TECHNICAL AND ENGINEERING COORDINATION SECTION

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YEAR 14 TECHNICAL REPORT

Assessment of the Environmental Impacts of the Hart-Miller Island Confined Disposal Facility, Maryland

Year 14 Exterior Monitoring Technical Report
(September 1994-August 1995)

Prepared By
Dredging Coordination and Assessment Division
Maryland Department of the Environment

Prepared For
Maryland Port Administration
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DEFINITION OF TERMS

Amphipod	Crustacean order containing laterally compressed members such as the sand hoppers.
Bathymetric	The topography below the surface of a body of water which reveals depth profiles.
Benthic	Referring to the bottom of a body of water.
Benthos	The organisms living in or on top of the sediments at the bottom-most layer of a body of water.
Bioaccumulation	The accumulation of contaminants in the tissue of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, pore water or dredged material.
Bioaccumulation factor	The degree to which an organism accumulates a chemical compared to the source. It is a dimensionless number or factor derived by dividing the concentration in the organism by that in the source.
Bioassay	A test using a biological system. It involves exposing an organism to a test material and determining a response. There are two major types of bioassays differentiated by response: toxicity tests which measure an effect (e.g., acute toxicity, sublethal/chronic toxicity) and bioaccumulation tests which measure a phenomenon (e.g., the uptake of contaminants into tissues).
Biogenic	Resulting from the activity of living organisms. For example, bivalve shells are biogenic materials.
Biomagnification	Bioaccumulation up the food chain, e.g., the route of accumulation is solely through food. Organisms at higher trophic levels will have higher body burdens than those at lower trophic levels.
Biota	The animal and plant life of a region.
Bioturbation	Mixing of sediments by the burrowing and feeding activities of sediment-dwelling organisms. This disturbs the normal, layered patterns of sediment accumulation.
Brackish	Salty, though less saline than sea water. Characteristic of estuaries, where freshwater and saline water are mixed.

Bryozoa	Phylum of colonial animals that often share one coelomic cavity. Encrusting and branching forms secrete a protective housing (zooecium) of calcium carbonate or chitinous material. Possess lophophore feeding structure.
Bulk sediment chemistry	Results of chemical analyses of whole sediments (in terms of wet or dry weight), without normalization (e.g., to organic carbon, grain-size, acid volatile sulfide).
Confined disposal	A disposal method that isolates the dredged material from the environment. Confined disposal is placement of dredged material within diked containment facilities via pipeline or other means.
Confined disposal facility(CDF)	A diked area, either in water or upland, used to contain dredged material. The terms confined disposal facility (CDF), dredged material containment area, diked disposal facility, and confined disposal area are used interchangeably.
Contaminant	A chemical or biological substance in a form that can be incorporated or ingested by, through one or more pathways, and that harms aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment, and includes but is not limited to the substances on the 307(a)(1) list of toxic pollutants promulgated on January 31, 1978 (43 FR 4109).
Contaminated material	Material dredged from Baltimore Harbor, originating to the northwest of a line from North Point to Rock Point, or other polluted sites. Material shows high concentrations of metals, PCBs, organics, etc.
Dendrogram	A branching, diagrammatic representation of the interrelations of a group of items sharing some common factors (as of natural groups connected by ancestral forms).
Desiccation	The process of drying thoroughly; exhausting or depriving of moisture.
Diversity index	A statistical measure that incorporates information on the number of species present in a habitat with the abundance of each species. A low diversity index suggests that the habitat has been stressed or disturbed.
Dominant (species)	An organism or a group of organisms that, by their size and/or numbers, constitute the majority of a given community.

Dredge	Any of various machines equipped with scooping or suction devices used in deepening harbors and waterways and in underwater mining.
Effluent	Something that flows out or forth; an outflow or discharge of waste, as from a sewer.
Enrichment factor	A method of normalizing geochemical data to a reference material, which partially corrects for variation due to grain size.
Epifauna	Benthic animals living on the surface of, not within, bottom sediments.
Fine-grained material	Sediments consisting of particles less than or equal to 0.062 mm in diameter.
Flocculation	An agglomeration of particles bound by electrostatic forces.
Gas chromatography	A method of chemical analysis in which a sample is vaporized and diffused along with a carrier gas through a liquid or solid adsorbent for differential adsorption. A detector records separate peaks as various compounds are released (eluted) from the column.
Gravity core	A sample of sediment from the bottom of a body of water, obtained with a cylindrical device, used to examine sediments at various depths.
Gyre	A circular motion or eddy. Used mainly in reference to the circular motion of water in each of the major ocean basins centered in subtropical high-pressure regions.
Hydrodynamics	The study of the dynamics of fluids in motion.
Hydrography	The scientific description and analysis of the physical condition, boundaries, flow, and related characteristics of oceans, rivers, lakes, and other surface waters.
Hydrozoa	A class of coelenterates that characteristically exhibit alternation of generations, with a sessile polypoid colony giving rise to a pelagic medusoid form by asexual budding.
Infauna	Benthic animals living within bottom sediments.
Leachate	Water or any other liquid that may contain dissolved (leached) soluble materials, such as organic salts and mineral salts, derived from a solid material.

Littoral zone	The benthic zone between the highest and lowest normal water marks; the intertidal zone.
Mixing zone	A limited volume of water serving as a zone of initial dilution in the immediate vicinity of a discharge point where receiving waters may not meet water quality standards or other requirements otherwise applicable to the receiving water. The mixing zone may be defined by the volume and/or the surface area of the disposal site or specific mixing zone definitions in the Code of Maryland Regulations (COMAR).
Nephelometric turbidity unit (NTU)	A unit of measurement of the amount of light scattered or reflected by particles within a liquid.
Open water disposal	Direct placement of dredged material in rivers, lakes or estuaries via pipeline or surface release from hopper dredges or barges.
QA	Quality Assurance, the total integrated program for assuring the reliability of data. A system for integrating the quality planning, quality control, quality assessment, and quality improvement efforts to meet user requirements and defined standards of quality with a stated level of confidence.
QC	Quality Control, the overall system of technical activities for obtaining prescribed standards of performance in the monitoring and measurement process to meet user requirements.
Radiograph	An image produced on a radiosensitive surface, such as a photographic film, by radiation other than visible light, especially by x-rays passed through an object or by photographing a fluoroscopic image.
Salinity	The concentration of salt in a solution. Full strength seawater has a salinity of about 35 parts per thousand (ppt). Normally computed from conductivity or chlorinity.
Secchi depth	The depth at which a standard, black and white Secchi disk disappears from view when lowered into water.
Sediment	Material, such as sand, silt, or clay, suspended in or settled on the bottom of a water body.
Seine	A large fishing net made to hang vertically in the water by weights at the lower edge and floats on the top.

Spectrophotometer	An instrument used in chemical analysis to measure the intensity of color in a solution.
Spillway	A channel for an overflow of water.
Substrate	A surface on or in which a plant or animal grows or is attached.
Supernatant	The clear fluid over sediment or precipitate.
Total suspended solids (TSS)	A measurement (usually in milligrams per liter or parts per million) of the amount of particulate matter suspended in a liquid.
Trace metal	A metal that occurs in minute quantities in a substance.
Trawl	A large, tapered fishing net of flattened conical shape, towed along the bottom of a body of water. To catch fish by means of a trawl.
Turbidity	The property of the scattering or reflection of light within a fluid, as caused by suspended or stirred-up particles.
Turbidity maximum	A zone in a water body where turbidity is typically the greatest, resulting from the influx of river-borne sediments, and flocculation of clay particles due to prevailing salinity patterns.
Water Quality Certification	A state certification, pursuant to Section 404 of the Clean Water Act, that the proposed discharge of dredged material will comply with the applicable provisions of Sections 301, 303, 306 and 307 of the Clean Water Act and relevant State laws.
Water Quality Standard	A law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body.

LIST OF ACRONYMS

AAS -	Atomic Absorption Spectrometry
AVS -	Acid Volatile Sulfide
CBL -	Chesapeake Biological Laboratory
CDF -	Confined Disposal Facility
CFR -	Code of Federal Regulations
CWA -	Clean Water Act
DNR -	Department of Natural Resources
EPA -	United States Environmental Protection Agency
FDA -	Food and Drug Administration
FR -	Federal Register
GC -	Gas Chromatography
ICAP -	Inductively Coupled Argon Plasma
MDE -	Maryland Department of the Environment
MES -	Maryland Environmental Service
MGS -	Maryland Geological Survey
MPA -	Maryland Port Administration
MS -	Mass Spectrometry
NEPA -	National Environmental Policy Act
NIST -	National Institute of Standards and Technology
NOAA -	National Oceanic and Atmospheric Administration
NPDES -	National Pollutant Discharge Elimination System

PAH - Polynuclear Aromatic Hydrocarbons

PCB - Polychlorinated Biphenyl

QA - Quality Assurance

QC - Quality Control

SAB - Science Advisory Board

SOP - Standard Operating Procedure

SQC - Sediment Quality Criteria

SQS - Sediment Quality Standards

SRM - Standard Reference Material

TDL - Target Detection Limit

TMDL - Total Maximum Daily Load

TOC - Total Organic Carbon

USACE - U.S. Army Corps of Engineers

USCS - Unified Soil Classification System

WQC - Water Quality Certification

WQS - Water Quality Standard

CONVERSIONS[1]

WEIGHT:

1Kg = 1000g = 2.205lbs
1g = 1000mg = 2.205 x 10^{-3}lbs
1mg = 1000μg = 2.205 x 10^{-3}lbs
1lb = 16oz = 0.4536Kg

LENGTH:

1m = 100cm = 3.28ft = 39.370in
1cm = 10mm = 0.3937in
1mm = 1000μm = 0.03937in
1ft = 12in = 0.348m

CONCENTRATION:

1ppm = 1mg/L = 1mg/Kg = 1μg/g = 1mL/m^3
1g/cc = 1Kg/L = 8.3454 lbs/gallon
1g/m^3 = 1mg/L = 6.243 x 10^{-5}lbs/ft^3
1lb/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 = 764.555L = 0.764m^3
1acre-ft = 1233.482m^3
1 gallon = 3785cc
1ft^3 = 0.028m^3 = 28.3168L

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 = 0.03048m/s
1yd^3/min = 0.45ft^3/s
1yd^3/s = 202.03gal/s = 764.555L/s

AREA:

1m^2 = 10.764ft^2
1hectare = 10000m^2 = 2.471acres
1ft^2 = 0.0929m^2
1acre = 4046.856m^2 = 0.405 hectares

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[1] Modified from the June 1994 Draft "Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. - Testing Manual" published by the United States Environmental Protection Agency and the U.S. Army Corp of Engineers, 16 pp.

CHAPTER 1: SCIENTIFIC COORDINATION AND DATA MANAGEMENT (PROJECT I)

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The Year 14 Hart-Miller Island (HMI) Exterior Monitoring Program would not have been successful without the help of several Technical and Regulatory Services Administration (TARSA) staff members, including: Mr. Visty P. Dalal, Chairman; Mr. Matthew Rowe, Technical Coordinator; Mr. Nathaniel Brown, Budget Manager; and, Ms. Ellen Lathrop-Davis, Environmental Specialist. The Chairman was responsible for making sure that the project work was done efficiently in a coordinated manner and met all the technical goals set by the Technical Review Committee for Year 14. The Technical Coordinator wrote the Project I sections of the HMI reports, standardized the Data and Technical reports among projects, conducted data management, and facilitated the peer review process. The Budget Manager was responsible for assuring that all project related budgetary products, services, and activities had been implemented by each Principal Investigator (PI) and accounted for in a budgetary tracking system. The Environmental Specialist provided insightful comments on and scientific review of the data and technical reports.

The Maryland Department of the Environment would like to thank all the members of the HMI Exterior Monitoring Program's Technical Review Committee and the HMI Citizens Oversight Committee for their useful comments and suggestions throughout the project year. Special thanks to the Maryland Port Administration, under the auspices of the Maryland Department of Transportation, for their continued commitment to and financial support of the Exterior Monitoring Program. The efforts and cooperation of the PIs for each project during the Year 14 monitoring effort were greatly appreciated. A thank you also goes out to the Maryland Environmental Service (MES) for providing information on the dredged material inputs to HMI for Year 14.

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

EXECUTIVE SUMMARY

The implementation and administration of a monitoring program sufficiently sensitive to the environmental effects of dredged material containment at Hart-Miller Island continues to be a complex and difficult endeavor. The scope and focus of the Exterior Monitoring Program has varied over the lifetime of the project. Baseline studies included characterizations of water chemistry, productivity, submerged aquatic vegetation, and sediments. Bathymetric studies were completed within the first three monitoring years. Fish population studies were conducted during the first five years of facility operation. The physical and chemical characterization of sediments, benthic community studies, and benthic tissue contaminant analyses are ongoing studies that will be continued through the operational lifetime of the facility.

Responsibility for Scientific Coordination and Data Management of the Hart-Miller Island Confined Disposal Facility was transferred to the Maryland Department of the Environment (MDE) from the Maryland Department of Natural Resources (DNR) in July 1995. Responsibility for Project I was transferred (in 1997) within MDE to the Dredging Coordination ans Assessment Division (DCAD). Beginning with the production of the Year 13 reports, DCAD assumed the responsibility for scientific and technical planning, coordination, and oversight of this project. The overall rationale of the monitoring program and the specific methodological approach of each project therein are coordinated by DCAD among the Principal Investigators. To ensure communication among the various scientists and managers collaborating on this project, DCAD facilitates regular meetings of the Technical Review Committee (TRC), Principal Investigators (PIs) and the Citizens Oversight Committee (COC). Lastly, DCAD is responsible for budget and database management, as well as compiling, editing, printing and distributing the HMI Data and Technical Reports.

INTRODUCTION

The maintenance of shipping lanes in the Baltimore Harbor and its approach channels is of vital importance to the economy of the state of Maryland. Keeping these shipping channels open requires annual dredging of naturally accumulated sediments. The Hart-Miller Island Confined Disposal Facility (HMI) was created to receive material dredged from navigation channel maintenance and improvement activities in Baltimore Harbor and its approaches.

HMI is located in Chesapeake Bay at the mouth of Back River and to the northeast of Baltimore Harbor. Construction of HMI began in 1981 by creating 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 interior of the facility. The eastern side of the dike was additionally 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 at HMI began with dike completion and continues to the present. The volumes, dates and project names for dredged material placed at HMI during Year 14 of the HMI Exterior Monitoring Program are provided in the following table:

Table 1-1: Dredged material placement at HMI (10/94-7/95).

Project	**Quantity** (cubic yards)
Fifty Foot	2,293,196
Rukert Terminal	45,450
Dundalk Marine Terminal	63,500
Bethlehem Steel Shipyard	258,139
Sue Creek	19,135
School House Cove	9,780
Pleasure Island	16,000
Total Quantity Placed at HMI	**2,705,200**

The HMI Exterior Monitoring Program was developed in response to a special condition of State Wetlands License [No. 72-127(R)], requiring monitoring of water quality and biota near the facility. Results from the monitoring are used to observe changes from baseline environmental conditions in the area surrounding HMI, and, if necessary, to guide decisions regarding operational changes and remedial actions. Past exterior monitoring efforts have characterized the sedimentary characterized the sedimentary environment and biotic community near the facility. Fish and crab population studies were discontinued after Year 5 due to the ineffectiveness of using the information as a monitoring tool. Beach erosion studies were discontinued after Year 13 in response to beach replenishment and stabilization with breakwaters.

The current monitoring program is divided into four projects: 1) Scientific Coordination and Data Management; 2) Sedimentary Environment (physical and chemical analysis); 3) Benthic Community Studies; and 4) Analytical Services (chemical analysis of sediments and biotic tissue). Monitoring in Year 14 was a continuation of the sediment and biota studies conducted in previous years.

Project I: Scientific Coordination and Data Management

In July 1995, responsibility for Project I, Scientific Coordination and Data Management, was transferred to the Maryland Department of the Environment (MDE) from the Maryland Department of Natural Resources (DNR). The Year 13 data entry that began at DNR was completed there and the files were then transferred to MDE. In September 1998, the Year 13 project reports were published, completing documentation for the first year of the HMI Exterior Monitoring Program conducted under MDE's supervision. Year 14 is the second year of MDE's technical oversight of the monitoring program.

MDE is responsible for ensuring the scientific integrity of the HMI Exterior Monitoring Program. This includes evaluating the sampling protocols and analytical methods used by the principal investigators (PIs) for each project. MDE makes sure that each monitoring project undergoes a rigorous program of peer review, whereby professional scientists expert in estuarine research review and comment on the HMI monitoring reports prior to publication. A three-tiered review process is utilized wherein 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 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 Citizen's Oversight Committee (COC) composed of concerned citizens representing the interests of the general 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 assurance and quality control in the HMI Exterior Monitoring Program.

Project I also includes data management and making the data available to the public through several media, including both written reports and the Internet. The Maryland Department of the Environment is responsible for standardizing the reports for each project so that they are in a consistent format. Also, MDE/DCAD coordinates all field sampling among PIs for each project to ensure efficient and timely sample collection. This includes evaluating sampling protocols and altering monitoring stations and locations to respond to findings of concerns. Finally, MDE/DCAD manages the budget for the entire program and produces fiscal reports to track spending on a project by project basis.

Project II: Sedimentary Environment

The Coastal and Estuarine Geology Program of the Maryland Geological Survey (MGS) within the Maryland Department of Natural Resources (DNR) has been involved in monitoring the physical and chemical behavior of near-surface sediments around HMI since the inception of the Exterior Monitoring Program. Surficial bottom sediments sampled at 47 stations during Year 14 (November 1994 and April 1995) were analyzed for grain size composition and trace metal content. The grain size distribution of the sandy portion of exterior bottom sediments during Year 14 was similar to that observed in Year 13. The distribution of sand around the facility has remained largely unchanged since November 1988.

The clay:mud ratios for Year 14 were somewhat different from the ratios found in Year 13. Typically the coarsest (siltiest) sediments flank the perimeter of the dike and the fine fraction becomes more clay-rich with distance from the dike. This pattern was consistent during the November 1993 cruise for Year 13 as well as the two Year 14 cruises. During the Year 13 (April 1994) cruise, however, sediments adjacent to the north-northeast perimeter of the dike, between HMI spillways #1 and #2, contained considerably more clay than silt (clay:mud ratios exceeded 0.70).

It is typical for the contours and southern extent of the clay-rich zone to vary from cruise to cruise. During both Year 13 cruises (November 1993 and April 1994), for example, the zone was discontinuous east of HMI spillway #1. This discontinuity is not evident in either of the Year 14 maps. In November 1993, April 1994 and April 1995, the clay-rich zone extended along the eastern perimeter of the dike to the southern extent of the study area. In November 1994, however, the zone extended no further south than the dike. Other than these slight differences, the clay:mud distribution is similar during all sampling periods for Years 13 and 14.

In April 1989, an area of elevated zinc (Zn) concentrations was detected southeast of HMI spillway #1. In response to that discovery, the scope of monitoring was expanded to include a greater number of samples distributed over a wider area. A modified version of that sampling scheme remained in effect through Year 14.

Since the initial detection of elevated zinc (Zn) concentrations in Year 8, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, higher than expected Zn levels persisted through Year 14 in the vicinity of the dike. Zinc levels have been correlated with the discharge rate of effluent from the facility, with maximum Zn loading occurring at releases of 0.3-10 million gallons/day (MGD). At higher discharge rates, flushing with large volumes of water effectively dilutes Zn loadings in the effluent, precluding concentration of Zn in the surrounding bottom sediments. Typically, discharge levels prior to the November cruises are low due to an operational emphasis on crust management and dewatering at HMI, with little or no active placement of dredged material inside the facility. The April cruises generally follow a period of active placement of dredged material inside the facility, resulting in higher discharge rates from HMI spillways. An unusual feature of Year 14 was that elevated levels of zinc found in the November cruise were also maintained into the April cruise. The expected lowering of metal levels did not occur for the Year 14 April cruise. Although discharge rates prior to the April cruise were higher than those in November, approximately 50% of the pre-April cruise discharges were 10 MGD or lower. The frequency of these low discharge rates may have been sufficient to maintain the elevated metal levels seen in November.

Project III: Benthic Community Studies

Benthic invertebrate populations in the vicinity of HMI were monitored by the University of Maryland Center for Environmental Science (UMCES) for the fourteenth consecutive year. In November 1994, April 1995 and August 1995, organisms living close to HMI (nearfield stations), either within the sediments (infaunal) or upon the concrete and wooden pilings (epifaunal), were collected along with organisms living at some distance from the facility (reference stations).

Sixteen infaunal stations were sampled during each cruise. These consisted of 8 nearfield stations (S1-S8); 5 reference stations (HM7, HM9, HM16, HM22, and HM26 [Back River station]); and three of the four stations in areas which had been reported by MGS to have sediments elevated in zinc (G5, G25, HM12). As of April 1994, station G84 (the fourth station) was dropped because it no longer appeared to have elevated zinc concentrations.

The infaunal stations are located in areas with sediments of varying composition, including silt/clay, oyster shell, and sand substrates. A total of 31 species were collected from these sixteen infaunal stations. The most abundant species were the worms *Scolecolepides viridis*, *Streblospio benedicti* and *Tubificoides sp.*; the crustaceans *Leptocheirus plumulosus* and *Cyathura polita*; and the clams *Rangia cuneata* and *Macoma balthica.*

Species diversity (H') values were calculated for each of the infaunal stations during the three sampling periods. The highest diversity value (3.568) was obtained at the zinc station G25, in November 1994. The lowest diversity value (0.965) occurred in April 1995 at nearfield station S1. Comparing the three sampling dates, the overall highest diversity values (with only five stations under 2.4) occurred in November 1994, while the lowest overall diversity occurred in April 1995.

Length-frequency distributions of the clams *Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli* were examined at the nearfield, reference, and zinc stations. *Rangia cuneata* continues to be the most abundant species for all three groups of stations, followed by *Macoma balthica. Macoma mitchelli* remains the least abundant of the 3 dominant clam species.

Cluster analysis performed by station for each of the three sampling periods continues to associate stations primarily in response to sediment type. Grain size or sediment type is the major abiotic factor determining benthic community composition. Variations in recruitment at the different stations explain why some specific stations did not form tight groupings. The clusters were consistent with studies from previous years and did not indicate any unusual groupings resulting directly from HMI. Rank analysis of differences in the mean abundances of eleven selected species at stations with silt/clay substrates indicated only a slightly significant difference for the nearfield stations in August 1995.

Epifaunal populations were similar to those observed in previous years. The epifaunal populations at both the nearfield and reference stations were very similar over all three sampling periods.

The results of the Year 14 studies suggest that no adverse effects to the benthic populations have occurred that can be attributed to the maintenance and operation of HMI. The University of Maryland has continued to monitor three of the stations (G5, G25, HM12) established in Year 9 as a result of MGS's discovery of sediments elevated in zinc concentrations in the vicinity of HMI. During this sixth year of sampling at these zinc stations, they do not appear to be statistically different from the original nearfield or reference epifaunal stations.

Project IV: Analytical Services

In April 1995, fourteen composite samples of the benthic clam *Rangia cuneata* were collected from six stations (four samples from two reference stations, four samples from two nearfield stations and six samples from two of the zinc stations) for determination of trace metal burdens. The laboratory work was performed again this year by Artesian Laboratories, Inc. while the data interpretation was conducted by UMCES. This was the first year during which *Rangia cuneata* was the only macroinvertebrate sampled. Because there are species differences in metal accumulation for various clams, comparisons should be between baseline data for the clam *Rangia* from the pre-construction studies at HMI or from other uncontaminated or nearby sites. Unfortunately, no *Rangia* were collected for tissue analyses during the baseline studies of the HMI Exterior Monitoring Program and no other literature values are available with which to compare present day metal burdens. The most appropriate tissue burden comparisons are between the present *Rangia* samples and tissue burdens reported for the soft shell clam *Mya arenaria*. While *Rangia* occasionally feeds from surface organic deposits and may ingest some sediment, it is primarily a suspension feeder like *Mya* (Chesapeake Bay Program 1994), making comparisons between the two valid.

Rangia samples were analyzed in the laboratory for the following eight metals: arsenic, cadmium, chromium, copper, nickel, zinc, iron, and manganese. Trace metal detection levels were greatly improved this year which lead to detectable burdens of all analytes in all samples. In general, precision of determinations also seemed to improve markedly based on within-site replication. No organic analytes were examined this year, but are scheduled for analysis again in Year 15.

This was the second year since the baseline studies in which arsenic had been monitored in tissues and it was detected at appreciable levels in all samples. While no *Rangia* were monitored during baseline studies, this species' burdens of arsenic, cadmium and nickel are appreciably higher than levels found in the clam, *Mya arenaria*, from Upper Chesapeake Bay.

RECOMMENDATIONS

Chairman's note (August 1999): The following recommendations were made shortly after the close of Year 14, at a time when management of the Hart-Miller Island project was undergoing transition from the Maryland Department of Natural Resources to the Maryland Department of the Environment. Some of the recommendations were implemented in Years 15 and 16, while others may no longer apply. In the interest of continuity, recommendations as suggested at the close of Year 14 have been retained in this Technical Report.

The original monitoring requirements for Hart-Miller Island are included in the Wetlands License (72-127(R); Section II.d.) which calls for monitoring water quality and biota to note "Any indication of unfavorable departure from baseline conditions...". In evaluating the monitoring design, the Technical Review Committee should recognize that the original intent was for the facility to primarily receive contaminated material; the original monitoring program and permit requirements reflected that purpose. Although it does receive contaminated material, a much larger proportion than originally anticipated is uncontaminated.

Since its inception, the monitoring design has been modified to be more efficient and effective as the results of past monitoring studies were evaluated. For example, fish population studies conducted during the first five years of monitoring were discontinued due to consistency problems. The Beach Erosion Study was terminated at the end of Year 13 because of beach replenishment and armoring. In Year 9 stations were added in response to elevated zinc concentrations in certain areas. Recommendations for changes in the monitoring design for Hart-Miller Island were made in the Year 12 report. Some of these changes were incorporated in the proposals submitted by the Principal Investigators for Year 15. These include more sensitive analytical techniques for organics, sampling only *Rangia cuneata* for tissue contaminant measurements, and simultaneous sampling of sediment and benthos.

The changes discussed and accepted by the Technical Review Committee were:

- Sampling locations for all projects should be re-evaluated annually to ensure continued collection of statistically valid data and to reflect changes in sediment chemistry detected around HMI.

- Sample sediments and biota from the same stations and at the same time for each monitoring event.

- Adopt more sensitive analytical techniques for target organic analytes so that true contaminant differences can be detected.

- Use *Rangia cuneata* as the only monitoring species to eliminate problems with comparing contaminant levels from different species among stations and over years. Furthermore, to allow flexibility in the selection of sampling locations for tissue analysis so that only those sites with enough individuals to provide adequate tissue and replication are used.

- Start using the Restoration Goals Index (RGI) for the Chesapeake Bay.

Notes On Recommendations:

In response to recommendations made by the Citizen's Oversight Committee (COC) and the Technical Review Committee (TRC) on the accumulation of zinc (Zn) in the sediments surrounding HMI, MDE contracted Universe Technologies, Incorporated (UTI) in 1998 to: (1) conduct a literature search in order to synthesize the historical and present-day information on Zn concentrations in the sediments around HMI; (2) identify possible sources of Zn near HMI; and (3) present the findings as a technical report to MDE. In February 1999, MDE received a draft copy of the "Comprehensive Zinc Study for Hart-Miller Island Contained Disposal Facility, Maryland" from UTI. The report has been reviewed by the HMI Technical Review Committee and Citizen's Oversight Committee and comments were submitted to the authors for response and incorporation into the final report. In addition, UTI has given presentations summarizing the results of the Zinc study to both the TRC and COC at their regular HMI meetings. The Maryland Department of the Environment expects to have a final copy of the zinc report by the end of September 1999.

CHAPTER 2: SEDIMENTARY ENVIRONMENT (PROJECT II)

By

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ABSTRACT

The Coastal and Estuarine Geology Program of the MGS has been involved in monitoring the physical and chemical behavior of near-surface sediments around HMI for more than a decade. In a separate effort, the program's staff has also documented the erosional and depositional changes along the recreational beach between Hart and Miller Islands. Beach monitoring has been discontinued because plans to armor the beach are moving forward. Only the results of monitoring the exterior sedimentary environment for Year 14 are presented in this report.

Surficial bottom sediments were sampled during two cruises (November 1994 and April 1995) and analyzed for grain size composition and trace metal content. The results of these analyses were compared with those reported for Year 13 (Hill et al. 1997). The grain size distribution of exterior bottom sediments, presented as percent sand and clay:mud ratios, was similar to last year's findings and consistent with earlier post-discharge periods. The distribution of sand around HMI has remained largely unchanged since November 1988. Lobes of sandy (>90% sand) sediment extend north-northeast of the dike and east of Black Marsh and become systematically finer (less sandy) offshore.

