ºC, whereas all of last year's late summer temperatures had differences of <1 ºC between surface and bottom. In April 2000, temperatures were approximately 50 % lower than the late summer with an average of 11.8 ºC ± 0.2 ºC (Table 9, range = 11.5 ºC -12.2 ºC). Last year's spring temperatures averaged 16.8 ºC ± 1.0 ºC (range = 15.4 ºC -18.4 ºC). Surface and bottom temperatures never differed more than 0.3 ºC at any station in April 2000.

Secchi depths in September 1999 (Table 8, range = 0.8 m-2.4 m, average=1.7 m ± 0.4 m) were substantially greater than those seen in April 2000 (Table 9, range = 0.2 m-1.0 m, average=0.7 m ± 0.2). The Back River station MDE-27 had the lowest Secchi depth during both seasons. This is not surprising due to the historically poorer water quality of Back River, due in part to the area's wastewater treatment plant and related nutrient loadings.

Although only three stations (reference station MDE-22, nearfield station MDE-24 and Harbor station MDE-41) were sampled prior to equipment malfunction, turbidity was fairly consistent at bottom depths during the late summer sampling (average = 7.8 NTU ± 1.9 NTU). Turbidities measured in the spring were higher and somewhat more variable than those in the late summer (average = 28.8 NTU ± 15.3 NTU).

During both seasons, dissolved oxygen (DO) concentrations remained above the Maryland water quality criterion of 5 parts per million [(ppm), COMAR 26.08.02.03-3A(2)].

Table 8: Water quality parameters measured *in situ* at all HMI stations on September 9, 1999.

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	8.2	25.8	7.6	7.1	2.4
		Bottom	2	8.5	25.6	7.5	7.2	
MDE-03	XIG5699	Surface	0.5	8.1	26.7	7.6	7.4	2.4
		Bottom	4.3	9.5	25.0	6.8	7.2	
MDE-07	XIF5302	Surface	0.5	9.0	25.5	7.1	7.2	1.8
		Bottom	4.7	10.0	24.9	6.2	7.1	
MDE-09	XIF4806	Surface	0.5	8.5	25.5	7.1	7.1	1.6
		Bottom	4.1	9.8	24.9	6.3	7.1	
MDE-16	XIF4615	Surface	0.5	9.2	24.8	6.3	7.1	2.0
		Bottom	3.2	9.6	24.6	6.3	7.1	
MDE-17	XIF4285	Surface	0.5	9.4	24.9	7.0	7.3	1.6
		Bottom	3.6	9.8	24.6	6.4	7.2	
MDE-19	XIF4221	Surface	0.5	9.5	25.1	7.2	7.3	1.2
		Bottom	3.6	9.9	24.9	6.9	7.3	
MDE-24	XIF4372	Surface	0.5	8.9	24.8	6.8	7.1	1.4
		Bottom	1.0	8.9	24.8	6.9	7.1	
MDE-33	XIF6008	Surface	0.5	8.1	26.5	8.7	7.7	1.6
		Bottom	1	8.7	25.5	8.4	7.6	
MDE-34	XIF5805	Surface	0.5	8.2	26.3	8.4	7.6	1.8
		Bottom	1	8.3	26.0	8.5	7.7	
MDE-35	XIF6407	Surface	0.5	8.1	26.7	8.8	7.8	1.8
		Bottom	2.5	9.3	25.1	7.2	7.3	
Reference Stations								
MDE-13	XIG3506	Surface	0.5	10.1	24.6	7.1	7.4	1.5
		Bottom	3.8	10.1	24.5	6.7	7.3	
MDE-22	XIF3224	Surface	0.5	10.4	24.9	7.6	7.6	1.2
		Bottom	4.2	10.4	24.9	7.6	7.6	
MDE-36	XIG7589	Surface	0.5	7.8	26.5	7.7	7.4	2.0
		Bottom	2.0	8.7	25.5	7.1	7.2	
Back River/Hawk Cove Stations								
MDE-27	XIF4642	Surface	0.5	8.8	26.8	8.0	7.7	0.8
		Bottom	2.5	8.9	26.2	7.6	7.4	
MDE-28	XIF5232	Surface	0.5	8.1	26.2	8.2	7.3	1.2
		Bottom	1.5	8.2	26.2	8.0	7.2	
MDE-30	XIF5925	Surface	0.5	8.1	26.2	9.3	8.0	2.0
		Bottom	2	8.1	26.0	9.1	7.8	
Baltimore Harbor Stations								
MDE-41	XIF1517	Surface	0.5	10.2	24.9	7.6	7.6	1.6
		Bottom	5	12.6	24.4	4.4	7.2	

Table 9: Water quality parameters measured *in situ* at all HMI stations on April 27-28, 2000.

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	0.9	11.7	9.6	7.8	0.6
		Bottom	3.0	0.9	11.7	9.6	7.8	
MDE-03	XIG5699	Surface	0.5	0.9	12.0	9.9	7.7	0.8
		Bottom	4.7	0.9	12.0	10.5	7.7	
MDE-07	XIF5302	Surface	0.5	1.0	11.7	9.7	7.8	0.6
		Bottom	4.0	1.0	11.7	9.9	7.8	
MDE-09	XIF4806	Surface	0.5	1.2	11.7	9.6	7.7	0.6
		Bottom	4.7	1.2	11.7	9.8	7.7	
MDE-16	XIF4615	Surface	0.5	1.3	11.8	9.5	7.7	0.6
		Bottom	3.7	1.2	11.8	9.5	7.7	
MDE-17	XIF4285	Surface	0.5	0.8	11.7	9.6	7.7	0.8
		Bottom	3.5	0.8	11.5	9.7	7.7	
MDE-19	XIF4221	Surface	0.5	1.0	11.5	9.7	7.7	0.6
		Bottom	3.5	1.0	11.5	9.7	7.7	
MDE-24	XIF4372	Surface	0.5	0.9	11.6	10.0	7.7	0.6
		Bottom	1.0	0.9	11.6	10.1	7.7	
MDE-33	XIF6008	Surface	0.5	0.8	11.8	9.9	7.8	1.0
		Bottom	1.3	0.8	11.9	10.0	7.8	
MDE-34	XIF5805	Surface	0.5	0.8	12.0	10.3	7.8	0.8
		Bottom	2.1	0.8	12.0	9.7	7.8	
MDE-35	XIF6407	Surface	0.5	0.6	11.8	9.8	7.8	0.6
		Bottom	2.7	0.6	11.8	9.9	7.8	
Reference Stations								
MDE-13	XIG3506	Surface	0.5	1.1	11.9	9.9	7.7	0.6
		Bottom	3.5	1.2	11.8	10.3	7.7	
MDE-22	XIF3224	Surface	0.5	1.6	11.6	9.7	7.7	0.6
		Bottom	4.0	1.8	11.6	9.6	7.7	
MDE-36	XIG7589	Surface	0.5	0.3	12.1	9.7	7.8	0.7
		Bottom	2.2	0.3	12.1	9.8	7.8	
Back River/Hawk Cove Stations								
MDE-27	XIF4642	Surface	0.5	1.0	12.2	9.8	7.8	0.2
		Bottom	2.8	1.0	12.2	9.8	7.8	
MDE-28	XIF5232	Surface	0.5	0.8	11.7	9.7	7.8	0.6
		Bottom	1.5	0.8	11.7	9.6	7.8	
MDE-30	XIF5925	Surface	0.5	0.6	11.8	10.2	7.8	1.0
		Bottom	1.9	0.6	11.8	10.3	7.8	
Baltimore Harbor Stations								
MDE-41	XIF1517	Surface	0.6	2.6	11.8	9.7	7.8	0.6
		Bottom	5.5	6.3	12.1	7.2	7.5	

with the exception of the Baltimore Harbor station MDE-41 which had a value of 4.4 ppm in the late summer. Bottom DO concentrations were lower in September 1999 than in April 2000. September 1999 values ranged from 4.4 to 9.1 ppm [average = 7.1 ppm ± 1.1 ppm], compared to values of 5.3 to 8.1 ppm [average = 7.5 ppm ± 0.7 ppm] in September 1998. This is typical of late summer conditions in the northern part of Chesapeake Bay. The highest DO concentration in September 1999 (9.1 ppm) was found at Back River/Hawk Cove station MDE-30 on the northern end of the facility. Differences in DO concentration between surface and bottom waters were generally no more than 1.6 ppm at all stations, with the exception of the Harbor station MDE-41, which had a difference of 3.2 ppm.

April 2000 DO concentrations (range = 7.2 - 10.5 ppm, average 9.7 ppm ± 0.7 ppm) were high compared to September 1999. This seasonal relationship is expected due to the lower temperatures, higher freshwater influx, and increased vertical mixing typical of the spring. The highest bottom DO concentration in April 2000 (10.5 ppm) was found northeast of the facility at Nearfield station MDE-3. The lowest bottom DO concentration (7.2 ppm) was found at Harbor station MDE-41. The Harbor station also had the largest difference between surface (9.7 ppm) and bottom (7.2 ppm) DO concentrations, although both measurements were higher than in September. In Year 17, the Back River/Hawk Cove station MDE-27 had the largest difference between surface (12.0 ppm) and bottom (8.5 ppm) DO concentrations. In April 2000, surface and bottom DO concentrations differed by no more than 0.6 ppm at all other stations.

There was only a marginal difference in pH between September 1999 and April 2000. September bottom-water pH values for all stations were near to above neutral (Table 10, range=7.1 pH units - 7.8 pH units, average = 7.3 ± 0.2 pH units). In April, pH values were also above neutral (Table 10, range = 7.5 pH units- 7.8 pH units, average = 7.7 ± 0.1 pH units). Differences between surface and bottom pH were low at all stations, < 0.6 pH units in September and < 0.4 pH units in April.

Significant relationships ($p<0.05$) were found among all the water quality parameters mentioned above (Table 10). Correlations found during this analysis were strong ($r>0.75$), moderate ($r =0.50$ to 0.74), or weak ($r<0.50$). Many of these correlations are likely due to different parameters responding in similar manners to seasonal changes. For example, temperature has a strong positive correlation with salinity ($r=0.953$). Both are expected to rise in the spring and summer, temperature with increasing solar radiation, and salinity with the decreasing freshwater influx. Some caution, however, must be exercised when using correlations because measures that respond similarly on a seasonal basis may not be causally related.

Temperature has a strong negative correlation with both pH ($r= -0.782$) and DO ($r= -0.809$). Concurrently, pH has a strong positive correlation with DO ($r=0.901$). These correlations support the hypothesis that increased temperatures not only affect DO concentrations directly, but also indirectly due to increased benthic metabolism. In brackish waters, such an increase in metabolism results in decreased pH by raising carbon dioxide levels.

A strong negative correlation exists between pH and salinity (r= -0.837). This result reflects the low salinities and strong freshwater influence of the upper Chesapeake Bay. In such an environment, increasing salinities during warmer seasons are still low enough that the CO_2 generated by increased benthic metabolism is not buffered; thus, the pH levels decrease (Reid and Wood 1976). A strong negative correlation exists between salinity and DO (r= -0.927). This is expected since DO saturation is inversely related to salinity and temperature (Reid and Wood 1976). The low salinities at HMI, and the strong correlation between DO and temperature, indicate that salinity probably did not play the major role in dissolved oxygen concentrations during the course of this study.

Secchi depth has a strong positive correlation with temperature (r= 0.843) and salinity (r= 0.795), a moderate negative correlation with pH (r= -0.704), and a moderate negative correlation with DO (r= -0.695).

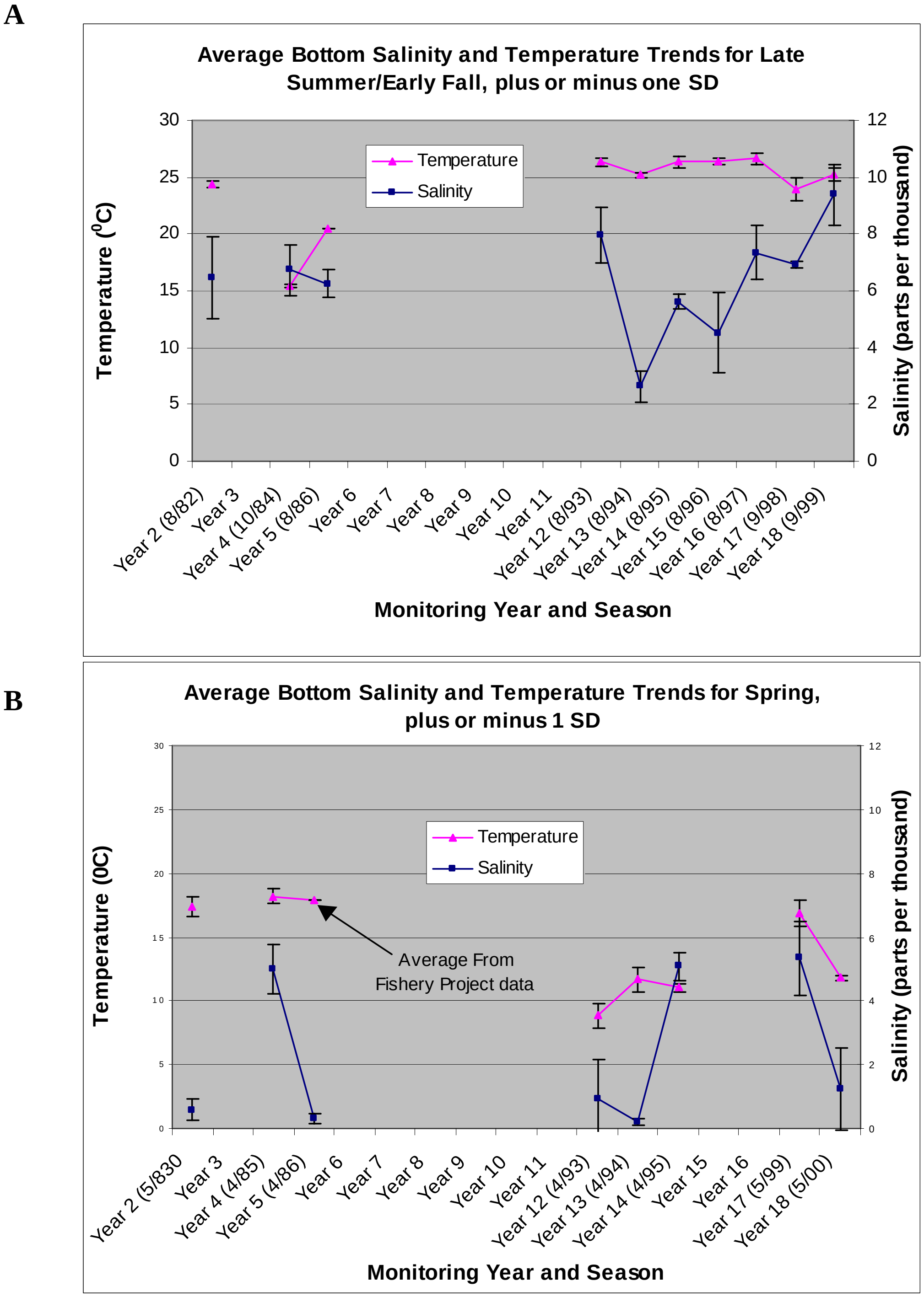
Table 10: Correlation Analysis of Late Summer 1999 and Spring 2000 HMI Year 18 water quality data (p=0.05, d.f.=35, critical value of r=0.325). Year 17 values given in parentheses.

	Temperature, ^oC	*pH*	*Dissolved Oxygen, mg/l*	*Salinity, ppt*	*Secchi Depth, m*
Temperature, ^oC	1.000				
pH	**-0.782(-0.797)**	1.000			
Dissolved Oxygen, mg/l	**-0.809(-0.794)**	**0.901(0.731)**	1.000		
Salinity, ppt	**0.953(0.666)**	**-0.837(-0.878)**	**-0.927(-0.666)**	1.000	
Secchi Depth, m	**0.843(-0.411)**	**-0.704(0.479)**	**-0.695(0.617)**	**0.795(-0.441)**	1.000

Table 10 shows the correlation coefficient or r-value between two parameters at a time. Values in parentheses are the correlation coefficients for Year 17 values. What these correlation coefficients show is that some parameters show consistent linear relationships between sampling years. For example, DO and temperature had consistent r-values between Years 17 and 18 (-0.809 and -0.794, respectively), as did pH and temperature, and pH and salinity. To a lesser degree, salinity and temperature, pH and DO, as well as salinity and DO, correlated consistently between sampling years, although correlations were strong in Year 18 while only moderate in Year 17. Secchi depths showed no consistent correlations with any of the other parameters and in fact went from positive correlations in one year to negative correlations in the next.

Long-term Water Quality Trends

Surface temperature and salinity have been measured at all stations as part of all previous HMI benthic community assessment studies. However, bottom water quality measurements have only been taken consistently since Year 12 (Figure 16, A & B). Temperatures in the Upper Chesapeake Bay vary seasonally, rising from spring lows in the teens (ºC) to summer highs (August and September) in the mid- to upper 20's. The


A

Average Bottom Salinity and Temperature Trends for Late Summer/Early Fall, plus or minus one SD

B

Average Bottom Salinity and Temperature Trends for Spring, plus or minus 1 SD

Figure 16 A&B: Average spring and fall temperature and salinity trends, plus or minus one standard deviation, for all stations sampled at HMI during a given monitoring year.

average bottom temperature for Year 18's summer sampling (September 1999, 25.20 ºC) was in the range of average summer temperatures measured in Years 2, 4-5 and 12-17 (range: 15.47 ºC-26.82 ºC, figure 3-3A) [Duguay et al. in review, Duguay et al. in press, Duguay et al. 1999, Duguay et al. 1998, Duguay et al. 1995, Casey 1987, Pfitzenmeyer 1985, Pfitzenmeyer and Millsaps 1984)] and comparable to last year's summer average (23.86 ºC). Similarly, the average bottom temperature for Year 18's spring sampling (April 2000, 11.81 ºC) was also in the range of average spring temperatures measured in Years 2, 4-5, 12-14 (range= 8.82-18.82 ºC) and considerably lower than the average bottom temperature last spring (May 1999, 16.82 ºC). No spring temperature measurements were taken in Years 15 or 16.

