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

Year 13 Exterior Monitoring Technical Report
(September 1993-August 1994)

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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	Referring to contours of depth below the water's surface.
Benthic	Referring to the bottom of a body of water.
Benthos	The organisms living in or on the bottom 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 estuarine water.

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 confined disposal 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 into, onto or be ingested by 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. 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 the 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 the bottom.
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. 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 material.
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 water quality may not meet 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 State water quality standards.
Nephelometric turbidity unit (NTU)	A unit of measurement of the amount of light scattered or reflected by particles within a liquid.
Open water disposal	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 sea bottom. 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 WaterAct, 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

CBL - Chesapeake Biological Laboratory

CDF - Contained Disposal Facility

CFR - Code of Federal Regulations

CWA - Clean Water Act

EPA - Environmental Protection Agency

FDA - Food and Drug Administration

FR - Federal Register

GC - Gas Chromatography

MDE - Maryland Department of the Environment

MGS - Maryland Geological Survey

MPA - Maryland Port Administration

MS - Mass Spectrometry

NEPA - National Environmental Policy Act

NIST - National Institute for Standards and Technology

NOAA - National Oceanic 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

TOC - Total Organic Carbon

USACE - U.S. Army Corps of Engineers

USCS - Unified Soil Classification System

WQC - Water Quality Certification

WQS - Water Quality Standard

EXECUTIVE SUMMARY

The Hart-Miller Island Contained Disposal Facility (HMI) was designed to receive dredged material from navigation channel maintenance and improvement activities in Baltimore Harbor and its approaches. The facility is located in the Chesapeake Bay at the mouth of Back River, to the northeast of Baltimore Harbor. Construction of the facility was completed in 1983. Operation of the facility has continued from that time through the present.

The exterior monitoring program for HMI was developed in response to a special condition of State Wetlands License [No. 72-127(R)], requiring that water quality and biota in the facility area be monitored comprehensively. Results from the monitoring are used to observe changes from baseline environmental conditions in the area surrounding HMI, and to guide decisions regarding operational changes and remedial actions, if necessary. Past exterior monitoring efforts have investigated the sedimentary environment and biota near the facility. Fish and crab population studies were discontinued after the fifth monitoring year due to the ineffectiveness of using the information as a monitoring tool. The current monitoring program is divided into four projects: 1) Scientific Coordination and Data Management; 2) Sedimentary Environment (physical and chemical analysis); 3) Benthic Ecology; and 4) Analytical Services (chemical analysis of sediments and biota). Monitoring in the thirteenth year was a continuation of the sediment and biota studies conducted in previous years.

Two significant changes in the sedimentary environment around the perimeter of HMI have been observed during the past ten years of monitoring. During construction of the HMI perimeter dike, a fluid mud layer was observed to extend from 525 to 1090 yards from the limits of the facility. Changes in the benthic biota accompanied the occurrence of the mud layer. However, the benthic population recovered in subsequent years. Secondly, an enrichment of zinc in the sediment near spillway #1 of the facility (on the northeastern shore of HMI) was documented in the eighth monitoring year. Monitoring stations around HMI were modified in the ninth monitoring year to further investigate the zinc concentrations in the sediments and any impacts to the aquatic biota. Observations during the ninth year indicated that zinc levels increased in response to the decreased rate of release of effluent from the dike. The 3-D hydrodynamic modeling effort reported in the tenth monitoring year explained the dispersion of contaminants in relation to the rate of release from the spillway.

Benthic populations observed at stations in the zinc enriched areas did not differ from the populations observed at the original nearfield and reference stations. Concentrations of zinc in benthic samples at the zinc enriched stations were not observed to be significantly different in comparison to other stations.

Project I: Scientific and Technical 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 begun at DNR was completed there, and the files were then transferred to MDE. Project reports for the individual monitoring studies were sent to Principal Investigators (PIs), members of the Citizens Oversight Commmittee, and members of the Technical Review Committee, for review and comment. Comments were forwarded by reviewers to MDE, who in turn sent them to the appropriate PIs. Revised project reports were then forwarded to MDE, who assembled the complete report and may be contacted for copies.

At the beginning of its responsibilities, MDE reviewed the structure and sampling design of the existing program, and made recommendations listed below, which were incorporated into the 16th year of monitoring.

Project II: Sedimentary Environment and Beach Erosion Study

The Coastal and Estuarine Geology Program of the Maryland Geological Survey (MGS) within DNR 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. The results of these two studies during the thirteenth year of monitoring are presented in this report.

Sedimentary Environment

Surficial bottom sediments sampled during two cruises, in November 1993 and April 1994, were analyzed for grain size composition and trace metal content. The grain size distribution of exterior bottom sediments during Year 13 was similar to that observed in Year 12. The distribution of sand around the facility has remained largely unchanged since November 1988. The typical seasonal pattern in the distribution of the fine (mud) fraction--coarsening over the summer and fining over the winter--was evident again this year. This indicates that, hydrodynamically, the depositional environment around the facility was more quiescent between the November 1993 and April 1994 cruises than it had been prior to the November 1993 cruise.

In April 1989, an area of zinc (Zn) enrichment was detected southeast of 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 the thirteenth year.

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 the thirteenth monitoring year 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 and, consequently, precludes Zn enrichment in the surrounding bottom sediments. The metal distribution around the HMI facility for the thirteenth year clearly demonstrates this relationship; discharge prior to the November sampling was low, resulting in higher levels of Zn in the external sediments, while discharge prior to the April cruise was higher, resulting in lower metals loading.

Continued monitoring is recommended. During the dewatering phase of operations, exposure of dredged material to the air is likely to result in the leaching and mobilization of metals associated with those sediments, in a process similar to acid mine drainage. Higher metal levels in the effluent may 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 amelioration protocol implemented to counteract the effects of exposing the contained dredged material to the atmosphere.

Beach Erosion Study

The recreational beach was replenished in April 1991, immediately prior to the last study year (May 1991 - May 1992). Approximately 14,700 yd^3 (11,240 m^3) of clean, medium-grained sand, dredged from an approach channel to Baltimore Harbor and stockpiled at the facility, was distributed in front of the existing, wave-cut escarpment, from station 28+00 to the northern end of the beach. Beach renourishment widened the foreshore and reduced the slope of the beach. Since replenishment, both shoreline position and the foreshore profile have changed. This study period (May 1993 - June 1994) shows removal of a significant quantity of previously replenished sand.

Designation of the erosional/depositional areas along the beach, present during the monitoring period (May 1993 - June, 1994), is essential for the planning of proper maintenance. The beach has sustained extensive erosion from Profile 30+00 south, with significant deposition north of Profile 32+00. Erosion at several profile locations has lowered the beach profile close to February 1991 levels, preceding beach renourishment.

It is recommended that a new plan for beach nourishment be devised and implemented during spring and summer 1996, unless fourteenth year monitoring shows severe changes that require immediate action. In that case, a Fall 1995 restoration plan may be required to enhance beach conditions for the upcoming winter. A volume of 10,000-14,000 yd^3 should be sufficient to sustain the recreational beach for the next few years. The profile data suggest that a four- to five-year cycle of beach restoration, with 10,000-14,000 yd^3 of sand, may be required to maintain the beach level at the recommended shape.

Project III: Benthic Studies

Benthic invertebrate populations in the vicinity of HMI in the Upper Chesapeake Bay were monitored for the thirteenth consecutive year in order to examine any potential effects from the operation of the HMI facility on these bottom-dwelling organisms. Organisms living close to the containment dike (referred to as the 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 containment facility (referred to as reference stations) in December 1993 and April and August 1994.

Sixteen infaunal stations were sampled on each cruise. These consisted of 8 nearfield stations (S1-S8); 5 reference stations (HM7, 9, 16, 22, 26); and three of the four stations in areas which had been reported by the Maryland Geological Survey to have sediments enriched in zinc (referred to as zinc-enriched, and numbered as G5, G25, HM12). As of April, 1994, station G84 (the fourth station) was dropped because it no longer appeared to be enriched with zinc. The G84 data from December were included in the Thirteenth Year Data Report, but will not be included in this report in order to better compare the different sampling periods.

The infaunal stations are located in areas with sediments of varying compositions, including silt-clay, oyster shell, and sand substrates. A total of 30 species were collected from these sixteen infaunal stations. The most abundant species were the worms, *Scolecolepides viridis*, *Nereis succinea* and *Tubificoides sp.*; the crustaceans, *Leptocheirus plumulosus*, *Corophium lacustre* and *Cyathura polita*; and the clam, *Rangia cuneata.*

Species diversity (H') values were evaluated at each of the infaunal stations at the three sampling periods. The highest diversity value (3.253) was obtained for the nearfield station S6, in December 1993. The lowest diversity value (0.244) occurred in April 1994 at the nearfield station S1. Comparing the three sampling dates, the overall highest diversity values (with only five stations under 2.5) occurred in December 1993, while the lowest overall diversity occurred in April 1994.

The length-frequency distributions of the clams, *Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli* were examined at the nearfield, reference, and zinc-enriched stations and there was 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* remains the least abundant of the 3 dominant clam species.

Cluster analysis of the stations over the three sampling periods continues to associate stations primarily in response to sediment type. 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.

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 13th monitoring year studies again suggest that no adverse effects to the benthic populations have occurred that could be attributed to the maintenance and operation of the Hart-Miller Island Dredged Material Contained Disposal Facility. We have continued to monitor three of the zinc enrichment stations (G5, G25, HM12) established in the 9th year of sampling as a result of Maryland Geological Survey's findings of zinc enriched sediments in the vicinity of HMI. During this the fifth year of sampling for these zinc-enriched stations, these stations do not appear to differ in any distinct manner from the original nearfield and reference epifaunal stations. Continued monitoring of the benthic populations is strongly recommended to follow any potential changes associated with the existence and operation of HMI.

Project IV: Analytical Services

In April 1994, fourteen composite samples of the benthic bivalves *Macoma* spp. and *Rangia cuneata*, and the benthic isopod *Cyathura polita,* were collected from eight stations for determination of contaminant burdens. One sample is suspect, and not used for analysis. The laboratory analyzed for eight metals (arsenic, cadmium, chromium, copper, nickel, zinc, iron, and manganese) and a restricted suite of organic contaminants from two classes: chlorinated pesticides/PCBs; and semivolatiles, including phthalate esters and selected polycyclic aromatic hydrocarbons (PAHs).

Trace metal detection levels were greatly improved this year, leading to detectable burdens of nearly all analytes in all species, save nickel and cadmium in some *Cyathura* samples. Analytical problems with organic analytes coupled with high, though somewhat improved, detection limits led to no detectable organics (except for phthalate esters) in the tissues or in the ten sediment samples. Due to problems with laboratory contamination, these reported phthalate data are unreliable.

This was the first year since the baseline studies in which arsenic had been monitored in tissues, and it was detected at appreciable levels in all samples. Burdens of arsenic, cadmium and zinc in both *Macoma* and *Cyathura*, and nickel in *Macoma,* have increased markedly since the baseline monitoring year of 1983, while other trace metal levels in these species have remained similar or have decreased since the Second Year. While no *Rangia* were monitored in baseline studies with which to compare current trace metal levels, this species' burdens of arsenic, cadmium and nickel are appreciably higher than levels found in the filter feeding bivalve, *Mya arenaria*, from the Upper Chesapeake Bay. During monitoring year 12, the highest levels of zinc enrichment recorded to date were observed in HMI sediments, while year 13 levels were more typical of prior enrichment. Assuming that other metal levels correlate with zinc, in general it appears that the deposit feeder, *Macoma* and the omnivore/carnivore, *Cyathura*, have retained a greater metal burden memory of last year's elevated metal levels, whereas in the suspension-feeding *Rangia,* metal burdens responded more rapidly to temporal changes in metal loadings to the environment.

The trends in patterns of zinc enrichment in the sediments around HMI and levels of metals in tissues suggest that the reference stations are often located in areas under the influence of HMI effluent discharge, and that the current "zinc enriched" benthic stations are no longer in the areas where zinc is enriched in the sediments. If the same stations were monitored in both the benthic and sedimentary projects, a more conclusive statement could be made. There are presently no benthic stations located in areas most affected by HMI effluent discharge. Given these observations, it is of little surprise that differences in tissue metal distributions according to station type could not be discerned this year, as in previous monitoring years.

With respect to the metal burdens cited above, it would appear that HMI effluent discharge may have an effect, though statistical analyses would be necessary to draw firm conclusions. Since all areas currently monitored for tissue burdens are affected to some degree by HMI effluent discharge, the only appropriate analysis of HMI influence may be over time rather than space. The monitoring program may wish to consider conducting a comprehensive review of the quality of historical tissue data to determine whether such trends can be assessed and as a guidance as to which data are important to collect in the future. For example, *Rangia* has been recommended as the only monitoring species to be used. However, there were no baseline studies conducted with this species. Of the three species monitored this year, *Macoma* and *Cyathura* represent two which were monitored during the baseline studies in the Second Year and for which yearly data exist since the Seventh Year. *Rangia* has been monitored yearly for metals only since the Fifth Year and has been the most consistent monitoring species recently in terms of availability at most stations and in sufficient numbers to yield adequate tissue mass for analyses. How *Rangia* accumulates metals in comparison to other monitoring species should be better assessed. In the baseline studies, *Macoma* was suggested as a monitoring species, and detailed studies assessed the appropriate number of individuals to collect to represent the population mean, seasonal and size dependent variability in metal accumulation, and comparison of metal accumulation with other species (Wright 1982; *idem* 1984). Information on the levels of metals in the water and sediments from the same stations was also available at that time. Given that this useful information exists for a monitoring species from the baseline years, perhaps *Macoma* should be retained and/or similar information gathered for *Rangia*.

Additional recommendations include:

- Re-evaluate the sampling locations. Relocate or add benthic stations in the more recently zinc enriched areas. Concentrate the monitoring where effects from the facility would be expected to be greatest, based on available knowledge. Design a sampling scheme able to detect contaminant gradients around the facility and to find reference sites (at least one) well-removed from the influences of HMI.

- Sample sediments and biota from the same locations and at the same times. Water samples would also be useful. Combine sediment and benthic stations on a single map so that sediment trends can clearly be seen in relation to benthic tissue and population trends.

- Monitor HMI effluent at a sensitive and comprehensive level to determine which analytes should be monitored in the surrounding environment.

- Adopt more sensitive analytical techniques for target organic analytes so that true contaminant differences can be detected. With present methodology, only gross contamination, which often exceeds FDA action limits, is sporadically detected and no trends can be assessed. Since the associated costs of improved detection limits will be high, monitoring of organic analytes could be performed less frequently. It is questionable whether anything is to be gained from using less sensitive analytical techniques in intervening years.

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

- Determine and collect the minimum number of individuals needed to provide an adequate and representative composite tissue sample for analyses for each species. Continue to measure individuals and maintain consistency in size classes, when possible.

- Tissue dry and wet weights should be determined and reported, so that more accurate comparisons with historical dry weight data can be performed.

- Consider repeating the sediment toxicity tests performed in the Eleventh Year. These tests were inconclusive due to predation and/or mortality in the reference sediment. To complete the sediment quality triad concept (Chapman *et al.* 1987), it is important to have the same stations for sediment and tissue contaminant burdens, as for toxicity tests and benthic community assessments.

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

Exterior Monitoring at the Hart-Miller Island Dredged Material Contained Disposal Facility (HMI)

September 1993 - August 1994

Prepared for

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The Maryland Department of the Environment would like to acknowledge the assistance provided by Mr. Roland Limpert and Mr. Mike Burch of Maryland Department of Natural Resources, in compiling the Data report and at other times when their expertise was required.

The Maryland Department of the Environment would like to thank all the members of the Hart-Miller Island Exterior Monitoring Program's Technical Review Committee and the HMI Citizens Oversight Committee for their useful comments and suggestions throughout the project year.

Lastly, thanks to Mr. Michael Haire, Director, and Mr. Narendra Panday, Technical Coordinator, Technical and Regulatory Services Administration for their guidance and suggestions throughout the project.

INTRODUCTION

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 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, and have since been discontinued. The physical and chemical characterization of sediments, benthic community ecology, and benthic tissue contaminant analyses are ongoing studies that will be perpetuated through the operational lifetime of the facility.

Responsibility for Scientific Coordination and Data Management of the Hart-Miller Island Contained Disposal Facility was transferred to the Maryland Department of the Environment (MDE) from the Maryland Department of Natural Resources (DNR) in July 1995. Project I responsibility was subsequently (in 1997) transferred within MDE to the Dredging Coordination and Assessment Division (DCAD). Beginning with the production of the 13th monitoring year reports, DCAD assumes the responsibility of 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 and the Principal Investigators. Lastly, DCAD is responsible for compiling, editing, printing and distributing yearly Data and Technical Reports.

Data collected in the course of the monitoring program are stored on the U.S. Environmental Protection Agency Chesapeake Bay Program's VAX 8600 mainframe computer in Annapolis, MD. The data are stored in SAS file format. Permanent storage in this location and format ensures that the data are readily available, and provides for a continuous, validated record of initial conditions, changes and trends in benthic community health, tissue contaminant concentrations, and the physical and chemical sedimentary environment.

RECOMMENDATIONS

Chairman's note (October 1998): The following recommendations were made shortly after the close of Year 13, 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 14, 15 and 16, while others may no longer apply. In the interest of continuity, recommendations as suggested at the close of the 13th monitoring year have been kept 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 Committee should recognize that the original intent was for this contained facility primarily to 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 were evaluated. For example, fish population studies conducted during the first five years of monitoring were discontinued thereafter. Also, in response to elevated zinc concentrations in certain areas, stations were added. Recommendations for changes in the monitoring design for Hart-Miller Island were made in the twelfth year report. Some of these changes were incorporated in the proposals submitted by the Principal Investigators for the fifteenth year. These include more sensitive analytical techniques for organics, sampling only *Rangia* for tissue contaminant measurements, and simultaneous sampling of sediment and benthos.

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

- Add biomass measurement to the benthic sampling, if it is not already done. This is a part of the RGI and an important parameter for evaluating the benthos.
- Drop the epibenthic monitoring on the pilings; it does not seem to tell us anything.
- Drop the Beach Erosion Study. This does not seem to be a permit requirement.
- Add a program to: (1) evaluate the suitability of the existing 14 years of data from the perimeter wells; (2) assess the necessity of continued well monitoring; and (3) if continued monitoring is deemed necessary, how to most effectively (e.g., in a nitrogen atmosphere) continue that effort. A proposal is being developed by MGS and Maryland Environmental Service (MES) for this purpose.

- Analysis of sediment organic carbon needs to be added to one proposal.

- Add a literature search on bioaccumulation in *Rangia*.

- Incorporate a method for purging the tissue samples of contained sediment as recommended in the 12th year report.

- All projects will provide verified data in an electronic (digital) format as ASCII, Lotus, dBASE, or Quattro-Pro files.

- The enclosed proposal summaries show that there is some inconsistency between the programs in metallic analytes, frequency of sampling, and station locations. These differences need to be resolved or justified.

- Project I, as proposed, will provide additional technical oversight, and a review of the existing data base.

CHAPTER 2. SEDIMENTARY ENVIRONMENT (PROJECT II)

Part 1: Sedimentary Environment
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ABSTRACT

The Coastal and Estuarine Geology Program of the Maryland Geological Survey (MGS) has been involved in monitoring the physical and chemical behavior of near-surface sediments around the Hart-Miller Island Dredged Material Contained Disposal Facility (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. The results of these two studies during the thirteenth year of monitoring are presented in this report.

SEDIMENTARY ENVIRONMENT

In April 1989, during the eighth monitoring year, an area of zinc (Zn) enrichment was detected southeast of 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 throughout the thirteenth year.

Surficial bottom sediments sampled during two cruises, in November 1993 and April 1994, were analyzed for grain size composition and trace metal content. 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 the facility has remained largely unchanged since November 1988. The typical seasonal pattern in the distribution of the fine (mud) fraction - coarsening over the summer and fining over the winter - was also evident again this year. This indicates that, hydrodynamically, the depositional environment around the facility was somewhat quieter between the November 1993 and April 1994 cruises than it had been prior to the November 1993 cruise.

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 the thirteenth monitoring year in the vicinity of the dike. In previous reports, Zn levels were correlated with the discharge rate of effluent from the facility. 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/day (MGD). At higher discharge rates, flushing with large volumes of water effectively dilutes Zn loadings in the effluent and, consequently, precludes Zn enrichment in the surrounding bottom sediments. The metal distribution around the HMI facility for the thirteenth year clearly demonstrates this relationship; discharge prior to the November sampling was low, resulting in higher levels of Zn in the external sediments, while discharge prior to the April cruise was higher, resulting in lower metals loading.

Continued monitoring is recommended. During the dewatering phase of operations, exposure of dredged material to the air is likely to result in the mobilization of metals associated with those 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 amelioration protocol implemented to counteract the effects of exposing the contained dredged material to the atmosphere.

BEACH EROSION STUDY

In accordance with previous recommendations, the recreational beach was replenished in April 1991, immediately prior to the last study year (May 1991 - May 1992). Approximately 14,700 yd^3 (11,240 m^3) of clean, medium-grained sand, dredged from an approach channel to Baltimore Harbor and stockpiled at the facility, was distributed in front of the existing, wave-cut escarpment, from station 28+00 to the northern end of the beach. Beach renourishment widened the foreshore and reduced the slope of the beach. Since replenishment, both shoreline position and the foreshore profile have changed. This study period (May 1993 - June 1994) shows removal of a significant quantity of previously replenished sand.

Designation of the erosional/depositional areas along the beach, present during the monitoring period (May 1993 - June, 1994), is essential for the planning of proper maintenance. The beach has sustained extensive erosion from Profile 30+00 south, with significant deposition north of Profile 32+00. Erosion at several profile locations has lowered the beach profile close to February 1991 levels, preceding beach renourishment.

It is recommended that a new plan for beach nourishment be devised and implemented for the Spring-Summer 1996, unless fourteenth year monitoring shows severe changes that require immediate action. In that case, a Fall 1995 restoration plan may be required to enhance beach conditions for the upcoming winter. A volume of 10,000-14,000 yd^3 should be sufficient to sustain the recreational beach for the next few years. The profile data suggest that a four- to five-year cycle of beach restoration, with 10,000-14,000 yd^3 of sand, may be required to maintain the beach level at the recommended shape.

PART ONE: SEDIMENTARY ENVIRONMENT

INTRODUCTION

Since 1981, the Maryland Geological Survey (MGS) has monitored the sedimentary environment in the vicinity of the Hart-Miller Island Dredged Material Contained Disposal Facility (HMI). HMI is a man-made enclosure in northern Chesapeake Bay, named for the two natural islands that form part of its western perimeter (Fig. 2-1). Designed specifically to contain material dredged from Baltimore Harbor and its approach channels, the oblong structure 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 the facility. 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.

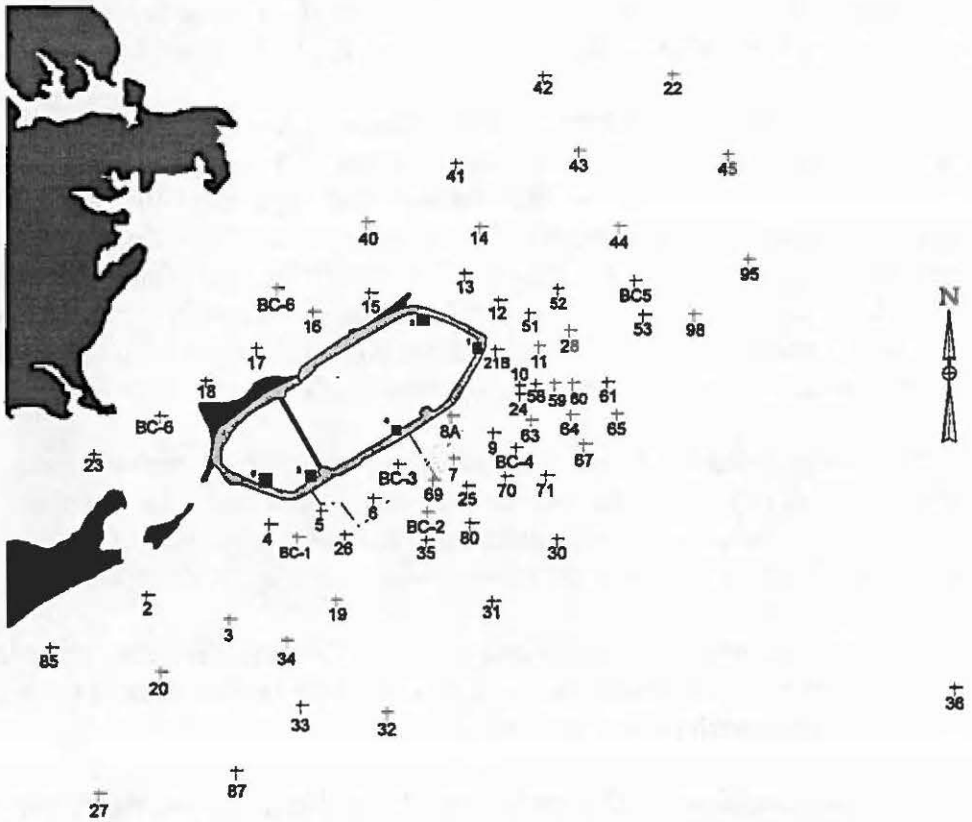


Figure 2-1. The Hart-Miller Island Contained Disposal Facility with the thirteenth year sampling stations.

PREVIOUS WORK

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

1. preconstruction (Summer 1981 and earlier)
2. construction (Fall 1981 - Winter 1983)
3. post-construction
   a. pre-discharge (Spring 1984 - Fall 1986)
   b. post-discharge (Fall 1986 - present).

The nature of the sedimentary environment prior to and during dike construction has been well-documented in 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 the facility. This layer is still evident in a few cores, although the uppermost sections of the layer have been bioturbated (reworked by bottom-dwelling organisms) and, in places, eroded.

For a number of years after the dike 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 spillway #1 (Hennessee *et al.*, 1990b). Zn 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 Bay Model (Wang 1993), a numerical, hydrodynamic model, which was used to predict the dispersion of discharge from the dike.

The factors which influence the metals loadings to the exterior sediments from the dike are circulation patterns in the northern 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 the *Tenth Year Interpretive Report* for details):

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

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

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

3. The circulation gyre is modulated by fresh water flow from the Susquehanna River. The higher the flow from the Susquehanna, the stronger the circulation pattern and the greater the compression against the dike. Conversely, the lower the flow, the less the compression against the dike. Consequently output from the facility is restricted close to the dike during high Susquehanna flow conditions and is allowed to disperse more during low flow periods.

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 *Eleventh 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 subaerial conditions, 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 the thirteenth monitoring year in the vicinity of the dike, as predicted by the Upper Bay Model and the model presented in the *Eleventh Year Interpretive Report*.

DIKE OPERATIONS

Certain activities associated with the operation of the facility 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 thirteenth year cruises are summarized below. Information was extracted from two *Operations Reports* prepared by MES, covering the periods April 1, 1993 - September 31, 1993, and October 1, 1993 - March 31, 1994.