For the four sampling periods of Years 13 and 14, differences in the distribution of the fine fraction of the sediment were minor. Typically, the siltiest sediments flank the perimeter of the dike, and the fine fraction becomes more clay-rich with distance from the dike. A zone of clay-rich sediment (clay:mud>0.55) wraps around the dike. Pockets of even finer sediment (clay:mud>0.60) occur within the clay-rich zone, usually offshore between HMI spillways #3 and #4. Differences among the four sampling periods were primarily related to (1) the continuity/discontinuity and the southern extent of the clay-rich zone, and (2) in April 1994, an anomalous clay-rich deposit (clay:mud>0.70) adjacent to the north-northeastern perimeter of the dike, between HMI spillways #1 and #2.

Since the initial detection of zinc (Zn) enrichment, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, higher than expected Zn levels persisted through Year 14 in the vicinity of the dike. In previous reports, Zn levels were correlated with the discharge rate of effluent from HMI. Metal levels in ponded water increase due to leaching of metals from the sediment in the dike, through a process analogous to acid mine drainage. The maximum Zn loading due to leaching occurs at releases between 0.3-10 million gallons a day (MGD). At higher discharge rates, flushing with large volumes of water effectively dilutes Zn loadings in the effluent and precludes Zn enrichment in the surrounding bottom sediments. The results of the metal distribution around HMI for Year 14 do not show the degree of variation both in areal extent and enrichment of the sediment compared to those found in previous years. Discharge prior to the November sampling was low, with resulting higher levels of Zn in the external sediments. Although discharge prior to the April cruise was higher, about half of the discharge periods were between 0.3-10 MGD. Consequently, the elevated levels found in November 1994 were maintained through April 1995.

Continued monitoring is recommended. During the dewatering phase of operations, exposure of dredged materials to the atmosphere is likely to result in the mobilization of metals contained in the sediments. Higher metal levels in the effluent may very well increase metal loadings to exterior bottom sediments, particularly if discharge rates are low. Future monitoring will be needed to detect such effects. Monitoring will also be valuable in assessing the effectiveness of any protocol implemented to counteract the effects of exposing the confined dredged material to the atmosphere.

INTRODUCTION

Since 1981, the MGS has monitored the sedimentary environment in the vicinity of the Hart-Miller Island Confined Disposal Facility (HMI). Hart-Miller Island is a man-made enclosure in Northern Chesapeake Bay, named for the two natural islands that form part of its western perimeter (Figure 2-1). The oblong structure, designed specifically to contain material dredged from Baltimore Harbor and its approach channels, was constructed of sediment dredged from the area that is now 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 dike also differs from recently deposited sediments outside of HMI. Much of the material generated by channel deepening is fine-grained and enriched in trace metals and organic constituents. These differences in sediment properties have allowed the detection of changes attributable to construction and operation of the dike.

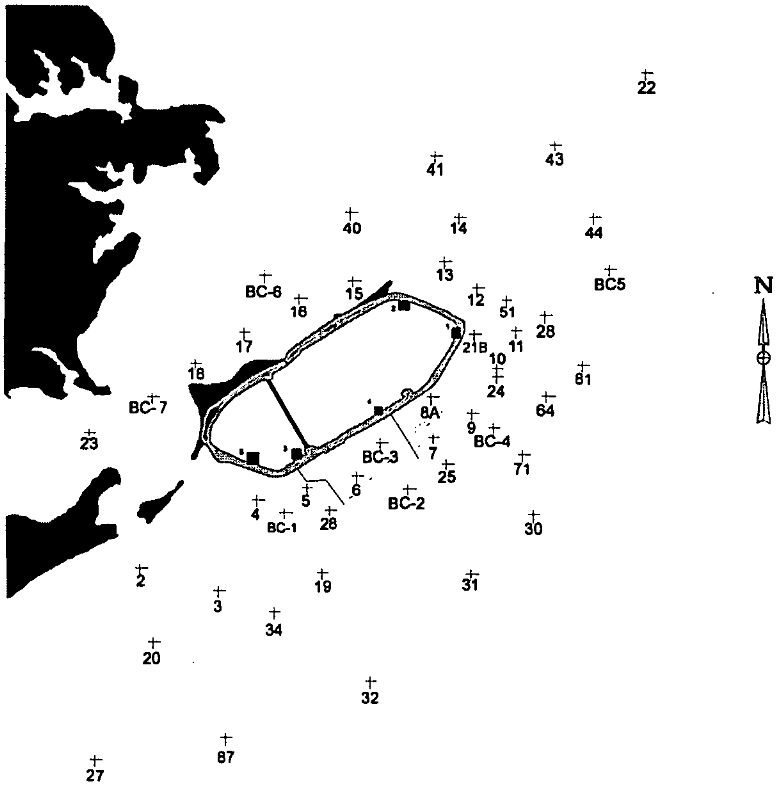

Figure 2-1: Location of sediment sampling stations around HMI for Year 14.

PREVIOUS WORK

Events in the history of HMI can be 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 previous reports (Kerhin et al. 1982a, 1982b; 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 HMI. This layer is still evident in a few cores, although the uppermost sections of the layer have been bioturbated and eroded.

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 dike, anomalously high zinc (Zn) values were detected in samples collected near HMI spillway #1 (Hennessee et al. 1990b). Zinc levels rose from the regional average enrichment factor of 3.2 to 5.5. Effluent discharged during normal operation of the dike was thought to be the probable source of excess Zn accumulating in the sediments. This was confirmed by use of the Upper Chesapeake Bay Model (Wang 1993), a numerical, hydrodynamic model, which was used to predict the dispersion of discharge from the dike.

The factors which influence metal loadings to the exterior sediments from the dike are circulation patterns in Northern Chesapeake Bay and the rate and nature of discharge from the dike. The results of the hydrodynamic model pertinent to a discussion of contaminant distribution around HMI follow (see also 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 HMI 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 HMI. Releases from HMI Spillway #2 are spread more evenly to the north, east, and west. However, dispersion is not as great as from HMI Spillways #1 and #4 because of lower shearing and straining motions which occur away from the influence of the circulation gyre.

3. The circulation gyre is influenced 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 dike 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 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. The source of the metals that enrich the exterior sediments is the sediments contained within the dike. 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 enrichment, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, higher than expected Zn levels persisted through Year 14 in the vicinity of the dike, as predicted by the Upper Bay Model and the model presented in the *11th Year Interpretive Report.*

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, 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 may 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 14 cruises are summarized below. Information was extracted from two *Operations Reports* prepared by MES, covering the periods April 1, 1994 - September 30, 1994, and October 1, 1994 - March 31, 1995.

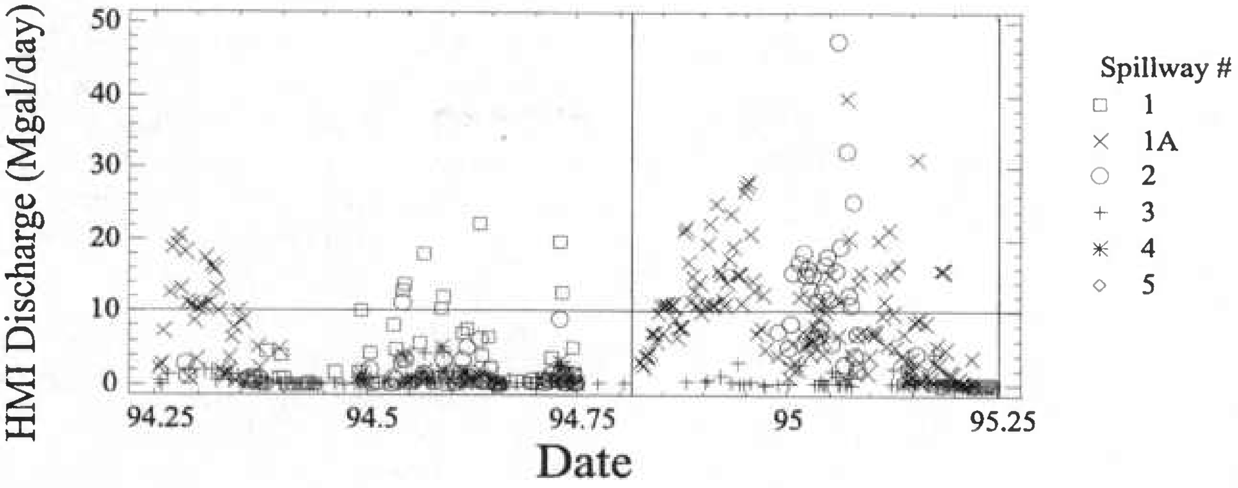

Figure 2-2: **Discharge from HMI spillways for Year 14. The Y-axis denotes discharge below which metal loading to the sediment has been noted; the X-axis represents the sediment sampling dates.**

During the period prior to the November sampling cruise the primary emphasis of dike operations was on dewatering and crust management. Only one dredging operation was completed in this period, with only 0.27 million cubic yards (M yd^3) of material (April 1 - 23, 1994) placed. This is reflected in the low discharge rates from the dike as shown in Figure 2-2. As noted in previous reports and shown in Figure 2-3, low discharge rates are accompanied by acidic conditions. The April 1995 cruise followed a period of active placement of sediments at HMI. There were six dredging operations active prior to sampling, depositing a total of ~2.7 M yd^3 of material. This is reflected in the higher discharge rates and the lack of mineral acidity in the discharge from the dike. However, approximately 50% of the discharges during this period were less than 10 MGD.

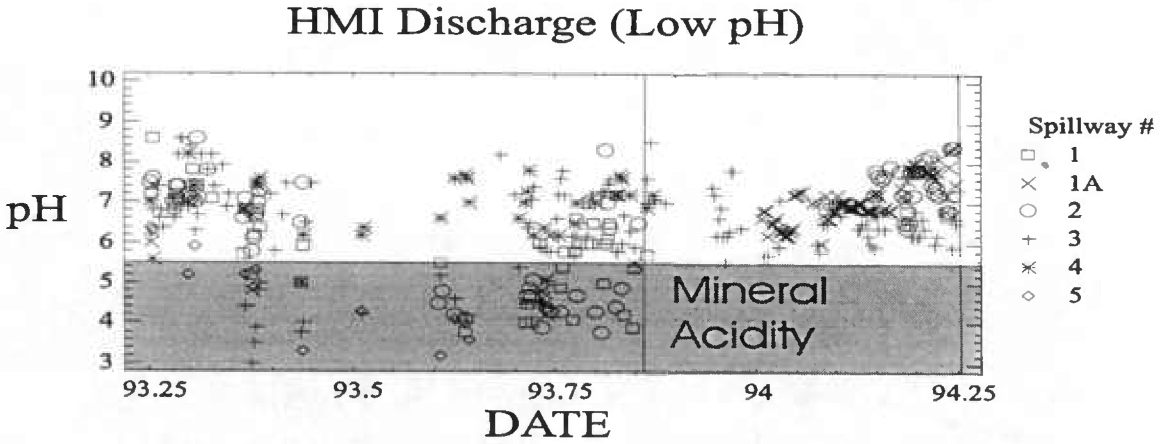

Figure 2-3: Low pH measured during discharge events. The shaded area denotes where mineral acidity is present and X-axis represents the sampling dates.

There were no periods of effluent non-compliance. There were, however, "several" occasions where sodium carbonate was used to raise the pH of the ponded water prior to discharge. In addition, there were several low pH excursions under Special Condition H (i.e., discharge of waters from HMI must have pH in the range of 6 -10. Excursions from this range may last no longer than 60 min. for each event and the monthly cumulative time must not exceed 7 hr and 26 min.). Both of these conditions occurred prior to each sampling period.

SUSQUEHANNA RIVER FLOW

Flow from the Susquehanna River for the period affecting the Year 14 samples is shown in Figure 2-4 as the daily discharge recorded at Conowingo Dam and normalized to the 10-year daily average (values equal to one indicate average flow conditions for any given day). For the most part, flows from the Susquehanna followed average flow for the river, except for two high flow periods corresponding to storm events. These were transitory in nature with respect to the discharge from HMI.

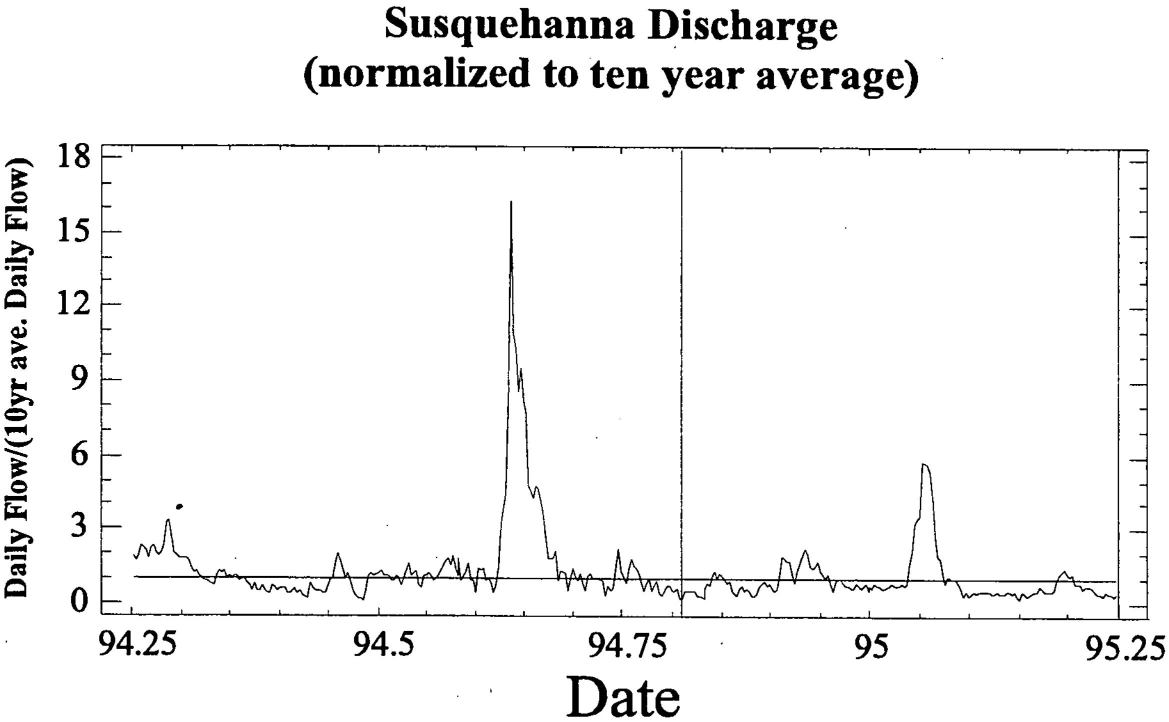

Figure 2-4: Daily flow at Conowingo Dam, normalized to the ten year average daily flow. The horizontal line indicates average conditions, while the two vertical lines indicate the sampling cruises.

OBJECTIVES

The main objectives of the Year 14 study were (1) to measure specific physical and geochemical properties of the near-surface sediments around HMI and (2) to assess changes detected in the sedimentary environment. Tracking the extent and persistence of the area of Zn enrichment was again of particular interest.

METHOD AND MATERIALS

FIELD METHODS

The information presented in this report is based on observations and analyses of sediment samples collected during two cruises aboard the *R/V Discovery* during Year 14. This year, sampling sites (Figure 2-1) were located in the field by means of an MX300 survey-grade Differential Global Positioning System (DGPS) with an MS50R radio beacon receiver for differential corrections. The DGPS replaced the LORAN-C navigation system that had been used to locate sampling stations during the preceding eleven monitoring years (Hill et al. 1998). To convert from LORAN-C coordinates (X and Y time delays, or TDs) to DGPS coordinates (latitude/longitude, North American Datum of 1983 or NAD83), the boat captain used LORAN-C to navigate to a sampling station and then recorded the DGPS coordinates at that point. Those geographic coordinates were subsequently used to locate stations occupied during both Year 14 cruises.

Switching from LORAN-C to DGPS greatly improved the crew's ability to return to a location at which a navigation fix had previously been obtained. LORAN-C is affected by seasonal and weather-related changes along the signal transmission path. Halka (1987) estimated that when a vessel equipped with LORAN-C re-occupies an established station in Chesapeake Bay, it is within about 100 m (328 ft) of its original location. In contrast, the accuracy of the DGPS unit, according to the manufacturer's specifications, is 3-5 m (10-16 ft). On the basis of experimental results, the actual accuracy is 1-3 m (3-10 ft). For each station sampled during Year 14, (1) the target LORAN-C TDs, (2) the 'corrected' latitude and longitude [(NAD27), derived from the LORAN-C TDs using a computer program that incorporated the results of a LORAN-C calibration in Chesapeake Bay (Halka 1987)], and (3) the latitude and longitude (NAD83) computed by the DGPS unit are listed (*Year 14 Data Report)*.

Surficial sediment samples were collected in November 1994 (Cruise 32) and April 1995 (Cruise 33). During Year 9 the number of sampling stations was increased in response to the detection of abnormally high zinc (Zn) levels in sediments near HMI spillway #1 (Hennessee and Hill 1992). Sampling sites were added to determine the extent of the area of elevated Zn concentrations and to coincide with benthic sampling stations. The expanded sampling scheme (60-66 locations/cruise) was retained through Year 11.

During Year 12 the number of stations occupied during each cruise was reduced to 47, based, in part, on output from a 3-D hydrodynamic model of the Upper Chesapeake Bay (Wang 1993). The 22 stations that had been monitored continuously since dike completion were retained, as were the stations that corresponded to benthic sampling sites. Selection of the remaining stations was based on discharge activity during the months preceding each cruise, coupled with the results of the 3-D model. All of the sites chosen on the basis of the 3-D model had been sampled previously. The same locations sampled during Year 12 were revisited during Years 13 and 14.

Undisturbed samples of the surficial sediments surrounding HMI were obtained with a dip-galvanized Petersen sampler. At least one grab sample was collected at each station and split for textural and trace metal analyses. Triplicate grab samples were collected at seven stations (11, 16, 24, 25, 28, BC3, and BC6). During the April cruise, additional grab samples were taken for organic contaminant analysis at eight stations (23, 24, 25, 28, 30, 34, BC3, and BC6)[2]. Upon collection, each sediment sample was described lithologically (*Year 14 Data Report*) and subsampled.

Sediment and trace metal subsamples were collected using plastic scoops rinsed with distilled water. These samples were taken several centimeters from the top, below the flocculent layer, and away from the sides of the sampler to avoid contamination from the sampler itself. They were placed in 18-oz Whirl-Pak™ bags. Samples designated for textural analysis were stored out of direct sunlight at ambient temperatures. Those intended for trace metal analysis were refrigerated and maintained at 4°C until they could be processed in the laboratory.

Subsamples for organic analysis were collected with an aluminum scoop (also rinsed with distilled water), placed in pre-treated glass jars, and immediately refrigerated[2]. They were delivered to the MES office at HMI, then transferred to a private laboratory for analysis.

In April 1995, gravity cores were collected at the seven box core (BC) stations and at stations 12 and 25 (Figure 2-1). A Benthos gravity corer (Model #2171) fitted with clean cellulose acetate butyrate (CAB) liners, 6.7 cm in diameter, was used. Each core was cut and capped at the sediment-water interface, then refrigerated until it could be x-rayed and processed in the lab.

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[2] Although samples were collected, no analysis for organic contaminants was conducted this year. See the Project IV Technical Report for details.

LABORATORY PROCEDURES

1. Radiographic Technique

Prior to processing, the upper 50 cm of each core were x-rayed at MGS, using a TORR-MED x-ray unit (x-ray settings: 90 kv, 5 mas, 30 sec). A negative x-ray image of the core was obtained by xeroradiographic processing. On a negative xeroradiograph, denser objects or materials, such as shells or sand, produce lighter images. Objects of lesser density permit easier penetration of x-rays and, therefore, appear as darker features. The xeroradiographs are reproduced in an appendix to the *Year 14 Data Report*.

Each core was then extruded, split with an osmotic knife, photographed, and described. Visual and radiographic observations of the cores are also presented in the *Year 14 Data Report*. On the basis of these observations, sediment samples for textural and trace metal analyses were taken at selected intervals from each core.

2. Textural Analysis

In the laboratory, subsamples 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 wet weight of the sediment:

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

where:
Wc = water content (%)
Ww = weight of water (g)
Wt = wet weight of 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 the water weight (Ww). Bulk density was also determined from water content measurements.

The relative proportions of sand, silt, and clay were determined using sedimentological procedures described by 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 2-5).

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

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

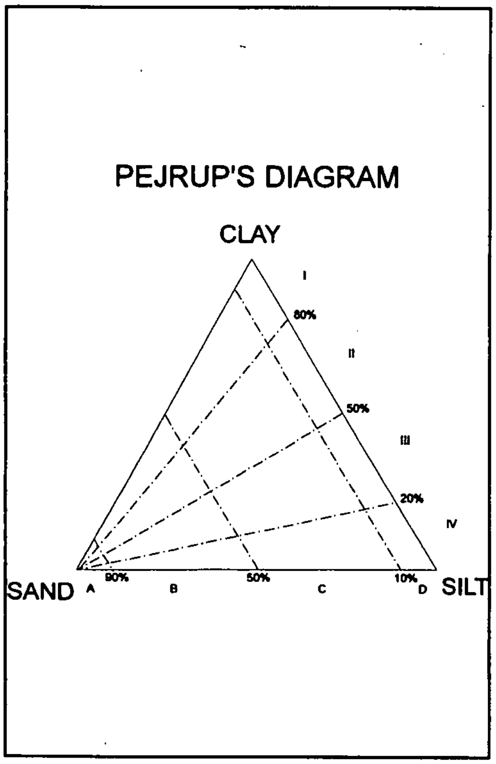


Figure 2-5: Pejrup's (1988) classification of sediment type.

The classification scheme is useful in reducing a three-component system to a single term, but 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.

3. Trace Metal Analysis

Sediment solids were analyzed for six trace metals - iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), and nickel (Ni). 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 EPA 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°C).

2. Approximately 10 g of wet sample were transferred to Teflon evaporating dishes and dried overnight at 105-110°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 HNO_3 (trace metal grade), 7.5 ml concentrated 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. (Preparation blanks were made by using 0.5 ml of high purity water plus the acids used in Step 5.)

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°C in 5.5 minutes, then maintained between 175-180°C for 9.5 minutes. (The pressure during this time peaked at approximately 6 atm for most samples.)

8. Vessels were cooled to room temperature and uncapped. The contents were transferred to a 100 ml volumetric flask, and high purity water was added to bring the volume to 100 ml. The dissolved samples were transferred to polyethylene bottles and stored for analysis.

9. The samples were 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 and SRMs were run every 10 samples.

Results of the analyses of three SRM's (NIST-SRM #1646 - Estuarine Sediment; NIST-SRM #2704 - Buffalo River Sediment; National Research Council of Canada #PACS-1 - Marine Sediment) are given in Table 2-1. The microwave/ICAP method has recoveries (accuracies) within ±5% for all of the metals analyzed, except Ni and Mn. The poorer recoveries for Ni and Mn are due to the concentrations of these elements being near detection limits. Although poorer, the recoveries for these two metals are good. For Mn, the SRM's have unrealistically low concentrations compared to the samples around HMI. The Buffalo River SRM has the highest Mn content of the three, and the recovery of Mn for this SRM is excellent.

Table 2-1: Results of MGS's analysis of three standard reference materials, showing the recovery of the certified metals of interest.

	Percent Recovery		*(n=15)*
Metal	**NIST 1646**	**Buffalo River**	**PACS**
Fe	97±4	97±2	94±3
Mn	85±6	102±4	79±5
Zn	87±1	96±1	98±2
Cu	93±5	100±4	100±2
Cr	102±4	98±5	95±4
Ni	86±9	88±9	84±8

RESULTS AND DISCUSSION

SEDIMENT DISTRIBUTION

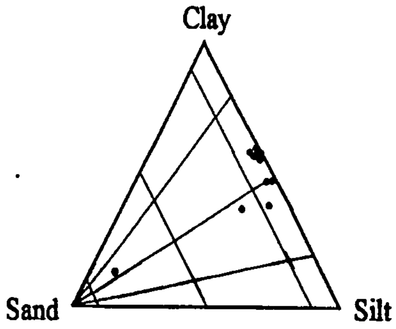
Although the number of sampling stations has varied over the monitoring years, 22 locations (2, 3, 5, 6, 7, 8A, 9, 10, 11, 12, 14, 16, 19, 20, 22, 23, 24, 25, 26, 27, BC3, and BC6) have been resampled during every cruise since November 1983. The grain size composition (sand-silt-clay percentages) of sediments collected at these 22 sites is depicted in ternary diagrams for five different sampling periods (Figure 2-6). The first diagram (Figures 2-6a) is typical of the post-construction, **pre-discharge** sediment distribution around HMI. The next four diagrams - all **post-discharge** - summarize the Year 13 (Figures 2-6b&c) and 14 (Figures 2-6d&e) findings. Related statistics are presented in Table 2-2. The ternary diagrams show very similar distributions of sediment type. All points fall fairly close to the line extending from the sand apex and bisecting the opposite side of the triangle (clay:mud=50). The number of stations containing more than 50% sand varies from three, prior to onset of effluent discharge, to as many as nine afterward. This increased sandiness is reflected in the average sand percentages shown in Table 2-2.

For the 22 continuously monitored sampling locations, Figure 2-7 depicts percent sand and clay:mud ratios, averaged over all 22 stations, for all post-construction cruises. The vertical line indicating the first release of effluent in October 1986 separates pre- and post-discharge cruises.

Table 2-2: Summary statistics for five cruises, based on 22 continuously monitored stations around HMI.

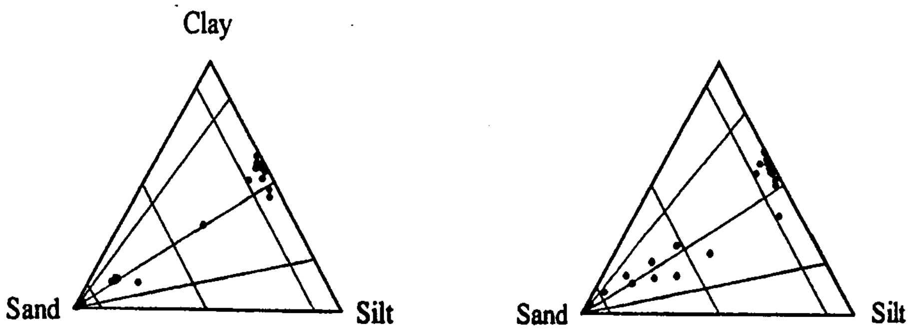
Cruise	Date	Clay:mud ratio		Sand (%)	
		Range	Average	Range	Average
9	11/83	0.42-0.63	0.55	0.33-97.34	25.31
30	11/93	0.35-0.61	0.52	1.23-99.05	34.42
31	4/94	0.35-0.78	0.57	0.72-96.07	34.16
32	11/94	0.38-0.70	0.54	1.16-98.50	34.87
33	4/95	0.38-0.62	0.53	1.13-97.62	34.59

(a) November 1983 (Cruise 9)



(b) November 1993 (Cruise 30)

(c) April 1994 (Cruise 31



(d) November 1994 (Cruise 32)

(e) April 1995 (Cruise 33)

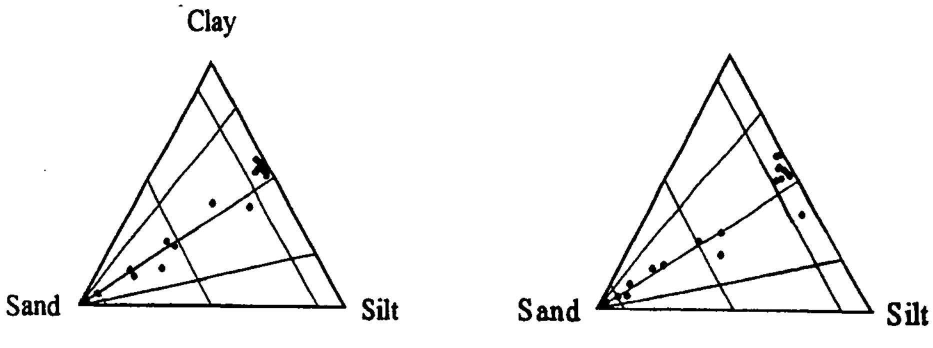


Figure 2-6: Sediment type of samples collected in (a) November 1983 (post-construction, pre-discharge), (b) November 1993, (c) April 1994, (d) November 1994, and (e) April 1995.

