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

Year 19 Technical Report (September 2000 – 2001)



Prepared by:

Maryland Department of the Environment

CONTENTS

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

ACKNOWLEDGMENTS 2
INTRODUCTION 3
SITE BACKGROUND 3
ENVIRONMENTAL MONITORING 3
PROJECT SUMMARIES 5

CHAPTER 2: SEDIMENTARY ENVIRONMENT (PROJECT II) 9

ACKNOWLEDGMENTS 10
EXECUTIVE SUMMARY 11
INTRODUCTION 14
PREVIOUS WORK 15
DIKE OPERATIONS 17
OBJECTIVES 21
METHODS AND MATERIALS 21
FIELD METHODS 21
LABORATORY PROCEDURES 22
RESULTS AND DISCUSSION 26
SEDIMENT DISTRIBUTION 26
ELEMENTAL ANALYSES 32
TRACE METALS 33
CONCLUSIONS AND RECOMMENDATIONS 43
REFERENCES 45

CHAPTER 3: BENTHIC COMMUNITY STUDIES (PROJECT III) 49

ABSTRACT 50
RESULTS AND DISCUSSION 59
WATER QUALITY 59
BENTHIC MACROINVERTEBRATE COMMUNITY 63
CONCLUSIONS AND RECOMMENDATIONS 88
REFERENCES 89

CHAPTER 4: ANALYTICAL SERVICES (PROJECT IV) 102

OBJECTIVES **103**
METHODS AND MATERIALS **103**
SAMPLING PROCEDURES 103
ANALYTICAL PROCEDURES FOR METALS 104
ANALYTICAL METHODS FOR ORGANIC CONTAMINANTS 105
RESULTS AND DISCUSSION **106**
REFERENCES **114**

LIST OF FIGURES

Figure 1: Sampling locations for Year 19. Contours show zones of influence found in previous studies. Solid circles show location of sites added in Year 18. 14
Figure 2: 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. The Pie Diagrams show the percentage of days prior to each period where the exterior would be influenced by discharge from HMI.. 19
Figure 3: Low pH measured for daily discharge from HMI. 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....................................... 20
Figure 4: Pejrup's (1988) classification of sediment... 22
Figure 5: Ternary diagrams showing the grain size composition of sediment samples collected in Years 17 and 18 from the 32 sampling sites common to all six cruises: (a) September 1998, (b) April 1999, (c) September 1999, and (d) April 2000. 27
Figure 6: Ternary diagrams showing the grain size composition of sediment samples collected in Year 19 from the 32 sampling sites common to Years 17-19: (e) September 2000, and (f) April 2001. 28
Figure 7: Sand distribution for Year 19 Monitoring. Contour intervals are 10%, 50%, and 90% sand. 30
Figure 8: Average water depths, based on Year 17 Monitoring. Contour interval = 5 ft. 31
Figure 9: Clay:mud ratios for Year 19 Monitoring. Contour interval = 0.10, plus 0.55. 31
Figure 10: A box and whisker diagram showing the range of the data for both the fall and spring cruise. 36
Figure 11: 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 (shaded in figures). 40
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 (shaded in figures). 41
Figure 13: Record of the maximum % Excess Zn for all of the cruises MGS analyzed the sediments.. 42
Figure 14: Year 19 Benthic Sampling Stations for the HMI Exterior Monitoring Program. 55
Figure 15: Total average abundance of infauna and epifauna taxa collected at each HMI station in year 19, September 2000 and April 2001. 92
Figure 16: Shannon-Weiner Diversity Index (SWDI), HMI year 19, September 2000 and April 2001... 92
Figure 17: Percent abundance comprised of pollution sensitive taxa abundance (PSTA), HMI year 19 September 2000 and April 2001. 93
Figure 18: Percent abundance comprised of pollution indicative species (PITA), HMI year 19 September 2000 and April 2001. 94
Figure 19: Average Abundance of *Rangia cuneata* at HMI stations, year 19 September 2000.. 95
Figure 20: Average Abundance of *Rangia cuneata* at HMI stations, year 19 April 2001. 96
Figure 21: Average Abundance of *Macoma mitchelli* and *Macoma balthica* in April 2001 HMI years 17-19.. 97
Figure 22: Average Abundance of *Macoma balthica* at HMI stations, year 19 April 2001......... 97

Figure 23: Average Abundance of *Macoma mitchelli* at HMI stations, Year 19, April 2001….. 98
Figure 24: Average Abundance of *Macoma balthica* at HMI stations, Year 19 September 2000. 98
Figure 25: Average Abundance of *Macoma mitchelli* at HMI stations, Year 19 September 2000. 99
Figure 26: B-IBI scores for all HMI stations in Year 19, September 2000. 99
Figure 27: Cluster analysis based on Euclidean distance matrix of infaunal abundances of all HMI stations, year 19 September 2000. 100
Figure 28: Cluster analysis based on Euclidean distance matrix of infaunal abundances of all HMI stations, year 19 April 2001. 101
Figure 29: Metal correlations with sediment organic content, HMI, April 2001. 108
Figure 30: Comparison of sediment mercury and silver concentrations for fall sampling for the last five years of measurement. 109
Figure 31: Sediment cadmium concentrations and overall metal trends for fall sampling over the last five years of measurement. 110
Figure 32: Bioaccumulation factors for metals in clams around HMI. 111
Figure 33: Total concentrations of organic contaminants in sediments for the Fall sampling. 112
Figure 34: Bioconcentration factors for organic contaminants in clams and their relationship to sediment organic content. 113

LIST OF TABLES

Table 1: Results of MGS's analysis of three standard reference materials, showing the recovery of the certified metals of interest. 25
Table 2: Summary statistics for Years 17-19, for 32 sediment samples common to all cruises. 26
Table 3: Nutrient ratios found in the study area for Year 19 as compared to Redfield's ratio.... 32
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. 34
Table 5: Summary statistics for elements analyzed. [All concentrations are in ug/g unless otherwise noted]. 36
Table 6: Target Locations (latitudes and longitudes in degrees, decimal minutes), and 7-digit codes of stations used for Year 19 benthic community monitoring. 53
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. 58
Table 8: Water quality parameters measured *in situ* at all HMI stations on September 20 and 21, 2000. 60
Table 9: Water quality parameters measured *in situ* at all HMI stations on April 24, 2001. 61
Table 10: Average and total abundance (individuals per square meter) of each taxon found at HMI during late summer, September 2000 sampling, by substrate and station type. 64
Table 11: Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 19 Spring sampling (April 2001), by substrate and station type. 66
Table 12: Summary of metrics for each HMI benthic station surveyed during the Year 19 late summer sampling cruise, September 2000. Total Infaunal Abundance and Total Abundance, excluding Bryozoa, are individuals per square meter. 69
Table 13: Summary of metrics for each HMI benthic station surveyed during the Year 19 spring sampling cruise, April 2001. Total Infaunal Abundance and Total Abundance, excluding Bryozoa, are individuals per square meter. 70
Table 14: Average number of Individuals collected per square meter at each station during the HMI Year 19 late summer sampling, September 2000, stations MDE-1 to MDE-22. 71
Table 15: Average number of Individuals collected per square meter at each station during the HMI Year 19 late summer sampling, September 2000, stations MDE-24 to MDE-41. 73
Table 16: Average number of individuals collected per square meter at each station during the HMI Year 19 spring sampling cruise, April 2001, stations MDE-1 to MDE-22. 75
Table 17: Average number of individuals collected per square meter at each station during the HMI Year 19 spring sampling cruise, April 2001, stations MDE-24 to MDE-41. 77
Table 18: Friedman Analysis of Variance and Kendall Coefficient of Concordance for infaunal abundances for all 21 stations in Late Summer, September 2000. ANOVA Chi square (N= 34, df = 20) = 31.7. P < 0.047; Coefficient of Concordance = 0.046, Average Rank = 0.018. 86
Table 19: Friedman Analysis of Variance and Kendall Coefficient of Concordance for infaunal abundances for all 21 stations in April 2001, ANOVA Chi Square (N= 43, df = 20) = 28.0; Coeffeciant of Concordance = 0.033; Average Rank = 0.009; P < 0.107. 87

Table 20: Friedman Analysis of Variance and Kendall Coefficient of Concordance of fall's 10 most abundant species among silt/clay; Back River/Hawk Cove, Nearfield, Reference and Harbor stations. ANOVA Chi Sqr. (N = 30, df = 3) = 0.9823, P < 0.80551; Coefficient of Concordance = 0.01092, Average rank = -.0232 87

LIST OF ACRONYMS AND ABBREVIATIONS

AAS - Atomic Absorption Spectrometry

Ag - Silver

As - Arsenic

AVS - Acid Volatile Sulfide

BAF - Bioaccumulation Factor

BCF - Bioconcentration Factor

B-IBI - Benthic Index of Biotic Integrity

CBL - Chesapeake Biological Laboratory

Cd - Cadmium

CDF - Confined Disposal Facility

COC - Citizens' Oversight Committee

COMAR - Code of Maryland Regulations

CWA - Clean Water Act

Cr - Chromium

Cu - Copper

CWA - Clean Water Act

DCAD - Dredging Coordination and Assessment Division

ERL - Effects Range Low

ERM - Effects Range Median

Fe - Iron

GC - Gas Chromatography

GFAAS - Graphite Furnace Atomic Absorption Spectrometry

Hg - Mercury

HMI - Hart-Miller Island Confined Disposal Facility

ICAP - Inductively Coupled Argon Plasma

LBP - Lipid Bioaccumulation Potential

MCY -Million Cubic Yards

MDE - Maryland Department of the Environment

MDNR - Maryland Department of Natural Resources

MES - Maryland Environmental Service

MGD - Million Gallons Per Day

MGS - Maryland Geological Survey

Mn - Manganese

MPA - Maryland Port Administration

MS - Mass Spectrometry

NBS - National Bureau of Standards

NEPA - National Environmental Policy Act

Ni - Nickel

NIST - National Institute of Standards and Technology

NOAA - National Oceanic and Atmospheric Administration

NRC - National Research Council of Canada

OC - Organochlorine Pesticide

PAH - Polynuclear Aromatic Hydrocarbon

Pb - Lead

PCB - Polychlorinated Biphenyl

PI(s) - Principal Investigator(s)

PPB - Parts Per Billion

PPM - Parts Per Million

PPT - Parts Per Thousand

QA - Quality Assurance

QC - Quality Control

SOP - Standard Operating Procedure

SQC - Sediment Quality Criteria

SQS - Sediment Quality Standard

SRM - Standard Reference Material

TBP - Theoretical Bioaccumulation Potential

TDL - Target Detection Limit

TEF - Toxicity Equivalency Factor

TOC - Total Organic Carbon

USACE - U.S. Army Corps of Engineers

UMCES - University of Maryland Center for Environmental Science

USCS - Unified Soil Classification System

USEPA - U.S. Environmental Protection Agency

USFDA - U.S. Food and Drug Administration

WMA - Water Management Administration

WQC - Water Quality Criteria

WQS - Water Quality Standards

Zn - Zinc

CONVERSIONS[1]

WEIGHT:

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

1 lb = 16oz = 0.454Kg

LENGTH:

1m = 100cm = 3.28ft = 39.370in
1cm = 10mm = 0.394in
1mm = 1000μm = 0.0394in

1ft = 12in = 0.348m

CONCENTRATION:

1ppm = 1mg/L = 1mg/Kg = 1μg/g = 1mL/m^3
1g/cc = 1Kg/L = 8.345 lbs/gallon
1g/m^3 = 1mg/L = 6.243 x 10^{-5}lbs/ft^3

1 lb/gal = 7.481 lbs/ft^3 = 0.120g/cc = 119.826g/L = 119.826Kg/m^3
1oz/gal = 7.489Kg/m^3

VOLUME:

1L = 1000mL
1mL = 1000μL
1cc = $10^{-6}$$m^3$

1yd^3 = 27ft^3 = 764.55L = 0.764m^3
1acre-ft = 1233.482m^3
1 gallon = 3785cc
1ft^3 = 0.028m^3 = 28.317L

FLOW:

1m/s = 196.850ft/min = 3.281ft/s
1m^3/s = 35.7ft^3/s

1ft^3/s = 1699.011L/min = 28.317L/s
1ft^2/hr = 2.778 x $10^{-4}$$ft^2$/s = 2.581 x $10^{-5}$$m^2$/s
1ft/s = 0.031m/s
1yd^3/min = 0.45ft^3/s
1yd^3/s = 202.03gal/s = 764.55L/s

AREA:

1m^2 = 10.764ft^2
1hectare = 10000m^2 = 2.471acres

1ft^2 = 0.093m^2
1acre = 4046.856m^2 = 0.405 hectares

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

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

Hart-Miller Island Exterior Monitoring Program

September 2000 - September 2001

Prepared for

Maryland Port Administration
Maryland Department of Transportation

By

Matthew C. Rowe
Ecological Assessment Division
Technical and Regulatory Services Administration
Maryland Department of the Environment
2500 Broening Highway
Baltimore, MD 21224

ACKNOWLEDGMENTS

The Hart-Miller Island Exterior Monitoring Program would not have been possible without the cooperation of many dedicated organizations and individuals. The Maryland Port Administration (MPA) provided funding for the Year 19 monitoring effort. Mr. David Bibo and Mr. John Vasina of MPA were particularly helpful in administering funds and providing coordination with the Citizen's Oversight Committee. Dr. James Hill of the Maryland Geological Survey and Dr. Rob Mason of the Chesapeake Biological Laboratory provided expertise in the chemical analysis of sediments and clam tissues surrounding Hart-Miller Island. Miss Karen Eason, Miss Caroline Meyers, Mr. Chris Luckett and Mr. Matthew Rowe of the Maryland Department of the Environment (MDE) collaborated on the benthic community studies for Year 19.

The Maryland Department of the Environment would like to thank all the members of the HMI Exterior Monitoring Program's TRC and the HMI Citizens' Oversight Committee (COC) for their useful comments and suggestions throughout the project year. The Maryland Environmental Service (MES) also deserves thanks for providing information on dredged material inputs to HMI for Year 19.

Lastly, thanks to Mr. Robin Grove, Director of MDE's Technical and Regulatory Services Administration, for his guidance, suggestions and commitment to the Hart-Miller Island Exterior Monitoring Program.

INTRODUCTION

Site Background

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

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

The last inflow of dredged material into the South Cell of HMI was completed on October 12th, 1990. The process of converting the 300-acre South Cell into a wildlife refuge is currently underway. The North Cell is projected to reach full capacity by the year 2009, at which time it will also be converted into a wildlife refuge. The remnants of Hart and Miller Islands, which lie outside of the dike, serve as a state park and receive heavy recreational use throughout the summer months.

Environmental Monitoring

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

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

The Hart-Miller Island Exterior Monitoring Program has evolved over the years in response to both changes in technology and/or administrative changes adopted by one or more stakeholders, including the TRC, principal investigators (PIs) and COC. Analytical methods to detect trace metal burdens in sediments and benthic macroinvertebrates, for example, have been changed throughout the monitoring program as improved technologies with lower detection limits and greater sensitivity have been developed. Fish and crab population studies were discontinued after Year 5 due to the ineffectiveness of using the information as a compliance monitoring tool. Furthermore, beach erosion studies were discontinued after Year 13 in response to beach replenishment and stabilization with breakwaters. The Exterior Monitoring Program is designed to be flexible enough to incorporate such changes without compromising the overall credibility and scientific integrity of the project.

Prior to the start of the Year 19 monitoring, a majority decision of the TRC was enacted to reduce the sampling protocol from monitoring 2-3 times per year (Spring, Summer and Fall), depending on the project, to one time per year (Summer) for all projects[3]. Additionally, the number of stations sampled for each project was reduced. As a result, Year 19 was conducted under a less comprehensive sampling protocol compared to past HMI monitoring years.

[3] Technical Review Committee agenda items and minutes received from Dr. Richard Eskin, past Chairman of the Hart-Miller Island Exterior Monitoring Program.

Project Summaries

Four independent projects, which have been conducted since the inception of the Exterior Monitoring Program, were continued during Year 19 of monitoring. Summaries of the objectives and results for each project are included below.

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

Year 19 marks the third year of the Maryland Department of the Environment's (MDE) technical oversight of the Hart-Miller Island Exterior Monitoring Program. MDE is responsible for ensuring the scientific integrity of the Exterior Monitoring Program, which includes evaluating the sampling protocols and analytical methods used by the PIs for each project. MDE makes sure that each monitoring project undergoes a rigorous program of peer review, whereby professional scientists with background in estuarine research review and comment on the HMI monitoring reports prior to publication. A three-tiered review process is utilized by MDE, whereby draft HMI reports are reviewed by: (1) the Dredging Coordination and Assessment Division (DCAD), the Technical and Regulatory Services Administration (TARSA) and the Water Management Administration (WMA) of MDE; (2) the HMI Technical Review Committee (TRC), composed of professional researchers and environmental scientists from both federal and state agencies; and (3) the HMI Citizens' Oversight Committee (COC), which is comprised of concerned citizens representing the diverse interests of the public. From the comments and concerns submitted by each level in this three-tiered approach, MDE formulates a set of recommendations for each of the PIs and their respective projects. These recommendations guarantee quality control in the monitoring effort.

MDE is responsible for report compilation and editing. MDE/DCAD coordinates all field sampling among PIs for each project to ensure efficient, timely and representative sample collection. This includes evaluating sampling protocols and monitoring stations/locations to respond to findings of previous years or address new concerns and technologies.

Project I also includes data management and providing HMI data to the public through several media, including written reports and the Internet. The Dredging Coordination and Assessment Division within MDE has recently consolidated all of the raw HMI data from the Chesapeake Bay Program's VAX server onto their NT server at MDE's Baltimore Office. In the near future, this data will be made available to the public via EPA's STORET database.

Lastly, MDE is accountable for tracking the budgetary status for each project. This includes confirming receipt of all deliverables, including invoices, seasonal reports, cruise reports, and draft Data and Technical reports. The Technical and Engineering Coordination Section (TECS) within DCAD coordinates receipt of all deliverables from the PIs for each project. From the quarterly reports received by the PIs, MDE prepares comprehensive seasonal reports for the Maryland Port Administration (MPA) which document the budgetary status and progress for each project. MDE keeps detailed financial records for each project and compiles a complete economic portfolio for the MPA.

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

During Year 19, the objectives of Maryland Geological Survey's characterization of the sedimentary environment surrounding HMI were twofold. The first objective was to analyze surficial sediments for grain size distribution in order to determine how current sediment fractionation compares with both baseline and more recent sediment analyses. Only 7 of the 17 stations sampled during Year 19 had been monitored in previous years. There are some PI concerns as to the comparability of this year's data to past monitoring years as a result of this abbreviated sampling protocol. In general, however, the percent sand and clay:mud ratios for the seventeen sites were well within expected levels according to distributions seen in past monitoring years.

The second objective was to analyze current trace metal concentrations in surficial sediments surrounding HMI for comparison with concentrations found in prior monitoring years. Past technical reports for Project II (Hill 1991, 1992 and 1993), coupled with the results of an upper Bay hydrodynamic model (Wang 1993), established a link between dike operations and metal concentrations in sediments surrounding HMI. Periods of low discharge, where crust management and dewatering are the primary activities at HMI and which typically precede the Fall cruise, result in oxidation of the sediments within the facility. Oxidation of sulfide estuarine sediments results in the formation of sulfuric acid, leaching metals from the sediments and releasing them with effluent discharge from the HMI spillways. Consequently, Fall sampling cruises, starting with Year 8, have shown elevated metal concentrations relative to those found during the Spring cruise, where inflow of dredged material is the primary operation at HMI and sediments generally do not become oxidized.

During Year 19, the metal distribution for the November cruise was typical of those seen in previous cruises following periods of low discharge. Metal levels were elevated significantly above background levels (150% excess zinc from baseline concentrations). As in Year 14, these elevated levels of zinc persisted through the Spring sampling period. This may be an indication that zinc is accumulating in the sediments surrounding HMI.

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

The objectives of the Year 19 benthic monitoring studies at HMI were to: (1) monitor nearfield benthic populations for changes in distribution and species composition; (2) continue monitoring established reference stations to compare with nearfield stations; (3) continue monitoring stations which had been designated as having elevated concentrations of zinc; and, (4) provide the clam *Rangia cuneata* for chemical analysis of trace metals and organics.

As in past monitoring years, the major factor driving the abundance and dominance of species at a particular station was the substrate type (sand, silt, clay, shell, or a combination thereof), as well as other abiotic factors such as dissolved oxygen and seasonal salinity patterns. The most abundant species during Year 19 monitoring were the worms *Scolecolepides viridis* and *Tubificoides heterochaetus*, the crustaceans *C. polita* and *L. plumulosus*, the clam *Rangia* *cuneata* and insect larvae of the midge family *Chironomidae*. A total of 26 different species were collected this year compared to a range of 26 to 35 total species found in prior years.

Due to changes in the sampling protocol, this year's data were not as easy to compare with previous HMI monitoring data. In general, however, it appears that the Year 19 data are similar to that of previous monitoring years and no significant changes in the benthic community can be attributed to HMI.

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

Objectives for the Analytical Services portion of the Year 19 Exterior Monitoring Program were to characterize trace metals and organics [Polychlorinated Biphenyls (PCBs) and Polycyclic Aromatic Hydrocarbons (PAHs)] concentrations in sediments and clams. Tissue data for the clam *Rangia cuneata* were collected at HMI and compared to data collected at Poplar Island for the clam *Mya arenaria*. Sediment trace metals and organics concentrations were compared to data from the Baltimore Harbor/Back River sediment study and to Bay-wide averages.

On the whole, comparison of tissue metal results showed no strong indication of higher metal concentrations at HMI. The only significant exception was nickel (Ni), which was clearly elevated at HMI in relation to clams from Poplar Island. To a lesser extent, silver (Ag) and cadmium (Cd) were also elevated. Overall, the differences observed between the two sites could be attributable to interspecies differences alone and do not necessarily indicate elevated metal burdens among HMI clams.

Comparisons were also made between the Year 19 data and data collected from HMI during Year 10 (1990-1991) and Year 13 (1993-1994). Metal concentrations observed during the current monitoring year are either comparable to or below levels detected in these two years. It was concluded that no elevation of metal concentrations in clams have occurred over the past six years.

Concentrations of organic contaminants detected in *Rangia* during Year 19 were compared to concentrations found in *Mya arenaria* at Poplar Island. Organics levels in *Rangia* were tenfold higher than those found in *Mya*. This is expected due to the higher concentrations of contaminants found in northern Chesapeake Bay relative to the mid-Bay region around Poplar Island. Furthermore, the concentrations of PCBs and PAHs are low overall and below the detection limits of previous HMI studies.

For sediment analyses, values observed during Year 19 were compared to those from the "Spatial Mapping of Sedimentary Contaminants in the Baltimore Harbor/Patapsco River/Back River System" (Baker et al. 1997). Concentrations of PAHs at HMI are not enriched above regional background levels. For some of the metals, including cadmium (Cd), lead (Pb), copper (Cu), zinc (Zn) and mercury (Hg), concentrations in the sediments of Back River station #75 are at least twice that of HMI average values. Thus, Back River may be a source of contaminants to sediments in the vicinity of HMI[4]. Compared to Chesapeake Bay average values for metals in sediments, HMI concentrations are not significantly different from sites uninfluenced by HMI. Further studies of Back River, and possibly Baltimore Harbor, as a source of contamination to sediments in the vicinity of HMI are suggested.

[4] An independent report by Universe Technologies, Inc. entitled "*Comprehensive Zinc Study for Hart-Miller Island Confined Disposal Site, Maryland*" and published in September 1999, addresses the issue of Back River, among other sites, as a possible source of contamination to sediments in the vicinity of HMI.

CHAPTER 2: SEDIMENTARY ENVIRONMENT (PROJECT II)

YEAR 19 TECHNICAL REPORT (September 2000 - September 2001)

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

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

File Report

submitted to

Maryland Department of the Environment
2500 Broening Highway
Baltimore, MD 21224

ACKNOWLEDGMENTS

For their assistance during the two Year 19 sampling cruises, we would like to thank the Maryland Department of Natural Resources for providing the research vessel *Kerhin*, Captain Rick Younger and First Mate Jake Hollinger, respectively, for piloting the vessel and collecting samples. We would also like to thank our colleagues at the Maryland Geological Survey, Liana Dunne, Dan Sailsbury, Bill Panageotou, Dale Shelton, Geoffrey Wikel, and Darlene Wells, for their assistance in the field and lab. Finally, we extend our thanks to Melissa Slatnick and Jennifer Harlan at MES, who provided us with much of the information related to site operation.

EXECUTIVE SUMMARY

The Coastal and Estuarine Geology Program of the Maryland Geological Survey (MGS) has been involved in monitoring the physical and chemical behavior of near-surface sediments around the Hart-Miller Island Dredged Material Containment Facility (HMI) from the initial planning stages of construction of the facility through to the present. As part of this year's exterior monitoring program, MGS collected bottom sediment samples from 40 sites on September 12 & 15, 2000, and again on April 23, 2001. Survey geologists then analyzed various physical and chemical properties of the samples: (1) grain size composition (relative proportions of sand, silt, and clay), and (2) total elemental concentrations of iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), cadmium (Cd), lead (Pb), phosphorous (P), carbon (C), nitrogen (N), and sulfur (S).

The grain size distribution of exterior bottom sediments, based on Year 19 sampling, shows slight variations in pattern from one cruise to the next. The reasons for the variations are difficult to decipher, due to the complexity of the depositional environmental and the multiple sources of material to the area. However, in general, sediment distribution is consistent with the findings of previous monitoring years, dating back to 1988 (the second year after the release of effluent from HMI began).

Discharge from HMI apparently leaves no 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. Nonetheless, there may 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. Nutrient levels found in samples collected from the mouth of Baltimore Harbor are not appreciably different from those found in sediments adjacent to HMI.

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

- Most of the samples (50 of 80) are below the detection level for Cd (0.10);
- Cr, Cu, Ni, Pb and Zn are found with concentrations that exceed the Effects Range Low (ERL) values; and
- Zn and Ni exceed the Effects Range Medium (ERM) values.

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

Within the context of the life of the facility, the Fall 2000 cruise shows slightly higher levels of Zn and Pb compared to Year 18 levels, which were the lowest since the onset of the elevated levels in 1989. The Spring 2001 cruise levels are lower than the Fall 2000 sampling period, more similar to the Year 18 levels. Levels of metals in the sediment reflect the discharge rates from HMI; generally, low rates of discharge have higher impact to the sediment load of metals. During this monitoring period there were no significant contiguous periods during which discharge rates were below 10 MGD; this is due to relatively high inflow rates into the dike, from ten dredging operations. Consequently, oxidation of the sediment was minimized; the most acidic daily discharge records showed no periods of free mineral acidity. Without the free mineral acidity, leaching is minimized and acid formation rates are low. This accounts for the relatively low observed levels of Zn and Pb in the exterior sediments.

Based on historical data, and the data from Years 18 and 19, 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. The pattern of higher levels of metals with lower discharge rates is consistent with previous years' studies. Currently, the dike is actively accepting material, but as the dike reaches its capacity and the volume of effluent declines, dewatering of the contained material will lead to higher metal levels in the effluent. Exposure of dredged material to the air is likely to result in the mobilization of metals associated with those sediments, an effect analogous to acid mine drainage. Metals released in the effluent, particularly at low discharge rates, are deposited on the surrounding Bay floor and are increasing the long-term sediment load in the Bay. Although these levels are currently much lower than any biological effects threshold, continued monitoring is needed (1) to detect if the levels increase to a point where action is required, (2) to document the effects that operations have on the exterior environment (for future project design), and (3) to assess the effectiveness of any amelioration protocol implemented by 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 that, to better assess the potential influence of Baltimore Harbor on the HMI exterior sediments, the additional sampling sites be maintained, at least temporarily.

INTRODUCTION

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

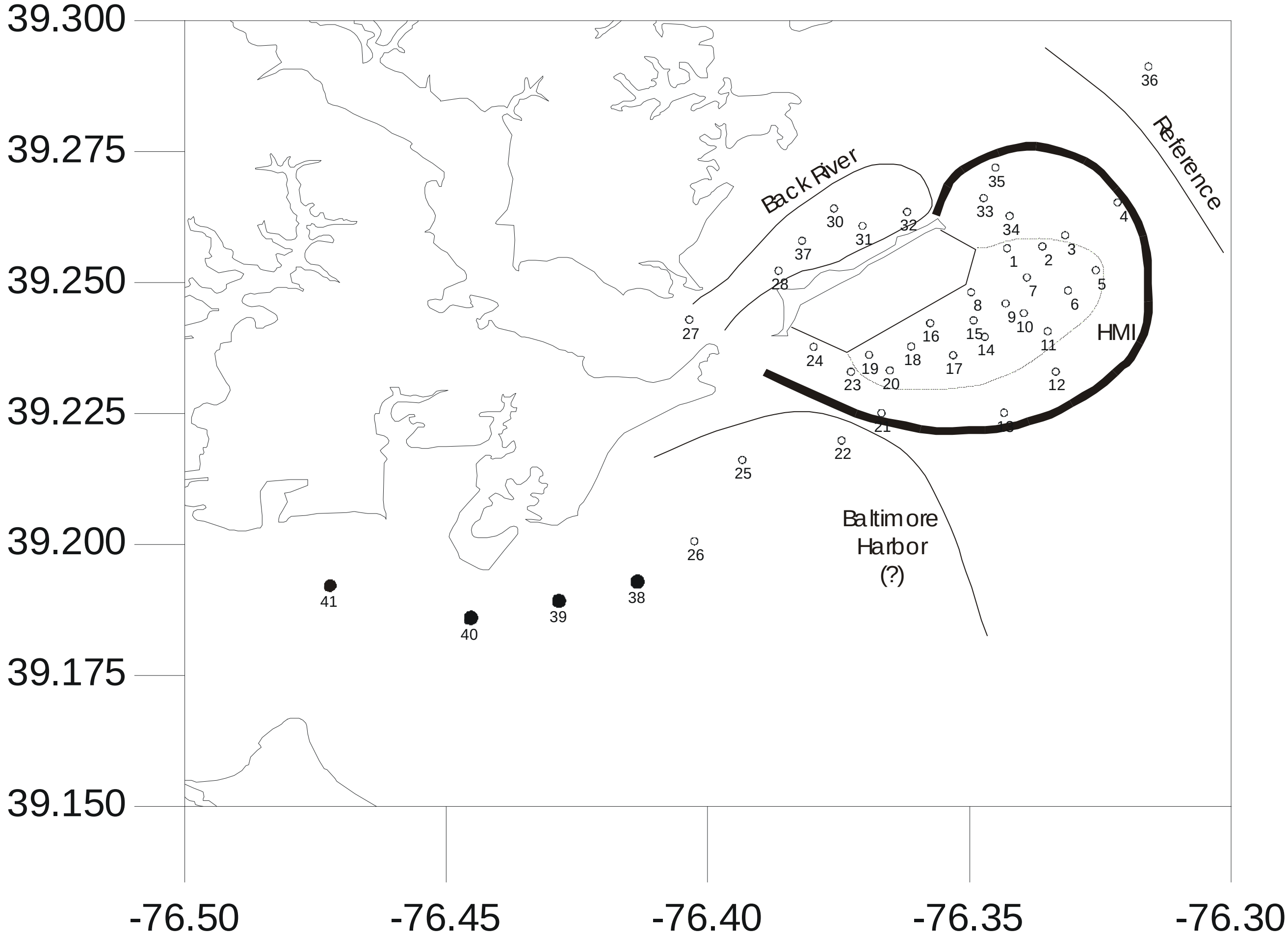


Figure 1: Sampling locations for Year 19. Contours show zones of influence found in previous studies. Solid circles show location of sites added in Year 18.