When examining dike operations, it is important to view the period prior to each sampling cruise to ascertain the primary influence to the external sediment monitoring. During the six months prior to the November sampling cruise, no new dredged material was placed inside the facility. This was the latter part of a planned, 18-month hiatus in disposal at the facility. Operations at this time continued to concentrate on crust management and dewatering of the sediments in the facility to gain additional volume and to stabilize the material in the dike. Discharge was maintained at very low levels, never exceeding 10 MGD at any of the spillways. Spillways #1, #2, and #3 were the principal discharge sites, each discharging between 50-60 MGD for the entire six months. Signs of sulfide oxidation occurred during this period, with elevated Cd and Cu levels and periods of increased acidity (low pH; see Fig. 2-2). With the increased levels of metals and low pH there were isolated non-compliance events, though the majority of the discharges were within compliance levels. To alleviate these problems, limestone and sodium carbonate were added to the ponded water in October 1993. A management solution to ameliorate the condition is presented in the operations report, which suggests mapping the soils in the dike based on chemical composition and neutralizing the areas appropriately.

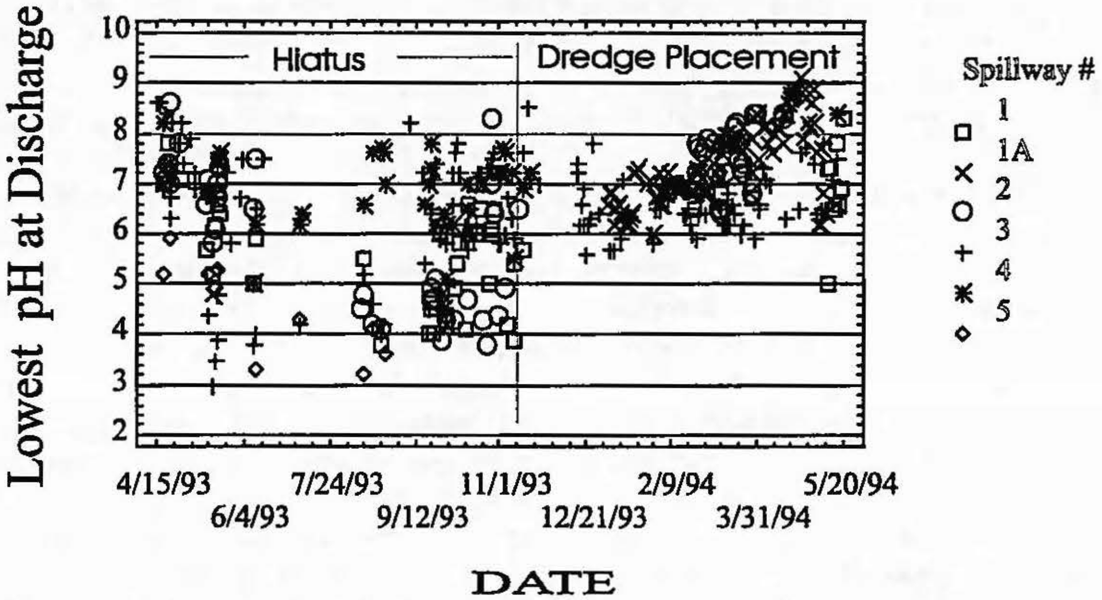


Figure 2-2. Lowest pH of discharged water from HMI for all spillways. Note low pH values during the hiatus.

Shortly after the November sampling cruise, placement of dredged material into the facility resumed. Approximately 2.5 million yd^3 of dredged material were placed in the facility prior to the April sampling cruise. Most of the material came from maintenance dredging of the 50-foot channel for Baltimore Harbor. Release of water from the facility was primarily from spillway #1a (~1300 MGD), with lesser amounts from spillway #2 (~260 MGD) and spillway #3 (~140 MGD). As expected during periods of material input, pH and metal levels were within compliance of the permit levels.

SUSQUEHANNA RIVER FLOW

Flow from the Susquehanna River for the period affecting thirteenth year samples is shown in Figure 2-3 - the daily discharge record from Conowingo Dam, normalized to the 10-year daily average (values equal to one indicate average flow conditions). Flows from the Susquehanna prior to the November cruise were below average, generally half the average flow. The Spring cruise, on the other hand, had high flow conditions ~50% of the time prior to the sampling cruise.

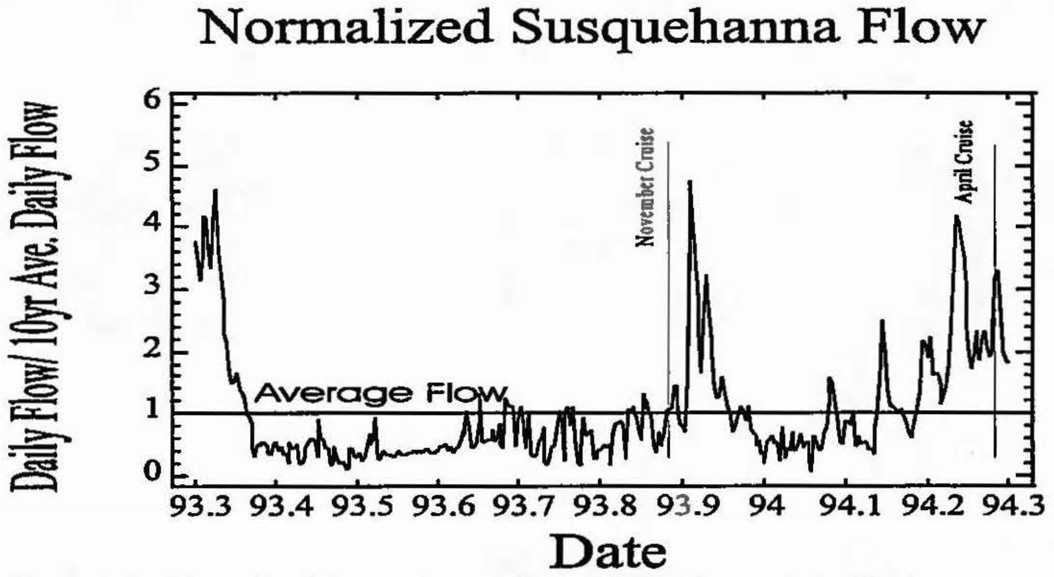


Figure 2-3. Normalized Susquehanna River flow for the period affecting samples collected during the thirteenth monitoring year.

OBJECTIVES

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

METHODOLOGY

FIELD METHODS

The information presented in this report is based on observations and analyses of samples collected on two cruises aboard the R/V Discovery during the thirteenth year of monitoring. Sampling sites (Fig. 2-1) were located in the field by means of the LORAN-C navigational system. For the past eleven years, the same LORAN X and Y time delays (TD's) have been used to locate the stations that were established during the initial phase of this project. The repeatability of LORAN-C navigation, that is, the ability to return to a location at which a navigation fix has previously been obtained, is affected primarily by seasonal and weather-related changes along the signal transmission path. Data recorded in 1982 from the U.S. Coast Guard Harbor Monitor at Yorktown, Virginia provide an approximate range of repeatable error. That year, variations in the X-lines amounted to 0.256 units and, in the Y-lines, 0.521 units. In the central Chesapeake Bay, one X-TD unit equals approximately 285 m (312 yd) and one Y-TD unit, 156 m (171 yd). Therefore, when a vessel reoccupies an established station in the Bay region, it should be within about 100 m (109 yd) of its original location (Halka 1987). LORAN-C TD's were converted to 'corrected' latitudes and longitudes (North American Datum of 1927) using a computer program that incorporates the results of a LORAN-C calibration in Chesapeake Bay (Halka 1987). The LORAN-C TD's, latitude, and longitude for each station are listed in the *Thirteenth Year Data Report*, along with the corresponding Resource Monitoring Database (RESMON) identifiers. The algorithm used to calculate the RESMON identifiers changed between the eleventh and twelfth monitoring years, to correct small errors and inconsistencies. Both the old and new RESMON identifiers are included in the data report.

Surficial sediment samples were collected in November 1993 (Cruise 30) and April 1994 (Cruise 31). During the ninth year of monitoring, the number of sampling stations was increased in response to the detection of abnormally high Zn levels in sediments near spillway #1 (Hennessee and Hill 1992). Sampling sites were added to determine the extent of the area of Zn enrichment and to coincide with benthic sampling stations. The expanded sampling scheme (60-66 locations/cruise) was retained throughout the eleventh monitoring year.

During the twelfth year, the number of stations occupied during each cruise was reduced to 47, based, in part, on output from the 3-D hydrodynamic model of the upper Chesapeake Bay. The 24 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 occupied previously. The same locations sampled during the twelfth monitoring year were revisited during the thirteenth.

Undisturbed samples of the surficial sediments 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). Upon collection, each sediment sample was described lithologically (see the *Thirteenth Year Data Report*) and subsampled.

Sediment and trace metal subsamples were collected using plastic scoops rinsed with distilled water. These samples were taken below the flocculent layer, and away from the sides of the sampler to avoid possible contamination by the grab sampler. 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 processing.

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

In April 1994, gravity cores were collected at the seven box core (BC) stations and at stations 12 and 25 (Fig. 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.

LABORATORY PROCEDURES

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 *Thirteenth Year 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 *Thirteenth Year Data Report*. On the basis of these observations, sediment samples for textural and trace metal analyses were taken at selected intervals from each core.

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 weight of the wet sediment:

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

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

Water weight was determined by weighing approximately 25 g of the wet sample, drying the sediment at 105-110°C, and reweighing it. The difference between total wet weight (Wt) and dry weight equals water weight (Ww). Bulk density was also determined from water content measurements.

The relative proportions of sand, silt, and clay were determined using the sedimentological procedures described in Kerhin *et al.* (1988). The sediment samples were pre-treated with hydrochloric acid and hydrogen peroxide to remove carbonate and organic matter, respectively. Then the samples were wet sieved through a 62-µm mesh to separate the sand from the mud (silt plus clay) fraction. The finer fraction was analyzed using the pipette method to determine the silt and clay components (Blatt *et al.* 1980). Each fraction was weighed; percent sand, silt, and clay were determined; and the sediments were categorized according to Pejrup's (1988) classification (Fig. 2-4).

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

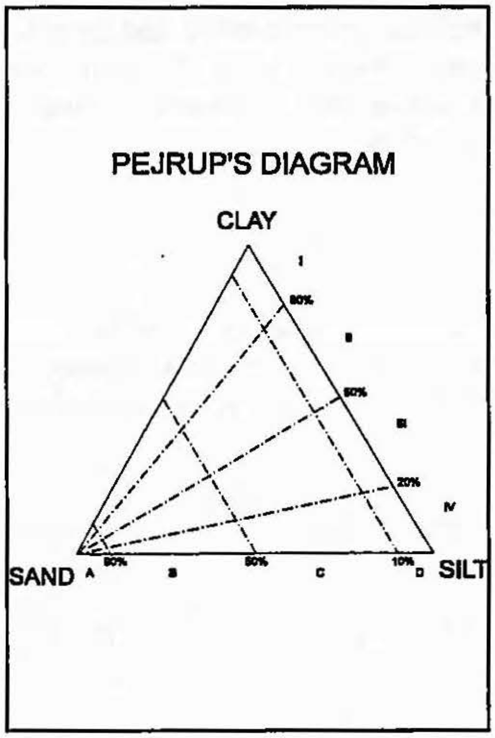


Figure 2-4. Pejrup's (1988) classification of sediment type.

all samples with less than 10% sand and a clay:mud ratio between 0.50 and 0.80.

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

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

Trace Metal Analysis

Sediment solids were analyzed for 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 sample was analyzed.

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

The dissolved samples were analyzed with a Jarrel-Ash AtomScan 25 sequential ICAP spectrometer using the method of bracketing standards (van Loon 1980). The instrumental parameters used to determine the solution concentrations were the recommended, standard ICAP conditions given in the Jarrel-Ash manuals, optimized using standard reference materials (SRM) from the National Institute of Standards and Technology (NIST) and the National Research Council of Canada. Blanks were run every 12 samples, and SRM's were run five times every 24 samples.

Results of the analyses of three SRM's (NIST-SRM #1646 - Estuarine Sediment; NIST-SRM #2704 - Buffalo River Sediment; National Research Council of Canada #PACS-1 - Marine Sediment) are given in Table 2-1. The microwave/ICAP method has recoveries (accuracies) within ±5% for all of the metals analyzed, except Ni and Mn. Although poorer, the recoveries for these two metals are good. The poorer recoveries for Ni and Mn are due to the concentrations of these elements being near detection limits. 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, 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 (Fig. 2-5). The first diagram (Fig. 2-5a) is typical of the post-construction, **pre-discharge** sediment distribution around the facility. The next four diagrams - all **post-discharge** - summarize twelfth year (Fig. 2-5b and c) and thirteenth year (Fig. 2-5d and e) findings. Related statistics are presented in Table 2-2.

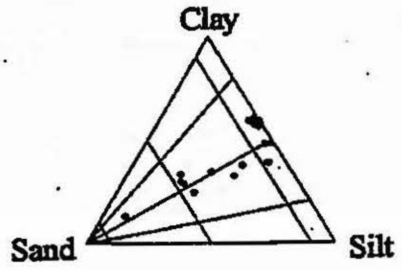
The ternary diagrams show very similar distributions of sediment type. All points fall fairly close to the line extending from the sand apex and bisecting the opposite side of the triangle (clay:mud=50). The number of stations containing more than 50% sand varies from three, prior to onset of effluent discharge, to as many as nine afterward. This increased sandiness is reflected in the average sand percentages shown in Table 2-2.

Table 2-2. Summary statistics for five cruises (two cruises per monitoring year), 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
28	11/92	0.40-0.63	0.55	0.59-97.79	34.83
29	5/93	0.38-0.68	0.55	0.71-98.29	29.18
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

For the 22 continuously monitored sampling locations, Figure 2-6 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.

(a) November 1983 (Cruise 9)



(b) November 1992 (Cruise 28)

(c) May 1993 (Cruise 29)

(d) November 1993 (Cruise 30)

(e) April 1994 (Cruise 31)

Figure 2-5. Sediment type of samples collected in (a) November 1983 (post-construction, pre-discharge), (b) November 1992, (c) May 1993, (d) November 1993, and (e) April 1994.

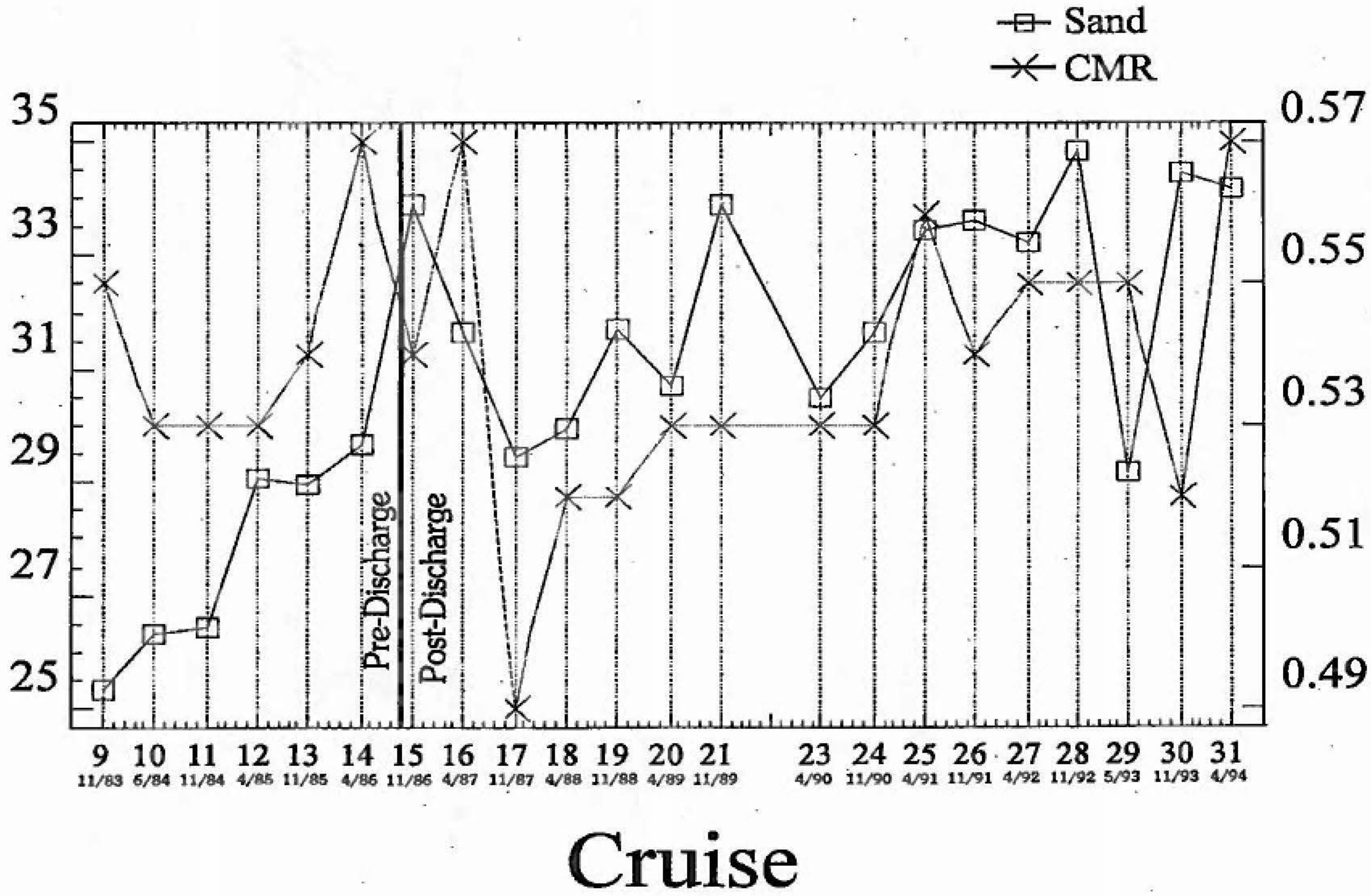


Figure 2-6. Average percent sand and clay:mud ratios (CMR), based on 22 continuously monitored stations, for all post-construction cruises through the thirteenth year. The y-axis is in units of percent for either Sand or CMR.

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 post-discharge period, sand content has tended to decrease during the winter and increase during the summer, though this seasonal trend is not nearly as consistent or pronounced as that of the pre-discharge period. Average sand content, in general, has continued to increase over the post-discharge period. With the exception of two post-discharge cruises (11/87 and 5/93), mean sand percentages have usually 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 is evident. During the post-discharge period, ratios have varied over a wider range (0.49-0.57). A fairly consistent seasonal pattern developed post-discharge and has persisted through the thirteenth year. The muddy fraction of the sediment becomes somewhat finer (more clay-rich) during the winter (between fall and spring cruises) and either remains the same or becomes somewhat coarser (siltier) during the summer. Overall, clay:mud ratios have risen gradually during the post-discharge period, indicating that the depositional environment has become increasingly quiet (less turbulent) over time.

Two sets of contour maps, based on the entire suite of samples, show the spatial distribution of sediment type during the twelfth and thirteenth monitoring years. Figures 2-7 and 2-8 depict percent sand; Figures 2-9 and 2-10, 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 (>90% sand) sediment extend north-northeast of the dike and east of Black Marsh and become systematically finer (less sandy) offshore.

The clay:mud ratio maps (Figs. 2-9 and 2-10) include, in addition to the contours, an ear-shaped boundary outlining an area around the dike that has been most densely sampled over time. Within this boundary, the zones lying between contours have been shaded - the more clay-rich the fine fraction, the darker the shading. During both cruises of the twelfth monitoring year (November 1992 and May 1993) and the first cruise of the thirteenth year (November 1993), the areal distribution of the fine fraction changed only slightly. The coarsest (siltiest) sediments flanked the perimeter of the dike. The area blanketed by silt-rich sediments (clay:mud ratio <0.50) gradually increased in extent, first along the eastern perimeter of the dike, then along the northern perimeter. Between the two thirteenth year cruises, however, the nature of the fine fraction changed considerably immediately north-northeast of the dike, in the area between spillways #1 and #2. Sediments here consist predominantly of sand (>90% sand). By April 1994, the fine fraction of these sandy sediments had become much finer, with clay:mud ratios exceeding 0.70. The higher clay:mud ratios presumably indicate a general decrease in turbulence in the area.

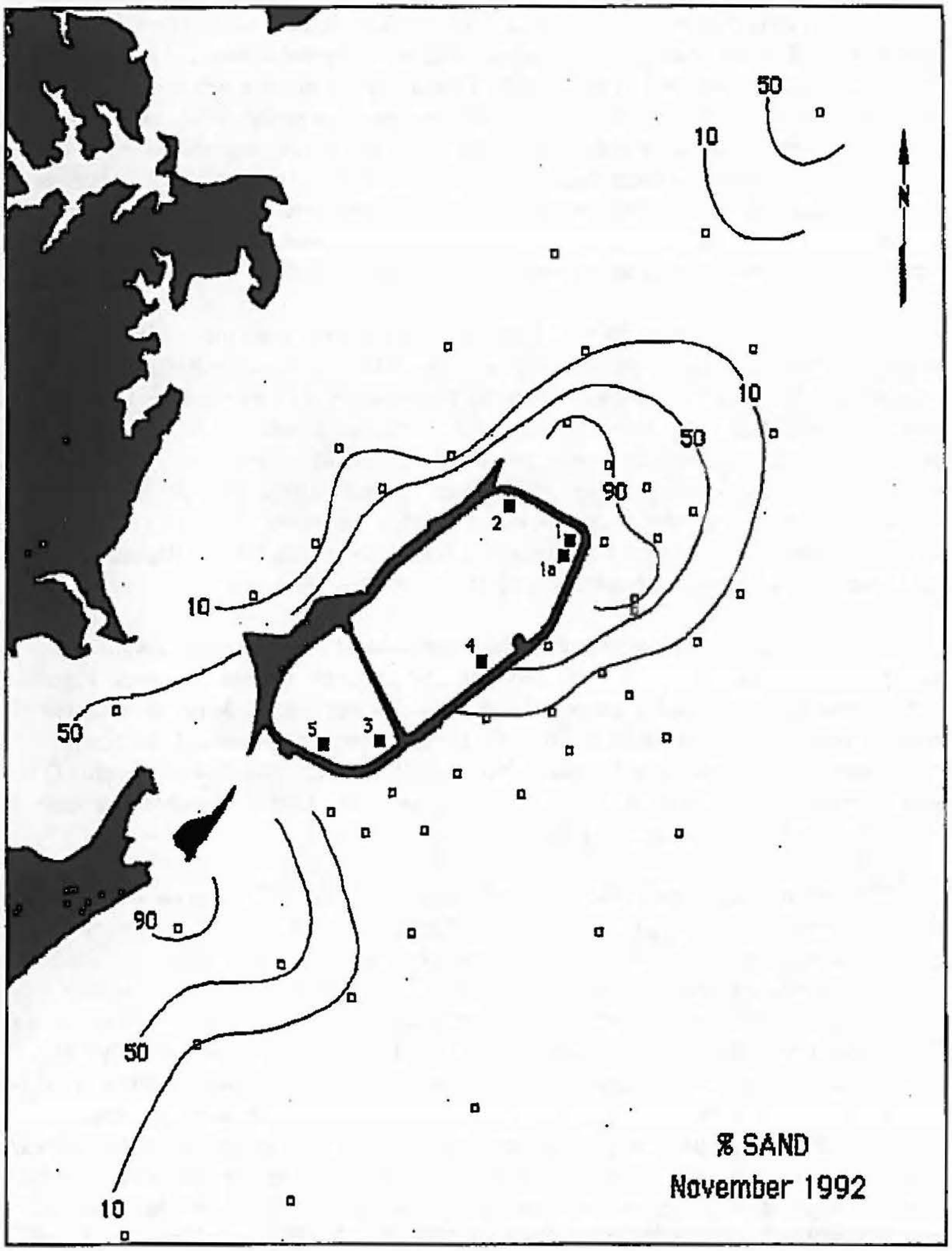


Figure 2-7 (a). Distribution of percent sand--twelfth year monitoring: November 1992.

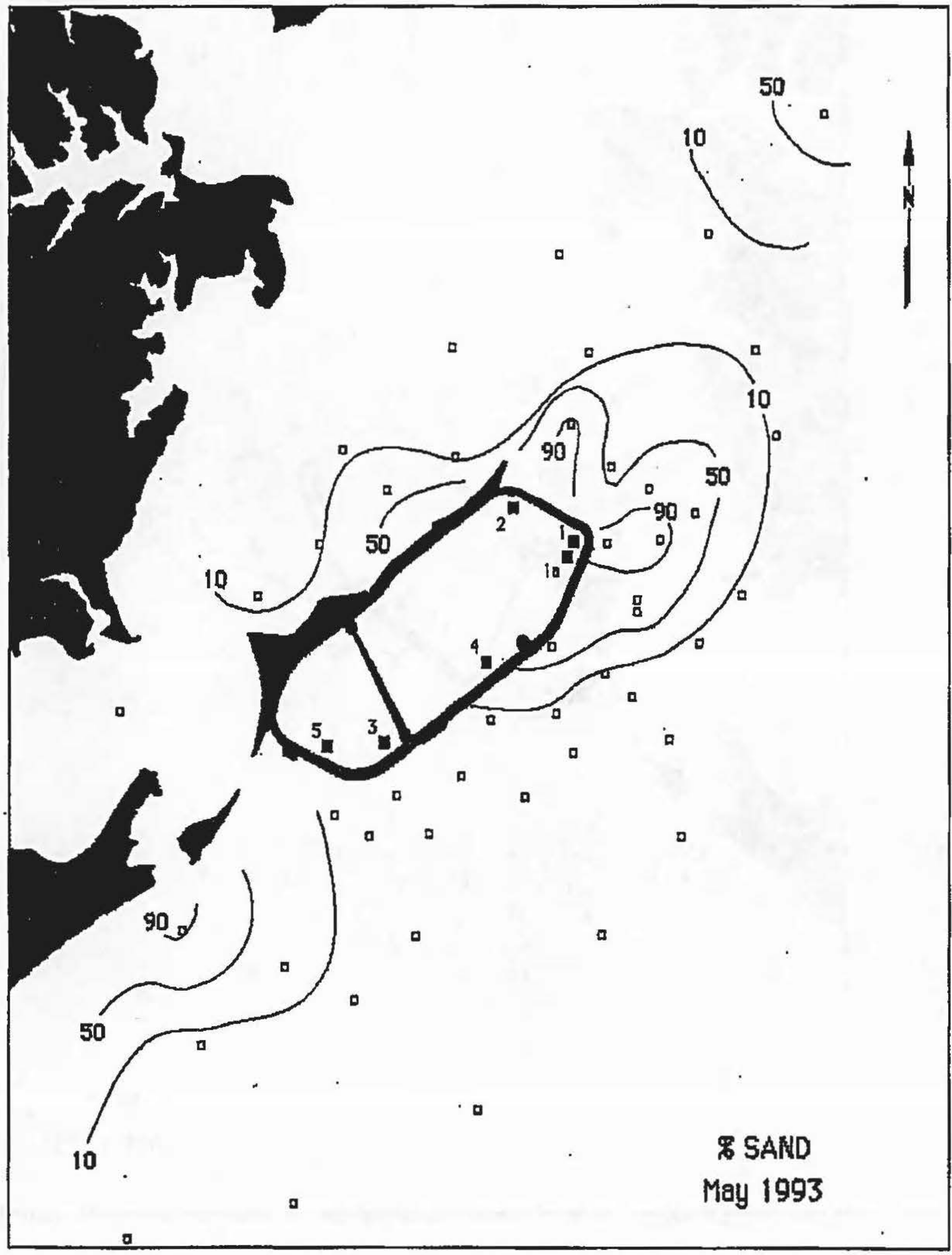


Figure 2-7 (b). Distribution of percent sand--twelfth year monitoring: May 1993.