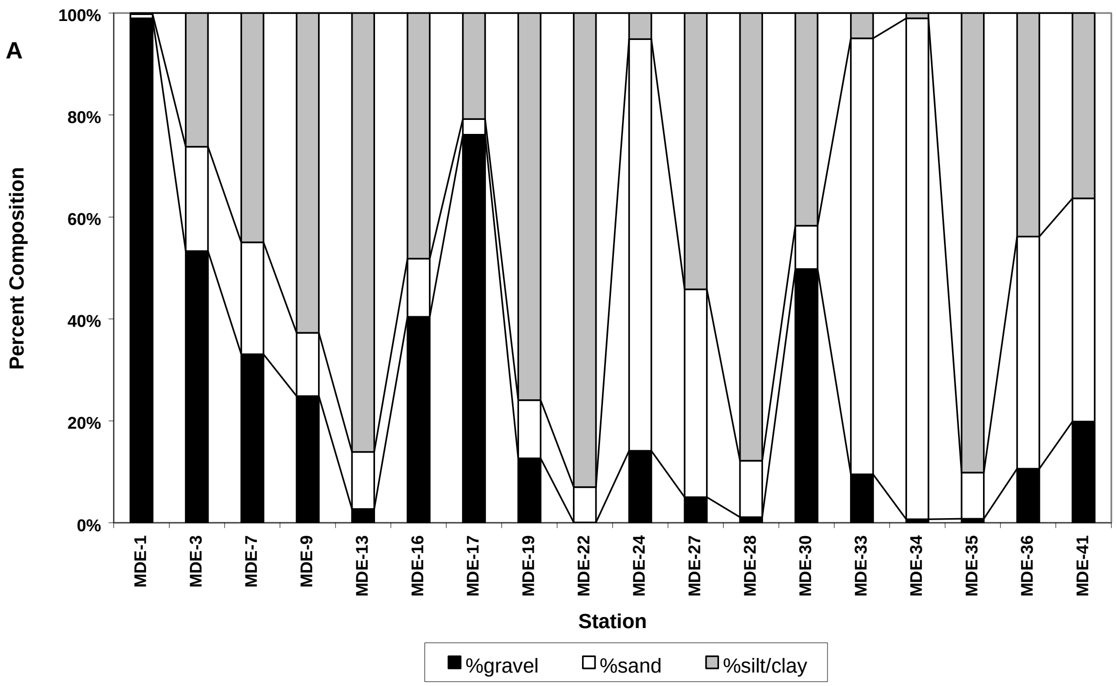
Salinity varies seasonally with the amount of precipitation. Abundant rainfall, typical of the spring, leads to higher freshwater input into the upper Chesapeake Bay from the Susquehanna River drainage and results in lower salinities in the HMI region. Likewise, periods of lower precipitation, characteristic of the summer months, may lead to higher than average salinities due to decreased freshwater input. This region of the bay typically ranges between the oligohaline (0.5‰-5‰) and mesohaline (5‰-18‰) salinity regimes (Weisberg et al., 1997). Bottom salinities in Year 18 were within these expected ranges. Summer (September 1999) values all fell within the low mesohaline range, while spring (April 2000) values were split between the tidal freshwater, oligohaline and mesohaline ranges. The same general pattern was seen for the summer samples from Years 2, 4-5, 12, 14, 16, and 17 and spring samples from Years 2, 5, 12, and 13.

Grain-size Distribution

Sediment samples were collected again this year in conjunction with the benthic sampling. Benthic organisms are particularly sensitive to substrate type and different substrate compositions can influence the species of benthic organisms present at a given site. Figure 17 (A and B) show the sediment grain-size composition at each site sampled for both seasons during Year 18 of the HMI exterior monitoring program.

With the exception of Harbor station MDE-41, all of the other stations showing a gravel component consist predominately of shell. The Harbor station is unique in that it is the only site with true gravel which, coupled with higher salinity, produced a unique benthic community from those in the HMI region. Since shell is an important biogenic material indicative of benthic activity, MDE retains the shell fraction of the sediment samples collected and includes this in the sediment analysis as gravel. A lesser amount of shell material may also be included as sand since smaller shell particles can be retained on the sieve containing the sand fraction. The natural spatial variation in shell density within a given site can significantly change interseasonal grain size distribution patterns. Therefore, the grain size analysis presented here is not intended for rigorous statistical comparison, but rather as a rough approximation of the substrate characteristics for a given station. See the *Project II: Sedimentary Environment* report for a more detailed account of the sedimentary conditions around HMI during Year 18.

Late Summer/Early Fall (September 1999) Grain-size Distribution for Year 18



Spring (April 2000) Grain-size Distribution for Year 18

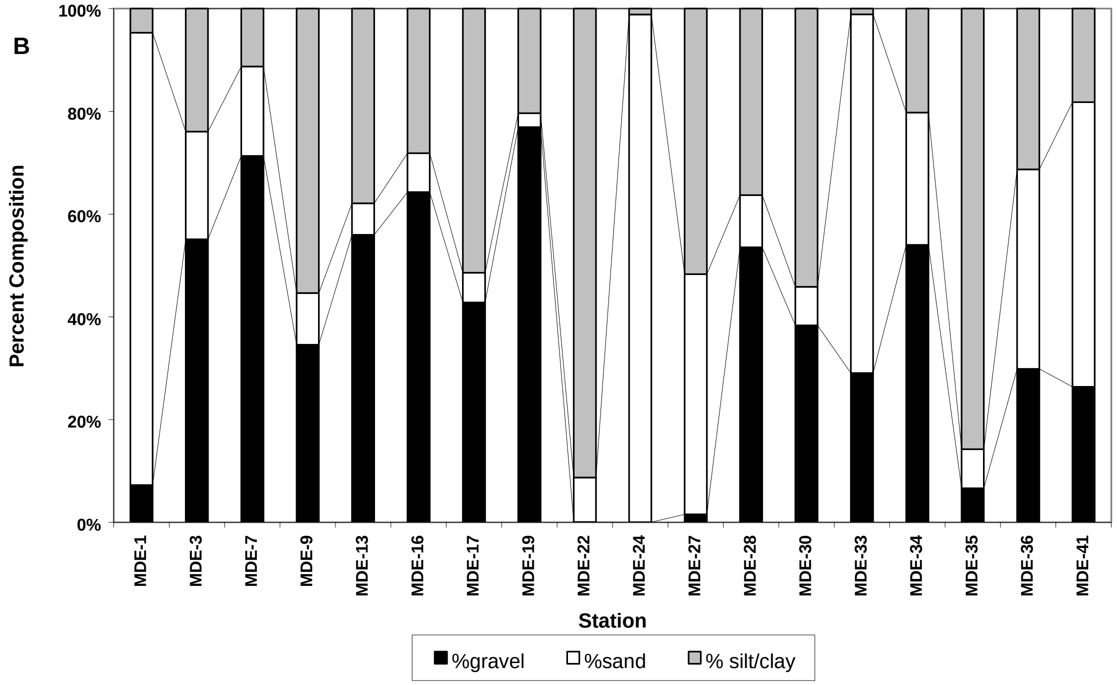


Figure 17 A&B: Grain-size distributions during September 1999 and April 2000 of the Year 18 HMI monitoring effort.

Benthic Macroinvertebrate Community

During Year 18, a total of forty-one taxa were found in the vicinity of Hart-Miller Island over two seasons of benthic community monitoring. This is somewhat higher than the number of taxa that had been found in Years 12 through 17 (30, 30, 31, 26, 29, and 32 taxa, respectively), and most likely due in part to the addition of Harbor Station MDE-41. Of the forty-one taxa found in Year 18, twenty-seven are considered truly infaunal; the other fourteen, epifaunal (see Ranasinghe et al. 1994). The most common taxa were members of the phyla Annelida (segmented worms) and Bivalvia (molluscs having two separate shells joined by a muscular hinge). Ten species of annelid worms in the class Polychaeta were found during the study. Fifteen species of arthropods were found. The most common arthropods were the isopods (such as *Cyathura polita*) and amphipods (such as *Leptocheirus plumulosus*). Epifaunal taxa, such as barnacles, bryozoans, and mud crabs were found more often at stations where the substrate (sediment) contained a large amount of oyster or clam shell (Table 11).

Table 11: Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 18 late summer sampling (September 1999), by substrate and station type.

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Substrate			Station Type			
			sand	shell	mud	Near-field	Ref.	Hawk Cove	Harbor Station
Platyhelminthes *	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Turbellaria *	0.4	6.4	0.0	1.6	0.0	0.6	0.0	0.0	0.0
Nematoda	4.3	76.8	0.0	1.6	7.1	4.1	2.1	8.5	0.0
Nemertea	2.5	44.8	9.0	0	0.0	3.5	0.0	0.0	6.4
Carinoma tremaphoros	56.2	1011.2	35.8	43.2	78.9	54.1	83.2	49.1	19.2
Bivalvia	6.0	108.8	6.4	0	8.5	5.2	14.9	2.1	0.0
*Mytilopsis leucophaeata**	1.1	19.2	1.3	1.6	0.7	1.2	0.0	0.0	6.4
Mytilidae *	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
*Congeria conradi **	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
*Ischadium recurvum **	6.8	121.6	1.3	22.4	3.6	10.5	2.1	0.0	0.0
*Geukensia demissa **	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Macoma sp.	9.6	172.8	5.1	6.4	12.1	8.1	19.2	2.1	19.2
Macoma balthica	46.6	838.4	7.7	56	65.4	46.5	85.3	23.5	0.0
Macoma mitchelli	14.9	268.8	6.4	0	23.5	8.1	21.3	38.4	0.0
Rangia cuneata	432.7	7788.8	509.4	483.2	421.0	581.2	179.2	285.9	0.0
Mulinia lateralis	0.4	6.4	1.3	0	0.0	0.0	0.0	0.0	6.4
Polychaeta	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Heteromastus filiformis	22.0	396.8	17.9	17.6	29.2	17.5	61.9	2.1	12.8
Eteone heteropoda	3.9	70.4	9.0	0	2.8	1.7	0.0	6.4	32.0
Hobsonia florida	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Marenzelleria viridis	12.8	230.4	15.4	3.2	12.1	11.6	29.9	4.3	0.0
Podarkeopsis levifuscina	0.4	6.4	1.3	0	0.0	0.0	0.0	0.0	6.4
Heteronereid	2.8	51.2	1.3	1.6	4.3	3.5	4.3	0.0	0.0
Nereidae	23.5	422.4	26.9	43.2	11.4	27.9	14.9	0.0	70.4
Neanthes succinea	175.6	3161.6	137.0	252.8	155.7	182.1	232.5	104.5	147.2
Glycinde solitaria	13.5	243.2	32.0	6.4	7.8	7.0	8.5	0.0	140.8
Spionidae	0.4	6.4	0.0	1.6	0.0	0.6	0.0	0.0	0.0
Polydora cornuta	4.6	83.2	2.6	12.8	2.1	5.2	0.0	6.4	6.4

Table 11: Continued.

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Substrate			Station Type			
			sand	shell	mud	Near-field	Ref.	Hawk Cove	Harbor Station
Streblospio benedicti	227.9	4102.4	261.1	219.2	199.1	89.6	177.1	558.9	908.8
Paraprionospio pinnata	5.0	89.6	17.9	0	0.0	0.0	0.0	0.0	89.6
Tubificidae	97.8	1760.0	74.2	107.2	109.5	67.5	123.7	147.2	204.8
Balanus spp. indetermined *	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Balanus improvisus *	368.7	6636.8	3.8	1512	64.0	601.0	8.5	0.0	0.0
Balanus subalbidus *	3.2	57.6	0.0	14.4	0.0	5.2	0.0	0.0	0.0
Rhithropanopeus harrisii *	42.7	768.0	3.8	134.4	20.6	66.9	10.7	0.0	0.0
Zoea larva *	0.4	6.4	1.3	0	0.0	0.6	0.0	0.0	0.0
Isopoda (juvenile)	1.1	19.2	0.0	0	2.1	0.0	6.4	0.0	0.0
Cyathura polita	90.0	1619.2	66.6	62.4	116.6	94.8	102.4	89.6	0.0
Chiridotea almyra	6.0	108.8	21.8	0	0.0	9.9	0.0	0.0	0.0
Edotea triloba *	10.0	179.2	20.5	1.6	6.4	11.1	4.3	14.9	0.0
Amphipoda	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Ameroculodes spp. complex	6.8	121.6	9.0	3.2	5.0	7.0	10.7	4.3	0.0
Apocorophium sp. *	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Apocorophium lacustre *	0.4	6.4	1.3	0	0.0	0.6	0.0	0.0	0.0
Gammaridae	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Gammarus sp.	0.4	6.4	0.0	0	0.7	0.6	0.0	0.0	0.0
Gammarus daiberi	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Leptocheirus plumulosus	188.4	3392.0	56.3	41.6	331.4	64.6	433.1	460.8	0.0
Melitidae *	1.1	19.2	0.0	0	2.1	0.6	2.1	2.1	0.0
Melita nitida *	13.9	249.6	1.3	30.4	13.5	12.2	23.5	14.9	0.0
Chironomidae	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Coelotanypus sp	9.6	172.8	0.0	22.4	9.2	1.7	0.0	51.2	0.0
Cryptochironomus sp.	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Mysidacea *	3.6	64.0	6.4	1.6	2.8	2.3	4.3	4.3	12.8
Neomysis americana *	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Mysidopsis bigelowi *	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Copepoda *	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Membranipora tenuis *	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Bryozoa indetermined *	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Cnidaria *	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Anthozoa *	14.6	262.4	15.4	9.6	16.4	10.5	23.5	0.0	76.8
Haliplanella luciae *	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0
Hydrozoa *	1.8	32.0	5.1	0	0.7	2.9	0.0	0.0	0.0

Note: Abundance of *Membranipora* spp. represents an estimate of the number of zooids present per square meter.
* Indicates taxa that are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Nearfield silt/clay station MDE-7 had the greatest number of taxa in the late summer [20, followed closely by the Nearfield stations MDE-33 (19, sand) and MDE-9 (18, silt/clay)]. The new Harbor sand station MDE-41 had the greatest number of taxa in the spring (23). The Nearfield sand station MDE-24 had the greatest number of taxa during both sampling seasons in Year 17. Also similar to last year, fewer taxa were found at the Back River/Hawk Cove stations, particularly silt/clay station MDE-30 (10 taxa), than at most other stations during the late summer. Only Nearfield station MDE-34, a sand station on the north side of HMI, had fewer taxa (8) in the late summer. Station MDE-34 lies in close proximity to the former station S1 used by the University of Maryland's Chesapeake Biological Laboratory. Taxa richness has been consistently low in this area throughout the years (Duguay et al. in review, Duguay et al. in press, Duguay et al. 1999, Duguay et al. 1998, Duguay et al.1995). The number of taxa was higher at most stations in the spring due to seasonal recruitment. Station MDE-1, a Nearfield station located both very close to HMI spillway number 1 and in a transitional substrate zone between silt/clay and shell, had the lowest number of taxa (11) in the spring.

In the late summer, the numerically most abundant taxa found during Year 18 of benthic community monitoring in the vicinity of HMI were the polychaete worms *Streblospio benedicti* and *Neanthes succinea*, the amphipod *Leptocheirus plumulosus*, the clam *Rangia cuneata*, and the barnacle *Balanus improvisus*. The average abundance of each taxon (in organisms per square meter) found at each station during Year 18 of benthic community monitoring at HMI is provided in Table 11. Large numbers of *S. benedicti*, *N. succinea*, *L. plumulosus* and *R. cuneata* were fairly evenly spread among all stations. These species have been among the most abundant throughout the course of the studies at HMI (Duguay et al. in review, Duguay et al. in press, Duguay et al. 1999, Duguay et al. 1998, Duguay et al. 1995). Specimens of *Balanus*, however, were mostly found at the Nearfield shell-silt/clay station MDE-1. In the spring, the numerically most abundant taxa were the polychaete worms *Marenzelleria viridis*, oligochaete worms in the family Tubificidae, and the amphipod *Leptocheirus plumulosus*. Large numbers of small juveniles of these species were found at most stations in April. During spring, these three taxa accounted for approximately 63% of the total individuals found at all stations.

Similar to last year, total combined abundances for all stations (excluding Bryozoa) was approximately two-times higher in the spring (April 2000) than in the late summer (September 1999) due to seasonal recruitment in the spring. In the late summer, total abundance by station ranged from 294 to 7,264 organisms per square meter (organisms/m^2) and averaged 1,913 organisms/m^2. This was somewhat reduced from last year's late summer abundance range of 570 to 12,275 organisms/m^2 with an average of 3,444 organisms/m^2. Average total abundance for Year 18 was similar between reference and nearfield stations. Abundance was highest at the nearfield shell-silt/clay station MDE-1 where high densities of the barnacle *B. improvisus* (6022/m^2), and much lower numbers of *B. subalbidus* (58/m^2), were found attached to shells and shell fragments. Abundance was lowest at the Nearfield sand station MDE-34. This station lies near former CBL station S1, which was found in several earlier HMI studies to have a reduced number of taxa (Duguay et al. in review, Duguay et al. in press, Duguay et al. 1999, Duguay et al. 1998, Duguay et al.1995).

In the spring, total abundance by station averaged 3,352 individuals/m^2 and ranged from 1,267 to 13,024 individuals/m^2, compared to a range of 3,322 to 32,032 organisms/m^2 with an average of 9,981 organisms/m^2 for Spring 1999. Abundances of the dominant taxa were fairly evenly distributed among all stations. Abundance was lowest at station MDE-19, which has been shown to be influenced by prop wash associated with barge traffic at the island (Duguay et al. 1998, Duguay et al. 1995a, Duguay et al. 1995b, Duguay 1992, Duguay 1990, Pfitzenmeyer and Tenore 1987). Abundance was also lower in the spring compared to the late summer at station MDE-19.

Table 12: Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 18 late spring sampling (April 2000), by substrate and station type.

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Substrate			Station Type			
			sand	shell	mud	Near-field	Ref.	Hawk Cove	Harbor Station
Platyhelminthes *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Turbellaria *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nematoda	3.6	64.0	6.4	0.9	3.8	4.8	0.0	2.1	6.4
Nemertea	3.2	57.6	8.5	0.0	1.3	4.8	0.0	0.0	51.2
Carinoma tremaphoros	15.6	281.6	10.7	18.3	17.9	11.2	21.3	27.7	0.0
Bivalvia	70.4	1267.2	200.5	3.7	7.7	101.3	2.1	14.9	128.0
*Mytilopsis leucophaeata**	1.4	25.6	2.1	1.8	0.0	2.1	0.0	0.0	12.8
Mytilidae *	0.4	6.4	0.0	0.9	0.0	0.5	0.0	0.0	0.0
*Congeria conradi **	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
*Ischadium recurvum **	8.0	144.0	0.0	15.1	7.7	12.0	0.0	0.0	0.0
*Geukensia demissa **	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Macoma sp.	17.4	313.6	40.5	3.7	9.0	24.5	2.1	4.3	230.4
Macoma balthica	48.0	864.0	28.8	40.2	81.9	30.9	136.5	27.7	108.8
Macoma mitchelli	19.9	358.4	26.7	10.1	25.6	20.3	27.7	10.7	128.0
Rangia cuneata	247.1	4448.0	187.7	309.0	231.7	285.3	89.6	251.7	6.4
Mulinia lateralis	8.9	160.0	26.7	0.0	0.0	13.3	0.0	0.0	160.0
Polychaeta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heteromastus filiformis	64.5	1161.6	88.0	44.8	64.0	62.9	94.9	40.5	217.6
Eteone heteropoda	10.3	185.6	30.9	0.0	0.0	15.5	0.0	0.0	185.6
Marenzelleria viridis	950.9	17116.8	1499.2	1036.8	172.8	1356.3	167.5	113.1	3372.8
Podarkeopsis levifuscina	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heteronereid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nereidae	13.5	243.2	10.7	19.2	9.0	19.7	0.0	2.1	64.0
Neanthes succinea	171.0	3078.4	196.3	144.5	177.9	234.1	42.7	46.9	1132.8
Glycinde solitaria	0.7	12.8	2.1	0.0	0.0	1.1	0.0	0.0	12.8
Spionidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polydora cornuta	17.4	313.6	24.0	11.4	17.9	20.0	3.2	21.3	134.4
Streblospio benedicti	263.5	4742.4	599.5	127.1	51.2	266.7	34.1	480.0	2835.2
Paraprionospio pinnata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tubificidae	827.0	14886.4	605.9	869.5	1033.0	870.4	759.5	721.1	710.4
Balanus spp. indetermined *	0.4	6.4	0.0	0.0	1.3	0.5	0.0	0.0	0.0
*Balanus improvisus **	22.2	400.0	6.4	48.9	3.8	33.3	0.0	0.0	38.4
*Balanus subalbidus **	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhithropanopeus harrisii *	5.3	96.0	0.0	7.3	9.0	8.0	0.0	0.0	0.0
Zoea larva *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isopoda (juvenile)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyathura polita	73.8	1328.0	30.9	101.0	87.0	65.9	117.3	61.9	0.0
Chiridotea almyra	112.9	2032.0	336.0	1.4	1.3	169.3	0.0	0.0	0.0
*Edotea triloba **	4.8	86.4	2.1	10.5	0.0	1.9	8.5	12.8	0.0
Amphipoda	1.8	32.0	4.3	0.9	0.0	2.7	0.0	0.0	0.0
Ameroculodes spp. complex	60.6	1091.2	101.9	37.5	43.5	72.0	52.3	23.5	64.0
Apocorophium sp. *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
*Apocorophium lacustre **	9.4	169.6	9.1	14.6	2.6	12.8	5.3	0.0	32.0
Gammaridae	13.5	243.2	5.3	29.3	1.3	19.7	2.1	0.0	6.4

Table 12: Continued.