Previous Work

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

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

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

For a number of years after HMI began operating, no major changes were observed in the surrounding sedimentary environment. Then, in April 1989, more than two years after the first release of effluent from the facility, anomalously high Zn values were detected in samples collected near spillway #1 (Hennessee et al., 1990b). 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 of periodic 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 19 in the vicinity of the dike.

Figure 1, in addition to showing the sampling sites for Year 19, shows zones that indicate influence of sources of material to the exterior sedimentary environment based on a elevated metal levels from previous years studies. These influences are noted in the figure as:

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

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

3. *HMI* - The area of influence from the dike is divided into two zones, 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,

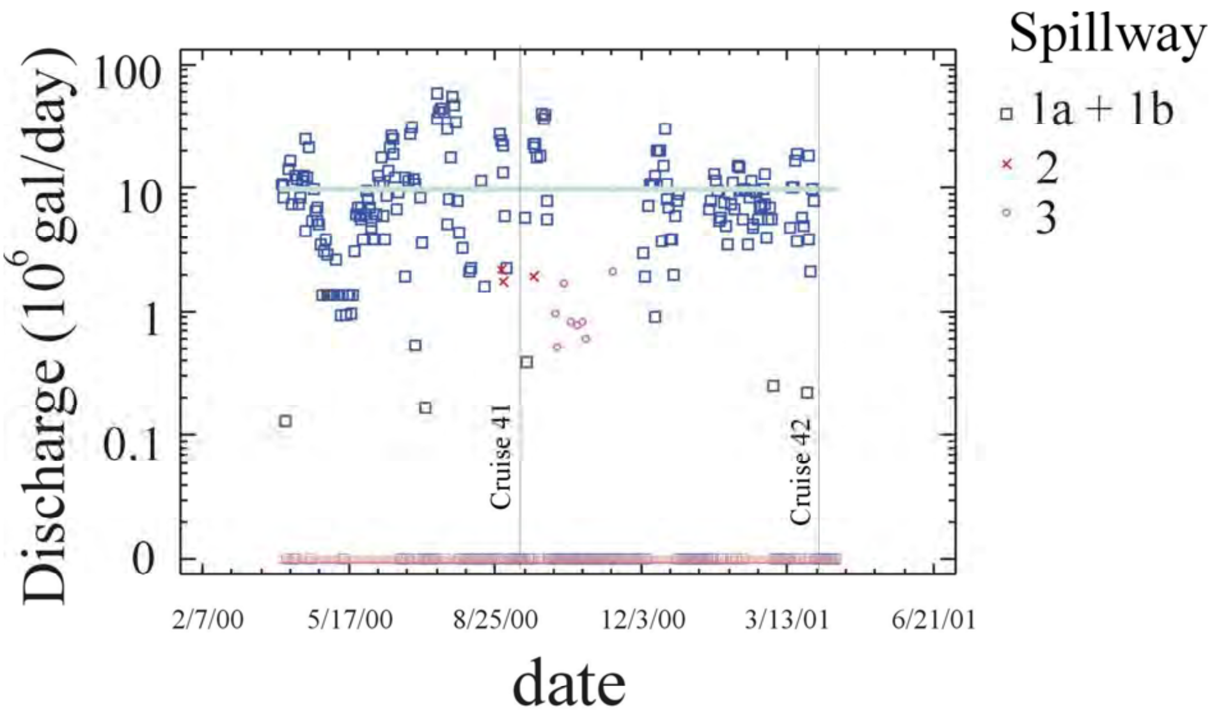
4. *Baltimore Harbor* - There are a handful of sites in the southern portion of the area studied in the exterior monitoring program which have consistently shown a gradient suggesting that there is a source of metals south of HMI in the direction of Baltimore Harbor. The pattern frequently seen in the monitoring studies is base level values near HMI which increase towards Baltimore Harbor. Baltimore Harbor, as the source of the material, was further implicated by the results of a hydrodynamic model analyses performed in conjunction with the 1997 sediment characterization of Baltimore Harbor and Back River (Baker et al., 1998). This analysis showed the potential of movement of material from the mouth of the harbor extending northward toward HMI. Four sites were added in the Year 18, and maintained in Year 19, to assess the role of Baltimore Harbor to the HMI external sedimentary environment. These sites are indicated by the solid circles in Figure 1.

Dike Operations

Certain activities associated with the operation of HMI have a direct impact on the exterior sedimentary environment. Local Bay floor sediments appear to be sensitive, both physically and geochemically, to the release of effluent from the dike. Events or operational decisions that affect the quality or quantity of effluent discharged from the dike account for some of the changes in exterior sediment properties observed over time. For this reason, dike operations during the periods preceding each of the Year 19 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 (Jennifer Harlan, personal communication).

This monitoring year was a period of high usage of the facility. Prior to the fall sampling cruise a total of approximately 1.2 million cubic yards were put into HMI from six separate dredging operations. The period before the spring sampling was similar, with a total of approximately 1.7 million cubic yards from four operations. This relatively high level of usage produced relatively high outflow (>10Mgal/day) at the spillways and preventing extended periods of low discharge. The conditions that were dominant at the facility during the study period tend to stabilize the sediment by reducing the potential for 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, which produce low pH discharge and optimal leeching conditions. During this monitoring year, acid formation and the accompanying leaching would not be expected to occur to any major extent. This expected result is supported by the pH of the water discharged from the facility. The discharge water stayed at values near or greater than neutral see (Figure 3). Therefore based on previous monitoring years, the external sedimentary environment would not be *greatly* affected by the dike operations during this period.

This is additionally supported by the fact that the effluent was in compliance with the discharge permit for the entire monitoring period.



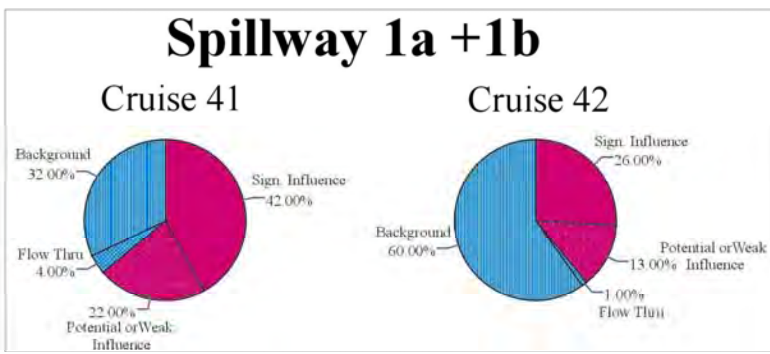


Figure 2: Total discharge from the spillways at HMI. The cruise dates are denoted by vertical lines, and the 10Mgal/day discharge shown as a horizontal line. The Pie Diagrams show the percentage of days prior to each period where the exterior would be influenced by discharge from HMI.

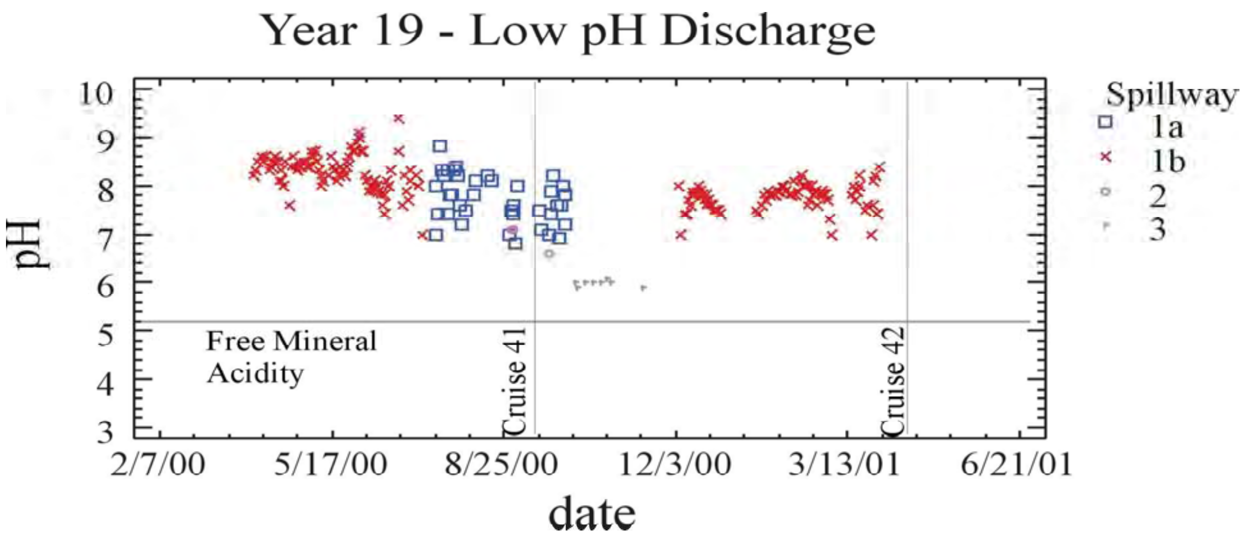


Figure 3: Low pH measured for daily discharge from HMI. Discharge only occurred from North Cell spillways during this monitoring year. Vertical lines denote sampling cruise dates. pH readings below the horizontal line indicates free mineral acidity.

However, it is expected that dike operations would have some effect on the exterior sedimentary environment. This is due to the discharge rate from the facility having a significant percent of time with low flow periods that should have some influence on the exterior sediments. Discharge rates from HMI can be grouped into four categories:

1. No discharge - here the exterior sediments are solely deposited from suspended loads from the Susquehanna River, and produce ***background*** loading to the sediment;

2. Low discharge rates (<10 Mgal/day) - this condition produces the maximum loading of excess metals from the dike and having ***significant influence*** to the exterior sediment

3. High discharge rates (>40 Mgal/day) - here the discharge rates are so fast that oxidation can't occur and sediment that is input to the dike flow through and add to the background level loading to the sediment; and,

4. Intermediate discharge rates (10 - 40 Mgal/day) - oxidation contributes some but to a lesser extent than at low discharge rates. Because of the lower time of contact with the atmosphere there is only a ***potential or weak influence***.

These four conditions are applied to the flow from Spillway 1 (1a+1b), and shown in the Pie Diagrams for Cruise 41 and 42 (see Figure 2). Cruise 41 (Fall 2000) had 64% of the time potentially influenced by the dike output while, Cruise 42 (Spring 2001) had only 39% of the time influenced by the dike. Therefore it is expected that the Cruise 41 will be more strongly affected by HMI than Cruise 42.

OBJECTIVES

As in the past, the main objectives of the Year 19 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. Sites that link the HMI study area to the Harbor were also monitored to provide an assessment of the influence of Baltimore Harbor to the HMI region.

METHODS AND MATERIALS

Field Methods

The information presented in this report is based on observations and analyses of surficial sediment samples collected around HMI during two cruises aboard the *R/V Kerhin*. The first cruise (Cruise 41) took place on September 12 & 15, 2000, and the second (Cruise 42), on April 23, 2001.

Sampling sites (Figure 1) were located in the field by means of a differential global positioning system, a Leica Model MX412B DGPS with built-in beacon receiver. The target coordinates (latitude and longitude -- North American Datum of 1983) of Year 19 sample locations are reported in the companion Year 19 Data Report. Actual geographic coordinates of sample locations were recorded only for the April 2001 cruise. For the September 2000 cruise, the captain estimated that the vessel was within 5-10 m of the target sampling locations, except at station MDE-23, where the vessel was about 15 m from the target. Where replicates were collected, the captain repositioned the vessel between samples to counteract drifting off station during sample retrieval. At most sites, the captain recorded water depth.

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

At 36 stations, a single grab sample was collected, described lithologically, and split. Triplicate grab samples were collected at the remaining four stations (MDE-2, MDE-7, MDE-9 and MDE-31) and, likewise, described and split. MGS analyzed one split for grain size composition, a suite of trace metals, and carbon/sulfur/nitrogen. The Chesapeake Biological Laboratory (CBL) analyzed the second split for a different suite of trace metals. Field descriptions of samples are included as appendices in the Year 19 Data Report.

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

Laboratory Procedures

Textural Analyses

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

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

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

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

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

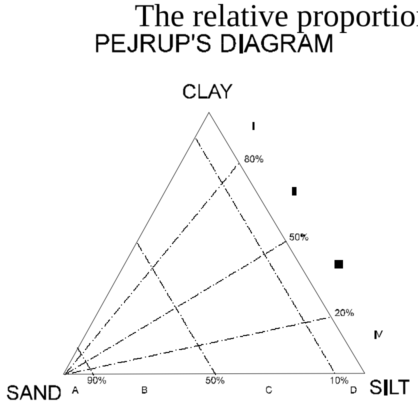


Figure 4: Pejrup's (1988) classification of sediment

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 **ej**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^{o}C);

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

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

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

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

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

7. Samples were irradiated using programmed steps appropriate for the number of samples in the carousel. These steps were optimized based on pressure and percent power. The samples were brought to a temperature of 175^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 MGS's analysis of three standard reference materials, showing the recovery of the certified metals of interest.

Percent Recovery *(n=10)*			
Metal	**NIST 1646**	**Buffalo River**	**PACS**
Fe	96±4	87±2	85±3
Mn	85±6	93±4	79±5
Zn	84±1	94±1	92±2
Cu	100±5	99±4	105±2
Cr	92±4	92±5	90±4
Ni	86±9	94±9	93±6
Cd	Below Detection	*94±1*	*Below Detection*
Pb	91±3	92±4	88±8

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 on 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, Year 19 results are discussed with respect to the previous one or two years.

Thirty-two of the 40 sampling sites visited during Year 19 yielded results that can be compared to those acquired since Year 17. The grain size composition (proportions of sand, silt, and clay) of the 32 sediment samples collected during Years 17-19 is depicted as Pejrup's diagrams in Figures 5 and 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 17-19, for 32 sediment samples common to all cruises.

Variable	Sept 1998 Cruise 37	Apr 1999 Cruise 38	Sept 1999 Cruise 39	Apr 2000 Cruise 40	Sept 2000 Cruise 41	Apr 2001 Cruise 42
Sand content (%)						
Mean	23.82	21.09	21.47	23.99	23.35	23.23
Median	3.59	5.52	3.68	5.42	5.05	3.38
Minimum	0.77	0.71	0.59	1.27	0.77	0.68
Maximum	96.94	97.73	91.25	100.00	97.81	96.36
Range	96.17	97.02	90.66	98.73	97.04	95.68
Clay:mud ratio						
Mean	0.56	0.54	0.57	0.52	0.56	0.55
Median	0.57	0.56	0.57	0.53	0.56	0.57
Minimum	0.48	0.36	0.47	0.25	0.48	0.17
Maximum	0.63	0.66	0.68	0.64	0.66	0.63
Range	0.15	0.30	0.21	0.39	0.18	0.46
Number of samples	32	32	32	32	32	32

The ternary diagrams show similar distributions of sediment type. Samples range widely in composition, from very sandy (>90% sand) to very muddy (<10% sand). Muddy sediments predominate; at least two-thirds of the samples contain less than 10% sand. Points fall fairly close to the line that extends from the sand apex and bisects the opposite side of the triangle (clay:mud = 0.50). In general, points lie above the 0.50 line, indicating that the fine (muddy) fraction of the sediments tends to be somewhat richer in clay than in silt.

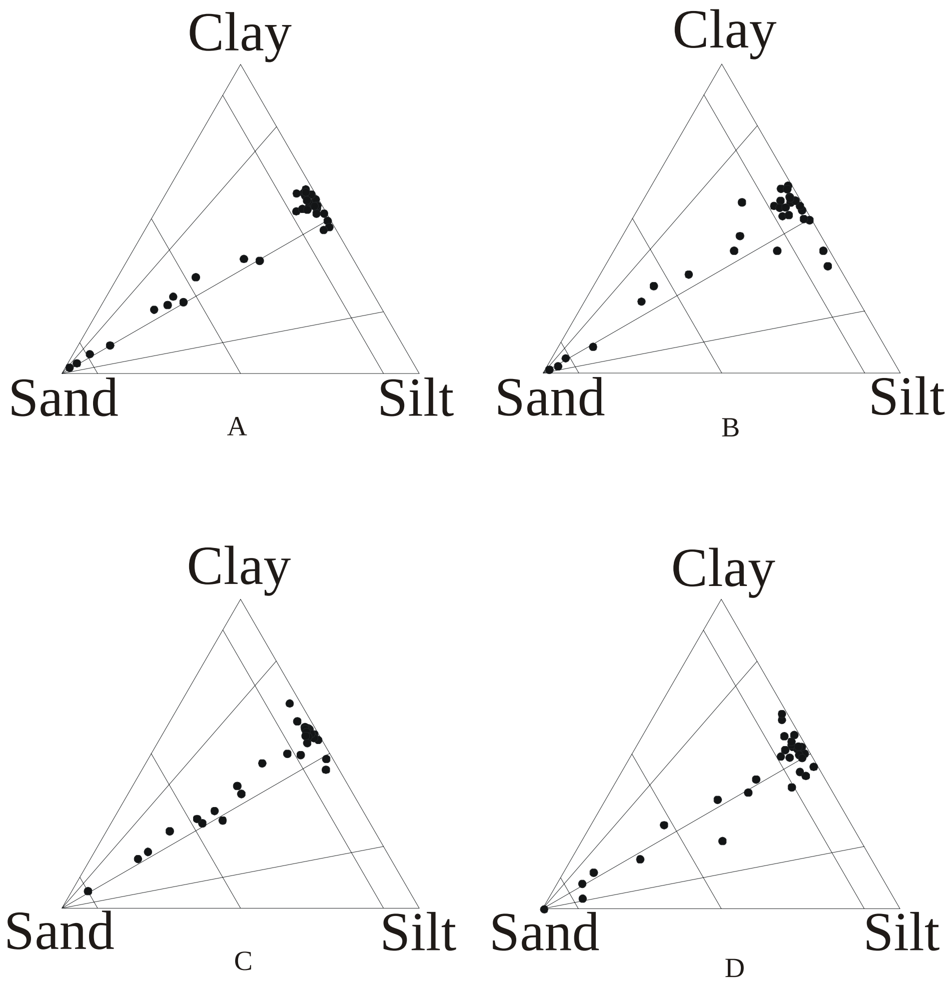
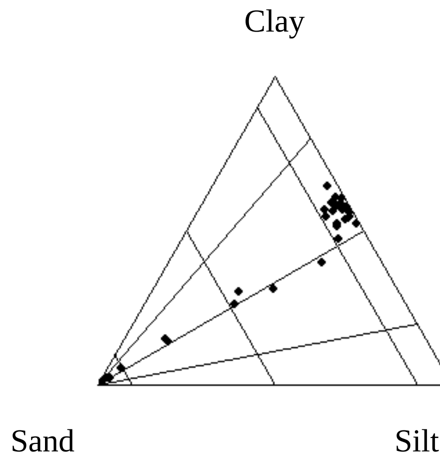
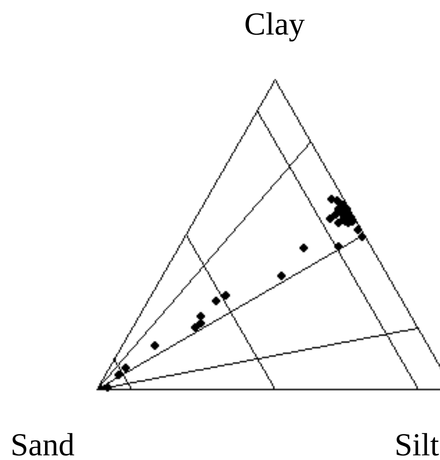


Figure 5: Ternary diagrams showing the grain size composition of sediment samples collected in Years 17 and 18 from the 32 sampling sites common to all six cruises: (a) September 1998, (b) April 1999, (c) September 1999, and (d) April 2000.



(e) September 2000
(Cruise 41)



(f) April 2001
(Cruise 42)

Figure 6: **Ternary diagrams showing the grain size composition of sediment samples collected in Year 19 from the 32 sampling sites common to Years 17-19: (e) September 2000, and (f) April 2001.**

Based on the summary statistics (Table 2), average grain size composition, reported as % sand and as clay:mud ratios, has varied little over the six sampling periods. Except for the clay:mud ratio range, no clear seasonal trends are evident. Clay:mud ratios tend to vary over a broader range in the spring (April) than they do in the fall (September). As reflected in the clay:mud minima, in the spring, certain localities are more turbulent, and consequently, 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 18-19, 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 6, three contour levels represent 10%, 50%, and 90% sand, coinciding with the parallel lines in Pejrup's diagram. Generally, sand content diminishes with distance from HMI. Scattered around the perimeter of the dike, the sandiest sediments (>50% sand) are confined to relatively shallow (<15 ft) waters (Figures 7 and 8). Broadest north and west of the facility, the shoals are the erosional remnants of a larger neck of land. The once continuous landmass has been reduced to a series of islands, including Hart and Miller, extending from the peninsula that forms the south shore of Back River. However, not all shallow water samples are sandy. In particular, several of the shallow water samples from Hawk Cove (e.g., MDE-30 and MDE-32) contain less than 10% sand. Sand distribution maps for Years 18 and 19 are similar in appearance. In fact, the distribution of sand around HMI has remained largely unchanged since November 1988, two years after the first release of effluent from the dike.

Compared to the distribution of sand, the distribution of clay:mud ratios has tended to be more variable over time. Year 19 was no exception (Fig. 9). The fine (mud) fraction of the sediments around HMI is generally richer in clay than in silt. In other words, the clay:mud ratio usually exceeds 0.50, as shown in the ternary diagrams above. In September 2000, the fine fraction of only two samples was silt-rich (clay:mud ratio < 0.50) -- MDE-27 at the mouth of Back River and MDE-16 in the vicinity of spillway #4. Clay:mud ratios were highest (> 0.60) in a fairly extensive lens of sediments deposited slightly offshore of the southeastern wall of the dike and in several small, scattered pockets around the dike – MDE-30 in Hawk Cove and MDE 33 in the vicinity of spillway #2. Two other pockets of clay-rich sediments occurred near or within the mouth of the Patapsco River (MDE-26 and MDE-41).

In April 2001, clay dominated the fine fraction at all locations except MDE-33. Here the sand fraction was so great (96%), that analysis of the fine fraction was problematic. Sediments with the highest clay:mud ratios occurred in the same general areas as in September 2000, but the areas themselves differed in extent. Along the southeastern wall of the dike, the clay-rich lens of September 2000 was reduced to two smaller pockets; in Hawk Cove, the area increased somewhat, to include two stations (MDE-30 and MDE-31). At a distance from HMI, only MDE-41, at the mouth of the Patapsco River, retained its high (> 0.60) clay:mud ratio.

Understanding the reasons for these variations in grain size is difficult. They involve the amount, quality, and timing of discharge from particular spillways and the interaction of the

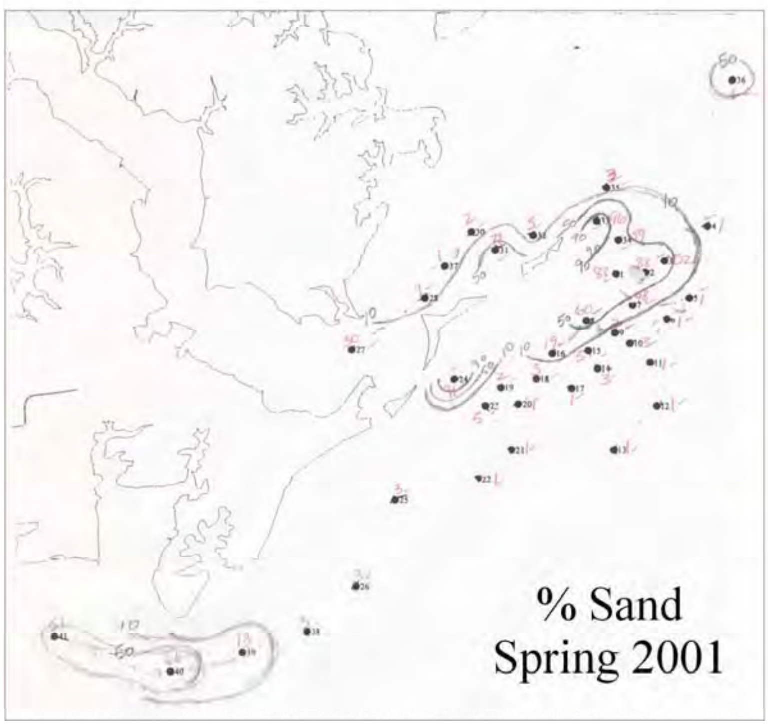


Figure 7: Sand distribution for Year 19 Monitoring. Contour intervals are 10%, 50%, and 90% sand.

Figure 8: Average water depths, based on Year 17 Monitoring. Contour interval = 5 ft.

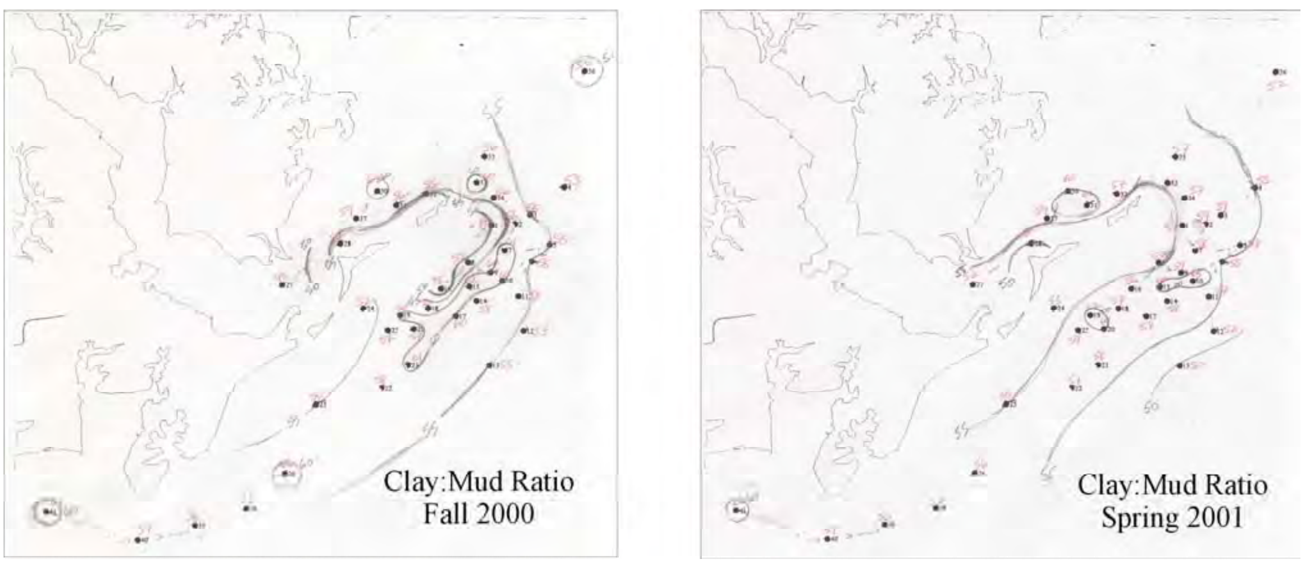


Figure 9: Clay:mud ratios for Year 19 Monitoring. Contour interval = 0.10, plus 0.55.

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. The grain size distribution of Year 19 samples is largely consistent with the findings of the past two monitoring years.

Elemental Analyses

<u>Nutrients: Carbon, Nitrogen, and Phosphorus</u>

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 3 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 there are two sources of carbon 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

Table 3: Nutrient ratios found in the study area for Year 19 as compared to Redfield's ratio.

Constituents	N/C	P/C	P/N
Redfield's Ratio	0.176	0.024	0.138
HMI (this study)	0.073	0.029	0.390
Standard Deviation	0.013	0.009	0.066
Relative Standard Deviation (RSD)	18%	31%	17%

RSD. Discharge from HMI does not leave a C, N or P signature in the exterior sediments. 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 18 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.

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

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

The strong correlation between the metals and the physical size fractions makes it possible to predict metal levels at a given site if the grain size composition is known. A metal concentration can be predicted by substituting the least squares coefficients from Table 4 for the constants in equation 2, and using the measured grain size at the site of interest. These predicted values can then be used to determine variations from the regional norm due to deposition; to exposure of older, more metal-depleted sediments; or to loadings from anthropogenic or other enriched sources.

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

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

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

<u>General Results</u>

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 (50 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 of termed preponderance of evidence. The method does not allow for unique basin conditions and does not take into account grain size induced variability in metal concentrations in the sediment. The values are useful as a guide, but are limited in applicability due to regional difference. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, 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].

Summary Statistics	Cd	Cr	Cu	Fe(%)	Mn	Ni	Pb	Zn
Count	30	80	80	80	80	80	80	80
Average	0.66	82.4	40.2	3.40	2913	70.1	49.5	281
Standard deviation	0.64	35.1	18.1	1.43	1805	33.8	22.6	125
Minimum	Bdl	4.59	2.16	0.29	348	5.99	3.88	24.1
Maximum	3.93	193	89.4	5.89	8955	156	98.4	584
Range	3.93	188	87.3	5.60	8607	151	94.5	559
ERL	1.3	81	34	N/A	N/A	20.9	46.7	150
# of Sample >ERL	(0)	(52)	(58)	N/A	N/A	(72)	(49)	(66)
ERM	9.5	370	270	N/A	N/A	51.6		410
# of Sample >ERM	(0)	(0)	(0)	N/A	N/A	(57)	(0)	(11)
	C(%)			N(%)		P		
Count	80			80		80		
Average	3.00			0.211		805		
Standard deviation	1.14			0.078		295		
Minimum	0.184			0.023		114		
Maximum	5.22			0.326		1262		
Range	5.04			0.303		1148		

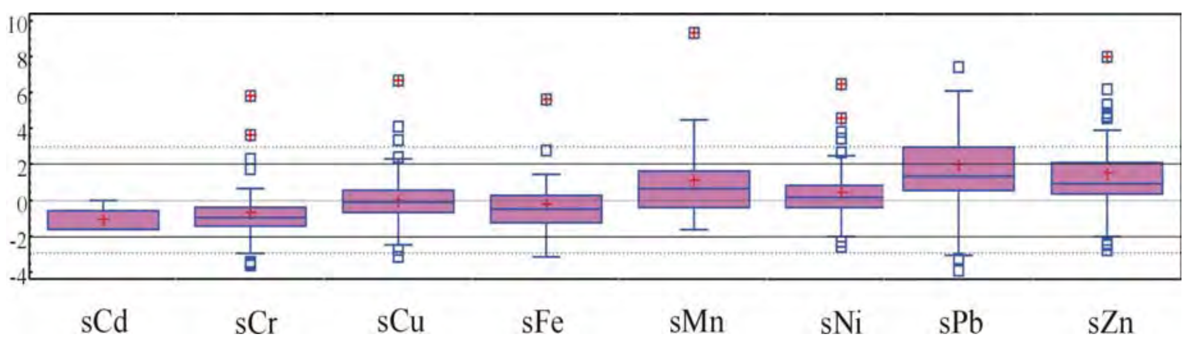


Figure 10: A box and whisker diagram showing the range of the data for both the fall and spring cruise.