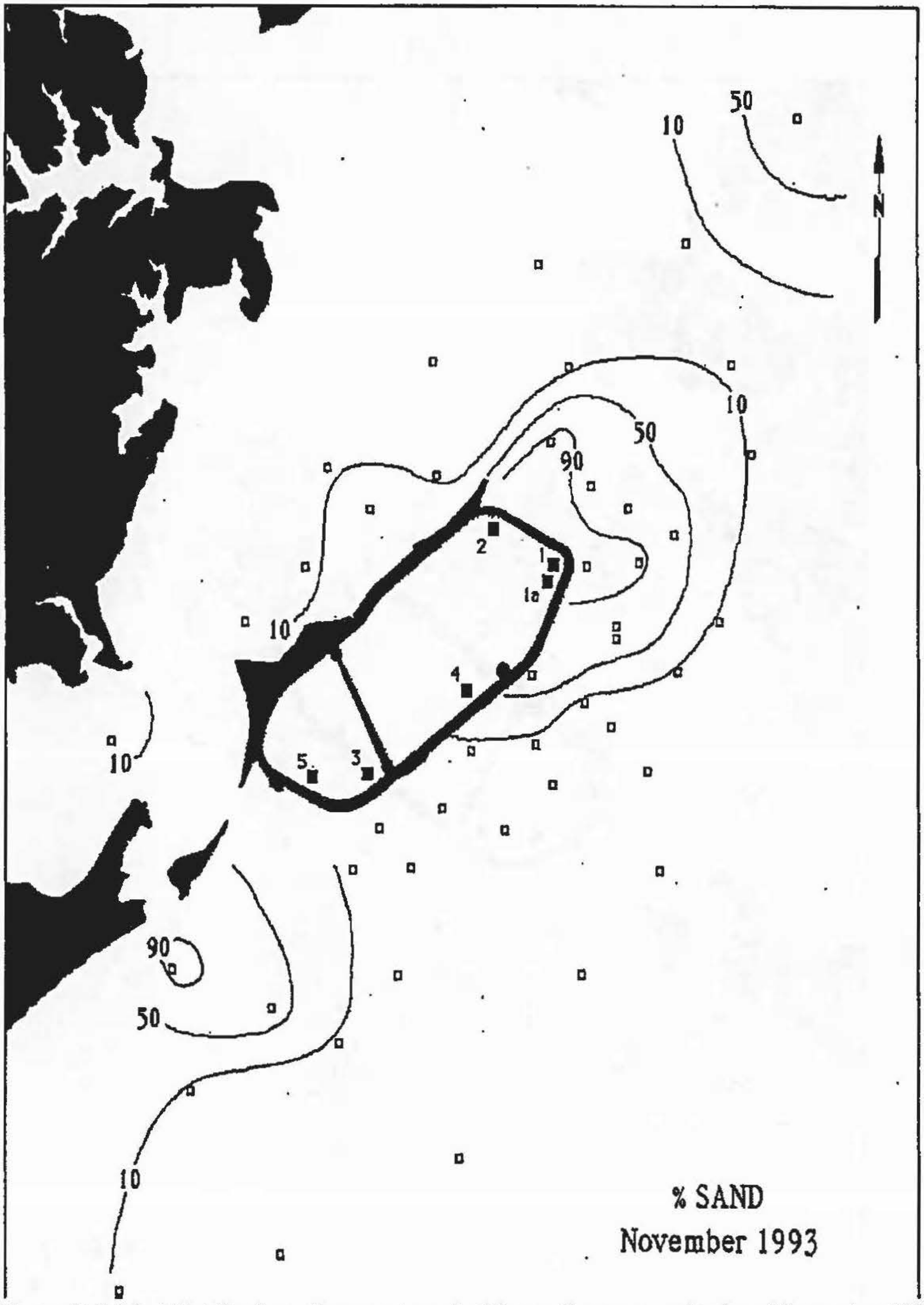


Figure 2-8 (a). Distribution of percent sand--thirteenth year monitoring: November 1993.

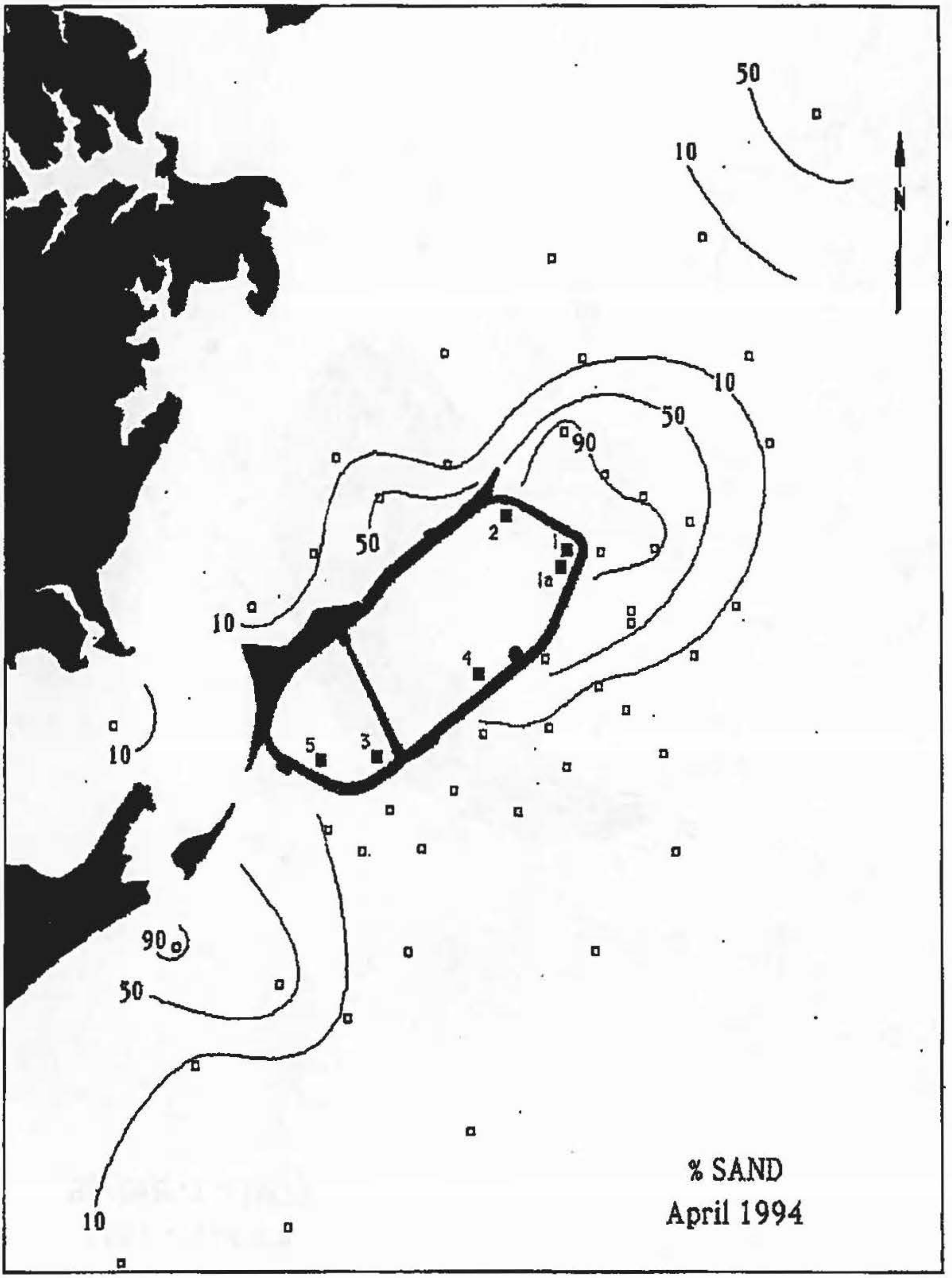


Figure 2-8 (b). Distribution of percent sand--thirteenth year monitoring: April 1994.

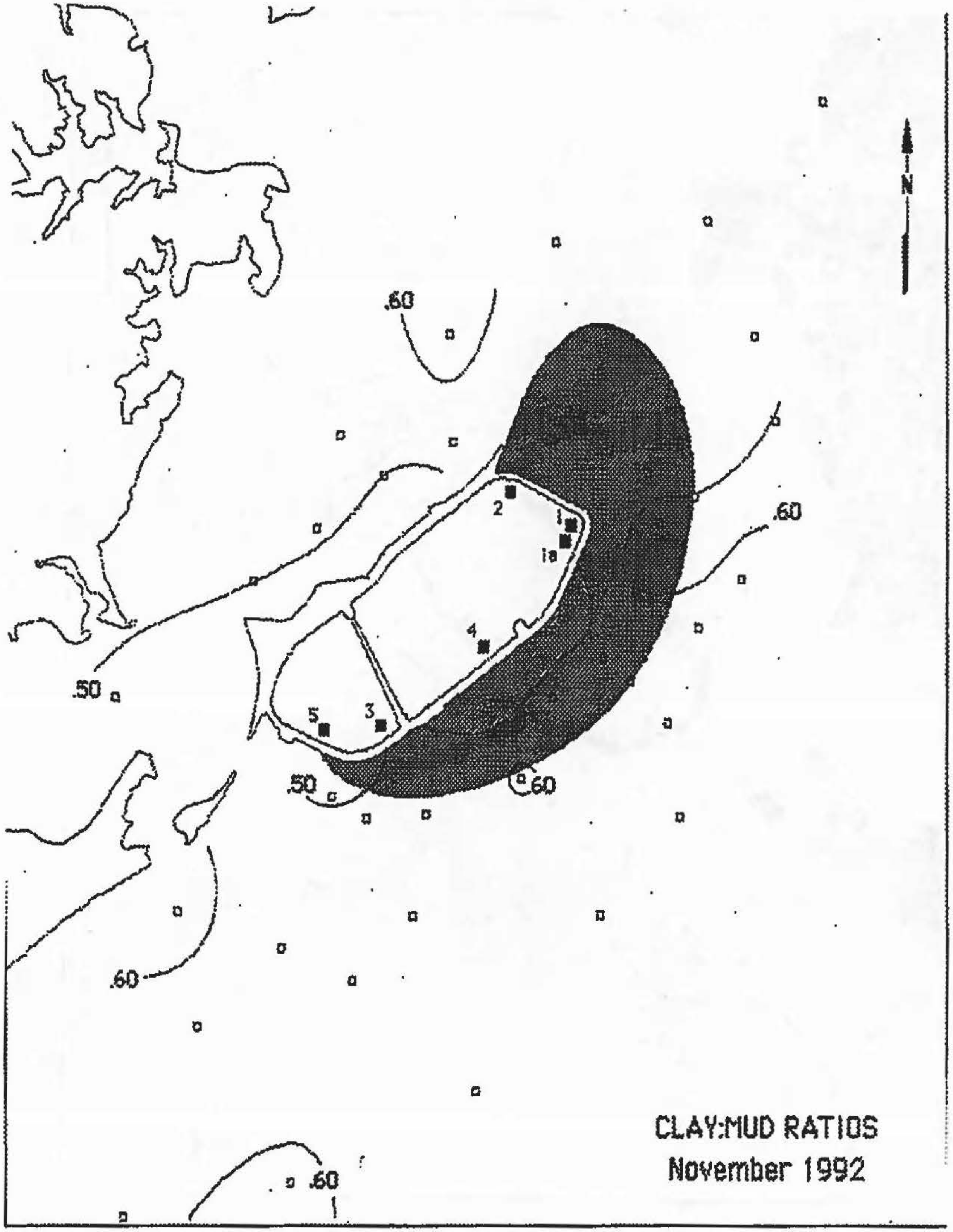


Figure 2-9 (a). Distribution of clay:mud ratios--twelfth year monitoring: November 1992.

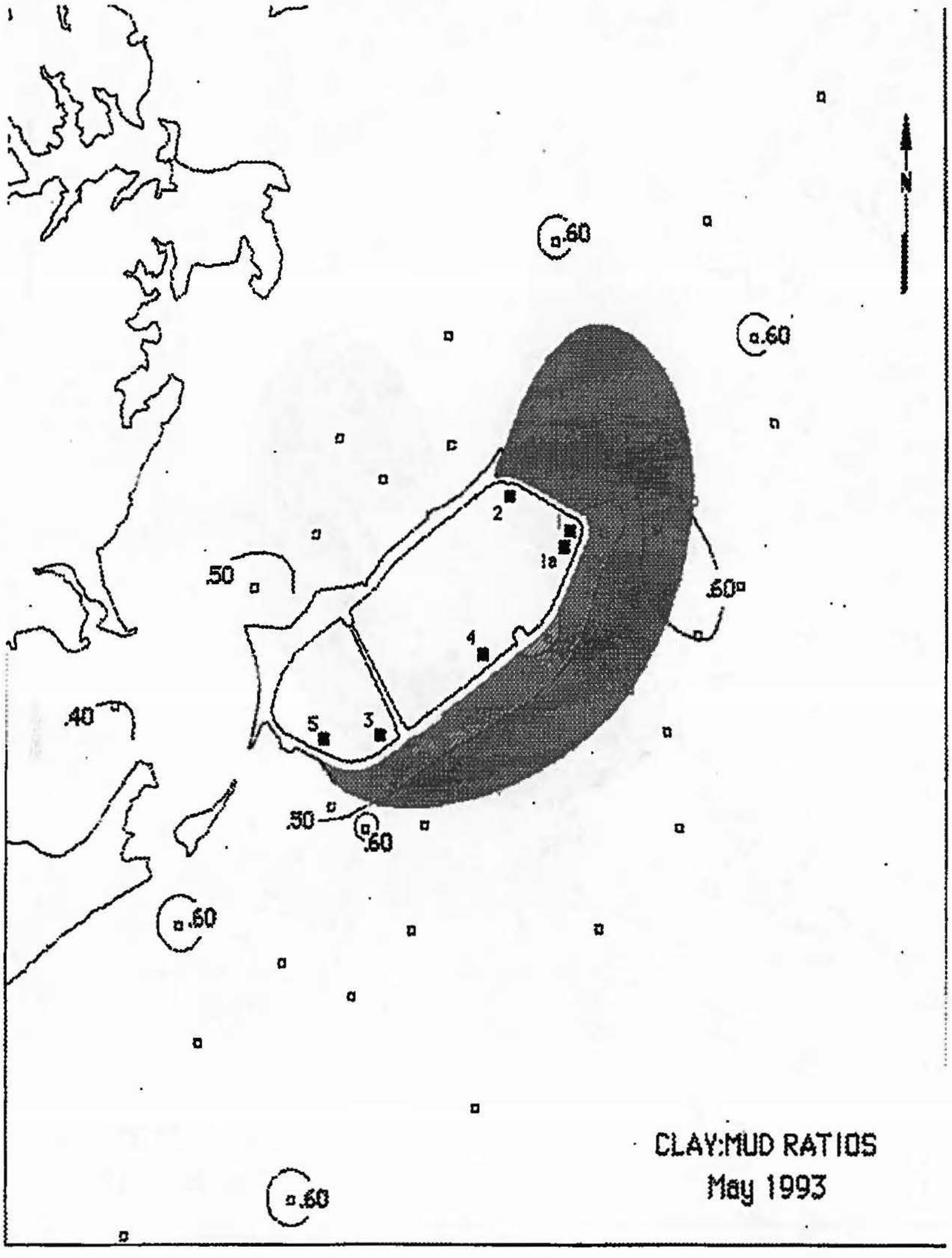


Figure 2-9 (b). Distribution of clay:mud ratios--twelfth year monitoring: May 1993.

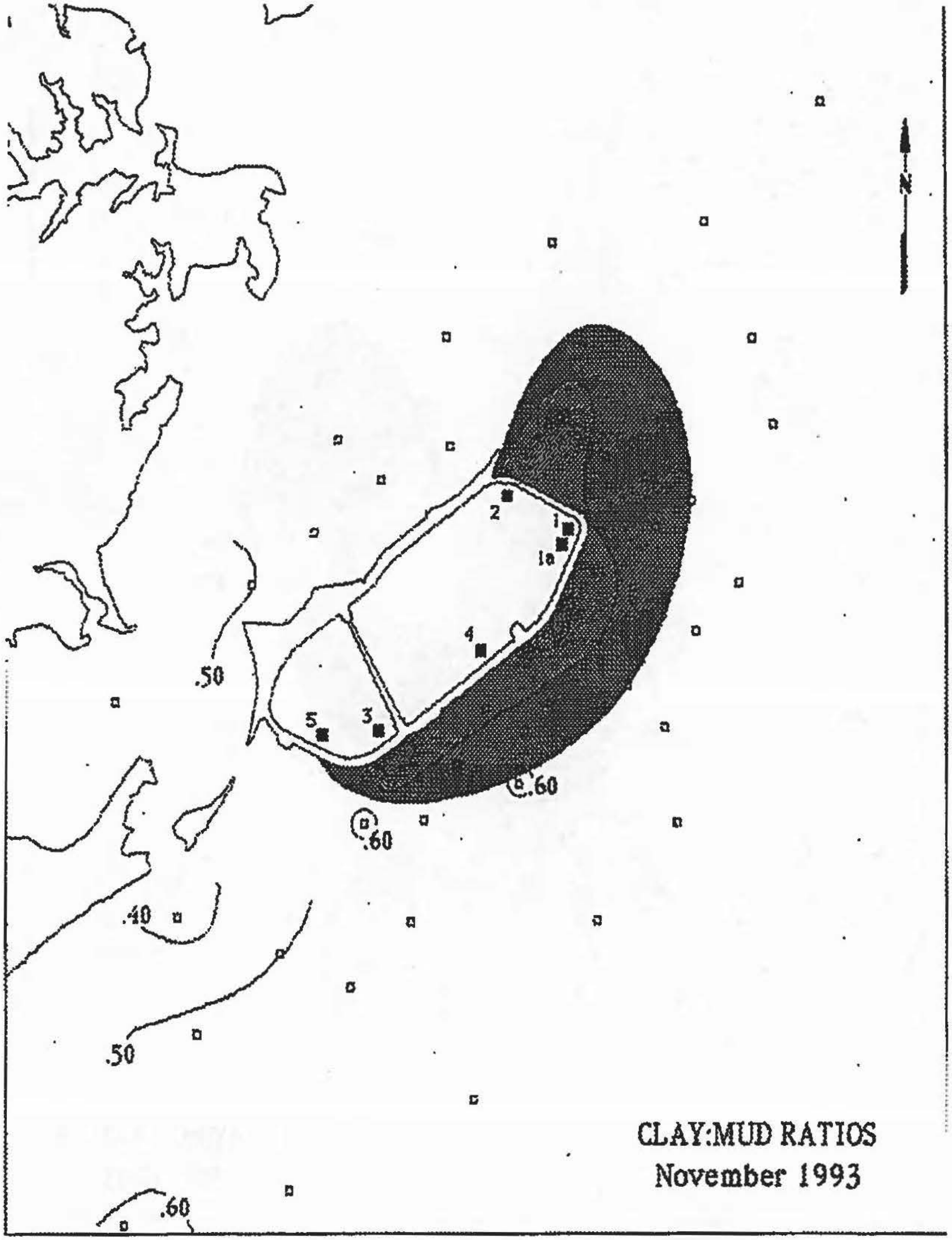


Figure 2-10 (a). Distribution of clay:mud ratios--thirteenth year monitoring: November 1993.

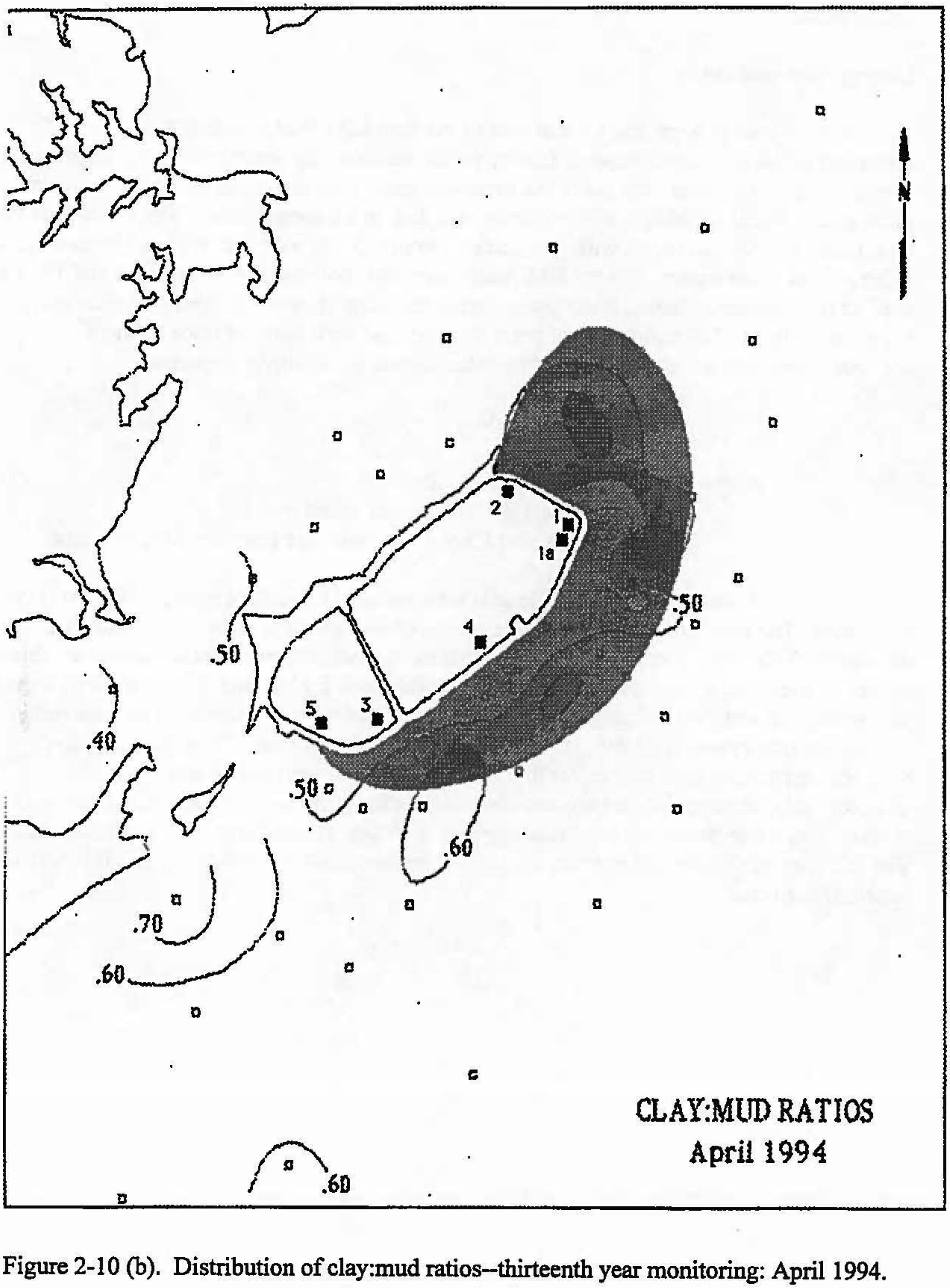


Figure 2-10 (b). Distribution of clay:mud ratios--thirteenth year monitoring: April 1994.

Trace Metals

Interpretive technique

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

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

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

A least squares fit of the data was obtained by using a Marquardt (1963) type algorithm. The results of this analysis are presented in Table 2-3. The correlations are excellent for Cr, Fe, Ni, and Zn, indicating that the concentrations of these metals are directly related to the grain size of the sediment. The correlations for Mn and Cu are weaker, though still strong. In addition to being part of the lattice and adsorbed structure of the mineral grains, Mn occurs as oxy-hydroxide chemical precipitate coatings. These coatings cover exposed surfaces, that is, they cover individual particles as well as particle aggregates. Consequently, the correlation between Mn and the disaggregated sediment size fraction is weaker than for elements, like Fe, that occur primarily as components of the mineral structure. The behavior of Cu is more strongly influenced by sorption into the oxy-hydroxide than are the other elements.

Table 2-3. Coefficients and R^2 for a best fit of trace metal data as a linear function of sediment grain size around HMI. The data are based on analyses of samples collected during eight cruises, from May 1985 to April 1988.

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

	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 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 2-3 for the determined coefficients in equation 2. These predicted values can then be used to determine variations from the regional norm due to deposition; to exposure of older, more metal-depleted sediments; or to loadings from anthropogenic or other enriched sources.

The following equation was used to examine the variation from the norm around the contained disposal facility:

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

Zn is used in the following discussion as an indicator of change in sediment chemistry. As elaborated in previous reports (Kerhin *et al.*, 1982a; Wells *et al.*, 1984), there are several reasons for focusing on Zn:

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 Bay that has been shown to be affected by anthropogenic input. This is true around HMI where Zn is the only metal to date to show consistently elevated levels.

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.

In Equation 3, the differences between the measured and predicted levels of Zn are normalized to predicted Zn levels. This means that a value of zero (0%) excess metal is at the regional norm, positive values are enriched, and negative values are depleted compared to the regional baseline. Direct comparisons of different metals in all sediment types can be made due to the method of normalization. As useful as the % Excess Metal values are, alone they do not give a complete picture of the loading to the sediments - natural variability in the samples as well as analytical variations must be taken into account. As result of the normalization of the data, Gaussian statistics can be applied to the interpretation of the data. Data falling within $\pm 2\sigma$ (± 2 standard deviations) are within normal background variability for the region. Samples with a value of $\pm 3\sigma$ can be within accepted background variability, but it is marginal depending on the trends in the distribution. Any values falling outside this range indicate a significant perturbation to the environment. The standard deviation (σ) of the baseline data set, the data used to determine the coefficients in Equation 2, is the basis for determining the sigma level of the data. Each metal has a different standard deviation, as reflected in the R^2 values in Table 2-3. The sigma level for Zn is ~30% (e.g. $1\sigma = 30\%$, $2\sigma = 60\%$, etc.)

Results

Since the eighth monitoring year, increased levels of Zn have been noted in bottom sediments east and south of spillway #1. The results of previous monitoring studies have shown that the areal extent and magnitude of 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 the HMI contained disposal facility at flows less than 10 MGD contribute excess metals to the sediment (see *Twelfth Year Interpretive Report*). The high metal loading to the exterior environment is the result of low input of water within the dike, which allows subaerial exposure of the sediment. When the sediments are exposed to atmospheric oxygen, naturally occurring sulfide minerals in the sediment oxidize to produce acidic conditions, which leach 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 inside the dike, minimizing subaerial exposure, and dilutes and buffers any acidic leachate. As a result, higher discharge rates produce metal loadings that are close to background levels.

2. Flow of freshwater into the Bay from the Susquehanna River - The hydrodynamics of the Bay in the area of HMI are controlled by mixing of freshwater with the brackish water south of the area. Details of the hydrodynamics of this region were determined by a modeling effort presented in an addendum to the *Tenth Year Interpretive Report* (Wang 1993). The effects of Susquehanna flow to the metal distribution around HMI follow:

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

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

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

3. The positions of the primary discharge points from the dike (see Figure 2-1). The areal distribution of the metals in the sediment also depends on the primary discharge locations to the Bay. The effects of discharge location were determined as part of the hydrodynamic model of the region around HMI. The effects of discharge location are:

a. Releases from spillways #1 and #4 travel in a narrow, highly concentrated band up and down the eastern side of the dike. This explains the location of the areas of periodic high metal enrichment to the east and southeast of the facility.