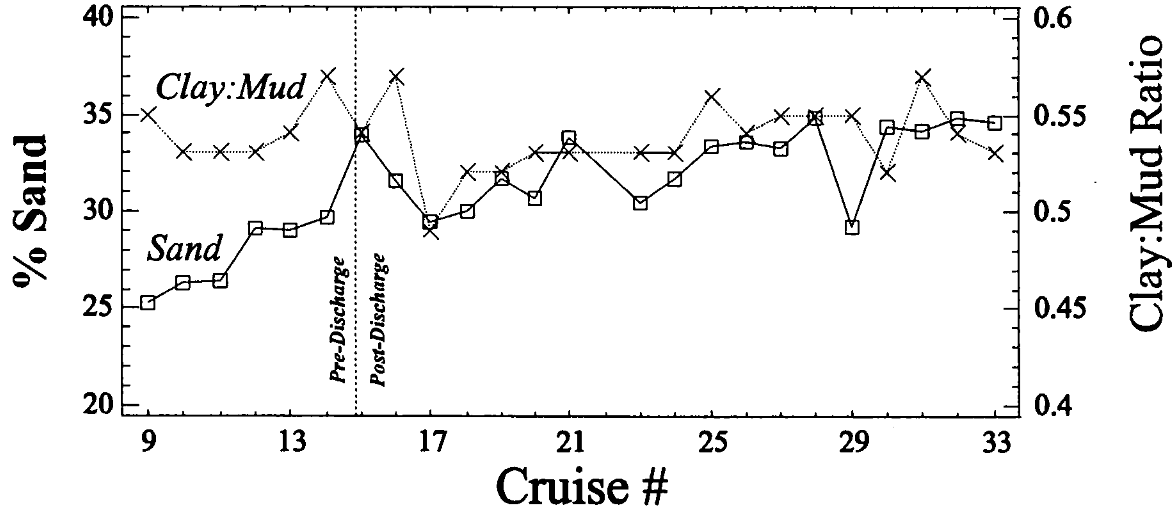


Figure 2-7: Average percent sand and clay:mud ratios, based on 22 continuously monitored stations, for all post-construction cruises through the Year 14.

During the pre-release period, the sand content of sediments increased systematically over time. Marked increases in percent sand occurred during the winter (between fall and spring cruises). Sand content then remained comparatively stable until the following fall, when another jump occurred. This pattern of steady, seasonal increases in sand content changed once discharging began. During the initial post-discharge period, sand content tended to decrease during the winter and increase during the summer, though this seasonal trend was not nearly as consistent or pronounced as that of the pre-discharge period. More recently, sand content has tended to remain consistently high (33-35%) throughout the year. With the exception of two cruises (11/87 and 5/93), mean sand percentages during the post-discharge period have generally remained well above the maximum pre-discharge level of 29.7%.

Average clay:mud ratios for the 22 stations also show different pre- and post-discharge patterns. Overall, pre-discharge ratios varied over a relatively small range (0.53-0.57). No seasonal trend was evident. During the post-discharge period, ratios have varied over a wider range (0.49-0.57), though most cruises fall within the pre-discharge range. A fairly consistent seasonal pattern developed post-discharge and persisted through the first cruise of Year 14. The muddy fraction of the sediment became somewhat finer (more clay-rich) during the winter (between fall and spring cruises) and either remained the same or became somewhat coarser (siltier) during the summer. One may infer from this trend that, generally, the depositional environment remained or became relatively quiet during the winter. During the summer, hydrodynamic conditions either stayed about the same or were slightly more turbulent. Both Susquehanna River flow and the release of effluent from the dike affect hydrodynamic conditions around HMI and, consequently, the texture of sediments deposited nearby. Typically, during the winter, river flow is low, and dike operations are scaled back, leading to less turbulent hydrodynamic conditions and the deposition of finer-grained sediment.

Two sets of contour maps, based on the entire suite of samples, show the spatial distribution of sediment type during Years 13 and 14. Figures 2-8 and 2-9 depict percent sand; Figures 2-10 and 2-11depict clay:mud ratios. Maps showing the distribution of sand are virtually identical for the four sampling periods. In fact, sand distribution has remained largely unchanged since November 1988. Lobes of sandy sediment (>90% sand) extend north-northeast of the dike and east of Black Marsh and become systematically finer (less sandy) offshore.

Clay:mud ratio maps show the distribution of the fine fraction of the sediment during Years 13 (Fig. 2-10) and 14 (Fig. 2-11). Contours are drawn at intervals of 0.10, with an additional line at 0.55, dividing the modal class (0.50-0.60). Certain aspects of the distribution of the clay:mud ratio are similar for all four sampling periods. Typically, the coarsest (siltiest) sediments flank the perimeter of the dike. The fine fraction becomes more clay-rich with distance from the dike. (Figure 2-10b, representing the distribution of clay:mud in April 1994, is anomalous insofar as the sediments adjacent to the north-northeast perimeter of the dike, between HMI spillways #1 and #2, contain considerably more clay than silt; clay:mud ratios exceed 0.70.) A zone of clay-rich sediment (clay:mud>0.55) wraps around the dike. Pockets of even finer sediment (clay:mud>0.60) occur within the clay-rich zone, usually offshore between HMI spillways #3 and #4.

The continuity and the southern extent of the clay-rich zone vary from cruise to cruise. During both Year 13 cruises, for example, the zone was discontinuous east of HMI spillway #1. The discontinuity is not evident in either of the Year 14 maps. In November 1993, April 1994, and April 1995, the clay-rich zone extended along the eastern perimeter of the dike to the southern limit of the study area. In November 1994, however, the zone extended no further south than the dike itself. Aside from these minor differences and the anomaly mentioned above, the clay:mud distribution during all four sampling periods is similar.

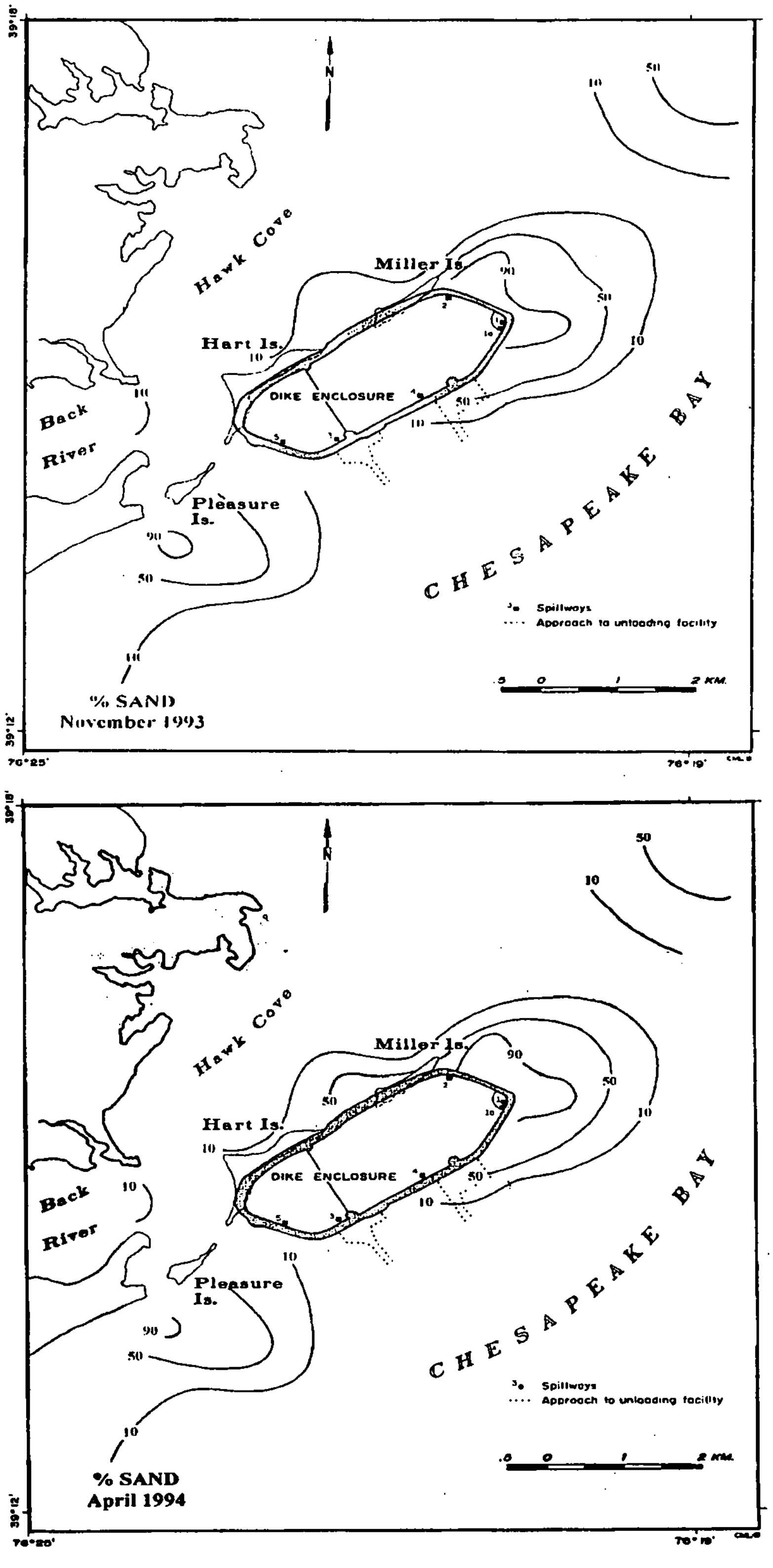


Figure 2-8: Distribution of percent sand - Year 13: (a) November 1993 and (b) April 1994.

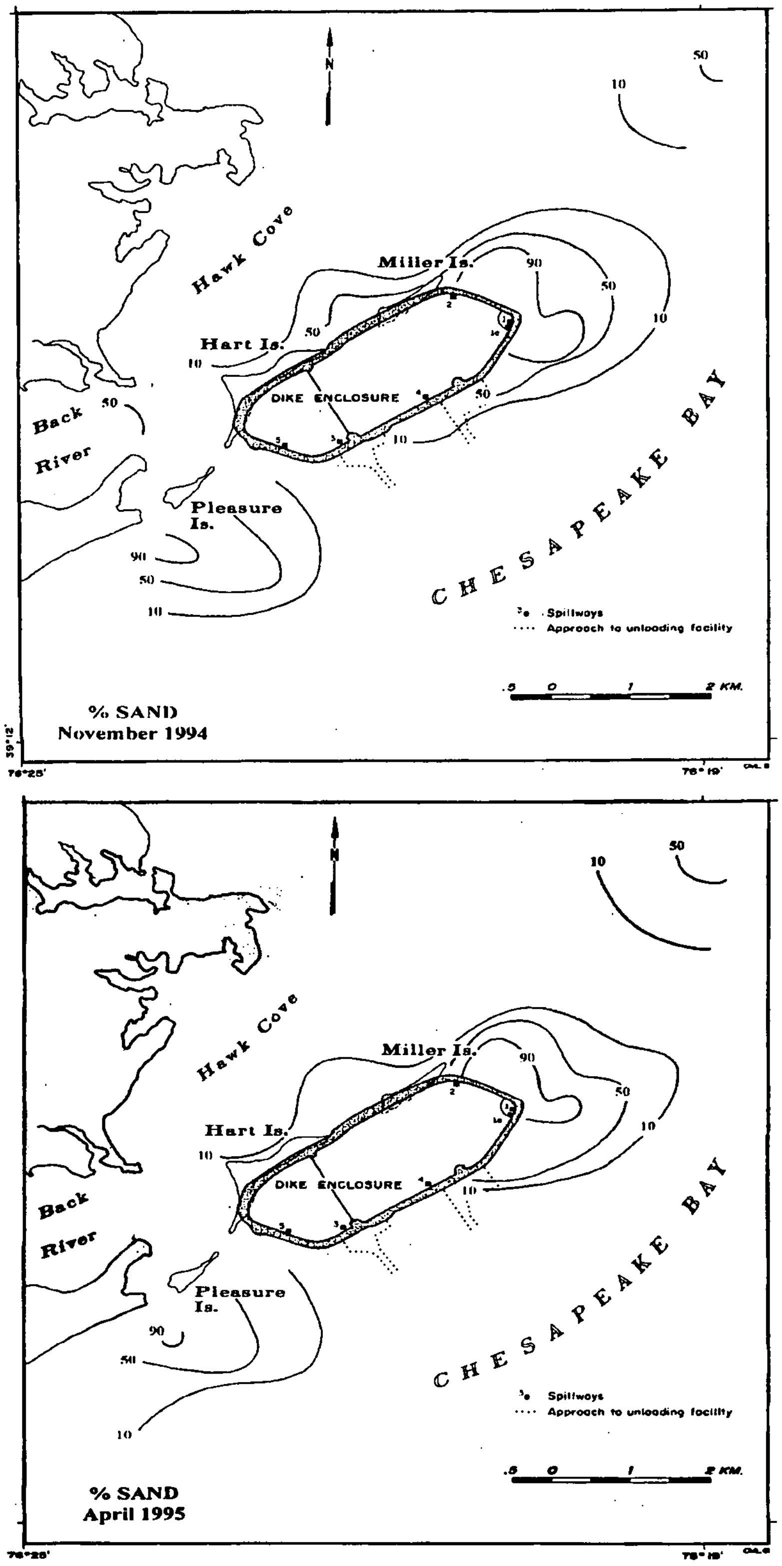


Figure 2-9: Distribution of percent sand - Year 14: (a) November 1994 and (b) April 1995

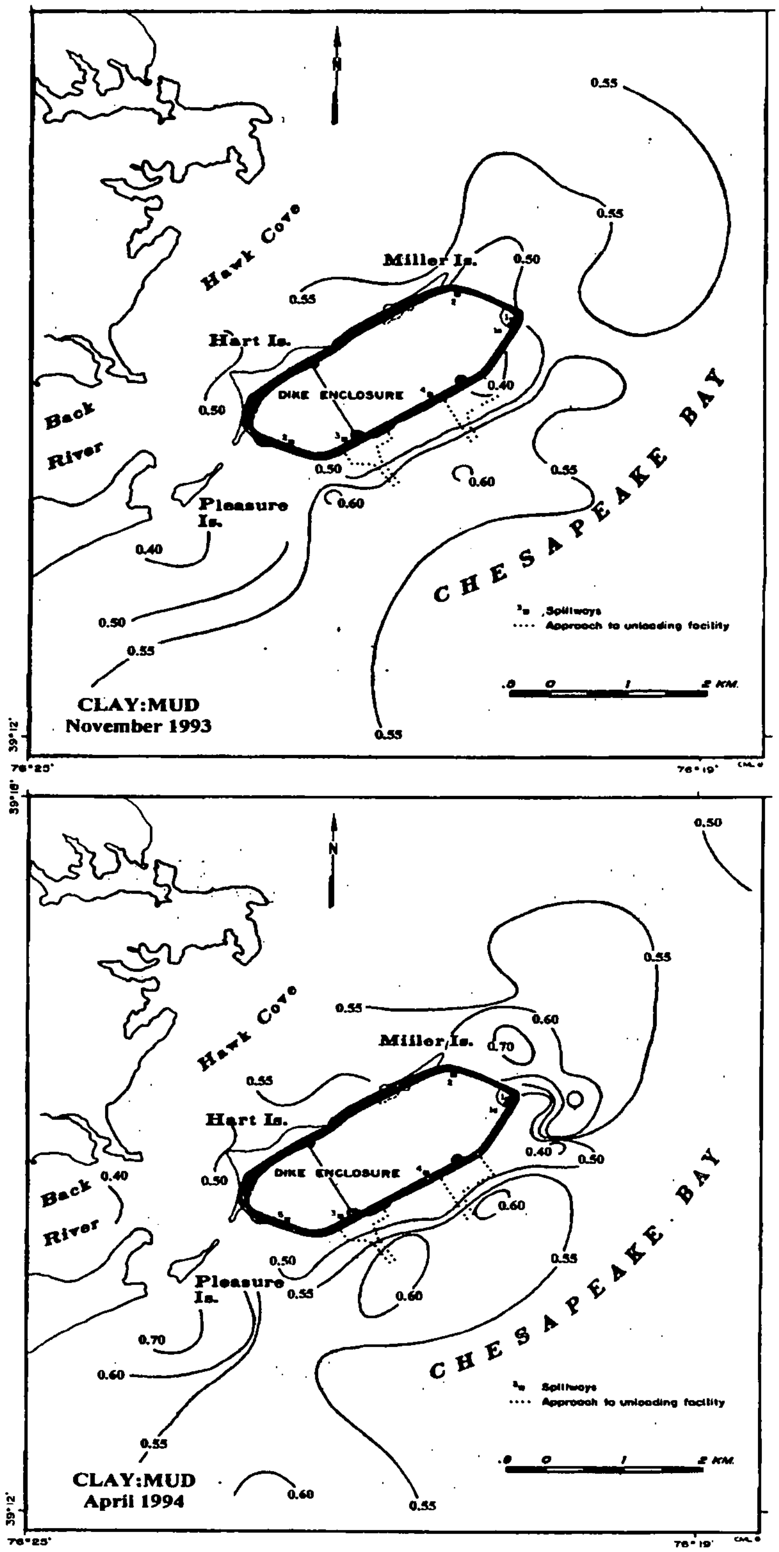


Figure 2-10: Distribution of clay:mud ratios - Year 13: (a) November 1993 and (b) April 1994.

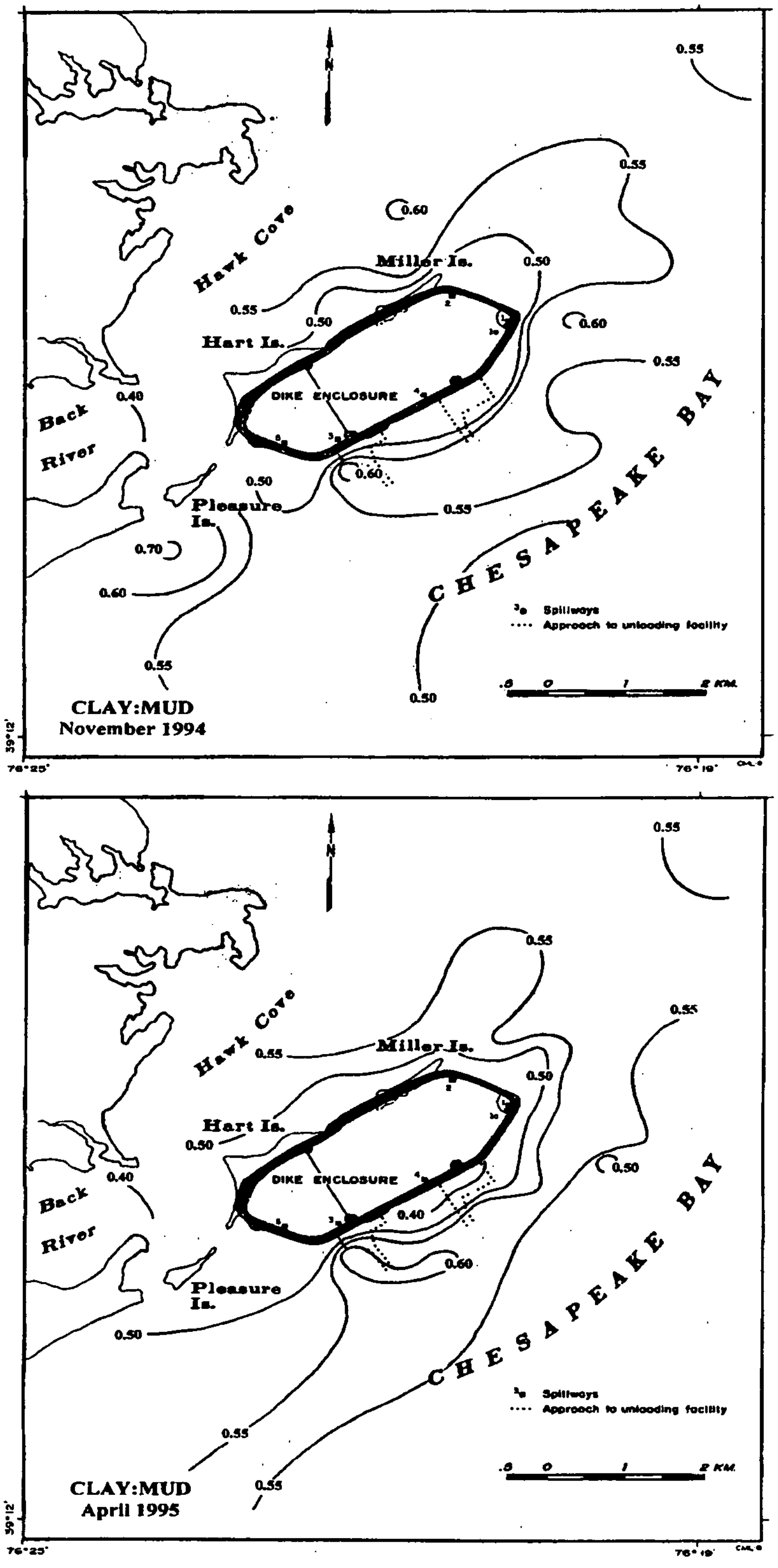


Figure 2-11: Distribution of clay:mud ratios - Year 14: (a) November 1994 and (b) April 1995.

TRACE METALS

1. Sediment total metal concentrations

Six trace metals were analyzed as part of an ongoing effort to assess the effects of HMI on the surrounding sedimentary environment. Statistics summarizing the data are given in Table 2-3. Listed for each metal is the average, range, and standard deviation.

Table 2-3. Summary statistics for metals measured for both sampling cruises for the Year 14 Monitoring effort.

	Average *(n=92)*	**Range**	**Standard Deviation**
Cr (ug/g)	95.7	4.9 - 145	40.5
Cu (ug/g)	38.6	1.9 - 76.2	17.5
Ni (ug/g)	68.9	6.4 - 147	31.5
Zn (ug/g)	283	19.7 - 614	136
Fe (%)	3.83	0.20 - 6.85	1.68
Mn (ug/g)	3052	445 - 7752	1709

Total metal concentrations generally cannot be used to determine metal loading to sediments. This is the case whether total loading, spatial distributions (e.g. used to pin-point sources of material to the sediment), or trends through time are sought. This restriction in their use is the result of the imprint of several factors which control the metals content of the sediment. These factors are:

1. *The source of the material* - around HMI there are several potential sources of sediment to the area. It is important to be able to determine what the sources are and if the facility is a significant source;

2. *The fractionation of the metals to the different components of the sediment* - most notable is the grain size induced variability. Metals are associated with different grain size fractions based on mineral composition and adsorption characteristics. Generally, different sources will have a different metal fractionation; and

3. *The authigenic biogeochemical environment of deposition* - the environments in which the sediment is deposited and buried determine what metals are stabilized in the sediment column and which ones are remobilized into the water column and transported out of the area. This is a major consideration if there is more than one environment within a given study area. Fortunately, the exterior sedimentary environment around HMI is within a uniform geochemical environment of Chesapeake Bay (Hill 1984, 1988); this reduces the

Total Sediment Metal Concentrations for All 14th Year Surficial Sediments

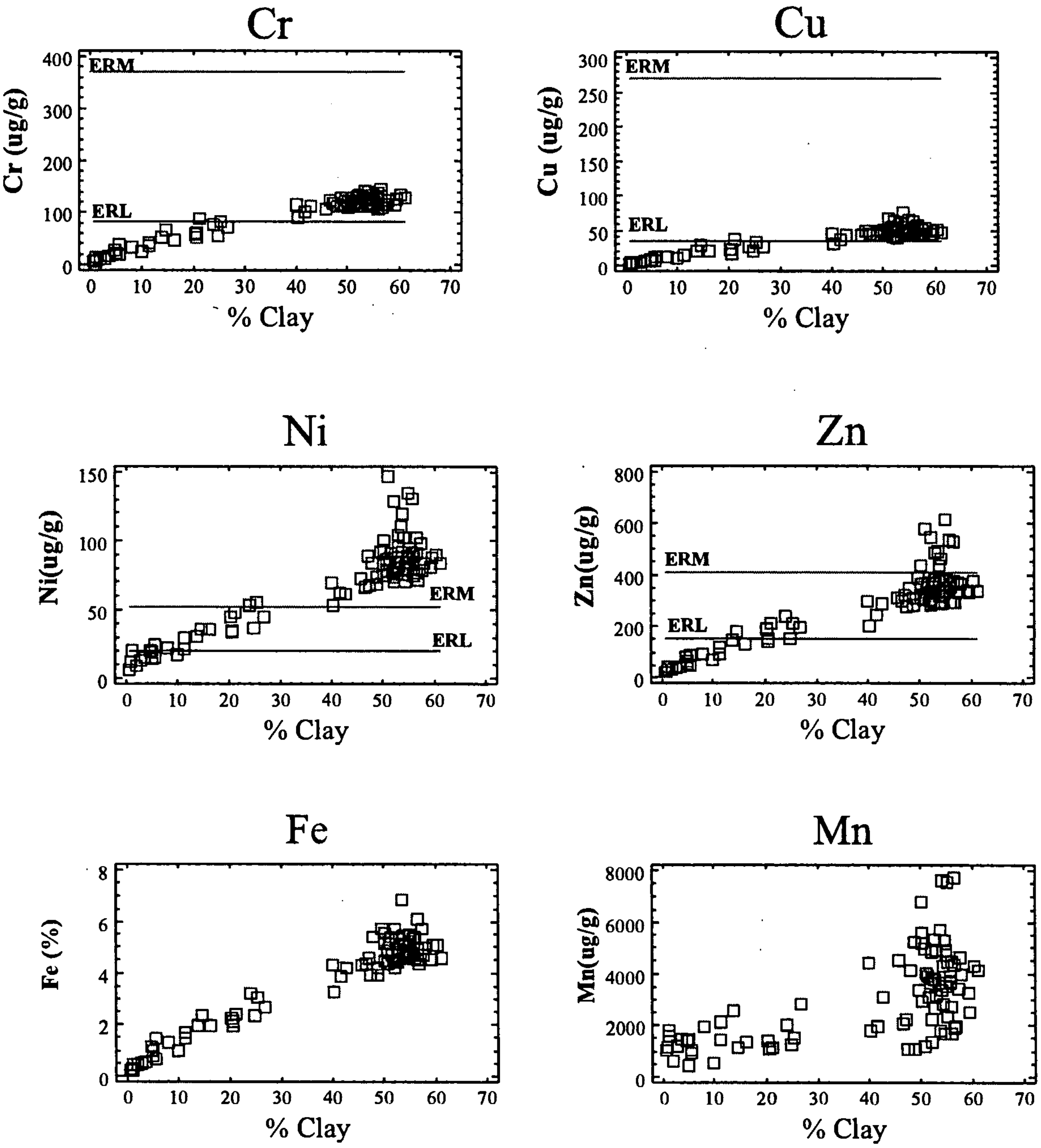


Figure 2-12: **Total metal content of all surficial samples collected for Year 14 as a function of clay content. Also indicated are the ERL and ERM (Long et al. 1995) where available.**

number of factors controlling the metal content to source and metal fractionation within the components of the sediment.

The information sought is the source of the material and the relative importance of the different sources. Therefore baseline fractionation of the metals, as a function of grain size, needs to be taken into account. This is demonstrated in Figure 2-12 in the concentrations of metals as a function of sediment clay content. It is apparent that there is a strong relationship between clay and the metal content of the sediment. Thus if the data were viewed strictly in terms of total metal concentrations, the high areas would correspond to fine sediments and the low areas to sands. Assuming metal fractionation to follow a simple linear relationship between clay and metals, there is grain size induced variability ranging from a factor of 17 to a factor of 40. This variability can easily overwhelm any potential increase to metal loading due to changes in source material and negate the use of simple statistics (i.e. averages, and standard deviations). Metal concentrations will simply follow grain size when using absolute metal concentrations. Thus the grain size induced variability must be taken into account in order to ascertain the sources of material. This is done in the following section.

In regard to Figure 2-12, one other feature to note is the horizontal lines. These lines mark sediment metal concentrations which correspond to the Effects Range Low (ERL) and Effects Range Median (ERM) (Long et al. 1995). These values are guidelines for *potential sediment toxicity* that are currently used in the literature. The way to view these numbers is:

- Concentration less than the ERL - no toxicological effects expected;

- Concentrations greater than the ERL, but less than the ERM - occasional toxicological effects expected; and

- Concentrations greater than the ERM would be expected to show some toxicological effects.

These values are based on a method of preponderance of evidence, meaning a large number of samples were analyzed and parsed according to the metal levels and observed toxicological effects. The samples were restricted to a higher salinity environments than Northern Chesapeake Bay, but extended over all of the coastal regions of the United States making no distinction on geochemical environment, grain size fractionation, or background mineralogy. These shortcomings are noted in the work, and emphasize that they are guidelines to be used to trigger further study. This work has been done at HMI, and no problems have been noted in the biota to date. The following section will describe a more appropriate technique, for assessing metal loading and levels which can be used to trigger further studies, which has been employed at HMI since 1990.