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.

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 2000 and Spring 2001: 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 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 in Figures 11 and 12: Back River, Baltimore Harbor, and HMI.

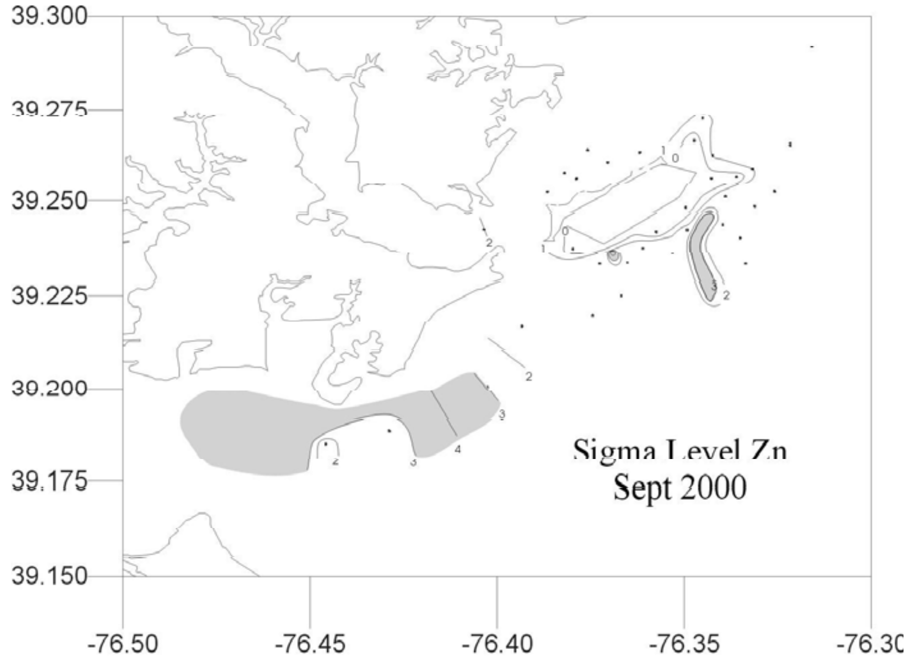
Back River - The Back River influence is strongly seen for Pb, but Zn levels in the area are within expected background levels. Generally the influence is comparable between the two sampling periods with the Fall period being slightly more elevated than the Spring. This most likely reflects the seasonally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

Baltimore Harbor - Elevated levels of metals extend into the area south of HMI, but do not reach the area adjacent to the island. The levels of Zn are comparable for the two sampling periods, reaching highs of ~3 sigma. The spatial extent of the Zn loadings is larger in the Fall than in the Spring, where it seems to be more localized to the Harbor. On the other hand, the spatial extent of Pb is comparable for the two sampling periods, however there is a marked difference in the Pb levels. Pb is higher in the Fall cruise than the Spring cruise.

HMI - For both cruises there is a signature from the facility, in both Pb and Zn. The spatial extent and magnitude of the metal enrichment reflect the pattern as seen during previous cruises. The pattern is based on discharge from the dike, low flow rates (<10 Mgal/day) have the greatest impact to the sedimentary environment. The Spring cruise samples showed levels within the expected baseline for the region. The Fall cruise, on the other hand had samples which were elevated above background levels, with a larger area of influence. This is due to the discharge from HMI. Prior to the Fall Cruise the discharge records showed a larger portion of time with lower discharges, as compared to the Spring cruise (see the section on *Dike Operations*).

Although the metals levels are enriched in the Fall cruise, they are well below any level of concern (Figure 13). This figure shows the maximum % excess Zn found within the zone historically influenced by HMI for each of the monitoring cruises, with criteria indicating severity of the metals levels. The last two points represent the maxima found during the cruises for Year 19. The Fall cruise is comparable with Year 18 Spring cruise and the Year 19 Spring cruise is slightly lower. The data fall within the Transitional area, that is they are within three sigma of the background, but they occur more frequently than is statistically expected. These points are well below an expected level of adverse biological impact.

The low metal levels in the exterior sediments during this monitoring year is because there was no significant contiguous periods during which discharge rates were below 10 MGD; the most acidic daily discharge records did not show any periods of free mineral acidity (see Figures 2 and 3). Without the free mineral acidity, leaching is minimized and acid formation rates are low.



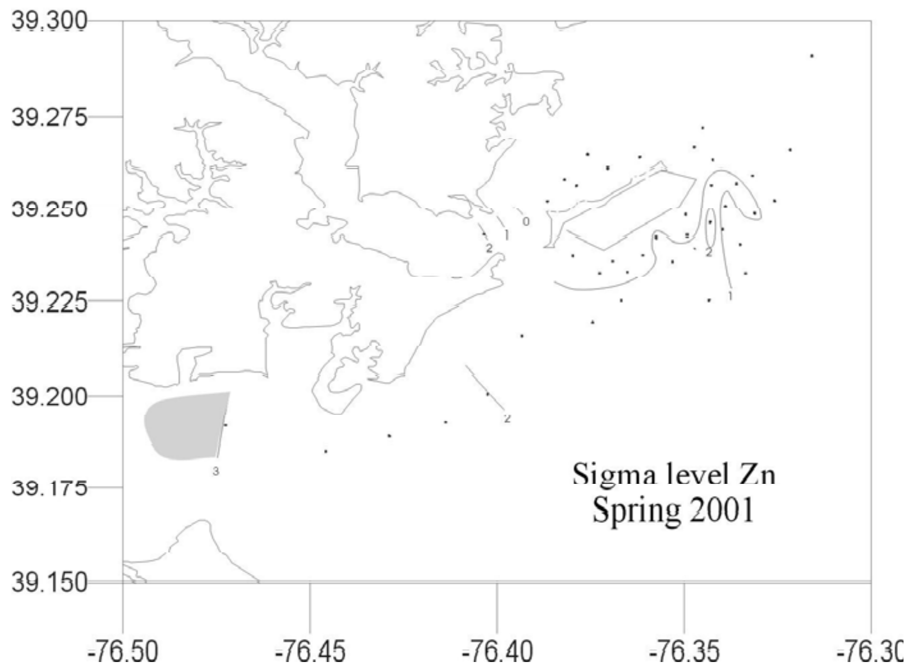


Figure 11: Distribution of Pb in the study area for the Fall and Spring sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional, >3 = significantly enriched (shaded in figures).

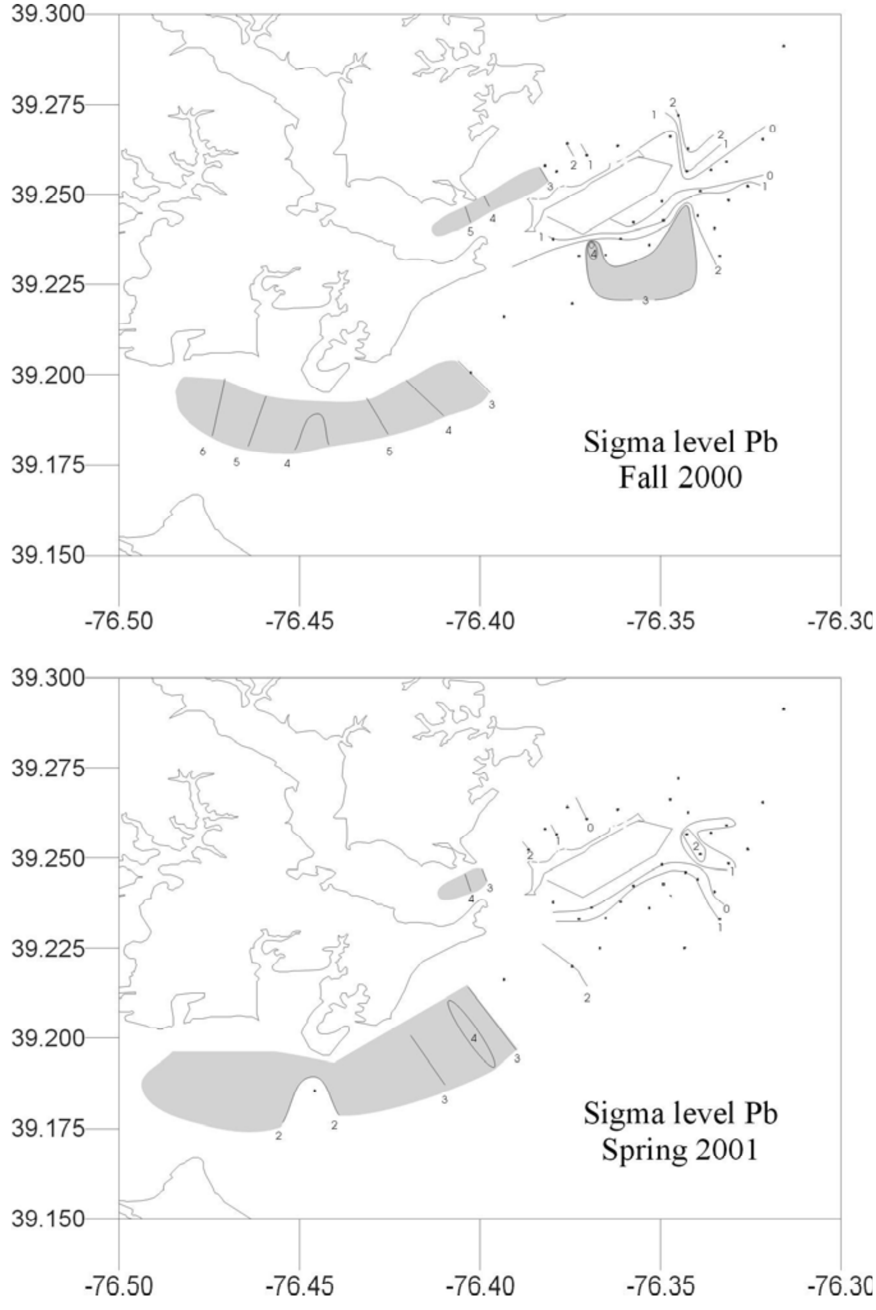


Figure 12: Distribution of Pb in the study area for the Fall and Spring sampling cruises. Units are in multiples of standard deviations - Sigma levels: 0 = baseline, +/- 2 = baseline, 2-3 = transitional, >3 = significantly enriched (shaded in figures).

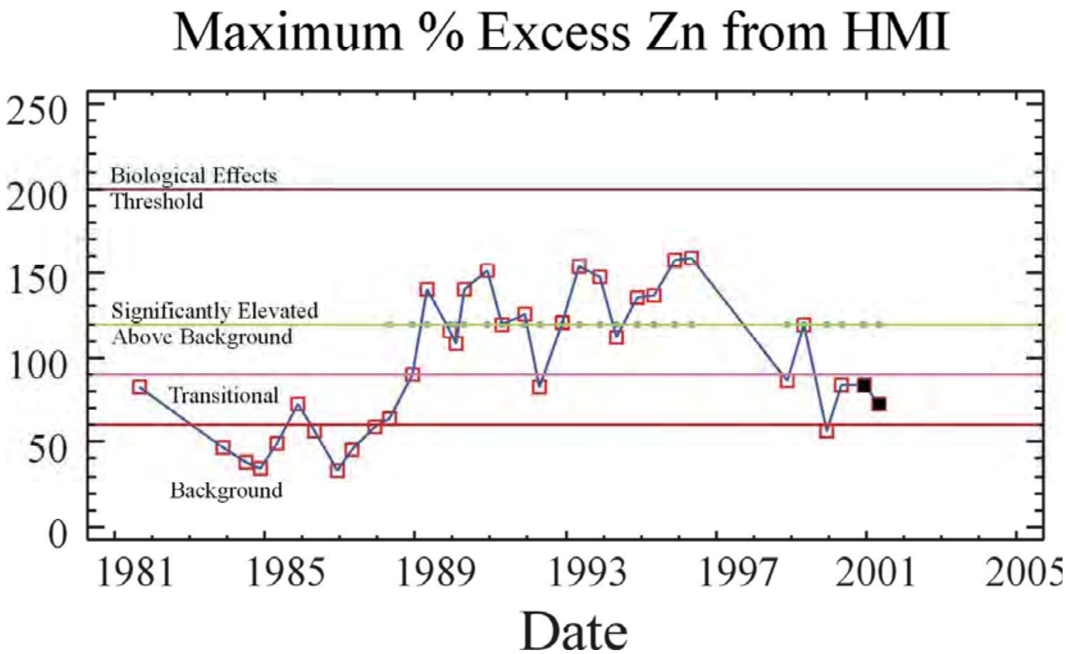


Figure 13: Record of the maximum % Excess Zn for all of the cruises MGS analyzed the sediments.

CONCLUSIONS AND RECOMMENDATIONS

The grain size distribution of Year 19 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 which extend into Baltimore Harbor do not show any appreciable difference than the sediments adjacent to HMI.

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

1. Most of the samples (50 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 of termed preponderance of evidence. The method does not allow for unique basin conditions and does not take into account grain size induced variability in metal concentrations in the sediment. The values are useful as a guide, but are limited in applicability due to regional difference. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, only Zn and Pb are found to be significantly enriched compared to the baseline; however, based on work done in Baltimore Harbor, the normalized values are well below anticipated biological effects thresholds.

Within the context of the life of the facility, Year 19 monitoring data shows some of the lowest levels of Zn since the onset of the elevated levels in 1989 and are approximately the same as the preceding monitoring year (Year 18) . There were no significant contiguous periods during which discharge rates were below 10 MGD; the most acidic daily discharge records did not show any periods of free mineral acidity. Without the free mineral acidity, leaching is minimized and acid formation rates are low. This accounts for the low observed levels of Zn in the exterior sediments. Based on the historical data, and the data from this report, it does not appear that material from the Harbor influences the sediments adjacent to the dike in the proximal zone ascribed to HMI . This is supported by both the sedimentation and metals distribution patterns in the area.

Persistent elevated metal levels in sediments around HMI indicate a need for continued monitoring, even though the levels were low during this sampling period. The metal levels in the exterior sediments continued to show a consistent response to the operations of the dike; low discharge rates increasing the metal loads to the sediment. Currently, the dike is actively accepting material, but as the dike reaches its capacity 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 assess the potential influence of Baltimore Harbor on the HMI exterior sediments better, the additional sampling sites be maintained, at least temporarily.

REFERENCES

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

CHAPTER 3: BENTHIC COMMUNITY STUDIES (PROJECT III)

(September 2000 – September 2001) Technical Report

Prepared by:

Karen Eason, Principal Investigator
Matthew Rowe, Co-Principal Investigator
Caroline Myers, Co-Principal Investigator
Chris Luckett, Taxonomist
Jeff Carter, Research Technician
Maryland Department of the Environment
Technical and Regulatory Services Administration
Environmental Assessment Division

Prepared for:
Maryland Port Administration
2310 Broening Highway
Baltimore, MD 21224

ABSTRACT

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

Twenty-one stations (11 Nearfield, 3 Reference, 3 Back River/Hawk Cove stations and 4 Harbor Station) were sampled on September 20 and 21, 2000, and again on April 24, 2001. The Baltimore Harbor stations, 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 surrounding Hart-Miller Island. Infaunal samples were collected using a Ponar grab sampler, which collects 0.05 m^2 of substrate. Water quality parameters were measured using a Hydrolab Surveyor II and a Global Water WQ700 turbidimeter (turbidity measured for the September 2000 sampling only) at one-half meter from the bottom and at one-meter intervals thereafter to develop vertical water quality profiles.

A total of 42 taxa of benthic macroinvertebrates were found at these twenty-one benthic community stations during Year 19 of monitoring. Of these 42 taxa, six taxa (the clams *Rangia cuneata* and *Macoma* sp, 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. The total abundance was higher at most stations in April 2001 than September 2000 due to high seasonal recruitment, especially of the polychaete worm *Marenzelleria viridis* and the amphipod crustacean *Leptocheirus plumulosus*.

Species diversity was examined using the Shannon-Wiener diversity index. Diversity ranged from 0.78 to 2.79 in September 2000 and from 0.41 to 2.84 in April 2001. Diversity was greatly influenced by the abundance of a few taxa; particularly the clam *Macoma sp*, the polychaete worm *Marenzelleria viridis*, the amphipod *Leptocheirus plumulosus*, and worms from the family of Tubificidae. These four taxa accounted for over 80% of the individuals at each station in April 2001. 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 *Marenzelleria viridis*. The proportion of pollution-indicative taxa (the polychaete worms *Eteone heteropoda, Streblospio benedicti*, the oligochaete worms in the family Tubificidae, the clam *Mulinia lateralis,* and the midge *Coelotanypus* sp.) was higher at all stations in September than in May. This was primarily due to the large numbers of *Streblospio benedicti* and worms in the Tubificidae family that were 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 15^{th} to

September 30th timeframe) of benthic macroinvertebrates, was calculated for all stations samples collected during the September 2000 cruise. Eight benthic stations met or exceeded the Restoration Goal of a B-IBI score of 3.0. The remaining 13 stations had a B-IBI score of less than three, indicating a stressed or impacted benthic macroinvertebrate community. This was the first monitoring year that more than 2 stations have failed the B-IBI score of 3.0. Statistical analyses found no significant differences in faunal abundances between nearfield or reference stations.

INTRODUCTION

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

As part of the environmental permitting process for dredged material containment facilities, an exterior monitoring program was developed to assess any environmental impacts associated with HMI. Various agencies have worked together since the inception of this program to monitor for environmental impacts resulting from dike construction and dredged material management activities. Studies were completed prior to and during the early construction period to determine baseline environmental conditions in the HMI vicinity. The results of post-construction monitoring have then been compared to this baseline, as well as to interseasonal and interannual data. This report represents the nineteenth consecutive year of the benthic macroinvertebrate community monitoring since 1981. In Year 19, the Maryland Department of the Environment was responsible for all aspects of benthic community monitoring.

The goals of the Year 19 benthic community monitoring were:

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

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

- To monitor other potential sources of contamination to the HMI region by sampling transects along the mouth of Back River and leading into the Baltimore Harbor/Patapsco River; and

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

METHODS AND MATERIALS

For the Year 19 benthic community studies, staff from the Maryland Department of the Environment's Biological Assessment Section collected benthic macroinvertebrate samples and measured several *in situ* water quality parameters. Field sampling cruises were conducted in late summer on September 20 and 21, 2000 (with assistance from MDE Field Operations Program and Chesapeake Biological Laboratory), and in spring on April 24, 2001 (with assistance from the Maryland Department of Natural Resources). Twenty-one benthic stations (Table 6; Figure 14) in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI) were included in the study. All stations sampled during Year 18 of monitoring were again sampled for Year 19. Stations can be classified as one of 4 types: Nearfield, Reference, Back River/Hawk Cove Transect, or Baltimore Harbor Transect stations (Table 6).

Table 6: Target Locations (latitudes and longitudes in degrees, decimal minutes), and 7-digit codes of stations used for Year 19 benthic community monitoring.

Station #	Latitude	Longitude	Maryland 7-Digit Station Designation
Nearfield Stations			
MDE-1	39° 15.3948	76° 20.568	XIF5505
MDE-3	39° 15.5436	76° 19.9026	XIG5699
MDE-7	39° 15.0618	76° 20.3406	XIF5302
MDE-9	39° 14.7618	76° 20.5842	XIF4806
MDE-16	39° 14.5368	76° 21.4494	XIF4615
MDE-17	39° 14.1690	76° 21.1860	XIF4285
MDE-19	39° 14.1732	76° 22.1508	XIF4221
MDE-24	39° 14.2650	76° 22.7862	XIF4372
MDE-33	39° 15.9702	76° 20.8374	XIF6008
MDE-34	39° 15.7650	76° 20.5392	XIF5805
MDE-35	39° 16.3182	76° 20.7024	XIF6407
Reference			
MDE-13	39° 13.5102	76° 20.6028	XIG3506
MDE-22	39° 13.1934	76° 22.4658	XIF3224
MDE-36	39° 17.4768	76° 18.9480	XIG7589
Back River/Hawk Cove			
MDE-27	39° 14.5770	76° 24.2112	XIF4642
MDE-28	39° 15.3900	76° 22.7304	XIF5427
MDE-30	39° 15.8502	76° 22.5528	XIF5925
Patapsco River/Baltimore Harbor			
MDE-38	39° 11.5500	76° 24.8298	X1F1652
MDE-39	39° 11.3298	76° 25.7298	X1F1343
MDE-40	39° 11.1252	76° 286.7498	X1F1133
MDE-41	39° 11.1917	76° 47.263	XIF1517

In Year 18, station MDE-41 was the only Baltimore Harbor station sampled. Three additional stations (MDE-38, MDE-39, and MDE-40) were added in Year 19 to form a transect from the Baltimore Harbor area to HMI. This transect was sampled in conjunction with sediment and benthic tissue analysis studies as part of a comprehensive study to assess the Harbor's influence on environmental conditions in the HMI vicinity. The inclusion of these stations will also provide a linkage to the 1996

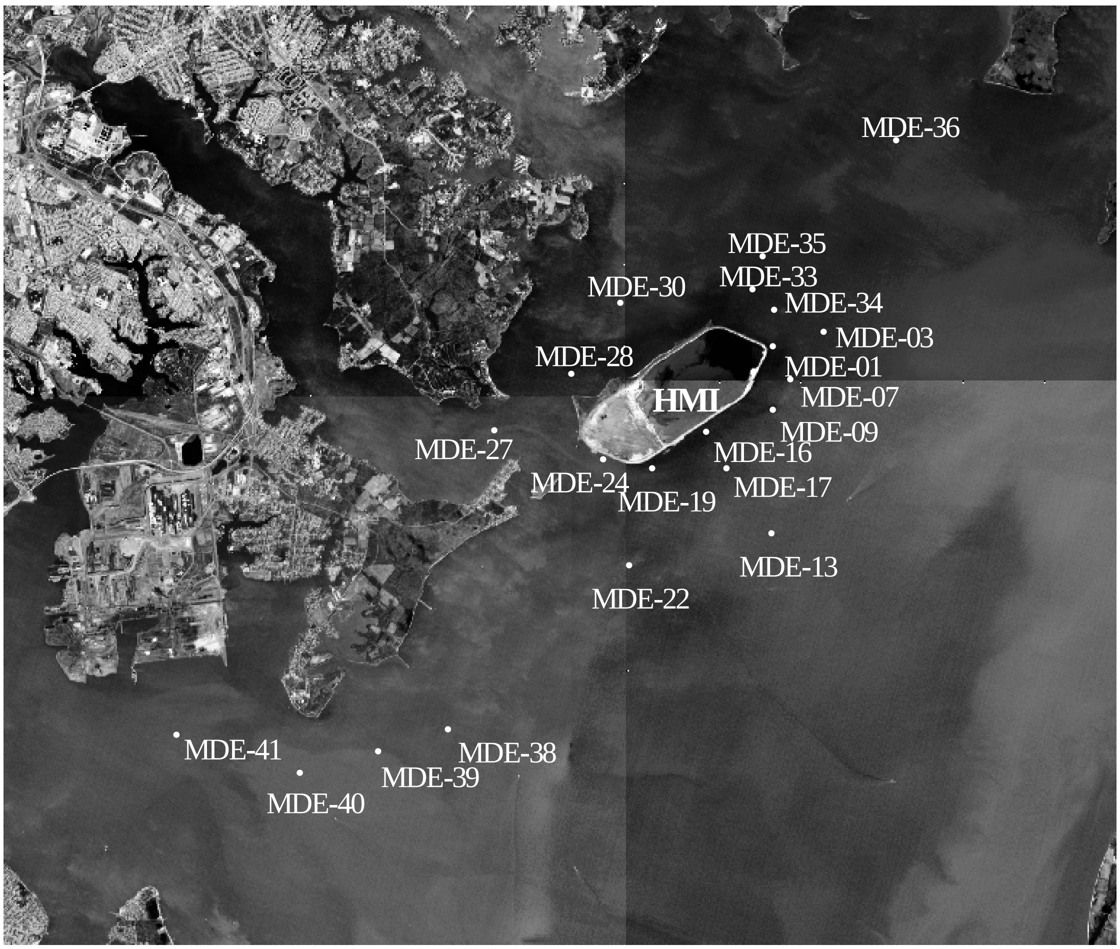


Figure 14: Year 19 Benthic Sampling Stations for the HMI Exterior Monitoring Program.

Baltimore Harbor benthic community structure study (Brown et al 1998). All benthic community sampling stations coincided with stations sampled by the Maryland Geological Survey (MGS) for sedimentary analysis. Stations were located using a differential global positioning system (GPS) navigation unit.

Temperature, depth, salinity, pH, conductivity, and dissolved oxygen were measured *in situ* using a Hydrolab Surveyor II water quality meter in September 2000 and April 2001. Water quality parameters were measured at approximately 0.5 m (1.6 feet) below the surface, 1.0 m (3.3 feet) above the bottom, and at 1.0 m intervals from bottom to surface in order to develop a vertical water quality profile at each station. The secchi depth was measured at all stations during both seasons. Water quality data from all depths are found under Project III of the *Year 19 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. Subjective estimates of the substrate composition [percent contributions of detritus, gravel, shell, sand, and silt/clay (mud)] were made at each station. Samples were then rinsed through a 0.5-mm sieve on board the vessel and preserved in a solution of 10% formalin and bay water, with rose bengal dye added to stain the benthic organisms.

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

Six main measures of benthic community condition were examined, including: total infaunal abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance of pollution-sensitive infaunal taxa, the Shannon-Wiener diversity index, taxa richness and total abundance of all taxa (excluding Bryozoa). The first four of these measures were used to calculate the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) for September 2000. The B-IBI is a multi-metric index of biotic integrity used to determine if benthic populations in different areas of the Chesapeake Bay are stressed (Weisberg et al. 1997). The B-IBI has not been calibrated for periods outside the summer index period (July 15 through September 30) and, thus, was not used with the April 2001 data. In addition to the above metrics, we examined the numerically dominant taxa during each season and the length frequency distributions of the three most common clams (*Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli*).

Abundance measures were calculated based on the average abundance of each taxon from the three replicate samples collected at each station. Total Abundance was calculated as the average abundance of epifaunal and infaunal organisms per meter squared (#/m^2), excluding Bryozoa, which are colonial. Qualitative estimates (i.e., present, common or abundant) of the number of live bryozoan zooids are included in the *Year 19 Data Report*. Total Infaunal Abundance was calculated as the average abundance of infaunal organisms per meter squared (#/m^2). Two different measures of total abundance were calculated because epifaunal organisms are not included in the calculation of the B-IBI (Ranasinghe et al. 1994).

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

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

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	*Neathes 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

To evaluate the numerical similarity of the infaunal abundances among the 21 stations, a single-linkage cluster analysis was performed on an Euclidean distance matrix comprised of station infaunal abundance values for all 21 stations. This analysis was performed separately for September 2000 and April 2001 data.

Analysis of variance (ANOVA) and the Ryan-Einot-Gabriel-Welsch multiple comparison post-hoc test were used to evaluate the difference of infaunal abundances between the 21 stations, however the data did not meet the assumption of these tests that the data set be normally distributed. Transformations may be used to transform the data in such a way that the resulting values will conform to the assumption of normality (Sokal and Rohlf, 1995). However, log, square root, reciprocal, inverse, sin, cosine and tangent transformations did not correct the non-normality of the data, so Friedman's nonparametric rank analysis test was used in lieu of the analysis of variance. Nonparametric tests do not assume that the data are normally distributed.

Friedman's nonparametric test was also used to analyze the differences of the 10 most abundant infaunal species among the Nearfield, Reference, Back River/Hawk Cove and Harbor stations for both September 2000 and spring. All of the statistical analyses were performed using Statistica, Version 6.0.

RESULTS AND DISCUSSION

Water Quality

Secchi depth, salinity, temperature, dissolved oxygen, conductivity, and pH were measured *in situ* at all stations for both sampling events. This report will address the first four of these parameters only. Water quality data for all parameters at all stations are found in the *Year 19 Project III Data Report*. Variations in water quality values throughout the water column were generally small, indicating that no vertical stratification occurred. Because the waters at the stations were not vertically stratified, and because water quality conditions at the bottom depths are the most relevant to the health of the benthic community, the following discussion focuses on seasonal variation within the bottom waters only.

The Secchi depths were greater in September 2000 (Table 8, range = 0.3 m – 1.4 m, average = 0.9 m ± 0.3 m) than those measured in April 2001 (Table 9, range = 0.3 m –0.7 m, average = 0.5 m ± 0.1 m). Secchi depths at three stations remained the same, or close to the same (within 0.1 m), during both seasons. These stations were the Back River/Hawk Cove stations MDE-27 and MDE 28, and Reference station MDE-36. Station MDE-27 had the lowest Secchi depth reading in the September 2000, but was similar to other stations in April 2001. It should be kept in mind that secchi depth measurements provide a snapshot of the conditions prevalent at the time of sampling, but do not necessarily reflect the dominant water clarity conditions for the entire season.