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Substrate			Station Type			
			sand	shell	mud	Near-field	Ref.	Hawk Cove	Harbor Station
Gammarus sp.	19.9	358.4	4.3	43.0	6.4	29.3	0.0	2.1	0.0
Gammarus daiberi	0.7	12.8	0.0	1.8	0.0	1.1	0.0	0.0	0.0
Leptocheirus plumulosus	463.3	8339.2	880.0	167.3	377.6	428.8	586.7	477.9	2918.4
Melitidae *	2.5	44.8	2.1	0.9	5.1	0.0	10.7	4.3	0.0
Melita nitida *	17.4	313.6	12.8	14.6	26.9	11.7	38.4	19.2	19.2
Haustoriidae	0.7	12.8	2.1	0.0	0.0	1.1	0.0	0.0	0.0
Chironomidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coelotanypus sp	11.9	214.4	3.7	7.3	28.2	1.6	3.2	61.9	0.0
Cryptochironomus sp.	0.4	6.4	1.1	0.0	0.0	0.5	0.0	0.0	0.0
Mysidacea *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Neomysis americana *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mysidopsis bigelowi *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copepoda *	8.2	147.2	23.5	0.0	1.3	11.7	0.0	2.1	0.0
Membranipora tenuis *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bryozoa indetermined *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cnidaria *	46.2	832.0	11.2	84.6	34.6	63.2	24.5	0.0	12.8
Anthozoa *	30.2	544.0	90.7	0.0	0.0	45.3	0.0	0.0	544.0
Haliplanella luciae *	0.7	12.8	2.1	0.0	0.0	1.1	0.0	0.0	12.8
Hydrozoa *	16.4	294.4	49.1	0.0	0.0	24.5	0.0	0.0	6.4

Note: Abundance of *Membranipora* spp. represents an estimate of the number of zooids present per square meter.
* Indicates taxa that are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

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 Benthic Index of Biotic Integrity (B-IBI; see Methods). Like Year 17, total infaunal abundance was similar to total abundance in Year 18, accounting for >90% of all organisms at most stations during both seasons. A major exception occurred at the Nearfield shell-silt/clay substrate station MDE-1 where epifaunal taxa accounted for approximately 90% of the total abundance during the late summer sampling.

Table 13: Summary of metrics for each HMI benthic station surveyed during the Year 18 late summer sampling cruise, September 1999. Total Infaunal Abundance and Total Abundance, excluding Bryozoa, are individuals per square meter.

Station	Total Infaunal Abundance	Total Abundance, excluding Bryozoa	Taxa Richness, All Taxa	Taxa Richness, Infauna only	Shannon-Wiener Diversity Index	Pollution Sensitive Taxa Abundance	Pollution Indicative Taxa Abundance	Benthic Index of Biotic Integrity
Nearfield Stations								
MDE-1	781	7578	13	7	2.25	15.6%	20.5%	2.5
MDE-3	1555	1581	15	12	2.61	57.2%	17.3%	4.5
MDE-7	2784	2918	20	13	1.77	76.3%	6.7%	4
MDE-9	890	928	18	14	3.08	60.4%	9.4%	4.5
MDE-16	1638	1670	14	11	2.55	64.8%	10.6%	4.5
MDE-17	1619	1715	16	11	3.02	43.9%	18.2%	4.5
MDE-19	730	1421	14	10	2.96	31.6%	8.8%	4.5
MDE-24	915	1062	15	12	3.15	36.4%	16.1%	4
MDE-33	2176	2259	19	14	1.55	75.9%	7.4%	4
MDE-34	269	294	8	7	2.24	52.4%	0.0%	3.5
MDE-35	845	858	12	11	2.64	41.7%	27.3%	3.5
Reference Stations								
MDE-13	1632	1773	15	11	3.17	33.3%	15.3%	4.5
MDE-22	1958	2048	13	12	2.43	13.7%	14.4%	3.5
MDE-36	1190	1242	14	12	3.08	33.9%	31.2%	3.5
Back River/Hawk Cove Stations								
MDE-27	2157	2259	16	14	2.39	10.1%	22.3%	3
MDE-28	1766	1779	13	12	2.46	15.2%	64.5%	3
MDE-30	1581	1581	10	10	2.09	45.8%	42.5%	3.5
Harbor Stations								
MDE-41	1664	1766	16	13	2.28	8.5%	74.6%	2.2

Table 14: Summary of metrics for each HMI benthic station surveyed during the Year 18 spring sampling cruise, April 2000. Total Infaunal Abundance and Total Abundance, excluding Bryozoa, are individuals per square meter.

Station	Total Infaunal Abundance	Total Abundance, excluding Bryozoa	Taxa Richness, All Taxa	Taxa Richness, Infauna only	Shannon-Wiener Diversity Index	Pollution Sensitive Taxa Abundance	Pollution Indicative Taxa Abundance
Nearfield Stations							
MDE-1	3008	3014	11	10	1.07	86.6%	1.9%
MDE-3	2227	2362	14	11	2.30	71.3%	17.2%
MDE-7	4186	5011	18	12	2.26	53.4%	31.4%
MDE-9	1459	1600	19	14	2.80	34.2%	39.4%
MDE-16	2509	2528	15	14	2.25	9.4%	66.8%
MDE-17	2970	3034	14	11	2.12	12.5%	56.7%
MDE-19	1184	1267	16	13	2.23	61.1%	4.3%
MDE-24	5062	6112	14	14	2.18	28.5%	0.5%
MDE-33	2586	2925	16	13	1.64	87.1%	7.4%
MDE-34	7555	7766	18	13	2.09	64.4%	25.2%
MDE-35	3258	3405	18	15	1.89	17.1%	69.6%
Reference Stations							
MDE-13	1984	2086	17	14	2.87	28.1%	41.0%
MDE-22	2874	3021	14	13	2.39	20.9%	15.8%
MDE-36	1565	1584	11	9	1.53	23.9%	71.8%
Back River/Hawk Cove Stations							
MDE-27	3974	4083	16	14	2.28	8.1%	58.2%
MDE-28	1523	1568	14	13	2.80	13.5%	58.4%
MDE-30	1626	1626	14	14	2.75	51.6%	36.2%
Harbor Stations							
MDE-41	12288	13146	23	16	2.73	28.5%	31.7%

Pfitzenmeyer et al. (1982) suggested that diversity, as measured by the Shannon-Wiener diversity index (H'), would be higher in summer, 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 the spring recruitment and consequent 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 Hayes 1987). In Year 18, diversity was higher at ten stations in September compared to May, but lower at four other stations in September (Tables 13 and 14). Diversity was similar between the two seasons at the remaining four stations (MDE-22, MDE-27, MDE-33 and MDE-34). Diversity ranged from 1.55 to 3.17 in the late summer and from 1.07 to 2.87 in the spring compared to H' values ranging from 1.06 to 2.63 in the late summer and 1.53 to 3.05 in the spring of Year 17 (Tables 13 and 14; Figures 24 and 25).

Table 15: Average number of individuals collected per square meter at each station during the HMI Year 18 late summer sampling cruise, September 1999, 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**
Platyhelminthes *	0	0	0	0	0	0	0	0	0
Turbellaria *	6	0	0	0	0	0	0	0	0
Nematoda	6	0	0	0	0	0	0	0	0
Nemertea	0	0	0	0	0	0	0	0	0
Carinoma tremophorus	6	70	77	90	96	83	90	64	134
Bivalvia	0	0	6	0	26	6	0	13	19
*Mytilopsis leucophaeata**	6	0	6	0	0	0	0	0	0
Mytilidae *	0	0	0	0	0	0	0	0	0
Congeria conradi *	0	0	0	0	0	0	0	0	0
Ischadium recurvum *	83	6	13	6	6	6	0	0	0
Geukensia demissa *	0	0	0	0	0	0	0	0	0
Macoma sp.	0	0	6	32	13	19	26	0	32
Macoma balthica	0	38	45	83	141	77	186	83	90
Macoma mitchelli	0	0	13	13	0	0	0	0	38
Rangia cuneata	122	717	1875	307	301	838	416	0	0
Mulinia lateralis	0	0	0	0	0	0	0	0	0
Polychaeta	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	0	26	26	13	115	19	45	13	70
Eteone heteropoda	0	0	6	0	0	0	0	0	0
Hobsonia florida	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	0	0	6	6	19	13	6	19	38
Podarkeopsis levifuscina	0	0	0	0	0	0	0	0	0
Heteronereid	0	0	0	13	13	6	6	6	0
Nereidae	90	6	0	0	26	51	77	26	0
Neanthes succinea	365	166	346	83	442	192	365	102	26
Glycinde solitaria	0	13	6	32	13	6	13	0	13
Spionidae	6	0	0	0	0	0	0	0	0
Polydora cornuta	32	0	0	0	0	0	6	13	0
Streblospio benedicti	102	122	128	77	128	83	102	51	154
Paraprionospio pinnata	0	0	0	0	0	0	0	0	0
Tubificidae	58	147	51	6	122	90	192	13	128
Balanus spp. indetermined *	0	0	0	0	0	0	0	0	0
Balanus improvisus *	6022	6	45	19	26	0	19	486	0
Balanus subalbidus *	58	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii *	525	6	51	6	0	6	6	122	0
Zoea larva *	0	0	0	0	0	0	0	0	0
Isopoda (juvenile)	0	0	0	0	0	0	0	0	19
Cyathura polita	0	122	192	109	70	128	90	128	128
Chiridotea almyra	0	0	0	0	0	0	0	0	0
Edotea triloba *	0	0	6	0	0	0	6	0	0
Amphipoda	0	0	0	0	0	0	0	0	0
Ameroculodes spp. complex	0	13	6	6	0	0	0	0	0
Apocorophium sp. *	0	0	0	0	0	0	0	0	0
Apocorophium lacustre *	0	0	0	0	0	0	0	0	0
Gammaridae	0	0	0	0	0	0	0	0	0

Table 15: Continued.

Taxon	Station								
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19	MDE-22
Gammarus sp.	0	0	0	6	0	0	0	0	0
Gammarus daiberi	0	0	0	0	0	0	0	0	0
Leptocheirus plumulosus	0	115	0	13	134	32	0	211	1088
Melitidae *	0	0	0	0	0	0	0	6	6
Melita nitida *	96	0	0	0	13	0	26	6	58
Chironomidae	0	0	0	0	0	0	0	0	0
Coelotanypus sp	0	0	0	0	0	0	0	0	0
Cryptochironomus sp.	0	0	0	0	0	0	0	0	0
Mysidacea *	0	6	0	0	0	0	0	0	6
Neomysis americana *	0	0	0	0	0	0	0	0	0
Mysidopsis bigelowi *	0	0	0	0	0	0	0	0	0
Copepoda *	0	0	0	0	0	0	0	0	0
Membranipora tenuis *	0	0	0	0	0	0	0	0	0
Bryozoa indetermined *	0	0	0	0	0	0	0	0	0
Cnidaria *	0	0	0	0	0	0	0	0	0
Anthozoa *	0	0	6	0	70	13	38	58	0
Haliplanella luciae *	0	0	0	0	0	0	0	0	0
Hydrozoa *	0	0	0	6	0	0	0	0	0

Note: Abundance of *Membranipora* spp. represents an estimate of the number of zooids present per square meter.
* Indicates taxa that are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Table 16: Average number of individuals collected per square meter at each station during the HMI Year 18 late summer sampling cruise, September 1999, 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-41
Platyhelminthes *	0	0	0	0	0	0	0	0	0
Turbellaria *	0	0	0	0	0	0	0	0	0
Nematoda	0	13	13	0	0	0	38	6	0
Nemertea	0	0	0	0	19	19	0	0	6
Carinoma tremophorus	77	102	38	6	0	13	26	19	19
Bivalvia	26	6	0	0	6	0	0	0	0
*Mytilopsis leucophaeata**	0	0	0	0	0	0	0	0	0
Mytilidae *	0	0	0	0	0	0	0	0	0
Congeria conradi *	0	0	0	0	0	0	0	0	0
Ischadium recurvum *	0	0	0	0	0	0	0	0	0
Geukensia demissa *	0	0	0	0	0	0	0	0	0
Macoma sp.	0	0	6	0	6	0	0	13	19
Macoma balthica	0	45	26	0	0	0	0	26	0
Macoma mitchelli	32	115	0	0	0	0	32	26	0
Rangia cuneata	198	26	154	678	1555	77	288	237	0
Mulinia lateralis	0	0	0	0	0	0	0	0	6
Polychaeta	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	51	6	0	0	0	0	0	0	13
Eteone heteropoda	0	19	0	0	13	0	0	0	32
Hobsonia florida	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	6	6	0	6	38	32	0	32	0
Podarkeopsis levifuscina	0	0	0	0	0	0	0	0	6
Heteronereid	0	0	0	0	6	0	0	0	0
Nereidae	13	0	0	0	45	0	0	19	70
Neanthes succinea	96	90	109	115	275	0	13	230	147
Glycinde solitaria	6	0	0	0	0	0	0	0	141
Spionidae	0	0	0	0	0	0	0	0	0
Polydora cornuta	0	0	6	13	6	0	0	0	6
Streblospio benedicti	128	262	864	550	147	0	45	250	909
Paraprionospio pinnata	0	0	0	0	0	0	0	0	90
Tubificidae	19	186	224	32	0	0	166	122	205
Balanus spp. indetermined *	0	0	0	0	0	0	0	0	0
Balanus improvisus *	0	0	0	0	13	0	0	0	0
Balanus subalbidus *	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii *	6	0	0	0	6	0	0	32	0
Zoea larva *	0	0	0	0	6	0	0	0	0
Isopoda (juvenile)	0	0	0	0	0	0	0	0	0
Cyathura polita	122	141	90	38	58	32	64	109	0
Chiridotea almyra	0	0	0	0	6	102	0	0	0
Edotea triloba *	96	38	6	0	6	0	6	13	0
Amphipoda	0	0	0	0	0	0	0	0	0
Ameroculodes spp. complex	19	0	13	0	6	6	19	32	0
Apocorophium sp. *	0	0	0	0	0	0	0	0	0
Apocorophium lacustre *	0	0	0	0	6	0	0	0	0
Gammaridae	0	0	0	0	0	0	0	0	0

Table 16: Continued.

Taxon	Station								
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36	MDE-41
Gammarus sp.	0	0	0	0	0	0	0	0	0
Gammarus daiberi	0	0	0	0	0	0	0	0	0
Leptocheirus plumulosus	147	1146	186	51	13	6	173	77	0
Melitidae *	0	6	0	0	0	0	0	0	0
Melita nitida *	0	45	0	0	0	6	0	0	0
Chironomidae	0	0	0	0	0	0	0	0	0
Coelotanypus sp	0	13	51	90	0	0	19	0	0
Cryptochironomus sp.	0	0	0	0	0	0	0	0	0
Mysidacea *	0	6	6	0	13	0	6	6	13
Neomysis americana *	0	0	0	0	0	0	0	0	0
Mysidopsis bigelowi *	0	0	0	0	0	0	0	0	0
Copepoda *	0	0	0	0	0	0	0	0	0
Membranipora tenuis *	0	0	0	0	0	0	0	0	0
Bryozoa indetermined *	0	0	0	0	0	0	0	0	0
Cnidaria *	0	0	0	0	0	0	0	0	0
Anthozoa *	0	0	0	0	0	0	0	0	77
Haliplanella luciae *	0	0	0	0	0	0	0	0	0
Hydrozoa *	19	0	0	0	6	0	0	0	0

Note: Abundance of *Membranipora* spp. represents an estimate of the number of zooids present per square meter.
* Indicates taxa that are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Table 17: Average number of individuals collected per square meter at each station during the HMI Year 18 spring sampling cruise, April 2000, 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
Platyhelminthes *	0	0	0	0	0	0	0	0	0
Turbellaria *	0	0	0	0	0	0	0	0	0
Nematoda	6	0	0	0	0	0	0	0	0
Nemertea	0	0	0	0	0	0	6	0	0
Carinoma tremophorus	0	0	26	13	38	19	19	0	26
Bivalvia	0	0	0	6	0	6	13	0	6
*Mytilopsis leucophaeata**	0	6	6	0	0	0	0	0	0
Mytilidae *	0	6	0	0	0	0	0	0	0
Congeria conradi *	0	0	0	0	0	0	0	0	0
Ischadium recurvum *	0	0	77	13	0	0	26	0	0
Geukensia demissa *	0	0	0	0	0	0	0	0	0
Macoma sp.	6	0	6	6	0	13	32	0	6
Macoma balthica	0	13	6	13	179	32	134	13	230
Macoma mitchelli	0	0	0	26	51	6	0	6	32
Rangia cuneata	90	493	512	102	32	38	96	13	6
Mulinia lateralis	0	0	0	0	0	0	0	0	0
Polychaeta	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	70	26	58	45	64	83	51	19	211
Eteone heteropoda	0	0	0	0	0	0	0	0	0
Marenzelleria viridis	2509	922	1690	275	186	77	58	621	211
Podarkeopsis levifuscina	0	0	0	0	0	0	0	0	0
Heteronereid	0	0	0	0	0	0	0	0	0

Table 17: Continued.

Taxon	Station								
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19	MDE-22
Nereidae	0	6	45	6	0	6	32	0	0
Neanthes succinea	0	173	416	64	64	96	678	19	64
Glycinde solitaria	0	0	0	0	0	0	0	0	0
Spionidae	0	0	0	0	0	0	0	0	0
Polydora cornuta	0	0	64	13	0	6	6	0	0
Streblospio benedicti	0	0	58	6	38	224	26	6	45
Paraprionospio pinnata	0	0	0	0	0	0	0	0	0
Tubificidae	58	384	1254	563	774	1453	1658	45	410
Balanus spp. indetermined *	0	0	0	0	0	0	6	0	0
Balanus improvisus *	0	6	307	13	0	0	6	0	0
Balanus subalbidus *	0	0	0	0	0	0	0	0	0
Rhithropanopeus harrisii *	0	6	45	32	0	0	6	0	0
Zoea larva *	0	0	0	0	0	0	0	0	0
Isopoda (juvenile)	0	0	0	0	0	0	0	0	0
Cyathura polita	6	160	26	109	160	90	83	77	154
Chiridotea almyra	51	0	0	0	0	0	0	0	0
Edotea triloba *	0	0	0	0	26	13	0	0	0
Amphipoda	0	0	6	0	0	0	0	0	0
Ameroculodes spp. complex	51	6	6	64	96	32	6	70	13
Apocorophium sp. *	0	0	0	0	0	0	0	0	0
Apocorophium lacustre *	0	0	26	13	6	0	0	51	0
Gammaridae	0	19	0	0	6	6	6	19	0
Gammarus sp.	0	0	0	6	0	0	0	13	0
Gammarus daiberi	0	0	13	0	0	0	0	0	0
Leptocheirus plumulosus	166	26	0	147	294	326	83	262	1466
Melitidae *	0	0	0	0	6	0	0	0	26
Melita nitida *	0	0	96	13	0	0	0	6	115
Haustoriidae	0	0	0	0	0	0	0	0	0
Chironomidae	0	0	0	0	0	0	0	0	0
Coelotanypus sp	0	0	0	0	0	0	0	0	0
Cryptochironomus sp.	0	0	0	0	0	0	0	0	0
Mysidacea *	0	0	0	0	0	0	0	0	0
Neomysis americana *	0	0	0	0	0	0	0	0	0
Mysidopsis bigelowi *	0	0	0	0	0	0	0	0	0
Copepoda *	58	0	0	0	0	0	0	0	0
Membranipora tenuis *	0	0	0	0	0	0	0	0	0
Bryozoa indetermined *	0	0	0	0	0	0	0	0	0
Cnidaria *	0	109	269	51	64	0	0	26	0
Anthozoa *	0	0	0	0	0	0	0	0	0
Haliplanella luciae *	0	0	0	0	0	0	0	0	0
Hydrozoa *	6	0	0	0	0	0	0	0	0

Note: Abundance of *Membranipora* spp. represents an estimate of the number of zooids present per square meter.
* Indicates taxa that are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Table 18: Average number of individuals collected per square meter at each station during the HMI Year 18 late spring sampling cruise, April 2000, stations MDE-24 to MDE-41.