2. Interpretive technique

The method used to interpret changes in 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 1985 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:

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

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 2-4. 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, although 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, including both 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. This can be seen by the scatterof the Mn data in Figure 2-12. The behavior of Cu, though strongly related to grain size, is noticeably influenced by sorption into the oxy-hydroxide coatings.

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

Table 2-4: 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.

$$X = [\, a^*\text{Sand} + b^*\text{Silt} + c^*\text{Clay}\,]/100$$

	Cr	Mn	Fe	Ni	Cu	Zn
a	25.27	668	0.553	15.3	12.3	44.4
b	71.92	218	1.17	0	18.7	0
c	160.8	4158	7.57	136	70.8	472
R^2	**0.733**	**0.36**	**0.91**	**0.82**	**0.61**	**0.77**

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

$$\%\ \text{Excess Metal} = \frac{(\text{measured Metal} - \text{predicted Metal})}{\text{predicted Metal}} * 100 \qquad (3)$$

In Equation 3, the differences between the measured and predicted levels of any given metal are normalized to predicted metal 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 percent excess metal values are, they do not alone 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 a result of the normalization procedure of the data, Gaussian statistics can be applied to the interpretation of the data. Data falling within $\pm 2\sigma$ (± 2 standard deviations) are within normal background variability for the region; $\pm 2\sigma$ accounts for >95% of the population in a Gaussian distribution. Samples with a value of $\pm 3\sigma$ can be within accepted background variability, but are marginal depending on the trends in the distribution. Any values falling outside this range indicate a significant 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 2-4; e.g. the sigma level for Zn is ~30% (e.g., $1\sigma = 30\%$, $2\sigma = 60\%$, etc.).

Figure 2-13 shows the distribution of all of the surficial data for the Year 14. There are several features to note in this figure. The predicted baseline behavior is noted by the tall vertical lines which mark the ideal baseline level at 0% and the acceptable ±2σ range in which the metal levels can vary and still be considered baseline levels. The short vertical lines mark the measured ±2σ range for the Year 14 surficial data, and the bell curve is the normal distribution based on the calculated standard deviation for the data. The figure shows that Cr, Cu, Ni, and Fe all fall well within the predicted baseline conditions, with the ±2σ range of the data matching the expected baseline. There are some minor variances in the depleted portion of the curves (i.e. the negative values). The variances correspond to areas of coarse grained sediment that would be expected to have input from erosion of older material; this is particularly noticeable in the distribution of Cr and Cu, and to a lesser extent Fe and Zn. On the other hand, Mn and Zn show strong significant positive variance from baseline behavior, with Mn having four samples significantly elevated above baseline. The ±2σ range of Mn and Zn exceed the ±2σ range of the baseline with some samples having a variance of greater than +5σ, and the overall distribution of the metals has shifted to levels greater than the 0% predicted baseline. For both of the metals, the samples show a greater elevation in metals levels in the November sampling than in the April sampling (this will be discussed in the following section). The discussion in the rest of the report will focus on Zn as an indicator of change in sediment chemistry. Although both metals are among the first metals to be released as a result of acid leaching of sediments, Mn is not toxic and its behavior is not as well defined as Zn due to its occurrence in grain coatings. Zn has been used since the start of the Exterior Monitoring Program (Kerhin et al. 1982a; Wells et al. 1984) for several reasons:

1. Of the chemical species measured, Zn has been the least influenced by variation in analytical technique. Since 1976, at least four different laboratories have been involved in monitoring the region around HMI. The most consistent results have been obtained for Zn.

2. Zn is one of the few metals in the Chesapeake Bay that has been shown to be affected by anthropogenic input.

3. There is a significant down-Bay gradient in Zn enrichment that can be used to detect the source of imported material.

4. Zn concentrations are highly correlated with other metals of environmental interest.

Percent "Excess" Metal Loading for all 14th Year Surficial Samples

(Based on Historic Metal-Grain Size Relationships)

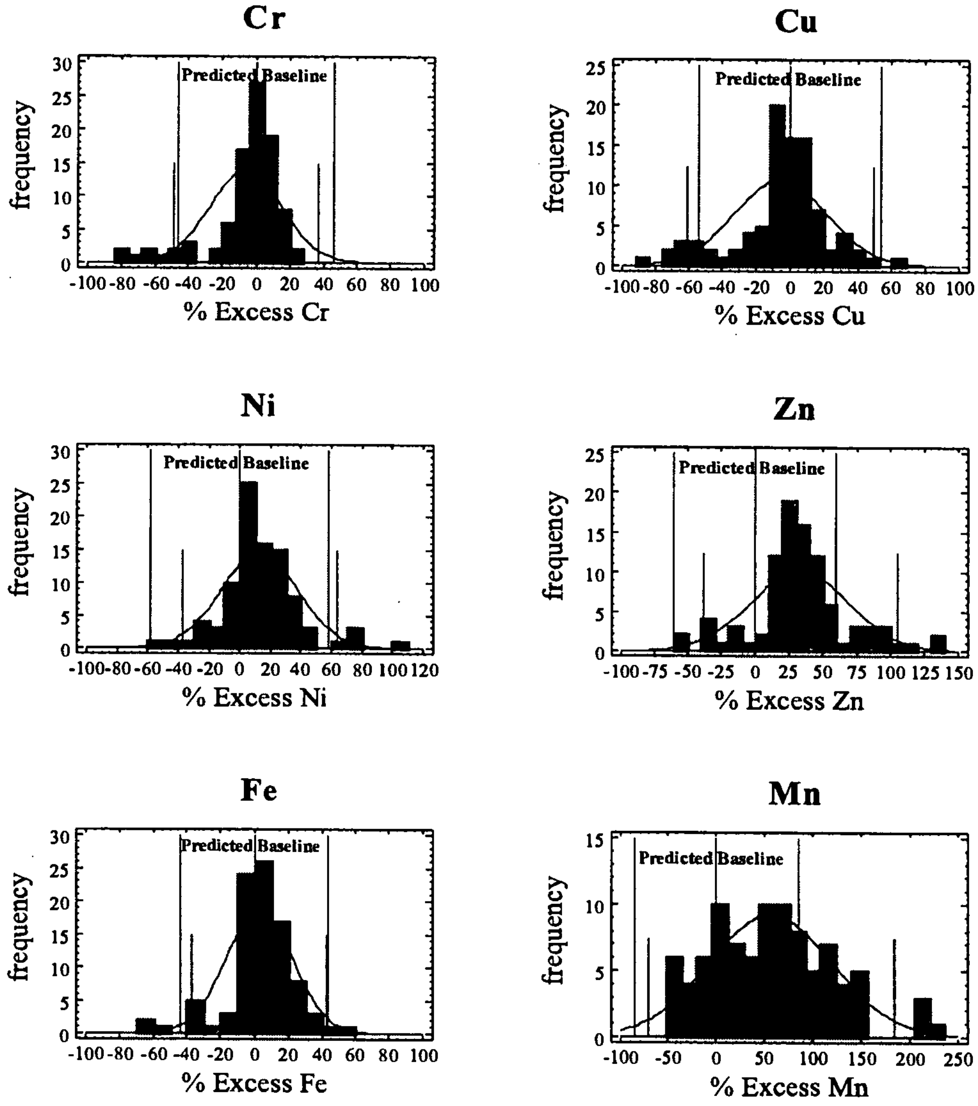


Figure 2-13: Distribution of all of the surficial metals data for Year 14. The predicted baseline behavior is noted by the tall vertical lines which mark the ideal baseline level at 0% and the acceptable ±2σ range in which the metal levels can vary and still be considered baseline levels. The short vertical lines mark the measured ±2σ range for Year 14 surficial data, and the bell curve is the normal distribution based on the calculated standard deviation for the data.

3. Results

Since Year 8, increased levels of Zn have been noted in bottom sediments east and south of HMI spillway #1. The results of previous monitoring studies have shown that the areal extent and magnitude of metal loading 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 *12th 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 in the dike, minimizing exposure to air, diluting and buffering any acidic leachate. As a result, higher discharge rates produce metal loadings that are close to background levels.

2. *Flow of freshwater into Chesapeake Bay from the Susquehanna River* - The hydrodynamics of the Bay in the area of HMI are controlled by the mixing of fresh 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 HMI against the eastern and southeastern perimeter of the dike.

    b. The circulation gyre is influenced 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.

    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 affected 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 HMI 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.

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

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 2-14 shows the percent excess Zn levels around HMI for the period of Years 7 through 12. The distribution of Zn shown for April 1987 is typical of the metals distribution during the pre-discharge phase of dike operations. The other sampling periods shown in Figure 2-14 display changes in the distribution magnitude and extent due to seasonal variability of Susquehanna River flow and discharge from the dike. Figure 2-15 shows the distribution of percent excess Zn, in sigma level contours, for the two Year 13 sampling cruises. The metal distribution for the November cruise was typical of the distribution seen in previous cruises following periods of low discharge rates. Prior to the November sampling cruise, crust management and dewatering were the primary operational activities at HMI. These activities resulted in low discharge rates, with associated low pH and high metal concentrations in ponded water in the dike (see section on *Dike Operations*). These conditions prompted remedial action to neutralize and manage the water prior to discharge. Metal levels were elevated significantly above background (120% Excess Zn; 4σ). These levels are comparable to those found after previous periods of low discharge (see Figure 2-14).

An unusual feature of Year 14 was that elevated levels of Zn found in the November cruise were maintained into the April cruise (Figure 2-16); although the affected area did diminish. April samples were collected following a period of active disposal of sediment inside of the dike, resulting in higher discharge rates. In previous years, high discharge rates lowered the load of excess Zn (Figure 2-11). This was due to the facility's acting as a flow-through system discharging material at ambient levels. This would, in turn, blanket and mix with any existing higher metal levels in the exterior sediments, effectively diluting the material and lowering levels to ambient concentrations. The expected lowering of metals levels apparently did not occur for the Year 14 April cruise. Although discharge rates were elevated, about 50% of the releases were 10 MGD or lower. The frequency of low discharge rates may have been sufficient to maintain the elevated levels from November.

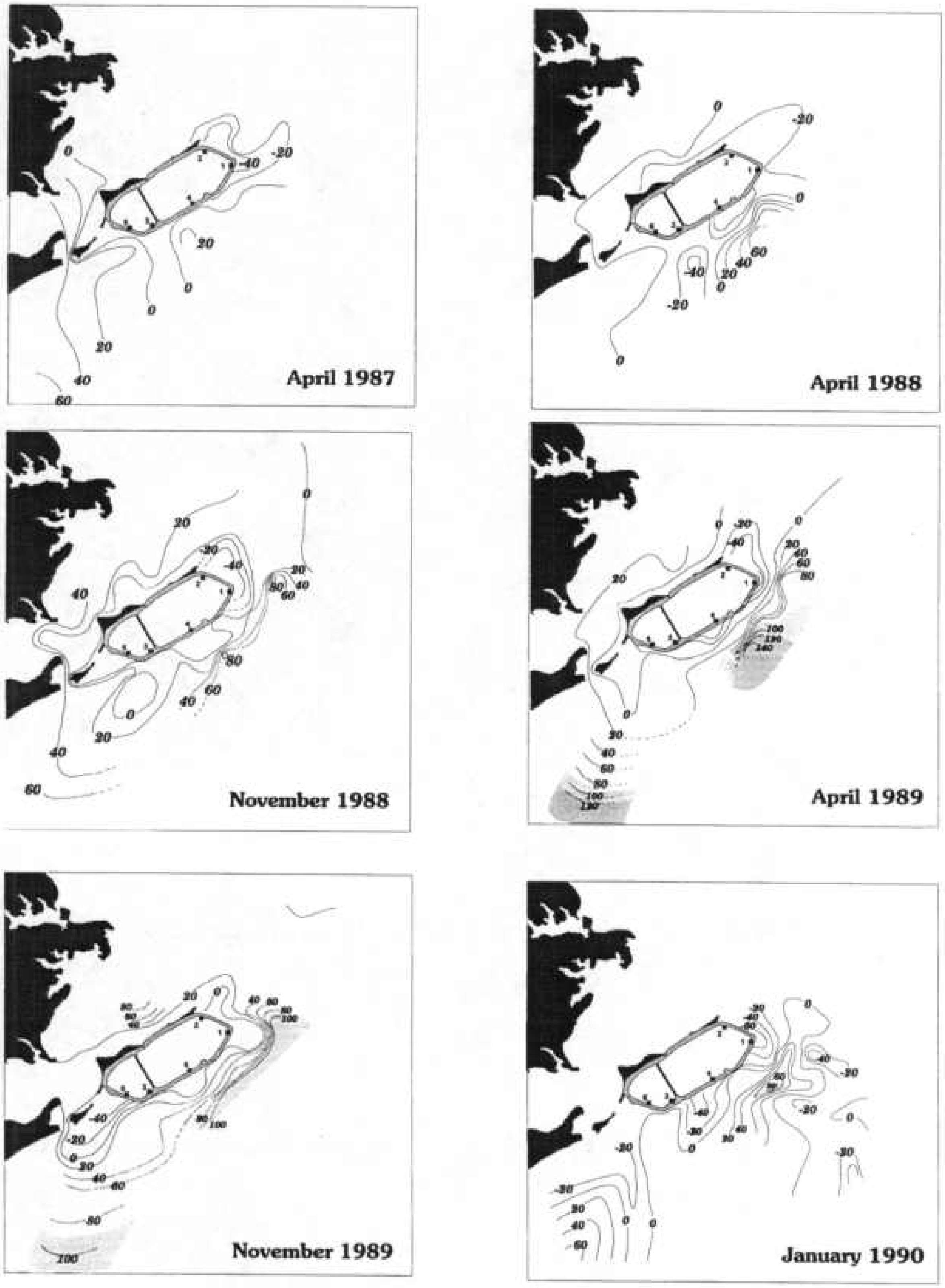


Figure 2-14: Percent excess Zn maps for Years 7 through 12.

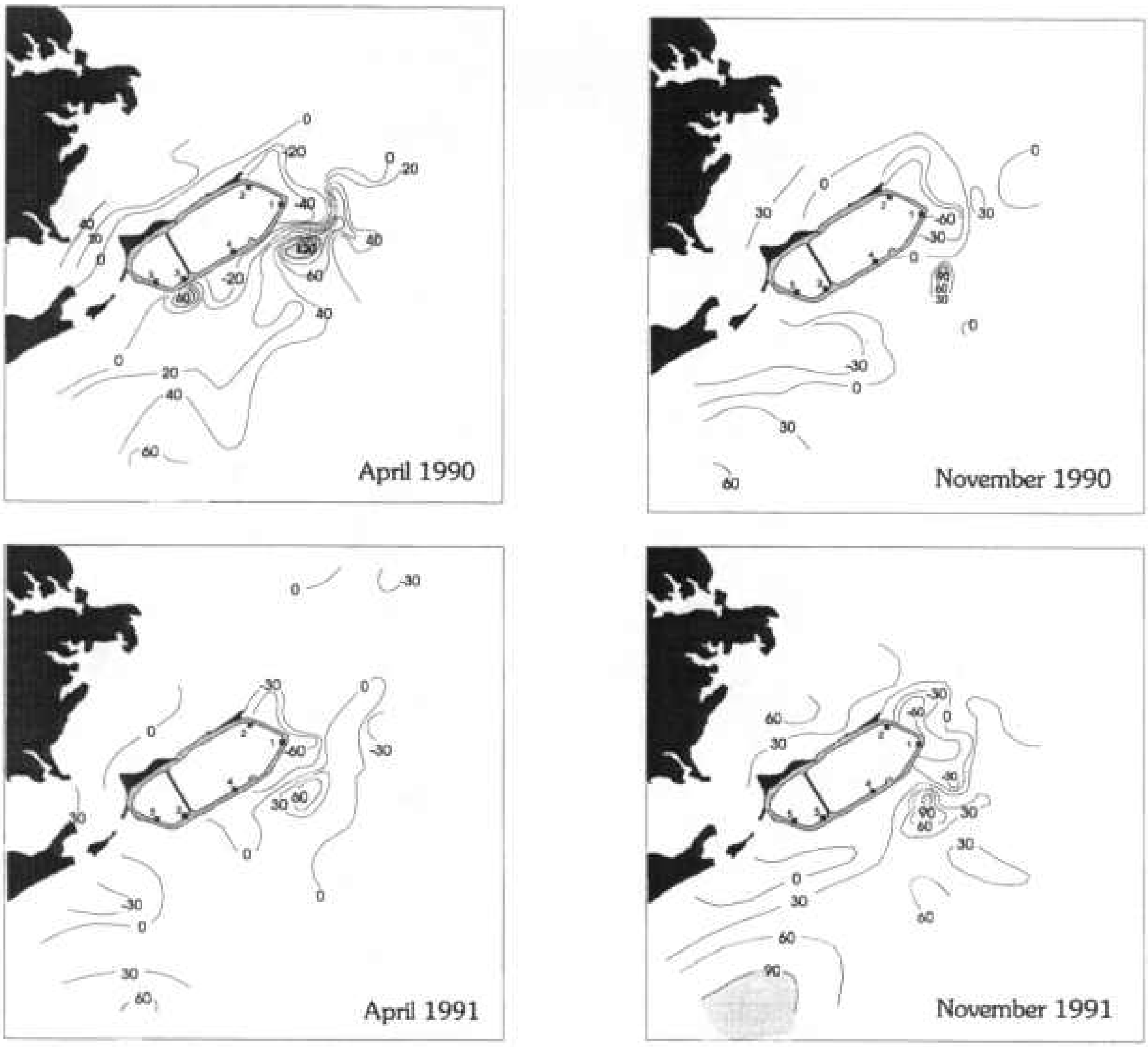


Figure 2-14 (con't): Percent excess Zn maps for Years 7 through 12.

Figure 2-14 (con't): Percent excess Zn maps for Years 7 through 12.

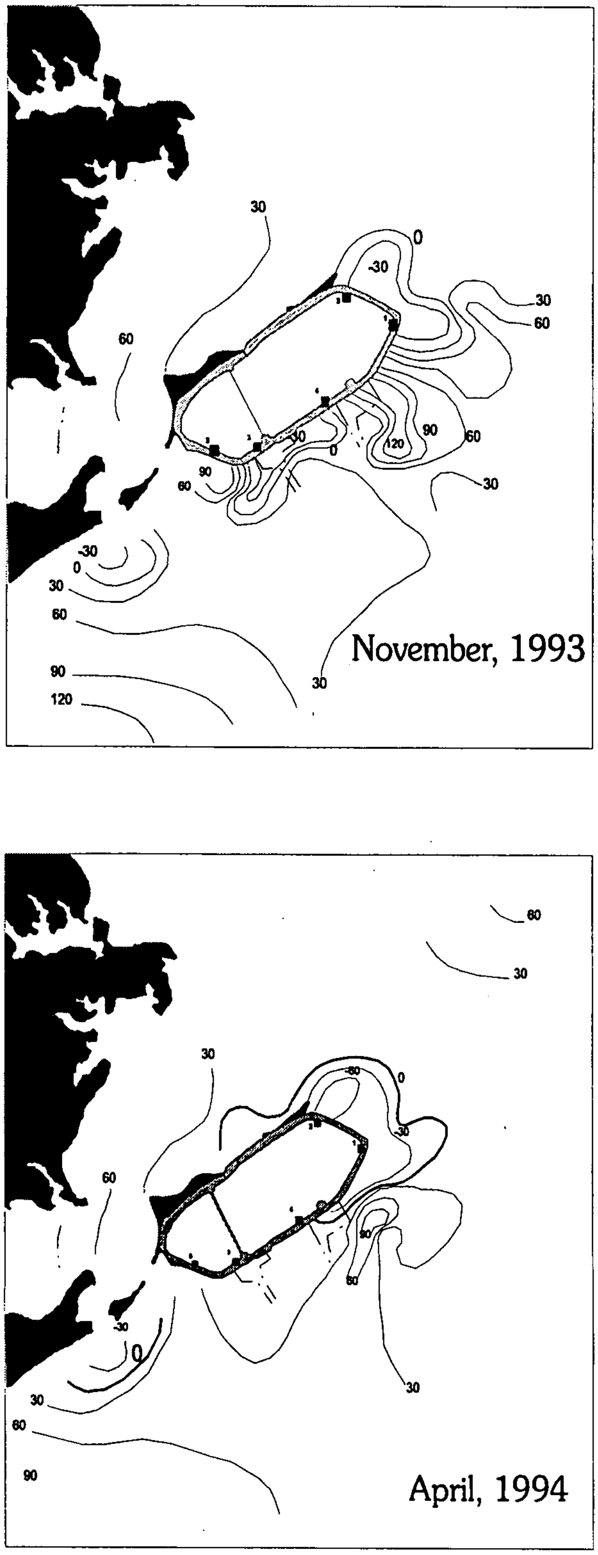


Figure 2-15: Percent excess Zn maps for Year 13.

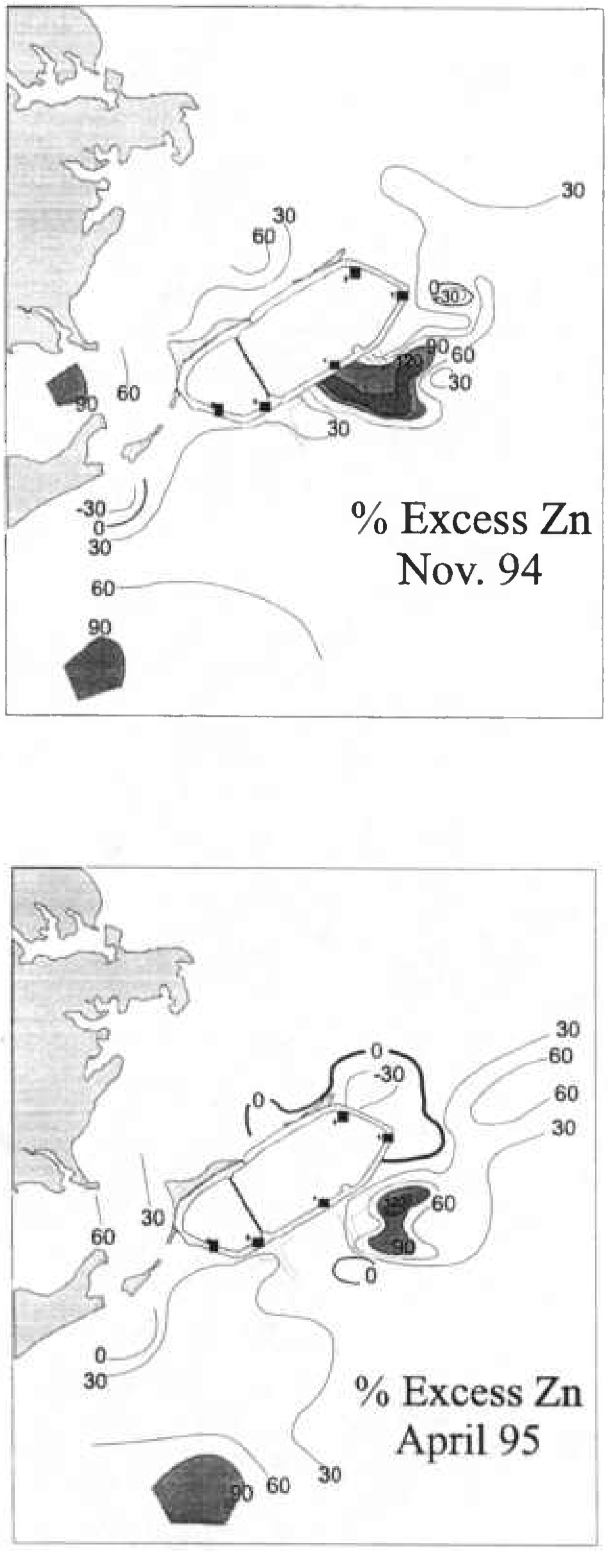


Figure 2-16: Percent excess Zn maps for Year 14.

CONCLUSIONS AND RECOMMENDATIONS

The grain size distribution of exterior bottom sediments mapped during Year 14 was similar to Year 13 findings and consistent with earlier post-discharge periods. The distribution of sand around HMI has remained largely unchanged since November 1988. For the four sampling periods of Years 13 through 14, differences in the distribution of the fine fraction of the sediment were minor, related to (1) the continuity and the southern extent of the clay-rich (clay:mud>0.55) zone and (2) in April 1994, an anomalous clay-rich deposit (clay:mud>0.70) adjacent to the north-northeastern perimeter of the dike, between HMI spillways #1 and #2.

Since the initial detection of Zn enrichment, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, higher than expected Zn levels persisted through Year 14 in the vicinity of HMI. In previous reports, Zn levels were correlated with the discharge rate of effluent from HMI. Metal levels in ponded water increase due to leaching of metals from the sediment in the dike, through a process similar to acid mine drainage. The maximum Zn loading due to leaching occurs at releases between 0.3-10 MGD. At higher discharge rates, flushing with large volumes of water effectively dilutes Zn loadings in the effluent, precluding Zn enrichment in the surrounding bottom sediments. The results of the metal distribution around the HMI for Year 14 do not show the degree of seasonal variation either in areal extent or enrichment of the sediment characteristic of prior Spring and Fall cruises. Discharge prior to the November sampling was low, with resulting higher levels of Zn in the external sediments. Although, discharge prior to the April cruise was higher, ~50% of the discharge periods were between 0.3-10 MGD. Consequently, the elevated levels found in November were maintained through April.

Persistent high metal levels in sediments around HMI indicate a need for continued monitoring. Even though the dike has nearly reached its capacity and the volume of effluent is expected to decline, dewatering of the confined 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. Metals released in the effluent, particularly at low discharge rates, will likely be deposited on the surrounding Chesapeake Bay floor. Continued monitoring is needed to detect such effects. Monitoring will also be valuable in assessing the effectiveness of any protocol implemented by MES to counteract the effects of exposing dredged material to the atmosphere. Close cooperation with MES will be important in this endeavor.

CHAPTER 3: BENTHIC STUDIES
(PROJECT III)

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ABSTRACT

Benthic macroinvertebrate populations in the vicinity of Hart-Miller Island Confined Disposal Facility (HMI) in Upper Chesapeake Bay were monitored for the fourteenth consecutive year in order to determine any effects on these bottom dwelling organisms from the operation of HMI. In November 1994, April and August 1995, organisms living close to HMI (nearfield stations), both within the sediments (infaunal) and upon pier pilings (epifaunal), were collected along with organisms living at some distance (reference stations) from HMI.

The infaunal samples were collected with a 0.05 m^2 Ponar grab and washed on a 0.7 mm mesh screen. Epifaunal samples (stations R2-R5) were removed from the pilings that support a series of piers surrounding HMI with a specially designed scraping apparatus. Sixteen infaunal stations were sampled on each cruise. Sampling sites included eight nearfield stations (S1-S8), 5 reference stations (HM7, HM9, HM16, HM22, HM26); and three of the four original stations (G5, G25, HM12) added over the course of the Year 9 study in areas found to be enriched with Zn. As of April 1994, station G84 (the fourth zinc station) was dropped because it no longer showed elevated Zn concentrations.

The various infaunal stations have sediments of varying compositions and include silt/clay, oyster shell and sand substrate stations. A total of 31 species were collected from these sixteen infaunal stations. The most abundant species were the worms *Scolecolepides viridis*, *Streblospio benedicti* and *Tubificoides sp.*; the crustaceans *Leptocheirus plumulosus* and *Cyathura polita*; and the clams *Rangia cuneata* and *Macoma balthica.*

Species diversity (H') values were calculated at each of the infaunal stations during the three sampling periods. The highest diversity value (3.568) was obtained at the Zn-enriched station G25, in November 1994. The lowest diversity value this year (0.965) occurred in April 1995 at the nearfield station S1. For the three sampling dates, the overall highest diversity values (with only five stations under 2.4) occurred in November 1994 and the lowest overall diversity occurred in April 1995.

Length-frequency distributions of the clams *Rangia cuneata*, *Macoma balthica* and *Macoma mitchelli* were examined at the nearfield, reference, and Zn-enriched stations. There was a good correspondence in terms of numbers of clams present and the relative size groupings for the three sampling dates. *Rangia cuneata* continues to be the most abundant species for all three groups of stations, followed by *Macoma balthica*. *Macoma mitchelli* is the least abundant of the three clam species.

Cluster analysis of the stations over the three sampling periods continues to associate stations primarily in response to sediment type. Variation in recruitment at the different stations explains why some specific stations did not form tight groupings. The clusters were again consistent with studies from previous years and did not indicate any unusual groupings resulting directly from HMI. Rank analysis of differences in the mean abundances of eleven selected species at stations with silt/clay substrates indicated only a slightly significant difference for one

source, the nearfield and reference stations, in August 1995.