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

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

Figure 2-11 shows the % Excess Zn levels around HMI for the period from the seventh monitoring year through the twelfth. The distribution of Zn shown for April 1987 is typical of the metals distribution during the pre-discharge phase of operation of the dike. The other sampling periods shown in Figure 2-11 display changes in the distribution magnitude and extent due to seasonal variability of Susquehanna River flow and discharge from the dike. Also note the area to the south of the dike, this area is consistently enriched, and is not as clearly associated with the dike as the areas immediately adjacent to the dike. The enrichment in this area may also be due to discharge from the dike; there are lower current velocities in this area so that any material which spreads southward from the dike may settle in this area. However, there may be some influence due to an enriched source of material from the south such as Baltimore Harbor. There are not enough stations south of the HMI area to distinguish between these two possible sources.

Figure 2-12 shows the distribution of % Excess Zn, in sigma level contours, for the two thirteenth year sampling cruises. The metal distribution follows the expected pattern, given the controlling parameters listed above. The April 1994 cruise was typical of high discharge from the dike, with metal levels within accepted background variability. The November 1993 cruise showed elevated levels, typical of low discharge conditions.

Prior to the November sampling cruise, the hiatus of sediment placement was still in force, and crust management and dewatering were actively underway. These activities produce low discharge rates, with the resulting 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. As in previous years, metals in the external environment reflect the activity in the dike. Metal levels in the enriched area adjacent to the dike were elevated significantly above background (120% Excess Zn; 4σ). These levels are comparable to those found following previous periods of low discharge (see Figure 2-11).

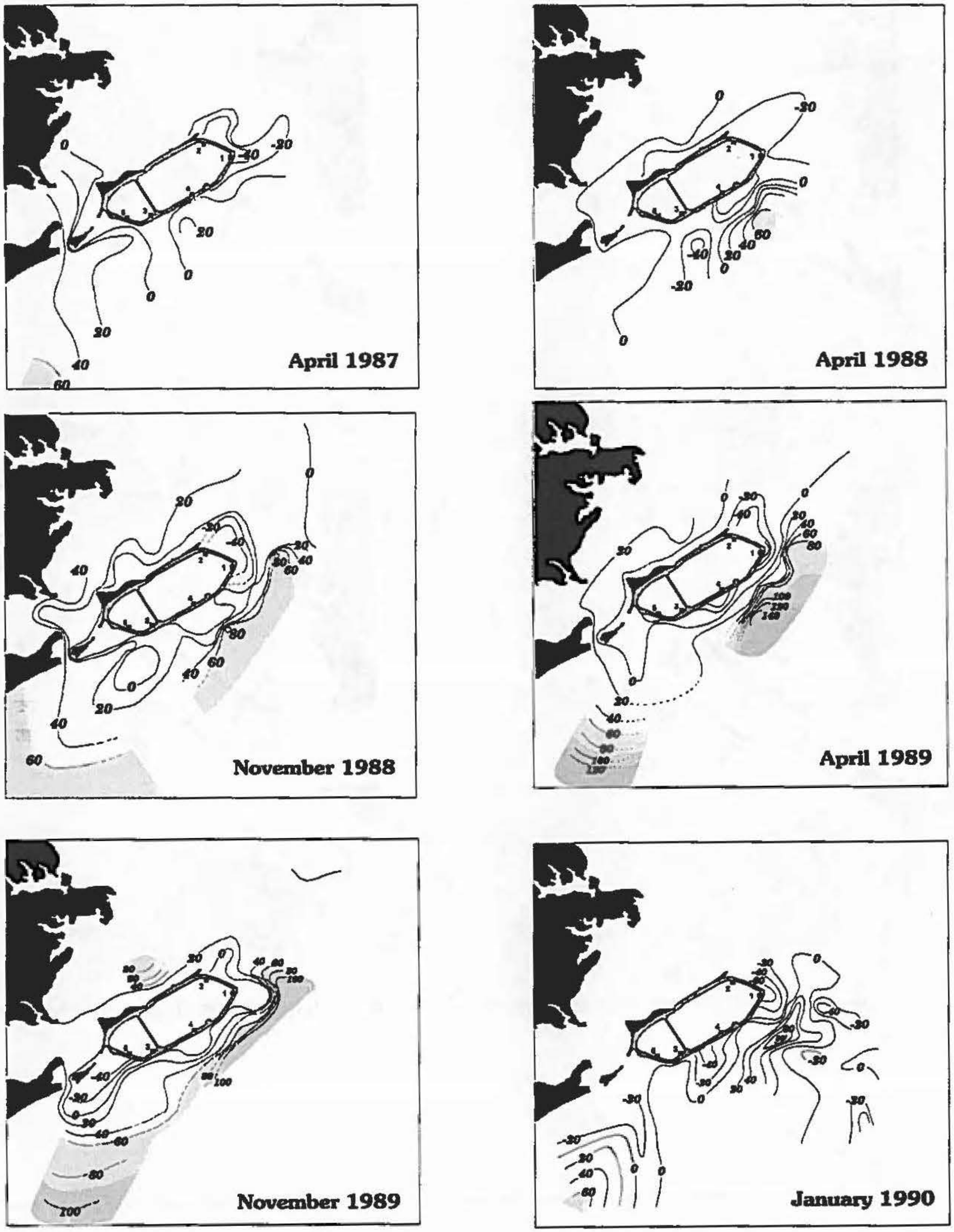


Figure 2-11. Percent excess Zn maps for the seventh through twelfth monitoring years.

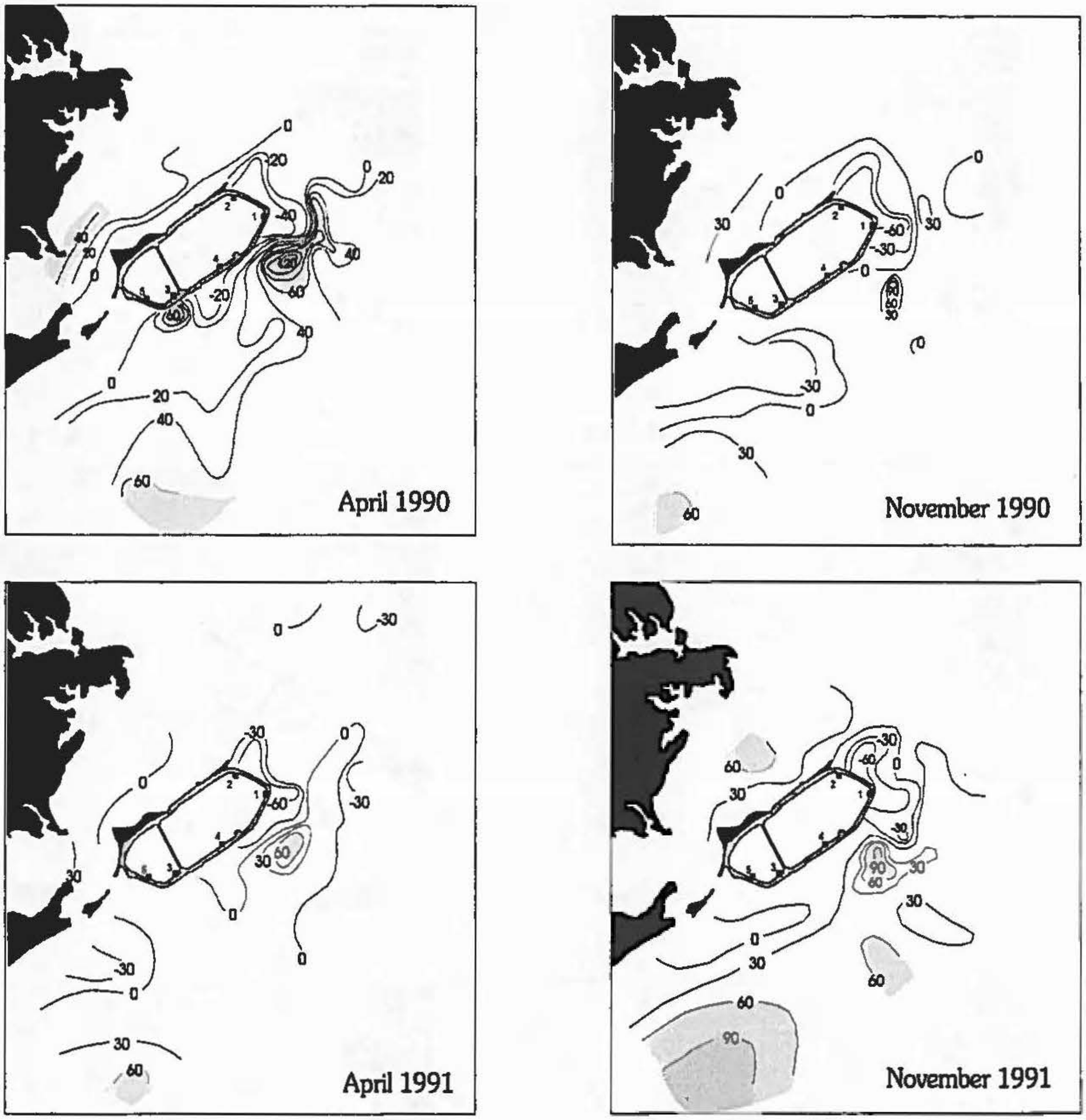


Figure 2-11 (con't). Percent excess Zn maps for the seventh through twelfth monitoring years.

Figure 2-11 (con't). % Excess Zn maps for the seventh through twelfth monitoring years.

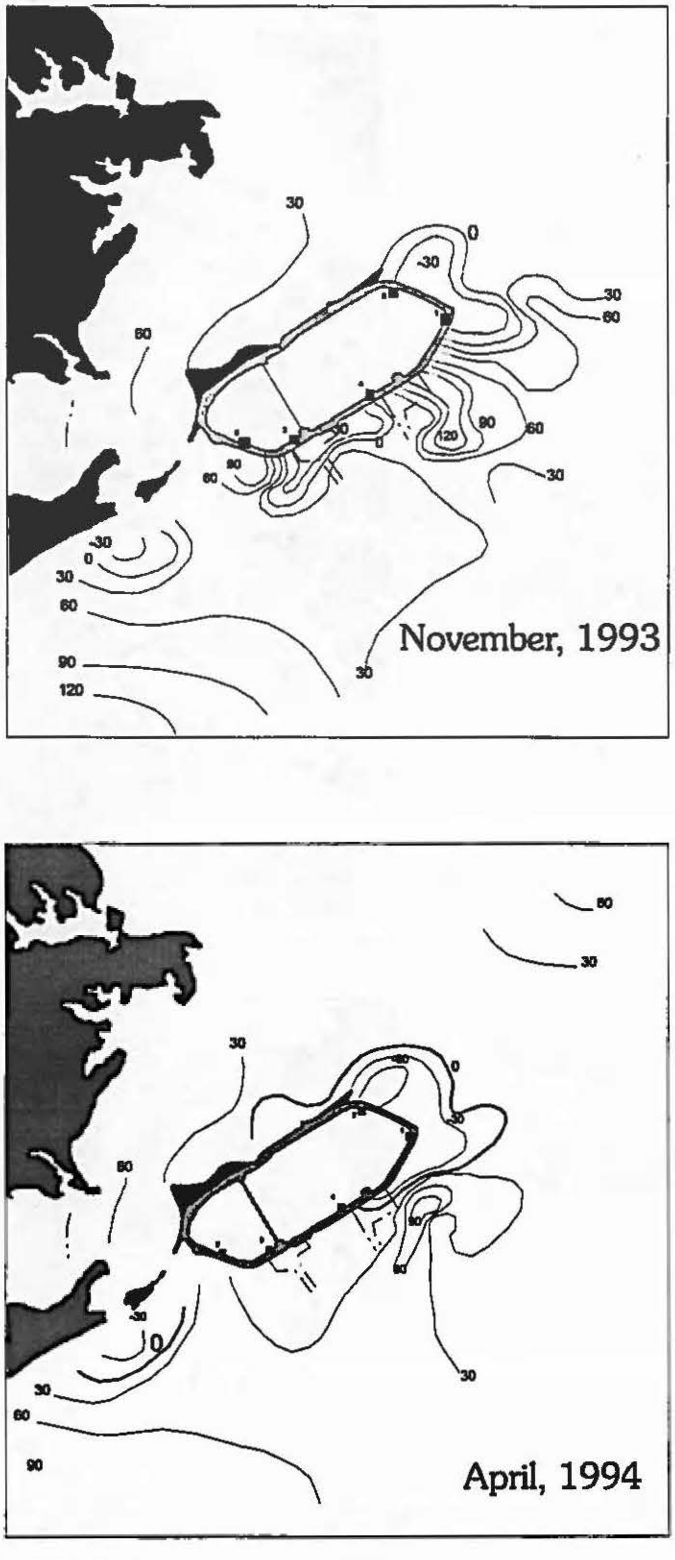


Figure 2-12. Percent excess Zn maps for the thirteenth monitoring year.

CONCLUSIONS

The grain size distribution of exterior bottom sediments, mapped during the thirteenth monitoring year, was similar to the twelfth year findings and consistent with earlier post-discharge periods. The distribution of sand around the facility has remained largely unchanged since November 1988. The typical seasonal pattern in the distribution of the fine (mud) fraction - coarsening over the summer and fining over the winter - was also evident again this year. This indicates that, hydrodynamically, the depositional environment around the facility was somewhat quieter between the November 1993 and April 1994 cruises than it had been prior to the November 1993 cruise.

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 the thirteenth monitoring year in the vicinity of the dike. In previous reports, Zn levels were correlated with the discharge rate of effluent from the facility. 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 MGD. At higher discharge rates, flushing with large volumes of water effectively dilutes Zn loadings in the effluent and, consequently, precludes Zn enrichment in the surrounding bottom sediments. The results of the metal distribution around the HMI facility for the thirteenth year clearly demonstrate this relationship; discharge prior to the November sampling was low, with resulting higher levels of Zn in the external sediments, while discharge prior to the April cruise was higher, with resulting lower metals loading.

RECOMMENDATIONS

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 contained material may lead to higher metal levels in the effluent. Exposure of dredged material to the air is likely to result in the mobilization of metals associated with those sediments, an effect analogous to acid mine drainage. Metals released in the effluent, particularly at low discharge rates, will probably be deposited on the surrounding Bay floor. Continued monitoring is needed to detect such effects. Monitoring will also be valuable in assessing the effectiveness of any amelioration protocol implemented by MES to counteract the effects of exposing contained dredged material to the atmosphere. Close cooperation with MES will be important in this endeavor.

It is further recommended that additional stations for sediment and metals analyses be added south of the facility, extending to Baltimore Harbor to ascertain the source of the enriched sediments observed to the south of the dike. These stations may only have to be done for one monitoring year, unless it is deemed important to monitor in future studies.

PART TWO: BEACH EROSION STUDY

INTRODUCTION

The recreational beach created between Hart and Miller Islands for use by the general public has been studied and monitored by the Maryland Geological Survey (MGS) since May 1984 (Fig. 2-13). The geologic processes operating on the beach have been identified and discussed in previous reports (Wells *et al.* 1985, 1986, 1987; Haines *et al.* 1989, 1990a, 1990b; Cuthbertson 1992; Kerhin 1993).

Identification of the erosional and depositional areas along the beach during the monitoring period (May 1993 - June, 1994) is essential for the planning of proper beach maintenance. The beach has sustained extensive erosion from profile 30+00 south, with significant deposition north of 32+00. Erosion at several profiles has lowered the beach profile close to February 1991 levels, preceding beach renourishment. Within the next year (1995-1996), erosion may reach February 1991 levels, and the beach may require further renourishment.

For several years, MGS had recommended that the shoreline be nourished with sand from an outside source. In April 1991, the plan was implemented, and sand was pumped onto the foreshore from Profile 24+00 north to Miller Island. The addition of sand reduced the slope of the beach, widened the foreshore, and provided an adequate recreational area for the general public. Since then, beach levels show removal of a significant quantity of previously renourished sand. It is our recommendation that further renourishment be given serious consideration for the upcoming year - late 1995 or early 1996.

PREVIOUS WORK

MGS has monitored the recreational beach since May 1984. The results of monitoring have been presented in many previous reports, as indicated in the introduction. Those reports describe the changes that the beach has experienced through the years as a result of the forces of man and nature. The reports also designate the three geomorphic areas of the beach: (1) the outer dike face, extending from the chain link fence at the edge of the dike roadway to the high water mark,

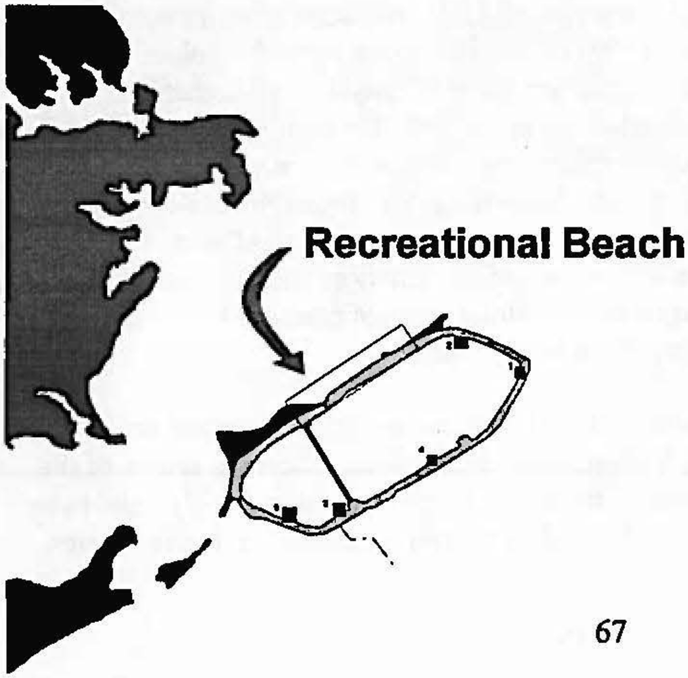


Figure 2-13. Location of the study area.

usually a wave-cut escarpment; (2) the foreshore, between the high water mark and mean low water (0 ft MLW); and (3) the nearshore, bayward of MLW.

The outer dike face was regraded to form two drainage ditches and two berms. The construction of these features, along with the subsequent planting of grass, adequately stopped erosion due to runoff.

In the past, the foreshore was modified by wind-generated waves assaulting the beach in conjunction with higher than normal tides. The result was a wave-cut escarpment of varying height, extending along much of the length of the beach. Bulldozing the foreshore temporarily removed the escarpment, which reappeared during the next severe storm event.

Net sediment gains and losses along the recreational beach are summarized in Table 2-4 for the period June 1984 to May 1992.

Table 2-4. Net volume change of sediment from the recreational beach (above 0 ft MLW) for each monitoring period, June 1984 to May 1992.

Time Period	Sediment Volume Gain/Lost*		
	(yd^3)	(m^3)	
June 1984 - March 1985	-1190	-910	
June 1985 - April 1986	-2083	-1593	
June 1986 - March 1987	-3472	-2656	
June 1987 - May 1988	-3129	-2394	
September 1988 - May 1989		-594	- 454
May 1989 - May 1990	-3081	-2356	
May 1990 - February 1991		-2100	-1606
February 1991- May 1991	+9428	+7252	
May 1991 - May 1992	+1863	+1433	
May 1992 - June 1993	-5828	-4479	
June 1993 - July 1994	-1315	-1005	

* based on ISRP (Birkemeier 1986)

OBJECTIVES

This report was written specifically to summarize the results of beach monitoring. The objectives of this report were to:

1. Identify the areas of erosion and deposition;
2. Calculate the amount of sediment eroded or deposited along the beach; and
3. Highlight the addition of sand to the foreshore through the use of cross-sectional profiles.

METHODOLOGY

FIELD METHODS

MGS monitored ten profile lines along the beach (Fig. 2-14). There were two surveys conducted along the ten profiles during the monitoring period, June 1993 - July 1994 (Table 2-5). Distance and elevation data collected during the two surveys are listed in the *Thirteenth Year Data Report*.

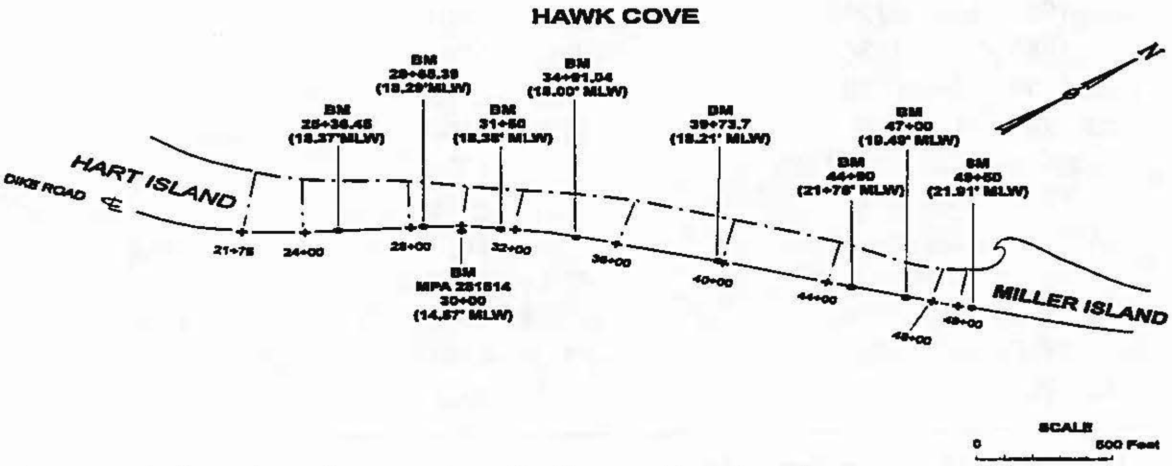


Figure 2-14. Location of surveyed profile lines and benchmarks.

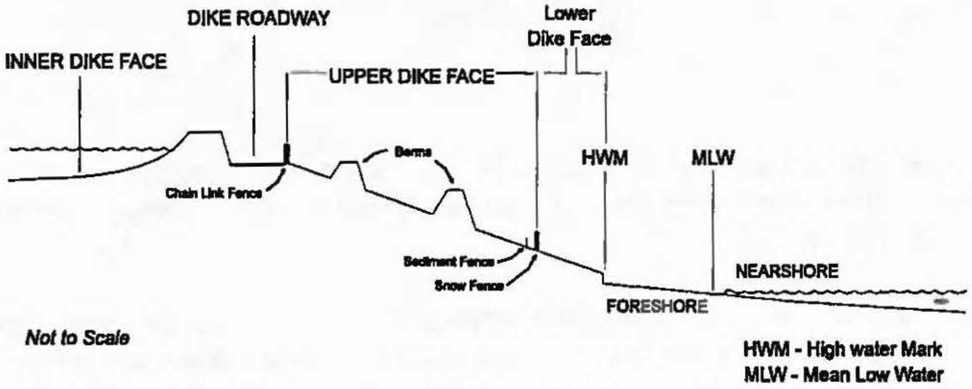


Figure 2-15. Post reconstruction (August 1988) schematic cross-section of the dike illustrating geomorphic regions of the beach

Table 2-5. Beach profile survey dates.

Profile	Survey 92	Survey 93	Survey 94
21+75	5-20-92	6-3-93	7-6-94
24+00	5-20-92	6-3-93	7-6-94
28+00	5-20-92	6-3-93	7-6-94
30+00	5-20-92	6-3-93	7-6-94
32+00	5-20-92	6-3-93	7-6-94
36+00	5-20-92	6-3-93	7-6-94
40+00	5-20-92	6-3-93	7-6-94
44+00	5-20-92	6-3-93	7-6-94
48+00	5-20-92	6-3-93	7-6-94
49+00	5-20-92	6-3-93	7-6-94

Standard techniques of surveying were followed in surveying the ten profiles using a Sokkisha engineer precision automatic level (Model B1).

Elevation points along each profile were transferred directly from the Maryland Port Administration bench mark number 281614 (elevation 14.57 ft MLW), located approximately

22 feet east of the centerline of the dike roadway at station 30+00, and benchmarks established by the Great Lakes Dredging Company along the dike roadway, shown in Figure 2-14 and listed in Table 2-6.

To locate the centerline of the dike roadway, from which point the survey profiles originated, 13 ft were measured from the chain link fence using a fiberglass survey rod. The correct azimuth of each profile was maintained by using a hand-held compass. The chain link fence was also marked with orange paint to indicate the azimuth of the profile as viewed through the level from the centerline of the dike roadway. Elevations were transferred from the centerline of the dike roadway to wooden stakes emplaced into the sand close to the snow fence. Each profile was then surveyed below the snow fence. The level was set up either uphill or downhill of the start of each profile, depending on the elevation changes and the amount of wind (potential for bending the survey rod).

Table 2-6. Benchmark location, elevation and type of structure.

Station	Elevation (ft)	Type of Structure
28+55.39	18.29	cemented pipe
30+00	14.57	nipple inside pipe
31+50	18.38	stake
34+91.04	18.00	cemented pipe
39+73.7	18.21	stake
44+00.91	21.75	fence crosspipe
49+50	21.91	fence crosspipe

DATA REDUCTION

To calculate the sediment gains and losses above and below the datum (0 ft MLW) for each profile, a computer program (Interactive Survey Reduction Program (ISRP)) was employed (Birkemeier 1986). Net beach sediment volumes were determined by the formula:

$$V_c = D/2(A_1+A_2) \qquad (1)$$

where V_c is volume change in yd^3

D is distance (ft) between profile stations

$A_{1,2}$ is volume loss (yd^3/ft of beach) for each profile

RESULTS AND DISCUSSION

In April 1991, the beach was nourished with sand dredged from the approach channel to Baltimore Harbor. Construction crews at HMI used dump trucks to transport sand from an on-island stockpile. A bulldozer smoothed the sand dumped from the trucks. The sand consisted mainly of clean, medium-grained (1.0ϕ–2.0ϕ) sand with some fine (3.0ϕ–4.0ϕ) sand. The sand was distributed from 28+00 north to the end of the beach, 49+00. Approximately 14,700 yd^3 (11,240 m^3) of sand were deposited in front of the existing, wave-cut escarpment. The shoreline was extended bayward approximately 30-40 ft (Table 2-7). By May 1991, the beach had experienced several strong weather events, and some erosion of the newly restored beach had occurred.

The result of monitoring the beach at Hart-Miller Island has been identifying the areas and extent of erosion or deposition. Both shoreline position and foreshore shape have changed during the period June 1993-July 1994. To assess the changing slope of the beach, ten cross-sectional profiles were constructed using ISRP (Appendix A).

Three distinct patterns emerged from a comparison of the previous profile period (June 1993) with the most recent profile (July 1994). At 21+75, the southern-most profile, deposition occurred along the foreshore, with progradation of the zero contour shoreline. The backshore underwent erosion and a lowering of the profile. The net volume change measured was -1095 yd^3, mostly from the backshore profile.