Taxon	Stations								
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36	MDE-41
*Platyhelminthes **	0	0	0	0	0	0	0	0	0
*Turbellaria **	0	0	0	0	0	0	0	0	0
Nematoda	6	0	6	0	19	0	19	0	6
Nemertea	0	0	0	0	0	0	0	0	51
Carinoma tremophorus	13	51	26	6	0	19	26	0	0
Bivalvia	1050	26	19	0	0	0	13	0	128
*Mytilopsis leucophaeata**	0	0	0	0	0	0	0	0	13
*Mytilidae **	0	0	0	0	0	0	0	0	0
*Congeria conradi **	0	0	0	0	0	0	0	0	0
*Ischadium recurvum **	0	0	0	0	0	29	0	0	0
*Geukensia demissa **	0	0	0	0	0	0	0	0	0
Macoma sp.	0	6	6	0	0	0	0	0	230
Macoma balthica	6	58	19	6	0	19	26	0	109
Macoma mitchelli	6	26	6	0	0	0	70	0	128
Rangia cuneata	0	45	96	614	755	979	339	230	6
Mulinia lateralis	0	0	0	0	0	0	0	0	160
Polychaeta	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	160	51	64	6	19	0	6	10	218
Eteone heteropoda	0	0	0	0	0	0	0	0	186
Marenzelleria viridis	1395	122	38	179	1491	3725	141	106	3373
Podarkeopsis levifuscina	0	0	0	0	0	0	0	0	0
Heteronereid	0	0	0	0	0	0	0	0	0
Nereidae	0	0	0	6	0	77	0	0	64
Neanthes succinea	0	38	32	70	6	211	13	0	1133
Glycinde solitaria	0	0	0	0	0	0	0	0	13
Spionidae	0	0	0	0	0	0	0	0	0
Polydora cornuta	0	0	0	64	0	10	6	10	134
Streblospio benedicti	6	736	563	141	0	0	38	19	2835
Paraprionospio pinnata	0	0	0	0	0	0	0	0	0
Tubificidae	19	1562	275	326	192	1901	2208	1094	710
*Balanus spp. indetermined **	0	0	0	0	0	0	0	0	0
*Balanus improvisus **	0	0	0	0	0	29	0	0	38
*Balanus subalbidus **	0	0	0	0	0	0	0	0	0
*Rhithropanopeus harrisii **	0	0	0	0	0	0	6	0	0
*Zoea larva **	0	0	0	0	0	0	0	0	0
Isopoda (juvenile)	0	0	0	0	0	0	0	0	0
Cyathura polita	38	96	51	38	6	144	51	38	0
Chiridotea almyra	1958	0	0	0	6	10	6	0	0
*Edotea triloba **	0	13	26	0	0	10	0	0	0
Amphipoda	26	0	0	0	0	0	0	0	0
Ameroculodes spp. complex	384	13	32	26	51	19	109	48	64
*Apocorophium sp. **	0	0	0	0	0	0	0	0	0
*Apocorophium lacustre **	0	0	0	0	13	19	0	10	32
Gammaridae	0	0	0	0	26	154	0	0	6
Gammarus sp.	6	0	0	6	19	288	19	0	0
Gammarus daiberi	0	0	0	0	0	0	0	0	0
Leptocheirus plumulosus	1024	1158	262	13	13	0	179	0	2918

Table 18: Continued.

Taxon	Stations								
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36	MDE-41
*Melitidae **	0	13	0	0	0	0	0	0	0
*Melita nitida **	0	58	0	0	0	0	6	0	19
Haustoriidae	13	0	0	0	0	0	0	0	0
Chironomidae	0	0	0	0	0	0	0	0	0
Coelotanypus sp	0	13	51	122	0	0	19	10	0
Cryptochironomus sp.	6	0	0	0	0	0	0	0	0
*Mysidacea **	0	0	0	0	0	0	0	0	0
*Neomysis americana **	0	0	0	0	0	0	0	0	0
*Mysidopsis bigelowi **	0	0	0	0	0	0	0	0	0
*Copepoda **	0	6	0	0	77	0	6	0	0
*Membranipora tenuis **	0	0	0	0	0	0	0	0	0
*Bryozoa indetermined **	0	0	0	0	0	0	0	0	0
*Cnidaria **	0	0	0	0	45	125	122	10	13
Anthozoa *	0	0	0	0	0	0	0	0	544
*Haliplanella luciae **	0	0	0	0	0	0	0	0	13
Hydrozoa *	0	0	0	0	282	0	0	0	6

Note: Abundance of *Membranipora* spp. represents an estimate of the number of zooids present per square meter.
* Indicates taxa that are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Diversity was lowest at the Nearfield sand station MDE-33 (H'=1.55) in the late summer due to large numbers of the clam *R. cuneata*. *Rangia* prefer sandy environments and therefore generally recruit larger numbers of individuals at sandy stations (Tenore et al. 1968). Diversity only increased slightly at Nearfield station MDE-33 in the spring to a value of 1.64. During the spring, diversity was lowest at the Nearfield shell station MDE-1. The station with the highest H' value during both seasons was the reference shell station MDE-13 (late summer H' = 3.17, spring H' = 2.87) which had a good number of taxa with a fairly even distribution among organisms. In general, however, diversity at Nearfield stations was comparable to diversity at Reference stations in late summer and spring.

Five taxa found during Year 18 benthic monitoring were designated as “pollution-sensitive” according to Weisberg et al. (1997). These were the clams *Rangia cuneata* and *Macoma balthica*, the isopod *Cyathura polita*, and the polychaete worms *Marenzelleria viridis* and *Glycinde solitaria*. Relative abundance of these taxa was calculated as a proportion of total infaunal abundance. Relative abundance of pollution-sensitive taxa (PSTA) ranged from 8.5% to 76.0% with an average of 39.8% over all stations in the late summer and from 8.1% to 87.1% with an average of 38.9% over all stations in the spring (Tables 13 and 14; Figures 28 and 29)[2]. There were no clear trends in PSTA between seasons. Like last year, PSTA was slightly higher at sand stations (average in late summer = 46.1%; average in spring = 69.9%) than at shell (average in late summer = 24.5%; average in spring = 57.3%) or silt/clay stations (average in late summer = 39.7%; average in spring = 27.2%). This was due to proportionately higher numbers of the clam *Rangia cuneata* at sand stations. The average PSTA was slightly higher at Nearfield stations than at Reference stations; this difference could be attributed to differences in substrate

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[2] Comparison of the PSTA between seasons is for illustrative purposes only. The B-IBI uses the PSTA as a quantitative metric only for the summer index period.

(i.e., there were no sand Reference stations).

Six taxa found during Year 18 of benthic monitoring were designated as "pollution-indicative" according to Weisberg et al. (1997). These were the polychaete worms *Streblospio benedicti*, *Paraprionospio pinnata*, and *Eteone heteropoda*, the clam *Mulinia lateralis* and the midge *Coelotanypus* sp. In addition, the oligochaete worms (Tubificidae) found during the study were classified as pollution-indicative because past studies have shown that *Limnodrillus hofmeisteri*, which is considered pollution-indicative, is common around HMI. Relative abundance of these taxa was calculated as a proportion of total infaunal abundance. Relative abundance of pollution-indicative taxa (PITA) ranged from 0.0% to 74.6% with an average of 22.6% in the late summer. PITA was significantly higher at 9 stations in the spring due to high seasonal recruitment of pollution-indicative taxa. Average PITA at the Back River/Hawk Cove stations (43.1% and 50.9%, late summer and spring, respectively) was higher than at Reference stations (20.3% and 43.8%, late summer and spring, respectively) during both seasons.

Length frequency distributions for the three most common infaunal clams were determined in order to distinguish any possible size/growth differences between the types of stations (reference, nearfield, and Back River/Hawk Cove stations, and the Baltimore Harbor station). The clams *Rangia cuneata, Macoma balthica,* and *Macoma mitchelli* were measured to the nearest millimeter. *Rangia*, which ranged in size from 1 mm to over 45 mm, were grouped into size classes at 5-mm intervals. *Macoma* spp., which ranged in size from 1 mm to 19 mm, were grouped into size classes of 2-mm increments. As in previous years, *Rangia* was the most common clam species in the waters around HMI (Tables 11 and 12). Low numbers of the pollution-indicative clam *Mulinia lateralis* were found at Harbor station MDE-41 (Tables 16 and 18). This clam was found at no other station, probably due to its preference for higher salinity waters (Lippson & Lippson 1997). Measurements of *M. lateralis* are not reported due to its low numbers and absence from other stations.

The average abundance of *Rangia cuneata* at all stations was noticeably lower in both seasons of Year 18 (September 1999=432.7 clams/m^2, April 2000=247.1 clams/m^2) than in Year 17 (September 1998=761 clams/m^2, May 2000=881 clams/m^2) [Figure 33 vs. Figure 34]. The most common size classes of *Rangia* in Year 18 were the 21-25 mm and 26-30 mm size classes in both spring and late summer (Figures 31). The highest numbers of *Rangia* in this size class were found at the nearfield and Back River/Hawk Cove stations. Based on information in Hopkins et al. (1973), these clams are probably 2-3 years old and may be sexually mature. The number of *Rangia* was low at reference stations for all size classes. However, in September 1999 the reference stations had higher numbers of clams in the larger size classes (31- >40 mm range) than any other type of station (Figure 32). This suggests a higher survival rate for older clams at reference stations than at other stations in the late summer. The average number of Rangia in all size classes at all station types decreased or remained approximately the same in Spring 2000 compared to Late Summer 1999, indicating low spring recruitment. Higher salinities at Harbor station MDE-41 during both spring and summer probably account for the almost complete absence of this brackish water clam from this location.

Both species of *Macoma* were generally rare around HMI during Year 18. *M. balthica* was more abundant than *M. mitchelli* in both seasons. This is in contrast to Year 17 when *M. mitchelli* was more common than *M. balthica* in the fall. Spring recruitment (April 2000) of both species was most noticeable at the reference stations and the Baltimore Harbor station (Figures 36 & 38). However, it is worth noting that no *Macoma* were found at the Baltimore Harbor station in September 1999. The average abundances of *M. balthica* and *M. mitchelli* per meter squared were higher at reference stations than at nearfield stations for both seasons sampled (Figures 35 through 38).

Most specimens of *Macoma balthica* found at any station during either season were less than 10 mm in length (Figures 35 & 36), as was the case in Year 17. Overall numbers of *M. balthica* were much higher in September 1999 (when specimens were found at 15 stations) than in September 1998 (when specimens were found at only 2 stations). However, this relationship was reversed for April 2000 versus May 1999. Spring recruitment of *M. balthica* was highest in the 3-4 and 5-6 mm size ranges (Figure 36). This clam was marginally more common at shell stations than at sand or silt/clay stations.

Overall numbers of the clam *Macoma mitchelli* were lower in both seasons of Year 18 than in Year 17. Most specimens were in the 5-6 and 7-8 mm size range, with strongest spring recruitment seen in the 3-4 mm range (Figures 37 & 38). A clear-cut preference for station type based on substrate was not discernable for *M. mitchelli* in this year's data.

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) was calculated for all stations based on late summer data only. Four metrics – total infaunal abundance, the Shannon-Wiener diversity index, relative abundance of pollution-sensitive taxa, and relative abundance of pollution-indicative taxa – were used to calculate the B-IBI for the low mesohaline stations. The new Harbor station MDE-41 fell in the high mesohaline sand category and used the same four metrics given above plus the additional metric of the abundance of carnivores and omnivores. 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 to be stressed by *in situ* environmental conditions. The eighteen benthic stations studied during Year 18 were compared to this benchmark.

Fourteen benthic stations, including all of the Reference stations, exceeded a B-IBI score of 3, which indicates minimal disturbance at these stations (Table 13; Figure 30). Two other stations, Back River/Hawk Cove stations MDE-27 and MDE-28, exactly met the standard with a score of 3.0. Nearfield station MDE-1, which lies very close to spillway one and exhibited a highly variable interseasonal substrate composition, and the new Harbor station MDE-41 were the only two stations which had a B-IBI score of less than 3.0. The percentage of pollution-indicative taxa (PITA) abundance at Nearfield station MDE-1 (20.5%) was the only metric that had a score of one, bringing down the average score for the combined metrics of the B-IBI to 2.5. It is noteworthy that this station failed to meet the B-IBI by only half of a percentage point in the calculation of the PITA. The new Harbor station MDE-41 is in the industrial Harbor/Patapsco River region of Baltimore, which has a legacy of environmental contamination from heavy industry. Depressed biological communities in this region are well documented (Brown et al. 1998).

In Year 17, seven stations (Nearfield station MDE-7, Nearfield station MDE-9, Nearfield station MDE-17, Reference station MDE-22, Nearfield station MDE-24, Nearfield station MDE-34, and Reference station MDE-36) exceeded, eight stations (Nearfield station MDE-1, Nearfield station MDE-3, Reference station MDE-13, Nearfield station MDE-16, Back River/Hawk Cove station MDE-29, Back River/Hawk Cove station MDE-30, Nearfield station MDE-33, and Nearfield station MDE-35) met and two stations (Nearfield station MDE-19 and Back River/Hawk Cove station MDE-27) failed to meet the B-IBI score of 3.0.

CONCLUSIONS AND RECOMMENDATIONS

The benthic community for Year 18, as measured by the B-IBI, showed significant improvement over last year's scores, with 7 more stations exceeding the 3.0 benchmark this year than last year. The same number of stations failed to meet the benchmark this year (Nearfield station MDE-1 and new Harbor station MDE-41) as last (Nearfield station MDE-19 and Back River/Hawk Cove station MDE-27). Another half a percentage point reduction, or four less individuals, in the number of pollution-indicative taxa (*Streblospio benedicti* and worms from the family Tubificidae) found at Nearfield station MDE-1 would have brought the score to 3.0 and allowed all longer-term HMI stations to meet the B-IBI standard for biological integrity during Year 18. Furthermore, and as in years' past, no discernable differences were seen between HMI reference and nearfield stations. Most of the faunal differences among stations can be explained on the basis of the dominant substrate type (i.e., shell, sand or silt/clay).

Looking at the longer-term trends in B-IBI scores from Year 15 (Figure 30) to the present, there are no consistent patterns of degradation at any of the sites throughout the past four monitoring years. As a general rule, most sites met the 3.0 benchmark for the B-IBI, indicating minimal ecological stress on the benthic community. However, a comprehensive analysis of the historical HMI dataset needs to be performed using the B-IBI retroactively in order to make any meaningful determinations on the overall health of the benthic community in the vicinity of HMI. Furthermore, other analytical tools that were used historically, such as cluster analysis, need to be used again to increase the robustness of the analyses.

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

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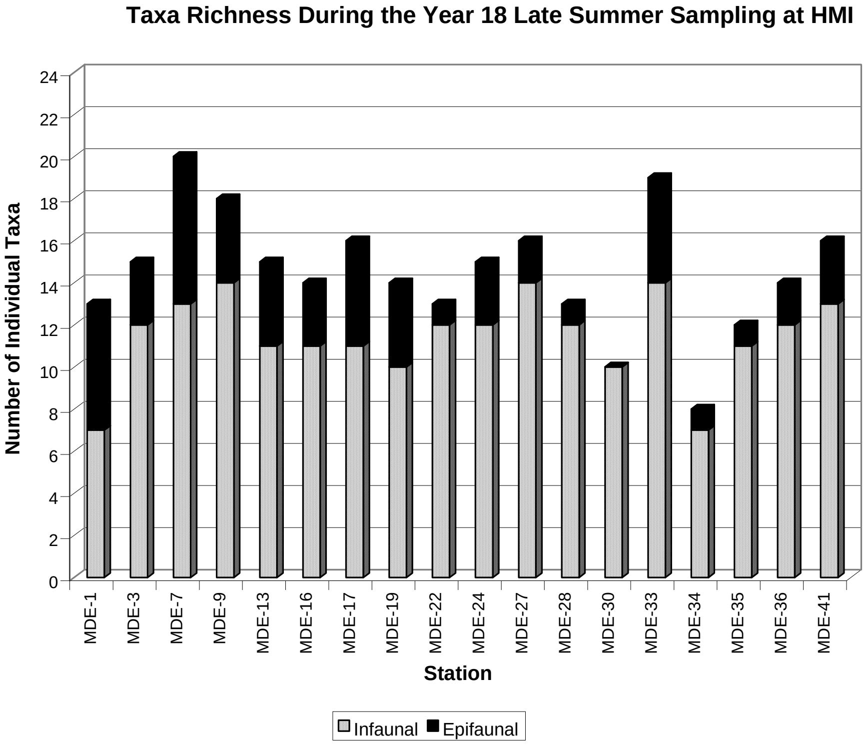

Figure 18: Total infaunal and epifaunal taxa collected at each station during the Year 18 late summer sampling.

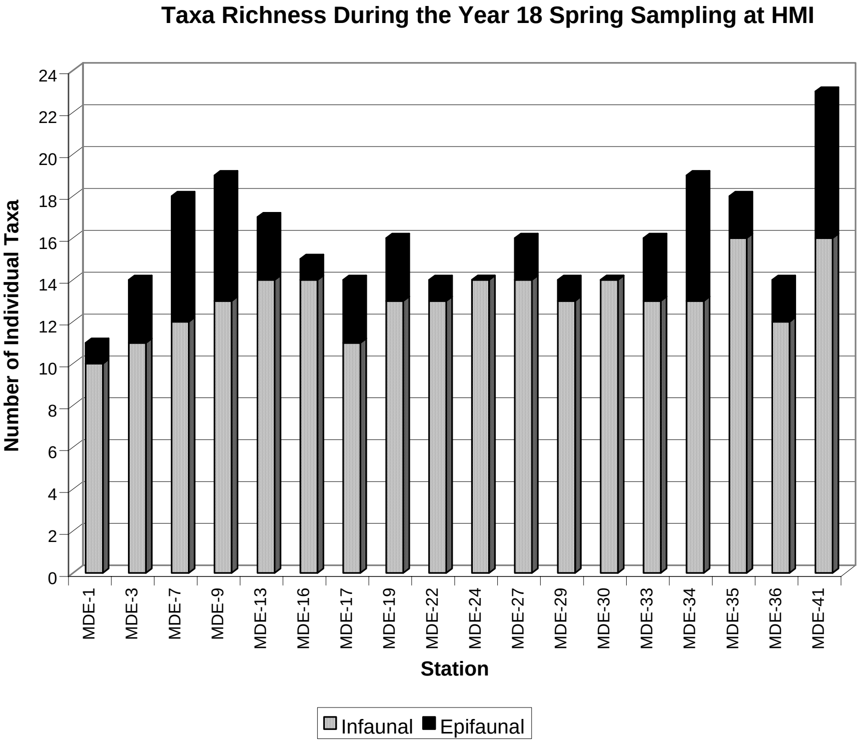

Figure 19: Total infaunal and epifaunal taxa collected at each station during the Year 18 spring sampling.