Epifaunal populations were similar to those observed in previous years. Samples were collected at two depths [about 3 feet (1 meter) and 6-10 feet (2-3 meters), depending on the station's total depth]; the lower depth is well below the winter ice scour zone. The epifaunal populations persisted throughout the year at all of the locations on the pilings. The epifaunal populations at both the nearfield and reference stations were very similar over all three sampling periods. The amphipod *Corophium lacustre* was one of the most abundant organisms present at nearly all nearfield and reference stations sampled during Year 14. The hydroid *Cordylophora caspia* and the bryozoan *Victorella pavida* were the next two most frequently observed species on the pilings.

The results of the Year 14 studies reveal that no adverse effects on benthic populations have been observed which could be attributed to HMI. Three of the Zn-enriched stations (G5, G25 and HM12) established in Year 9, as a result of MGS's findings of sediments with elevated Zn concentrations in the vicinity of HMI, continue to be monitored. During the sixth year of sampling, the Zn-enriched stations did not exhibit any statistical difference from the original nearfield and reference stations. Continued monitoring of the benthic populations in the area is strongly recommended in order to track any changes associated with HMI.

INTRODUCTION

The results of the benthic population studies conducted in the vicinity of HMI during Year 14 of the HMI Exterior Monitoring Program are presented in this report. Hart-Miller Island lies within the estuarine portion of Chesapeake Bay that experiences seasonal salinity and temperature fluctuations. This region of Chesapeake Bay encompasses vast soft-bottom shoals, which serve as critical breeding and nursery grounds for many commercial as well as non-commercial species of invertebrates and migratory fish. Because it is an area that is environmentally unpredictable from year to year, it is necessary to maintain as complete a record as possible on all components of the ecosystem. Holland (1985, 1987) completed long-term studies of more stable mesohaline [5-18 parts per thousand salinity (Weisberg et al. 1997)] areas further south in Chesapeake Bay. Most macrobenthic species showed significant year-to-year fluctuations in abundance, primarily as a result of slight salinity changes. The spring season was also found to be a critical period for the establishment of both regional and long-term distribution patterns.

One would expect even greater fluctuations in the benthic communities inhabiting the region of HMI which is located in the highly variable oligohaline [0.5-5 parts per thousand salinity (Weisberg et al. 1997)] portion of Chesapeake Bay. Indeed, past studies indicate that the benthic invertebrate populations in this region are predominantly opportunistic or r-selected species with short life spans, small body size and often high numerical densities (Pfitzenmeyer and Tenore 1987; Duguay et al. 1989; Duguay 1989, 1990, 1992, 1993, 1994, 1995 and 1998). These opportunistic species are characteristic of disturbed or environmentally variable regions (Beukema 1988). The major objectives of the Year 14 benthic monitoring studies were:

1. To monitor the nearfield benthic populations for possible effects of discharged effluent and seepage of dredged materials from HMI by following changes in population size and species composition over the seasonal cycle;

2. To collect samples of the epibenthic fauna on the pilings along the perimeter of HMI in order to check for any immediate sign of detrimental effects to these organisms;

3. To continue monitoring benthic and epibenthic populations at established reference stations for comparisons with the nearfield stations surrounding HMI;

4. To continue monitoring benthic populations at three stations at which the MGS sedimentary group found elevated levels of Zn; and

5. To provide selected species of benthic invertebrates for chemical analysis of trace metals (arsenic, cadmium, chromium, copper, iron, manganese, nickel, and zinc) concentrations by an outside laboratory (Artesian Laboratories, Inc) to ascertain contaminant levels in organisms and determine if there is any bioaccumulation.

METHODS AND MATERIALS

Three cruises were conducted during Year 14 on November 14, 1994, April 10, 1995 and August 7, 1995. The location of all the sampling stations (infaunal - reference, nearfield and zinc-enriched; epifaunal - reference and nearfield) are shown in Figure 3-1 with their Chesapeake Biological Laboratory (CBL) designations. The stations were located in the field by means of the LORAN-C navigational system of the ship. Latitude and longitude of each station and the state identification numbers can be found in the *Year 14 Data Report*. The state designation numbers are also listed in Table 3-6 of this report. Station depths were recorded by the ship's fathometer. Surface and bottom temperatures were determined with a Hydrolab Surveyor 3 Multiparameter Water Quality Logging system to the nearest 0.01°C. Salinity for the surface and bottom waters was also determined with the Surveyor 3 to a tenth of a part per thousand (ppt).

Three replicate grabs were taken with a 0.05 m^2 Ponar grab at the established benthic infaunal stations (S1-S8, HM7, HM9, HM16, HM22, HM26, HM12, G5, G25) for each sampling period. All the individual samples were washed on a 0.7 mm screen and fixed in 10% formalin/seawater on board the ship. In the laboratory, the samples were washed on a 0.5 mm sieve and then transferred to 70% ethyl alcohol. Next, the samples were sorted and each organism was removed, identified, and enumerated. Measurements of length-frequency were made on the three most abundant clam species.

A qualitative sample was scraped from the pilings at the epifaunal stations (R2-R5, Figure 3-1) using a specially designed scraping device. The scrape samples were preserved and handled in a manner similar to the infaunal samples. However, only a qualitative or relative estimate of abundance was made for each species through a set of numerical ratings where 1 = very abundant, 2 = abundant or common, and 3 = present.

Quantitative infaunal sample data were analyzed by a series of statistical tests carried out with the Statistical Analysis Software package (SAS Institute, Cary, North Carolina). Simpson's (1949) method of rank analysis was used to determine the dominance factor. The Shannon-Wiener (H') diversity index was calculated for each station after data conversion to base $_2$ logarithms (Pielou 1966). After constructing a distance matrix comprised of pairwise station abundance chi-square values, stations were grouped according to numerical similarity of the fauna by single-linkage cluster analysis performed using the SASTAXAN computer program developed and provided by Dr. Dan Jacobs (Maryland Sea Grant, College Park, Maryland). Analysis of variance and the Ryan-Einot-Gabriel-Welsch multiple comparison procedure (Ryan 1960; Einot and Gabriel 1975; Welsch 1977) were used to determine differences in faunal abundance between stations. Friedman's nonparametric rank analysis test (Elliott 1977) was used to compare mean numbers of the 11 most abundant species between the silt/clay - nearfield, reference, and Zn-enriched stations singly. The reference and nearfield or Zn-enriched stations were added together and retested.

RESULTS AND DISCUSSION

Since the beginning of the benthic survey studies in 1981, a small number of species have been the dominant benthic macroinvertebrates collected at the nearfield and reference sites surrounding HMI. The most abundant species this year were the annelid worms *Scolecolepides viridis*, *Tubificoides sp.*, and *Streblosbio benedicti*; the crustaceans *Leptocheirus plumulosus* and *Cyathura polita*; and the clams *Rangia cuneata* and *Macoma balthica* (Tables 3-3, 3- 4, and 3-5). Variations in the range and average number of *S. viridis, L. plumulosus*, and *R. cuneata* at the reference stations since the initial sampling in August 1981 are presented in Table 3-1. The populations of these three species have remained relatively stable over the monitoring period. This year, numbers of *S.viridis* have dropped back to a more normal level compared to the numbers of previous years. Numbers of *R. cuneata* were the highest they have ever been.

The major differences observed in the dominant or most abundant species for a station occur primarily as a result of different bottom types (Table 3-2). Soft bottoms are preferred by the annelid worms *S. viridis*, *Tubificoides sp.*, and *S. benedicti*, as well as the crustaceans *L. plumulosus* and *C. polita*. The most common inhabitants of the predominately old oyster shell substrates are often more variable with the barnacle *Balanus improvisus*, the worm *Nereis succinea*, or the encrusting bryozoan *Membranipora tenuis* amongst the dominant organisms. This year the most common organism found at the soft bottom stations was the worm *S. benedicti*. On the shell bottom stations, the clam *R. cuneata* was the dominant organism. It was a particularly abundant year for both of these organisms.

Station HM26, at the mouth of the Back River, usually had the most diverse annelid worm fauna in past years. However, both this year and last, nearfield station S7 had the highest overall annelid diversity with 6 species in November 1994, and 7 species in April and August 1995. A diverse annelid fauna was also recorded this year at stations HM9, HM16, S2, S6, G25, and HM12, all of which had between 5 and 7 species of worms per sampling period (Tables 3-3, 3-4 and 3-5). This year the most abundant worm species at the nearfield and Zn-enriched stations was *S. viridis*. The most abundant worm at the reference stations was *S. benedicti*.

The worms *S. viridis*, *S. benedicti* and *Tubificoides sp.*, the clams *R. cuneata* and *M. balthica*, and the crustaceans *C. polita* and *L. plumulosus* occurred frequently at all three sets of stations (nearfield, reference, and Zn-enriched). These five species were not only the most frequently found but were also among the most abundant organisms at the various stations (Tables 3-3, 3-4, and 3-5). Over the course of the benthic monitoring studies, the worm *S. viridis* has frequently alternated with the crustaceans *C. polita* and *L. plumulosus* as the foremost dominant species. It appears that slight modifications in the salinity patterns during the important seasonal recruitment period in late spring play an important role in determining the dominance of these species. The crustaceans *C. polita* and *L. plumulosus* become more abundant during low salinity years while the worm *S. viridis* prefers slightly higher salinities. This year *R. cuneata* was the most abundant species, followed by *L. plumulosus.*

Once again, *L. plumulosus* was more abundant than *C. polita* at all three sets of stations (Tables 3-3, 3-4, 3-5) and was present at nearly all stations on all dates sampled. The isopod crustacean *Cyathura* was present at all stations on all sampling dates. *Cyathura* appears to be very tolerant of physical and chemical disturbances and repopulates areas such as dredged material disposal piles more quickly than other crustacean species (Pfitzenmeyer 1985).

All of the dominant species, with the exception of *R. cuneata*, brood their young. This is an advantage in an area of unstable and variable environmental conditions such as the low salinity regions of Upper Chesapeake Bay. Organisms released from their parents as juveniles are known to have high survival rates and often reach high densities of individuals (Wells 1961). The total number of individual organisms collected at the various reference, nearfield, and Zn-enriched stations are comparable and ranged for the most part between 1,000 and 13,000 individuals/m^2. The highest recorded value was found at station HM26. In August 56,161 individuals/m^2 were recorded at this station as a result of high concentrations of the clam *R. cuneata* (12,227 individuals/m^2) and the crustacean *S. benedicti* (31,453 individuals/m^2). The lowest recorded value occurred at station S1 in November (520 individuals/m^2). There did not appear to be any consistent pattern in terms of high or low abundance at the reference or nearfield stations. The predominant benthic populations at the three sets of stations (nearfield, reference, and Zn-enriched) are similar and consist of detrital feeders which have an ample supply of fine substrates in this region of Chesapeake Bay, particularly around HMI (Wells et al. 1984).

Salinity and temperature (both surface and bottom) were recorded at most infaunal stations on all sampling dates (Table 3-6). In November, the surface salinity ranged from 6.2 - 8.1 ppt., whereas the salinity varied between 4.2 and 5.6 ppt. in April. In August the surface salinity ranged from 4.9 - 5.9 ppt. Surface salinity ranges were higher than the previous year's values for all three sampling periods. Last year the salinity range in December was 0.05 - 2.6 ppt and the salinity ranges for April and August were 0.0 - 0.5 ppt and 1.8 - 3.1 ppt, respectively. All the bottom salinities were the same or higher than the surface salinities for all sampling dates. The bottom salinity ranges were as follows: November, 6.5 - 9.7 ppt; April, 4.3 - 5.7 ppt; August, 5.1 - 6.0 ppt. This year the average temperatures for surface waters were: 12.58°C in November, 11.26°C in April, and 26.43°C in August, compared with the previous year's temperature of 3.9, 12.0 and 25.2°C, respectively. The average bottom water temperatures were: 12.18°C in November, 11.03°C in April, and 26.41°C in August.

Species diversity values must be interpreted carefully in analyzing benthic data from the Upper Chesapeake Bay. Usually, high diversity values reflect a healthy, stable fauna with the numbers of all species in the population somewhat equally distributed and no obvious dominance by one or two species. In this area of Chesapeake Bay, however, we have observed this year, as in years past, that the normal condition is for one, two or three species to assume numerical dominance. This dominance is variable from year to year depending on environmental factors, in particular the amount of freshwater entering the Bay from the Susquehanna River. Because of the overwhelming numerical dominance of a few species, diversity values are fairly low in this productive area of Chesapeake Bay compared to values obtained elsewhere. Diversity values for each of the quantitative benthic samples for the three different sampling dates are presented in Tables 3-7, 3-8, and 3-9. This year the highest diversity values for the various stations were found mostly in August and November. Seven stations had their highest values in August and six stations were highest in November. Highest diversity values occurring in the summer months was postulated in the Year 1 technical report (Pfitzenmeyer et al. 1982) and were frequently the case for a majority of the stations during the early years of the study. This year, the summer (August) sampling period had a slightly greater number of stations exhibiting their peak diversity values in the winter (November) sampling period. The overall highest diversity value (3.568) was recorded in November at G25 while the lowest overall diversity value (0.965) was recorded in April for S1. The largest number of species recorded for any station was 23 at stations G25 (Zn-enriched) in November and S7 (nearfield) in April. The lowest number of species, 11, was recorded in November at nearfield station S1.

Three species of clams, *Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli*, were measured to the nearest millimeter in shell length to determine whether any size/growth differences were noticeable between the reference, nearfield, and Zn-enriched stations (see Figures 3-2, 3-3, and 3-4). The most abundant clam both this year and last was *R. cuneata*. The majority of *Rangia* were observed during the August sampling period were in the 5-10mm size class. In November and April, the largest numbers of *Rangia* clams were recorded in the <5mm size class. Overall, the nearfield and reference stations had somewhat higher numbers of *R. cuneata* than did the Zn-enriched stations (Figure 3-2).

The next most abundant clam during the Year 14 studies, as was the case for the seven previous Years (6 through 13), was *M. balthica* (Figure 3-3). *M. balthica* was the most abundant in the 2mm size class in November. In the April sampling periods, *M. balthica* was most abundant in the 2, 4 and 7mm size classes and in August the highest numbers were found in the 7, 10, and 15-mm size classes. Again, this year, the highest population densities were recorded in April. Overall, the nearfield stations had higher numbers of this clam than did the reference and Zn-enriched stations.

M. mitchelli is the least abundant of the three clam species recorded in the vicinity of HMI (Figure 3-4). As has been reported for the previous 7 years (Duguay et al. 1989; Duguay 1989, 1990, 1992, 1993, 1995, and 1996), there had been a slight shift in relative dominance to greater numbers of *M. balthica* than *M. mitchelli* over the past few years. In general, *M. mitchelli* was most abundant at the nearfield stations.

This was an abundant year for *Rangia* and *M. balthica*, whose numbers increased significantly. In Year 13 the total number of *Rangia* (individuals/m^2) was 4,543 and in Year 14 increased to 60,426 (individuals/m^2). For Year 14 the number of *M. balthica* was 36,327, while the total in Year 13 was 2,095. Abundance of *M. mitchelli* remained about the same.

Cluster analysis was employed again in this year's study in order 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 3-5, 3-6, and 3-7, stations with faunal similarity (based on chi-square statistics derived from the differences between the values of the variables for the stations) are linked by vertical connections in the three 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). 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. Most of the time, experience and familiarity with the area under examination can 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 November 1994 sampling period is presented in Figure 3-5. There is an initial joining of a nearfield and reference station (S3, silt/clay bottom and HM22, silt/clay bottom). The next station to join the initial pair of stations was a silt/clay, Zn-enriched station, HM12. As with the first three stations to join the dendrogram, the nearfield, reference, and Zn-enriched stations were well mixed throughout the dendrogram. As usual, station HM26 (reference) was one of the last stations to join the dendrogram in November. The clustering of stations observed for November is similar to that observed in previous reports (Duguay et al. 1989; Duguay 1989, 1990, 1992, 1993, and 1995) and the Zn-enriched stations appear in clusters with both the reference and nearfield stations. All indications are that no anomalous changes are occurring at either the nearfield or Zn-enriched stations.

In April 1995 (Figure 3-6), the first two stations to join the dendrogram were S5 and S8, two nearfield stations; both are silt/clay stations. The next nine stations to join this pair were also silt/clay stations; these were 3 nearfield, 3 reference, and 3 Zn-enriched stations. The last station to join the dendrogram was HM26, as was the case for November.

The August sampling period represents a season of continued recruitment for the majority of benthic species, as well as a period of heavy stress from predatory activities, higher salinity, and higher water temperature. These stresses exert a moderating effect on the benthic community, which holds the various populations in check. This year, the first three pairs of stations to join the dendrogram were a good mixture of silt/clay stations. The first pair to join the dendrogram consisted of HM12, a Zn-enriched station, and HM16, a reference station. The second pair included HM22 and HM7, both of which are reference stations. The third pair of stations to join the dendrogram was G5 (Zn-enriched) and S8 (nearfield). As was the case for the November and April sampling dates, the final station to join the dendrogram was HM26. The clusters formed over these three sampling dates, during the 1994-95 sampling period, represented previously observed normal groupings for the reference and nearfield stations with no unusually isolated stations. These clusters were consistent with earlier studies and often grouped stations according to bottom type and general location within the study area. The Zn-enriched stations clustered along with the nearfield and reference stations and indicated no unusually isolated stations among this recently sampled group. If the benthic invertebrates in this region were being affected by some adverse or outside force, it would appear in the groupings. No such indications were found during the three sampling periods reported in this study.

The Ryan-Einot-Gabriel-Welsch Multiple Comparison test was used to determine whether a significant difference could be detected when population means of benthic invertebrates were compared at the various sampling stations. The total number of individuals of each species was log transformed before the analysis was performed. Subsets of groups, the highest and lowest means of which do not differ by more than the shortest significant range for a subset of that size, are listed as homogeneous subsets. The results of these tests for the three different sampling dates are presented in Tables 3-10, 3-11 and 3-12.

In November 1994, the stations sorted themselves out into only two subsets (Table 3-10). The nearfield station, S8 and the reference station, HM26 formed the first subset. All the other stations were in the second subset, which means there was a mixture of nearfield, reference, and Zn-enriched stations indicating no major differences in the population means of these three types of stations.

In April, five subsets were evident (Table 3-11). The first subset was comprised of one nearfield station, S3 and one reference station, HM26. The second subset consisted of two reference stations (HM26, HM9), one Zn-enriched station (G5) and six nearfield stations (S1, S7, S6, S2, S5, and S8). All three of the other subsets were even better mixtures of stations.

The analysis of the August 1995 data resulted in four subsets. The first subset consisted of only one reference station, HM26. Subset 2 consisted of reference station (HM9) and two nearfield stations (S6 and S7). The last two subsets contained a mixture of nearfield, reference, and Zn-enriched stations.

The results of Friedman's non-parametric test for differences in the means of samples (for ranked abundances of 11 selected species), taken only at the silt/clay stations for the nearfield, reference, and Zn-enriched stations, are presented in Table 3-13. The only significant difference ($p<0.05$) was found in August, at the nearfield and reference stations. No differences were found in any of the stations for December and April.

Table 3-14 provides the data for the epifaunal samples from a series of pilings surrounding HMI (nearfield) and one located in the Pleasure Island boat channel (reference). Samples this year were again limited to depths of about 3 feet (1.0 to 1.3 m) below the surface and at 6-8 feet (2-3 m) below the surface to avoid the region of ice scour in the upper levels of the pilings where the fauna becomes depauperate in winter. Reasonably well-developed fauna occurred on all three sampling dates and there were no obvious major differences between the upper and lower samples. The densities and distribution of the various epifaunal species on both the nearfield pilings (R2-R4) and the reference piling (R5) are quite similar and sometimes nearly identical. Essentially, the same 10 species observed this year were the predominant species over the past seven study years (Pfitzenmeyer and Tenore 1987; Duguay et al. 1988; Duguay 1989, 1990, 1992, and 1993). The amphipod *Corophium lacustre* was again one of the most abundant and widespread species (Pfitzenmeyer and Tenore 1987; Duguay et al. 1988; Duguay 1989, 1990, 1992; Duguay, Shoemaker and Smith 1994, 1995, 1997). Overall, *Corophium lacustre* was the most abundant organism and the hydroid *Cordylophora caspia* was the second most abundant species. Other abundant, but at times more variable, organisms included of the worm *Polydora*, the barnacle *Balanus improvisus*, and the bryozoans *Membranipora* and *Victorella. Corophium* is a small amphipod crustacean which is extremely opportunistic and constructs tubules out of detritus in which it lives a protected existence. The tubules are quite tough and other colonial forms attach themselves to the tubule network. *Corophium* is not limited to the pilings but also occurs on shell and/or other hard surfaces on the bottom. No particular zonation of species was observed on the pilings. The same species which were found at the first meter were also collected at 2-3 m. The area is relatively shallow and no specific depth restrictions would be expected for the common species.

CONCLUSIONS AND RECOMMENDATIONS

For the Year 14 sampling and monitoring of the benthic populations of organisms in and around HMI, the sampling locations, sampling techniques, and analysis of the data were again maintained as close as possible to that of the previous years in order to minimize variation. Maintenance of sampling locations, techniques and analysis should make any differences due to effects of HMI more readily apparent. The special piling scraping device developed during monitoring Year 7 for qualitative epifaunal samples is still used. Monitoring three of the four Zn-enriched stations established over the course of Year 9 continued.

The results presented in this report are similar to those presented in the reports of the last nine years (Years 5 through 13). A total of 31 species (compared with 30, 30, 35, 32, 34, 31, 35, 30 and 26 for Years 13 through 5, respectively) were collected in the quantitative infaunal grab samples. Four species were numerically dominant on soft bottoms, including the worms *S. benedicti* and *Tubificoides sp.*, the crustacean *L. plumulosus*, and the clam *R. cuneata.* The oyster shell substrate stations had two numerically dominant species; these were the worm *S. viridis* and the clam *R. cuneata.* Salinity fluctuations on yearly and seasonal time scales appear to be important in regulating the position of dominance of the major species in this low and variable salinity region of Chesapeake Bay.

The average number of individuals per square meter (m^2) per station was highest for the reference (29,524) stations. Decreasing values were observed for the nearfield (20,245) and Zn-enriched (15,769) stations over the three sampling periods. However, the average abundance at all three sets of stations increased significantly compared to last year. The average abundance at the reference stations more than doubled.

The highest average species diversity values this year were found in November and the lowest diversity values were in April. The Zn-enriched clam populations appeared comparable to those observed at the reference and nearfield stations. This year the largest recruitment of young *Rangia cuneata* clams was observed in August.

In previous years, cluster analysis grouped stations of similar faunal composition in response to sediment type and general location within the study area. There were no incidences of individual stations being isolated from common groupings during the three sampling periods. This year the Back River reference (silt/clay) station HM26 was the last station to join the cluster for each sampling period. The Ryan-Einot-Gabriel-Welsch multiple range test resulted in subsets of stations which contained a mix of nearfield, reference, and Zn-enriched stations. Friedman's non-parametric test indicated a slightly significant difference for the nearfield and reference stations source in August only.

The epifaunal species were similar in distribution at the nearfield and reference stations at all three sampling periods. Because sampling this year was confined to the region below winter ice scour and low tide desiccation levels, no absence of species from the pilings was recorded.

The amphipod *Corophium* was the most abundant organism followed by the hydroid *Cordylophora*.

At present, there do not appear to be any discernible differences in the nearfield, reference and Zn-enriched populations of benthic organisms resulting directly from HMI. HMI will continue to operate at least until the year 2009. It is strongly recommended that the infaunal and epifaunal populations continue to be sampled at the established locations along with the more recently added Zn-enriched areas. This way any effects due to the operation of HMI can be ascertained. Station locations and sampling techniques should be maintained as close as possible to those of the last few years to minimize variation and permit rapid recognition of effects resulting from HMI.

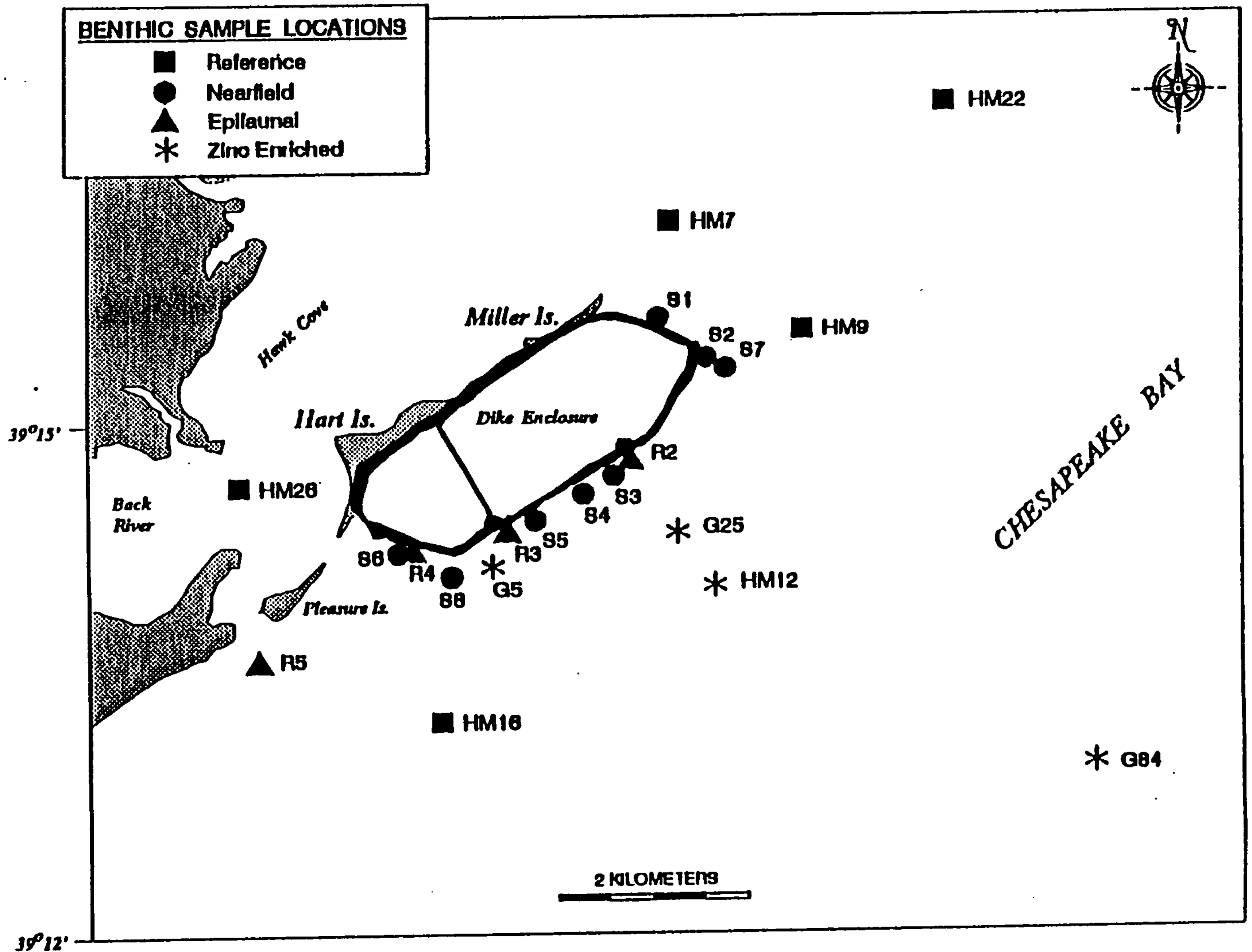

Figure 3-1: Benthic infaunal and epifaunal sampling station locations at HMI. University of Maryland, Chesapeake Biological Laboratory designations.