The second pattern was erosion along the entire profile. From 28+00 to 34+00, erosion dominated the entire profile, from the edge of vegetation along the backshore to the point of closure in the nearshore. At 28+00, 30+00, and 32+00, erosion of the backshore created a two-foot escarpment at the base of the lower dike face. The erosional volume changes decreased from -636 yd^3 at 24+00 to -174 yd^3 at 32+00 (Fig. 2-16). Between 48+00 and 49+00, the northernmost profiles, the entire profile eroded from the point of closure in the nearshore to the upper backshore. The volume losses, however, were considerably less than the losses for the area between profiles 24+00 to 36+00.

The third pattern is one of deposition along the upper foreshore and progradation of the zero contour on the average of 5 ft. This is evident between 40+00 and 44+00, with deposition of +878 yd^3 of sand. Deposition occurred along the entire profile, from the upper backshore to the lower foreshore.

Table 2-7. Distance (ft) from the centerline of the dike roadway to the 0 ft contour (MLW), by survey date.

Profiles	**Feb 91**	**May 91**	**May 92**	**June 93**	**June 94**
Prof 21	341	328	330	368	375
Prof 24	283	279	289	304	291
Prof 28	219	237	236	238	233
Prof 30	192	229	219	223	209
Prof 32	182	237	212	217	200
Prof 36	216	255	234	241	233
Prof 40	220	260	249	238	240
Prof 44	185	222	210	202	207
Prof 48	174	208	186	179	163
Prof 49	192	219	191	187	179

Deposition will continue as long as there is sand to be eroded and wind-driven waves approach from the proper angle. The amounts of erosion and deposition will be determined by the frequency of storm events; the direction, intensity, and duration of the wind-driven waves; and the slope of the foreshore.

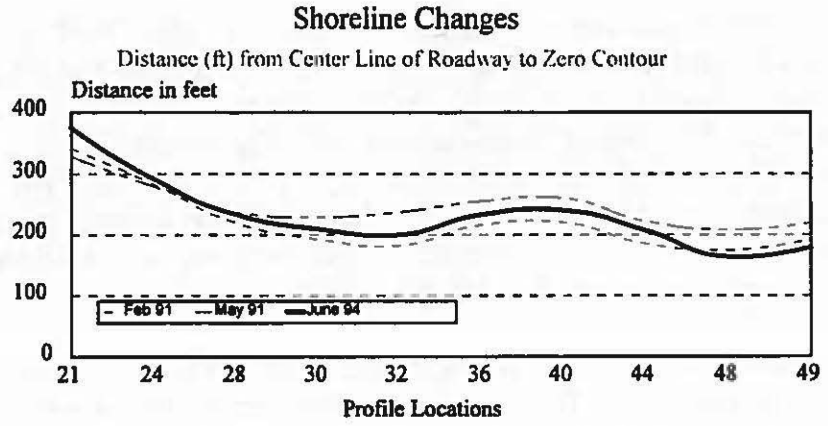


Figure 2-16. Shoreline Changes compared with Base Year (1991).

The HMI beach displayed an erosional character between 21+75 to 36+00 and 48+00 to 49+00 and a depositional one between 40+00 to 44+00. Profiles 21+75 to 24+00 exhibited the greatest volume loss of sand, but with progradation of the shoreline. At 21+75, the backshore underwent significant adjustment, with a lowering of the profile by 1.5 feet with a corresponding progradation of the shoreline. A percentage of sand lost from the upper backshore aggraded to the lower foreshore, pushing the zero contour line seaward. The erosional conditions between 28+00 to 36+00 and 48+00 to 49+00 differ from the erosional conditions at 21+75 in that the entire profile underwent erosion with landward translation of the zero contour line. Interestingly, the volume losses were much lower than the volume losses at 21+75. Two reasons account for the lower volume losses:

1. The beach is wider at 21+75 by 30-40 ft, and erosional changes occurred along the entire profile; and

2. Between 28+00 and 36+00, the erosion of the backshore coincided with deposition along the upper foreshore, thus lowering the net erosional volume loss.

Comparing the volume changes at 40+00 and 44+00 for the time periods 1992-1993 and 1993-1994, there was a complete reversal in the profile change. In 1992-1993, erosion dominated the entire shoreline, with the greatest volume loss at 40+00 and 44+00. The following year, this reporting period, 40+00 to 44+00 showed a net gain of +876 yd^3.

The objective of beach monitoring is to collect and analyze beach profile data for possible beach restoration. In 1991, the beach was reshaped with more than 14,000 yd^3 of sand. Using 1991 as the base year, changes in the distance of the shoreline from the baseline or changes in net volumes provide methods for comparisons. Figure 2-16 details the changes in the shoreline position from the 1991 base year to this profiling year. Between 21+75 to 28+00, the shoreline prograded 47 to 2 ft respectfully. Along the northern profiles, from 30+00 to 49+00, recession of the shoreline dominated, averaging approximately 20 ft. In comparing the shoreline position with the pre-base year configuration, the 1994 shoreline position is at the same position as the pre-base year position, pre-beach restoration shoreline. Although the shoreline has receded to the pre-restoration profile shape, the cumulative sand volumes still show a net gain over the entire shoreline. Certain profiles have experienced a net cumulative loss. At 21+75, the cumulative volume loss is over 1000 yd^3, even though the shoreline prograded seaward. The losses at 21+75 were along the backshore and redistributed at the lower foreshore. Profiles 28+00, 30+00, 32+00, and 40+00 experienced no change in the cumulative volume from the restoration period (Figure 2-17). Profile 24+00 had a net cumulative gain, while 32+00 and 49+00 underwent net cumulative loss. At 26+00 and

44+00, approximately 50% and 25%, respectively, of sand remain from the restoration volumes.

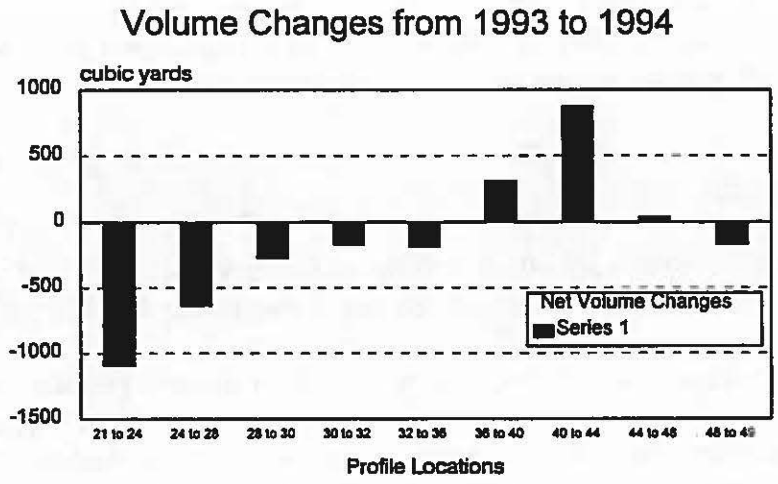


Figure 2-17. Volume changes from 1993 to 1994.

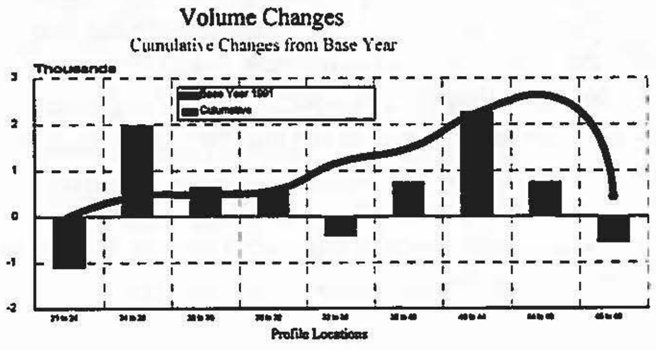


Figure 2-18. Cumulative volume changes as compared with 1991 base year.

RECOMMENDATIONS

The shorelines developed during the February 1991 beach nourishment project are the benchmark against which future beach conditions should be referenced. The net cumulative change between the February 1991 and May 1991 profiles serves as the reference volume for comparison (Figure 2-18).

As shown by the profile comparisons, many of the profiles are approaching the 1991 base year measurements. Three of the profiles actually show lower sand volumes than pre-nourishment conditions. The remaining seven profiles show sand volumes greater than the pre-restoration volumes, but less than the sand volume added during restoration. Essentially, erosion and shoreline recession are removing the sand placed during the 1991 restoration, though pre-restoration levels have not yet been reached.

It is recommended that a new plan for beach nourishment be devised and implemented for Spring-Summer 1996, unless fourteenth year monitoring shows severe changes requiring immediate action. In that case, a Fall 1995 restoration plan may be required to enhance beach conditions for the upcoming winter. Volumes of 10,000-14,000 yd^3 should be sufficient to sustain the recreational beach for the next few years. The profile data suggest a four- to five-year cycle of beach restoration, with 10,000-14,000 yd^3 of sand required to maintain the beach level at the recommended shape.

CHAPTER 3. PROJECT III: BENTHIC COMMUNITY ECOLOGY

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ABSTRACT

Benthic invertebrate populations in the vicinity of the Hart-Miller Island Dredged Material Containment Disposal Facility (HMI) in the upper Chesapeake Bay were monitored for the thirteenth consecutive year in order to examine any potential effects from the operation of the HMI facility on these bottom-dwelling organisms. Organisms living close to the containment dike (referred to as the 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 (referred to as reference stations) in December 1993 and April and August 1994.

The infaunal samples were collected with a 0.05 m^2 Ponar grab and washed on a 0.7 mm mesh screen. The epifaunal samples were scraped from the pilings, that support a series of piers which surround HMI, with a specially designed scraping apparatus. Sixteen infaunal stations were sampled on each cruise (8 nearfield/experimental stations, S1-S8; 5 reference stations HM7, 9, 16, 22, 26) and three of the four original stations which were added over the course of the 9th year study in areas which had been reported by the sedimentary group from the Maryland Geological Survey to have sediments which were substantially enriched in zinc (referred to as zinc-enriched, and numbered as G5, G25, HM12). As of April, 1994, station G84 (the fourth station) was dropped because it no longer appeared to be enriched with zinc. The G84 data from December was included in the thirteenth year data report, but it will not be included in this report in order to better compare the different sampling periods. The various infaunal stations have sediments of varying compositions, including silt-clay stations, oyster shell stations and sand substrate stations. A total of 30 species were collected from these sixteen infaunal stations. The most abundant species were the worms, *Scolecolepides viridis*, *Nereis succinea* and *Tubificoides sp.*; the crustaceans, *Leptocheirus plumulosus*, *Corophium lacustre* and *Cyathura polita*; and the clam, *Rangia cuneata*.

Species diversity (H') values were evaluated at each of the infaunal stations at the three sampling periods. The highest diversity value (3.253) was obtained for the nearfield station S6, in December 1993. The lowest diversity value (0.244) occurred in April 1994 at the nearfield station, S1. For the three sampling dates, the overall highest diversity values (with only five stations under 2.5) occurred in December 1993 and the lowest overall diversity occurred in April 1994.

The length-frequency distributions of the clams, *Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli* were examined at the nearfield, reference and zinc-enriched stations. There was good correspondence in terms of numbers of clams present and the relative size groupings for the three sampling dates. *Rangia cuneata* continued to be the most abundant species at all three groups of stations, followed by *Macoma balthica*. *Macoma mitchelli* remained the least abundant of the 3 dominant clam species.

Cluster analysis of the stations over the three sampling periods continued to associate stations primarily in response to sediment type. Variations in recruitment at the different stations explain 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 the nearfield stations in August.

Epifaunal populations were similar to those observed in previous years. Samples were collected at two depths (about 3 feet/1 meter and 6-8 feet/2-3 meters, dependent on the station 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 and as previously reported, the amphipod, *Corophium lacustre*, was one of the most abundant epifaunal organisms present at nearly all nearfield and reference stations sampled during the Thirteenth Year. The hydroid, *Cordylophora caspia* was the next most frequently observed epifaunal species on the pilings.

The results of the 13th monitoring year studies again reveal that no adverse effects on the benthic populations have been observed which could be attributed to the maintenance and operation of the Hart-Miller Island Dredged Material Containment Disposal Facility. We have continued to monitor 3 of the zinc enrichment stations (G5,G25, HM12) established in the 9th year of sampling as a result of Maryland Geological Survey's findings of zinc enriched sediments in the vicinity of HMI. During this the fifth year of sampling for these zinc-enriched stations, these stations do not appear to differ in any distinct manner from the original nearfield and reference epifaunal stations. Continued monitoring of the benthic populations in the area is strongly recommended in order to continue to follow any potential changes associated with the existence and operation of the Hart-Miller Island Dredged Material Containment Disposal Facility.

INTRODUCTION

The results of the benthic population studies conducted during the thirteenth consecutive year of the exterior monitoring program in and around the vicinity of the Hart-Miller Island Dredged Material Containment Disposal Facility are presented in this report. The HMI site lies within the upper portion of the Chesapeake Bay and experiences seasonal salinity and temperature fluctuations. This region of the Chesapeake Bay encompasses vast soft-bottom shoals, which are important to protect as they serve as important breeding and nursery grounds for many commercial as well as non-commercial species of invertebrates and migratory fish. Since this is an area that is environmentally unpredictable from year to year, it is important to maintain as complete a record as possible on all facets of the ecosystem. Holland (1985) and Holland *et al.* (1987) completed long-term studies of more stable mesohaline (mid range of salinity) areas which are further down-Bay and found that most macrobenthic species showed significant year-to-year fluctuations in abundance, primarily as a result of slight salinity changes and that the spring season was a critical period for the establishment of both regional and long-term distribution patterns. One would expect even greater fluctuations in the benthic organisms inhabiting the region of HMI which is located in the highly variable oligohaline (low salinity) portion of Chesapeake Bay. Indeed past studies (Pfitzenmeyer and Tenore 1987; Duguay, Tenore, and Pfitzenmeyer 1989; Duguay 1989, 1990, 1992, 1993, 1995) 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. These opportunistic species are characteristic of disturbed to environmentally variable regions (Beukema 1988) such as the upper Bay.

The major objectives of the thirteenth year benthic monitoring studies were:

1. To monitor the nearfield benthic populations for possible effects of discharged effluent and possible seepage of dredged materials from the containment facility. This was done by following changes in population size and species composition over the seasonal cycle. Compare to previous years and baseline conditions.

2. To collect samples of the epibenthic fauna on the pilings along the perimeter of the containment facility to check for any immediate sign of detrimental effects to these organisms as a result of discharge or seepage from the facility.

3. Continued monitoring of benthic and epibenthic populations at established reference stations for comparisons with the nearfield stations surrounding the containment facility.

4. Continued monitoring of benthic populations at three stations at which the Maryland Geological Survey sedimentary group found elevated levels of zinc.

5. To provide selected species of benthic invertebrates for chemical analysis of organic and metal concentrations by an outside laboratory (Artesian Laboratories, Inc. in Newark, Delaware), in order to ascertain various contaminant levels of organisms and to follow if there is any possible bioaccumulation.

METHODS AND MATERIALS

Three cruises were conducted during the thirteenth monitoring year on December 13, 1993, April 11, 1994 and August 8, 1994. 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 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 thirteenth year data report and the state designation numbers are also listed in Table 3-6 of this report. 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,) at 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. Back in the laboratory the samples were again washed on a 0.5 mm sieve and then transferred to 70% ethyl alcohol. The samples were then sorted and each organism was removed, identified, and enumerated. Measurements of length-frequency were made on the three most abundant clams. A qualitative sample was scraped from the pilings at the epifaunal stations (R2-R5, see Figure 3-1) by a specially designed piling scraping device. The scrape samples were treated in a similar manner to the infaunal benthic samples with regard to preservation and general handling. However, only a qualitative or relative estimate of abundance was made for each species through a set of numerical ratings, which ranged from 1 - very abundant, 2 - abundant or common, to 3 - present. Station depths were recorded from 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 - ‰).

Quantitative infaunal sample data were analyzed by a series of statistical tests carried out with the SAS statistical software package (SAS Institute, Cary, N.C.). 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, MD). 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 slit/clay - nearfield, reference, and zinc-enriched stations singly and then the reference and nearfield or zinc-enriched stations were added together and retested.

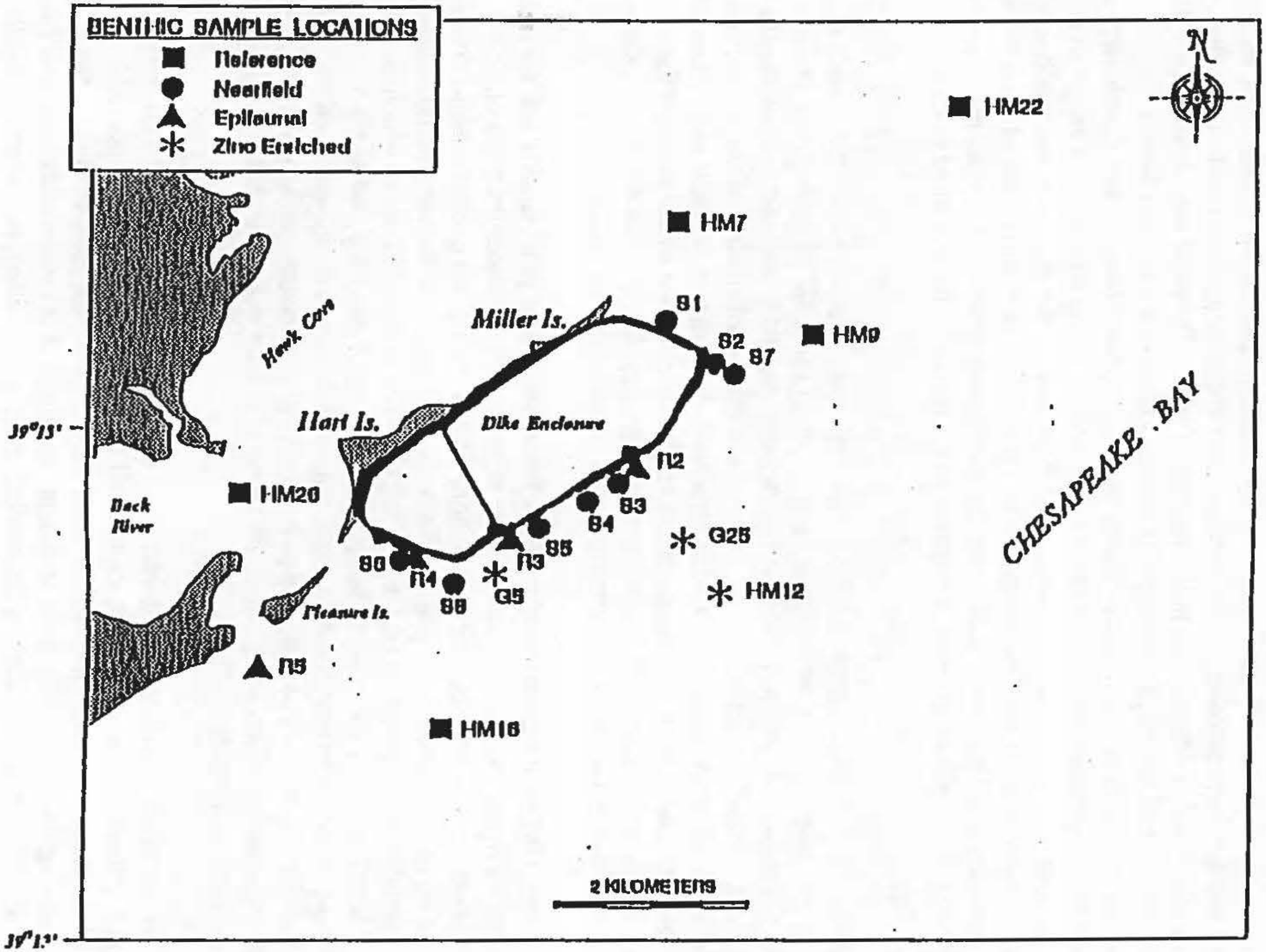

Figure 3-1: Benthic infaunal and epifaunal sampling station locations at HMI. University of Maryland, Chesapeake Biological Laboratory designations.

RESULTS AND DISCUSSION

Since the beginning of the benthic survey studies in 1981, a small number of species have been the dominant members of the benthic invertebrate populations collected at the various nearfield and reference sites in the vicinity of HMI. The most abundant species this year were the annelid worms, *Scolecolepides viridis*, *Tubificoides sp.*, and *Nereis succinea*; the crustaceans, *Leptocheirus plumulosus*, *Corophium lacustre* and *Cyathura polita* and the clam, *Rangia cuneata* (see 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, the *S.viridis* numbers have increased considerably compared to the results of the last three years of sampling.

The major variations observed in dominant or most abundant species for a station occur primarily as a result, of the 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 more variable often 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 *L. plumulosus* and all the shell bottom stations, *Membranipora tenuis*.

Station HM26, at the mouth of the Back River has in past years usually had the most diverse annelid worm fauna; this area is high in organics, which makes it a good place for worms. However, this year the nearfield station, S4 had the highest overall annelid diversity with 8 species in December, 5 in April and 7 species in August. A diverse annelid fauna was also recorded this year at stations HM26, S3, S6, G5, G25, and HM12, all of which had between 5 and 7 species of worms per sampling period (see Tables 3-3, 3-4 and 3-5). This year the most abundant worm species at the nearfield, reference and zinc-enriched stations was *S. viridis*; the total *S. viridis* population numbers (all station data combined) were over eight times that observed last year. The second most abundant worm was *Tubificoides sp.*, last year's most abundant worm.

The worms, *S. viridis* and *Tubificoides sp.* the clam, *R. cuneata* and the crustaceans, *C. polita* and *L. plumulosus* occurred frequently at all three sets of stations, the nearfield, reference, and zinc enriched. These five species were not only the most frequently found but were also among the numerically most abundant organisms at the various stations (see 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 *S. viridis* was the most abundant species followed by *L. plumulosus*.

Once again *L. plumulosus* was ahead of *C. polita* in terms of overall abundance at all three sets of stations (see Tables 3-3, 3-4, 3-5) and was present at nearly all stations on all dates sampled. The isopod crustacean, *Cyathura*, was also present at nearly all stations on all sampling dates; it 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 the upper Chesapeake Bay because the animals are further developed, making them resilient to variations. 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 zinc-enriched stations are comparable and ranged for the most part between 1000 and 10,000 individuals/m^2. The highest recorded value was found at station S5; in April, 30,235 individuals/m^2 were recorded as a result of high concentrations of the worm, *S. viridis* (26,820 individuals/m^2) and the crustacean, *C. lacustre* (1240 individuals/m^2). The lowest recorded value occurred at station S1 in December (188 individuals/m^2). There did not appear to be any consistent pattern in terms of the highs and lows at the reference or nearfield stations. The predominant benthic populations at the three sets of stations, nearfield, reference, and zinc-enriched areas are similar and consist of primarily suspension feeders which have an ample supply of fine substrates in this region of the Chesapeake Bay and particularly around the Hart-Miller Island Dredged Material Containment Disposal Facility itself (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 December the surface salinity ranged from 0.5 - 2.6 ‰, whereas, in April the surface salinity varied between 0 and 0.5 ‰. In August, the surface salinity ranged from 1.8 - 3.1 ‰. The salinity ranges (surface) were about the same as the previous years values in April, when the values were 0.1 - 1.0 ‰, but last years values for December (2.9 - 5.9‰) and August (6.4 - 8.9‰) were somewhat higher. All the bottom salinities were the same or higher than the surface salinities for all sampling dates; the bottom salinities ranges were as follows: December (0.6 - 5.9 ‰), April (0.1 - 0.5 ‰), August (1.8 - 3.4 ‰). This year the average temperatures for surface waters were: 3.9°C in December, 12.0°C in April, and 25.2°C in August, compared with the previous year of 4.7, 9.3 and 26.8°C, respectively. The average bottom water temperatures were: 4.0°C in December, 11.7°C in April, and 25.2°C in August.

Species diversity values must be interpreted carefully when analyzing benthic data from the upper Chesapeake Bay. Generally, 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. However, in this area of the Chesapeake, we have observed this year, as in the past monitoring studies, 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 the Bay when 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, 3-9. This year the highest diversity values for the various stations were found mostly in December; eleven stations had their highest values in December and the remaining five stations were highest in August. Highest diversity values occurring in the summer months was postulated in the First Interpretive Report (Pfitzenmeyer *et al.* 1982) and was frequently the case for a majority of the stations during the early years of the study. This year, the winter (December) sampling period had the greatest number of stations exhibiting their peak diversity values, however highest diversity values for some of the stations were also recorded for August (S5, S8, HM16, HM26, G5). The overall highest diversity value (3.253) was recorded in December at S6 while the lowest overall diversity value (0.244) was recorded in April for S1.

The largest number of species recorded for any station was 19 at stations HM12 in December and S4 in August. The lowest number of species, 8, was recorded in April at nearfield station S1.

Three species of clams, *Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli*, were measured to the nearest mm in shell length to determine if any size/growth differences were noticeable between the reference, nearfield, and zinc-enriched stations (see Figures 3-2, 3-3, 3-4). Shell length is indicative of size/growth. The most abundant clam again this year was *R. cuneata*. *Rangia* clams were most abundant during the April sampling period and the majority was observed at this time in the 5mm size class. In December, the largest number of *Rangia* clams was recorded in the 35 and 40 mm size classes. In August, most of the *Rangia* population was in the 35 to 40+ mm size range. Overall, the nearfield and reference stations had somewhat higher numbers of *R. cuneata* than the zinc-enriched stations (see Figure 3-2).

The next most abundant clam during the thirteenth year of studies, as was the case for the seven previous years (sixth through twelfth), was *M. balthica* (see Figure 3-3). *M. balthica* was the most abundant in the 2mm size class in the December and April sampling periods, but in August the highest numbers were found in the 26+ size class. Once again the highest populations densities were recorded in December. Overall, the nearfield stations had higher numbers of this clam than the reference and zinc-enriched stations indicating that this was a good settlement year for the nearfield stations.

M. mitchelli is the least abundant of the three clam species recorded in the vicinity of

HMI (see Figure 3-4). There was a significant increase in the numbers of *M. mitchelli* in the December sampling compared to the previous year; this year there were 192 individuals and last year there were only 58. As has been reported for the previous 6 years, (Duguay *et al.* 1989, 1995; Duguay 1989, 1990, 1992, 1993) there had been a slight shift in relative dominance to greater numbers of *M. balthica* than *M. mitchelli* over the past few years. Like *M. balthica, M. mitchelli* also had the highest numbers at the nearfield stations, which indicates that *M.mitchelli* had a good year at these stations.