Table 8: Water quality parameters measured *in situ* at all HMI stations on September 20 and 21, 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	6.2	21.4	7.6	7.4	1
	XIF5505	Bottom	2	6.4	20.8	7.4	7.4	
MDE-03	XIG5699	Surface	0.5	6.5	21.2	7.9	7.6	1.1
	XIG5699	Bottom	4	7	20.5	7.2	7.4	
MDE-07	XIF5302	Surface	0.5	6.4	21.3	7.8	7.5	0.9
	XIF5302	Bottom	4.1	7	20.3	7.9	7.4	
MDE-09	XIF4806	Surface	0.5	6.5	21	7.7	7.5	1.2
	XIF4806	Bottom	4	7	20.5	7.5	7.4	
MDE-16	XIF4615	Surface	0.5	6.4	21	7.6	7.6	0.8
	XIF4615	Bottom	3	6.5	20.4	7.5	7.4	
MDE-17	XIF4285	Surface	0.5	6.6	21.3	7.9	7.6	1.4
	XIF4285	Bottom	3.5	6.9	20.6	7.6	7.5	
MDE-19	XIF4221	Surface	0.5	6.6	20.8	7.4	7.5	1
	XIF4221	Bottom	3.5	6.7	20.3	7.4	7.4	
*MDE-24	XIF4372	Surface	0.5	6.4	20.4	7.9	7.5	0.8
	XIF4372	Bottom	0.5	6.4	20.4	7.9	7.5	
MDE-33	XIF6008	Surface	0.5	6.5	20.5	7.4	7.2	1
	XIF6008	Bottom	1	6.6	20.5	7.4	7.2	
MDE-34	XIF5805	Surface	0.5	6.6	20.6	7.31	7.37	0.8
	XIF5805	Bottom	1.8	6.6	20.56	7.33	7.25	
MDE-35	XIF6407	Surface	0.5	6.7	20.8	7.8	7.5	0.8
	XIF6407	Bottom	2.2	6.7	20.8	7.9	7.4	
Reference Stations								
MDE-13	XIG3506	Surface	0.5	7.4	21.2	7.5	7.6	1.2
	XIG3506	Bottom	3.4	7.4	20.7	7.4	7.5	
MDE-22	XIF3224	Surface	0.5	6.6	20.6	7.8	7.6	1.1
	XIF3224	Bottom	4	7.1	20.4	7.4	7.5	
MDE-36	XIG7589	Surface	0.5	6.3	20.8	7.5	7.4	0.6
	XIG7589	Bottom	2	6.3	20.8	7.4	7.4	
Back River/Hawk Cove Stations								
MDE-27	XIF4642	Surface	0.5	6.3	21.2	7.8	7.9	0.3
	XIF4642	Bottom	2.2	6.3	21.2	7.8	7.8	
MDE-28	XIF5232	Surface	0.5	6	21.1	7.6	7.8	0.5
	XIF5232	Bottom	1.2	6.1	21.1	7.7	7.8	
MDE-30	XIF5925	Surface	0.5	6.2	20.8	7.4	7.4	0.8
	XIF5925	Bottom	1.8	6.2	20.8	7.4	7.3	
Baltimore Harbor Stations								
MDE-38	XIF1652	Surface	0.5	6.9	20.23	7.7	7.67	1.4
	XIF1652	Bottom	3	7.7	20.35	6.78	7.64	
MDE-39	XIF1343	Surface	0.5	6.7	20	7.6	7.6	1.2
	XIF1343	Bottom	3	8.9	21.2	5.6	7.6	

Table 8: Continued.

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt)	Temp (C)	Dissolved Oxygen (mg.l)	pH	Secchi Depth (m)
MDE-40	XIF1133	Surface	0.5	7.2	20.1	7.4	7.9	1
	XIF1133	Bottom	2.6	8.7	21.1	6.2	7.7	
MDE-41	XIF1517	Surface	0.5	9.8	21.49	6.61	8.02	1
	XIF1517	Bottom	4.8	10	21.75	6.24	7.9	
Other								
**MDE-26	XIF2038	Surface	0.5	6.9	20.4	7.9	7.7	1.4
	XIF2038	Bottom	3.2	7.7	20.6	7	7.6	

*Surface and bottom readings are the same because of shallow depth

**MGS station, no benthic samples were collected at this station

Table 9: Water quality parameters measured *in situ* at all HMI stations on April 24, 2001.

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt)	Temp (C)	Dissolved Oxygen (mg/l)	pH	Secchi Depth (m)
Nearfield stations								
MDE-01	XIF5505	Surface	0.5	1.8	15.6	9.6	7.1	0.4
	XIF5505	Bottom	3	2	15.3	9.5	7.1	
MDE-03	XIG5699	Surface	0.5	2	14.6	9.5	7	0.4
	XIG5699	Bottom	5	2	14.3	9.6	7	
MDE-07	XIF5302	Surface	0.5	1.9	15.6	9.7	7.1	0.5
	XIF5302	Bottom	5.5	2.2	14.3	9.5	7	
MDE-09	XIF4806	Surface	0.5	2.1	14.9	9.6	7	0.5
	XIF4806	Bottom	5	2.2	14.2	9.5	7	
MDE-16	XIF4615	Surface	0.5	2.2	15.2	9.6	7	0.4
	XIF4615	Bottom	3.5	2.2	14.5	9.6	7	
MDE-17	XIF4285	Surface	0.5	2.4	14.9	9.6	7	0.5
	XIF4285	Bottom	4	2.5	13.8	9.5	6.9	
MDE-19	XIF4221	Surface	0.5	2.2	15.3	9.6	7	0.3
	XIF4221	Bottom	4	2.2	15.1	9.6	7.1	
MDE-24	XIF4372	Surface	0.5	2.2	16.6	9.7	7.2	0.4
	XIF4372	Bottom	1.5	2.2	16.5	9.7	7.2	
MDE-33	XIF6008	Surface	0.5	2	15.8	9.4	7.1	0.4
	XIF6008	Bottom	2.5	2	15.7	9.4	7.1	
MDE-34	XIF5805	Surface	0.5	1.9	15.1	9.4	7	0.4
	XIF5805	Bottom	2.5	2	15.1	9.4	7	
MDE-35	XIF6407	Surface	0.5	1.9	15.4	9.5	7.1	0.5
	XIF6407	Bottom	3.5	1.9	15.5	9.6	7.1	
Reference Stations								
MDE-13	XIG3506	Surface	0.5	2.6	13.9	9.6	6.9	0.4
	XIG3506	Bottom	4	2.9	13.9	9.7	7	
MDE-22	XIF3224	Surface	0.5	2.3	15.4	9.6	7	0.4
	XIF3224	Bottom	4.5	2.8	14	9.7	7	

TABLE 9: continued.

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt)	Temp (C)	Dissolved Oxygen (mg/l)	pH	Secchi Depth (m)
MDE-36	XIG7589	Surface	0.5	1.7	14	9.5	6.9	0.5
	XIG7589	Bottom	2.5	1.7	13.9	9.5	7	
Back River/Hawk Cove Stations								
MDE-27	XIF4642	Surface	0.5	2.7	16	8.4	6.97	0.4
	XIF4642	Bottom	3.5	2.7	15.8	8.4	7	
MDE-28	XIF5232	Surface	0.5	2.2	15.6	9.1	7.1	0.5
	XIF5232	Bottom	2	2.3	15.5	8.8	7.1	
MDE-30	XIF5925	Surface	0.5	1.6	14.9	9.2	7	0.5
	XIF5925	Bottom	2.5	1.8	15.1	9.1	7.1	
Baltimore Harbor Stations								
MDE-38	XIF1652	Surface	0.5	3.4	14.2	9.8	7	0.7
	XIF1652	Bottom	3.5	3.5	13.4	9.7	7	
MDE-39	XIF1343	Surface	0.5	3.2	15.4	9.8	7	0.5
	XIF1343	Bottom	3.5	4.4	13.1	9	6.8	
MDE-40	XIF1133	Surface	0.5	3.3	15.8	9.9	7	0.5
	XIF1133	Bottom	3.5	4.6	13.7	9.2	6.9	
MDE-41	XIF1517	Surface	0.5	3.6	15.3	10	7.1	0.6
	XIF1517	Bottom	5.5	7.7	12.3	8.5	6.8	

The variations seen in bottom salinity between September 2000 and April 2001 were typical of seasonal variations in the upper region of the Chesapeake Bay. This region of the Bay typically ranges between the oligohaline (0.5 ppt – 5 ppt) and mesohaline (>5ppt – 18 ppt) salinity regimes (Lippson and Lippson 1997). In September 2000, bottom salinity ranged from 6.1 ppt –10.0 ppt (low mesohaline) with an average of 7.1 ppt ± 1.0 ppt (Table 8), this is lower than Year 18's average September 2000 bottom salinity (9.4 ppt ± 1.1 ppt); however, this result was expected due to the fact that Year 18 September 2000 sampling was conducted during a drought year. In both Year 18 and Year 19 the highest bottom salinities were recorded at the Harbor Transect stations (stations MDE-38 – MDE-41). In September 2000, the lowest salinities were recorded for the Back River/Hawk Cove stations and Reference station MDE-36, all of which are within the path of freshwater flows (from the Back and Susquehanna Rivers, respectively).

The April 2001 bottom salinity measurements ranged from 1.7 ppt – 7.7 ppt (oligohaline/low mesohaline) and averaged 2.8 ppt ± 1.4 ppt (Table 9). This is somewhat higher than Year 18's average bottom salinity (1.2 ppt ± 1.3 ppt). The highest spring bottom salinities were again found at the Harbor stations. The lowest spring bottom salinities were found at Back River/Hawk Cove station MDE-30 and Reference station MDE-36, although the salinities at these stations were only marginally lower than those found at many other stations in the area.

The September 2000 bottom water temperatures in Year 19 (Table 8, range = 20.3 ºC – 21.8 ºC, average = 20.7 ºC ± 0.4 ºC) were a few degrees cooler than those seen in the previous two monitoring years. It is interesting to note that the bottom temperatures at all four Harbor stations were slightly higher than their surface temperatures. This is generally not the case for other stations in the HMI vicinity, which usually have bottom temperatures the same or lower than their surface temperatures. The highest bottom temperature was found at Harbor station MDE- 41 (21.8 ºC). Temperatures were seasonably lower in April 2001 with a range of 12.3 ºC – 16.5 ºC and an average of 14.5 ºC ± 1.0 ºC. In contrast to the September 2000 conditions, the Harbor stations had the lowest bottom temperatures in April 2001 with the lowest temperature at MDE-41 (12.3 ºC).

Dissolved oxygen (DO) concentrations remained above the Maryland water quality criterion of 5 ppm [COMAR 26.08.02.03 – 3A(2)] during both seasons. Bottom DO conditions were lower in September 2000 than in April 2001. September 2000 values ranged from 5.6 ppm – 7.9 ppm, with an average of 7.3 ppm ± 0.6 ppm (Table 8). This is consistent with the DO levels found during the previous two September sampling events. The lowest DO levels found in September 2000 were found at the Harbor stations, the lowest being MDE-39 at 5.6 ppm. All other stations had bottom DO levels that were fairly similar to each other.

In April 2001 DO values were consistent with previous spring values, ranging from 8.4-10.0 ppm and averaging 9.4 ppm ± 0.4 ppm (Table 9). The lowest DO values were found at the Harbor and Back River/Hawk Cove stations, with the lowest values at MDE 27 (8.4 ppm) and MDE- 41 (8.5 ppm). All other stations had bottom DO levels that were fairly similar to each other.

Benthic Macroinvertebrate Community

Taxa Richness and Dominance

A total of 42 taxa were found over two seasons of sampling during Year 19 of benthic community monitoring in the vicinity of Hart-Miller Island. This is similar to Year 18's total of 41 taxa. Both of these monitoring years have exceeded the number of taxa found in previous years' studies (mid-20's to low 30's) presumably due to the addition of the Harbor transect stations. Five taxa found in Year 19 occurred only at the Harbor stations [the clams *Mya arenaria* and *Mulinia lateralis;* the polychaete worm *Glycinde solitaria;* an undetermined species of the phylum Anthozoa (anemone); and an undetermined species of nudibranch (a shell-less snail)]. Of the 42 taxa found in Year 19, twenty-six are considered truly infaunal; the other sixteen epifaunal (see Ranasinghe et al. 1994). The most common taxa were members of the phyla Arthropoda (joint-legged organisms), Annelida (segmented worms), and bivalve mollusks (shellfish having two separate shells joined by a muscular hinge). Eight species of annelid worms in the class polychaeta were found in the course of the study. Eighteen species of arthropods were found. The most common types of arthropods were the amphipods (such as *Leptocheirus plumulosus*) followed by isopods (such as *Cyathura polita*). Epifaunal taxa, such as barnacles (*Balanus improvisus*), bryozoans, Anthomud crabs (*Rhithropanopeus harrisii*), were found more often at stations where the substrate (sediment) contained a large amount of oyster or clam shell (Tables 10 and 11).

Table 10: Average and total abundance (individuals per square meter) of each taxon found at HMI during late summer, September 2000 sampling, by substrate and station type.

Taxon	Average Abundance, All stations	Total Abundance, All stations	Substrate			Station Type			
			Silt/Clay	Shell	Sand	Near-field	Ref.	Back River	Harbor
Polycladida*	1.5	32.0	0.0	8.0	0.0	1.2	0.0	0.0	4.8
Nematoda	0.6	12.8	0.5	2.1	0.0	0.0	0.0	2.1	1.6
Nemertea	0.9	19.2	0.5	4.3	0.0	1.2	0.0	2.1	0.0
Carinoma tremophoros	7.0	147.2	4.1	10.7	19.2	10.5	6.4	4.3	0.0
Bivalvia	68.2	1363.2	78.3	8.5	106.7	81.9	87.5	36.3	43.2
Macoma sp.	38.1	800.0	44.8	40.5	17.1	12.2	64.0	42.7	86.4
Macoma balthica	24.7	518.4	34.3	4.3	8.5	8.7	55.5	0.0	64.0
Macoma mitchelli	12.5	262.4	17.8	4.3	0.0	2.3	36.3	10.7	24.0
Rangia cuneata	116.4	2444.8	91.9	270.9	113.1	132.7	93.9	226.1	6.4
Mulinia lateralis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
*Ischadium recurvum**	10.1	211.2	0.5	46.9	4.3	7.0	0.0	0.0	33.6
*Mytilopsis leucophaeata**	6.7	140.8	0.9	38.4	4.3	4.1	2.1	0.0	22.4
Polychaeta	1.5	32.0	0.0	10.7	0.0	0.0	0.0	0.0	8.0
Capitellidae	9.1	192.0	10.5	8.5	6.4	8.1	6.4	0.0	20.8
Capitella capitata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heteromastus filiformis	56.1	1177.6	42.1	138.7	55.5	31.4	44.8	4.3	171.2
Spionidae	0.3	6.4	0.0	0.0	2.1	0.6	0.0	0.0	0.0
Marenzellaria viridis	8.8	185.6	6.4	19.2	10.7	13.4	12.8	0.0	0.0
Streblospio benedicti	1303.8	27379.2	1528.7	962.1	906.7	685.4	482.1	3731.2	1800.0
Paraprionospio pinnata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polydora cornuta	75.3	1580.8	16.0	313.6	134.4	59.9	2.1	51.2	190.4
Nereidae	55.2	1158.4	12.8	264.5	36.3	40.7	4.3	2.1	172.8
Neanthes succinea	122.5	2572.8	43.4	563.2	32.0	101.8	10.7	25.6	336.0
Heteronereid	1.2	25.6	1.4	0.0	0.0	0.6	0.0	2.1	3.2
Goniadidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glycinde solitaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Phyllodocidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eteone heteropoda	10.7	224.0	15.1	4.3	0.0	2.3	6.4	0.0	44.8
Oligochaeta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 10: Continued.

Taxon	Average Abundance, All stations	Total Abundance, All stations	Substrate			Station Type			
			Silt/Clay	Shell	Sand	Near-field	Ref.	Back River	Harbor
Tubificidae	646.7	13580.8	736.0	537.6	524.8	448.6	541.9	1992.5	260.8
Crustacea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphipoda	39.9	838.4	58.1	0.0	8.5	25.6	32.0	32.0	91.2
Gammaridea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ameroculodes spp. complex	59.1	1241.6	82.7	0.0	27.7	8.7	0.0	10.7	278.4
Leptocheirus plumulosus	794.8	16691.2	1133.7	2.1	270.9	570.8	1053.9	957.9	1094.4
Gammaridae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gammarus sp	1.2	25.6	0.5	2.1	4.3	2.3	0.0	0.0	0.0
Gammarus daiberi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melitadae*	3.4	70.4	4.6	2.1	0.0	1.7	4.3	0.0	9.6
*Melita nitida**	46.3	972.8	65.4	8.5	0.0	29.1	61.9	61.9	70.4
Corophiidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Apocorophium sp.*	95.7	2009.6	0.0	6.4	663.5	182.7	0.0	0.0	0.0
*Apocorophium lacustre**	30.8	646.4	0.9	2.1	206.9	57.0	0.0	4.3	1.6
Isopoda	0.6	12.8	0.9	0.0	0.0	0.0	4.3	0.0	0.0
Cyathura polita	77.4	1625.6	96.5	38.4	53.3	87.3	119.5	100.3	1.6
*Edotea triloba**	4.0	83.2	5.5	0.0	2.1	2.3	0.0	17.1	1.6
Chirodotea sp.	0.3	6.4	0.0	0.0	2.1	0.6	0.0	0.0	0.0
Chirodotea almyra	1.2	25.6	1.4	0.0	2.1	0.6	0.0	6.4	0.0
Cirripedia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Balanus sp.*	0.6	12.8	0.0	4.3	0.0	0.0	0.0	0.0	3.2
*Balanus improvisus**	162.1	3404.8	0.9	676.3	4.3	125.7	0.0	0.0	505.6
*Balanus subalbidus**	3.7	76.8	0.0	4.3	0.0	6.4	0.0	0.0	1.6
Decapoda*	0.3	6.4	0.0	0.0	0.0	0.6	0.0	0.0	0.0
Xanthidae*	3.7	76.8	0.0	23.5	0.0	3.5	0.0	0.0	9.6
*Rhithropanopeus harrisii**	30.8	646.4	8.7	100.3	21.3	47.1	4.3	2.1	27.2
Mysidacea*	3.0	64.0	4.1	0.0	2.1	1.2	2.1	8.5	4.8
Mysidae*	1.2	25.6	1.8	0.0	0.0	1.2	2.1	0.0	1.6
Bryozoa*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Membranipora sp.*	+	+	0.0	+	+	+	0.0	0.0	+
Insecta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chironomidae	0.3	6.4	0.5	0.0	0.0	0.0	2.1	0.0	0.0
Chironomid sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coelotanypus sp.	8.2	172.8	12.3	0.0	0.0	0.6	21.3	34.1	0.0
Chironomini	0.3	6.4	0.5	0.0	0.0	0.0	0.0	2.1	0.0
Cnidaria*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anthozoa*	38.7	812.8	0.0	270.9	0.0	0.0	0.0	0.0	203.2
Hydrozoa*	0.3	6.4	0.0	0.0	2.1	0.6	0.0	0.0	0.0
Nudibranchia*	1.8	38.4	0.0	12.8	0.0	0.0	0.0	0.0	9.6

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

*Indicates taxa are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Table 11: Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 19 Spring sampling (April 2001), by substrate and station type.

Taxon	Average Abundance All	Total Abundance All	Substrate			Station Type			
			Silt/Clay	Shell	Sand	Near-field	Ref.	Back River	Harbor
Turbellaria*	2.1	44.8	2.6	0.0	1.6	0.0	0.0	12.8	1.6
Nematoda	0.3	6.4	0.4	0.0	0.0	0.0	0.0	2.1	0.0
Carinoma tremophoros	0.3	6.4	0.0	0.0	1.6	0.6	0.0	0.0	0.0
Bivalvia	197.0	4137.6	199.4	44.8	225.6	220.5	88.5	6.4	356.8
Macoma sp.*	525.1	11027.2	639.6	64.0	182.4	502.7	723.2	452.3	492.8
Macoma balthica	517.2	10860.8	624.0	38.4	209.6	552.1	512.0	512.0	428.8
Macoma mitchelli	87.8	1843.2	102.4	6.4	49.6	66.3	106.7	106.7	118.4
Rangia cuneata	106.8	2243.2	63.8	0.0	305.6	157.7	43.7	123.7	1.6
Mulinia lateralis	8.5	179.2	11.2	0.0	0.0	0.0	0.0	0.0	44.8
Mya arenaria	4.9	102.4	2.0	0.0	17.6	0.0	0.0	0.0	25.6
*Ischadium recurvum**	9.1	192.0	0.4	32.0	38.4	3.5	0.0	0.0	38.4
*Mytilopsis leucophaeata**	1.5	32.0	0.8	0.0	4.8	1.2	0.0	0.0	4.8
Capitellidae	5.2	108.8	6.4	0.0	1.6	0.0	8.5	17.1	8.0
Capitella capitata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heteromastus filiformis	27.3	572.8	29.0	0.0	27.2	14.0	43.7	4.3	68.8
Spionidae	1.5	32.0	0.0	0.0	8.0	2.9	0.0	0.0	0.0
Marenzellaria viridis	5273.9	110752.0	2708.4	4006.4	15852.8	7480.4	2118.4	4682.7	2016.0
Streblospio benedicti	160.3	3366.4	185.2	0.0	100.8	8.1	40.5	514.1	403.2
Paraprionospio pinnata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polydora cornuta	17.1	358.4	6.0	70.4	48.0	11.6	0.0	14.9	46.4
Nereidae	33.2	697.6	12.0	70.4	108.8	16.9	10.7	8.5	113.6
Neanthes succinea	216.2	4540.8	140.2	352.0	486.4	118.7	28.8	42.7	755.2
Heteronereid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glycinde solitaria	0.3	6.4	0.4	0.0	0.0	0.0	0.0	0.0	1.6
Eteone heteropoda	33.8	710.4	42.0	0.0	9.6	0.0	0.0	0.0	177.6
Hypaniola grayi	0.3	6.4	0.4	0.0	0.0	0.0	2.1	0.0	0.0
Tubificidae	2298.1	48259.2	2707.0	921.6	1006.4	1345.7	796.8	7861.3	1870.4
Amphipoda	142.9	3001.6	175.2	25.6	43.2	197.2	198.4	38.4	30.4
Gammaridea	86.2	1811.2	70.8	550.4	32.0	104.7	76.8	104.5	28.8
Ameroculodes spp. complex	44.5	934.4	54.0	0.0	17.6	9.3	2.1	245.3	22.4
Leptocheirus plumulosus	2738.6	57510.4	3098.0	57.6	1971.2	2592.6	3168.0	2124.8	3278.4
Gammaridae	0.9	19.2	0.8	0.0	1.6	0.6	0.0	4.3	0.0
Gammarus sp	112.0	2352.0	75.0	896.0	64.0	176.9	56.5	74.7	3.2
Gammarus daiberi	54.9	1152.0	24.8	704.0	12.8	104.1	0.0	0.0	1.6
Melitadae*	7.0	147.2	2.4	51.2	14.4	9.3	0.0	0.0	11.2
*Melita nitida**	104.4	2192.0	108.2	256.0	51.2	93.1	107.7	91.7	142.4
Apocorophium sp.*	26.4	553.6	4.6	0.0	120.0	45.4	5.3	8.5	3.2
*Apocorophium lacustre**	58.5	1228.8	14.0	454.4	137.6	84.9	0.0	0.0	73.6
Isopoda	0.6	12.8	0.0	0.0	3.2	1.2	0.0	0.0	0.0
Cyathura polita	87.0	1827.2	101.4	0.0	51.2	97.2	148.3	83.2	16.0
*Edotea triloba**	29.1	611.2	15.0	0.0	92.8	36.1	7.5	59.7	3.2

Table 11: Continued.

Taxon	Average Abundance All	Total Abundance All	Substrate			Station Type			
			Silt/Clay	Shell	Sand	Near-field	Ref.	Back River	Harbor
Chirodotea almyra	1.2	25.6	0.4	0.0	4.8	1.7	0.0	2.1	0.0
Cassidinidea ovalis	0.3	6.4	0.0	0.0	1.6	0.6	0.0	0.0	0.0
Balanus sp.*	0.3	6.4	0.0	6.4	0.0	0.6	0.0	0.0	0.0
*Balanus improvisus**	88.7	1862.4	15.2	1408.0	52.8	154.8	0.0	0.0	40.0
*Balanus subalbidus**	2.1	44.8	0.0	44.8	0.0	4.1	0.0	0.0	0.0
Decapoda*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Xanthidae*	1.8	38.4	0.8	12.8	3.2	2.9	0.0	0.0	1.6
*Rhithropanopeus harrisii**	23.5	492.8	10.4	198.4	32.0	35.5	6.4	0.0	20.8
Mysidacea*	0.3	6.4	0.4	0.0	0.0	0.6	0.0	0.0	0.0
Mysidae*	0.3	6.4	0.4	0.0	0.0	0.0	0.0	0.0	1.6
Copepoda*	3.0	64.0	3.6	0.0	1.6	1.2	0.0	14.9	1.6
Membranipora sp.*	0.0	0.0	0.0	+	+	+	0.0	0.0	+
Chironomidae	1.2	25.6	0.4	19.2	0.0	1.7	0.0	2.1	0.0
Chironomid sp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coelotanypus sp.	12.8	268.8	16.8	0.0	0.0	2.9	42.7	36.3	0.0
Chironomini	0.3	6.4	0.4	0.0	0.0	0.0	0.0	2.1	0.0
Tanypodinae	1.2	25.6	1.6	0.0	0.0	0.6	0.0	6.4	0.0
Coelotanypodini	0.6	12.8	0.8	0.0	0.0	0.0	0.0	4.3	0.0
Orthocladiinae	1.8	38.4	0.4	12.8	4.8	3.5	0.0	0.0	0.0
Procladiini	0.3	6.4	0.4	0.0	0.0	0.0	0.0	2.1	0.0
Anthozoa*	33.2	697.6	2.4	0.0	164.8	0.0	0.0	0.0	174.4
Hydrozoa*	0.0			0.0	0.0	0.0	0.0	0.0	0.0
Nudibranchia*	14.6	307.2	0.8	0.0	73.6	0.0	0.0	0.0	76.8

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

*Indicates taxa are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Harbor station MDE-40 had the highest number of taxa in the September 2000 (19), followed closely by Nearfield sand station MDE-7, Nearfield shell station MDE-34, and Nearfield silt/clay station MDE-35 (18 each) (Table 12). Of the latter three stations it should be noted that MDE-7 had the greatest number of taxa in the September 2000 of Year 18, while, in previous years, taxa richness has been consistently low at Nearfield station MDE-34 (MDE year 17 in review & MDE year 18 in review). The station with the fewest taxa in September 2000 of Year 19 was found at Harbor station MDE-41 (7). This station is located the furthest upstream in the mouth of the Patapsco River of all the Harbor transect stations. It experiences higher salinities and may have greater pollution impacts from the Baltimore Harbor/Patapsco River area than other stations. Overall, average taxa richness was highest at the Nearfield stations but did not vary greatly between station types (average taxa richness: Nearfield=14.7 taxa, Reference=13.0 taxa, Back River/Hawk Cove=13.0 taxa, Harbor=12.5 taxa).

Table 12: Summary of metrics for each HMI benthic station surveyed during the Year 19 late summer sampling cruise, September 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	Benthic Index of Biotic Integrity
Nearfield Stations								
MDE-1	755.2	2438.4	15	7	2.03	1.69%	61.02%	2
MDE-3	1081.6	1120	14	11	2.68	22.49%	58.58%	2.5
MDE-7	3475.2	3603.2	18	12	2.20	7.00%	79.01%	2
MDE-9	1491.2	1625.6	15	12	2.78	12.45%	63.95%	2.5
MDE-16	1504	1644.8	16	12	2.38	10.64%	61.28%	2.5
MDE-17	1510.4	1779.2	10	9	2.01	8.90%	36.02%	2.5
MDE-19	3014.4	3552	11	8	1.56	5.94%	29.51%	1.5
MDE-24	1644.8	1792	14	11	1.53	1.95%	66.15%	2
MDE-33	1561.6	4364.8	13	10	2.69	18.03%	29.51%	3
MDE-34	3808	4096	18	12	2.49	19.66%	53.95%	2
MDE-35	4684.8	4966.4	18	14	1.99	9.43%	37.43%	2
Reference Stations								
MDE-13	2188.8	2310.4	16	12	2.29	9.65%	33.04%	2.5
MDE-22	4204.8	4659.2	14	12	2.25	7.00%	40.03%	2
MDE-36	1299.2	1324.8	11	9	2.90	26.11%	57.64%	2.5
Back River/Hawk Cove Stations								
MDE-27	14681.6	15040	13	11	1.55	0.83%	86.14%	1
MDE-28	4915.2	5004.8	14	11	2.14	10.55%	66.67%	2
MDE-30	2016	2060.8	12	10	2.29	16.83%	66.98%	2.5
Harbor Stations								
MDE-38	4518.4	5011.2	12	9	1.64	1.98%	19.12%	2
MDE-39	4160	4467.2	12	10	2.65	4.62%	25.23%	2.5
MDE-40	4665.6	8032	19	8	2.56	0.14%	39.09%	2.5
MDE-41	4876.8	4928	7	6	0.78	0.00%	96.06%	1.5

In April 2001 of Year 19 Harbor station MDE-40 again had the highest number of taxa (22), this time followed closely by Nearfield sand station MDE-34 and Harbor station MDE-41 (21 each). The number of taxa was higher at most stations in April 2001 than September 2000 and may be due to seasonal recruitment (Table 13). Nearfield station MDE-17 had the fewest taxa (12) in April 2001. Overall, the average taxa richness was highest at the Harbor transect stations, and varied slightly more among stations types than in September 2000 (average taxa richness: Nearfield=15.6 taxa, Reference=14.3 taxa, Back River/Hawk Cove=17 taxa, Harbor=18.5 taxa).

Table 13: Summary of metrics for each HMI benthic station surveyed during the Year 19 spring sampling cruise, April 2001. 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	7219.2	10304	16	9	2.13	56.03%	12.77%
MDE-3	12249.6	13350.4	17	10	1.74	62.28%	19.44%
MDE-7	4294.4	5075.2	18	12	2.51	5.96%	43.37%
MDE-9	6368	7091.2	15	13	2.4	19.80%	9.35%
MDE-16	8313.6	8928	13	11	2.54	38.80%	14.24%
MDE-17	8595.2	9337.6	12	11	2.66	29.26%	14.97%
MDE-19	13555.2	14579.2	16	12	2.35	38.86%	3.26%
MDE-24	26035.2	26752	17	14	1.4	79.67%	1.47%
MDE-33	25875.2	26380.8	13	10	0.41	95.60%	0.22%
MDE-34	22598.4	23648	21	15	1.23	79.69%	9.91%
MDE-35	10873.6	11494.4	14	12	2.51	31.96%	32.84%
Reference Stations							
MDE-13	5158.4	5708.8	13	11	2.38	14.52%	17.37%
MDE-22	10963.2	11404.8	15	11	2.38	40.46%	8.14%
MDE-36	7436.8	7916.8	15	12	2.35	44.15%	11.45%
Back River/Hawk Cove Stations							
MDE-27	31059.2	31590.4	17	14	1.73	12.80%	70.97%
MDE-28	11296	11552	17	14	2.08	61.76%	16.77%
MDE-30	8428.8	8652.8	17	13	2.03	62.34%	15.41%
Harbor Stations							
MDE-38	12729.6	13299.2	18	13	2.66	19.76%	32.08%
MDE-39	11462.4	12006.4	13	11	2.56	22.72%	26.86%
MDE-40	7680	9779.2	22	12	2.84	29.42%	23.25%
MDE-41	7705.6	8537.6	21	16	2.51	33.47%	13.46%

Since the first benthic survey studies of the Hart-Miller Island area in 1981, a small number of taxa have been dominant. Year 19 was no exception. During both seasons, 3 taxa were clearly dominant. In September 2000, these taxa were the polychaete worm *Streblospio benedicti*, the amphipod *Leptocheirus plumulosus*, and oligochaete worms of the family Tubificidae (Table 10). These three taxa combined accounted for >50% of the organisms found at all stations but one (MDE-40, 39.1%). The average abundance of each taxon (individuals per meter squared) found at each station during September 2000 is provided in Tables 14 and 15. *Streblospio benedicti* was one of the three most numerically abundant species at all 21 stations sampled during this season.