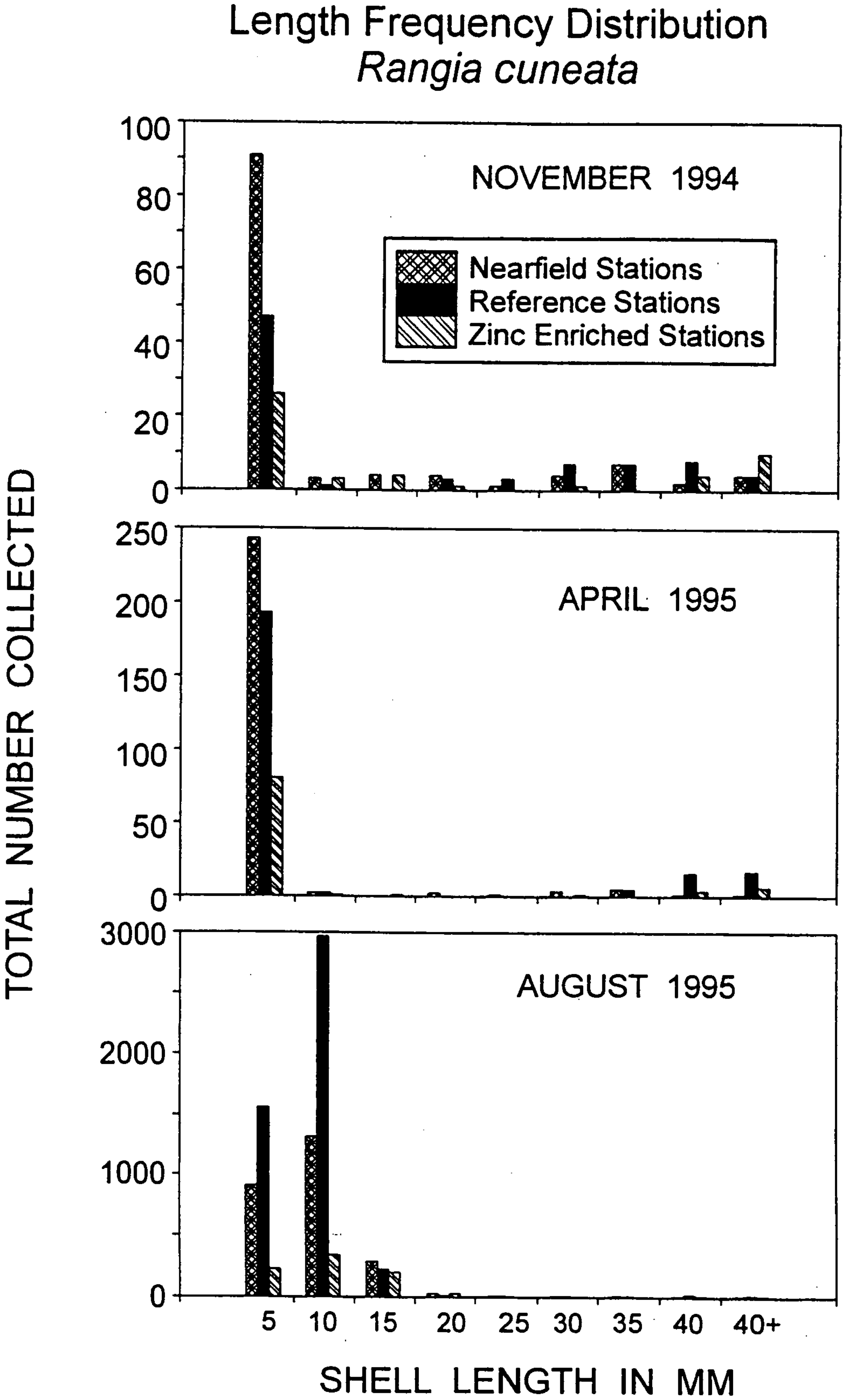

Figure 3-2: Length Frequency Distribution of the Clam *Rangia cuneata,* during Year 14 of Benthic Monitoring Studies at HMI.

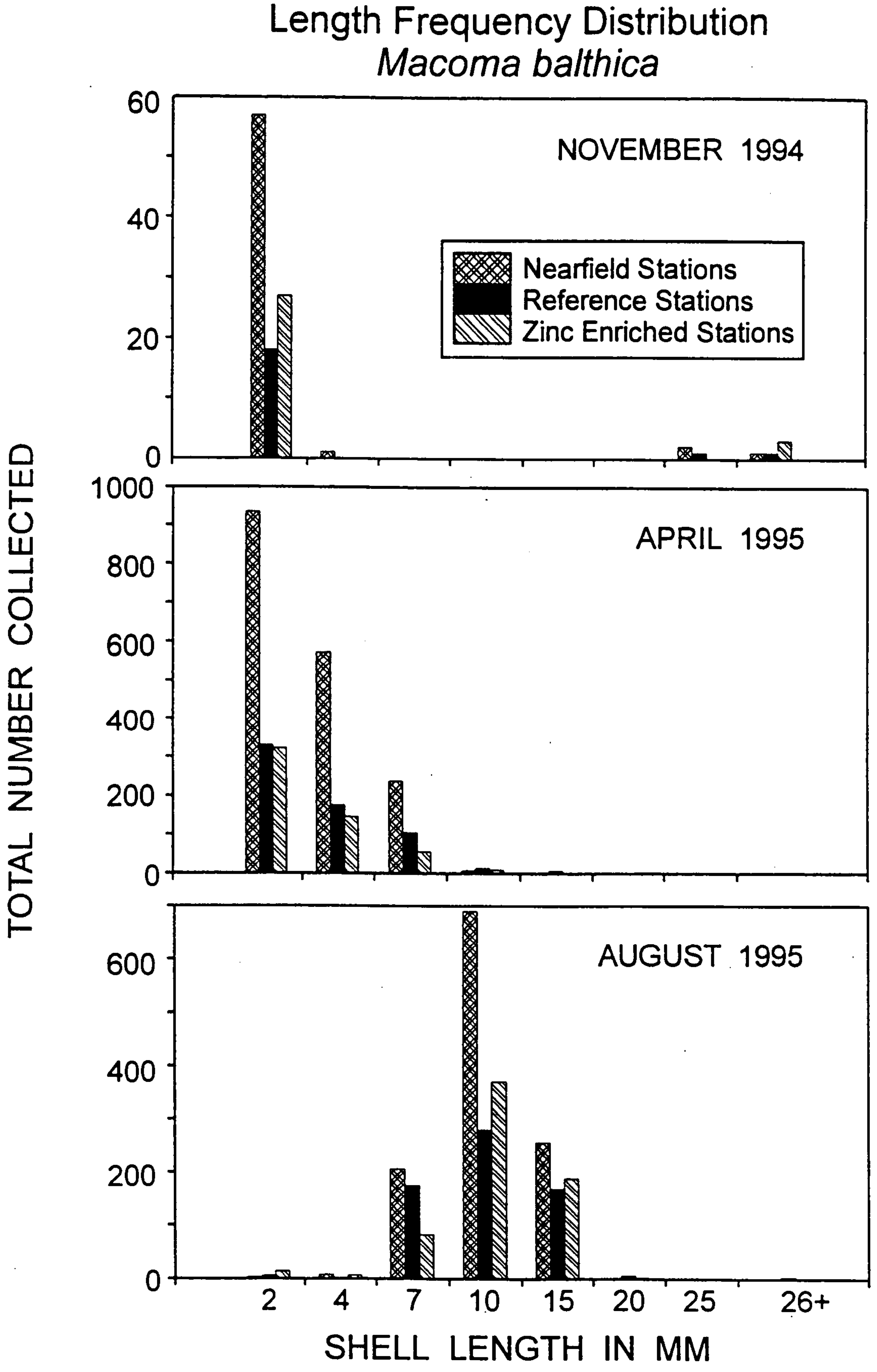

Figure 3-3: Length Frequency Distribution of the Clam *Macoma balthica*, during Year 14 of Benthic Monitoring Studies at HMI.

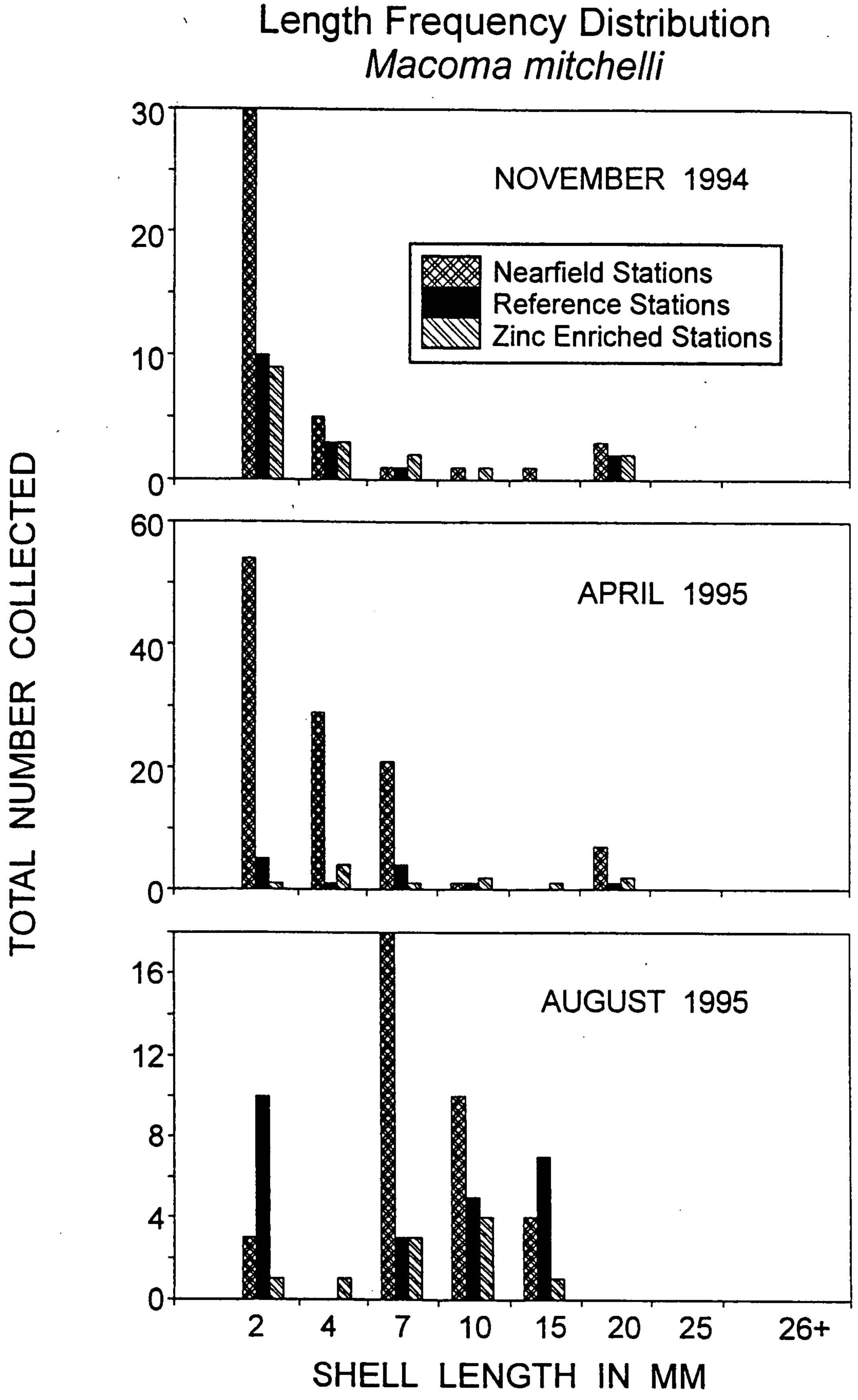

Figure 3-4: Length Frequency Distribution of the Clam *Macoma mitchelli*, during Year 14 of Benthic Monitoring Studies at HMI.

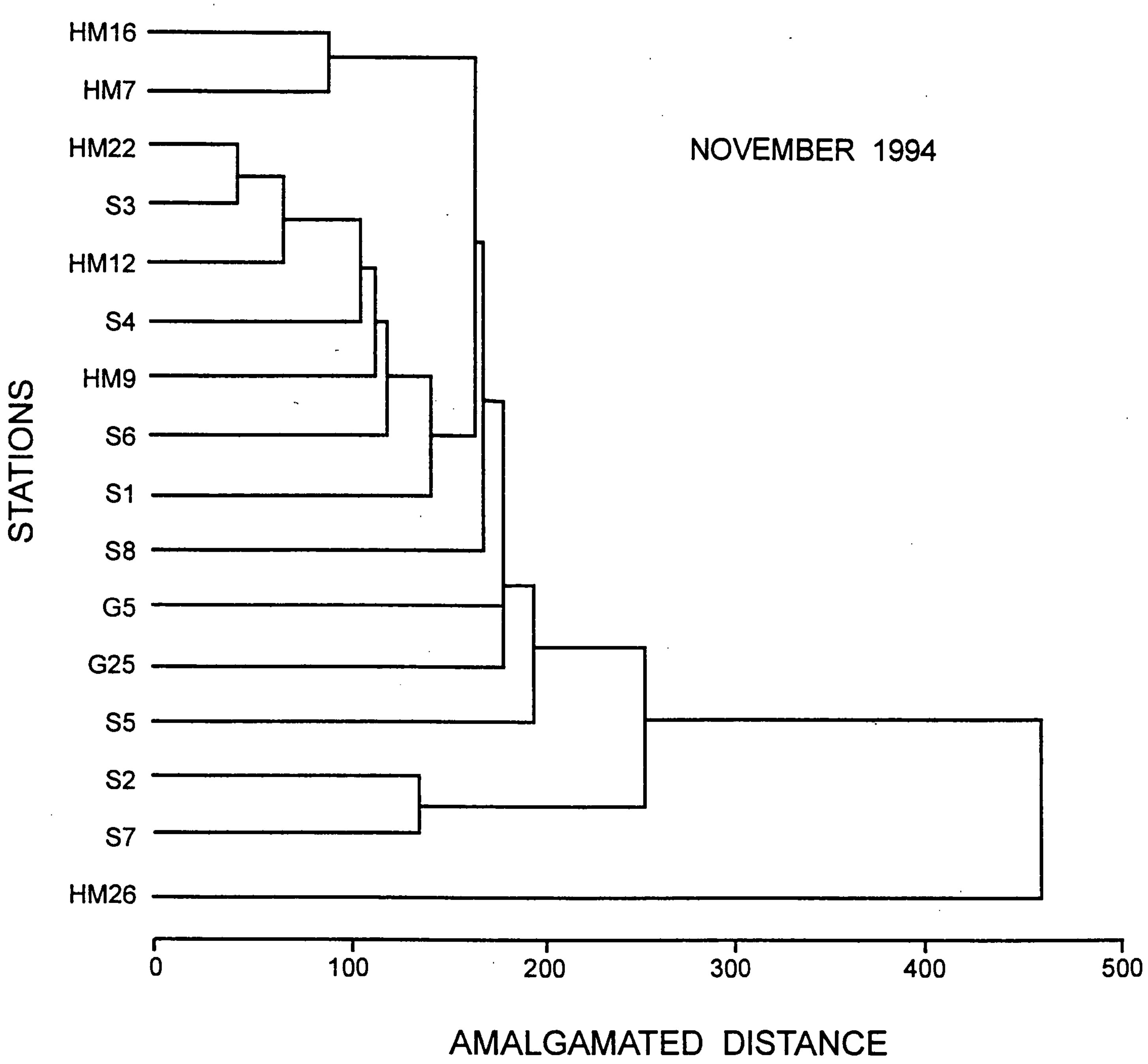

Figure 3-5: Cluster Analysis for all of the HMI Sampling Stations in November 1994 during Year 14 of Benthic Studies.

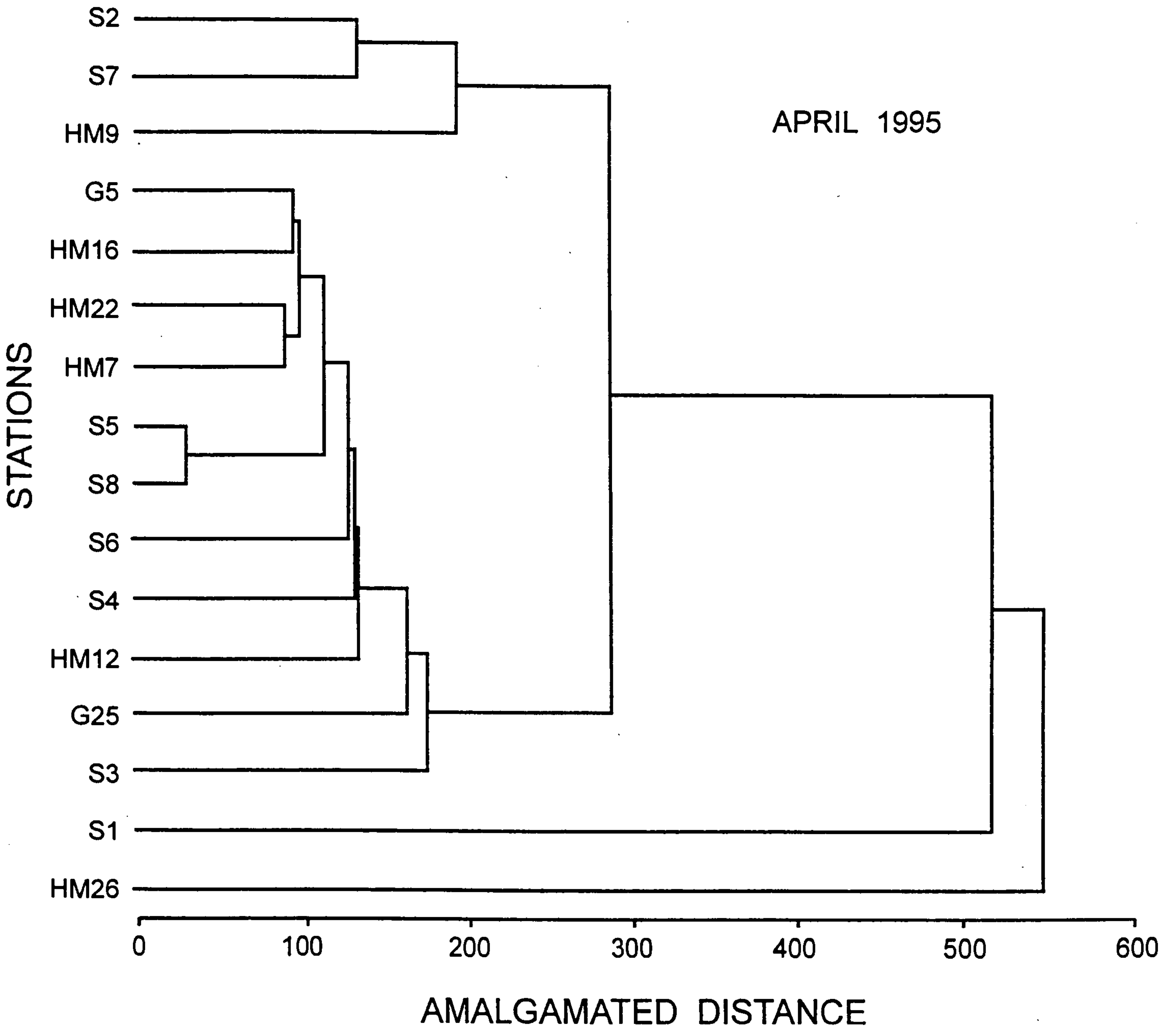

Figure 3-6: Cluster Analysis for all of the HMI Sampling Stations in April 1995 during Year 14 of Benthic Studies.

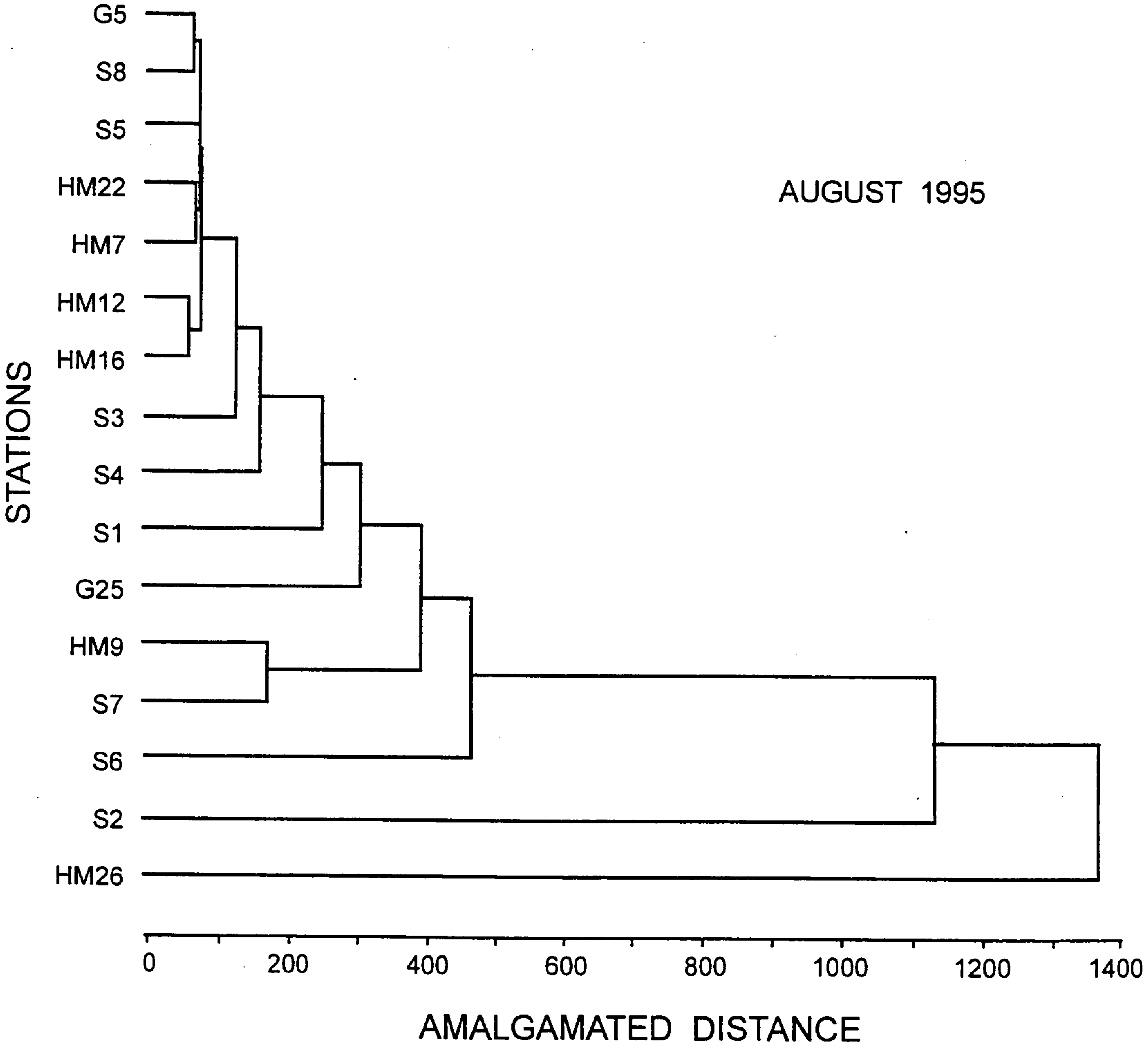

Figure 3-7: Cluster Analysis for all of the HMI Sampling Stations in August 1995 during Year 14 of Benthic Studies.

TABLE 3-1: Relative abundances (#/m^2) of three of the most abundant species of benthic organisms which occur at the HMI Reference Stations (HM7, HM9, HM16, HM22, HM26) over the Year 14 study period from August 1981 to August 1995.

	Aug.,Nov. 1981	Feb.,May, Aug.,Nov. 1982	Feb.,May 1983	Sep.1983 Mar.1984	Oct.1984 Apr.1985	Dec. 1985 Apr., Aug. 1986	Dec.1986 Apr.,Aug. 1987	Dec.1987 Apr.,Aug. 1988	Dec.1988 Apr.,Aug. 1989
Scolecolepides viridis									
Range/m2	0-1825	0-286	0-264		11-153	7-1287	13-447	0-657	20-3420
Avg./m2	229	121	69	546	92	398	179	178	998
Leptocheirus plumulosus									
Range/m2	0-2960	0-5749	7-6626		20-441	7-1293	7-3312	0-3693	0-2474
Avg./m2	832	1459	2259	614	272	308	1111	398	327
Rangia cuneata									
Range/m2	0-46	0-99	0-135		0-75	0-273	13-3007	0-2267	0-580
Avg./m2	9	9	22	455	27	102	687	359	123

TABLE 3-1 continued:

	Dec.1989 Apr.,Aug. 1990	Dec.1990 Apr.,Aug. 1991	Dec.1991 Apr.,Aug. 1992	Dec.1992 Apr.,Aug. 1993	Dec.1993 Apr.,Aug. 1994	Nov.1994 Apr.,Aug. 1995
Scolecolepides viridis						
Range/m2	27-9393	7-2313	20-880	60-693	47-8413	0-2813
Avg./m2	2012	231	231	277	1682	523
Leptocheirus plumulosus						
Range/m2	67-2820	0-3607	0-2740	0-7580	0-4820	33-3713
Avg./m2	829	808	1064	1392	953	1296
Rangia cuneata						
Range/m2	13-12420	0-9000	0-853	73-2487	0-307	20-12660
Avg./m2	1587	1647	289	484	124	2272

TABLE 3-2: A list of the 3 numerically dominant benthic organisms collected from each bottom type on each sampling date during Year 14 of Benthic Studies at HMI.