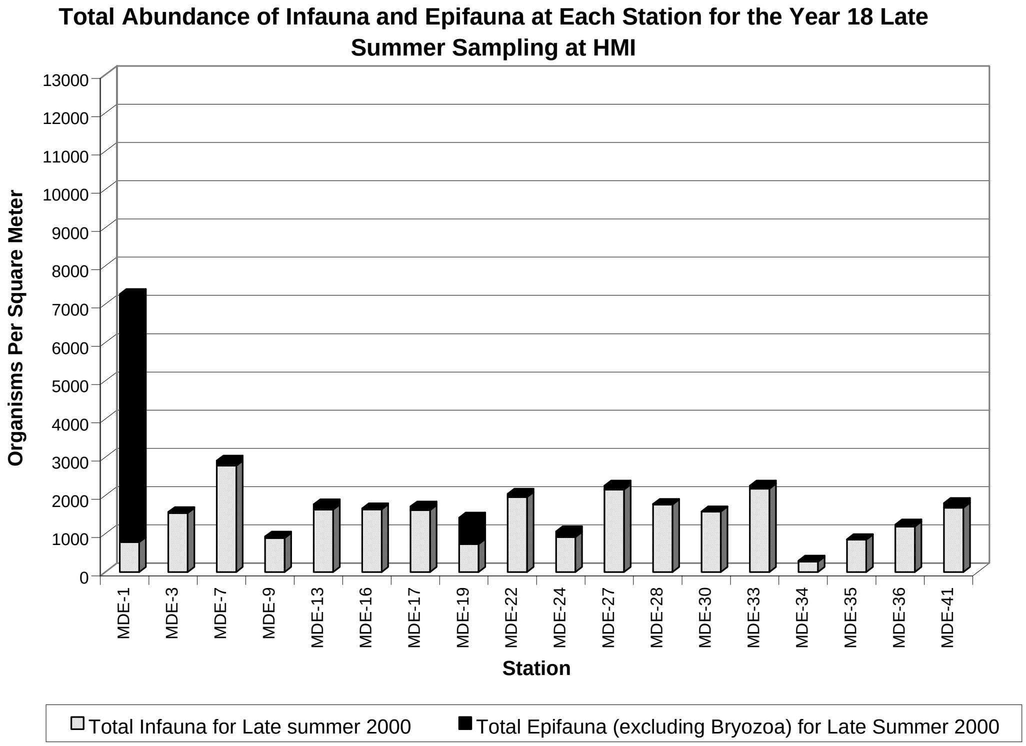

Figure 20: Total abundance of infauna and epifauna at each station for the Year 18 late summer sampling at HMI.

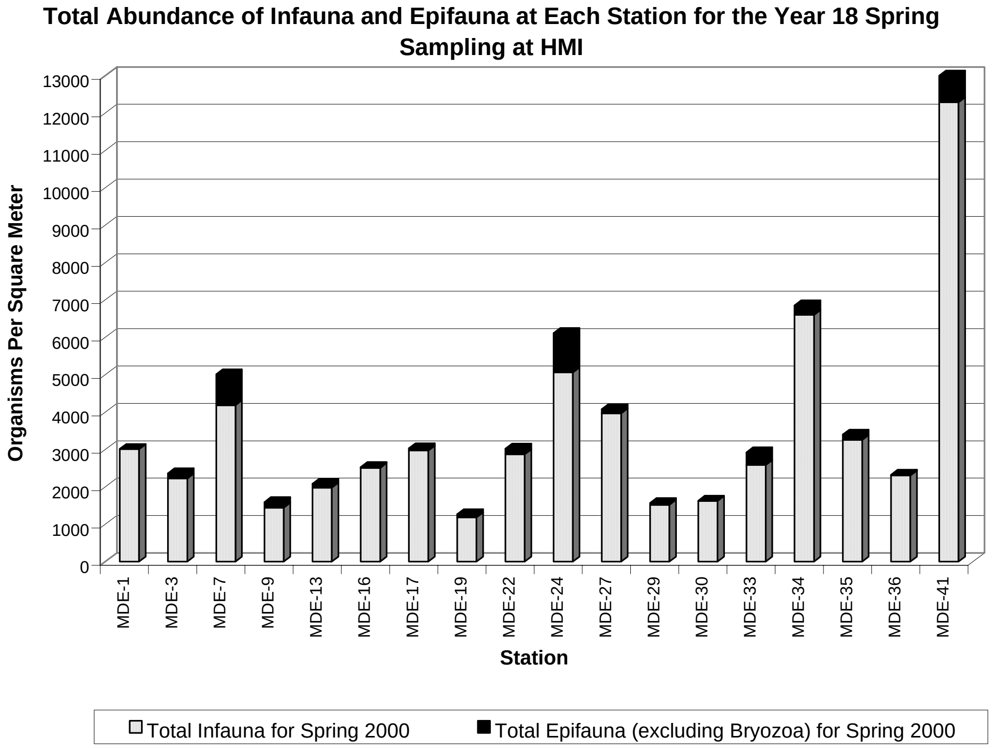

Figure 21: Total abundance of infauna and epifauna at each station for the Year 18 spring sampling at HMI.

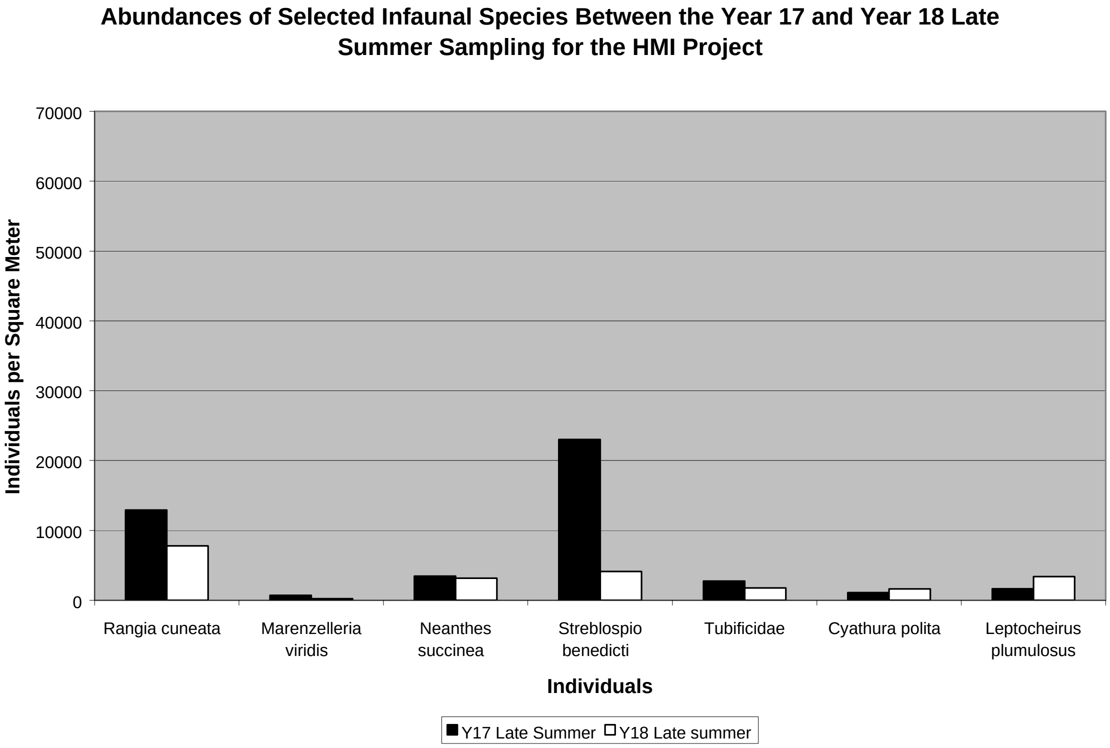

Figure 22: Abundances of selected infaunal species between Year 17 and Year 18 late summer samplings for the HMI project.

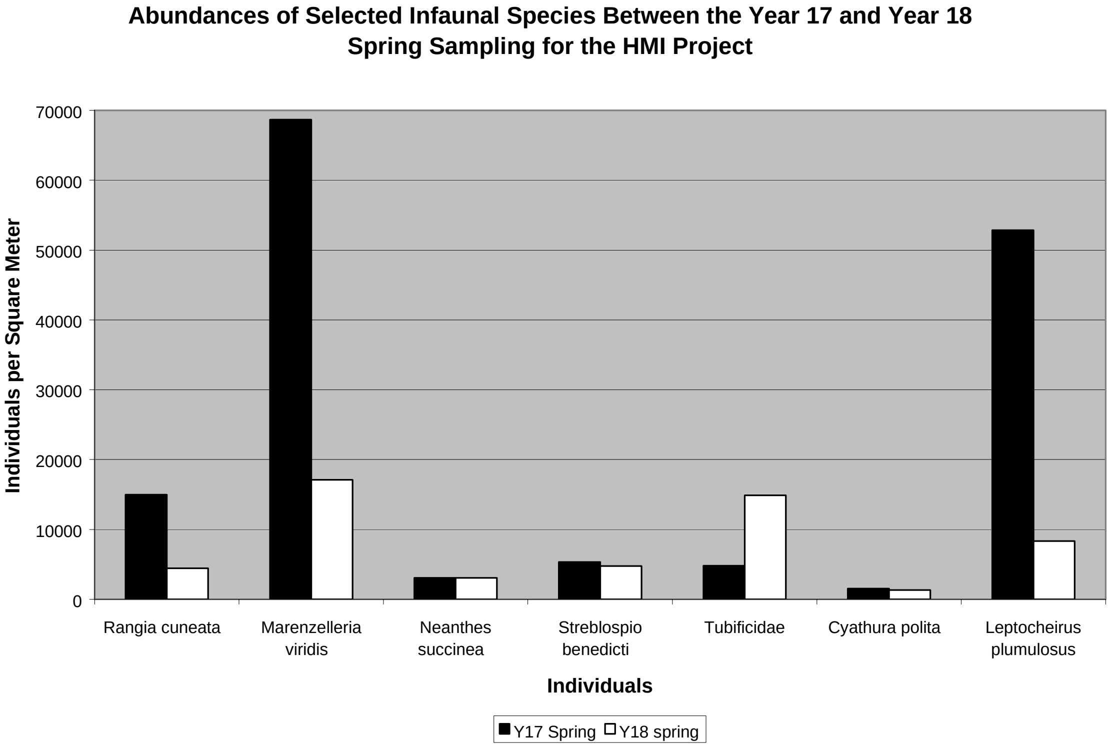

Figure 23: Abundances of selected infaunal species between Year 17 and Year 18 spring samplings for the HMI project.

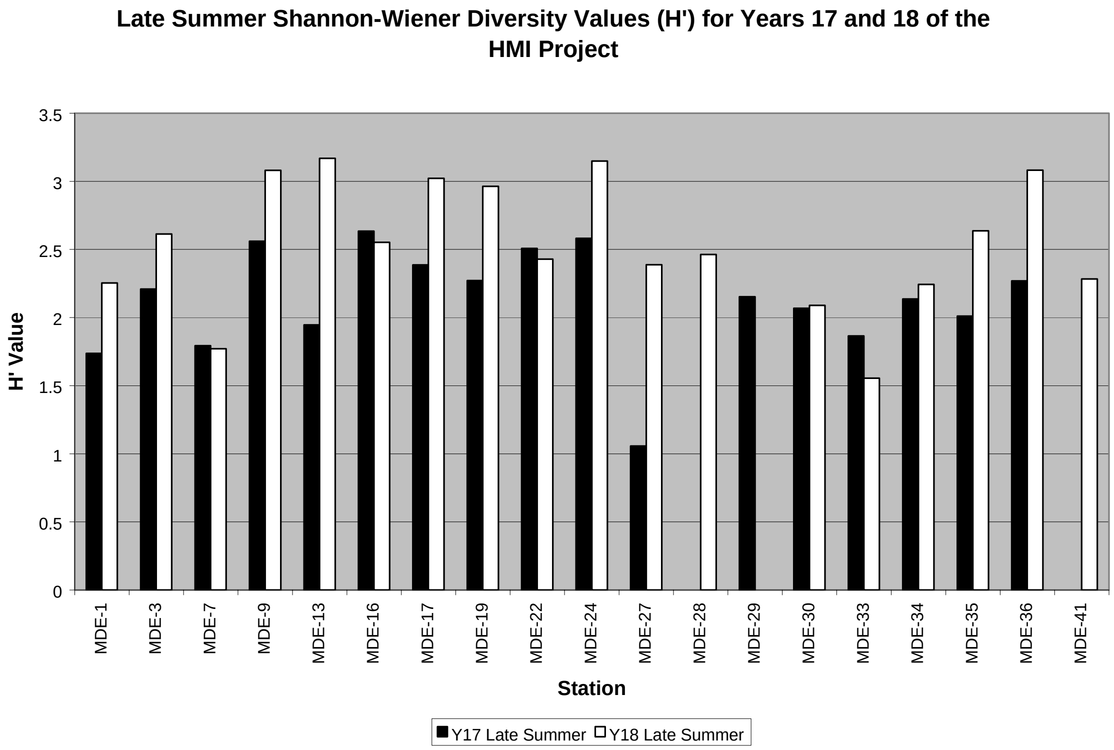

Figure 24: Late summer Shannon-Wiener Diversity Values (H') for Years 17 and 18 of the HMI project.

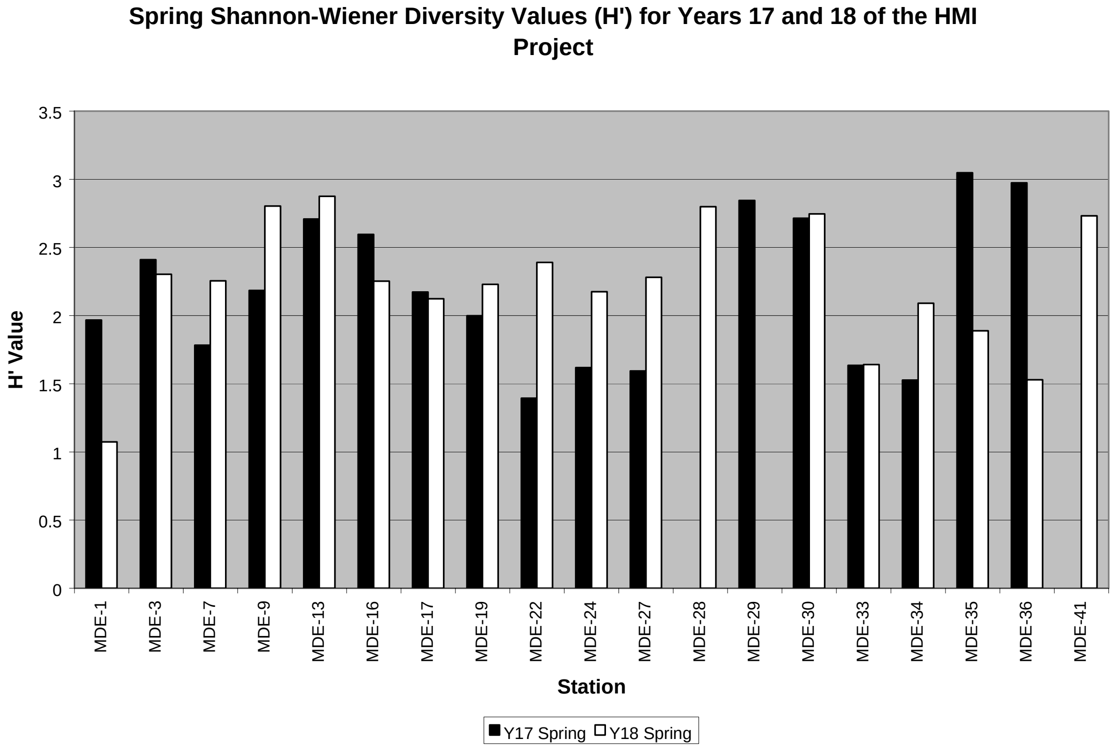

Figure 25: Spring Shannon-Wiener Diversity Values (H') for Years 17 and 18 of the HMI project.

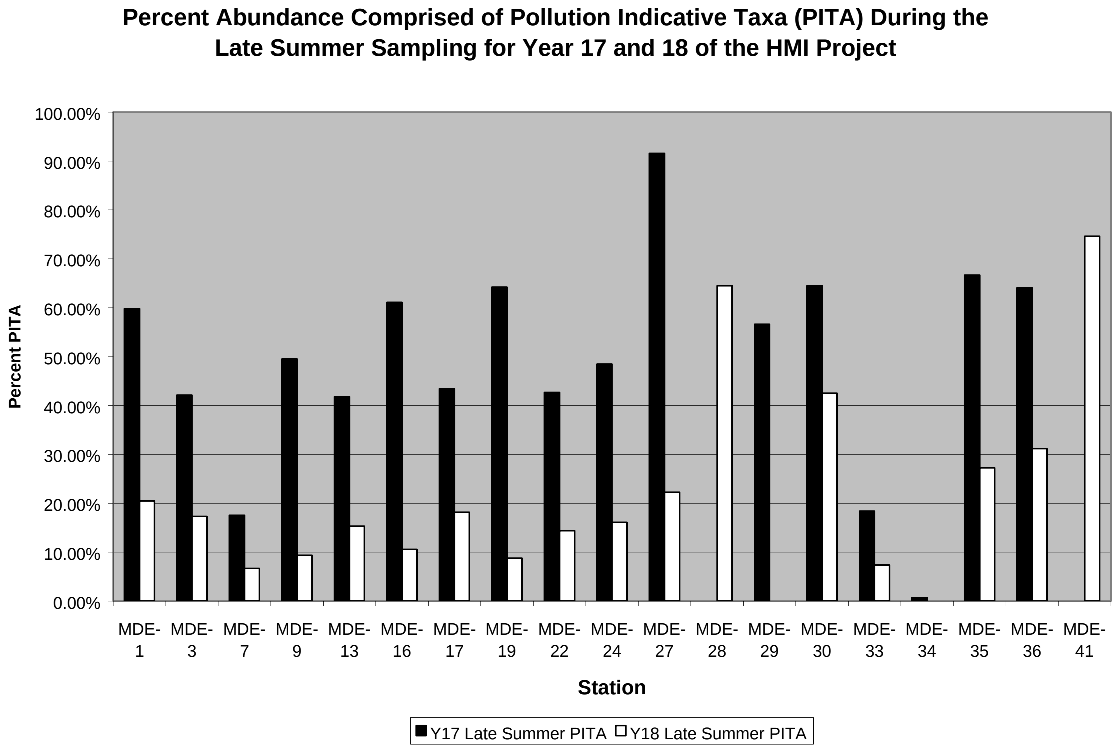

Figure 26: Percent abundance comprised of pollution indicative taxa (PITA) during the late summer samplings for Years 17 and 18 of the HMI project.