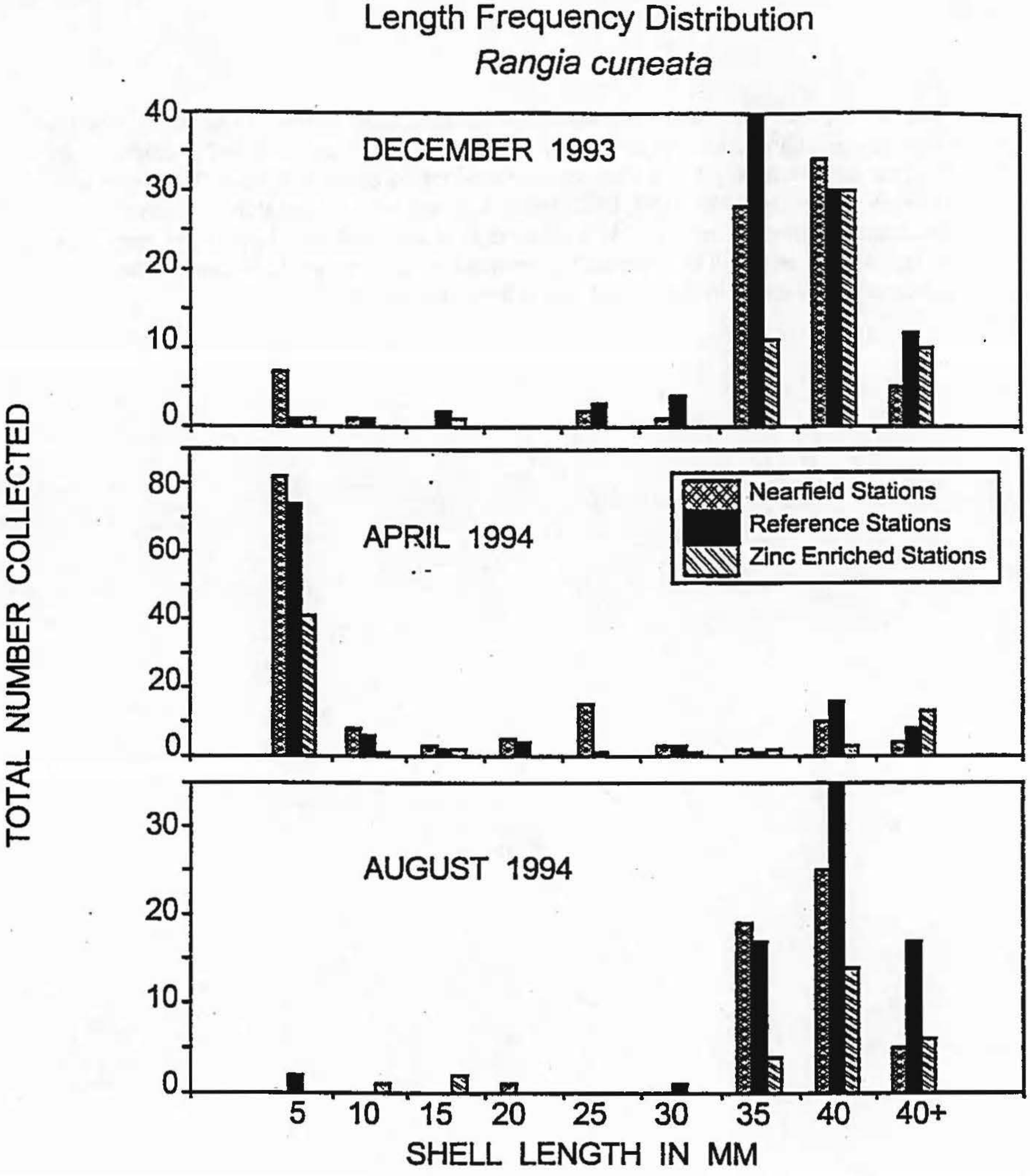

Figure 3-2: Length Frequency Distribution of the Clam, *Rangia cuneata*, during the Thirteenth Year of Benthic Monitoring Studies at HMI

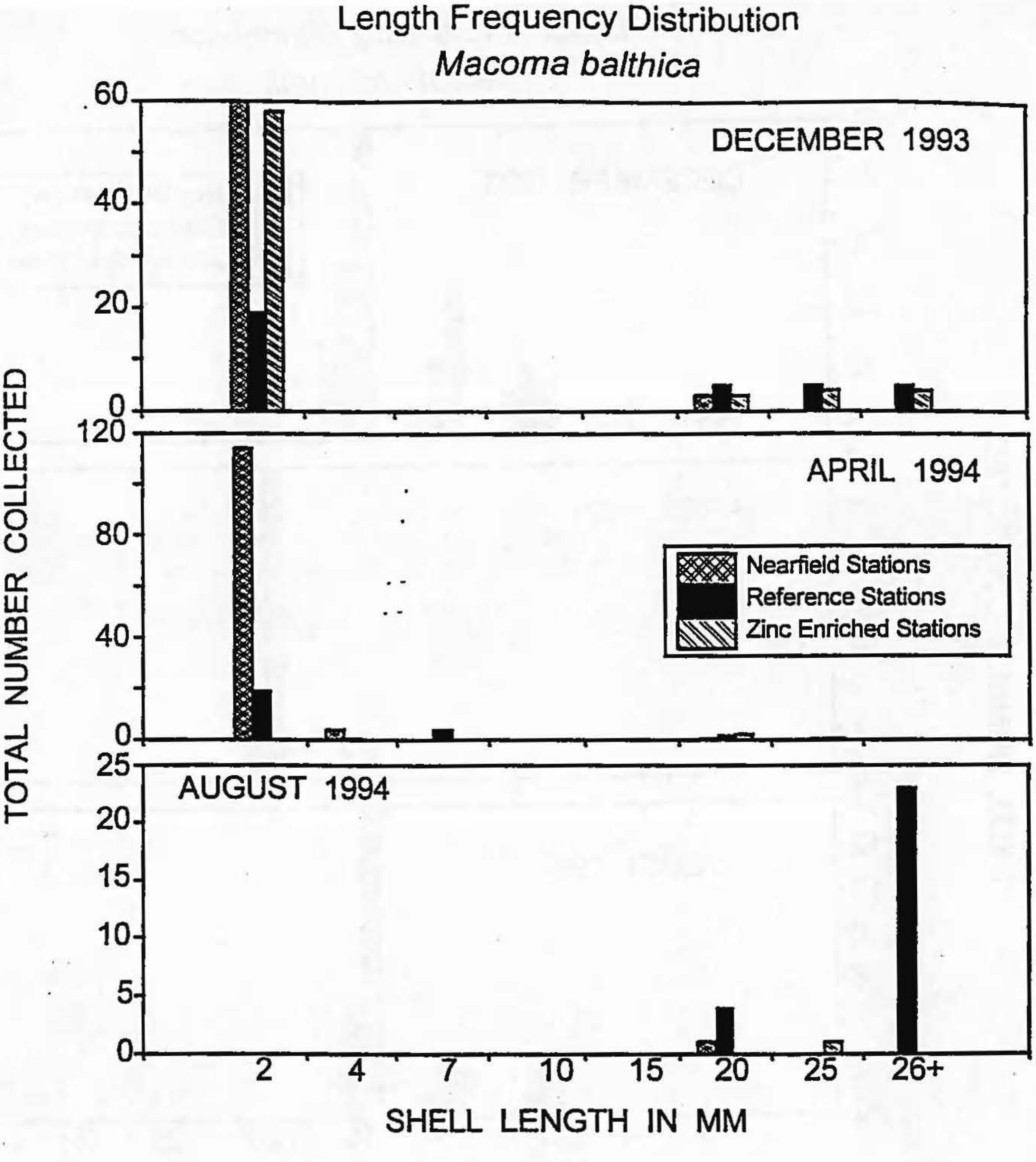

Figure 3-3: Length Frequency Distribution of the Clam, *Macoma balthica*, during the Thirteenth Year of Benthic Monitoring Studies at HMI

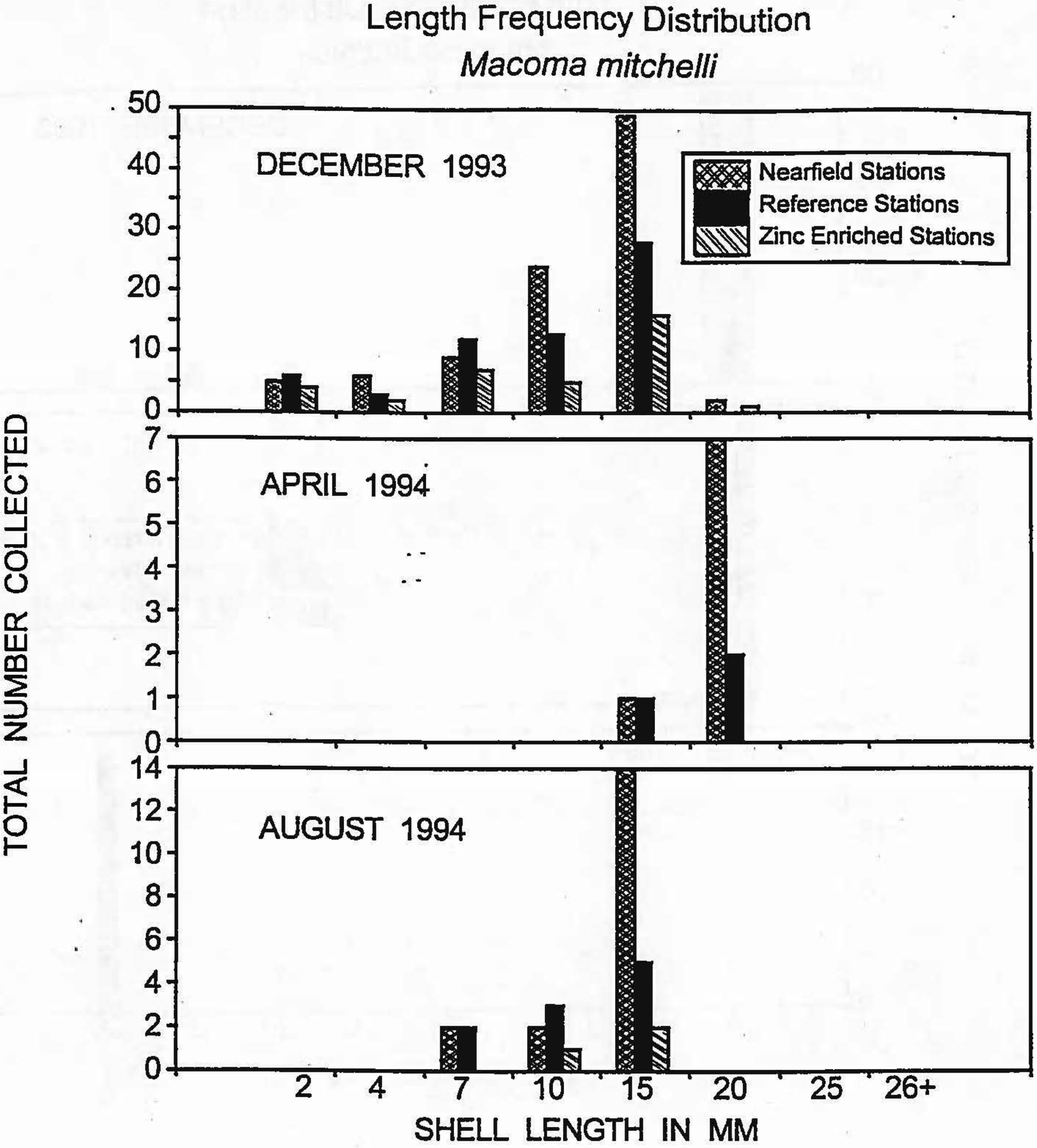

Figure 3-4: Length Frequency Distribution of the Clam, *Macoma mitchelli*, during the Thirteenth Year of Benthic Monitoring Studies at HMI

We again employed cluster analysis 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 the 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 study 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 December 1993 sampling period is presented in Figure 3-5. There is an initial joining of two nearfield stations, S1 and S7 (both shell bottom). The next eight stations to join the initial pair of stations were silt/clay stations, HM12 and G5, (both zinc-enriched stations), HM7, HM16, and HM22, (three reference stations), and S3, S6, and S8, (three nearfield stations). The last two stations to join the dendrogram were HM26 (reference station) and S5 (nearfield station), both silt/clay stations; as usual, station HM26 was one of the last stations to join the dendrogram in December. The clustering of stations observed for December is similar to that observed in previous reports (Duguay *et al.* 1989, 1995; Duguay 1989, 1990, 1992, 1993) and the zinc-enriched stations appear in clusters with both the reference and nearfield stations. All indications are that no anomalous changes were occurring at either the nearfield or zinc-enriched stations in December 1993.

In April 1994 (Figure 3-6), the first two stations to join the dendrogram were HM12 and S3 (a zinc-enriched and a nearfield station respectively); both stations are silt/clay stations. The next five stations to join this pair were HM7, HM22, HM16, S8 and S6 (all silt/clay stations). The last two stations to join the other groupings of stations were S2, a shell station and HM26, a silt/clay station.

The August summer 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 holding the various populations in check. This year there were two main sub-clusters, both composed of a mixture of nearfield, reference, and zinc-enriched stations; both clusters included six stations. One cluster was made up of all silt/clay stations and the other cluster was made up of all the sand and shell stations and two silt/clay stations. The outermost members of the whole cluster consisted of HM7 and HM26. The clusters formed over these three sampling dates, during the 1993-94 sampling period, represented previously observed normal groupings for the reference and nearfield stations with no unusually isolated

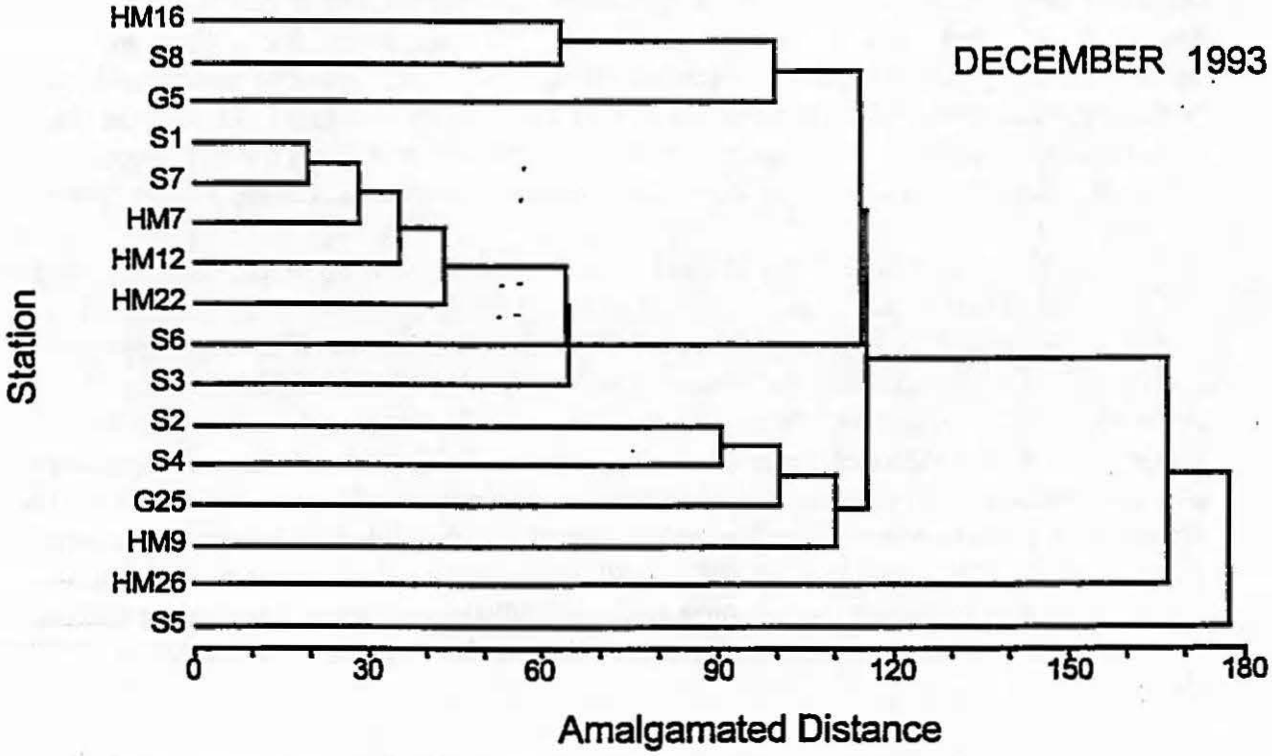

Figure 3-5: Cluster Analysis for all of the HMI Sampling Stations in December 1993 during the Thirteenth Year of Benthic Studies

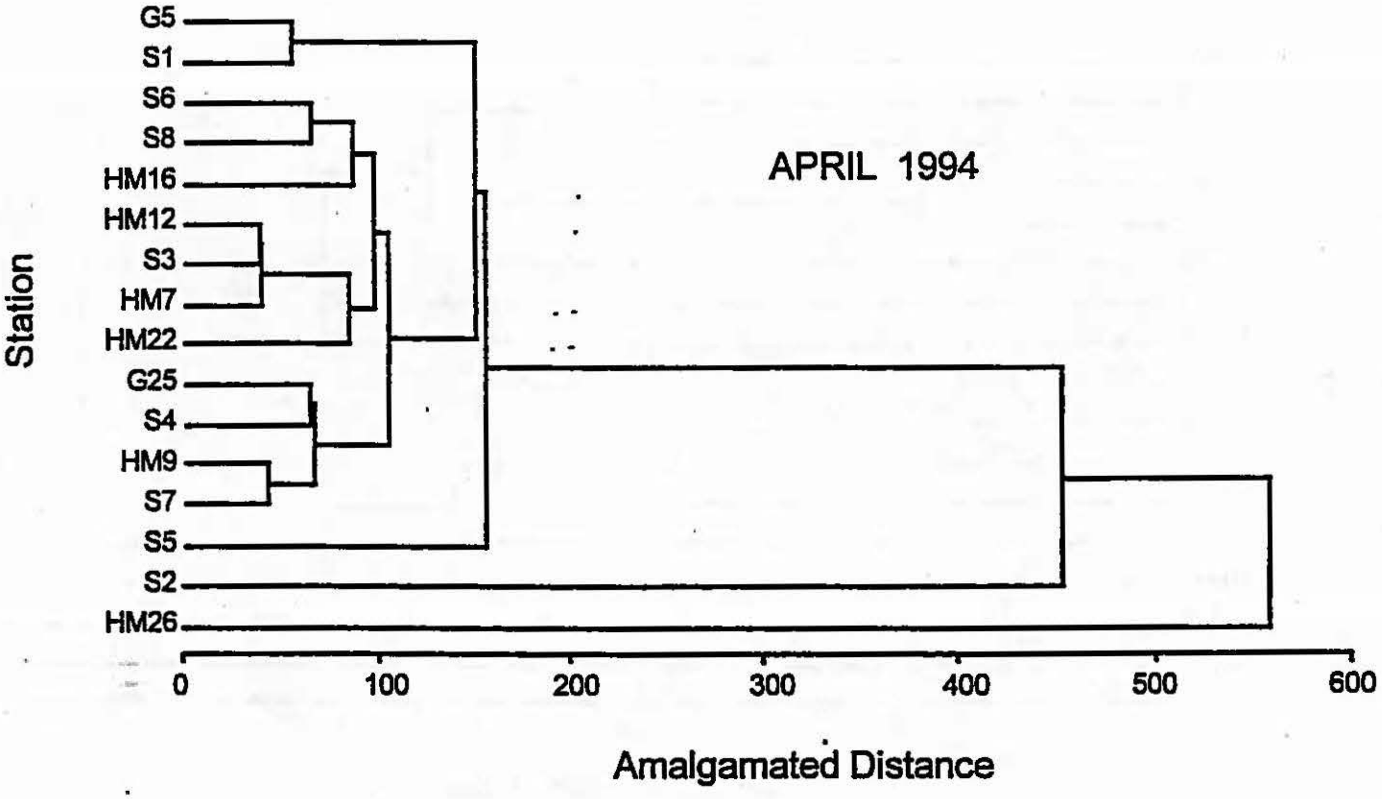

Figure 3-6: Cluster Analysis for all of the HMI Sampling Stations in April 1994 during the Thirteenth Year of Benthic Studies

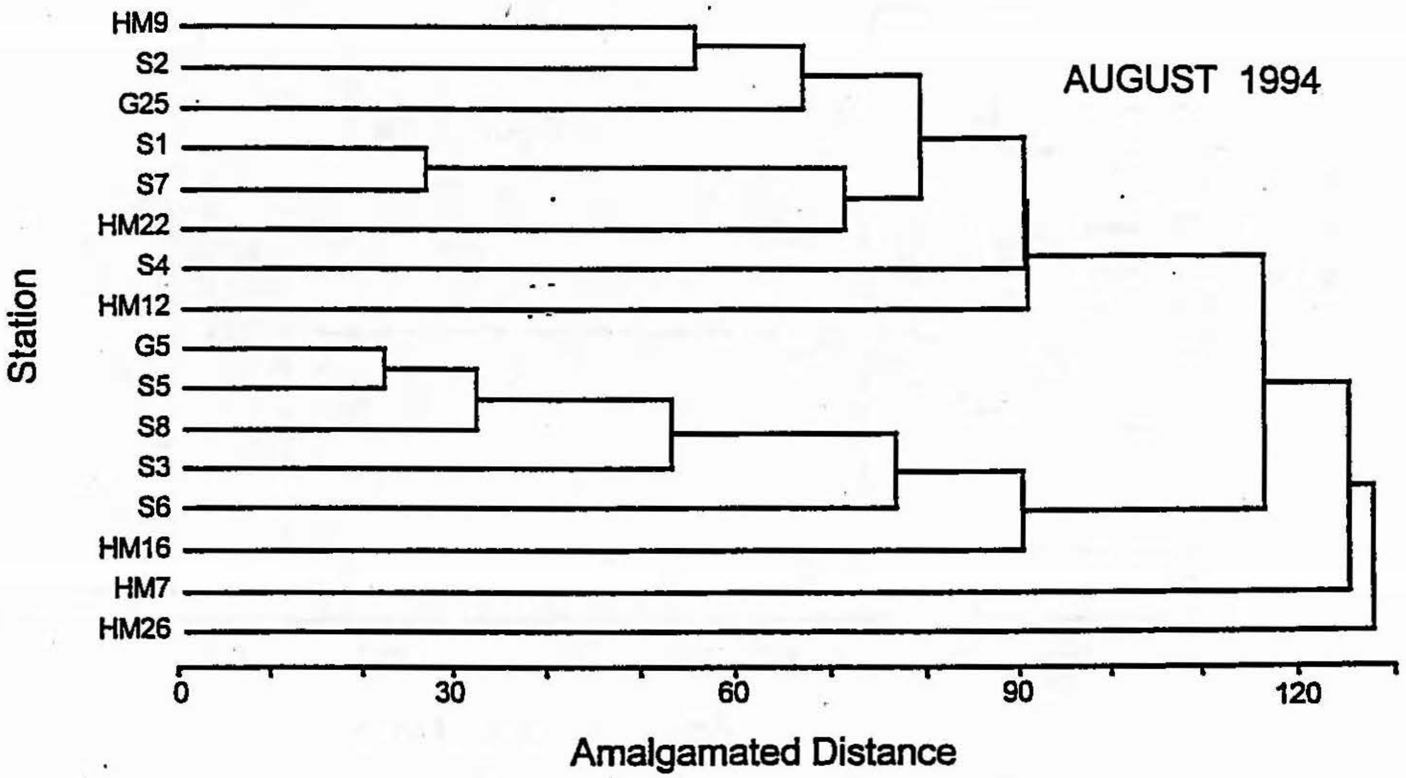

Figure 3-7: Cluster Analysis for all of the HMI Sampling Stations in August 1994 during the Thirteenth Year of Benthic Studies

stations. These clusters were consistent with earlier studies and often grouped stations according to bottom type and general location within the study area. The zinc-enriched stations clustered along with the nearfield and reference stations and indicated no unusually isolated stations in this recently sampled group of stations. If the benthic invertebrates in this region were being affected by some adverse or outside force, such as effluent from HMS, 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 if a significant difference could be detected when population means of benthic invertebrates were compared at the various sampling stations (Ryan 1960; Einot and Gabriel 1975; Welsch 1977). The total number of individuals of each species was transformed (log) 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 December 1993, the stations sorted themselves out into seven subsets (Table 3-10). The first subset was composed of 3 stations; reference station, HM16, G5, a zinc enriched station and HM26, Back River station formed the first subset. All the other subsets in December had a mixture of nearfield, reference, and zinc-enriched stations indicative of no major differences in the population means of these three types of stations.

In April, six subsets were evident (Table 3-11). The first subset was comprised of just one nearfield station, S5. The second subset consisted of two reference stations (HM26, HM9), two zinc-enriched station (G5, G25) and four nearfield station (S1, S2, S4, S7). All four of the other subsets consisted of a mix of nearfield, reference, and zinc enriched.

The analysis of the August 1994 data resulted in the occurrence of five subsets. The five subsets all contained a large number (9-12) of stations composed of a mixture of nearfield, reference, and zinc-enriched stations.

The results of running Friedman's non-parametric test (Elliot 1977) 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 zinc-enriched stations are presented in Table 3-13. The only significant difference ($p<0.05$) was found in August, at the nearfield stations and that was very slight. 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 the facility (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. Thus, a 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, 1993). The amphipod, *Corophium lacustre*, again was one of the most abundant and widespread species (Pfitzenmeyer and Tenore 1987; Duguay *et al.* 1988; Duguay 1989, 1990, 1992, 1993). 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 consisted of the worm, *Nereis*, the barnacles, *Balanus subalbidus* or *B. improvisus* and the bryozoan, *Membranipora*. *Corophium* is a small amphipod crustacean which is extremely opportunistic and constructs tubules out of detritus in which it lives a protected existence on the piling. 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 thirteenth year of sampling and monitoring the benthic populations of organisms in and around the Hart-Miller Island Dredged Material Containment Disposal Facility, the sampling locations, sampling techniques and analysis of the data were again maintained as close as possible to that for the previous years in order to eliminate as much variation as possible. Maintenance of sampling locations, techniques and analysis should render differences due to effects of the containment facility more readily apparent. We have continued to use the special piling scraping device developed in the seventh year program for our qualitative epifaunal samples. We have continued to monitor three of the four infaunal sampling stations which were established over the course of the ninth year in response to the findings of the sedimentary group, from Maryland Geological Survey (MGS), of an observable enrichment of zinc in the sediments of these stations beginning in the eighth monitoring year.

The results presented in this report are similar to those presented in the reports of the last eight years (fifth through twelfth year of monitoring). A total of 30 species (compared with 30, 35, 32, 34, 31, 35, 30 and 26 for the twelfth through the fifth years, respectively) were collected in the quantitative infaunal grab samples. Four species were numerically dominant on soft bottoms; these four dominants are the worms, *S. viridis* and *Tubificoides sp.*, and the crustaceans, *L. plumulosus* and *C. polita*. The oyster shell substrate stations had two numerically dominant species; these were the worm *S. viridis* and the bryozoan, *M. tenuis*. 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 the Bay.

The average number of individuals per square meter (m^2) per station was highest for the nearfield (16,022) stations with slightly decreasing values observed for the zinc-enriched stations (14,653) and reference (13,371) over the three sampling periods.

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

The cluster analysis grouped stations of similar faunal composition in response to sediment type and general location within the HMI study area, as has been the case in previous years. There were no incidences of individual stations being isolated from common groupings during the three sampling periods. The Back River reference (silt/clay) station HM26 was frequently the last station to join the cluster. The Ryan-Einot-Gabriel-Welsch multiple range test resulted in subsets of stations which contained a mix of nearfield, reference, and zinc-enriched stations. Friedman's non-parametric test indicated a slightly significant difference for the nearfield stations in August only. The epifaunal species were quite similar in terms of distribution at the nearfield and reference stations at all three sampling periods. Since sampling this year was again 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 and the hydroid, *Cordylophora* was the second. At present, there does not appear to be any discernible differences in the nearfield, reference and zinc-enriched populations of benthic organisms resulting directly from operations of the Hart-Miller Island Dredged Material Containment Disposal Facility itself.