Table 14: Average number of Individuals collected per square meter at each station during the HMI Year 19 late summer sampling, September 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
Polycladida*	6.4	6.4	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0
Nemertea	0	6.4	0	0	0	0	0	0	0
Carinoma tremophoros	0	6.4	57.6	12.8	6.4	6.4	0	0	0
Bivalvia	0	12.8	25.6	25.6	51.2	57.6	0	403.2	211.2
Macoma sp.	0	6.4	0	32	76.8	19.2	6.4	0	96
Macoma balthica	0	0	12.8	6.4	38.4	6.4	6.4	19.2	108.8
Macoma mitchelli	0	6.4	0	0	19.2	12.8	6.4	0	64
Rangia cuneata	6.4	128	83.2	89.6	6.4	32	0	0	12.8
Mulinia lateralis	0	0	0	0	0	0	0	0	0
*Ischadium recurvum**	51.2	0	12.8	0	0	6.4	0	0	0
*Mytilopsis leucophaeata**	0	6.4	6.4	6.4	6.4	0	0	0	0
Polychaeta	0	0	0	0	0	0	0	0	0
Capitellidae	0	6.4	19.2	25.6	6.4	0	19.2	0	12.8
Capitella capitata	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	6.4	32	166.4	76.8	32	12.8	6.4	32	102.4
Spionidae	0	0	0	0	0	0	0	0	0
Marenzellaria viridis	6.4	38.4	32	19.2	19.2	12.8	12.8	0	19.2
Streblospio benedicti	371.2	473.6	1229	576	275.2	569.6	211.2	665.6	723.2
Paraprionospio pinnata	0	0	0	0	0	0	0	0	0
Polydora cornuta	12.8	96	38.4	44.8	0	0	0	6.4	6.4
Nereidae	76.8	38.4	83.2	44.8	12.8	6.4	0	0	0
Neanthes succinea	179.2	12.8	38.4	89.6	19.2	25.6	19.2	0	12.8
Heteronereid	6.4	0	0	0	0	0	0	0	0
Goniadidae	0	0	0	0	0	0	0	0	0
Glycinde solitaria	0	0	0	0	0	0	0	0	0
Phyllodocidae	0	0	0	0	0	0	0	0	0
Eteone heteropoda	0	12.8	0	6.4	6.4	6.4	0	0	12.8
Oligochaeta	0	0	0	0	0	0	0	0	0
Tubificidae	89.6	147.2	1517	371.2	441.6	345.6	332.8	224	947.2
Crustacea	0	0	0	0	0	0	0	0	0
Amphipoda	0	0	0	0	38.4	44.8	89.6	44.8	44.8
Gammaridea	0	0	0	0	0	0	0	0	0
Ameroculodes spp. complex	0	0	6.4	0	0	0	0	6.4	0
Leptocheirus plumulosus	0	0	76.8	25.6	1081.6	339.2	774.4	1900.8	1932.8
Gammaridae	0	0	0	0	0	0	0	0	0
Gammarus sp.	0	0	0	0	0	0	0	0	0

Table 14: Continued.

Taxon	Station								
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19	MDE-22
Gammarus daiberi	0	0	0	0	0	0	0	0	0
Melitadae*	0	0	0	0	0	0	0	19.2	12.8
*Melita nitida**	32	0	0	0	6.4	19.2	25.6	57.6	179.2
Corophiidae	0	0	0	0	0	0	0	0	0
Apocorophium sp.*	0	0	0	0	0	0	0	0	0
*Apocorophium lacustre**	6.4	0	6.4	0	0	0	0	0	0
Isopoda	0	0	0	0	12.8	0	0	0	0
Cyathura polita	0	76.8	115.2	70.4	147.2	108.8	115.2	160	153.6
*Edotea triloba**	0	0	0	0	0	6.4	0	6.4	0
Chirodotea sp.	0	0	0	0	0	0	0	0	0
Cirripedia	0	0	0	0	0	0	0	0	0
Balanus sp.*	0	0	0	0	0	0	0	0	0
*Balanus improvisus**	1350.4	0	12.8	12.8	0	0	0	0	0
*Balanus subalbidus**	64	6.4	0	0	0	0	0	0	0
Decapoda*	6.4	0	0	0	0	0	0	0	0
Xanthidae*	6.4	0	0	0	0	0	0	0	0
*Rhithropanopeus harrisii**	160	0	64	89.6	6.4	6.4	0	0	0
Mysidacea*	0	0	0	0	0	0	0	6.4	6.4
Mysidae*	0	0	0	0	0	0	0	0	0
Bryozoa*	0	0	0	0	0	0	0	0	0
Membranipora sp.*	+	0	+	0	0	0	0	0	0
Insecta	0	0	0	0	0	0	0	0	0
Chironomidae	0	0	0	0	0	0	0	0	0
Chironomid sp.	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	0	0	0	0	0	0	0
Chironomini	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	0
Hydrozoa*	0	0	0	0	0	0	0	0	0
Nudibranchia*	0	0	0	0	0	0	0	0	0

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

*Indicates taxa are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Table 15: Average number of Individuals collected per square meter at each station during the HMI Year 19 late summer sampling, September 2000, stations MDE-24 to MDE-41.

Taxon	Station											
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36	MDE-38	MDE-39	MDE-40	MDE-41
Polycladida*	0	0	0	0	0	0	0	0	0	0	19.2	0
Nematoda	0	0	6.4	0	0	0	0	0	0	0	6.4	0
Nemertea	0	0	6.4	0	0	6.4	0	0	0	0	0	0
Carinoma tremophoros	0	0	6.4	6.4	0	25.6	6.4	12.8	0	0	0	0
Bivalvia	128	108.8	0	0	166.4	0	0	0	121.6	0	12.8	38.4
Macoma sp.	6.4	89.6	38.4	0	44.8	12.8	6.4	19.2	128	89.6	102	25.6
Macoma balthica	0	0	0	0	12.8	6.4	25.6	19.2	83.2	166.4	6.4	0
Macoma mitchelli	0	32	0	0	0	0	0	25.6	25.6	64	6.4	0
Rangia cuneata	6.4	6.4	377.6	294.4	249.6	684.8	179.2	262.4	0	25.6	0	0
Mulinia lateralis	0	0	0	0	0	0	0	0	0	0	0	0
*Ischadium recurvum**	0	0	0	0	0	6.4	0	0	0	0	134	0
*Mytilopsis leucophaeata**	0	0	0	0	6.4	19.2	0	0	0	0	89.6	0
Polychaeta	0	0	0	0	0	0	0	0	0	0	32	0
Capitellidae	0	0	0	0	0	12.8	6.4	0	64	12.8	6.4	0
Capitella capitata	0	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	0	12.8	0	0	0	0	12.8	0	108.8	185.6	384	6.4
Spionidae	0	0	0	0	6.4	0	0	0	0	0	0	0
Marenzellaria viridis	0	0	0	0	0	19.2	6.4	0	0	0	0	0
Streblospio benedicti	1081.6	8160	1945.6	1088	409.6	985.6	966.4	448	736	736	1427	4301
Paraprionospio pinnata	0	0	0	0	0	0	0	0	0	0	0	0
Polydora cornuta	32	0	51.2	102.4	332.8	83.2	12.8	0	0	0	762	0
Nereidae	6.4	0	6.4	0	19.2	172.8	0	0	19.2	6.4	582	83.2
Neanthes succinea	6.4	25.6	0	51.2	51.2	684.8	12.8	0	96	185.6	992	70.4
Heteronereid	0	6.4	0	0	0	0	0	0	6.4	0	0	6.4
Goniadidae	0	0	0	0	0	0	0	0	0	0	0	0
Glycinde solitaria	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodocidae	0	0	0	0	0	0	0	0	0	0	0	0
Eteone heteropoda	0	0	0	0	0	0	0	0	12.8	6.4	0	160
Oligochaeta	0	0	0	0	0	0	0	0	0	0	0	0
Tubificidae	6.4	4429	1331.2	217.6	51.2	1069	780.8	236.8	115.2	307.2	397	224
Crustacea	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	0	57.6	12.8	25.6	25.6	0	76.8	12.8	179.2	185.6	0	0
Gammaridea	0	0	0	0	0	0	0	0	0	0	0	0
Ameroculodes spp. complex	64	6.4	19.2	6.4	12.8	0	6.4	0	0	1114	0	0
Leptocheirus plumulosus	390.4	1734	979.2	160	345.6	6.4	2419	147.2	3117	1261	0	0
Gammaridae	0	0	0	0	0	0	0	0	0	0	0	0
Gammarus sp.	6.4	0	0	0	6.4	6.4	6.4	0	0	0	0	0
Gammarus daiberi	0	0	0	0	0	0	0	0	0	0	0	0
Melitadae*	0	0	0	0	0	0	0	0	32	0	6.4	0
*Melita nitida**	0	166.4	19.2	0	0	6.4	179.2	0	147.2	115.2	19.2	0
Corophiidae	0	0	0	0	0	0	0	0	0	0	0	0

Table 15: Continued.

Taxon	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36	MDE-38	MDE-39	MDE-40	MDE-41
Apocorophium sp.*	6.4	0	0	0	1984	19.2	0	0	0	0	0	0
*Apocorophium lacustre**	0	0	0	12.8	614.4	0	0	0	0	0	6.4	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0
Cyathura polita	25.6	115.2	140.8	44.8	19.2	38.4	230.4	57.6	6.4	0	0	0
*Edotea triloba**	6.4	0	51.2	0	0	0	6.4	0	6.4	0	0	0
Chirodotea sp.	6.4	0	0	0	0	0	0	0	0	0	0	0
Cirripedia	0	0	0	0	0	0	0	0	0	0	0	0
Balanus sp.*	0	0	0	0	0	0	0	0	0	0	12.8	0
*Balanus improvisus**	0	0	0	0	0	6.4	0	0	0	0	2022	0
*Balanus subalbidus**	0	0	0	0	0	0	0	0	0	0	6.4	0
Decapoda*	0	0	0	0	0	0	0	0	0	0	0	0
Xanthidae*	0	0	0	0	0	32	0	0	0	0	38.4	0
*Rhithropanopeus harrisii**	0	0	0	6.4	0	192	6.4	6.4	0	0	109	0
Mysidacea*	6.4	25.6	0	0	0	0	0	0	6.4	0	0	12.8
Mysidae*	0	0	0	0	0	0	12.8	6.4	0	6.4	0	0
Bryozoa*	0	0	0	0	0	0	0	0	0	0	0	0
Membranipora sp.*	0	0	0	0	0	0	0	0	0	0	+	0
Insecta	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae	0	0	0	0	0	0	0	6.4	0	0	0	0
Chironomid sp.	0	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	57.6	0	44.8	0	0	6.4	64	0	0	0	0
Chironomini	0	6.4	0	0	0	0	0	0	0	0	0	0
Cnidaria*	0	0	0	0	0	0	0	0	0	0	0	0
Anthozoa*	0	0	0	0	0	0	0	0	0	0	813	0
Hydrozoa*	0	0	0	0	6.4	0	0	0	0	0	0	0
Nudibranchia*	0	0	0	0	0	0	0	0	0	0	38.4	0

Note: Presence of *Membranipora* sp. is indicated by +
*Indicates taxa are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

In April 2001, *Leptocheirus plumulosus* and Tubificid worms continued to numerically dominate the benthic macroinvertebrate community, while the polychaete *Marenzelleria viridis* replaced *Streblospio benedicti* (Table 11). These three taxa combined accounted for >50% of the organisms found at all stations. The average abundance of each taxon (individuals per meter squared) found at each station during April 2001 is provided in Tables 16 and 17. While *Marenzelleria viridis* was present in high numbers in April (due to heavy spring recruitment) and was found at every station, it never achieved the dominance at those stations demonstrated by *Streblospio benedicti* in September 2000. *Streblospio benedicti* was absent from one-third of the stations in April 2001. The majority of the April 2001 population of *Streblospio benedicti* was found at the Back River/Hawk Cove and Harbor Transect stations. (General note: Declaring a species as numerically dominant one season or one monitoring year and not in the next does not necessarily mean the numbers of that species have declined; rather, it denotes the number of these organisms present in relation to the numbers of other organisms present in a given season or year).

Table 16: Average number of individuals collected per square meter at each station during the HMI Year 19 spring sampling cruise, April 2001, stations MDE-1 to MDE-22.

Taxon	Station								
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19	MDE-22
Turbellaria*	0	0	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0
Carinoma tremophoros	0	0	0	0	0	0	0	0	0
Bivalvia	44.8	832	236.8	422.4	0	0	19.2	51.2	9.6
Macoma sp.*	64	275.2	185.6	448	524.8	691.2	1625.6	1081.6	844.8
Macoma balthica	38.4	134.4	160	467.2	275.2	1011.2	1139.2	1491.2	979.2
Macoma mitchelli	6.4	6.4	25.6	76.8	83.2	64	147.2	192	211.2
Rangia cuneata	0	83.2	32	12.8	19.2	70.4	38.4	128	9.6
Mulinia lateralis	0	0	0	0	0	0	0	0	0
Mya arenaria	0	0	0	0	0	0	0	0	0
*Ischadium recurvum**	32	0	6.4	0	0	0	0	0	0
*Mytilopsis leucophaeata**	0	12.8	0	0	0	0	0	0	0
Capitellidae	0	0	0	0	0	0	0	0	0
Capitella capitata	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	0	32	25.6	0	25.6	6.4	0	12.8	105.6
Spionidae	0	0	0	0	0	0	0	0	0
Marenzellaria viridis	4006.4	7328	6.4	697.6	294.4	2048	1171.2	3449.6	3206.4
Streblospio benedicti	0	0	0	0	25.6	6.4	19.2	51.2	96
Paraprionospio pinnata	0	0	0	0	0	0	0	0	0
Polydora cornuta	70.4	0	32	0	0	0	0	0	0
Nereidae	70.4	0	25.6	6.4	25.6	6.4	12.8	0	0
Neanthes succinea	352	211.2	345.6	64	19.2	57.6	12.8	12.8	67.2
Heteronereid	0	0	0	0	0	0	0	0	0
Glycinde solitaria	0	0	0	0	0	0	0	0	0
Eteone heteropoda	0	0	0	0	0	0	0	0	0
Hypaniola grayi	0	0	0	0	0	0	0	0	0
Tubificidae	921.6	2380.8	1856	588.8	870.4	1177.6	1267.2	390.4	796.8
Amphipoda	25.6	19.2	134.4	166.4	499.2	441.6	550.4	652.8	76.8
Gammaridea	550.4	83.2	0	0	0	96	83.2	83.2	57.6
Ameroculodes spp. complex	0	0	0	12.8	6.4	0	6.4	0	0
Leptocheirus plumulosus	57.6	1702.4	1241.6	3507.2	2828.8	3059.2	2982.4	6393.6	4396.8
Gammaridae	0	0	0	0	0	0	0	0	0
Gammarus sp.	896	12.8	179.2	236.8	0	19.2	0	44.8	9.6
Gammarus daiberi	704	0	115.2	147.2	0	0	6.4	102.4	0
Melitadae*	51.2	12.8	6.4	19.2	0	0	0	0	0
*Melita nitida**	256	25.6	57.6	51.2	44.8	64	89.6	204.8	259.2

Table 16: Continued.

Taxon	Station								
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19	MDE-22
Apocorophium sp.*	0	0	0	0	0	0	0	12.8	9.6
*Apocorophium lacustre**	454.4	12.8	32	64	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0
Cyathura polita	0	83.2	57.6	83.2	160	96	166.4	198.4	240
*Edotea triloba**	0	0	0	0	6.4	12.8	0	12.8	9.6
Chirodotea sp.	0	0	0	0	0	0	0	6.4	0
Chirodotea almyra	0	0	0	0	0	0	0	0	0
Cassidinidea ovalis	0	0	0	0	0	0	0	0	0
Balanus sp.*	6.4	0	0	0	0	0	0	0	0
*Balanus improvisus**	1408	6.4	236.8	0	0	0	0	0	0
*Balanus subalbidus**	44.8	0	0	0	0	0	0	0	0
Decapoda*	0	0	0	0	0	0	0	0	0
Xanthidae*	12.8	12.8	0	0	0	0	0	0	0
*Rhithropanopeus harrisii**	198.4	76.8	70.4	0	0	0	0	0	19.2
Mysidacea*	0	6.4	0	0	0	0	0	0	0
Mysidae*	0	0	0	0	0	0	0	0	0
Copepoda*	0	0	0	0	0	0	0	6.4	0
Membranipora sp.*	+	+	+	0	0	0	0	0	0
Chironomidae	19.2	0	0	0	0	0	0	0	0
Chironomid sp.	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	0	6.4	6.4	0	0	0	0	0
Chironomini	0	0	0	0	0	0	0	0	0
Tanypodinae	0	0	0	6.4	0	0	0	0	0
Coelotanypodini	0	0	0	0	0	0	0	0	0
Orthocladiinae	12.8	0	0	6.4	0	0	0	0	0
Procladiini	0	0	0	0	0	0	0	0	0
Anthozoa*	0	0	0	0	0	0	0	0	0
Hydrozoa*	0	0	0	0	0	0	0	0	0
Nudibranchia*	0	0	0	0	0	0	0	0	0

Note: Presence of *Membranipora* sp. is indicated by +
*Indicates taxa 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 19 spring sampling cruise, April 2001, stations MDE-24 to MDE-41.

Taxon	Station											
	MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36	MDE-38	MDE-39	MDE-40	MDE-41
Turbellaria*	0	32	0	6.4	0	0	0	0	0	0	6.4	0
Nematoda	0	6.4	0	0	0	0	0	0	0	0	0	0
Carinoma tremophoros	0	0	0	0	0	6.4	0	0	0	0	0	0
Bivalvia	32	12.8	6.4	0	76.8	441.6	268.8	256	236.8	211.2	352	627.2
Macoma sp.*	211.2	563.2	281.6	512	128	160	659.2	800	844.8	614.4	230.4	281.6
Macoma balthica	614.4	1286.4	160	89.6	57.6	83.2	876.8	281.6	672	748.8	83.2	211.2
Macoma mitchelli	121.6	288	32	0	0	12.8	76.8	25.6	211.2	179.2	64	19.2
Rangia cuneata	1011.2	140.8	134.4	96	96	115.2	147.2	102.4	0	0	0	6.4
Mulinia lateralis	0	0	0	0	0	0	0	0	12.8	38.4	0	128
Mya arenaria	0	0	0	0	0	0	0	0	0	0	70.4	32
*Ischadium recurvum**	0	0	0	0	0	0	0	0	0	0	153.6	0
*Mytilopsis leucophaeata**	0	0	0	0	0	0	0	0	0	0	19.2	0
Capitellidae	0	6.4	0	44.8	0	0	0	25.6	12.8	12.8	6.4	0
Capitella capitata	0	0	0	0	0	0	0	0	0	0	0	0
Heteromastus filiformis	57.6	12.8	0	0	0	0	19.2	0	140.8	70.4	51.2	12.8
Spionidae	0	0	0	0	0	32	0	0	0	0	0	0
Marenzellaria viridis	18982	2412.8	6598	5036.8	24563	17760	2272	2854.4	1779.2	1856	2106	2323.2
Streblospio benedicti	6.4	1100.8	320	121.6	0	6.4	0	0	601.6	435.2	390.4	185.6
Paraprionospio pinnata	0	0	0	0	0	0	0	0	0	0	0	0
Polydora cornuta	0	0	0	44.8	0	25.6	0	0	0	0	166.4	19.2
Nereidae	12.8	19.2	0	6.4	0	44.8	6.4	6.4	32	19.2	377.6	25.6
Neanthes succinea	12.8	108.8	6.4	12.8	12.8	217.6	6.4	0	256	204.8	1702	857.6
Heteronereid	0	0	0	0	0	0	0	0	0	0	0	0
Glycinde solitaria	0	0	0	0	0	0	0	0	0	0	0	6.4
Eteone heteropoda	0	0	0	0	0	0	0	0	345.6	256	38.4	70.4
Hypaniola grayi	0	0	0	0	0	0	0	6.4	0	0	0	0
Tubificidae	377.6	20915.2	1568	1100.8	57.6	2233.6	3552	723.2	3123.2	2349	1357	652.8
Amphipoda	51.2	44.8	12.8	57.6	19.2	83.2	25.6	19.2	51.2	38.4	19.2	12.8
Gammaridea	51.2	128	89.6	96	57.6	12.8	134.4	172.8	44.8	44.8	6.4	19.2
Ameroculodes spp. complex	19.2	6.4	729.6	0	44.8	6.4	12.8	0	6.4	38.4	0	44.8
Leptocheirus plumulosus	4339.2	3968	1254	1152	774.4	1740.8	2720	2278.4	4620.8	4640	1030	2822.4
Gammaridae	0	0	12.8	0	0	6.4	0	0	0	0	0	0
Gammarus sp.	102.4	64	83.2	76.8	96	57.6	300.8	160	6.4	0	0	6.4
Gammarus daiberi	19.2	0	0	0	6.4	19.2	25.6	0	0	0	6.4	0
Melitadae*	0	0	0	0	0	12.8	0	0	0	0	44.8	0
*Melita nitida**	51.2	243.2	12.8	19.2	12.8	25.6	185.6	19.2	204.8	243.2	115.2	6.4

Table 17: Continued.

Taxon	Station MDE-24	MDE-27	MDE-28	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36	MDE-38	MDE-39	MDE-40	MDE-41
Apocorophium sp.*	108.8	0	12.8	12.8	332.8	38.4	6.4	6.4	6.4	6.4	0	0
*Apocorophium lacustre**	102.4	0	0	0	0	268.8	0	0	0	0	179.2	115.2
Isopoda	0	0	0	0	0	12.8	0	0	0	0	0	0
Cyathura polita	134.4	134	83.2	32	19.2	51.2	179.2	44.8	64	0	0	0
*Edotea triloba**	320	57.6	121.6	0	0	51.2	0	6.4	12.8	0	0	0
Chirodotea sp.	6.4	0	0	0	0	0	0	0	0	0	0	0
Chirodotea almyra	0	0	6.4	0	19.2	0	0	0	0	0	0	0
Cassidinidea ovalis	0	0	0	0	0	6.4	0	0	0	0	0	0
Balanus sp.*	0	0	0	0	0	0	0	0	0	0	0	0
*Balanus improvisus**	0	0	0	0	0	51.2	0	0	0	0	160	0
*Balanus subalbidus**	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda*	0	0	0	0	0	0	0	0	0	0	0	0
Xanthidae*	0	0	0	0	0	6.4	0	0	0	0	6.4	0
*Rhithropanopeus harrisii**	0	0	0	0	0	44.8	0	0	0	0	83.2	0
Mysidacea*	0	0	0	0	0	0	0	0	0	0	0	0
Mysidae*	0	0	0	0	0	0	0	0	6.4	0	0	0
Copepoda*	0	12.8	0	32	6.4	0	0	0	6.4	0	0	0
Membranipora sp.*	0	0	0	0	0	+	0	0	0	0	+	0
Chironomidae	0	6.4	0	0	0	0	0	0	0	0	0	0
Chironomid sp.	0	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus sp.	0	25.6	6.4	76.8	0	0	19.2	128	0	0	0	0
Chironomini	0	0	6.4	0	0	0	0	0	0	0	0	0
Tanypodinae	0	0	6.4	12.8	0	0	0	0	0	0	0	0
Coelotanypodini	0	0	0	12.8	0	0	0	0	0	0	0	0
Orthocladiinae	6.4	0	0	0	0	12.8	0	0	0	0	0	0
Procladiini	0	0	6.4	0	0	0	0	0	0	0	0	0
Anthozoa*	0	0	0	0	0	0	0	0	0	0	659.2	38.4
Hydrozoa*	0	0	0	0	0	0	0	0	0	0	0	+
Nudibranchia*	0	0	0	0	0	0	0	0	0	0	294.4	12.8

Note: Presence of *Membranipora* sp. is indicated by +
*Indicates taxa are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Taxa Abundance

Total abundance was higher in the spring (April 2001) than in the late summer (September 2000) due to seasonal recruitment in April 2001. In the September 2000 total abundance in the vicinity of HMI ranged from 1,120 to 15,040 organisms per meter squared (individuals/m^2) and averaged 3,991 individuals/m^2. This number does not include the Bryozoa, which are colonial epifauna and can reach high numeric densities on shell and other hard substrates. The highest September 2000 abundance was found at the Back River/Hawk Cove station MDE-27, due primarily to large numbers of the polychaete worm *Streblospio benedicti* and members of the oligochaete family Tubificidae. The lowest September 2000 abundance was found at the Nearfield sand station MDE-03 (Table 12, Figure 15). Average total abundance was similar between Reference and Nearfield stations in the September 2000 (2764.8 individuals/m^2 and 2816.6 individuals/m^2, respectively); however, total abundance was almost twice as high at the Harbor Stations (5608.0 individuals/m^2) and approximately 3 times higher at the Back River/Hawk Cove stations (7368.5 individuals/m^2).

In April 2001, total abundance ranged from 5,075 to 31,590 organisms per meter squared and averaged 13,207 individuals/m^2. The station with the highest abundance was again the Back River/Hawk Cove station MDE-27, due to very high numbers of oligochaete worms in the family Tubificidae. The lowest spring abundance occurred at the Nearfield silt/clay station MDE-07. This was due in part to the near absence of the polychaete worm *Marenzelleria viridis*, which generally occurred in high numbers at other stations (Table 13, Figure 15). The average total abundance was lowest at the Reference stations (8,344 individuals/m^2) and highest at the Back River/Hawk Cove stations (17,265 individuals/m^2), with the Harbor and Nearfield stations falling in between (10,905 individuals/$m^2$and 14,264 individuals/m^2, respectively).

Total infaunal abundance and epifaunal abundance are subsets of total abundance. Infaunal abundance excludes certain organisms that have been omitted from the calculation of the B-IBI (see *Methods*). In Year 19 total infaunal abundance was similar to total abundance, accounting for >90% of all organisms at most stations during both seasons. Exceptions occurred at three stations: Nearfield station MDE-01 in both September 2000 and April 2001 (epifauna accounted for 69% and 24% of total abundance, respectively), Nearfield station MDE-33 in September 2000 (epifauna = 60% of total abundance), and the Harbor station MDE-40 in both September 2000 and April 2001 (epifauna = 41% and 17.5% of total abundance, respectively). The substrate at stations MDE-01 and MDE-40 was composed primarily of shell in the September 2000 samples, while grab samples taken at all three stations in April 2001 were predominantly sand.

Diversity

Species diversity was examined using the Shannon-Wiener diversity index, which measures diversity on a numerical scale from . A lower score, with a score of one being the lowest, indicates an unbalanced community dominated by only one or two species whereas a higher score suggests a balanced, diverse benthic community. Pfitzenmeyer et al. (1982) suggested that diversity, as measured by the Shannon-Wiener Diversity Index (SWDI), would be higher in the summer than the spring, when recruitment decreased and predation increased thus reducing the numbers of the dominant taxa. Diversity has often been lowest at most stations in spring (April or May) due to an influx of juveniles, especially of the dominant species (Duguay et al. 1998, Duguay et al. 1995a, Duguay et al. 1995b, Duguay 1992, Duguay 1990, Pfitzenmeyer and Tenore 1987). Diversity values for Year 19 are presented in Table 12 and 13. In this monitoring year, diversity values were not distinctly higher in one season versus the other. Diversity was higher in September than in April at eight of the twenty-one stations, lower in September than in April at another nine stations, and similar (≤ 0.10 difference) between the two seasons at the remaining 4 stations (Figure 16). These results are similar to Year 17 when 7 stations out of 17 had higher diversity values in the summer than in April 2001, 8 stations were lower in the summer than in April 2001, and 2 were similar between the two seasons. Diversity values in Years 17 and 19 differed somewhat from Year 18. Diversity values from Year 18 exhibited a pattern more similar to that predicted by Pfitzenmeyer et al. (1982) in which 12 of 18 stations had higher diversity values in summer vs. spring, 4 had lower diversity in the summer vs. spring, and 2 were similar between the 2 seasons.

Shannon Weiner diversity Index (SWDI) values in Year 19 averaged 2.20 in September 2000 and 2.16 in April 2001. The lowest diversity value in Sept. 2000 occurred at Harbor station MDE-41 (0.78). This was due to the predominance of the polychaete worm *Streblospio benedicti*, which accounted for 88.2% of total infaunal abundance at this station. The highest September 2000 diversity was fairly equally shared by three stations: Nearfield stations MDE-09 (2.78) and MDE-33 (2.77), and Harbor station MDE-39 (2.79). The lowest diversity values for April 2001 were found at the Nearfield sand station MDE-33 (0.41) due to the large numbers of the polychaete worm *Marenzelleria viridis* (24,563.2 individuals/m^2), which accounted for 94.9% of the total infaunal abundance. The highest diversity value for this season was found at the Harbor station MDE-40 (2.84), where a wider variety species was present in more moderate numbers.

For the most part, Nearfield stations had diversity values similar to Reference stations in both seasons, with the exception of Nearfield stations MDE-24, MDE-33, and MDE-34 in April 2001. These three stations all had low diversity values due to the fact that they were all strongly dominated by the polychaete worm *Streblospio benedicti*. These stations all had a predominantly sandy substrate composition, which is preferred by this worm species (Sarda et al., 1995). Stations along the Back River/Hawk Cove Transect tended to have lower SWDI values than most other stations during both seasons studied. The Harbor Transect stations tended to have diversity values comparable to Nearfield and Reference stations, with the exception of lower scoring stations MDE-38 (SWDI=1.81) and MDE-41 (SWDI=0.78) in September 2000.