STATION	November 1994	April 1995	August 1995
NEARFIELD SOFT BOTTOM (S3,4,5,6,8)	Leptocheirus plumulosus Tubificoides sp. Streblospio benedicti	Leptocheirus plumulosus Macoma balthica Scolecolepides viridis	Streblospio benedicti Rangia cuneata Macoma balthica
NEARFIELD SHELL BOTTOM (S2,7)	Membranipora tenuis Polydora ligni Corophium lacustre	Scolecolepides viridis Membranipora tenuis Corophium lacustre	Rangia cuneata Balanus improvisus Membranipora tenuis
REFERENCE SOFT BOTTOM (HM7,16,22)	Leptocheirus plumulosus Tubificoides sp. Scolecolepides viridis	Leptocheirus plumulosus Scolecolepides viridis Macoma balthica	Rangia cuneata Macoma balthica Cyathura polita
REFERENCE SHELL BOTTOM (HM9)	Tubificoides sp. Leptocheirus plumulosus Streblospio benedicti	Scolecolepides viridis Macoma balthica Membranipora tenuis	Rangia cuneata Cyathura polita Tubificoides sp.
BACK RIVER REFERENCE SOFT BOTTOM (HM26)	Tubificoides sp. Leptocheirus plumulosus Streblospio benedicti	Tubificoides sp. Leptocheirus plumulosus Macoma balthica	Streblospio benedicti Rangia cuneata Tubificoides sp.
ZINC ENRICHED SOFT BOTTOM (G5,25,HM12)	Leptocheirus plumulosus Scolecolepides viridis Tubificoides sp.	Leptocheirus plumulosus Macoma balthica Scolecolepides viridis	Rangia cuneata Macoma balthica Cyathura polita

TABLE 3-3: Number of benthic organisms per meter squared (m^2) found at the Reference Stations during Year 14 (November 1994 - August 1995) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	HM7			HM9			HM16			HM22			HM26			TOTALS
			Nov	Apr	Aug	Nov	Apr	Aug	Nov	Apr	Aug	Nov	Apr	Aug	Nov	Apr	Aug	
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2		7	33	20		127	7		107	27	13		7	33	293	674
ANNELIDA (worms)	Heteromastus filiformis	3	7		7	127	93	93	60	87	260	20	13	33	67	20	13	900
	Nereis succinea	5		7		40	53	107	7	20				7	7		27	275
	Eteone heteropoda	8	7			7					7				40			61
	Polydora ligni	9				120	20	320				13	7	20	7		240	747
	Scolecolepides viridis	10	327	833	420	307	2813	147	187	893	167	320	547	227		327	327	7842
	Streblospio benedicti	11	287	40	240	513	80	447	107	40	47	80		133	727	140	31453	34334
	Limnodrilus hoffmeisteri	13																0
	Tubificoides sp.	14	540	73	100	687	560	740	740	300	73	620	20	87	8947	6207	7707	27401
	Capitella capitata	15																0
MOLLUSCA (mollusks)	Ischadium recurvus	16																0
	Congeria leucophaeta	17			7	13	47	33		7				7				114
	Littoridinops sp.	18								7								
	Macoma balthica	19	13	667	1133	40	900	600	20	807	1327	7	613	520	53	1167	660	8527
	Macoma mitchelli	20	13	20	13		7	13	53	20	100			13	40	33	27	352
	Rangia cuneata	21	113	380	4780	140	733	12660	20	60	820	133	133	1520	127	240	12227	34086
	Mya arenaria	22					40						13					53
	Hydrobia sp.	23																0
	Doridella obscura	25																0
ARTHROPODA (crustaceans)	Balanus improvisus	27				33	53	67										153
	Balanus subalbidus	28																0
	Leucon americanus	29																0
	Cyathura polita	30	200	260	733	113	240	1040	320	213	807	147	107	533	267	53	447	5480
	Cassidinidea lunifrons	31																0
	Edotea triloba	33			7		13	47			20						27	114
	Gammarus palustris	35																0
	Leptocheirus plumulosus	36	3060	1673	387	580	687	33	3713	1800	893	553	540	367	2367	1320	1460	19433
	Corophium lacustre	37		87		127	133	20	13	7			20		20	7		434
	Gammarus daiberi	38																0
	Gammerus tigrinus	39														7		7
	Melita nitida	40	193	47	33	13	13	113	160	40	93	7	7	53	53	100	60	985
	Chirodotea almyra	41																0
	Monoculodes edwardsi	42	7	7	60		20	47	7		53			47		7	53	308
	Chironomid sp.	43	153	127	327		7		13	20	73	67	273	193	407	493	1113	3266
	Rithropanopeus harrisi	44				27	27	273			7						27	361
COELENTERA (hydroids)	Garveia franciscana	47																0
PLATYHELMIA (flatworms)	Stylochus ellipticus	48																0
BRYOZOA (bryozoans)	Membrania tenuis	49				353	787	413	127	7			13		7	7		1714
	Victorella pavida	50																0
	TOTAL NUMBERS		4920	4228	8280	3260	7326	17340	5554	4328	4854	1994	2319	3760	13143	10161	56161	147621

TABLE 3-4A: Number of benthic organisms per meter squared (m^2) found at the Nearfield Stations during Year 14 (November 1994-August 1995) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	S1 Nov	S1 Apr	S1 Aug	S2 Nov	S2 Apr	S2 Aug	S3 Nov	S3 Apr	S3 Aug	S4 Nov	S4 Apr	S4 Aug
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2	93		20			20	40	27	167	27	47	200
ANNELIDA (worms)	Heteromastus filiformis	3		7	7	13	60		27	27	67	27	7	100
	Nereis succinea	5				167	33	73		13			47	13
	Eteone heteropoda	8							27	27			7	
	Polydora ligni	9				1220	67	7						
	Scolecolepides viridis	10	133	6833	627	413	3133	13	640	3173	527	753	673	227
	Streblospio benedicti	11	20	7		627	7	93	480	80	1087	120		1293
	Limnodrilus hoffmeisteri	13												
	Tubificoides sp.	14		7		613	133	193	1793	1960	753	460	427	567
	Capitella capitata	15												
MOLLUSCA (mollusks)	Ischadium recurvus	16												
	Congeria leucophaeta	17	7			107	27	27						
	Macoma balthica	19	13	93	40	40	453	13	47	3847	1833	20	573	787
	Macoma mitchelli	20			7			7	53	60	33	13	507	20
	Rangia cuneata	21	147	353	893	100	147	40	100	460	1613	20	27	1420
	Mya arenaria	22					7							
	Hydrobia sp.	23												
	Doridella obscura	25												
ARTHROPODA (crustaceans)	Balanus improvisus	27				473	193	3253					13	193
	Balanus subalbidus	28				60		7						
	Leucon americanus	29												
	Cyathura polita	30	13	33	480	93	127	80	333	287	873	327	213	853
	Cassidinidea lunifrons	31			7	7		20						
	Edotea triloba	33							7	20				7
	Gammarus palustris	35												
	Leptocheirus plumulosus	36	40	600	167	80	933		1313	2433	547	1460	2120	373
	Corophium lacustre	37	7	53		553	647	27	33	13			27	7
	Gammarus daiberi	38												
	Gammarus tigrinus	39		33			67							
	Melita nitida	40			13	87	27	100	60	40	80	13	40	80
	Chirodotea almyra	41	27		373	20	7							
	Monoculodes edwardsi	42	20	73	213						47			73
	Chironomid sp.	43		7			20		73	93	33	7	60	13
	Rithropanopeus harrisi	44				47	27	347						113
	Gammarus mucronatus	45												
COELENTERA (hydroids)	Garvela franciscana	47				7								
PLATYHELMIA (flatworms)	Stylochus ellipticus	48				27								
BRYOZOA (bryozoans)	Membranipora tenuis	49			7	1113	580	1253		27		213	107	247
	Victorella pavida	50				20								
	TOTAL NUMBERS		520	8099	2854	5887	6695	5573	5026	12587	7660	3460	4895	6586

TABLE 3-4B: Number of benthic organisms per meter squared (m^2) found at the Nearfield Stations during Year 14 (November 1994-August 1995) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	S5 Nov	S5 Apr	S5 Aug	S6 Nov	S6 Apr	S6 Aug	S7 Nov	S7 Apr	S7 Aug	S8 Nov	S8 Apr	S8 Aug	TOTALS ALL STATIONS ALL DATES
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2	40	53	60	7		253		7	73	47	20	160	1361
ANNELIDA (worms)	Heteromastus filiformis	3		47	60	93	60	253		73	13	20	40	60	1061
	Nereis succinea	5	7			13			47	160	7	7	7		594
	Eteone heteropoda	8				20	7				7				95
	Polydora ligni	9	40			27		13	153	53	80				1660
	Scolecolepides viridis	10	27	220	67	240	1553	420	147	3000	820	687	333	327	24986
	Streblospio benedicti	11	260	113	313	560	73	7240	227	73	307	973	27	940	14920
	Limnodrilus hoffmeisteri	13													0
	Tubificoides sp.	14	1873	793	233	873	333	720	273	360	433	4353	733	153	18036
	Capitella capitata	15													0
MOLLUSCA (mollusks)	Ischadium recurvus	16													0
	Congeria leucophaeta	17	20		33	7			73	7					308
	Macoma balthica	19	53	1747	1320	187	2780	1993		580	333	47	1607	1100	19506
	Macoma mitchelli	20	40	27	27	73	93	80	7	13	20	87	47	40	1254
	Rangia cuneata	21	60	67	533	280	40	2320	13	507	8853	113	120	1200	19426
	Mya arenaria	22					7		7	13					34
	Hydrobia sp.	23													0
	Doridella obscura	25													0
ARTHROPODA (crustaceans)	Balanus improvisus	27							93	267	33				4518
	Balanus subalbidus	28							13						80
	Leucon americanus	29													0
	Cyathura polita	30	273	320	720	120	260	587	20	173	1287	360	320	1047	9199
	Cassidinidea lunifrons	31							7						41
	Edotea triloba	33	13	7		140	73	13		40	60			7	387
	Gammarus palustris	35													0
	Leptocheirus plumulosus	36	2353	2793	580	366	1847	760		467	33	6220	2200	1253	28938
	Corophium lacustre	37	220	20		67	7		433	833	13	27			2987
	Gammarus daiberi	38													0
	Gammarus tigrinus	39	7						7	220					334
	Melita nitida	40	273	73	80		40	20	13	100	47	420	100	80	1786
	Chirodotea almyra	41							20			7			454
	Monoculodes edwardsi	42	13	7			7	60		7	73			87	680
	Chironomid sp.	43	207	147	127		127	487		7		107	100	360	1975
	Rithropanopeus harrisi	44	7		7			120	20	47	227			7	969
	Gammarus mucronatus	45													0
COELENTERA (hydroids)	Garvela franciscana	47													7
PLATYHELMIA (flatworms)	Stylochus ellipticus	48													27
BRYOZOA (bryozoans)	Membranipora tenuis	49	13	7	60	33	60	13	1047	1047	473		7	7	6314
	Victorella pavida	50													20
	TOTAL NUMBERS		5799	6441	4220	3106	7367	15352	2620	8054	13192	13475	5661	6828	161957

TABLE 3-5: Number of benthic organisms per meter squared (m^2) found at the Zinc Enriched Stations during Year 14 (November 1994 - August 1995) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	G5			G25			HM12			TOTALS
			Nov	Apr	Aug	Nov	Apr	Aug	Nov	Apr	Aug	
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2	27	7	120	33	53	167	53	47	273	626
ANNELIDA (worms)	Heteromastus filiformis	3	13		7	27	27	40	127	67	280	568
	Nereis succinea	5		7	7	87	93	93	7	40	33	353
	Eteone heteropoda	8				7			27	7	13	54
	Polydora ligni	9			7	387	27	87	20			528
	Scolecolepides viridis	10	1993	493	273	433	553	33	267	347	167	4559
	Streblospio benedicti	11	27		247	53	47	547	293	27	113	1354
	Limnodrilus hoffmeisteri	13										0
	Tubificoides sp.	14	180	240	93	527	380	620	493	193	507	3233
	Capitella capitata	15										0
MOLLUSCA (mollusks)	Ischadium recurvus	16										0
	Congeria leucophaeta	17	7			40		13	7			67
	Littoridinops sp.	18										0
	Macoma balthica	19	40	1107	1140	93	1027	960	67	1527	2333	8294
	Macoma mitchelli	20	53	20	27	20	27	13	40	27	27	254
	Rangia cuneata	21	127	60	1140	87	287	3407	113	273	1420	6914
	Mya arenaria	22				7	13			13		33
	Hydrobia sp.	23										0
	Doridella obscura	25										0
ARTHROPODA (crustaceans)	Balanus improvisus	27				13	167	587	7			774
	Balanus subalbidus	28										0
	Leucon americanus	29										0
	Cyathura polita	30	373	260	760	447	267	820	207	213	927	4274
	Cassidinidea lunifrons	31										0
	Edotea triloba	33	33		13	40					7	93
	Gammarus palustris	35										0
	Leptocheirus plumulosus	36	2773	3247	693	460	1073	13	900	500	1247	10906
	Corophium lacustre	37	27	53		340	33		27	7		487
	Gammarus daiberi	38										0
	Gammerus tigrinus	39					20					20
	Melita nitida	40	220	73	67	40	33	33	27	7	113	613
	Chirodotea almyra	41	7				7					14
	Monoculodes edwardsi	42			27	13	7	27		7	60	141
	Chironomid sp.	43	80	60	113	67	20	7	7	33	40	427
	Rithropanopeus harrisi	44			13	13	147	293			33	499
COELENTERA (hydroids)	Garvela franciscana	47										0
PLATYHELMIA (flatworms)	Stylochus ellipticus	48										0
BRYOZOA (bryozoans)	Membranipora tenuis	49		7	20	640	653	613	7	73	20	2033
	Victorella pavida	50										0
	TOTAL NUMBERS		5980	5634	4767	3874	4961	8373	2696	3408	7613	47306

TABLE 3-6: **Salinity (in parts/thousand-ppt.), temperature (°C), and depth (ft.) for the benthic sampling stations on the 3 collection dates during Year 14 of Benthic studies at HMI.**

CBL STA. ID	STATE STA. #	NOVEMBER 94			APRIL 95			AUGUST 95		
		DEPTH	TEMP.	SAL.	DEPTH	TEMP.	SAL.	DEPTH	TEMP.	SAL.
R2	X1F4813	0	12.73	7.2	0	11.29	4.8	0	26.23	5.4
R2	X1F4813	**NR	NR	NR	11	11.13	5.1	NR	NR	NR
R3	X1F4514	NR	NR	NR	0	11.25	4.9	0	26.50	5.4
R3	X1F4514	NR	NR	NR	10	11.04	5.2	NR	NR	NR
R4	XIF4518	NR	NR	NR	0	11.17	5.0	NR	NR	NR
R4	XIF4518	NR	NR	NR	8	11.15	5.1	NR	NR	NR
R5	XIF3638	0	13.10	7.7	0	11.57	5.6	0	25.93	5.4
R5	XIF3638	NR	NR	NR	4	11.61	5.7	NR	NR	NR
S1	XIF5710	0	12.48	6.2	0	11.34	4.5	0	26.50	5.5
S1	XIF5710	6	12.21	6.5	7	11.35	4.5	6	26.51	5.6
S2	XIF5406	0	12.43	6.4	0	11.27	4.4	0	26.38	5.5
S2	XIF5406	13	12.11	7.5	13	11.14	4.8	12	26.52	5.6
S3	XIF4811	0	12.16	7.2	0	11.17	4.8	0	26.41	5.5
S3	XIF4811	15	11.98	7.4	16	NR	4.9	14	26.43	5.6
S4	XIF4715	0	12.46	7.3	0	11.00	4.8	0	26.44	5.6
S4	XIF4715	15	11.87	7.5	15	10.64	5.2	13	26.44	5.6
S5	XIF4420	0	12.17	7.6	0	10.80	4.9	0	26.33	5.4
S5	XIF4420	19	12.08	7.6	NR	NR	NR	18	26.06	5.5
S6	XIF4327	0	12.35	8.1	0	11.66	5.2	0	25.64	4.9
S6	XIF4327	10	12.02	8.0	11	10.88	5.7	9	25.14	5.2
S7	XIG5405	0	12.54	6.4	0	11.26	4.4	0	26.66	5.9
S7	XIG5405	12	12.14	7.0	NR	NR	NR	14	26.67	5.9
S8	XIF4124	0	12.32	7.5	0	10.66	5.1	0	26.35	5.4
S8	XIF4124	15	12.06	7.8	13	10.58	5.3	12	26.35	5.5
HM7	XIF6388	0	12.53	6.3	0	11.20	4.4	0	26.35	5.8
HM7	XIF6388	12	12.30	7.4	13	11.21	4.5	11	26.38	5.8
HM9	XIF5297	0	13.04	7.0	0	11.16	4.5	0	26.88	5.7
HM9	XIF5297	18	12.32	7.3	18	10.92	4.9	16	26.88	6.0
HM12	XIF5805	0	12.65	7.8	0	11.08	4.6	0	26.98	5.3
HM12	XIF5805	17	12.47	7.9	18	10.52	5.0	15	27.22	5.7
HM16	XIF3325	0	12.36	7.8	0	10.65	5.5	0	27.06	5.9
HM16	XIF3325	18	12.56	9.7	18	10.50	5.7	NR	NR	NR
HM22	XIG7689	0	13.61	6.5	0	11.70	4.2	0	26.52	5.4
HM22	XIG7689	13	12.42	6.9	13	11.53	4.3	12	26.54	5.7
HM26	XIF5145	0	12.87	7.9	0	13.18	5.0	0	25.79	5.1
HM26	XIF5145	19	12.20	8.0	18	11.27	5.3	16	25.79	5.1
G5	XIF4221	0	12.18	7.5	0	10.77	4.9	0	26.35	5.5
G5	XIF4221	15	12.06	7.6	NR	NR	NR	13	26.31	5.5
G25	XIF4405	0	12.38	7.2	0	11.06	4.4	0	26.82	5.9
G25	XIF4405	17	12.06	7.5	NR	NR	NR	15	26.85	6.0

**NR= NOT RECORDED

TABLE 3-7: Number of species and the total number of individuals collected in three grab samples ($0.05m^2$ each) at the infaunal stations for November 1994. Bottom substrate, species diversity (H') and dominance factor (S.I.) are also shown. Data for Year 14 of Benthic Studies at HMI.

STATION	SUBSTRATE	NO. SPECIES	NO. INDIVIDUALS	SPECIES DIVERSITY (H')	DOMINANCE FACTOR S.I.
NEARFIELD					
S1	Sand	11	78	2.761	0.191
S2	Shell	22	883	3.415	0.123
S3	Silt/Clay	15	754	2.604	0.226
S4	Silt/Clay	13	519	2.402	0.257
S5	Silt/Clay	20	870	2.458	0.279
S6	Silt/Clay	17	466	3.195	0.149
S7	Shell	19	393	2.861	0.215
S8	Silt/Clay	15	2021	2.089	0.327
REFERENCE					
HM 7	Silt/Clay	13	738	2.012	0.411
HM 9	Shell	18	489	3.316	0.129
HM16	Silt/Clay	16	833	1.829	0.471
HM22	Silt/Clay	12	299	2.602	0.213
BACK RIVER REFERENCE					
HM26	Silt/Clay	16	1971	1.578	0.501
ZINC ENRICHED					
G5	Silt/Clay	16	897	2.117	0.333
G25	Silt/Clay	23	581	3.568	0.106
HM12	Silt/Clay	19	404	3.031	0.178

TABLE 3-8: Number of species and the total number of individuals collected in three grab samples ($0.05m^2$ each) at the infaunal stations for April 1995. Bottom substrate, species diversity (H') and dominance factor (S.I.) are also shown. Data for Year 14 of Benthic Studies at HMI.

STATION	SUBSTRATE	NO. SPECIES	NO. INDIVIDUALS	SPECIES DIVERSITY (H')	DOMINANCE FACTOR S.I.
NEARFIELD					
S1	Sand	12	1215	0.965	0.719
S2	Shell	20	1004	2.675	0.262
S3	Silt/Clay	17	1888	2.472	0.221
S4	Silt/Clay	16	734	2.636	0.242
S5	Silt/Clay	16	966	2.354	0.282
S6	Silt/Clay	17	1105	2.421	0.254
S7	Shell	23	1208	3.147	0.184
S8	Silt/Clay	14	849	2.422	0.256
REFERENCE					
HM 7	Silt/Clay	14	634	2.555	0.234
HM 9	Shell	21	1099	2.920	0.201
HM16	Silt/Clay	16	649	2.418	0.259
HM22	Silt/Clay	14	348	2.631	0.199
BACK RIVER REFERENCE					
HM26	Silt/Clay	16	1524	1.965	0.408
ZINC ENRICHED					
G5	Silt/Clay	13	845	1.974	0.383
G25	Silt/Clay	22	744	3.322	0.134
HM12	Silt/Clay	18	511	2.705	0.248

TABLE 3-9: Number of species and the total number of individuals collected in three grab samples ($0.05m^2$ each) at the infaunal stations for August 1995. Bottom substrate, species diversity (H') and dominance factor (S.I.) are also shown. Data for Year 14 of Benthic Studies at HMI.

STATION	SUBSTRATE	NO. SPECIES	NO. INDIVIDUALS	SPECIES DIVERSITY (H')	DOMINANCE FACTOR S.I.
NEARFIELD					
S1	Sand	13	428	2.595	0.201
S2	Shell	18	836	1.988	0.398
S3	Silt/Clay	13	1149	2.952	0.155
S4	Silt/Clay	19	988	3.297	0.132
S5	Silt/Clay	15	633	2.972	0.173
S6	Silt/Clay	17	2303	2.567	0.271
S7	Shell	20	1979	1.939	0.468
S8	Silt/Clay	16	1024	3.094	0.140
REFERENCE					
HM 7	Silt/Clay	15	1242	2.149	0.367
HM 9	Shell	20	2601	1.776	0.542
HM16	Silt/Clay	16	728	2.941	0.171
HM22	Silt/Clay	15	564	2.738	0.221
BACK RIVER REFERENCE					
HM26	Silt/Clay	17	8424	1.881	0.381
ZINC ENRICHED					
G5	Silt/Clay	18	715	2.935	0.169
G25	Silt/Clay	19	1256	2.896	0.210
HM12	Silt/Clay	18	1142	2.921	0.178

TABLE 3-10: **The Ryan-Einot-Gabriel-Welsch Multiple F test of significance among mean number of individuals per station for stations sampled in November 1994. Subsets show groupings of stations different at ($P<0.05$). Stations in a separate vertical row and column are significantly different from others. Year 14 of Benthic Studies at HMI.**

NOVEMBER 1994

SUBSET	STATION NUMBERS															
1	S8	HM26														
2			G5	S2	S5	HM16	S3	HM7	G25	S4	HM9	S6	HM12	S7	HM22	S1

ANALYSIS OF VARIANCE

SOURCE	D.F	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB.
BETWEEN GROUPS	15	1432492	95499	9.23	0.0001
WITHIN GROUPS	32	331257	10352		
TOTAL	47	1763750			

TABLE 3-11: The Ryan-Einot-Gabriel-Welsch Multiple F test of significance among mean number of individuals per station for stations sampled in April 1995. Subsets show groupings of different stations ($P<0.05$). Stations in a separate vertical row and column are significantly different from others. Year 14 of Benthic Studies at HMI.

APRIL 1995

SUBSET			STATION NUMBERS													
1	S3	HM26														
2		HM26	S1	S7	S6	HM9	S2	S5	S8	G5						
3			S1	S7	S6	HM9	S2	S5	S8	G5	G25	S4	HM16	HM7		
4					S6	HM9	S2	S5	S8	G5	G25	S4	HM16	HM7	HM12	
5							S2	S5	S8	G5	G25	S4	HM16	HM7	HM12	HM22

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB.
BETWEEN GROUPS	15	750154	50010	7.44	0.0001
WITHIN GROUPS	32	215163	6724		
TOTAL	47	965316			

TABLE 3-12: The Ryan-Einot-Gabriel-Welsch Multiple F test of significance among mean number of individuals per station for stations sampled in August 1995. Subsets show groupings of stations different at (P<0.05). Stations in a separate vertical row and column are significantly different from others. Year 14 of Benthic Studies at HMI.

AUGUST 1995

SUBSET			STATION NUMBERS													
1	HM26															
2		HM9	S6	S7												
3				S7	G25	HM7	S3	HM12	S8	S4	S2					
4					G25	HM7	S3	HM12	S8	S4	S2	HM16	G5	S5	HM22	S1

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	15	18357159	1223811	83.72	0.0001
WITHIN GROUPS	32	467793	14619		
TOTAL	47	18824952			

TABLE 3-13: Results of Friedman's non-parametric test for differences in the abundances of (11) selected species between stations with silt/clay substrates for Year 14 of Benthic Studies at HMI. (Silt/clay stations are: NEARFIELD STAS.- S3, S4, S5, S6,S8; REFERENCE STAS.- HM7, HM16, HM22; ZINC ENRICHED STAS.- G5, G25, HM12.)

	SOURCE	D.F.	CHI-SQUARE	CHI-SQUARE (0.05)
NOV 1994	NEARFIELD	4	4.44	9.49
	REFERENCE	2	2.36	5.99
	ZINC ENRICHED	2	2.23	5.99
	NEARFIELD & REFERENCE	7	12.13	14.07
	ZINC ENRICHED & REFERENCE	5	3.44	11.07
APR 1995	NEARFIELD	4	6.22	9.49
	REFERENCE	2	2.23	5.99
	ZINC ENRICHED	2	4.14	5.99
	NEARFIELD & REFERENCE	7	13.15	14.07
	ZINC ENRICHED & REFERENCE	5	8.47	11.07
AUG 1995	NEARFIELD	4	4.95	9.49
	REFERENCE	2	3.45	5.99
	ZINC ENRICHED	2	0.55	5.99
	NEARFIELD & REFERENCE	7	14.83 *	14.07
	ZINC ENRICHED & REFERENCE	5	4.77	11.07

*SIGNIFICANT DIFFERENCE AT THE 0.05 LEVEL.

TABLE 3-14: **Benthic species listed in descending order of density found on the piers and pilings surrounding HMI and at a reference piling at 1m and 2-3m depth for the three sampling periods for Year 14 of Benthic Studies at HMI.**

	STATIONS R2-R4 DEPTH (M)		REFERENCE STATION R5 DEPTH (M)	
NOV 1994	1.0 m	2-3 m	1.0 m	2-3 m
	Corophium	Victorella	Corophium	Corophium
	Victorella	Corophium	Victorella	Garveia
	Polydora	Polydora	Polydora	Cordylophora
	Cordylophora	B. subalbidus	B. improvisus	Polydora
	Membranipora	Cordylophora	B. subalbidus	Membranipora
		Membranipora	Cordylophora	Victorella
APR 1995	1.0 m	2-3 m	1.0 m	2-3 m
	Cordylophora	Corophium	Corophium	Corophium
	Corophium	Cordylophora	G. tigrinus	Membranipora
	Polydora	Polydora	Cordylophora	Nereis
	G. tigrinus	Membranipora	Polydora	Cordylophora
	Chironomidae	Nereis	B. subalbidus	Polydora
		G. tigrinus		
AUG 1995	1.0 m	2-3 m	1.0 m	2-3 m
	B. improvisus	Corophium	Victorella	Corophium
	Cordylophora	B. improvisus	Corophium	Victorella
	Rithropanopeus	Victorella	Rithropanopeus	B. improvisus
	Membranipora	Rithropanopeus	Polydora	Nereis
	Victorella	Polydora	B. improvisus	Cordylophora
			Cordylophora	Polydora

CHAPTER 4: ANALYTICAL SERVICES (PROJECT IV)

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INTRODUCTION

A long-term monitoring program has been conducted since 1981 in order to examine impacts from the construction and operation of Hart-Miller Island Confined Disposal Facility (HMI). Biological studies have monitored the populations and abundance of fish and benthos while physical studies have characterized the nature of currents and sediments. Chemical studies have measured the levels of nutrients in the water column as well as the levels of selected trace metal and organic contaminants in sediments and biota. The Coastal and Estuarine Geology Program of the Maryland Geological Survey is responsible for the collection and characterization of sediment samples under Project II: Sedimentary Environment. The Chesapeake Biological Laboratory of the University of Maryland, Center for Environmental Science, is responsible for the collection and characterization of the biota samples under Project III: Benthic Studies. This Year 14 report for Project IV: Analytical Services covers trace metal contaminants in the biological samples. Organic contaminants were not analyzed this year due to problems with detection levels by the contract lab and a decision by the HMI management to select a new laboratory with better analytical methods for organic contaminant analysis every other year. Data on metal contaminant levels in sediments can be found under the Project II report on the sedimentary environment.

Analyses of contaminant burdens in various species surrounding HMI have been performed since the inception of the Exterior Monitoring Program, with the first three years (pre-operation 1981-1983) used as a baseline against which to compare subsequent years. No chemical analyses were performed during the period from August 1983 - August 1984. The sampling program since 1984 has evolved from modest in 1984-1987 to more intensive sampling in years 1987 and 1988 and back to less intensive sampling in the most recent surveys. In previous reports, the data set was comprised of three sampling times: Winter (December), Spring (April), and Summer (August) and included both fish and benthic invertebrate tissue contaminant determinations. Beginning in Year 11 and continuing to the present, data for contaminant burdens in biota were collected only in the Spring and this year were restricted to a single species of benthic invertebrate, the clam *Rangia cuneata*.

METHODS AND MATERIALS

SAMPLING AND CHEMICAL ANALYSIS

Six benthic stations were sampled for trace metal analysis of biota. These represent a subset of about one third of the sampling stations for the benthic studies project (Figure 4-1). Benthic stations fall into three categories. Stations G25 and HM12 are two of four stations which were added in Year 9 to examine the elevated zinc (Zn) concentrations described in the Year 8 sedimentary environment report. Stations S2 and S4 are designated as nearfield stations and are immediately adjacent to HMI. Stations HM16 and HM22 are designated as reference stations and are removed from HMI.

On April 10, 1995, fourteen composite samples of the benthic bivalve (clam) *Rangia cuneata* were collected by the Chesapeake Biological Laboratory using a 0.05 m^2 Ponar grab. Samples were collected in conjunction with the spring benthic population sampling cruise. Biota samples were enumerated, identified to genus and species, measured, placed in pre-cleaned glass containers with teflon lined lids and immediately frozen onboard. Samples were logged on chain of custody forms with species and station identification and relinquished to Maryland Environmental Service (MES) staff at HMI on the same day of collection.

Samples were held frozen until extraction and analyses by the contractor, Artesian Laboratories, Inc. (ALI) several months later. ALI analyzed for eight metals (arsenic [As], cadmium [Cd], chromium [Cr], copper [Cu], iron [Fe], manganese [Mn], nickel [Ni], and zinc [Zn]). This is the second year that tissues were analyzed for arsenic burdens since the original baseline studies of 1981-1983.

A complete listing of analytical methods, as provided by ALI, are given in Table 4-1. Tissues were dissected, digested and analyzed for metal burdens utilizing the United States Environmental Protection Agency (USEPA) analytical methods. Arsenic and Cr were analyzed by graphite furnace atomic absorption (AA), Fe by flame AA, and Cd, Cu, Mn, Ni, and Zn by inductively coupled argon plasma (ICAP) emission.

The Year 14 analytical tissue data were accompanied by quality control (QC) data provided by the contractor ALI, as in the previous two monitoring years. MES adopted a program to check the quality of the contractor's analytical methods with reference materials prior to HMI sample analyses. QC method performance was evaluated through replicated analyses of external standard reference material (SRM) for metal analyses (oyster tissue 1566a from the National Institute of Standards and Technology, NIST). Internal QC controls included laboratory reagent blanks and fortified blanks, replicated sample tissue matrix spike recoveries on two samples, surrogate spike recoveries, and replicate analyses on two samples. While these QC data results are discussed in this report, the full data set is not included within the context of this interpretive report. One may find the entire data set in the *Year 14 Data Report*.

A summary of the benthic sample data is compiled in Table 4-2 which includes sample ID numbers (ALI and CBL), number of organisms, length distribution, percent lipid and weight per sample composite (as provided by the contractor). This was the second year since the baseline studies in which tissue percent lipid was analyzed, though the lipid data were not used in any normalization of the biota metal data. In this report, chemical concentrations for metals are reported as µg/g (ppm) wet weight values. Since many bivalve sampling programs report dry weight values, approximate comparisons can be made by decreasing dry weight values 8-fold (i.e., biological tissues are typically 80-90% water).

DATA ANALYSIS

Several recommendations cited in previous years were implemented beginning in the Year 12 and continued in Year 14. Where possible, larger tissue samples were used and organisms were sorted into samples according to size distribution. Only organisms larger than 35mm were used for analysis in this study. Most studies designed to determine contaminant differences among stations and or sampling years incorporate a standardization protocol (e.g., size, age, sex and lipid content) in order to reduce unwanted variance (Popham and D'Auria 1983; Lobel et al. 1991a).