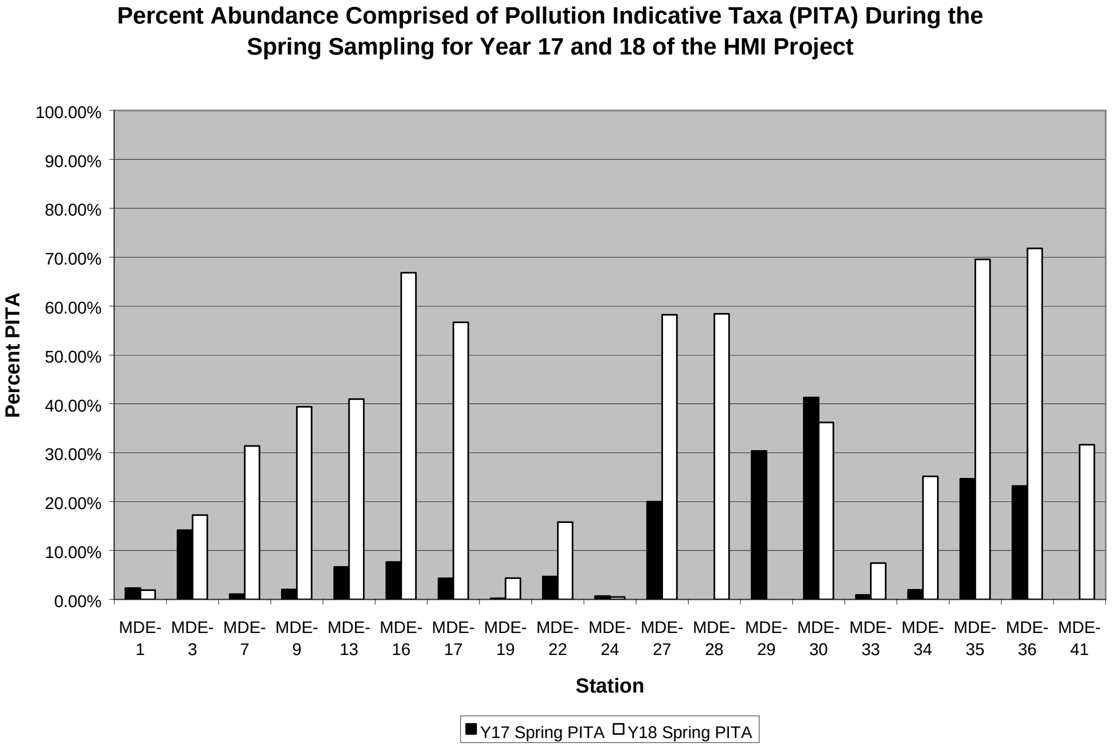

Figure 27: Percent abundance comprised of pollution indicative taxa (PITA) during the spring samplings for Years 17 and 18 of the HMI project.

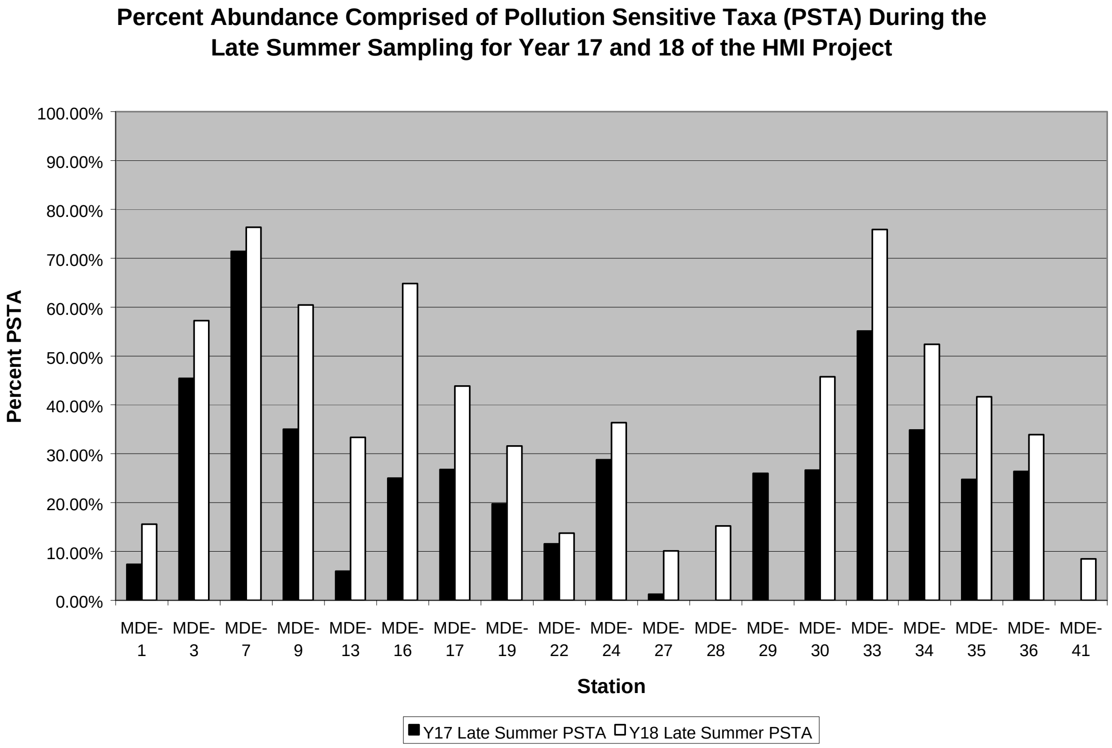

Figure 28: Percent abundance comprised of pollution sensitive taxa (PSTA) during the late summer samplings for Years 17 and 18 of the HMI project.

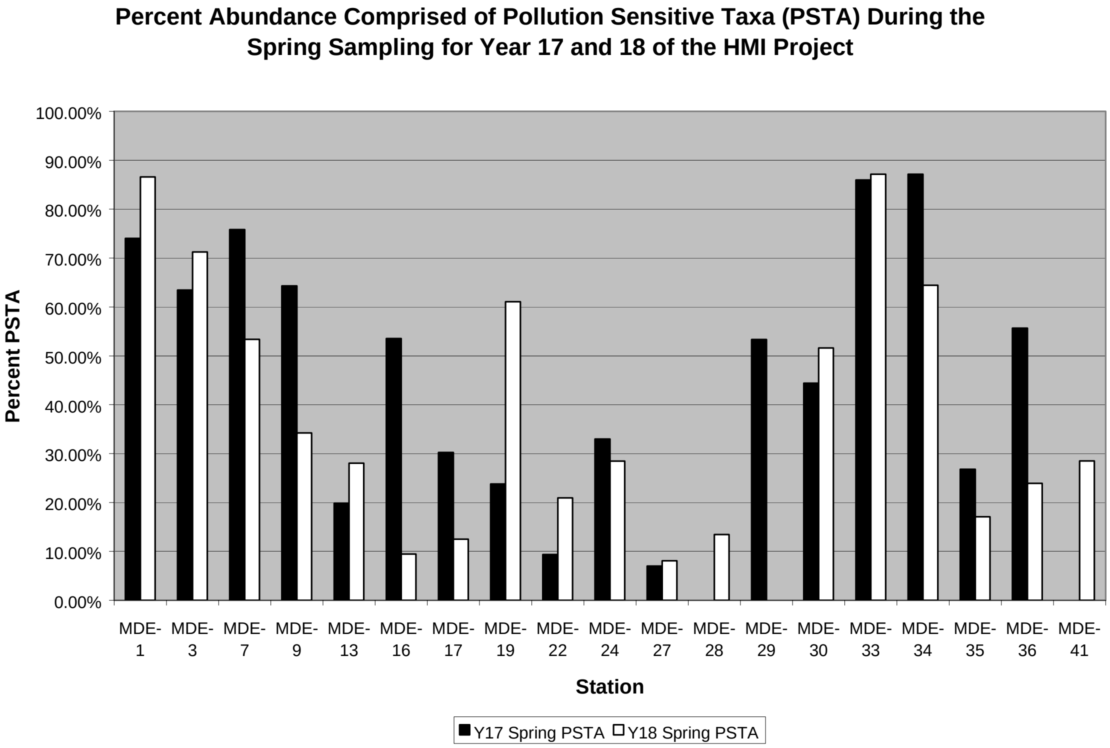

Figure 29: Percent abundance comprised of pollution sensitive taxa (PSTA) during the spring samplings for Years 17 and 18 of the HMI project.

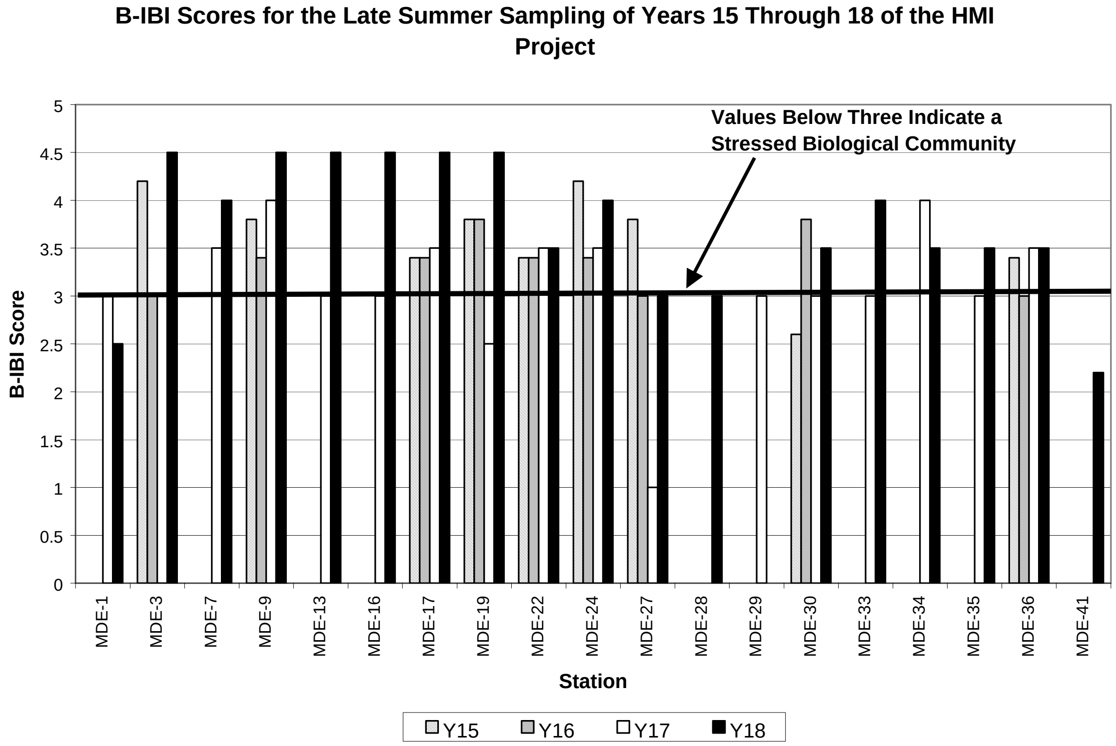

Figure 30: B-IBI scores of the late summer samplings for Years 15 through 18 of the HMI project.

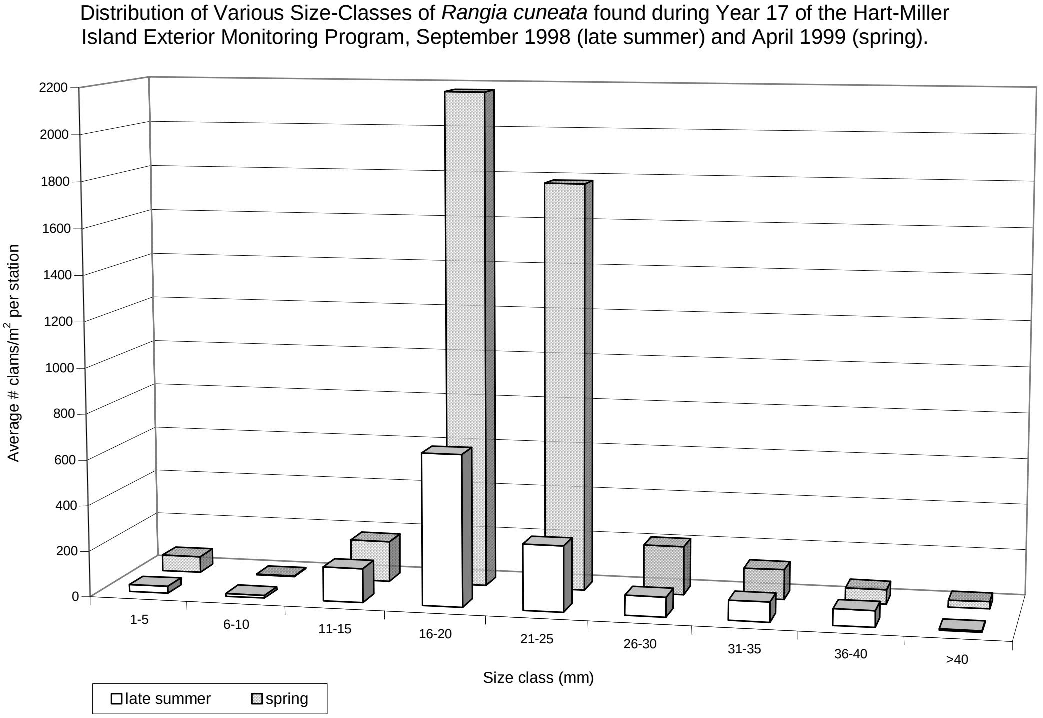

Figure 31: Distribution of various size-classes of *Rangia cuneata* found during Year 17 of the Hart-Miller Island Exterior Monitoring Program, September 1998 and April 1999.

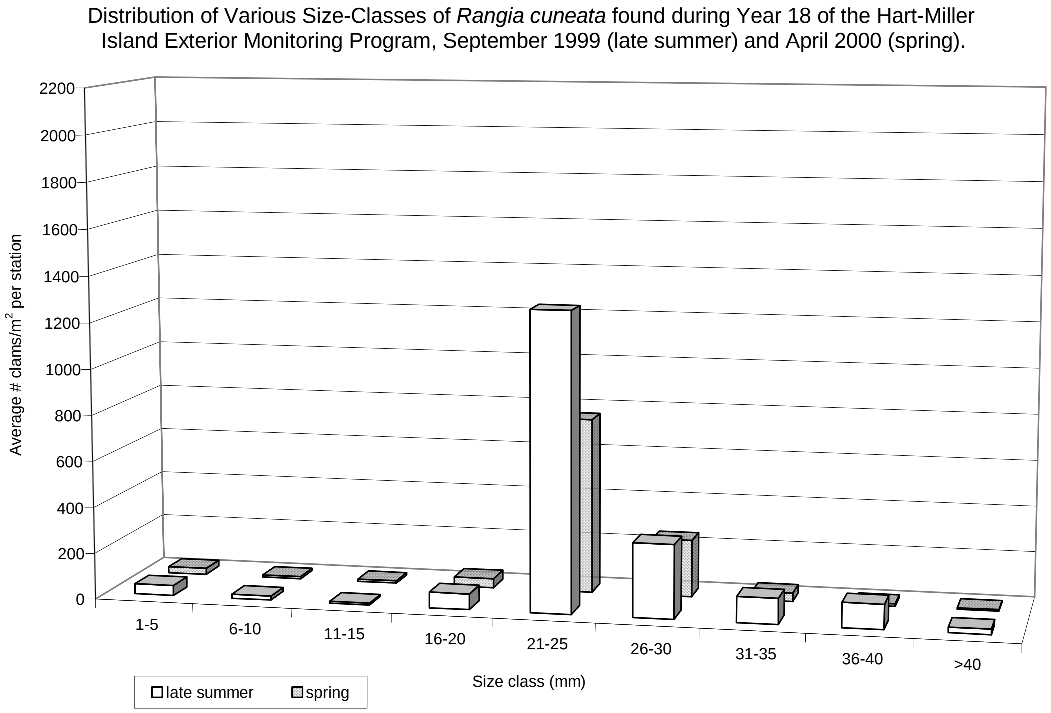

Figure 32: Distribution of various size-classes of *Rangia cuneata* found during Year 18 of the Hart-Miller Island Exterior Monitoring Program, September 1999 and April 2000.

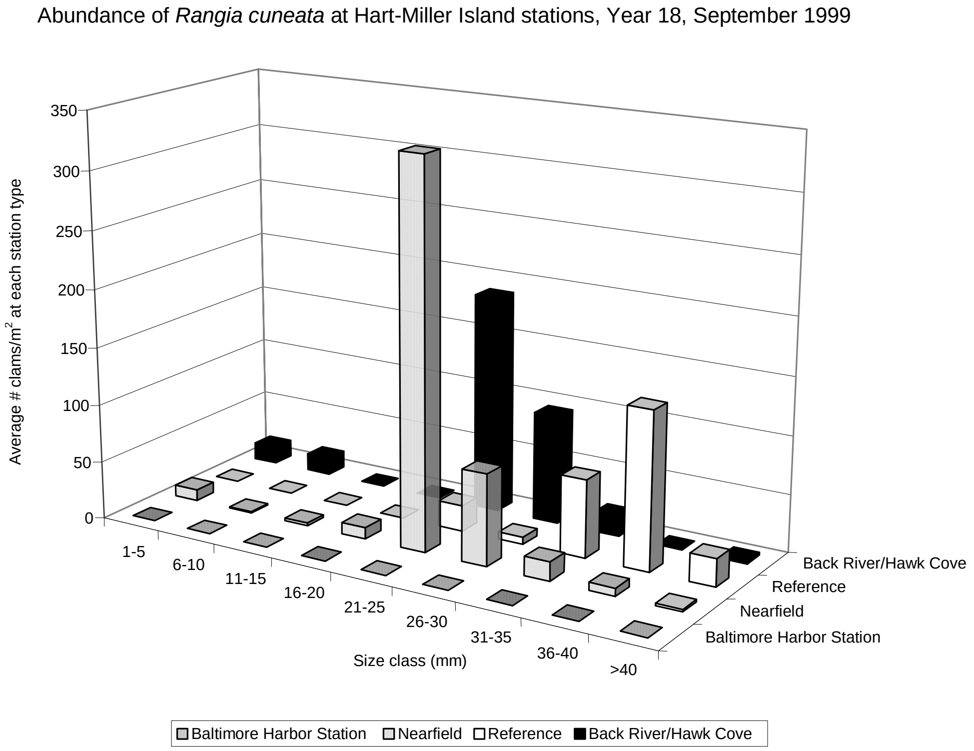

Figure 33: Abundance of *Rangia cuneata* at Hart-Miller Island stations, Year 18, September 1999.

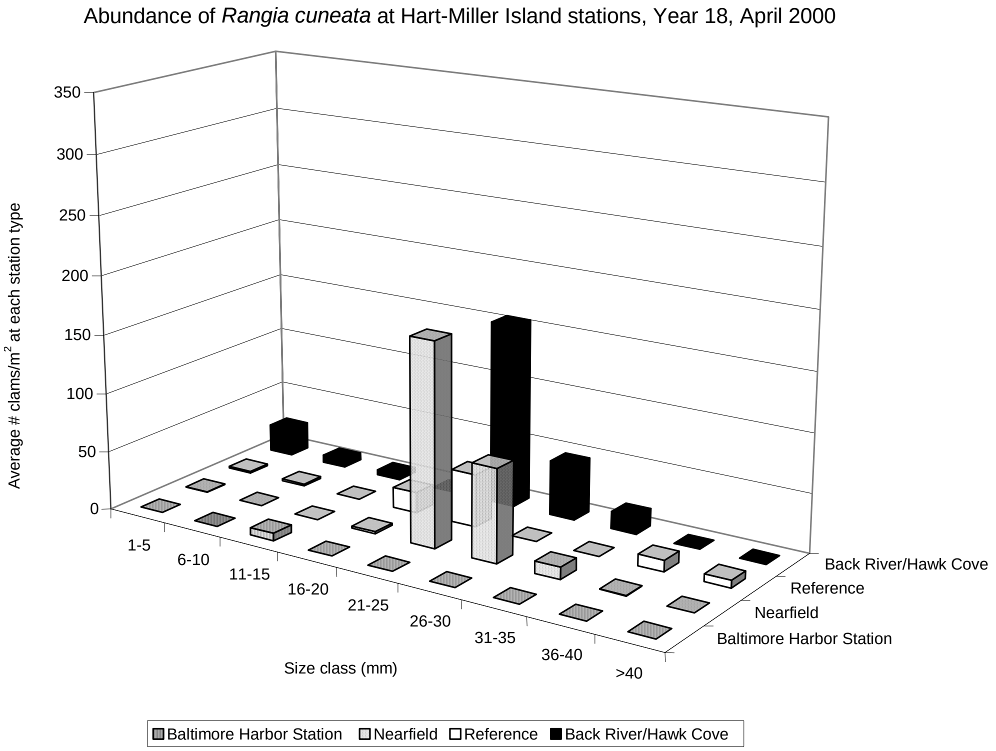

Figure 34: Abundance of *Rangia cuneata* at Hart-Miller Island stations, Year 18, April 2000.