Pollution Sensitive Taxa Abundance

Six taxa found during Year 19 benthic monitoring were designated as "pollution-sensitive" according to Weisberg et al. (1997). These were the clams *Rangia cuneata, Macoma balthica* and *Mya arenaria;* the polychaete worms *Marenzelleria viridis* and *Glycinde solitaria;* and the isopod crustacean *Cyathura polita.* Relative abundance of these taxa was calculated as a proportion of total infaunal abundance. Relative abundance of pollution-sensitive taxa (PSTA) ranged from 0.0% (MDE-41) to 25.9% (MDE-36) with an average of 9.2% over all stations in September 2000 (Table 12, Figure 17), and from 5.8% (MDE-07) to 95.5% (MDE-33) with an average of 41.4% over all stations in April 2001 (Table 3-8, Figure 3-4). The PSTA increased at all stations but one (MDE-07) in April 2001. These increases are due to seasonal recruitment, primarily of the polychaete worm *Marenzelleria viridis*. At MDE-07, the slight decrease in PSTA can be explained by the fact that while total infaunal abundance increased slightly from September 2000 to April 2001, the numbers of two pollution-sensitive species, *Marenzelleria viridis* and *Cyathura polita*, actually decreased. This decrease may be explained by the patchy nature of the substrate at this station. The replicate samples collected in September 2000 were predominantly composed of a sandy substrate, which is preferred by both *Marenzelleria viridis* and *Cyathura polita* (Lippson & Lippson, 1997); whereas, the replicate samples collected in April 2001 were predominantly silt/clay in composition.

The average PSTA in September 2000 was higher at Reference stations (14.1%) than at Nearfield, Back River/Hawk Cove, or Harbor stations (10.6%, 9.3 % and 1.6% respectively). In April 2001, the average PSTA was highest at the Nearfield stations (48.3%) followed by the Back River/Hawk Cove stations (45.5%), Reference stations (32.5%), and the Harbor stations (26.3%).

Pollution Indicative Taxa Abundance

Five taxa found during Year 19 benthic monitoring were designated as "pollution-indicative" according to Weisberg et al. (1997). These were the midge *Coelotanypus* sp., the clam *Mulinia lateralis*, and the polychaete worms *Streblospio benedicti* and *Eteone heteropoda*. In addition, oligochaete worms of the family Tubificidae were classified as pollution-indicative because past studies have shown *Limnodrillus hoffmeisteri*, which is considered pollution-indicative, to be common in the vicinity of HMI. Relative abundance of these taxa was calculated as a proportion of total infaunal abundance. Relative abundance of pollution-indicative taxa (PITA) ranged from 18.4% (MDE-38) to 96.1% (MDE-41) with an average of 52.2% in September 2000 (Table 12, Figure 18). In April 2001 the PITA decreased at all stations but three (MDE-35, MDE-38 and MDE-39) where it increased or remained approximately the same. The April 2001 PITA values ranged from 0.2% (MDE-33) to 70.9% (MDE-27) with an average of 18.7% (Table 13, Figure 18). The general decrease in spring PITA values is due to a substantial decrease in the numbers of the pollution-indicative species *Streblospio benedicti* that had been dominant in September 2000, and to the high seasonal recruitment of other taxa, particularly the pollution-sensitive species *Marenzelleria viridis.*

The average PITA at the Back River/Hawk Cove stations was higher in both seasons (72.8 % in Sept. 2000 and 34.2% in April 2001) than that at Nearfield, Reference, or Harbor Transect stations. The numeric and relative abundance of *Streblospio benedicti* and Tubificid worms was higher at Back River/Hawk Cove stations than at other stations. Reference stations had the lowest average PITA in both seasons (43.0% in Sept. 2000, 11.8% in Apr. 01). The PITA varied considerably among Nearfield stations, but was generally similar to the Reference stations (51.9% in Sept. 2000, 14.4% in April 2001). The average PITA of Harbor Transect stations was closest to that of Reference stations in Sept. 2000 (44.4%) but higher than both Reference and Nearfield stations in Apr. 2001 (23.8%). However in September 2000, MDE-41 skewed the average PITA for the Harbor stations with a value of 96.1%. The average PITA value of Harbor stations MDE-38, MDE-39 and MDE-40 without MDE-41 was 27.2%, which is lower than all other station types in September 2000.

Clam Length Frequency Distribution

The length frequency distributions for the three most common infaunal clams were determined. The clams *Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli* were measured to the nearest millimeter. *Rangia cuneata*, which ranged in size from 2 mm to over 45 mm, was grouped into size classes at 5 mm intervals. *Macoma* sp., which ranged in size from 1 mm to 26 mm, were grouped into size classes of 2 mm increments. As in previous years, *Rangia cuneata* was the most common clam species in the waters around HMI for the September 2000 sampling season (Table 10). However, unlike previous years, clams in the genus *Macoma* were the most common clam species in the HMI vicinity during the April 2001 sampling season (Table 11).

The most common size classes of *Rangia cuneata* were the 26-30 mm size class in September 2000 and the 1-5 mm size class in April 2001. Based on information in Hopkins et al. (1973), *Rangia* clams in the 26-30 mm range are probably 2-3 years old and may be sexually mature. Clams in the 1-5 mm range are probably less than 1 year old and represent new recruitment. All size classes, except the 1-5 mm class, decreased in number from September 2000 to April 2001.

The average number of *Rangia cuneata* (individuals/m^2/station) found at the different categories of stations around HMI is shown in Figures 19 and 20 for September 2000 and April 2001, respectively. Overall, *Rangia cuneata* tends to be the most abundant at Nearfield stations followed in decreasing order by Back River/Hawk Cove stations, Reference stations, and Harbor stations. *Rangia cuneata* was practically absent from the Harbor transect stations in both seasons. This is probably due to the higher salinities generally found at these stations.

In general, the abundance of *Rangia* clams in the sampling area has been gradually decreasing over the past 3 monitoring years. This decrease has occurred across all station types and is most likely occurring over a wider portion of the Upper Bay. However, the data collected in this study are not sufficient to determine if this is a widespread phenomenon. Spring recruitment has been low for *Rangia cuneata* both last year (Year 18) and this year (Year 19). However, this may not be the peak spawning period for *Rangia* clams in this area of the Bay. Hopkins et al. (1973) indicate that to induce spawning in these clams they must be exposed to either an increase in salinity from 0‰ or a decrease in salinity from approximately 15‰ at a time when the clams hold mature gametes. Additionally, survival of embryos and early larval stages requires salinities between 2‰ and 10‰. If salinity conditions do not fall within this range, or if they are too stable (and, therefore, not suitable for spawning), the population will consist of only 1or 2 size classes and few or no young of the year. It is unclear whether these shifts are occurring at a time when the *Rangia cuneata* in this region of the Upper Chesapeake are holding mature gametes. A population studied in Virginia's James River held ripe gametes from May to late November, with the major spawning peak in autumn (Cain, 1975 in Hopkins et al. 1973). It has been suggested that limited successful spawning might occur annually, but successful recruitment may have no specific pattern and may only occur at intervals of several years because predators and/or parasites eliminate small annual crops in most years (Hopkins et al. 1973).

Both species of *Macoma* were found in numbers similar to those found in September 1999 (Year 18), with *Macoma balthica* in only slightly higher abundances than *Macoma mitchelli*. In contrast, April 2001 abundances of both species of *Macoma* were higher than in any season in the previous two monitoring years (Figure 21). In particular, the number of *Macoma balthica* found in April 2001 were approximately 5 times the number of either *Rangia cuneata* or *Macoma mitchelli* in the same season (Table 11). For both species of *Macoma*, spring recruitment was strong in the 1-2 mm and 3-4 mm size classes in all stations types. Spring recruitment was also strong in the 5-6 mm and 7-8 mm size classes for *Macoma balthica* and moderate for *Macoma mitchelli* in these size classes. Spring recruitment was notable at all four types of stations (Nearfield, Reference, Back River/Hawk Cove, and Harbor), but was strongest for *Macoma balthica* at the Nearfield stations in the 1-2 mm size class and for *Macoma mitchelli* at the Harbor stations in the 1-2 mm size class (Figures 22 and 23). It should be noted that the actual numbers of one or both species of *Macoma* are probably higher than reported here due to the large number of damaged specimens that could not be confidently identified beyond genus and were counted as *Macoma* sp. Both species of *Macoma* were more common at silt/clay stations than at sand or shell stations.

Macoma balthica numbers were substantially lower in September 2000 than in April 2001. This springtime increase was seen across all types of stations. In September 2000, most *Macoma balthica* specimens were 11 mm or larger with the highest average abundance occurring at the Harbor and Reference stations. It is worth noting that no *Macoma balthica* were found at the Back River/Hawk Cove stations in September 2000 and the number found at Nearfield stations was marginal (Figure 24). The abundances of *Macoma balthica* at Back River/Hawk Cove stations have also been low in previous monitoring years. In September 2000, the abundances of *Macoma mitchelli* were highest at Reference stations and lowest at Nearfield stations and most specimens were under 16 mm in size (Figure 25).

The overall average abundance of *Macoma mitchelli* was approximately the same in September 2000 (Year 19) as in September 1999 (Year 18). The spring abundance in April 2001 (Year 19) increased approximately 4.5 times over that found in the previous two spring seasons. Most clams were greater than 16mm in length in September 2000 and less than 10mm in length in April 2001, similar to previous monitoring years.

<u>Benthic Index of biotic Integrity (B-IBI)</u>

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) was calculated for all stations based on September 2000 data only (see Methods and Materials). Four metrics were used to calculate the B-IBI for these stations under the low mesohaline classification (> 5-12 ppt). These metrics were total infaunal abundance, the Shannon-Wiener diversity index, relative abundance of pollution-sensitive taxa, and relative abundance of pollution-indicative taxa [Note: the relative abundance of pollution-sensitive taxa was included as an accepted substitution for biomass-based metrics (Weisberg et al 1997)]. The B-IBI was developed as a benchmark to determine whether any given benthic sample taken from the Bay either approximates (B-IBI score = 5), deviates slightly (B-IBI score = 3), or deviates greatly (B-IBI score = 1) from conditions at the best Reference sites (Weisberg et al., 1997). A B-IBI score greater than or equal to 3.0 represents a benthic community that is not considered stressed by *in situ* environmental conditions. The twenty-one benthic stations studied during Year 19 were compared to this benchmark.

The Benthic Index of Biotic Integrity scores dropped at all stations but one (Reference station MDE-36) when compared to Year 18. Thirteen stations, including one Reference station (MDE-22), failed to meet the benchmark score of 3.0. There were only two stations (MDE-33 and MDE-36) that exceeded this benchmark. The remaining six stations met the benchmark with a B-IBI score of exactly 3.0 (Figure 26). This is the first time that more than two stations have failed to meet the benchmark in a given year. The most obvious change in the metric scores that was seen during September of Year 19 was in the relative abundance of pollution-indicative taxa (PITA). Seventeen of the eighteen stations that were sampled in both Year 18 and Year 19 increased in the relative abundance of pollution-indicative taxa and, therefore, decreased in the score for this metric. This is primarily due to the dominance of the pollution-indicative polychaete worm, *Streblospio benedicti*.

The lowest scoring stations in Year 19 (MDE-27 at 1.0 and MDE-41 at 1.5) have both failed the B-IBI in previous years (Year 17 and Year 18, respectively). Station MDE-27 lies in the mouth of the Back River and MDE-41 lies in the mouth of the Patapsco River. Both of these rivers have histories of poor water quality and the condition of these stations is more representative of conditions in their respective rivers than impacts from the facility at HMI.

Of the next lowest scoring stations – Nearfield stations MDE-1, MDE-19, and MDE-24, all at 2.0 – the first two also failed the B-IBI in previous years (Year 18 and Year 17, respectively). Station MDE-1 lies very close to Spillway 1 of the HMI facility (Figure 14) and has exhibited a highly variable interseasonal substrate composition. MDE-19 lies in shallow water in an area that has historically been associated with disturbance of the substrate by barge traffic serving HMI (MDE, year 18 in review). Station MDE-24 has always exceeded the benchmark in previous years for which the B-IBI was calculated. However, this year it suffered a substantial drop in diversity and the percentage of pollution sensitive species, as well as a substantial increase in the percentage of pollution indicative species (primarily *Streblospio benedicti*).

Statistical Analysis

Cluster analyses was employed in this year's study to examine relationships among the different groups of stations based upon the numerical distribution of the numbers of species and individuals of a species. In Figures 27 and 28, the stations with faunal similarity (based on a Euclidean distance matrix comprised of station infaunal abundance values for all 21 stations), are linked by vertical connections in the dendrograms. Essentially, each station was considered to be a cluster of its own and at each step (amalgamated distances) the clusters with the shortest distance between them were combined (amalgamated) and treated as one cluster. Cluster analysis in past studies at HMI has clearly indicated a faunal response to bottom type (Pfitzenmeyer, 1985; Duguay et al, 1999). Thus, any unusual grouping of stations tends to suggest changes are occurring due to factors other than bottom type and further examinations of these stations may be warranted. Experience and familiarity with the area under study can usually help to explain the differences. However, when they cannot be explained other potential outside factors must be considered.

The basic grouping of the stations for the September 2000 sampling period is presented in Figure 27. The first stations to join the dendrogram are the Nearfield silt/clay station MDE-3 and the Reference silt/clay station MDE-36. The next stations to join are the Nearfield shell station MDE-1 and the Nearfield silt/clay station MDE-9 followed by Nearfield silt/clay MDE 16 and Nearfield sand station MDE –33, these stations form a cluster of Nearfield stations except for Reference station MDE-36. Stations MDE-39, MDE-40 and MDE-41 form a grouping of Harbor stations. Overall, the Nearfield, Reference, Back River/Hawk Cove, and Harbor stations are well mixed throughout the dendrogram and show no distinct grouping by sediment or station type as has been shown in previous monitoring years. As in previous years for which cluster analysis was performed, Back River/Hawk Cove station MDE-27 was one of the last to join.

In April 2001, the first stations to join the dendrogram are the silt/clay Harbor Stations MDE-38 and MDE-39, followed by the Nearfield silt/clay station MDE-9 and the Reference station MDE-13 (Figure 28). Overall, the clusters that formed during April 2001 indicate a faunal response to sediment type. Faunal response to sediment type has also been observed in previous monitoring years. The Back River/Hawk Cove station MDE-27 was the last station to join the dendrogram as it did for September 2000 and previous monitoring years. This analysis showed no unusually isolated stations, which suggests that the area is not being adversely affected.

Friedman's nonparametric test was used to determine if a significant difference could be detected among the various sampling stations for two different factors: (1) The average infaunal abundances of benthic invertebrate communities and (2) the average abundance of the 10 most abundant infaunal species. Friedman's nonparametric test indicated that there were no significant ($P < 0.05$) differences among the infaunal abundances of the 21 stations for either September 2000 or April 2001 (Tables 18 and 19). This test also indicated that there were no significant ($P < 0.05$) differences in the 10 most abundant infaunal species between Nearfield, Reference, Back River/Hawk Cove and Harbor stations for September 2000 or April 2001 (Tables 20 & 21).

Table 18: Friedman Analysis of Variance and Kendall Coefficient of Concordance for infaunal abundances for all 21 stations in Late Summer, September 2000. ANOVA Chi square (N= 34, df = 20) = 31.7. P < 0.047; Coefficient of Concordance = 0.046, Average Rank = 0.018.

Station	Average Rank	Sum of Ranks	Mean	Std Dev.
MDE-1	9.10	309.50	22.21	71.22
MDE-3	10.63	361.50	31.81	86.61
MDE-7	12.06	410.00	102.21	326.78
MDE-9	11.56	393.00	43.86	115.21
MDE-13	11.84	402.50	65.88	200.47
MDE-16	10.68	363.00	45.55	123.70
MDE-17	9.85	335.00	47.06	145.87
MDE-19	9.76	332.00	89.98	342.01
MDE-22	12.28	417.50	124.99	376.87
MDE-24	9.85	335.00	48.38	194.53
MDE-27	11.94	406.00	433.51	1584.47
MDE-28	11.27	383.00	144.94	425.32
MDE-30	10.22	347.50	60.05	193.74
MDE-33	10.78	366.50	46.68	109.44
MDE-34	11.77	400.00	112.0	284.17
MDE-35	12.13	412.50	140.05	454.67
MDE-36	10.28	349.50	38.59	96.27
MDE-38	12.06	410.00	138.17	542.22
MDE-39	12.21	415.00	127.62	304.20
MDE-40	11.06	376.00	137.22	331.00
MDE-41	9.678	329.00	143.43	736.20

Table 19: Friedman Analysis of Variance and Kendall Coefficient of Concordance for infaunal abundances for all 21 stations in April 2001, ANOVA Chi Square (N= 43, df = 20) = 28.0; Coeffeciant of Concordance = 0.033; Average Rank = 0.009; P < 0.107.

Station	Average Rank	Sum of Ranks	Mean	Std Dev.
MDE-1	10.53	453.00	208.04	673.51
MDE-3	9.61	413.00	287.97	1183.86
MDE-7	10.81	465.00	112.19	337.79
MDE-9	11.22	482.00	163.24	549.62
MDE-13	10.13	435.50	133.92	455.68
MDE-16	10.34	444.50	206.40	594.33
MDE-17	10.65	458.00	215.19	581.18
MDE-19	11.80	507.50	336.19	1113.02
MDE-22	10.88	468.00	259.32	833.41
MDE-24	11.81	508.00	611.84	2946.86
MDE-27	12.44	535.00	727.19	3235.27
MDE-28	11.51	495.00	267.28	1038.42
MDE-30	10.87	467.50	201.49	794.23
MDE-33	9.36	402.50	606.93	3742.22
MDE-34	12.20	524.50	531.91	2722.91
MDE-35	11.59	498.50	263.41	750.65
MDE-36	10.41	447.50	179.47	562.48
MDE-38	11.98	515.00	299.73	875.65
MDE-39	11.36	488.50	269.81	825.89
MDE-40	10.63	457.00	181.55	468.63
MDE-41	10.86	467.00	182.00	562.63

Table 20: Friedman Analysis of Variance and Kendall Coefficient of Concordance of fall's 10 most abundant species among silt/clay; Back River/Hawk Cove, Nearfield, Reference and Harbor stations. ANOVA Chi Sqr. (N = 30, df = 3) = 0.9823, P < 0.80551; Coefficient of Concordance = 0.01092, Average rank = -.0232

Station Type	Average Rank	Sum of Ranks	Mean	Std. Dev
Nearfield	2.32	69.50	141.01	206.97
Reference	2.50	75.00	243.84	425.06
Back River	2.57	77.00	705.92	1684.62
Harbor	2.62	78.50	430.93	962.11

TABLE 21: Friedman Analysis of Variance and Kendall Coefficient of Concordance of April, 2001's 10 most abundant species among silt/clay; Back River/Hawk Cove, Nearfield, Reference and Harbor stations. ANOVA Chi Sqr. (N = 30, df = 3) = 2.602; Coefficient of Concordance = 0.02891; Average Rank = -0.0046, P < 0.4571

Station Type	Average Rank	Sum of Ranks	Mean	Std. Dev.
Reference	2.32	69.5	710.19	1505.88
Back River	2.32	69.5	692.27	1172.09
Nearfield	2.68	80.5	1605.97	3984.18
Harbor	2.68	80.5	973.65	1349.02

CONCLUSIONS AND RECOMMENDATIONS

The condition of the benthic macroinvertebrate community for Year 19, as measured by the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI), showed a substantial decrease compared to previous years for which the B-IBI was calculated (Years 15-18). In Year 19, thirteen stations fell below the benchmark of 3.0. Prior to this, no more than 2 stations had ever failed to meet the benchmark score of 3.0 in a given monitoring year. However, it should be noted that B-IBI scores for Year 19 decreased at all stations that were previously sampled but one (Reference station MDE-36). Statistical analyses confirmed that there were no significant differences among any of the stations, and most faunal differences among stations can be explained on the basis of the dominant substrate and/or general location within the study area. This decline across all station types (including two Reference stations, MDE-13 and MDE-22) implies that the condition of the benthic community was most likely depressed in this general region of the Upper Chesapeake rather than just in the vicinity of the HMI facility. Extreme drought conditions and the resultant higher than normal salinities in the HMI region during the September 2000 sampling is the likely cause of the environmental stress to the benthic community.

The data collected for this project are not sufficient to provide a picture of the spatial extent of the depressed condition of the benthic communities in the Upper Bay. Based on the results of Year 19's statistical analyses and the fact that B-IBI scores from previous years showed no consistent patterns of degradation at any of the sampling sites, it is recommended that no immediate actions be taken at this time. However, due to this substantial and sudden decline in B-IBI scores, it is particularly important that benthic community monitoring continue at HMI in the immediate future. It is also strongly recommended that a comprehensive analysis of the historical HMI dataset be performed to make any meaningful determinations regarding the overall health of the benthic community in the vicinity of HMI.

REFERENCES

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

Cain, T.S. 1975. Reproduction and recruitment of the brackish water clam *Rangia Cuneata* in the James River, Virginia. Fishery Bulletin, 73 no. 2, 412-430.

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

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

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

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

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

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

Hopkins S.H., J.W. Anderson, J.W. and K. Horvath. 1973. The Brackish water clam Rangia cuneata as indicator of ecological effects of salinity changes in coastal waters. U.S. Army engineer waterways experiment station. Vicksburg, Mississippi.

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

Maryland Department of the Environment. *in review*. Assessment of the Environmental Impacts of the Hart-Miller Island Dredged Material Containment Facility Dredged material containment facility, Maryland. Year 17 Exterior Monitoring Technical Report, September 1998-August 1999. *Prepared by* Dredging Coordination and Assessment Division of Maryland Department of the Environment *for* Maryland Port Administration.

Maryland Department of the Environment. *in review*. Assessment of the Environmental Impacts of the Hart-Miller Island Dredged Material Containment Facility Dredged material containment facility, Maryland. Year 18 Exterior Monitoring Technical Report, July 1999-April 2000. *Prepared by* Dredging Coordination and Assessment Division of Maryland Department of the Environment *for* Maryland Port Administration

Maryland Department of the Environment. *in review*. Assessment of the Environmental Impacts of the Hart-Miller Island Dredged Material Containment Facility Dredged material containment facility, Maryland. Year 19 Exterior Monitoring Data Report, September 2000-April 2001. *Prepared by* Dredging Coordination and Assessment Division of Maryland Department of the Environment *for* Maryland Port Administration.

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

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

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

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

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

Sokal, R.R. and F.J. Rohlf. 1995. Biometry. W. H. Freeman and Company, New York.

Sarda, R, I. Valiela, & K. Foreman. 1995. Life cycle, demography, and production of *Marenzelleria viridis* in a salt marsh of southern New England. Journal of the Marine Biological Association, U.K. Vol. 75, 725-738.

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

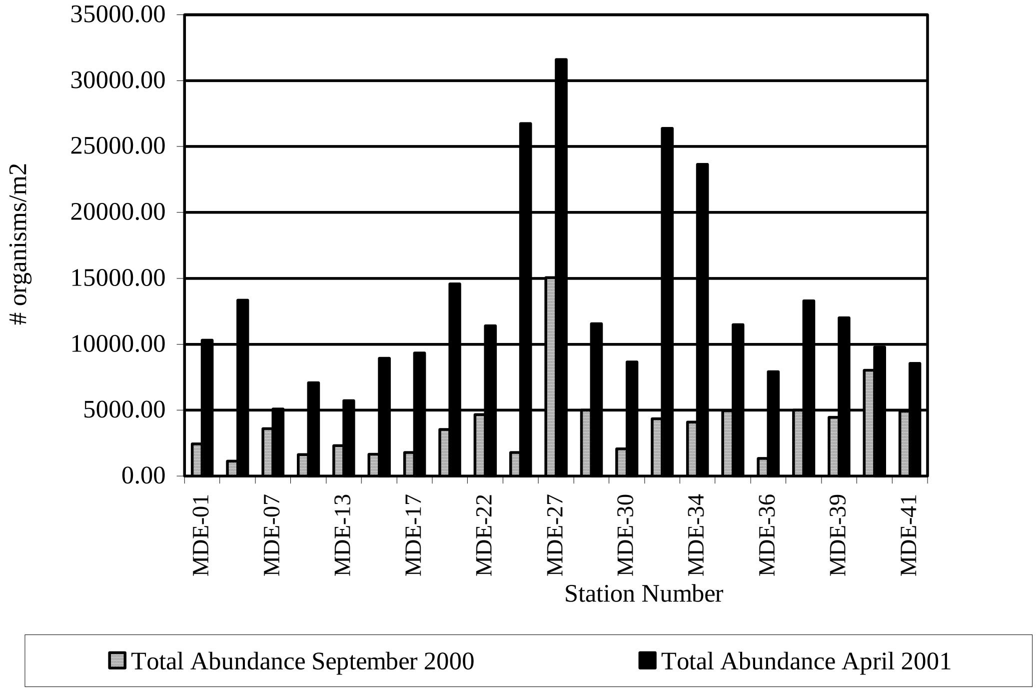


Figure 15: Total average abundance of infauna and epifauna taxa collected at each HMI station in year 19, September 2000 and April 2001.

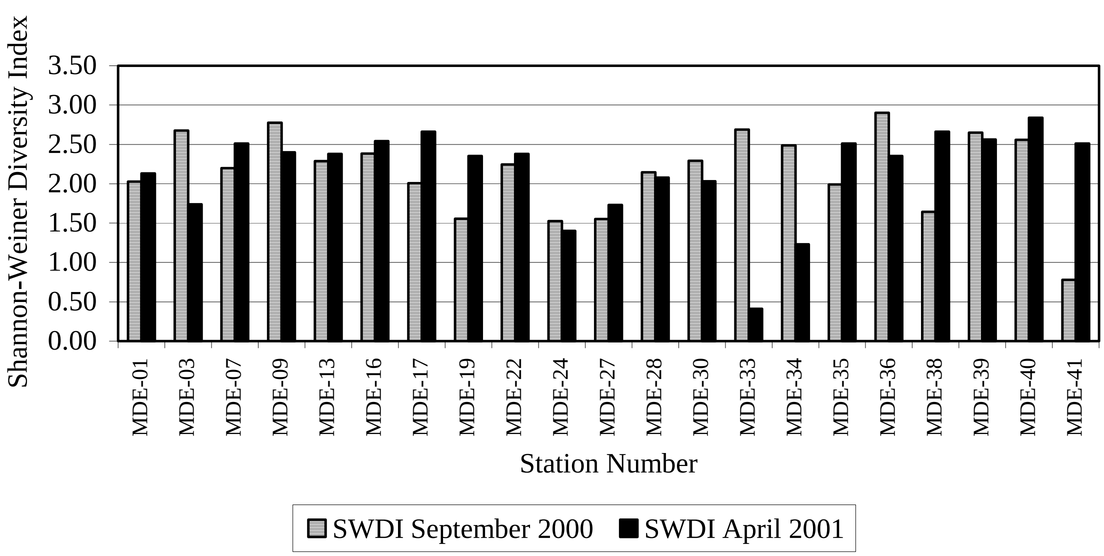


Figure 16: Shannon-Weiner Diversity Index (SWDI), HMI year 19, September 2000 and April 2001.

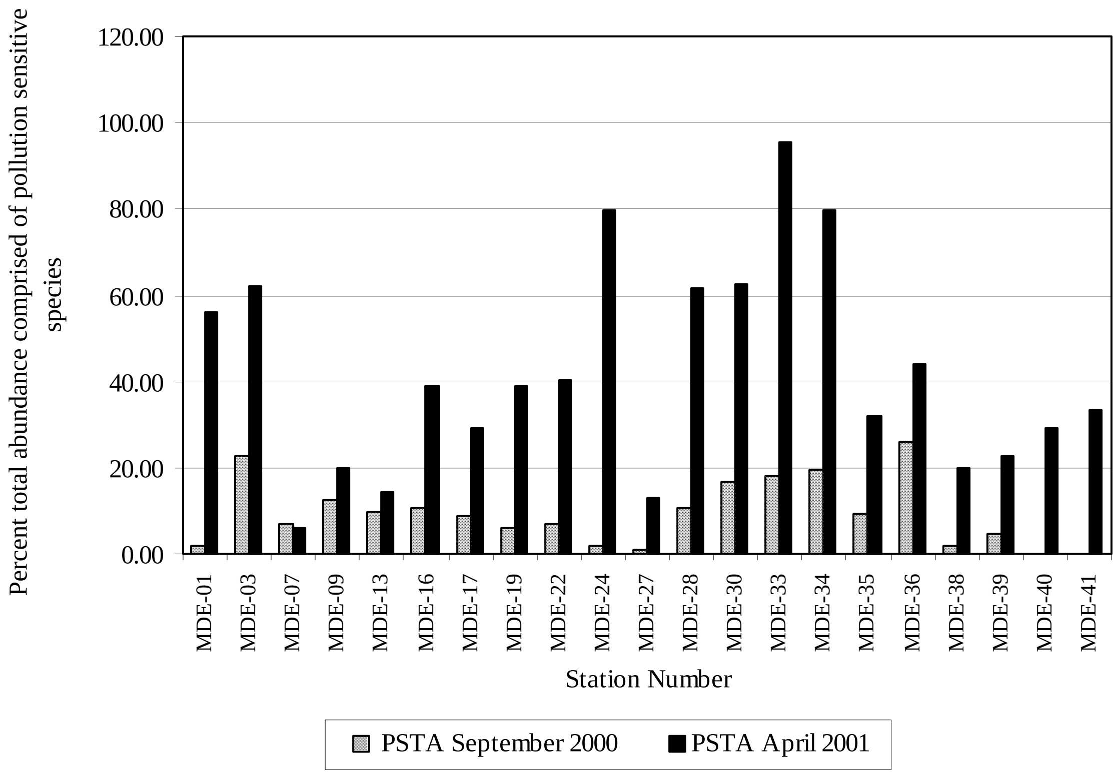


Figure 17: Percent abundance comprised of pollution sensitive taxa abundance (PSTA), HMI year 19 September 2000 and April 2001.