The Hart-Miller Island Dredged Material Containment Disposal Facility will continue to operate at least until the year 2010. It is strongly recommended that the infaunal and epifaunal populations continue to be sampled at the established locations along with the more recently added zinc-enriched areas during this continued period of active operation of the containment facility to ascertain any possible effects. Station locations and sampling techniques should be maintained as close as possible to the last few years to eliminate sampling variations and permit rapid recognition of effects resulting from the operations of the HMI facility.

TABLES

TABLE 3-1. Relative abundances (#/m2) of three of the most abundant species of benthic organisms which occur at the HMI Reference Stations (HM7, HM9, HM16, HM22, HM26) over the thirteen year study period from August 1981 to August 1994.

	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	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
Scolecolepides viridis														
Range/m2	0-1825	0-286	0-264		11-153	7-1287	13-447	0-657	20-3420	27-9393	7-2313	20-880	60-693	47-8413
Avg./m2	229	121	69	546	92	398	179	178	998	2012	231	231	277	1682
Leptocheirus plumulosus														
Range/m2	0-2960	0-5749	7-6626		20-441	7-1293	7-3312	0-3693	0-2474	67-2820	0-3607	0-2740	0-7580	0-4820
Avg./m2	832	1459	2259	614	272	308	1111	398	327	829	808	1064	1392	953
Rangia cuneata														
Range/m2	0-46	0-99	0-135		0-75	0-273	13-3007	0-2267	0-580	13-12420	0-9000	0-853	73-2487	0-307
Avg./m2	9	9	22	455	27	102	687	359	123	1587	1647	289	484	124

TABLE 3-2: Dominant benthic organisms collected from each bottom type during the Thirteenth Year of Benthic Studies at HMI.

STATION	December 1993	April 1994	August 1994
NEARFIELD SOFT BOTTOM (S3,4,5,6,8)	Leptocheirus plumulosus	Scolecolepides viridis	Leptocheirus plumulosus
	Tubificoides sp.	Leptocheirus plumulosus	Scolecolepides viridis
	Nereis succinea	Tubificoides sp.	Cyathura polita
NEARFIELD SHELL BOTTOM (S2,7)	Membranipora tenuis	Scolecolepides viridis	Scolecolepides viridis
	Nereis succinea	Membranipora tenuis	Cyathura polita
	Rangia cuneata	Corophium lacustre	Membranipora tenuis
REFERENCE SOFT BOTTOM (HM7,16,22)	Leptocheirus plumulosus	Scolecolepides viridis	Leptocheirus plumulosus
	Cyathura polita	Leptocheirus plumulosus	Scolecolepides viridis
	Macoma mitchelli	Tubificoides sp.	Hydrobia sp.
REFERENCE SHELL BOTTOM (HM9)	Membranipora tenuis	Scolecolepides viridis	Scolecolepides viridis
	Nereis succinea	Membranipora tenuis	Membranipora tenuis
	Scolecolepides viridis	Rangia cuneata	Cyathura polita
BACK RIVER REFERENCE SOFT BOTTOM (HM26)	Tubificoides sp.	Tubificoides sp.	Leptocheirus plumulosus
	Scolecolepides viridis	Scolecolepides viridis	Chironomid sp.
	Leptocheirus plumulosus	Leptocheirus plumulosus	Scolecolepides viridis
ZINC ENRICHED SOFT BOTTOM (G5,25,HM12)	Leptocheirus plumulosus	Scolecolepides viridis	Scolecolepides viridis
	Membranipora tenuis	Leptocheirus plumulosus	Leptocheirus plumulosus
	Nereis succinea	Tubificoides sp.	Cyathura polita

TABLE 3-3: Number of benthic organisms per m squared (m2) found at the Reference Stations during the Thirteenth Year (December 1993 - August 1994) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	HM7			HM9			HM16			HM22			HM26			TOTALS
			Dec	Apr	Aug	Dec	Apr	Aug	Dec	Apr	Aug	Dec	Apr	Aug	Dec	Apr	Aug	
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2		7	7	13	13		73	47	47	20	33	20	40	40	7	367
ANNELIDA (worms)	Heteromastus filiformis	3	60	33	7	40	73	73	200	113	27	40	40	40	40	7	20	813
	Nereis succinea	5	7			440	7	7	13			67	7		60	13		621
	Eteone heteropoda	8							53						133			186
	Polydora ligni	9	7															7
	Scolecolepides viridis	10	53	1427	727	380	8413	2613	47	1687	740	167	2300	1240	707	4113	620	25234
	Streblospio benedicti	11	20			27		7	7		7	20			33		120	241
	Limnodrilus hoffmeisteri	13																0
	Tubificoides sp.	14	33	107	40	40	107	267	107	487	847	40	87	20	1833	8347	307	12669
	Capitella capitata	15																0
MOLLUSCA (mollusks)	Ischadium recurvus	16																0
	Congeria leucophaeta	17						7									7	14
	Macoma balthica	19	7			7			113	20	27			153	100	160		587
	Macoma mitchelli	20	80	7		13	7		193	7	13	33			100	47	7	507
	Rangia cuneata	21	27	60	227	307	227	200	13		133	227	180	80	33	13	127	1854
	Mya arenaria	22																0
	Hydrobia sp.	23			1287						67			40				1394
	Doridella obscura	25																0
ARTHROPODA (crustaceans)	Balanus improvisus	27																0
	Balanus subalbidus	28																0
	Leucon americanus	29																0
	Cyathura polita	30	67	73	327	133	127	320	347	287	393	80	93	233	80	80	233	2873
	Cassidinidea lunifrons	31																0
	Edotea triloba	33			13	13	7	20		7			7	13	40	7	20	147
	Gammarus palustris	35																0
	Leptocheirus plumulosus	36	447	500	1187		53	40	4820	3440	1307	67	133	347	520	480	960	14301
	Corophium lacustre	37	7	40		13	107	7	40	27			20		7	13		281
	Gammarus daiberi	38																0
	Gammerus tigrinus	39											7	20			20	47
	Melita nitida	40	27		127				40	7	140		27	13	20		33	434
	Chirodotea almyra	41			47					13			7				27	94
	Monoculodes edwardsi	42	20	13	33	27	13	13		13	7	20	7	13		7		186
	Chironomid sp.	43	27	73	187			13	7		100	40	7	67	100	47	927	1595
	Rithropanopeus harrisi	44				47	73	27										147
COELENTERA (hydroids)	Garveia franciscana	47																0
PLATYHELMIA (flatworms)	Stylochus ellipticus	48																0
BRYOZOA (bryozoans)	Membrania tenuis	49	7		7	607	840	773		13								2247
	Victorella pavida	50	7															7
	TOTAL NUMBERS		903	2340	4223	2107	10067	4387	6073	6168	3855	821	2955	2299	3846	13374	3435	66853

TABLE 3-4A: Number of benthic organisms per m squared (m2) found at the Nearfield Stations during the Thirteenth Year (December 1993-August 1994) of Benthic Studies at HMI.

				S1			S2			S3			S4	
PHYLUM	SPECIES NAME	#	Dec	Apr	Aug	Dec	Apr	Aug	Dec	Apr	Aug	Dec	Apr	Aug
RHYNCHOCOELA (ribbon worms	Micrura leidyi	2							60	80	13	27	13	7
ANNELIDA (worms)	Heteromastus filiformis	3			7	13	13	133	60	93	20	40	33	13
	Nereis succinea	5	7			340	100	13	33	7		1053	60	40
	Eteone heteropoda	8							20			7		
	Polydora ligni	9				20		20	7			20		20
	Scolecolepides viridis	10	27	9453	940	27	9347	2180	673	3413	1273	67	6493	1120
	Streblospio benedicti	11				20		7	13		7	7		7
	Limnodrilus hoffmeisteri	13												
	Tubificoides sp.	14		7		227	913	220		280	33	127	107	247
	Capitella capitata	15												
MOLLUSCA (mollusks)	Ischadium recurvus	16												
	Congeria leucophaeta	17						27			7			20
	Macoma balthica	19							80	67				
	Macoma mitchelli	20	7						167	27	7			
	Rangia cuneata	21	7	7	7	220		207	93	27	260	127	13	93
	Mya arenaria	22												
	Hydrobia sp.	23			7						167			
	Doridella obscura	25												
ARTHROPODA (crustaceans)	Balanus improvisus	27				140	320					133		47
	Balanus subalbidus	28					100							7
	Leucon americanus	29												
	Cyathura polita	30	27	27	147	27	53	300	113	200	480	127	200	427
	Cassidinidea lunifrons	31	20			13	27							
	Edotea triloba	33						20	7	13	60	7		7
	Gammarus palustris	35												
	Leptocheirus plumulosus	36	27	113	27	7	27	113	333	667	1553	7	513	180
	Corophium lacustre	37	13	7	7	193	1627	80	133	40		313	200	40
	Gammarus daiberi	38												
	Gammarus tigrinus	39									13			
	Melita nitida	40				13	33	7			73	27	20	7
	Chirodotea almyra	41	20	27	20			20			7			
	Monoculodes edwardsi	42	33	87	47			7		53	13	7	20	
	Chironomid sp.	43					20		47		207		7	7
	Rithropanopeus harrisi	44				20	140	47				140	7	193
	Gammarus mucronatus	45												
COELENTERA (hydroids)	Garvela franciscana	47												
PLATYHELMIA (flatworms)	Stylochus ellipticus	48				7								
BRYOZOA (bryozoans)	Membranipora tenuis	49				907	2813	320			7	787	333	193
	Victorella pavida	50												
	TOTAL NUMBERS		188	9728	1209	2194	15533	3721	1839	4967	4200	3023	8019	2675

TABLE 3-4B: Number of benthic organisms per m squared (m2) found at the Nearfield Stations during the Thirteenth Year (December 1993-August 1994) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	S5 Dec	S5 Apr	S5 Aug	S6 Dec	S6 Apr	S6 Aug	S7 Dec	S7 Apr	S7 Aug	S8 Dec	S8 Apr	S8 Aug	TOTALS ALL STATIONS ALL DATES
RHYNCHOCOELA (ribbon worms	Micrura leidyi	2	60	47		27	53	40		27		13	53	27	547
ANNELIDA (worms)	Heteromastus filiformis	3	27	13		93	60	27		67	100	20	60	27	919
	Nereis succinea	5		27		20	13			20			7		1740
	Eteone heteropoda	8	7			160						7			201
	Polydora ligni	9													87
	Scolecolepides viridis	10		26820	387	200	1773	527	27	12027	1427	140	1020	747	80108
	Streblospio benedicti	11				100		13						7	181
	Limnodrilus hoffmeisteri	13													0
	Tubificoides sp.	14	1967	847		53	407	80		133	7	13	200	213	6081
	Capitella capitata	15													0
MOLLUSCA (mollusks)	Ischadium recurvus	16													0
	Congeria leucophaeta	17						7			7				68
	Macoma balthica	19		7		193	293	7				147	227		1021
	Macoma mitchelli	20	207			133	53	33	7			113	40	13	807
	Rangia cuneata	21	7		7	7	7	233	33	280	7	20	7	67	1736
	Mya arenaria	22				7									7
	Hydrobia sp.	23			87				7		40			60	368
	Doridella obscura	25													0
ARTHROPODA (crustaceans)	Balanus improvisus	27													640
	Balanus subalbidus	28													107
	Leucon americanus	29													0
	Cyathura polita	30	100	173	260	120	100	293	33		173	187	127	340	4034
	Cassidinidea lunifrons	31													60
	Edotea triloba	33				20	7	60				7			208
	Gammarus palustris	35													0
	Leptocheirus plumulosus	36	160	587	980	607	1413	987	93	133	200	2653	1967	1927	15274
	Corophium lacustre	37		1240	13	27	27	20		160		93	53		4286
	Gammarus daiberi	38													0
	Gammarus tigrinus	39		47	7		7								74
	Melita nitida	40			80					13	13	13		53	352
	Chirodotea almyra	41				7	7	67	7	7	33				222
	Monoculodes edwardsi	42	7	100	7		20		7	13	40	7	33	20	521
	Chironomid sp.	43	27		127	67	13	153				13	60	160	908
	Rithropanopeus harrisi	44		7						27					581
	Gammarus mucronatus	45													0
COELENTERA (hydroids)	Garvela franciscana	47													0
PLATYHELMIA (flatworms)	Stylochus ellipticus	48													7
BRYOZOA (bryozoans)	Membranipora tenuis	49		320		7			7	1313	13		7		7027
	Victorella pavida	50													0
	TOTAL NUMBERS		2569	30235	1955	1848	4253	2547	221	14220	2060	3446	3861	3661	128172

TABLE 3-5: Number of benthic organisms per m squared (m2) found at the Zinc Enriched Stations during the Thirteenth Year (December 1993-August 1994) of Benthic Studies at HMI.

PHYLUM	SPECIES NAME	#	G5 Dec	G5 Apr	G5 Aug	G25 Dec	G25 Apr	G25 Aug	HM12 Dec	HM12 Apr	HM12 Aug	TOTALS
RHYNCHOCOELA (ribbon worms)	Micrura leidyi	2	67	7	40	60	40	33	40	93	67	333
ANNELIDA (worms)	Heteromastus filiformis	3	47	40	7	80	40	33	80	33	40	306
	Nereis succinea	5	40	20		580	53	13	247	13		906
	Eteone heteropoda	8	40						13			53
	Polydora ligni	9						7			20	27
	Scolecolepides viridis	10	120	11540	887	100	7047	1813	160	2833	853	25353
	Streblospio benedicti	11	7		7			20	13		7	54
	Limnodrilus hoffmeisteri	13										0
	Tubificoides sp.	14	527	93	80	13	140	107	73	267	133	1433
	Capitella capitata	15										0
MOLLUSCA (mollusks)	Ischadium recurvus	16										0
	Congeria leucophaeta	17						7				7
	Littoridinops sp.	18										0
	Macoma balthica	19	393		7		7		67	13		487
	Macoma mitchelli	20	127	13		47			60	7		254
	Rangia cuneata	21	33	20	47	47	80	120	273	80	253	953
	Mya arenaria	22							7			7
	Hydrobia sp.	23			147							147
	Doridella obscura	25										0
ARTHROPODA (crustaceans)	Balanus improvisus	27				53	7	13			7	80
	Balanus subalbidus	28										0
	Leucon americanus	29										0
	Cyathura polita	30	60	300	373	140	127	533	160	180	313	2186
	Cassidinidea lunifrons	31										0
	Edotea triloba	33							53	53	7	113
	Gammarus palustris	35										0
	Leptocheirus plumulosus	36	3033	113	1767	13	207	20	853	887	340	7233
	Corophium lacustre	37	100	53	13	53	27	7	7	27	20	307
	Gammarus daiberi	38										0
	Gammerus tigrinus	39								7	7	14
	Melita nitida	40	7		107	20		7	7		20	168
	Chirodotea almyra	41			7					20		27
	Monoculodes edwardsi	42	7	107		67	40	7	27	40	27	322
	Chironomid sp.	43	20		200			7		7	13	247
	Rithropanopeus harrisi	44				60	7	160	7		27	261
COELENTERA (hydroids)	Garvela franciscana	47										0
PLATYHELMIA (flatworms)	Stylochus ellipticus	48										0
BRYOZOA (bryozoans)	Membranipora tenuis	49		7		1067	440	853	13	20	13	2413
	Victorella pavida	50										0
	TOTAL NUMBERS		4628	12313	3689	2400	8262	3760	2160	4580	2167	43959

TABLE 3-6: Salinity (in parts/thousand-0/00), temperature (in degrees centigrade-oC), and depth (in feet-ft.) for the benthic sampling stations on the 3 collection dates during the Thirteenth Year of Benthic studies at HMI.

CBL STA. ID	STATE STA. #	DECEMBER 93 DEPTH	TEMP.	SAL.	APRIL 94 DEPTH	TEMP.	SAL.	AUGUST 94 DEPTH	TEMP.	SAL.
R2	X1F4813	0	3.85	2.2	0	13.2	0.4	0	25.78	1.8
R2	X1F4813	10	3.96	2.2	**NR	NR	NR	11	25.52	1.8
R3	X1F4514	0	4.49	2.4	NR	NR	NR	NR	NR	NR
R3	X1F4514	16	4.58	2.5	NR	NR	NR	NR	NR	NR
R4	XIF4518	0	3.46	2.6	NR	NR	NR	NR	NR	NR
R4	XIF4518	10	3.4	2.6	NR	NR	NR	NR	NR	NR
R5	XIF3638	0	2.8	2.4	0	13.16	0.3	0	26.46	2.2
R5	XIF3638	6	2.81	2.4	NR	NR	NR	NR	NR	NR
S1	XIF5710	0	3.69	1.7	0	12.65	0.3	0	25.26	1.9
S1	XIF5710	7	3.59	1.7	7	12.62	0.3	6	25.23	1.9
S2	XIF5406	0	3.24	1.6	0	12.32	0.2	0	25.16	1.9
S2	XIF5406	12	3.23	1.6	12	12.17	0.2	12	24.91	1.9
S3	XIF4811	0	3.93	1.4	0	12.53	0.2	0	24.7	2.7
S3	XIF4811	19	3.62	2	16	12.35	0.4	16	25.19	2.8
S4	XIF4715	0	3.89	1.8	0	11.97	0.3	0	25.59	2.4
S4	XIF4715	16	3.78	2.1	15	11.86	0.3	14	25.17	2.8
S5	XIF4420	0	3.95	2	0	11.08	0	0	23.63	2.7
S5	XIF4420	23	4.67	2.6	19	11.02	0.1	21	25.54	3.2
S6	XIF4327	0	4.54	2.3	0	11.83	0.3	0	25.34	2.6
S6	XIF4327	16	4.55	2.4	12	11.69	0.3	11	25.08	2.8
S7	XIG5405	0	3.15	1.8	0	12.3	0.2	0	25.31	1.9
S7	XIG5405	15	3.17	1.9	15	12.24	0.2	13	25.18	2.7
S8	XIF4124	0	4.37	2	0	11.39	0.1	0	25.19	2.4
S8	XIF4124	18	4.78	3	15	11.51	0.2	15	25.49	3.1
HM7	XIF6388	0	3.77	1.2	0	13.49	0.2	0	25.27	1.9
HM7	XIF6388	13	3.62	1.3	11	12.19	0.2	10	24.87	1.9
HM9	XIF5297	0	4.58	0.8	0	11.9	0.1	0	25.47	2.3
HM9	XIF5297	18	3.75	1.8	17	11.77	0.1	16	25.19	2.6
HM12	XIF5805	0	4.8	0.5	0	9.75	0.1	0	25.62	3.1
HM12	XIF5805	19	6	4.4	17	9.67	0.1	16	25.07	3.1
HM16	XIF3325	0	4.9	1.8	0	10.53	0.1	0	25.93	2.9
HM16	XIF3325	25	6.2	5.9	19	10.37	0.1	16	25.23	3.4
HM22	XIG7689	0	3.31	0.6	0	11.77	0.1	0	25.07	1.9
HM22	XIG7689	13	3.23	0.6	12	11	0.1	12	24.93	2
HM26	XIF5145	0	3.16	2.1	0	14	0.5	0	25.01	2.3
HM26	XIF5145	18	3.7	3.1	15	13.43	0.5	13	24.91	2.3
G5	XIF4221	0	4.24	2	0	10.82	0.1	0	24.97	2.7
G5	XIF4221	19	4.72	3.1	15	11	0.1	17	25.51	3.2
G25	XIF4405	0	3.75	1.5	0	11.83	0.2	0	24.79	2.8
G25	XIF4405	18	3.66	1.8	19	11.67	0.2	17	25.47	3.2
G84	XIG3570	0	4.86	1.3	**NS	NS	NS	NS	NS	NS
G84	XIG3570	20	6.76	7	NS	NS	NS	NS	NS	NS

*NS= NOT SAMPLED **NR= NOT RECORDED

TABLE 3-7. Number of species and the total number of individuals collected in three grab samples (0.05m2 each) at the infaunal stations for DECEMBER 1993. Bottom substrate, species diversity (H') and dominance factor (S.I.) are also shown. Data for the Thirteenth Year of Benthic Studies at HMI.

STATION	SUBSTRATE	NO. SPECIES	NO. INDIVIDUALS	SPECIES DIVERSITY (H')	DOMINAN FACTOR S.I.
NEARFIELD					
S1	Sand	10	28	3.125	0.125
S2	Shell	16	329	2.702	0.228
S3	Silt/Clay	15	276	2.971	0.192
S4	Silt/Clay	18	453	2.824	0.211
S5	Silt/Clay	10	385	1.349	0.600
S6	Silt/Clay	18	277	3.253	0.156
S7	Shell	9	33	2.483	0.245
S8	Silt/Clay	15	517	1.465	0.601
REFERENCE					
HM 7	Silt/Clay	17	135	2.778	0.273
HM 9	Shell	15	316	2.801	0.186
HM16	Silt/Clay	15	911	1.377	0.636
HM22	Silt/Clay	12	123	3.114	0.151
BACK RIVER REFERENCE					
HM26	Silt/Clay	16	577	2.517	0.284
ZINC ENRICHED					
G5	Silt/Clay	16	694	1.938	0.453
G25	Silt/Clay	15	360	2.625	0.266
HM12	Silt/Clay	19	327	3.039	0.198

TABLE3-8. Number of species and the total number of individuals collected in three grab samples (0.05m2 each) at the infaunal stations for APRIL 1994. Bottom substrate, species diversity (H') and dominance factor (S.I.) are also shown. Data for the Thirteenth year of Benthic Studies at HMI.

STATION	SUBSTRATE	NO. SPECIES	NO. INDIVIDUALS	SPECIES DIVERSITY (H')	DOMINAN FACTOR S.I.
NEARFIELD					
S1	Sand	8	1459	0.244	0.945
S2	Shell	14	2330	1.839	0.410
S3	Silt/Clay	13	745	1.711	0.496
S4	Silt/Clay	14	1203	1.216	0.663
S5	Silt/Clay	13	4535	0.785	0.790
S6	Silt/Clay	16	638	2.209	0.299
S7	Shell	13	2133	0.940	0.725
S8	Silt/Clay	14	579	2.159	0.338
REFERENCE					
HM 7	Silt/Clay	11	351	1.841	0.423
HM 9	Shell	14	1510	1.047	0.706
HM16	Silt/Clay	14	925	1.786	0.395
HM22	Silt/Clay	15	443	1.422	0.615
BACK RIVER REFERENCE					
HM26	Silt/Clay	14	2006	1.369	0.486
ZINC ENRICHED					
G5	Silt/Clay	12	1847	0.507	0.879
G25	Silt/Clay	14	1239	1.021	0.732
HM12	Silt/Clay	17	687	1.914	0.426

TABLE 3-9. Number of species and the total number of individuals collected in three grab samples (0.05m2 each) at the infaunal stations for AUGUST 1994. Bottom substrate, species diversity (H') and dominance factor (S.I.) are also shown. Data for the Thirteenth Year of Benthic Studies at HMI.

STATION	SUBSTRATE	NO. SPECIES	NO. INDIVIDUALS	SPECIES DIVERSITY (H')	DOMINAN FACTOR S.I.
NEARFIELD					
S1	Sand	9	181	1.217	0.624
S2	Shell	17	558	2.297	0.367
S3	Silt/Clay	18	630	2.492	0.250
S4	Silt/Clay	19	401	2.801	0.227
S5	Silt/Clay	10	293	2.126	0.317
S6	Silt/Clay	15	382	2.726	0.221
S7	Shell	12	309	1.698	0.500
S8	Silt/Clay	13	549	2.192	0.334
REFERENCE					
HM 7	Silt/Clay	14	633	2.598	0.214
HM 9	Shell	15	658	1.959	0.398
HM16	Silt/Clay	14	578	2.619	0.214
HM22	Silt/Clay	14	345	2.315	0.331
BACK RIVER REFERENCE					
HM26	Silt/Clay	15	515	2.691	0.199
ZINC ENRICHED					
G5	Silt/Clay	14	553	2.264	0.304
G25	Silt/Clay	18	564	2.247	0.308
HM12	Silt/Clay	18	325	2.759	0.220

TABLE 3-10. The Ryan-Einot-Gabriel-Welsch Multiple F test of significance among mean number of individuals per station for stations sampled in December 1993. Subsets show groupings of stations different at ($P<0.05$). Stations in a separate vertical row and column are significantly different from others. Thirteenth Year of Benthic Studies at HMI.

DECEMBER 1993

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

ANALYSIS OF VARIANCE

SOURCE	D.F	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB.
BETWEEN GROUPS	15	279341	18623	10.3	0.0001
WITHIN GROUPS	32	57640	1801		
TOTAL	47	336981			

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 Subsets show groupings of different stations (P<0.05). Stations in a separate vertical row and column are significantly different from others. Thirteenth Year of Benthic Studies at HMI.

APRIL 1994

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

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB.
BETWEEN GROUPS	15	5436139	362409	13.02	0.0001
WITHIN GROUPS	32	890503	27828		
TOTAL	47	6326642			

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 1994. Subsets show groupings of stations different at ($P<0.05$). Stations in a separate vertical row and column are significantly different from others. Thirteenth Year of Benthic Studies at HMI.

AUGUST 1994

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

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	15	106902	7127	4.13	0.0004
WITHIN GROUPS	32	55214	1725		
TOTAL	47	162116			

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 the Thirteenth Year 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, G84, HM12.)

	SOURCE	D.F.	CHI-SQUARE	CHI-SQUARE (0.05)
DEC 1993				
	NEARFIELD	4	7.20	9.49
	REFERENCE	2	0.95	5.99
	ZINC ENRICHED	2	0.73	5.99
	NEARFIELD & REFERENCE	7	10.68	14.07
	ZINC ENRICHED & REFERENCE	5	4.69	11.07
APR 1994				
	NEARFIELD	4	0.18	9.49
	REFERENCE	2	1.77	5.99
	ZINC ENRICHED	2	0.55	5.99
	NEARFIELD & REFERENCE	7	8.35	14.07
	ZINC ENRICHED & REFERENCE	5	6.61	11.07
AUG 1994				
	NEARFIELD	4	9.58 *	9.49
	REFERENCE	2	1.14	5.99
	ZINC ENRICHED	2	0.32	5.99
	NEARFIELD & REFERENCE	7	10.86	14.07
	ZINC ENRICHED & REFERENCE	5	2.53	11.07

*SIGNIFICANT DIFFERENCE
AT THE 0.05 LEVEL.