Data were entered into Excel for Windows for presentation and summary purposes. The nature of the data set and the limited resources for conducting more exhaustive sampling precludes rigorous statistical analysis. Appropriate statistical tests are not generally available for this type of data. While somewhat improved over previous years, there is still insufficient data to estimate both among-sample and within-sample variability so that statistically significant among-station comparisons could be performed. Therefore, the data presentation is primarily a summarization of the analytical results in tabular format with average values calculated for duplicate samples. Unusual or atypical results were noted and compared largely with data from Years 11, 12 and 13. The order and format used to present the current data was kept similar to Years 10 through 13 to facilitate between-year comparisons. The data were grouped by station type for comparative purposes. It is believed that this presentation will aid in among-station comparisons and facilitate trend observation in future years

RESULTS AND DISCUSSION

QC METAL DATA

The overall QC data for metals were good and within specified limits. Percent recoveries generally ranged from 82-107% for sample tissue matrix spikes for all analytes. Method precision was lower for replicated field samples (wet tissue) than for the dry tissue Standard Reference Material (SRM). The relative percent difference (RPD) for SRM replicates ranged from 0-5% but the two *Rangia* duplicates samples ranged from 0-9 %, for sample 07 from HM12, and 3-47 % for sample 03 from G25. Similar ranges in RPD were noted for some of the field sample replicates. Given this variability in method precision and the difficulties encountered with obtaining homogenous subsamples from wet tissue matrices, differences in reported tissue burdens that vary less than 50% may not be meaningful.

TRACE METALS

Fourteen composite *Rangia* samples were collected from 6 stations in Year 14: four samples from two reference stations (HM16 and HM22), four samples from two nearfield stations (S2 and S4) and six samples from two of the Zn-enriched stations (G25 and HM12). Summary statistics for individual trace metal concentrations in the benthic biota (the clam *Rangia cuneata*), including the detection limits, individual and average values by station, averages by station type and overall are provided in Table 4-3.

Since there are species differences in metal accumulation for various bivalves, the most appropriate comparisons would be between baseline data for the clam *Rangia* from the pre-construction studies at HMI or from other uncontaminated or nearby sites. Unfortunately, no *Rangia* were collected for tissue analyses during the baseline studies around HMI and no other literature values are available with which to compare present day metal burdens. Thus, the most appropriate tissue burden comparisons that are possible to make at this time are between the present *Rangia* tissue burdens and those reported for the soft shell clam *Mya arenaria* (Table 4-4). While *Rangia* occasionally feed from surface organic deposits and may ingest some sediment, it is primarily a suspension feeder like *Mya* (Chesapeake Bay Program 1994). Thus, comparisons with *Mya arenaria* are the most appropriate.

Table 4-4 is a summary of trace metal concentrations found in soft shell clams *Mya arenaria* from Upper Chesapeake Bay during 1990-1994. These data cover stations from the mouth of the Patapsco River south to Sandy Point on the west side and from Rock Hall south to Kent Island on the east side of the Bay. These unpublished data were obtained from a Maryland Department of the Environment (MDE) data base and are the original reported wet weight data.

Arsenic, with a detection limit of 0.4 µg/g wet wt, was detected in all of the Year 14 *Rangia* samples. Values ranged from 0.67-1.45 µg/g wet wt from samples from each of the two reference sites, with little difference among the three station types. The means of samples from each station were all close to 1.02 µg/g wet wt., which is the overall average for all 6 stations. In Year 13, values were similar and ranged from 0.61 to 1.89 µg/g wet wt. In contrast, As was frequently below the detection limit of 0.05 µg/g for *Mya arenaria* tissues from the Upper Chesapeake (Table 4-4), but spanned the range of *Rangia* burdens observed this year at HMI.

Cadmium was detected in all *Rangia* samples collected during Year 14 and values ranged from 0.07 µg/g wet wt for one sample from G25 to 0.23 µg/g wet wt for a sample from S2. In Year 13, values ranged from 0.19 to 0.42 µg/g wet wt with a median value of 0.25 µg/g wet wt. The Cd detection limits of 0.04 µg/g for the present year were similar to those for Year 13. There appeared to be no trends among station types in either year. The grand average value of 0.13 µg/g observed this year was about one-half the median value reported for Year 13. The Year 14 values are about twice that reported for soft shell clams in Upper Chesapeake Bay (Table 4-4).

Chromium was found in all of the Year 14 samples with a detection limit of 0.08 µg/g wet wt. The range for all samples was from 0.24 µg/g wet wt at G25 to 0.59 for a sample from HM22. Last year, the values ranged from 0.26 to 0.72 µg/g wet wt for all stations except S7 which had 2 extreme values of 3.24 and 7.72 µg/g wet wt. Chromium detection limits in the present year are one to two orders of magnitude more sensitive than Year 12 when only 83% of the samples carried detectable burdens. Chromium was detected in none of the samples in Year 11 (above the detection levels of 1 to 2 µg/g) and in only 33% of the samples from Year 10 when one of two samples from the reference station (HM22) yielded the highest concentration of 66 µg/g. Similarly, Cr has frequently been below the detection limit of 0.5 µg/g in soft shell clams from Upper Chesapeake Bay over the same time frames (Table 4-4).

Copper was detected in all of the Year 14 *Rangia* samples with a detection limit of 0.03 µg/g wet weight. The highest concentration (2.44 µg/g) was found at reference station HM22 (Table 4-3) and the lowest value of 1.21 µg/g wet wt at station G25. Mean copper concentrations at each station type were relatively close to the mean value of 1.67 µg/g. Last year, values ranged from 1.8 to 2.9 µg/g wet wt with no particular trend among station types. The narrow range of Cu concentrations found in the present year are similar to those found in Years 10, 11 and 13 and show a decrease from the higher range of Cu concentrations in Year 12.

Iron and Mn were detected at substantial levels in all tissue samples from Year 14 (Table 4-3). Burdens of these two metals were substantially elevated in samples from reference station HM22 compared to the other stations. An enhanced burden of Fe and Mn was not found at station HM22 in Year 13, although some very high values of Mn concentration (greater than 70 µg/g wet wt) were noted in some of the samples from all near-field stations. In Year 14, the lowest level for Fe (23.9 µg/g wet wt) was noted at reference station HM16, while the lowest value for Mn occurred in a duplicate sample from HM12, a Zn-enriched station. The ranges reported this year are similar to those in the previous three monitoring years.

Nickel was detected in all of the *Rangia* samples with a detection limit of 0.11 µg/g wet wt. The highest values were found in samples from the reference stations (HM16 and HM22) with lower, similar values at near-field and Zn-enriched stations. Year 13 Ni values had a relatively narrower range from 4.8 to 7.9 µg/g wet wt. In Years 11 and 12, the largest Ni burdens in *Rangia* samples were observed at reference station HM22. Nickel concentrations at this station decreased an order of magnitude in Year 13. The mean Ni value of 7.3 µg/g for the Year 14 is over an order of magnitude greater than median Ni burdens in soft shell clams from the Upper Chesapeake (Table 4-4).

Zinc was detected in all samples in Year 13 with a detection limit of 0.03 µg/g wet wt. The highest concentrations occurred at reference station HM22, and lowest concentrations at Zn-enriched station G25 with an overall average of 25.6 µg/g wet wt. The range of Zn concentrations in the present year are similar to those in Years 10, 11 and 13 and considerably lower than the elevated levels reported in Year 12. The mean and range of *Rangia* Zn concentrations in Year 14 are similar to those found in the soft shell clam from the Upper Chesapeake Bay (Table 4-3).

SUMMARY OF SELECTED METAL DISTRIBUTIONS BY STATION

The distributions of metals in *Rangia* from the three stations are presented graphically in Figure 4-2. For most metals there were no apparent trends among stations or station types. The major exception to this was Reference station HM22. For Cu, Fe, Mn and Zn, there appears to be enrichment in the Year 14 samples.

CONCLUSIONS AND RECOMMENDATIONS

Fourteen composite tissue samples of the clam *Rangia cuneata* from six stations were analyzed for the presence of eight metals in Year 14. Trace metal detection levels were greatly improved this year which led to detectable burdens of all analytes in all samples. In general, precision of determinations improved markedly based on the within-site replication. No organic analytes were examined this year, but are scheduled for analysis in Year 15.

This was the second year in which As had been monitored in tissues since the baseline studies and it was detected in all samples. While no *Rangia* were monitored in baseline studies with which to compare current trace metal levels, this species' burdens of As, Cd and Ni are appreciably higher than levels found in the filter-feeding clam *Mya arenaria*, from Upper Chesapeake Bay.

The HMI Technical Review Committee assembled under Maryland Department of the Environment (MDE) has recommended several changes to sampling and analysis for the HMI Exterior Monitoring Program which will begin in Year 15. These changes should address the problems of detecting interannual and station differences in metal and organic contaminant burdens. The major changes include:

- Re-evaluation of the sampling locations. Relocation and addition of benthic stations in the more recently Zn-enriched areas, a revised sampling scheme to detect contaminant gradients around the facility and the addition of reference sites well-removed from the influences of HMI.

- Sample sediments and biota from the same locations, at the same time in August/September each year.

- Adoption of more sensitive analytical techniques for target organic analytes so that true contaminant differences can be detected.

- Use of *Rangia* as the only monitoring species to eliminate problems with comparing contaminant levels from different species among stations and over years and to allow flexibility in the selection of sampling locations so that only those sites with enough individuals to provide adequate tissue and replication are used.

Table 4-1: Analytical methods used to determine concentrations of metals in biota.

Parameter	Media	Method Number/Reference
Arsenic (As)	Tissues	(EPA 206.2/EPA 1983)
Cadmium (Cd)	Tissues	(EPA 200.7/EPA 1983)
Chromium (Cr)	Tissues	(EPA 218.2/EPA 1983)
Manganese (Mn)	Tissues	(EPA 200.7/EPA 1983)
Iron (Fe)	Tissues	(EPA 200.7/EPA 1983)
Copper (Cu)	Tissues	(EPA 200.7/EPA 1983)
Zinc (Zn)	Tissues	(EPA 200.7/EPA 1983)
Nickel (Ni)	Tissues	(EPA 200.7/EPA 1983)
Tissue digestion (metals)	Tissues	(EPA 200.3/EPA 1991)

Table 4-2: HMI Benthic Sample Descriptions. Year 14, April 10, 1995.

SPECIES	ALI SAMPLE NUMBER	CBL SAMPLE STATION	NUMBER CLAMS	SIZE RANGE (mm)	%LIPIDS	TISSUE WT. (G)	
						TOTAL SAMPLE	METAL SAMPLE
Rangia	01A	HM 16-1	5	35-43	2.04	27.97	5
Rangia	02A	HM 16-2	5	47-50	3.14	27.9	5.06
Rangia	03A	G 25-1	24	46-51	2.64	87.92	5.81
Rangia	03B	G 25-1 DUP					5.32
Rangia	03C	G 25-1 SPK			2.96		5.49
Rangia	04A	G 25-2	20	35-41	2.48	66.19	5.07
Rangia	05A	G 25-3	14	43-48	4.51	42.66	5.69
Rangia	06A	G 25-4	14	43-48	3.14	50.13	5.21
Rangia	07A	HM 12-1	13	41-46	2.59	56.26	5.46
Rangia	07B	HM12-1 DUP			3.12		5.38
Rangia	07C	HM12-1 SPK					5.62
Rangia	08A	HM12-2	13	41-46	3.19	50.06	6.4
Rangia	09A	S4-1	13	40-46	2.29	47.43	6.08
Rangia	10A	S4-2	12	40-46	4.34	43.94	5.27
Rangia	11A	S2-1	4	36-40	4.1	10.7	4.51
Rangia	12A	S2-2	5	36-41	3.91	14.06	4.88
Rangia	13A	HM22-1	14	35-39	4.14	28.41	5.73
Rangia	14A	HM22-2	13	35-40	3.35	24.13	5.23
Reference	15A	MES-R1					0.55
Reference	15B	MES-R2					0.52
Reference	15C	MES-R3					0.5

DUP = DUPLICATE SAMPLE
SPK = SPIKED SAMPLE
MES-R = STANDARD REPLICATE TISSUE SAMPLE (oyster)

TABLE 4-3: HMI benthic sample (Rangia) results of metal analyses for Year 14 (April 10, 1995).

Species	ALI SAMPLE NUMBER	STATION/ SAMPLE	NUMBER OF CLAMS	LIPIDS %	TISSUE WT. (GRAM TOTAL SAMPLE	METAL SAMPLE	As		Cd		Cr		Cu		Fe		Mn		Ni		Zn	
							µg/ g wet wt															
	Detection Li	n/a	n/a	n/a	n/a	n/a	0.4	$\bar{X}$	0.04		0.1		0.03		0.1		0.1		0.1		0	
	Reference Sites							Avg		Avg		Avg		Avg		Avg		Avg		Avg		Avg
Rangia	01A	HM 16-1	5	2.04	27.97	5.00	0.67		0.11		0.40		1.36		24		7.5		8.1		17	
Rangia	02A	HM 16-2	5	3.14	27.90	5.06	1.09	0.88	0.10	0.11	0.50	0.45	1.33	1.35	50	36.7	22	14.9	8.7	8.4	21	19.0
Rangia	13A	HM22-1	14	4.14	28.41	5.73	1.45		0.17		0.59		2.3		153		54		13		47	
Rangia	14A	HM22-2	13	3.35	24.13	5.23	0.85	1.15	0.18	0.18	0.50	0.55	2.44	2.37	141	147	78	65.8	11	12	42	44.8
		AVERAGE					1.02		0.14		0.50		1.86		91.9		40.4		10.1		31.9	
	Zn Enriched Sites							Avg		Avg		Avg		Avg		Avg		Avg		Avg		Avg
Rangia	03A	G 25-1	24	2.64	87.92	5.81	0.91		0.10		0.2		1.43		47		8.3		4.3		16	
Rangia	04A	G 25-2	20	2.48	66.19	5.07	0.86		0.07		0.3		1.21		96		14		4.7		17	
Rangia	05A	G 25-3	14	4.51	42.66	5.69	1.42		0.13		0.3		1.64		79		15		5.6		22	
Rangia	06A	G 25-4	14	3.14	50.13	5.21	1.05	1.06	0.10	0.10	0.3	0.30	1.61	1.47	63	71.3	10	12.0	5.9	5.13	19	18.2
Rangia	07A	HM 12-1	13	2.59	56.26	5.46	1.03		0.08		0.3		1.58		44		7.6		7.7		20	
Rangia	08A	HM12-2	13	3.19	50.06	6.40	0.70	0.87	0.11	0.10	0.3	0.29	1.49	1.54	48	46.1	14	10.9	6.5	7.05	21	20.3
		AVERAGE					1.00		0.10		0.29		1.49		62.9		11.6		5.77		18.9	
								% Var		% Var		% Var		% Var		% Var		% Var		% Var		% Var
Rangia	03B	G 25-1 DUP				5.32	1.23	30%	0.13	26%	0.3	25%	1.47	3%	64	31%	11	23%	5.4	23%	27	48%
		HM12-1 DUP		3.12		5.38	1.08	5%	0.08	2%	0.3	0%	1.58	0%	43	2%	6.9	9%	7.9	3%	20	0%
Rangia	07B																					
	Near Field Sites							Avg		Avg		Avg		Avg		Avg		Avg		Avg		Avg
Rangia	09A	S4-1	13	2.29	47.43	6.08	1.25		0.11		0.36		1.65		61		19		6.2		24	
Rangia	10A	S4-2	12	4.34	43.94	5.27	0.70	0.98	0.12	0.12	0.36	0.36	1.47	1.56	63	61.7	24	21.4	5.7	5.95	24	24.3
Rangia	11A	S2-1	4	4.1	10.7	4.51	0.93		0.23		0.41		1.80		37		15		8.9		29	
Rangia	12A	S2-2	5	3.91	14.06	4.88	1.36	1.15	0.18	0.21	0.47	0.44	2.06	1.93	111	74.1	40	27.4	6.6	7.71	40	34.3
		AVERAGE					1.06		0.16		0.40		1.75		67.9		24.4		6.8		29.3	
		GRAND AVERAGE					1.02		0.13		0.38		1.67		72.6		23.5		7.3		25.6	
	Standards																					
	15A	MES-R1				0.55	17.60		3.50		0.60		58.8		390		10		2.4		750	
	15B	MESR-2				0.52	16.20		4.05		0.68		59.4		390		11		1.8		766	
	15C	MESR-3				0.50	13.70		4.10		0.50		63.2		450		11		1.4		825	
	Spiked Samples																					
Rangia	03C	G 25-1 SPK		2.96		5.49	5.35		1.02		4.9		6.03		88		13		9.2		34	
Rangia	07C	HM12-1 SPK				5.62	4.85		1		4.7		5.94		81		12		12		24	

Table 4-4: Levels of trace metals in the soft shell clam, *Mya arenaria*, from the Upper Chesapeake Bay: 1990-1994. Original wet weight data (µg/g) from Maryland Department of the Environment (unpublished).

Metal	Range	Median	DL	% detects
Arsenic	<0.05-2.47	A	0.05	39
Cadmium	<0.05-0.2	0.05	0.01	70
Chromium	0.1-<0.5	A	0.5	22
Nickel	<0.05-1.35	0.21	0.05	61
Zinc	13.5-39.3	23		100

Data summaries are from 23 samples composited from 30 individuals or greater.

A: Median not calculated due to non-detects in majority of samples.

DL: Detection limit.

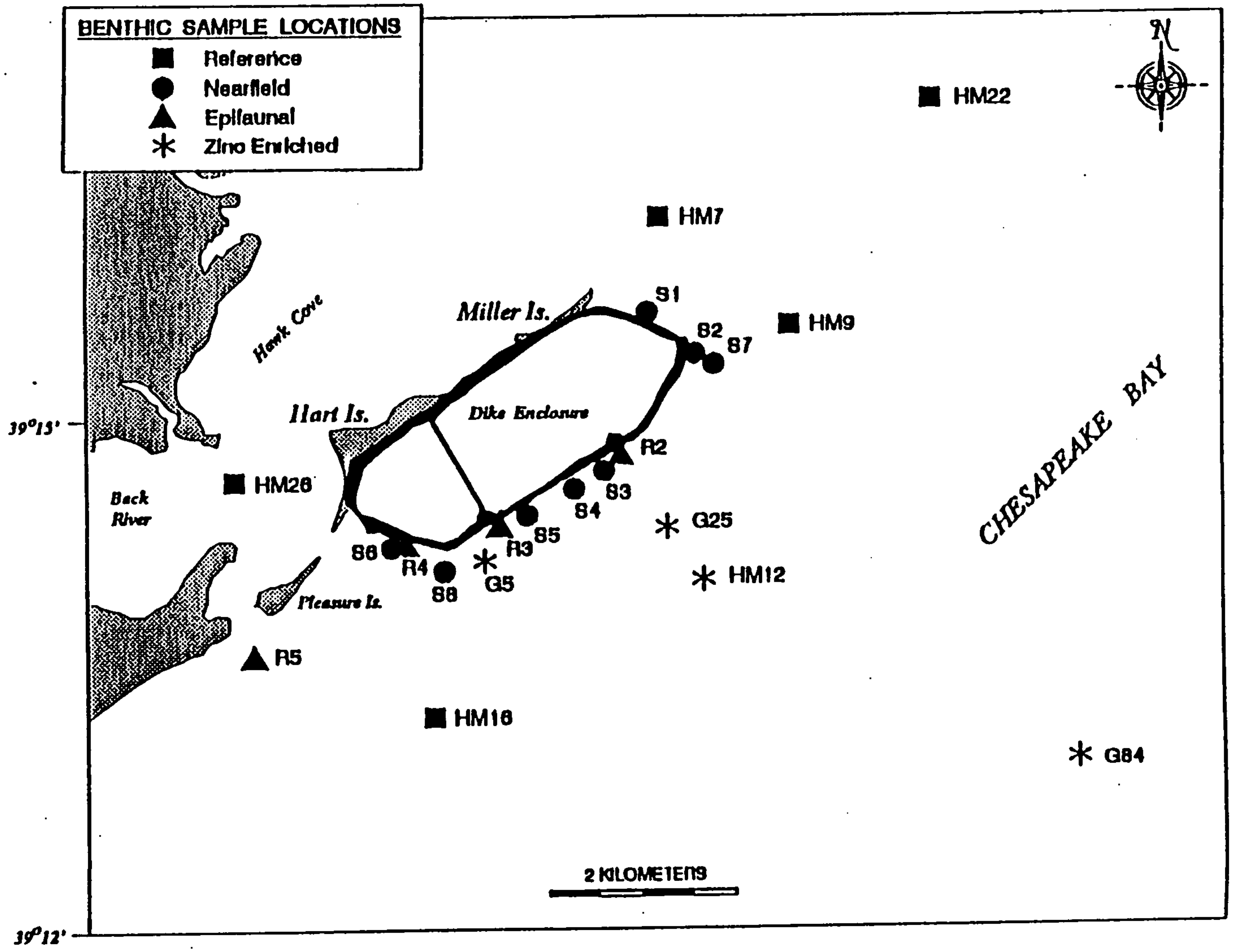


Figure 4-1: Benthic Infaunal and Epifaunal Sampling Station Locations at HMI

Figure 4-2 A & B: Average metal concentrations (ug/g wet wt.) for replicate samples from each of 6 stations. (Blank boxes serve as Spacers)

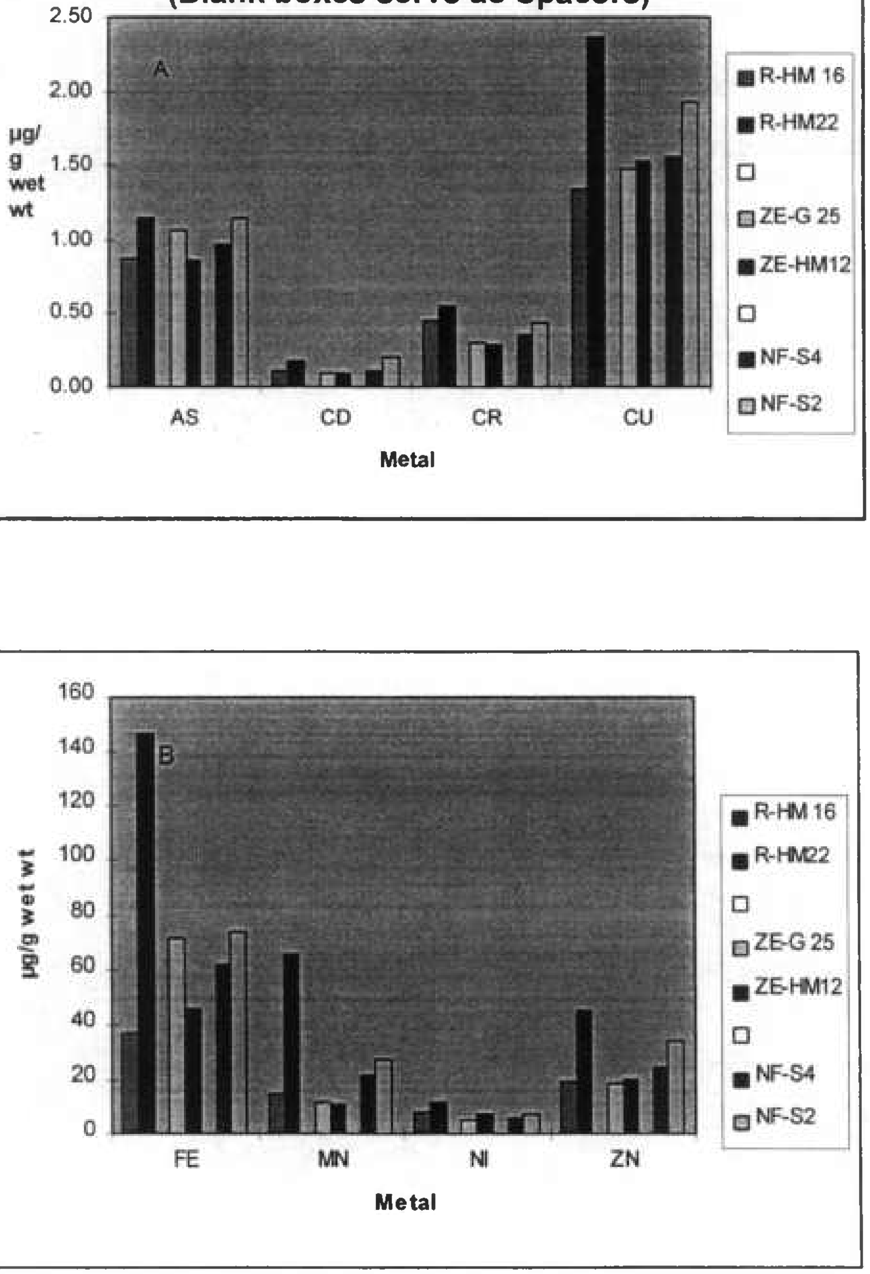
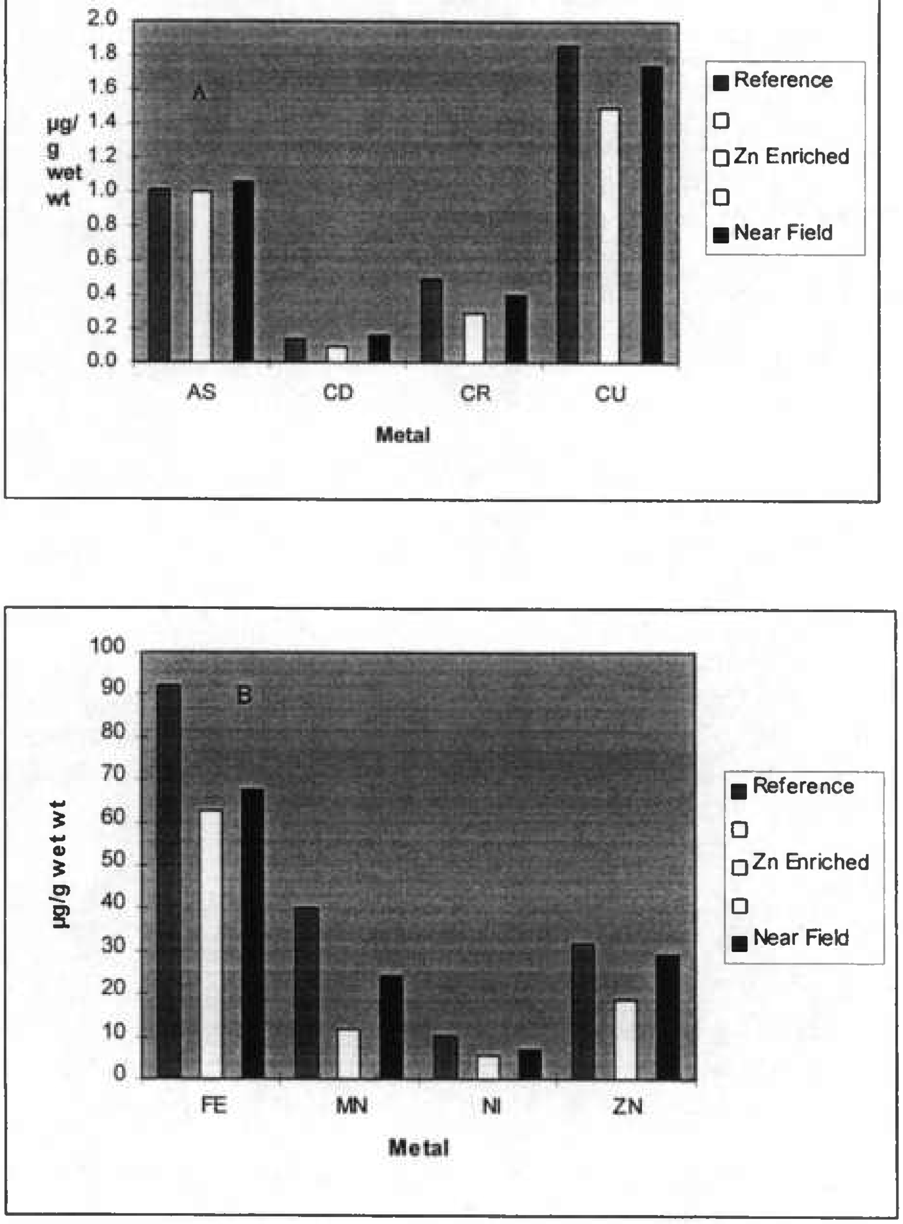


Figure 4-3 A & B: Average metal concentrations (ug/g wet wt.) for the different station types - Enriched, Near (Blank boxes serve as spacers)



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