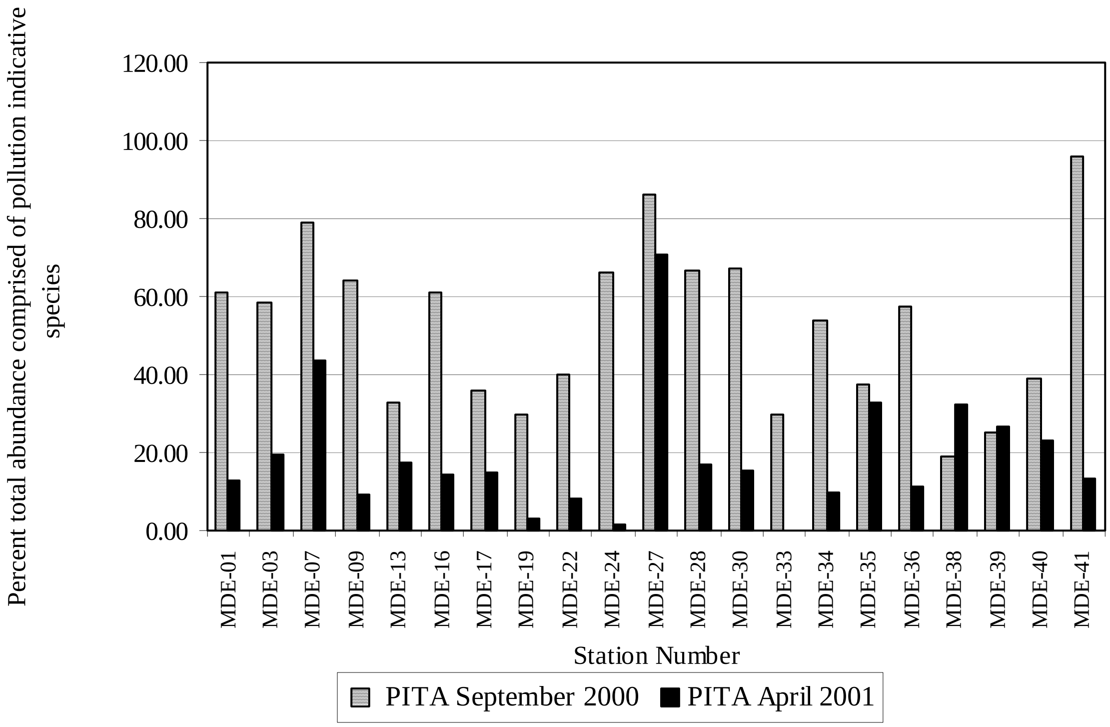


Figure 18: Percent abundance comprised of pollution indicative species (PITA), HMI year 19 September 2000 and April 2001.

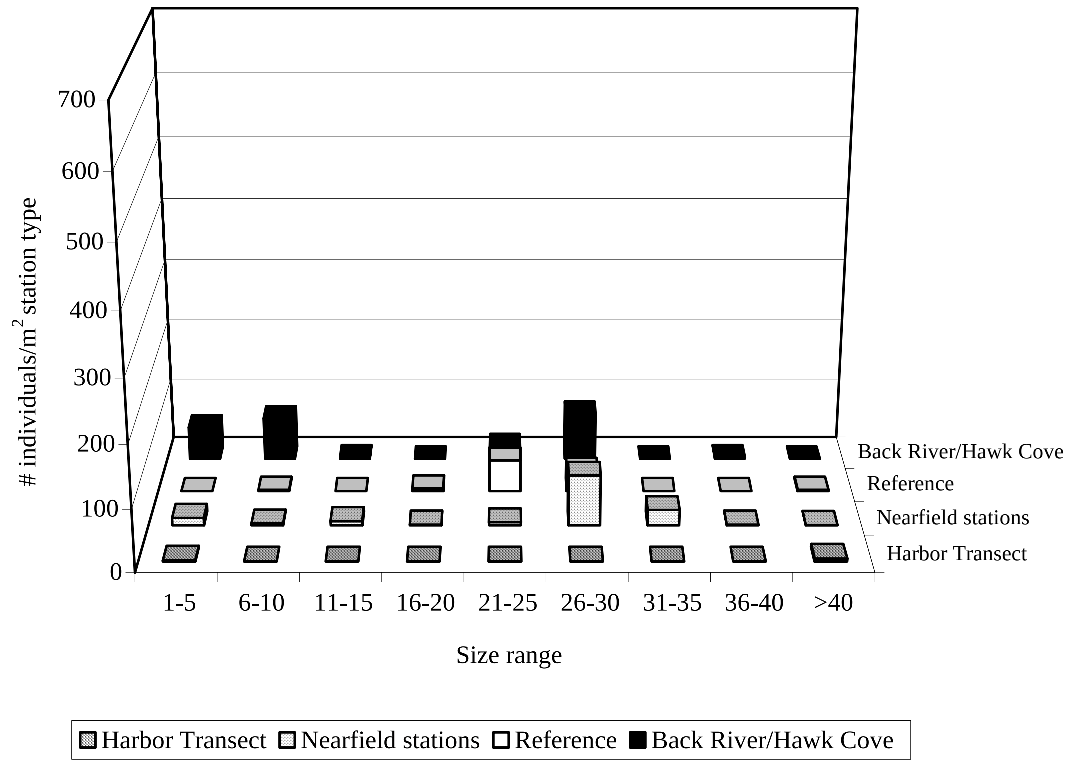


Figure 19: Average Abundance of *Rangia cuneata* at HMI stations, year 19 September 2000.

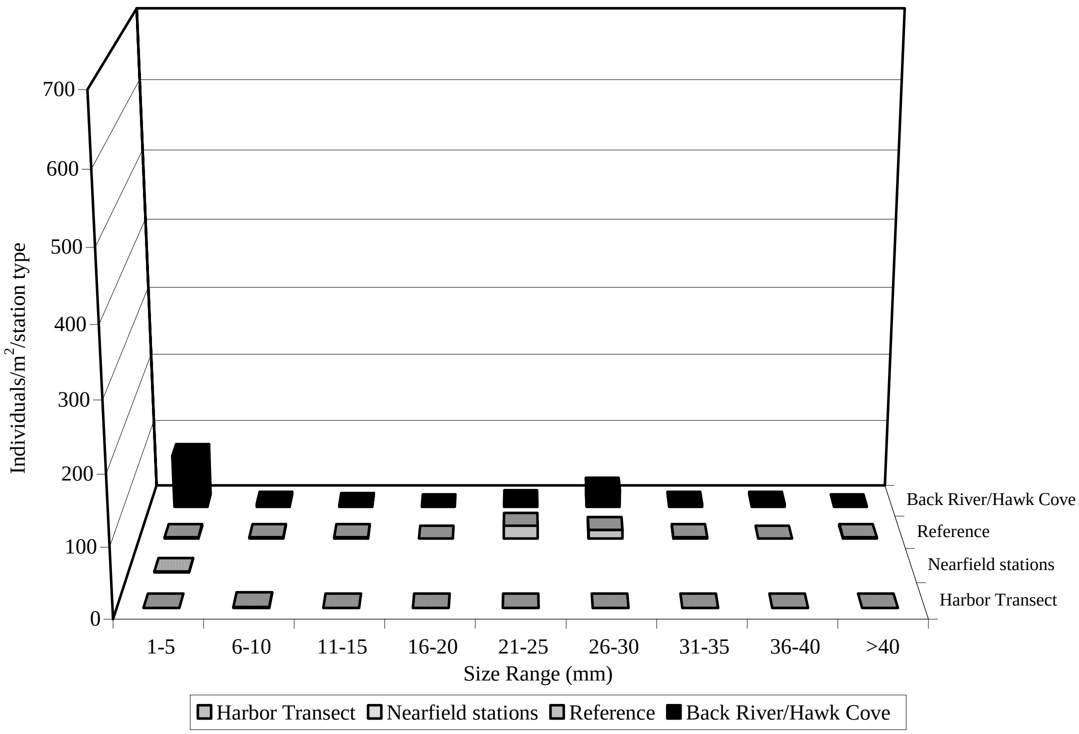


Figure 20: Average Abundance of *Rangia cuneata* at HMI stations, year 19 April 2001.

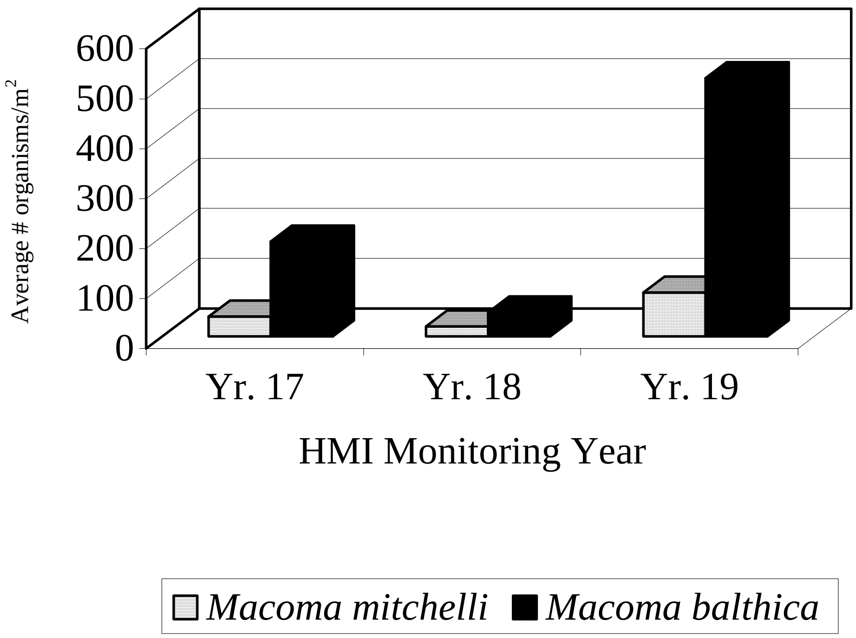


Figure 21: Average Abundance of *Macoma mitchelli* and *Macoma balthica* in April 2001 HMI years 17-19.

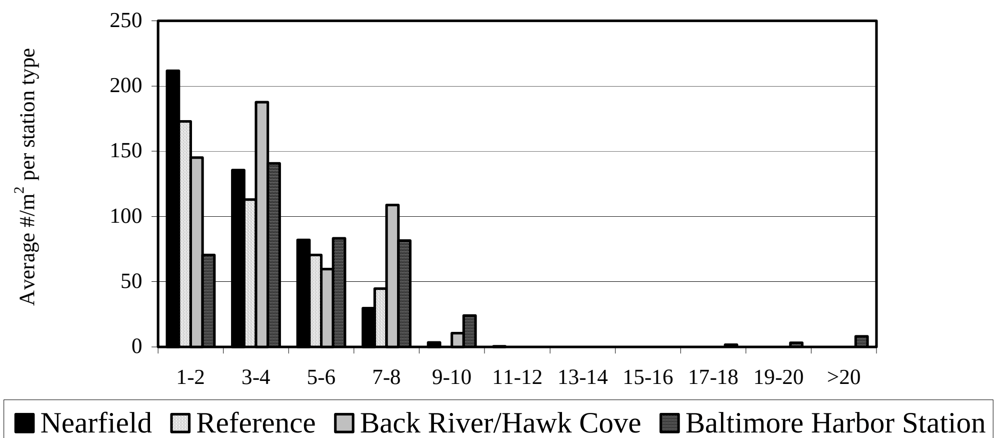


Figure 22: Average Abundance of *Macoma balthica* at HMI stations, year 19 April 2001.

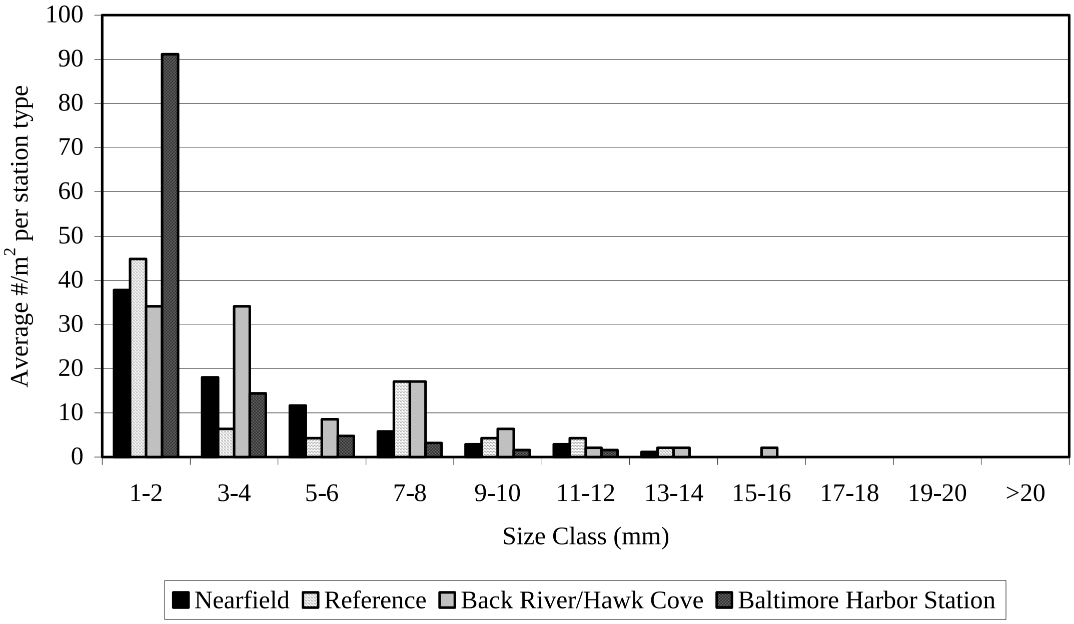


Figure 23: Average Abundance of *Macoma mitchelli* at HMI stations, Year 19, April 2001.

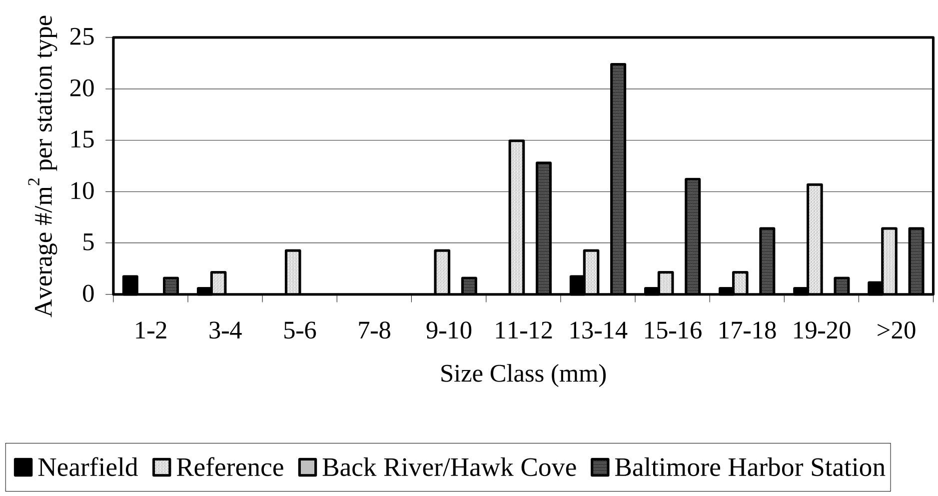


Figure 24: Average Abundance of *Macoma balthica* at HMI stations, Year 19 September 2000.

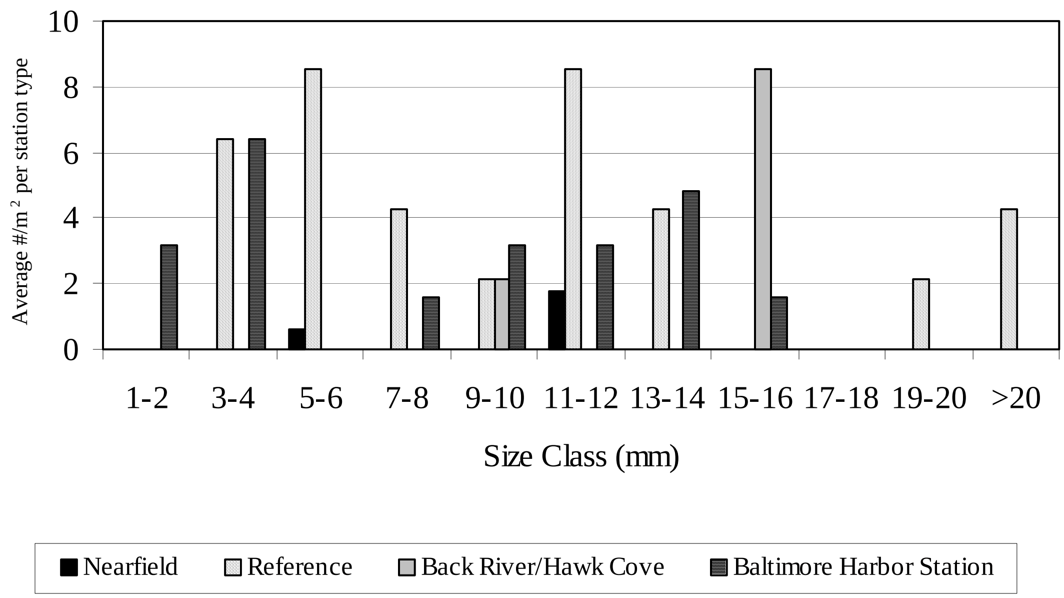


Figure 25: Average Abundance of *Macoma mitchelli* at HMI stations, Year 19 September 2000.

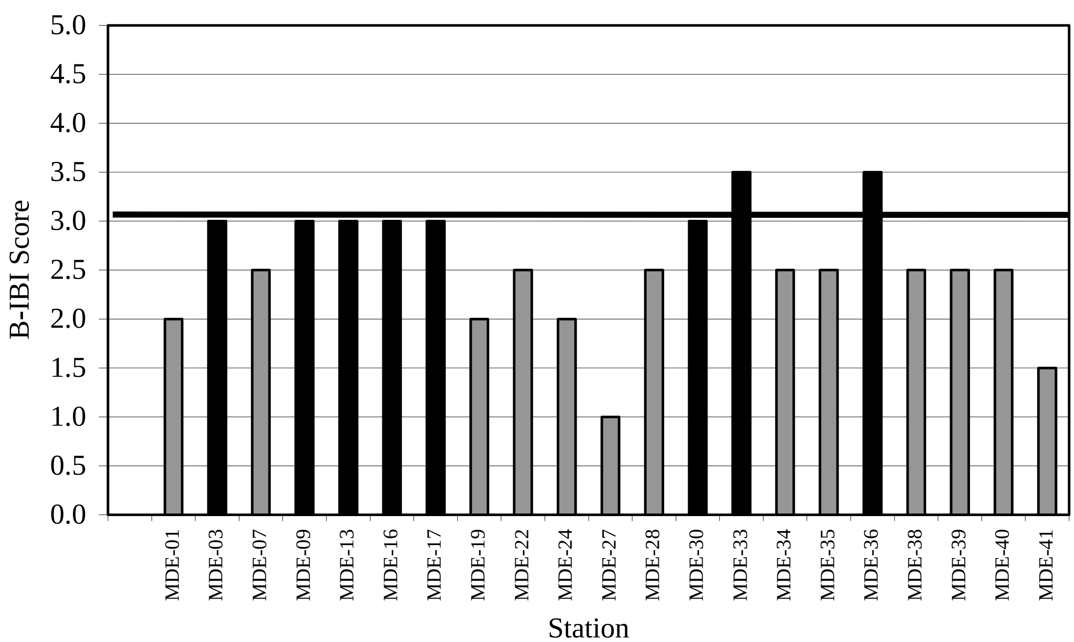


Figure 26: B-IBI scores for all HMI stations in Year 19, September 2000.

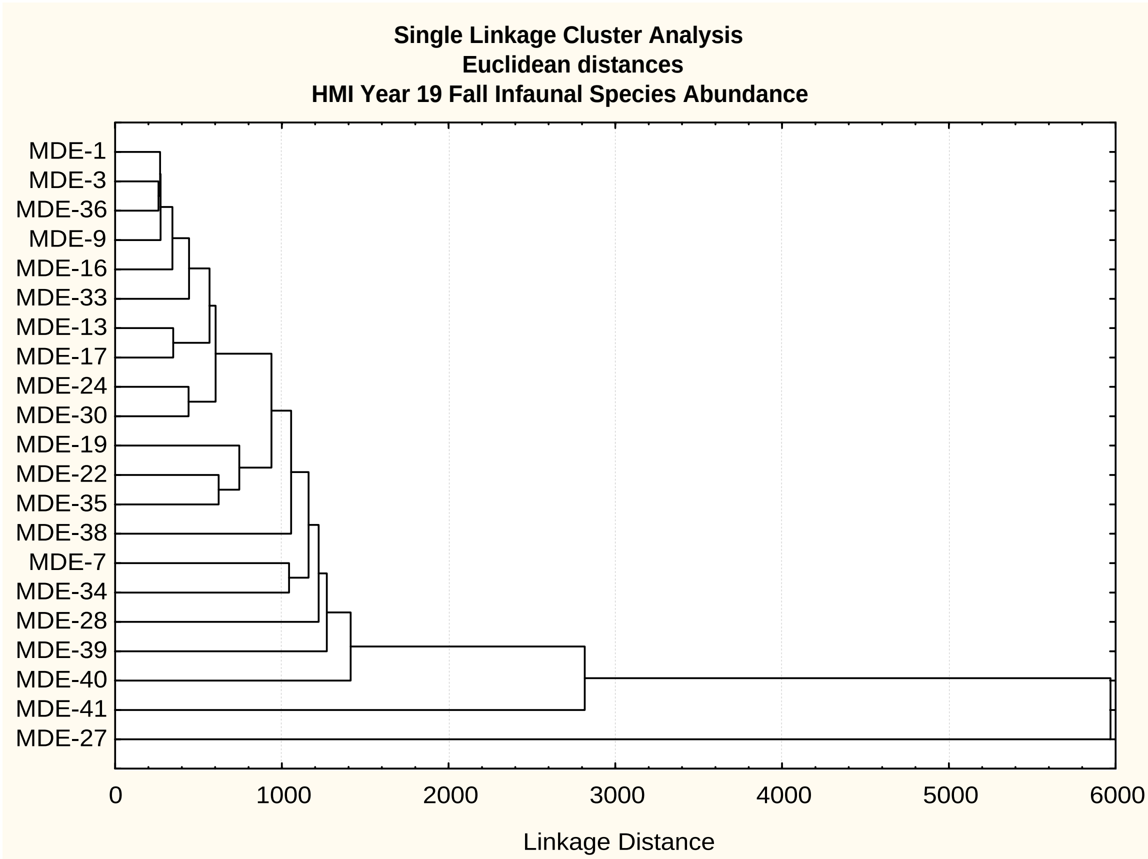


Figure 27: Cluster analysis based on Euclidean distance matrix of infaunal abundances of all HMI stations, year 19 September 2000.

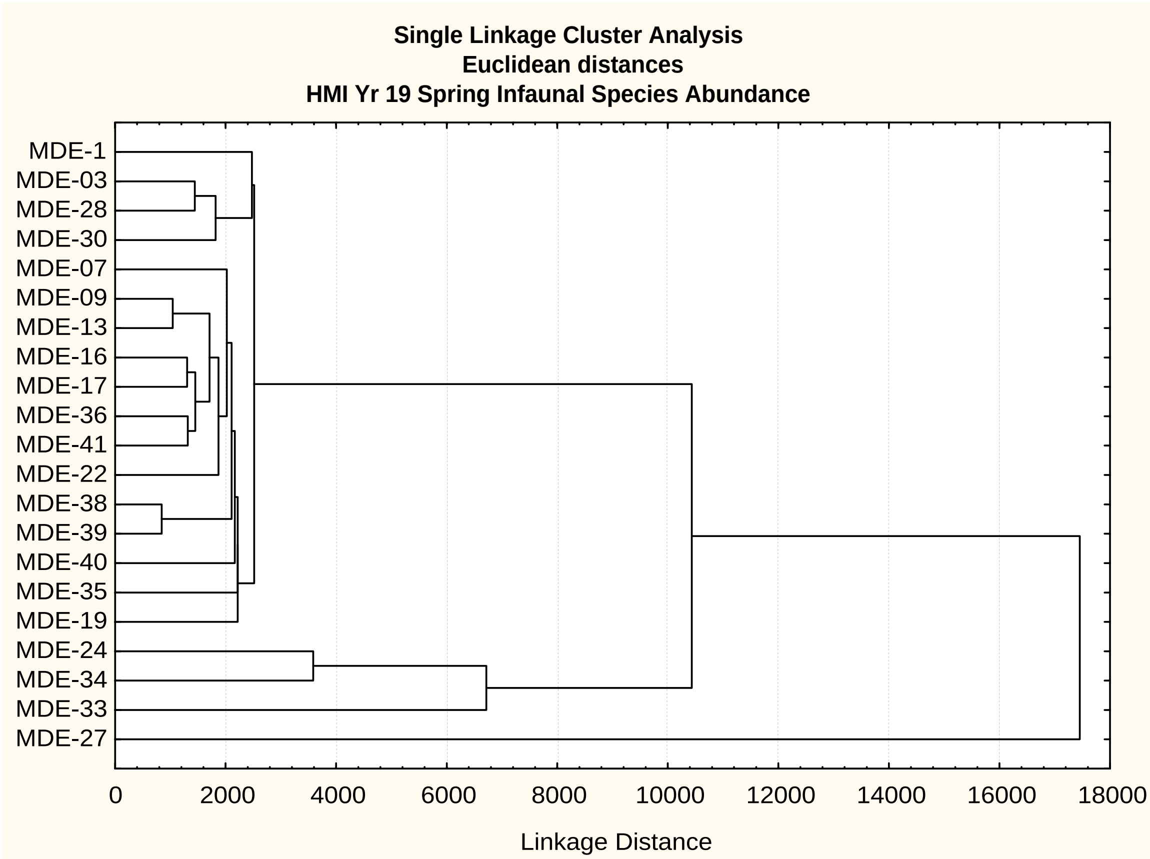


Figure 28: Cluster analysis based on Euclidean distance matrix of infaunal abundances of all HMI stations, year 19 April 2001.

CHAPTER 4: ANALYTICAL SERVICES (PROJECT IV)

By
R. Mason, Principal Investigator
J. Baker, Principal Investigator
Andrew Heyes, Associate Research Scientist
F-C Ko, Assistant Research Scientist
Debby Heyes, Faculty Research Assistant
Dan Liebert, Faculty Research Assistant

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

OBJECTIVES

The objective of this study was to characterize contaminant levels in a resident clam, *Rangia cuneata*, and sediments at Hart-Miller Island Dredged Material Contaminant Facility (HMI). Samples have been collected since 1981 at HMI as part of an Exterior Monitoring Program. The current Year 19 sampling effort for Project IV was initiated in concert with the HMI Exterior Monitoring Program. The goals of the project are to continue to measure and evaluate the current levels of contaminants in the vicinity of HMI (Figure 29) in sediments and biota, and to relate these, as far as possible, to historical data. Samples of clams and sediments were collected for trace metal and organic contaminant analysis. Comparison and correlation of this data with historical HMI data, will indicate the extent of contamination and any trend in concentrations at this location.

The results of the quality assurance (QA/QC) procedures and the description of the analytical and field protocols are contained in the *Year 19 Data Report*. Overall, the QA/QC results were acceptable for a study of this nature. No evidence of bias or lack of precision or accuracy was indicated by the QA/QC results. Comparisons of duplicate analyses and comparison of measured values to certified values for the analyzed Standard Reference Materials are also discussed in the *Year 19 Data Report*. Again, the QA/QC objectives were met in this regard.

METHODS AND MATERIALS

Sampling Procedures

Samples were collected from sites designated by the revised sampling plan, developed by the Maryland Department of the Environment (Figure 29) in September 2000 and April 2001. Sediment samples were collected from 14 of the 36 designated sample sites for organic analysis (see below). On both cruises trace metal samples were collected using plastic spatulas intergrating the top several centimeters and avoiding the sides of the sampler to minimize the possibility of contamination. Sediments were placed in 18 oz. Whirl-Pak™ bags and were kept cooled in an ice chest or refrigerator until they could be processed in the laboratory.

Clam (*Rangia cuneata*) samples were taken for trace element sampling from 14 sites in September 2000 and April 2001. Several pulls of the dredge were taken at each site to provide enough clams for contaminant analysis. Clams were placed in zip-lock bags and stored on ice until they were returned to the laboratory. Many clams were taken that were less than 3.5 cm, but most clams selected for analysis were >3.0 cm. In the laboratory, the clam samples were cataloged and divided into subsamples for trace metal and organic contaminant analysis. For organic analysis, composite samples of clams from each site were prepared by removing fresh clams whole from their shells with a stainless steel scalpel. All body fluids were retained in the sample. The scalpel was cleaned with methanol between each sample set to avoid cross contamination between stations. Tissue was placed in a clean glass jar with a Teflon-lined lid and stored in the dark below 0^0C. For metals analysis, clams were removed whole from their shells with a Teflon-coated spatula. Most of the water and body fluids were allowed to drain.

The spatula was acid rinsed between each site to avoid cross contamination between sites. The clam bodies from each site were homogenized in a plastic blender with a stainless steel blade. Unused samples were returned to their respective bags and stored in the freezer until further analysis.

Analytical Procedures for Metals

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

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

Samples for mercury (1-3 g wet weight) were digested in a solution of 70% sulfuric/30% nitric acid in Teflon vials, heating overnight in an oven at 60^0C (Mason et al. 1995). The digestate was then diluted to 10 mLs with distilled-deionized water. Prior to analysis, the samples were further oxidized for 30 minutes with 2 mLs of bromine monochloride solution. The excess oxidant was neutralized with 10% hydroxylamine solution and the concentration of mercury in an aliquot of the solution was determined by tin chloride reduction cold vapor atomic fluorescence (CVAFS) detection after gold amalgamation in accordance with protocols outlined in USEPA Method 1631 (Mason et al. 1993).

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

Analytical Methods for Organic Contaminants

Whole clams were removed from shells using a stainless steel scalpel and stored in pre-cleaned glass jars with Teflon lined lids. The clams were separated by site and collection date. In Fall of 1998 the clams were also separated into two size classes, based on shell length, prior to homogenization. The clams' bodies were homogenized in a stainless steel tissue blender and returned to respective sample jars. The clam homogenates were extracted and purified using the method described by Kucklick et al. (1996). For this method, a subsample of clam homogenate, 5 g wet weight, is removed and ground with anhydrous sodium sulfate (~50 g). A perdueterated polyaromatic hydrocarbon (PAH) cocktail (d_8-napthalene, d_{10}-fluorene, d_{10}-fluoranthene, d_{12}-perylene) and a noncommercial polychlorinated biphenyl (PCB) solution (IUPAC #'s 14, 65, 166) are added as surrogates to each sample to track extraction efficiency. The mixture is then extracted in a Soxhlet apparatus with 250 mL of dichloromethane (DCM) for 24 hours. The extracts are then concentrated to 2 mL using a vacuum rotary evaporator and transferred into hexane. Each sample is transferred to a 4 ml Waters autosampler vial with sample and rinses amounting to approximately 4 mL. Gravimetric lipid analysis is performed on each sample with subsampled fractions determined gravimetrically (Kucklick et al. 1996). Samples are again concentrated in similar fashion as above, then solvent exchanged to hexane. To remove lipids the extracts are then eluted with 25 mL petroleum ether over 4 g deactivated Alumina [6% (w/w) water]. After concentrating, the extracts are spiked with a perdueterated PAH mixture (d_{10}-acenapthene, d_{10}-phenanthrene, d_{12}-benz[*a*]anthracene, d_{12}-benzo[*a*]pyrene, d_{12}-benzo[*g,h,I*]perylene) for quantification of PAH's. The samples are then analyzed using a Hewlett Packard 5890 gas chromatograph (GC) with a HP-5MS (cross linked 5% phenyl methyl siloxane) capillary column (30m x 0.25mm x 0.25um film thickness) and a HP-5972 series mass spectrometer (MS) for PAH's (Ko and Baker 1995). Each sample is separated after GC/MS analysis into two fractions with 35 mL of petroleum ether and 50 mL of DCM/PET (1:1), respectively, over 8 g of deactivated Florisil (2.5% (w/w) water (Kucklick et al.1996). The first fraction (F-1), contains PCBs and 1-100%, by weight of the less polar organochlorine pesticides [heptachlor (100%), 4,4-DDT (40%), 4,4-DDE (100%), t-nonachlor (24%), heptachlor (1%), 4,4-DDT(44%)]. The second fraction, (F-2), contains 56-100% of the more polar organochlorine pesticides [a-HCH (100%), g-HCH (100%), c-chlordane (100%), t-chlordane (100%), t-nonachlor (76%), heptachlor (99%), heptachlor epoxide (100%), dieldrin (100%), 4,4-DDD (100%), 4,4-DDT (56%)]. Both fractions are solvent exchanged to hexane and concentrated to ~ 1 mL.