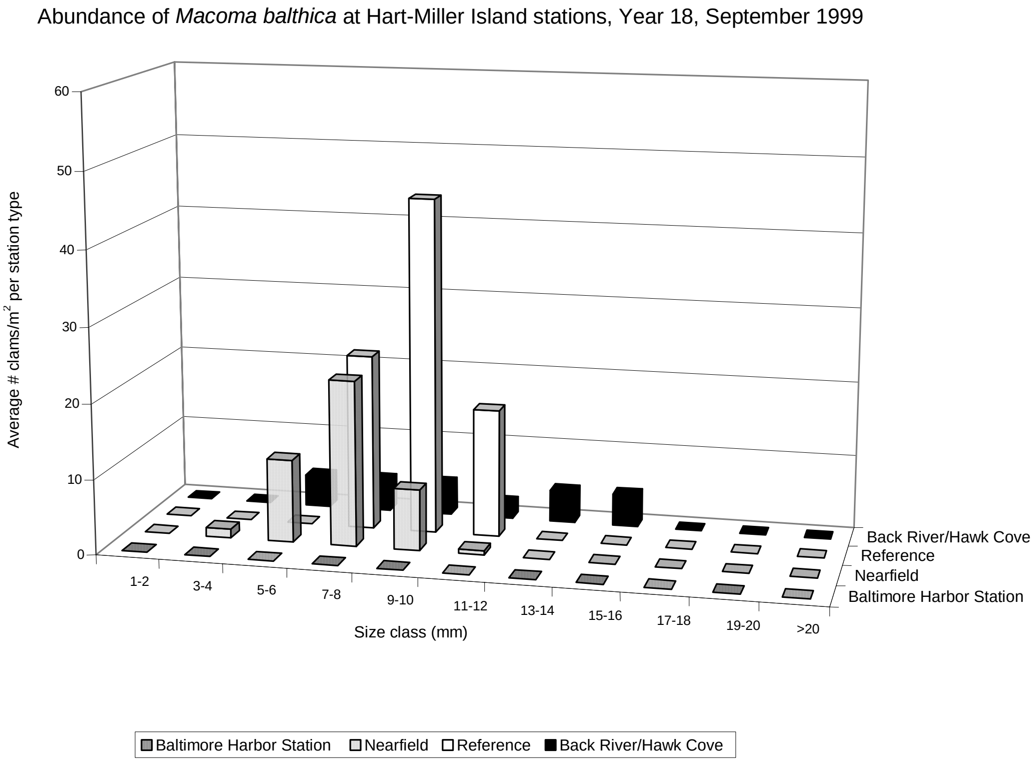

Figure 35: Abundance of *Macoma balthica* at Hart-Miller Island stations, Year 18, September 1999.

Abundance of *Macoma balthica* at Hart-Miller Island stations, Year 18, April 2000

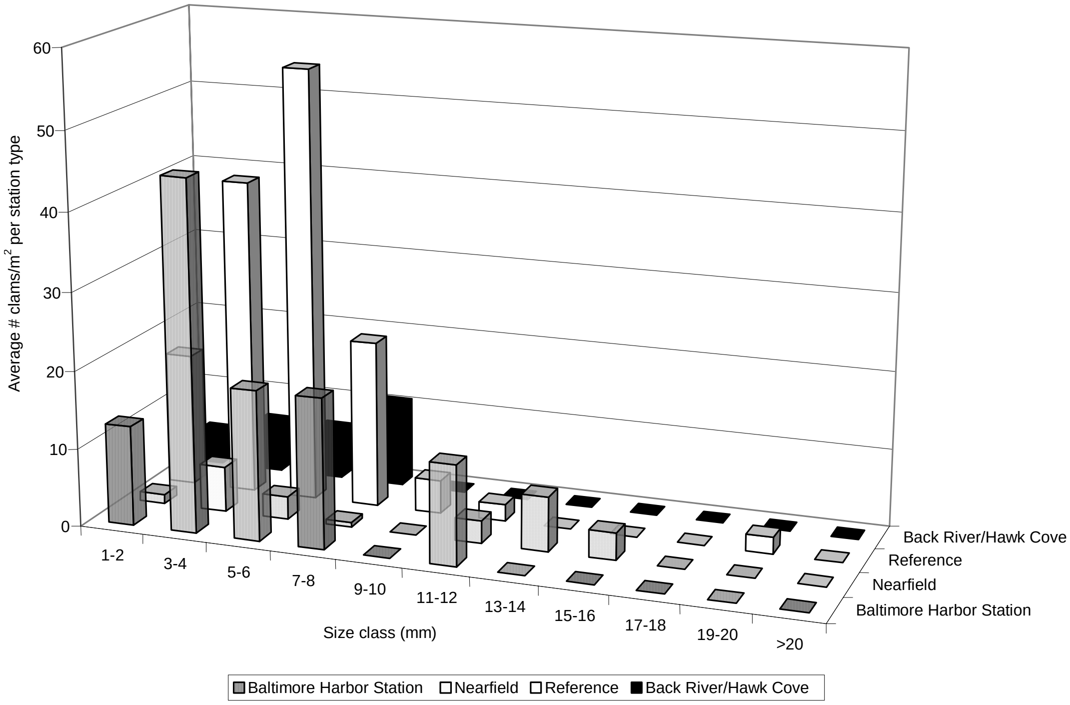

Figure 36: Abundance of *Macoma balthica* at Hart-Miller Island stations, Year 18, April 2000.

Abundance of *Macoma mitchelli* at Hart-Miller Island stations, Year 18, September 1999

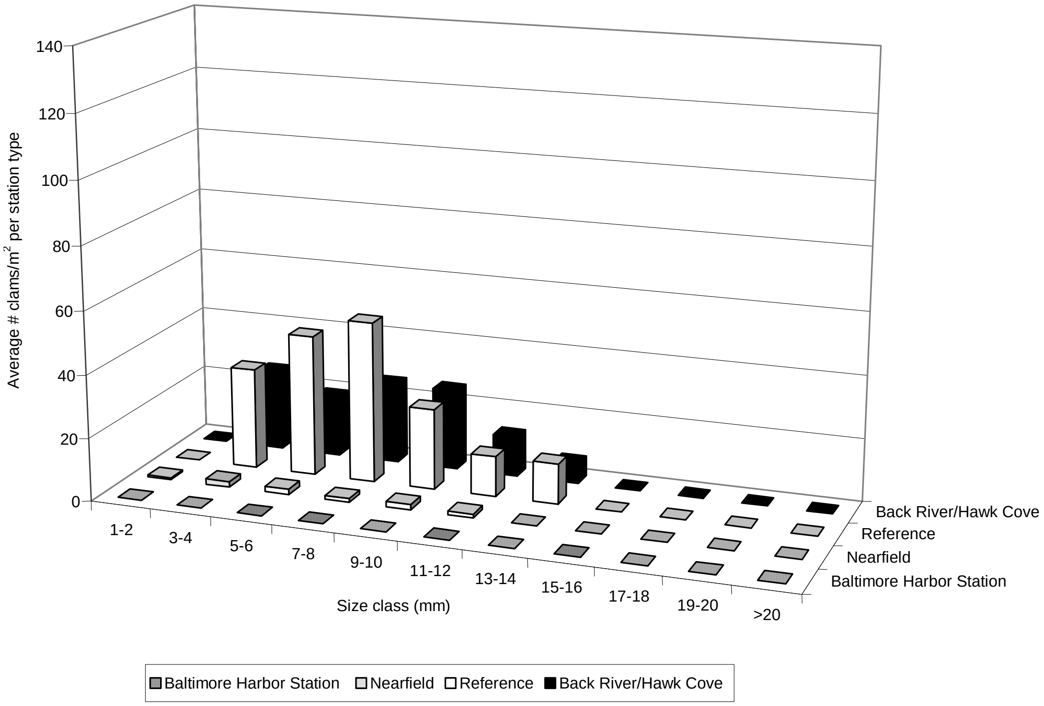

Figure 37: Abundance of *Macoma mitchelli* at Hart-Miller Island Stations, Year 18, September 1999.

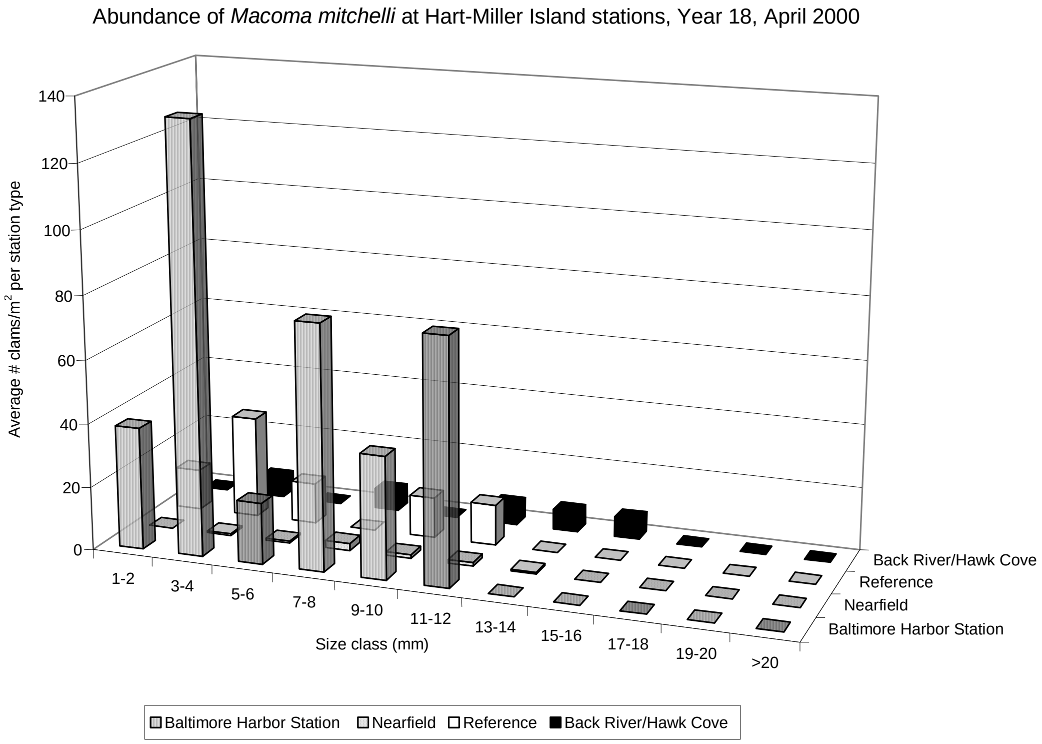

Figure 38: Abundance of *Macoma mitchelli* at Hart-Miller Island Stations, Year 18, April 2000.

CHAPTER 4: ANALYSIS OF CONTAMINANTS IN SEDIMENTS COLLECTED NEAR HART-MILLER ISLAND (PROJECT 4)

Hart-Miller Island Exterior Monitoring Program, Year 18
September 1999 – September 2000

Prepared for

Maryland Port Administration
Maryland Department of Transportation

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OVERVIEW

The objective of this study is to characterize contaminant levels in sediment at Hart-Miller Island Dredged Material Contaminant Facility (HMI) - see Figure 39 for sampling sites - as part of a long-term exterior monitoring program. Sediment samples have been collected since 1981 and the current effort by the Chesapeake Biological Laboratory (CBL) was initiated in concert with the 15th year of the Monitoring Program. The charge of this effort is to measure current levels of contaminants in the vicinity of Hart-Miller Island in sediment, and to relate these, as far as possible, to historic data. Comparison and correlation of these data with other nearby locations, and with historic Hart-Miller Island data, indicate the extent of contamination, and any trend in concentrations, at this location. To understand the potential contamination for sediments around HMI with contaminants from Baltimore Harbor, a transect was established in Year 18 from the outer reaches of Baltimore Harbor to HMI (Figure 40; sites MDE 38-41). Samples of clams and sediments were collected for trace metal and organic contaminant analysis in Year 17. In Year 18, only sediments were collected in the Fall of 1999 and the Spring of 2000.

The results of the quality assurance (QA/QC) procedures and the description of the analytical and field protocols are contained in the 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. Results of duplicate analyses and comparison of measured values to certified values for the analyzed Standard Reference Materials are discussed in the data report. Again, the QA/QC objectives were met in this regard.

INTERPRETATION OF THE RESULTS

The average sediment metal concentrations for the late summer and spring sampling are shown in Fig. 41. Overall, there was little difference, on average, between metals concentrations in the Fall of 1999 and the Spring of 2000 (Fig. 41) except perhaps for Arsenic (As). Of all the elements measured, Arsenic appears to have the highest variability between sampling events in Year 18. Values were generally lower in Spring 2000 compared to Fall 1999. On a larger scale, sediment metal concentrations also vary in time. In Table 19, results from Year 18 are compared to the three previous sampling years (Years 15-17), to show how sediment metal concentrations have varied from year to year. Arsenic values appear to fluctuate by a factor of 2 (Table 19). Highest concentrations in Year 18 were around 20 ppm compared to 50 ppm in Year 17 and 25 ppm in Years 15 and 16. Thus, Year 17 appears to be about a factor of 2 higher than the other years. For Cadmium (Cd), Year 18 appears to have some higher concentrations than the previous years. However, while there is a larger range in concentration, the average value is similar to earlier studies.

Other metals also show variation that could be due to differences such as sediment composition. The plots in Fig. 42 show that all metals have some relationship with sediment organic content (OC), and that increased concentrations can be explained, to a large degree, by increases in OC. For example, for Cadmium and Silver (Ag), a change in OC from 2-10%, i.e. a factor of 5, is associated with a change in metal concentration of a factor of 2-3. Thus, the differences between years discussed above could easily be explained by differences in sediment OC for these metals. The same is true for the other metals.

Susquehanna River sediments had much higher concentrations than found in the Upper Bay region and around HMI (Fig. 43). Furthermore, the similarity of sediment metal concentrations at HMI with the Upper Bay concentrations indicate that it is reasonable to conclude that the concentrations of the metals are not elevated compared to the surrounding environment, and are much lower than in the Susquehanna (the major source of sediment to the Bay). However, this does not mean that the concentrations are necessarily at "background" levels. A comparison of the concentrations found, to those of toxicity screening values - the Effects Range-Low (ER-L) and the Effects Range-Median (ER-M) - is shown in Table 19. The ER-L value is the concentration at which effects are possible but not likely, or rarely observed, while the ER-M value represents that value at which effects of the particular contaminant on benthic organisms is likely to occur. While some of the concentrations found around HMI exceed the ER-L, none exceed the ER-M. This contrasts with the Baltimore Harbor, where many samples have values above the ER-M. Again, while these results indicate that the sediments are impacted to a certain degree, which is not surprising given the anthropogenic insult to the surroundings since the arrival of Europeans, they are not more impacted than the upper Bay in general and are substantially cleaner than the sediments in Baltimore Harbor (Table 19).

Figure 4-6 compares the sediment metal concentrations measured at the Baltimore Harbor mouth to data from six selected HMI stations that occur along a sampling transect with the Baltimore Harbor station. The transect samples (Fig. 44) do not suggest any gradient in metal concentration from the mouth of the Harbor toward HMI. Most metal concentrations are relatively constant along the transect. There is also little change in OC along the transect, so the effect of OC on concentration is minor. Thus, in contrast to the results from Year 16 when a strong gradient in sediment metal concentration was found down the Back River toward HMI, there is little gradient from the mouth of the Harbor to HMI. This suggests that the influence of sediment movement from the Harbor to HMI is small and not likely a contributor to the concentrations found around HMI. The concentrations found at the MDE 38-41 sites are comparable to those measured previously during the Baltimore Sediment Mapping Study (Sites 2, 5 and 10), which were among the lower end of the concentrations found within the greater Harbor region.

CONCLUSIONS

1. Concentrations of trace metals in surficial sediments around the Hart-Miller Island facility are generally low, and are consistent with typical sediments in the northern Chesapeake Bay;

2. Concentrations of trace metals in surficial sediments around the Hart-Miller Island Facility are much less than those in nearby Back River and in the Baltimore Harbor. Large gradients down the Back River indicate that, for some metals, the river is transporting contaminants to the Hart-Miller Island area (Year 16 Study). The results of this year's study suggest that the Baltimore Harbor region is not a significant contributor to the contaminant levels observed around the Hart-Miller Island facility; and,

3. Concentrations of trace metals in surficial sediments sampled around the Hart-Miller Island facility are relatively low for an environment impacted by multiple anthropogenic sources, based on published sediment guidelines.

RECOMMENDATIONS

While the measurements contained in the Year 18 Report continue to show little indication of significant input and might be construed to suggest that continued sampling is not necessary, this is not recommended. The following are the recommendations for future work:

1. Continue to collect sediment and biota samples, but on a biannual basis, as measurements of loadings in organisms provides insight not apparent from sediment analysis alone; and,

2. Continue to periodically re-investigate seasonal patterns by sampling at other times of the year besides late-summer/early fall, such as at the startup and/or abatement of discharge.

Table 19: Concentrations of metals in HMI sediments collected in Years 15-18 (1996-2000). Comparison is made on a dry weight basis. Also included is the range in values for Baltimore Harbor and the respective ER-L and ER-M screening values for these elements in sediments (Long et al., 1995).

Metal (µg/g dry wt.)	Year 15	Year 16*	Year 17	Year 18*	BH Study**	ER-L/ER-M Values
Cd	0.18-0.63	0.13-1.5	0.1-0.6	0.1-2.4	0.01-17.6	1.2/9.6
Pb	14-59	12-86	60-160	7-122	1-1014	47/218
Ag	0.2-0.9	0.04-2.5	0.25-2.5	0.1-2.7	-	-
As	4.6-25.9	0.5-25.4	5-50	1-20.3	-	-
Hg	0.06-0.35	0.08-0.70	0.05-0.5	0.02-0.3	0.004-3.13	0.15/0.71

Notes: * Year 16 data excludes site BSM 75 while Year 18 excludes sites 39-41.