PCB congeners are analyzed by gas chromatography using a J&W Scientific DB-5 capillary column (60m x 0.32mm, 0.25µm film thickness) coupled with an electron capture detector. Individual PCB congeners are identified and quantified using the method of Mullins et al. (1985) using the noncommercial PCB congeners IUPAC 30 and 204 as internal standards. After quantification of PCB congeners, the two Florisil fractions from each sample are recombined and pesticides are quantified by gas chromatography (30 m DB-5 column) with negative chemical ionization mass spectrometric (NCI-MS) detection. Chemical ionization with methane reagent gas is used. Pesticides are identified by their chromatographic retention times and confirmed by the relative abundance of negative fragments (confirmation ions) relative to the quantification fragment. Five-point calibration curves are used for each pesticide analyzed. Polychlorinated biphenyl congener 204 is used as the internal standard for the pesticide quantification.

RESULTS AND DISCUSSION

Metal concentrations in fall 2000 were again strongly correlated with sediment organic content with higher concentrations being found for all metals with increasing organic matter in sediments (Fig. 29). Such relationships have been seen before at HMI and elsewhere (Mason and Lawrence, 1999) and suggest that organic matter is the phase important for metal binding in sediments. The correlation relationships are strongest for the metals that bind strongly with organic matter such as Pb, and to a lesser degree with Cd and Hg. The lack of a strong correlation is somewhat surprising as this metal is normally considered to form strong complexes with organic matter (Mason and Lawrence, 1999). The lack of correlation could be a result of the fact that Hg concentrations are generally low and organic matter content is relatively high, and thus the excess amount of organic matter is masking the trend. In spring 2001, the correlation for Hg was stronger, as it was generally with the other metals (Fig. 29). For the metalloids, As and Se, there is also a good correlation between concentration and sediment organic content.

The metal concentrations in sediments for the fall sampling of the 19^{th} Year are compared to those of the previous years in Fig. 30, for all stations where data is available for all, or most of, the years. Overall, for Hg and Cd, there is little difference in the average concentrations over the years (Fig. 30). For Ag, there is much more variability in the data, and this reflects the greater difficulty of measuring Ag in sediments compared to the other metals. However, while there is the semblance of a trend, it should be noted that the error bars overlap and thus the trend is not statistically significant although it does suggest a decrease in concentration of Ag in sediments over time. Looking at the individual sites, there appears to be a few high values at individual sites in the early years that are biasing the average values (Fig. 30). However, overall, the lowest concentrations at the various sites were measured in 2000. As Ag is a good indicator of sewage, or urban inputs, due to its use widely in the photographic industry, this trend may indicate a decrease in inputs to the HMI environs from the city from the urban environment. More analysis and sampling would be needed to further assess this trend. For the other metals, while there are values that are higher than average at some stations in each year, there does not appear to be a statistical trend overall in the data, even on an individual station basis (Fig. 30).

Bioaccumulation factors (BAF; the concentration in clams relative to the sediment at the same site) were calculated for the sites where both sediment and clams were collected and plotted against the sediment organic content in Fig. 31. As has been seen before at HMI and elsewhere (Mason and Lawrence, 1999), there is generally a non-linear decrease in BAF with increasing sediment organic content. Such trends are more discernable for those metals and metalloids that are concentrated to a higher degree. At the low organic sites, MMHg had the highest BAF, followed by Ag, Cd and Se. As, Pb and Hg had low BAFs even at the lowest organic matter sites. At high organic content, it appears that Ag is less effected by sediment composition than MMHg (Fig. 31) and that it has the highest BAFs. The BAFs for all the other elements discussed here are low (<5) at the highest organic content sites.

The concentrations of the various organic contaminants in sediments collected during the fall sampling are shown in Fig. 32. While the clam data collected in Year 19 are not shown in a figure, it can be confirmed by comparison of the data in the data report, that averages concentrations of PAHs and PCBs in this year were similar to previous years. The same appears true for PCBs and PAH's but more data is required for a definitive answer.

The BAF values were lowest for PAHs and more similar for PCBs and pesticides (Fig. 33). For PAHs, the values were relatively similar across sites except for site 33 where a much higher BAF was found. Note that site 33 has a low sediment concentration (Fig. 32). This site also had higher BAFs for the other organic contaminants. Indeed, if the BAFs for the organic contaminants are plotted against sediment organic content, then a similar trend to that found for the more bioaccumulative metals (Fig. 31) is seen i.e. BAFs decrease with increasing sediment organic content (Fig. 33). This is intriguing that the some metals and the organic contaminants behave similarly in this regard and suggest that similar processes are involved in defining these relationships. In direct comparison, it can be noted that the BAF values for the organic contaminants are much lower (<7) than those for the metals being more compable to those of metals that are not considered strongly accumulated, such as Pb. In contrast, the BAF for MMHg is somewhat greater than 140 at the lowest organic matter content. It has been shown for metals that bioavailability is a function of organic content of the sediment as this controls the degree to which the metal is released into solution during the digestion in the organism's gut (Lawrence et al., 1999), and this degree of solubilization is directly related to bioaccumulation potential. It is likely that a similar relationship exists for the organic contaminants. Thus, concentrations in sediments, and the resulting concentration in the biota are governed by fundamental processes that are now well-known and must be taken into account in determining whether a level of metal or organic contaminant in sediment is bioavailable or an environmental risk.

ıt

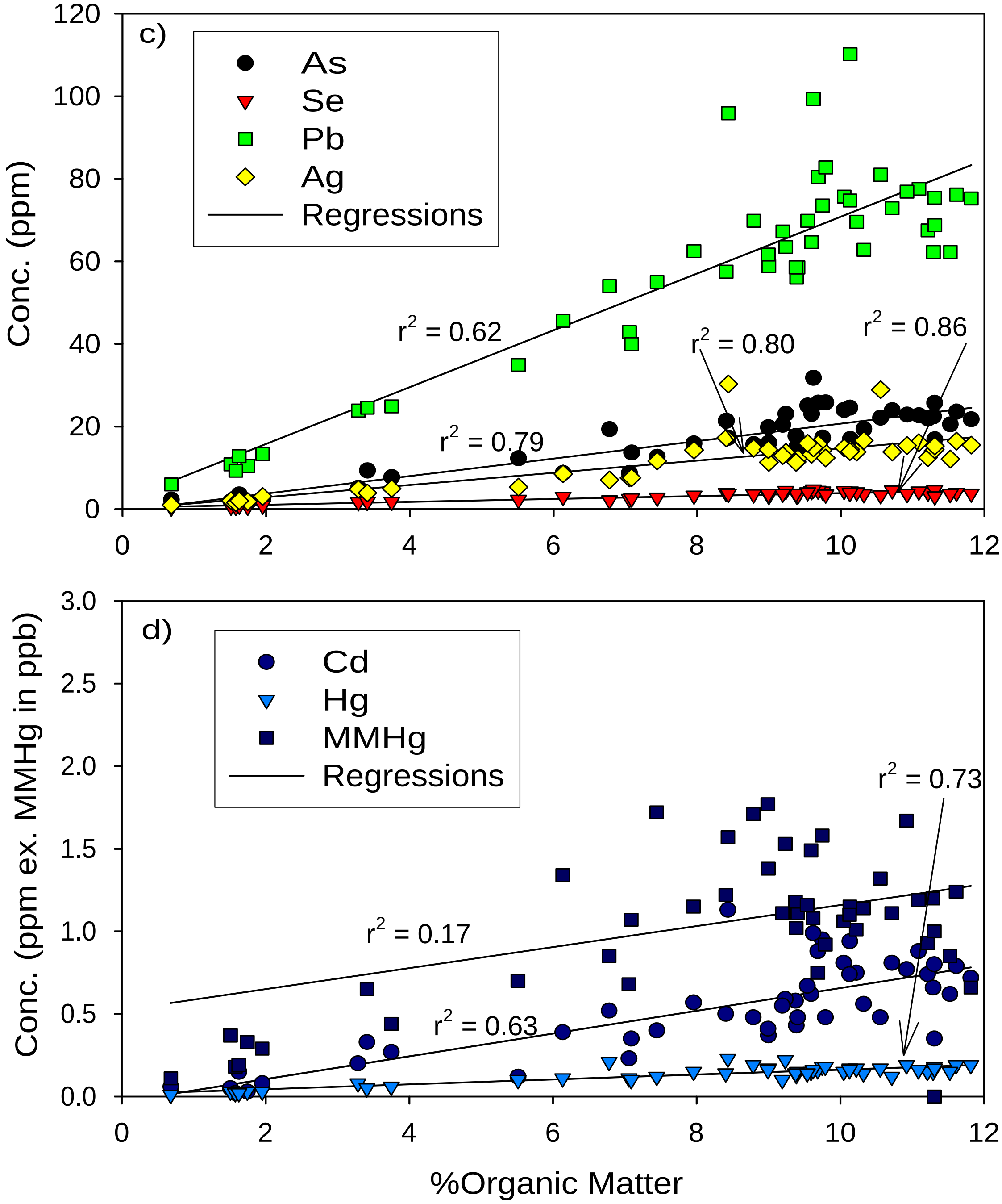


Figure 29: Metal correlations with sediment organic content, HMI, April 2001.

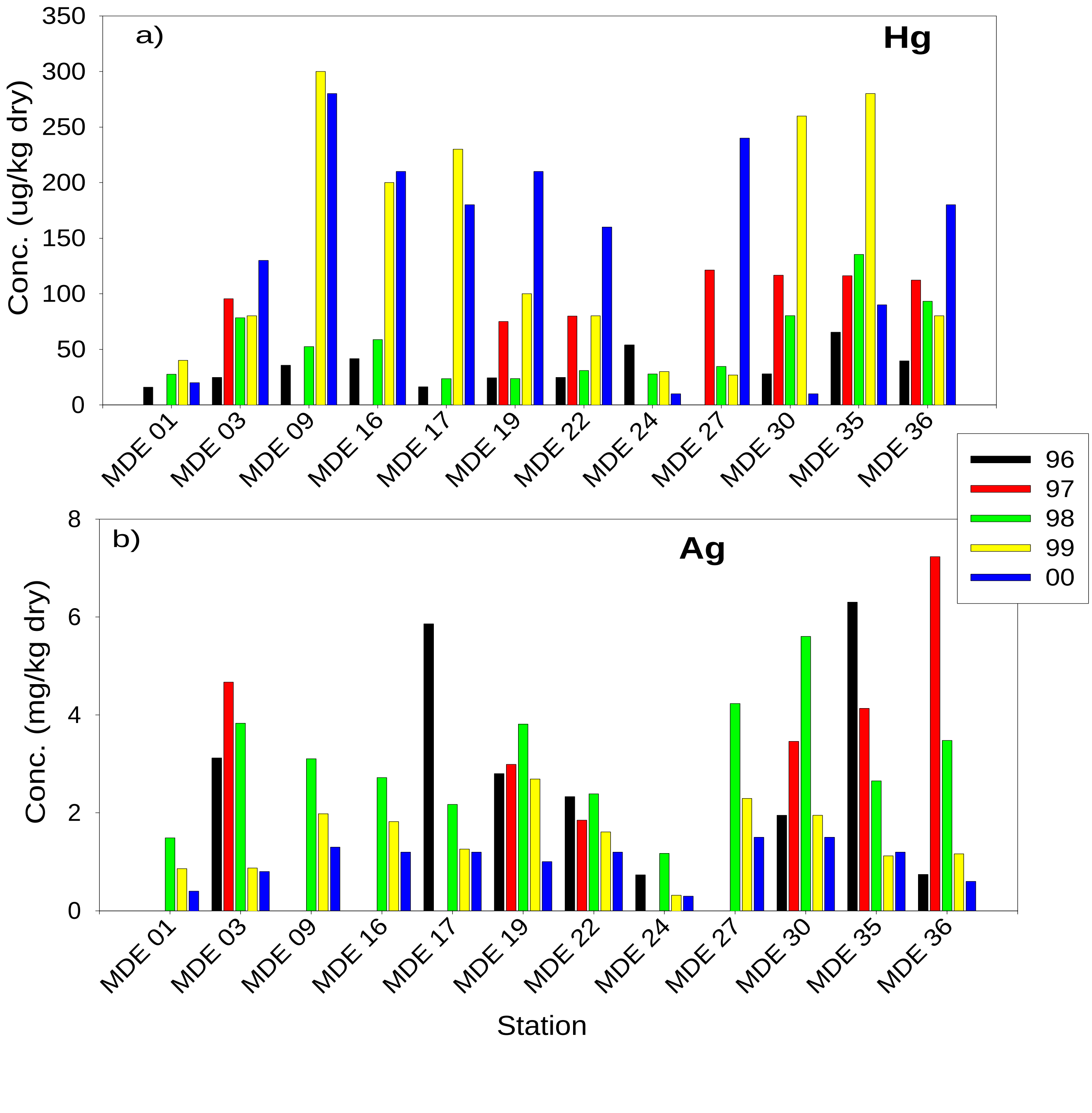
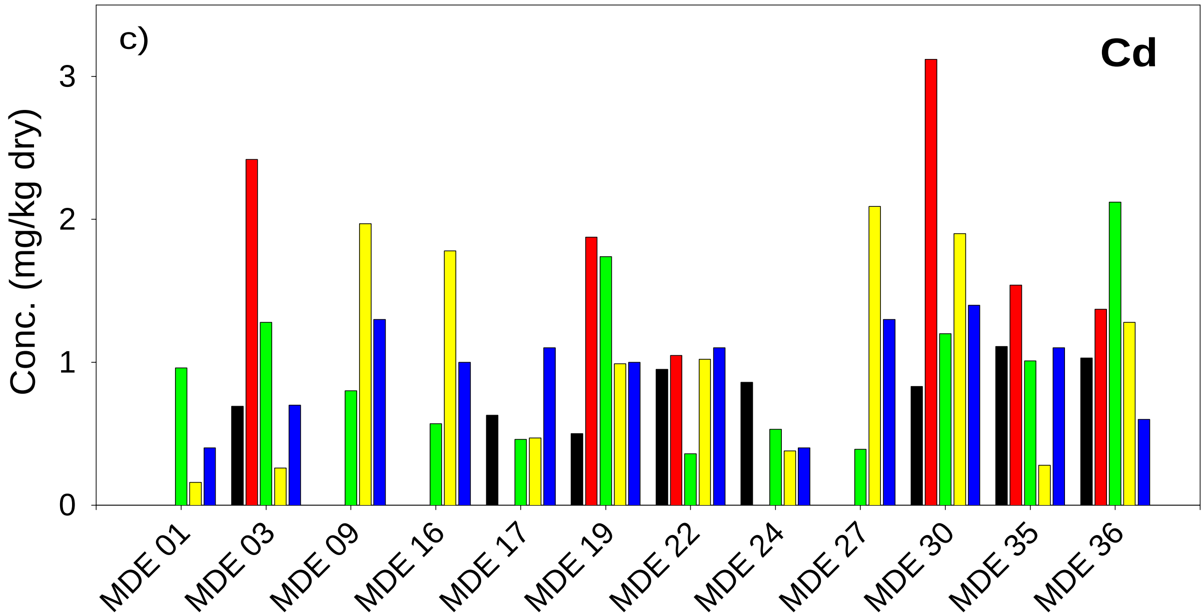


Figure 30: Comparison of sediment mercury and silver concentrations for fall sampling for the last five years of measurement.



Yearly Trends

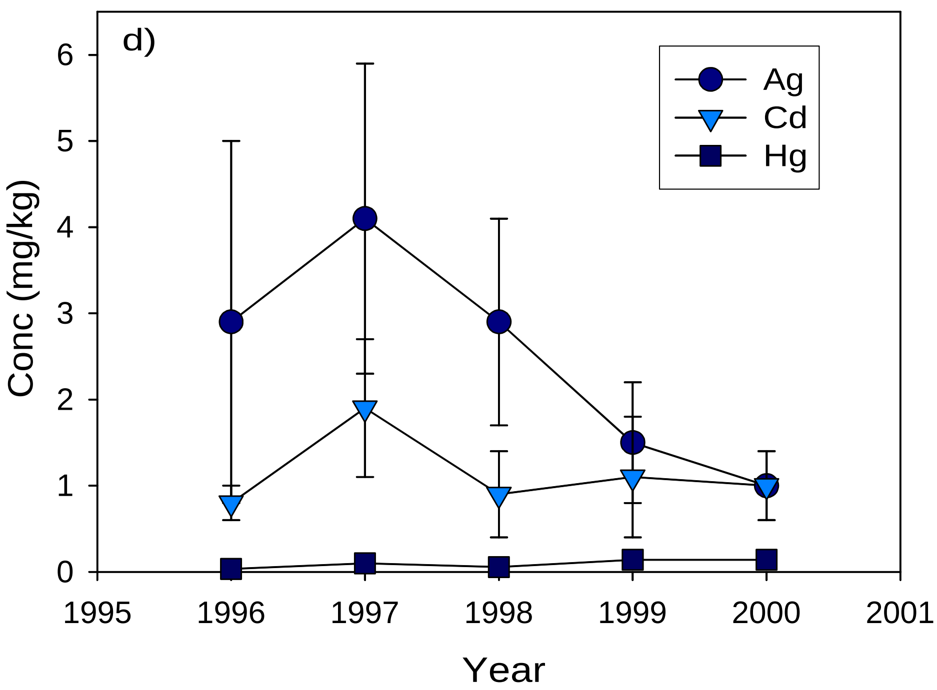
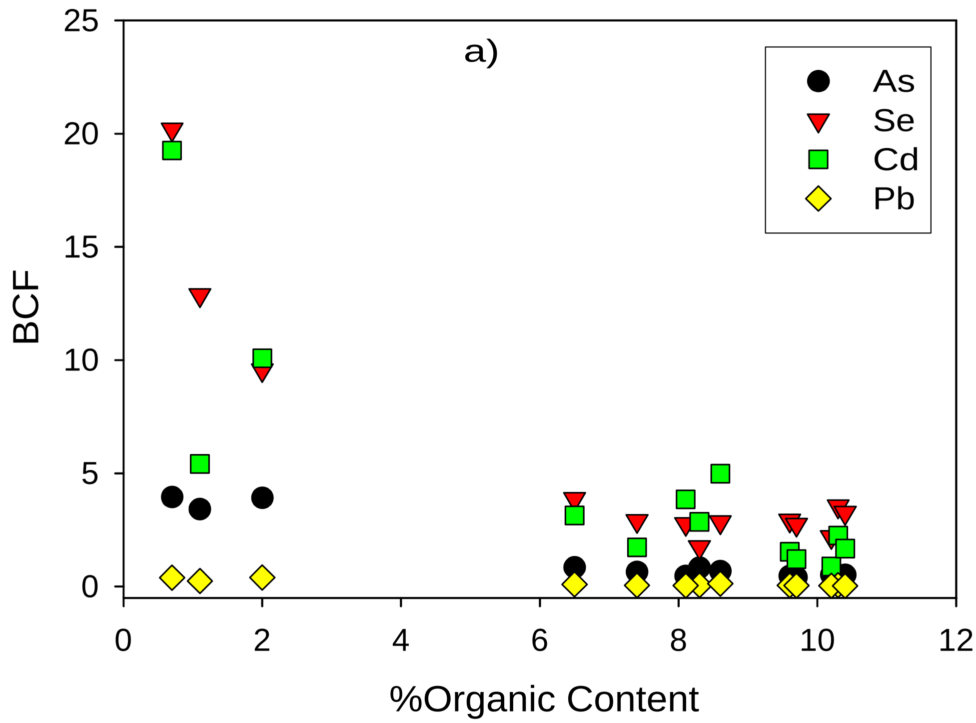


Figure 31: Sediment cadmium concentrations and overall metal trends for fall sampling over the last five years of measurement.



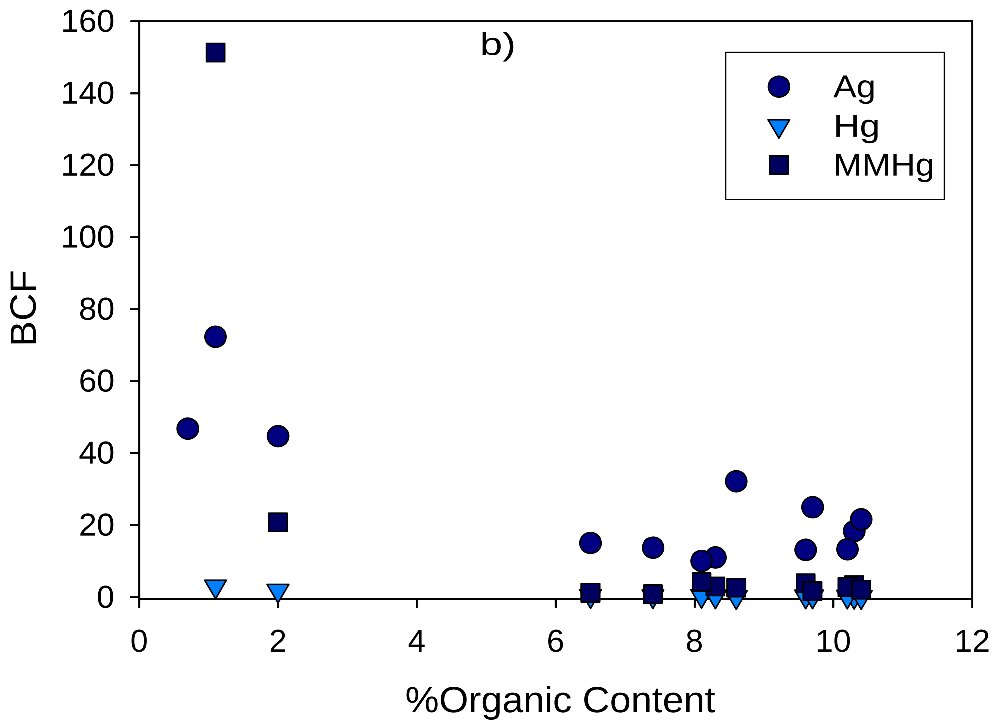


Figure 32: Bioaccumulation factors for metals in clams around HMI.

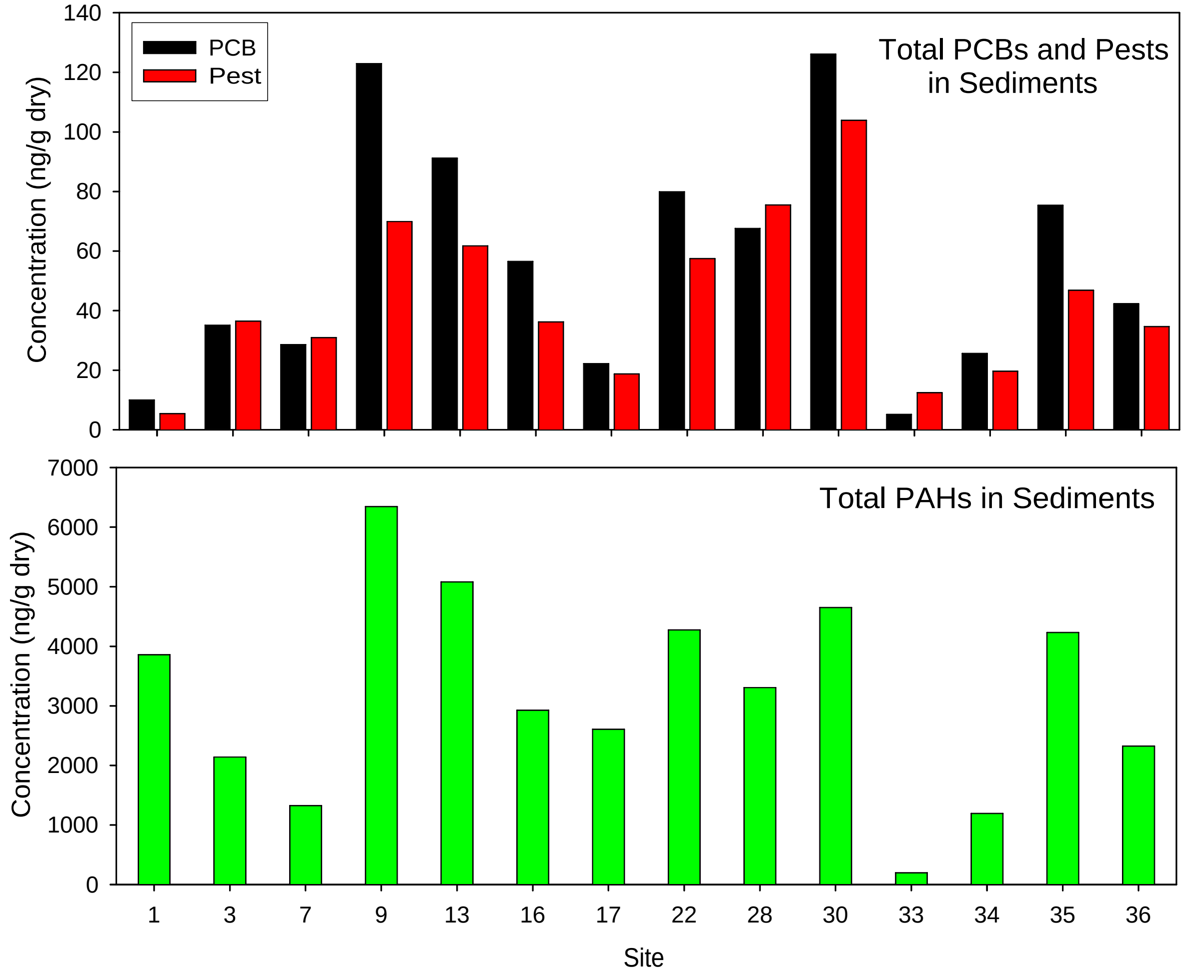


Figure 33: Total concentrations of organic contaminants in sediments for the Fall sampling.

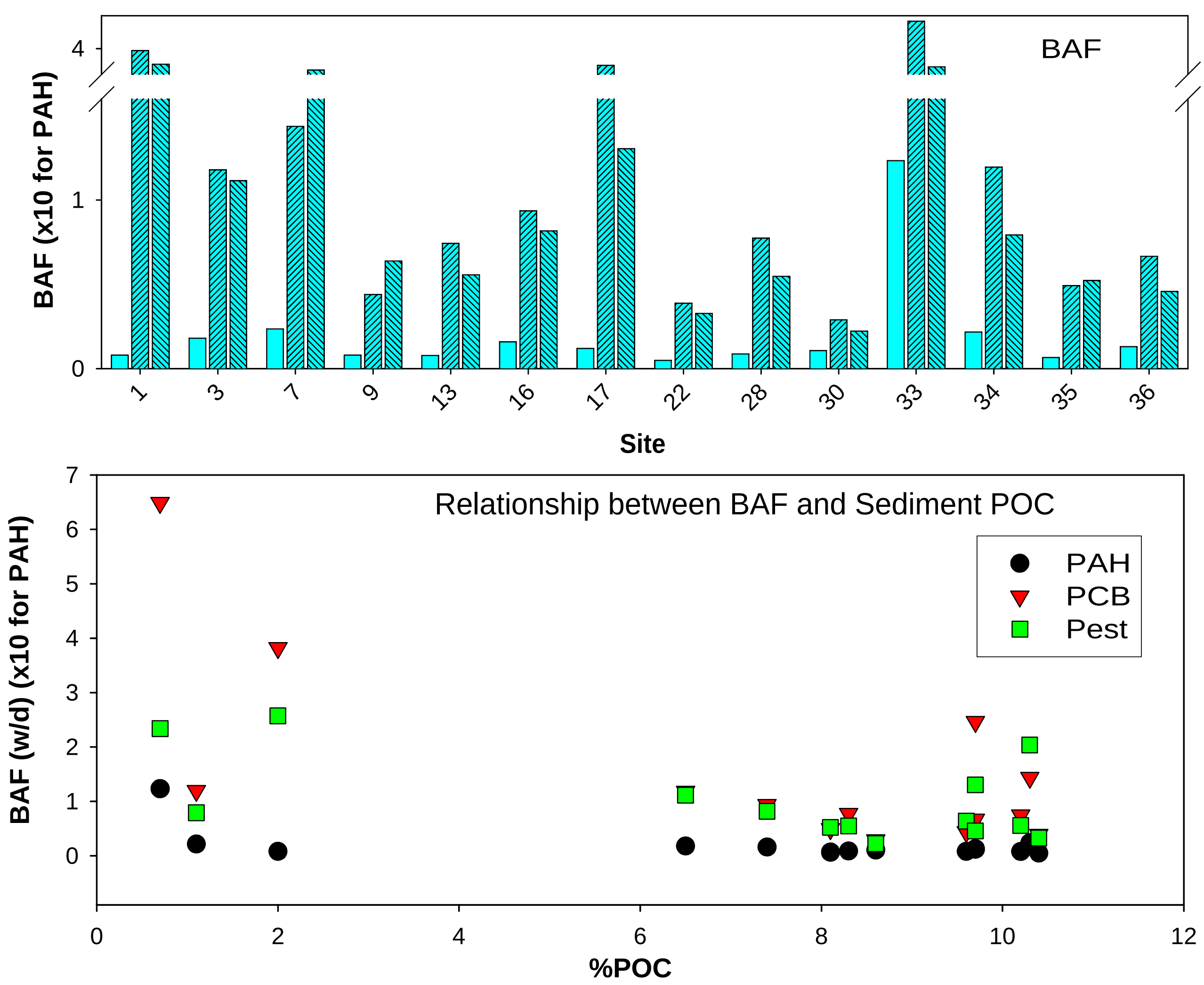


Figure 34: Bioconcentration factors for organic contaminants in clams and their relationship to sediment organic content.

REFERENCES

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

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

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

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

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

Lawrence, A.L., K.M. McAloon, R.P. Mason, and L.M. Mayer. 1999. Intestinal solubilization of particle-associated organic and inorganic mercury as a measure of bioavailability to benthic invertebrates. Environ. Sci. Technol. **33**:1871-1876.

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

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

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

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