** Data from Baltimore Harbor Mapping Report.

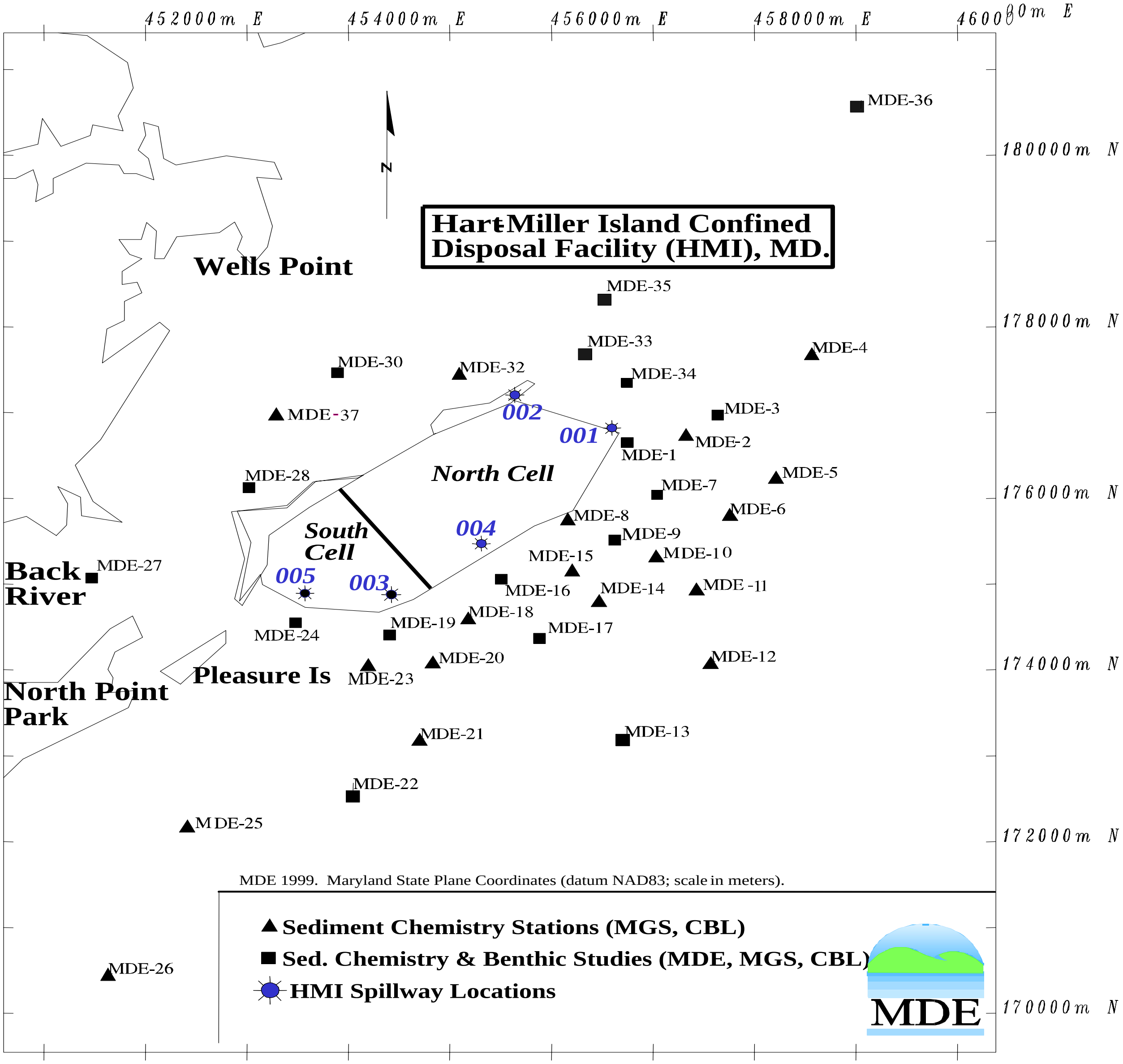

Figure 39: Map showing the location of the Hart-Miller Island sampling sites.

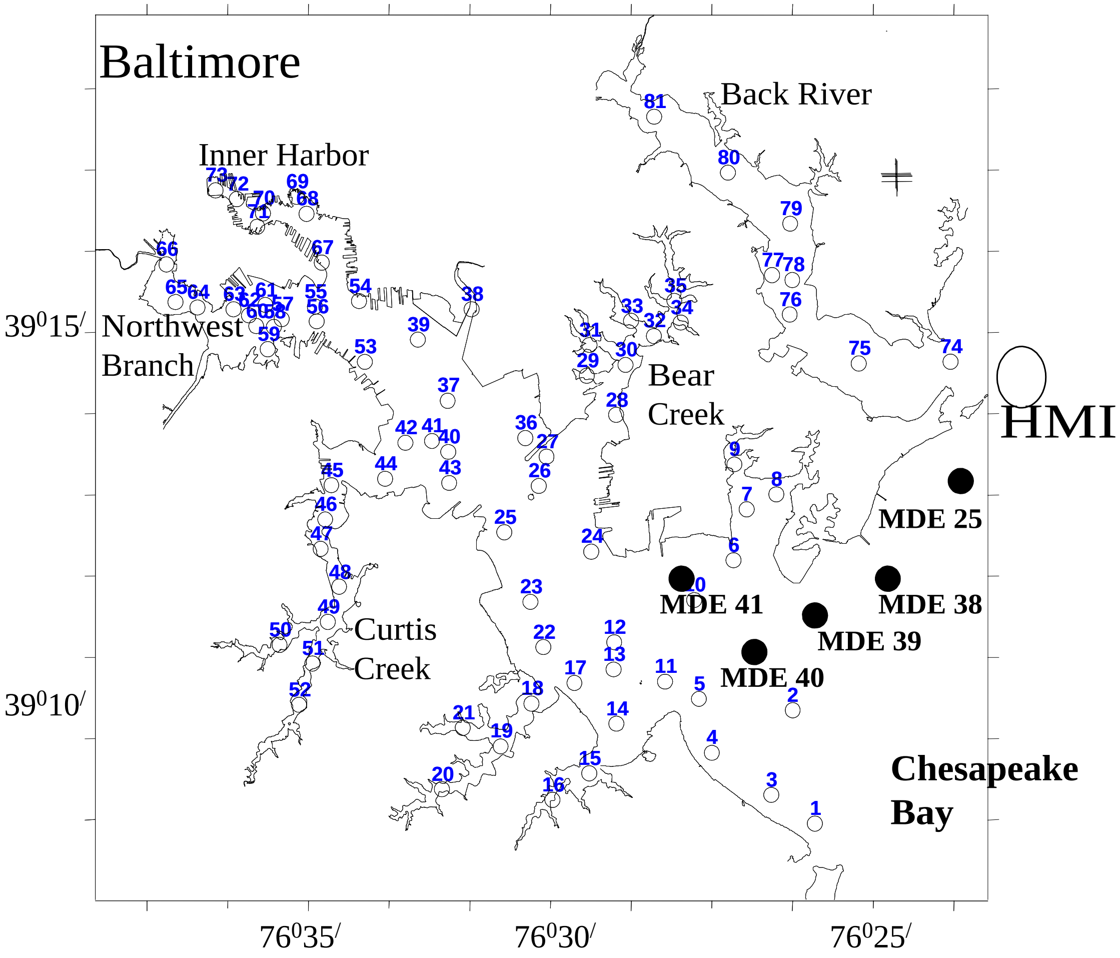

Figure 40: Map showing the location of the additional four sampling sites for Year 18 in relationship to the other HMI sites (MDE-25) and the Baltimore sediment mapping sites (#'s 1-81).

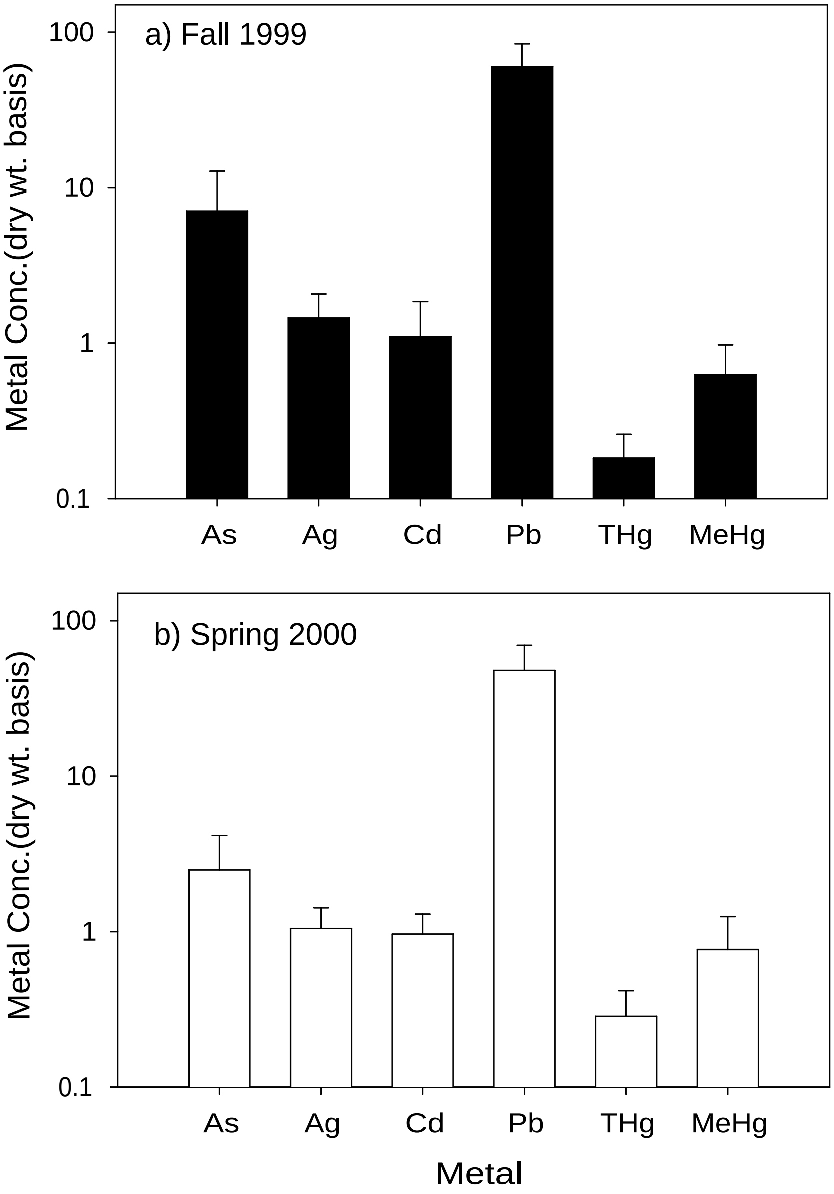

Figure 41: Average concentration of metals (measured in µg/g) in sediments in Fall 1999 and Spring 2000.

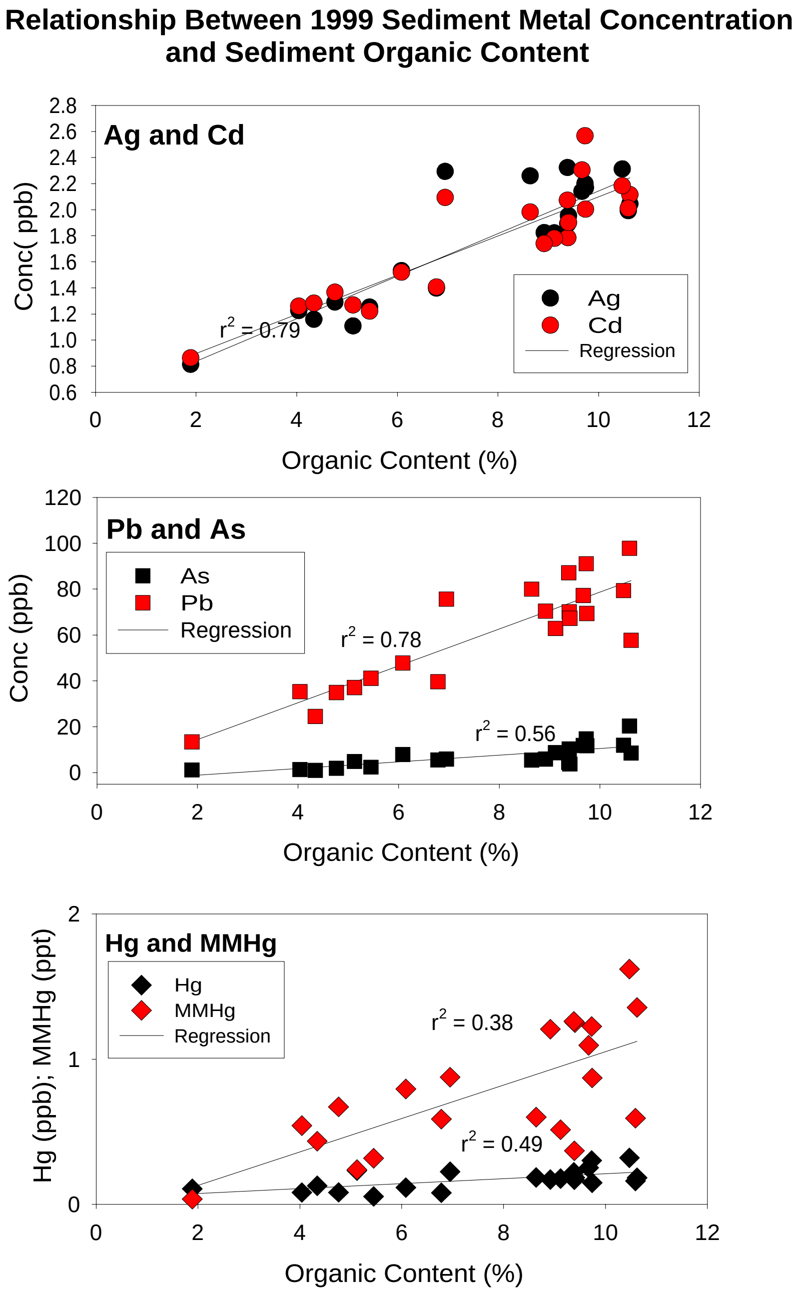

Figure 42: Relationship between 1999 metal concentration and sediment organic content.

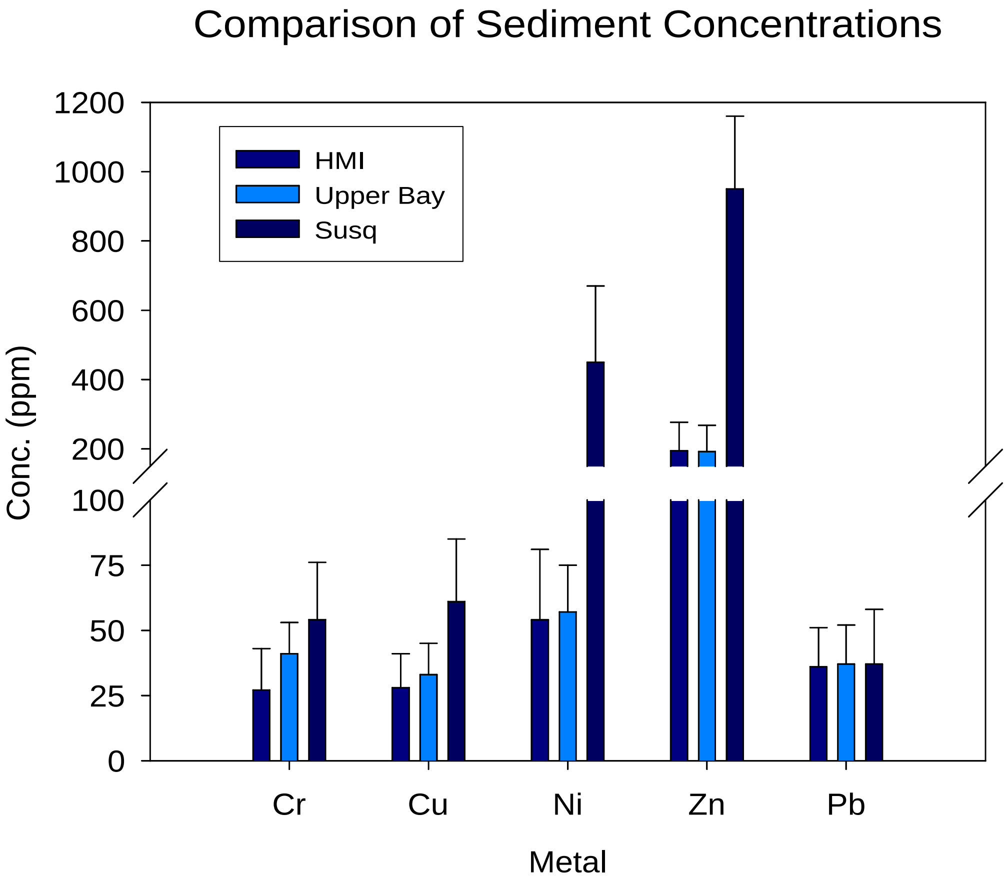

Figure 43: Comparison of sediment concentrations.

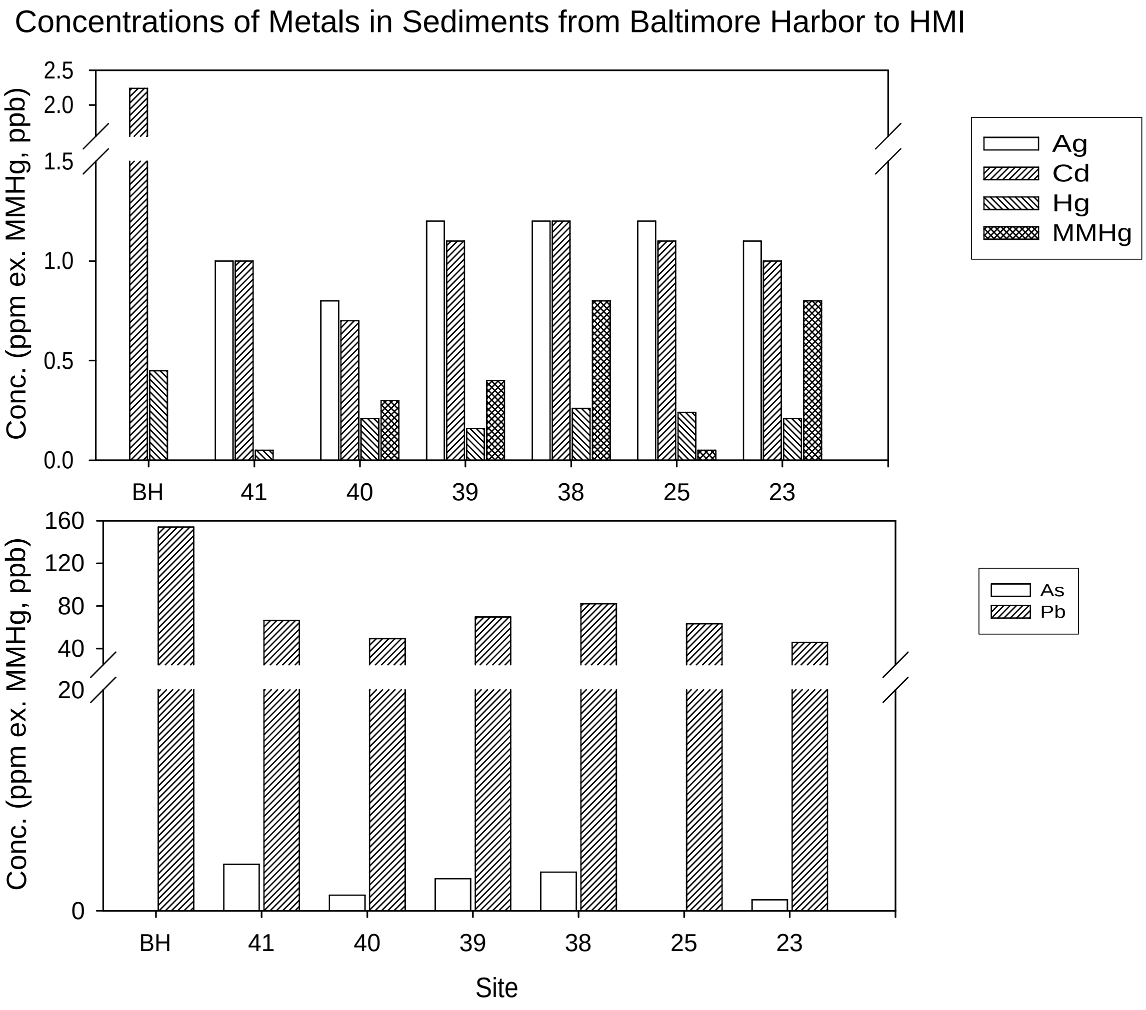

Figure 44: Concentrations of metals in sediments from Baltimore Harbor to HMI.

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