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

	STATIONS R2-R4 DEPTH (M)		REFERENCE STATION R5 DEPTH (M)	
DEC 1993	1.0 m	2-3 m	1.0 m	2-3 m
	Corophium	Corophium	Corophium	Corophium
	Polydora	Nereis	Cordylophora	Cordylophora
	Cordylophora	Membranipora	Polydora	Polydora
	Nereis	Polydora	B. improvisus	Membranipora
	B. improvisus	B. subalbidus	Membranipora	Nereis
	B. subalbidus		Victorella	
APR 1994	1.0 m	2-3 m	1.0 m	2-3 m
	Corophium	Nereis	Corophium	Nereis
	Rithropanopeus	B. improvisus	G. tigrinus	Cordylophora
	Cordylophora	Membranipora	Cordylophora	Membranipora
	B. improvisus	G. tigrinus	Membranipora	Rithropanopeu
	G. tigrinus	Cordylophora		Chironomid
		Rithropanopeus		
AUG 1994	1.0 m	2-3 m	1.0 m	2-3 m
	Corophium	Corophium	Corophium	Corophium
	Cordylophora	Cordylophora	B. subalbidus	B. improvisus
	B. improvisus	B. subalbidus	Cordylophora	B. subalbidus
	B. subalbidus	Congeria	Victorella	Cordylophora
	Congeria	B. improvisus	B. improvisus	Victorella
	Rithropanopeus			

CHAPTER 4. PROJECT IV: ANALYTICAL SERVICES

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ABSTRACT

Thirteen composite tissue samples of either *Macoma* sp., *Rangia cuneata*, or *Cyathura polita* from eight stations were analyzed for eight metals and a suite of organic analytes in the Thirteenth Year. Trace metal detection levels were greatly improved this year which lead to detectable burdens of nearly all analytes in all species, save nickel and cadmium in some *Cyathura* samples. Analytical problems with organic analytes coupled with high, yet somewhat improved, detection limits lead to no detectable organics in the tissues nor in the ten sediment samples except for phthalate esters. Due to problems with laboratory contamination, these reported phthalate data are unreliable.

This was the first year in which arsenic had been monitored in tissues since the baseline studies and it was detected at appreciable levels in all samples. Burdens of arsenic, cadmium and zinc in both *Macoma* and *Cyathura* and nickel in *Macoma* have increased dramatically since the baseline monitoring year of 1983, while other trace metal levels in these species have remained similar or have decreased since the Second Year. While no *Rangia* were monitored in baseline studies with which to compare current trace metal levels, this species' burdens of arsenic, cadmium and nickel are appreciably higher than levels found in the filter feeding bivalve, *Mya arenaria*, from the upper Chesapeake Bay. Last year, the highest levels of zinc enrichment ever recorded were observed in HMI sediments, while this year levels were more typical of prior enrichment. Assuming that other metal levels correlate with zinc, in general, it appears that the deposit feeder, *Macoma* and the omnivore/carnivore, *Cyathura*, have retained a greater metal burden memory of last year's elevated metal levels, whereas in the suspension-feeding *Rangia* metal burdens responded more rapidly to temporal changes in metal loadings to the environment.

The trends in patterns of zinc enrichment in the sediments around HMI and levels of metals in tissues suggest that the reference stations are often located in areas under the influence of HMI effluent discharge and that the current zinc enriched benthic stations are no longer in the areas where zinc is enriched in the sediments. If the same stations were monitored in both the benthic and sedimentary projects a more conclusive statement could be made. There are presently no benthic stations located in areas most affected by HMI effluent discharge. Given these observations, it is of little surprise that differences in tissue metal distributions according to station type could not be discerned this year, as in previous monitoring years.

INTRODUCTION

A long-term monitoring program has been conducted since 1981 in order to examine the possible impacts of the construction and operation of the Hart and Miller Islands Dredged Material Contained 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 levels of nutrients in the water column as well as 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. The Chesapeake Biological Laboratory of the University of Maryland, Center for Environmental and Estuarine Studies, is responsible for the collection and characterization of the biota samples under Project III: Benthic Studies. This interpretive report covers trace metal and organic contaminants in biological samples and organic contaminants in selected sediment samples. 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 program, with the first three years (pre-operation 1981-1983) used as a baseline with which to compare subsequent operational years. No chemical analyses were performed, however, 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 Fall (August) and included both fish and benthic invertebrate tissue contaminant determinations. Beginning in the Eleventh Year (1992) and continuing to the present (Thirteenth Year), data for contaminant burdens in biota were collected only in the Spring and were restricted to three species of benthic invertebrates.

METHODS

Sampling and Chemical Analyses

Eight benthic stations were sampled for chemical analysis of biota. These represent a subset of the overall 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 (Ninth Year) in order to examine the zinc enrichment issue described under the sedimentary environment report (i.e. zinc was enriched in the sediments at these stations beginning in the Eighth Year relative to the baseline years). Stations S1, S4, S6 and S7 are designated as nearfield stations and are immediately adjacent to the facility. Stations HM16 and HM22 are designated as reference stations.

According to the chain of custody sheets, fourteen composite samples of the benthic bivalves, *Macoma sp.* and *Rangia cuneata.*, and the benthic isopod, *Cyathura polita* were collected by the Chesapeake Biological Laboratory on April 11, 1994, in conjunction with the Spring benthic population sampling cruise, using a 0.05 m^2 Ponar grab. Biota samples were enumerated, identified to genus or species, measured, placed in pre-cleaned Teflon 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 the HMI facility the same day. According to MES, one of the sample jars (a composite *Rangia* sample replicate from station HM22-2) was empty when the samples were logged in at HMI. Thus, only thirteen biota samples were analyzed and reported for the Thirteenth Year.

Samples were held frozen until extraction and analyses by the contractor, Artesian Laboratories, Inc. (ALI) several months later. ALI analyzed for eight metals (arsenic, cadmium, chromium, copper, nickel, zinc, iron, manganese) and a restricted suite of organic contaminants from two classes: chlorinated pesticides/PCBs and semivolatiles (phthalate esters and selected polycyclic aromatic hydrocarbons (PAHs)). This is the first year that tissues were analyzed for arsenic burdens since the early baseline studies of 1981-1983.

Complete listing of analytical methods, as provided by ALI, are given in Table 4-1. Tissues were dissected, digested and analyzed for metal burdens by Environmental Protection Agency (EPA) methods. As and Cr were analyzed by graphite furnace atomic absorption (AA), Fe by flame AA and Cd, Cu, Mn, Ni, and Zn by inductively coupled plasma emission. ALI used National Oceanic and Atmospheric Administration (NOAA) National Status and Trends (1993) methods for tissue extraction and EPA methods for organic contaminant analyses. The small tissue masses for the *Macoma* and *Cyathura* samples continued to present problems with detection limits, while the more adequate tissue masses in the *Rangia* samples likely contributed to greatly improved levels of detection for some analytes in the Thirteenth Year.

The Thirteenth Year analytical tissue data were accompanied by extensive quality control (QC) data by the contractor, as in the previous two monitoring years. MES adopted a program to check the quality of the contractor's analytical methods with reference materials

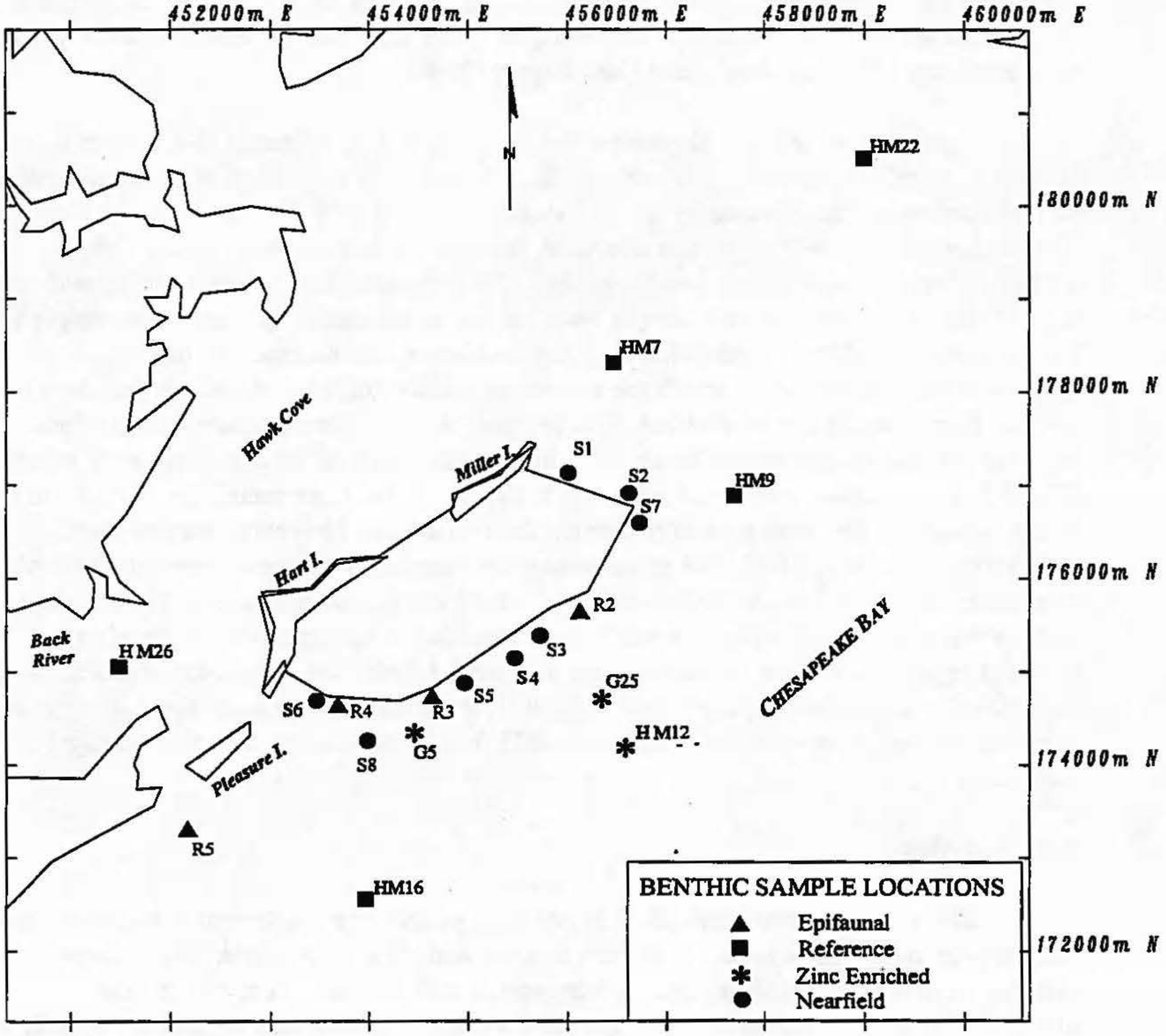

Figure 4-1. Benthic Infaunal and Epifaunal Sampling Stations at HMI. University of Maryland, Chesapeake Biological Laboratory Designations.

prior to HMI sample analyses. QC method performance was evaluated through replicated analyses of external standard reference material (SRM) (oyster tissue 1566a from the National Institute of Standards and Technology, NIST) for metal analyses, fish tissue SRM (EPA QC C-4 and EPA QC PCB) for pesticides and PCBs, and replicated analyses on a spiked lab-prepared oyster homogenate (ALPOH) for other organic analytes. Internal QC controls included laboratory reagent blanks and fortified blanks (metals only), replicated sample tissue matrix spike recoveries on two samples, surrogate spike recoveries, and replicate analyses on two samples for both metal and organic data. While these QC data results are discussed under the appropriate sections, the data set is too large to include in total within the context of this interpretive report. One may find the entire data set in the accompanying 13th Year Analytical Data Report (1998).

A summary of the benthic sample data is compiled in Appendix B-1, which includes sample ID numbers, number of organisms, length distribution, percent lipid and weight per sample composite (as provided by the contractor). This was the first year since the baseline studies in which tissue % lipid was analyzed, though the data were not used in any normalization, due to the questionable quality of the organic data set. One should note that the last entry in Table 4-A1 for sample 94477 gives an anomalously high tissue weight for a *Cyathura* sample. After consultation with the contractor, the accuracy of the sample weight determination was verified, though the species identification, as provided on the chain of custody forms, could not be verified. It is believed that the tissue contaminant burdens reported for this sample may actually be values for the missing *Rangia* sample for station HM22-2. This follows from the tissue weight as well as the trace metal distributions in these tissues which are far more typical of *Rangia* than *Cyathura*. However, none of these suppositions can be verified. The metal values for sample 94477 have been entered in the data tables as ?*Cyathura* S4-1?/ ?*Rangia* HM-22-2? with cautionary notes. They are not discussed further in this report. In this report, chemical concentrations for metals are reported as_μg/g (ppm) wet weight values and_μg/kg (ppb) wet weight for organics. Since many bivalve sampling programs report dry weight values, approximate comparisons can be made by decreasing dry weight values by 8-fold (i.e. biological tissues are typically 80-90% water).

Data Analysis

Several recommendations cited in previous years were implemented beginning in the twelfth year and continuing in the thirteenth 13th year. Where possible, larger tissue samples were available and organisms were sorted into samples according to size distribution. At many stations, however, there were still insufficient organisms to make up one fully adequate composite tissue sample for analyses. This was particularly true for the *Cyathura* and *Macoma* samples, as noted by the contractor. Most sampling programs designed to determine contaminant differences among stations and or sampling years, incorporate a standardization protocol (e.g. size, age, sex, lipid content) in order to reduce unwanted variance (Popham and D'Auria 1983; Lobel *et al.* 1991). Sorting organisms according to size distributions allowed sample replication at five stations in the twelfth year. But since contaminant burdens are often correlated with size or age, having two replicates of different age/ size groups may increase variability within a site, as observed in the summary metal table (Appendix B-2) of this report. High variability within a site due to different size-dependent tissue burdens or variable sediment content makes true among-station differences difficult to assess statistically. It may be preferable to have station replicates consisting of similar size classes when organisms are available at a particular site.

Analytical methods changed beginning in year twelve, based on recommendations aimed at improving detection limits for certain organic contaminants. ALI used National Oceanic and Atmospheric Administration (NOAA) National Status and Trends (1993) tissue and extraction and cleanup methods, and Environmental Protection Agency (EPA) methods for organic contaminant analyses. Complete listing of analyses methods, as provided by ALI, are given in Table 4-1. The contractor encountered several problems with these methods, which were compounded by frequent small sample volumes. For certain classes of compounds, namely the phthalate esters and low molecular weight compounds, the methods provided were inadequate for trace compound recovery.

Data were entered into Quattro Pro 6.0 for Windows for presentation and for summary purposes. The nature of the data set and the limited resources for conducting more exhaustive sampling and/or chemical analyses sensitive enough for some analytes precludes rigorous statistical analysis. Appropriate statistical tests are not generally available for this type of data. As in years past, the data set is characterized by small sample sizes, few appropriate replicates per site and a substantial number of non-detects with varying detection limits. 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 contrasts could be performed. Therefore, the data presentation is primarily a summarization of the analytical results in tabular format with appropriate summary statistics. Unusual or atypical results were noted and compared largely with data from year ten, eleven and twelve. The order and format used to present the current data is similar to years ten through twelve to facilitate between-year comparisons. Although not statistically significant, selected metal data for each genus was arranged according to station type, where data permitted, using data from similar size classes. It is believed that this presentation will aid in among station contrasts and facilitate observed trends in future years

RESULTS AND DISCUSSION

Trace Metals

Summary statistics for individual trace metal concentrations in benthic biota, including the frequency of detection, detection limits, maximum and individual values by station, and species summaries (median, maximum, and range) are provided in Tables 4-2A-H. Individual sample summaries are provided in Appendix Table 4-A2.

Two tables have been provided as reference information from which to compare selected trace metal concentrations in HMI benthic samples. Table 4-3 is a summary of trace metal concentrations found in soft shell clams, *Mya arenaria*, from the 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. Table 4-4 is a compilation of baseline data on metal levels in *Macoma* and *Cyathura* from all stations surrounding HMI in the Spring of 1983 from the Second Year of the monitoring program. This information was selected over the First Year's data since more species common to the present data set were analyzed and over a larger geographical area similar to present day station locations. The data were converted from the original dry weight data by using a conversion factor of 8 (i.e. dry weight data were decreased by 8-fold to account for an approximate 80% water content of biological tissue).

Since there are species differences in metal accumulation, the most appropriate comparisons are between the present *Rangia* tissue burdens and the soft shell clam data (Table 4-3) and between the historical baseline data (Table 4-4) and current tissue metal burdens in *Macoma* and *Cyathura*. Unfortunately, no *Rangia* were collected for tissue analyses during the baseline studies of the HMI monitoring program with which to compare present day metal burdens. In the Twelfth Year Interpretive Report (Warner *et al.* 1994) *Rangia* was referred to as a deposit feeder along with the other two HMI invertebrates, which limited comparisons with the suspension feeding *Mya arenaria*. While *Rangia* occasionally feeds from surface organic deposits and may ingest some sediment, it is primarily a suspension feeder (Chesapeake Bay Program, Restoration Goals, 1994) and thus comparisons with *Mya arenaria* are appropriate.

QC Metal Data

The overall QC data for metals were good and within specified limits. There was low recovery for chromium and nickel in some replicates of the SRM during the pre-testing QC phase, but acceptable recovery of these analytes when analyses were repeated during field sample runs. Percent recoveries were within specified limits and generally ranged from 83-106% for sample tissue matrix spikes for all analytes except for an over recovery

(165%) of manganese in one replicate. Method precision was lower for replicated field samples (wet tissue) than for the dry tissue SRM. The relative percent difference (RPD) for SRM replicates ranged from 0-5% but ranged from 1-55% in the *Rangia* matrix spike samples. Similar ranges in RPD were noted for 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.

Rangia cuneata

Eight *Rangia* samples were collected in the Thirteenth year, one sample from a reference area, five from nearfield and two from zinc enriched stations.

Arsenic was detected in all of the *Rangia* samples from the Thirteenth Year with most values near the median level of 1.21_µg/g and well above the detection limits (Table 4-2A). In contrast, arsenic is frequently below the detection limit of 0.05_µg/g in *Mya arenaria* tissues from the upper Chesapeake, but similar in range to *Rangia* burdens (Table 4-3).

Cadmium was detected in all *Rangia* samples from the Thirteenth Year in contrast to 75% detection in the Twelfth year samples. Cadmium detection limits for the present year are an order of magnitude more sensitive than the previous monitoring year. The Thirteenth Year median value of 0.25_µg/g (Table 4-2B) is within the small range of values reported for the Twelfth Year, but an order of magnitude higher than median cadmium values for soft shell clams in the upper Chesapeake (Table 4-3).

Chromium was detected in 100% of the Thirteenth Year samples with the highest concentration, 7.72_µg/g, found in one replicate from the nearfield station S7. Most of the chromium burdens from other stations are near or below the median value of 0.64_µg/g (Table 4-2C). Chromium detection limits in the present year are one to two orders of magnitude more sensitive than the Twelfth year when 83% of the samples carried detectable burdens. Chromium was detected in none of the samples in the Eleventh Year (above the detection levels of 1 to 2_µg/g) and in only 33% of the samples from the Tenth Year when one of two samples from the reference station (HM22) yielded the highest concentration of 66_µg/g. Similarly, chromium has frequently been below the detection limit of 0.5_µg/g in soft shell clams from the upper Chesapeake over the same time frames (Table 4-3).

Copper was detected in all Thirteenth Year *Rangia* samples with the highest concentration (2.93_µg/g) at nearfield station S6 (Table 4-2D). Most copper concentrations at all other stations were near the median value of 2.33_µg/g. The narrow range of copper concentrations found in the present year are similar to those found in the Tenth and Eleventh and Years and show a decrease from the larger range of copper concentrations in the Twelfth Year.

Nickel was detected in all of the *Rangia* samples with the highest value of 7.9_µg/g at nearfield station S6 (Table 4-2E). In the previous two monitoring years the largest nickel burdens in *Rangia* samples were observed at reference station HM22. Nickel concentrations at this station have decreased an order of magnitude in the Thirteenth Year. There were no clear trends in the nickel distributions among station type and the range of nickel concentrations are narrower presently than in the previous three monitoring years. The median nickel value of 5.57_µg/g, however, is an order of magnitude greater than median nickel burdens in soft shell clams from the upper Chesapeake (Table 4-3).

Zinc was detected in all samples in the Thirteenth Year with the highest value (40.2_µg/g) and the lowest value (18.8_µg/g) in duplicate samples (but of different size classes) from the same nearfield station, S1 (Tables 4-2F and 4-A2). Zinc distributions at the zinc enriched stations were slightly below levels at reference station HM22. While zinc levels were similar between these two station types in the previous year, the levels then were generally two to three times greater. The range of zinc concentrations in the present year are similar to those in the Tenth and Eleventh and considerably lower than the elevated levels in the Twelfth Year. The median and range of *Rangia* zinc concentrations in the Thirteenth Year are similar to those found in the soft shell clam from the upper Chesapeake (Table 4-3).

Macoma sp.

Only one *Macoma* sample, from reference station HM16, was collected in the Thirteenth Year. The composite sample was comprised of a few small (16-17mm) individuals with a reported tissue mass of less than one gram (Table 4-A1). There were no indications in the data reports of analysis problems encountered from excessive sediment in this tissue sample, as had been the case with all *Macoma* samples from the Twelfth Year.

There were detectable levels of all metal analytes in this sample. The arsenic burden (7.89_µg/g) was much greater than the ranges found in the *Rangia* samples (Table 4-2A), and two orders of magnitude greater than the maximum baseline levels in *Macoma* surrounding HMI from 1983 (Table 4-4). The cadmium burden (1.83_µg/g) exceeded slightly the maximum level detected in *Macoma* samples from the Twelfth Year (at station HM16). The present cadmium burden is also roughly three times higher than the maximum baseline levels in *Macoma* from the Second Year study (Table 4-4).

Chromium and copper levels in *Macoma* at station HM16 do not appear to have changed much since the previous monitoring year, if one restricts comparisons to tissue burdens in samples from similar size classes. The chromium level this year (3.6_µg/g) is within the range found in the previous three monitoring years, with the exception of the Eleventh, when chromium was not detected (Table 4-2C). Likewise, the present copper burden (26_µg/g) is similar to levels reported in *Macoma* from the Eleventh and Twelfth Years, but higher than the range reported for the Tenth (Table 4-2D). The levels of both chromium and copper in the Thirteenth Year sample were similar in magnitude to levels in *Macoma* samples from the Second Year (Table 4-4).

Nickel and zinc burdens in *Macoma* tissues at HM16 from the Thirteenth Year are within the ranges found in *Macoma* replicates at this station the previous year. The 5_μg/g nickel burden is similar in magnitude to *Macoma* levels in the Tenth and Twelfth Years, but roughly half the value reported for the Eleventh Year when only one sample was collected (Table 4-2E). The present *Macoma* nickel level is nearly double the median value and exceeded the maximum value from baseline monitoring in the Second Year (Table 4-4). The current zinc burden of 203_μg/g (Table 4-2F) is within the elevated ranges in zinc reported in the Twelfth Year but well above zinc burdens in *Macoma* in the prior two monitoring years as well as baseline zinc ranges (Table 4-4).

Cyathura polita

Four samples of *Cyathura* were collected in the Thirteenth Year, two from nearfield stations, one from a zinc enriched station and one from a reference area. As previously discussed, it is believed that one of the samples was lost. The sample in question is from the nearfield station, S4. If one examines the reportedly accurate tissue weight for this sample 94477 (Table 4-A1) and the distributions of metals, particularly Cu, Ni, Zn and Fe levels (Table 4-A2) it seems clear that the sample is *not* a *Cyathura* sample, but much more likely a *Rangia* sample and perhaps the missing replicate from station HM22 (see discussion under **Sampling and Chemical Analyses**). The metal burdens reported for this sample (94477) have not been retained in the *Cyathura* sections of the tables as they are considered spurious.

Arsenic was detected at high levels in all samples with median and maximum values of 7.6 and 11.3_μg/g, respectively (Table 4-2A). These values are two and three orders of magnitude greater than *Cyathura* median and maximum values respectively, in the baseline year of 1983 (Table 4-4).

Cadmium was detected in two samples, both of which exceeded the maximum value in *Cyathura* from the Twelfth Year, which was the first time cadmium had been analyzed since the baseline studies. The present cadmium burdens (1.2 and 2.4_μg/g, Table 4-2B) are well outside the range found for *Cyathura* before HMI was operational (Table 4-4).

Chromium was detected in all samples in the Thirteenth Year with values at the nearfield and zinc-enriched stations double or greater the value at the reference station (Table 4-2C). Chromium detection limits for *Cyathura* this year are an order of magnitude more sensitive than in the previous few monitoring years when chromium was largely undetected below levels of 1-2_μg/g. Chromium levels in *Cyathura* surrounding HMI have decreased appreciably since the baseline studies of 1983 (Table 4-4).

Copper was detected in all samples of *Cyathura*. The highest value (137_μg/g), at a nearfield station, was also the highest of all HMI tissue samples from the Thirteenth Year (Table 4-2D). Copper burdens in *Cyathura* tissues have remained extremely elevated since the Twelfth Year, relative to the moderate levels reported in the previous three monitoring years. The current median and maximum values, however, are very close to the corresponding *Cyathura* copper burdens during the baseline studies of 1983 (Table 4-4).

Nickel was detected in only one of the *Cyathura* samples at a level of 1.5_μg/g (Table 4-2E). There have been continuing problems in analyzing nickel burdens in *Cyathura* tissues over the past four monitoring years due to high and variable detection limits, which may be compounded by the typically small tissue mass available for analyses. When detected, nickel levels have ranged from 1-14_μg/g since the Ninth Year, which is close to the range reported for *Cyathura* during the baseline study in the Second Year (Table 4-4).

Zinc was found at elevated levels in all of the *Cyathura* samples with a maximum value of 359_μg/g at nearfield station S6 (Table 4-2F), which is double the maximum value last year. The lowest value was found at the zinc enriched station. This trend is exactly opposite from zinc distributions in the Twelfth Year when zinc burdens were greater at the zinc enriched stations than at a nearfield station. Although zinc levels are currently elevated over levels in the previous three monitoring years, they are lower than, but within, the extreme range of values reported in the Eighth and Ninth Years. These elevated zinc burdens of the past few years are an order of magnitude greater than levels found during the baseline study in 1983 (Table 4-4).

Iron and Manganese

Iron and manganese were detected at substantial levels in all tissue samples from the Thirteenth Year (Tables 4-2G and 4-2H). The ranges reported this year are similar to those in the previous three monitoring years. Levels of both analytes are higher in *Cyathura,* an omnivore/carnivore, and *Macoma,* a deposit feeder, than in *Rangia*, a suspension feeder, which may be an indication of enrichment from sediment sources. As was mentioned earlier, the contractor did not note any problems with sediment in the tissue samples this year, as was the case in the Twelfth Year.

Summary of Selected Metal Distributions by Station

The distributions of arsenic, copper, nickel, and zinc in the three types of benthic invertebrates from three station types (reference: HM16, HM22; zinc-enriched: HM12, G25; nearfield: S1, S7, and S6) are presented in Figure 4-2. The average values of *Rangia* replicates from station S1, comprised of different size classes, were used in these comparisons in contrast to last year's treatment of the data when only composite samples of size classes less than 31-32 mm were utilized. This year there were no *Rangia* samples comprised of individuals less than 31mm and the tendency, when there were size dependent differences in tissue burdens at a given station, was for the smaller size class to have the greater burden (Table 4-A2). Last year, the reverse was true for both the *Macoma* and *Rangia* samples when sediment in the tissue samples may have contributed to the observation of higher burdens in samples comprised of larger individuals.

Among species type, the deposit feeder, *Macoma* and, the omnivore/carnivore, *Cyathura*, tend to accumulate much higher levels of metals, with the exception of nickel, than the suspension feeding *Rangia*. Metal burdens in *Rangia* tissues show no appreciable differences according to station type. Copper levels in *Cyathura* tissues continue to dwarf all other species monitored, as was observed last year. The highest burdens of arsenic, copper,

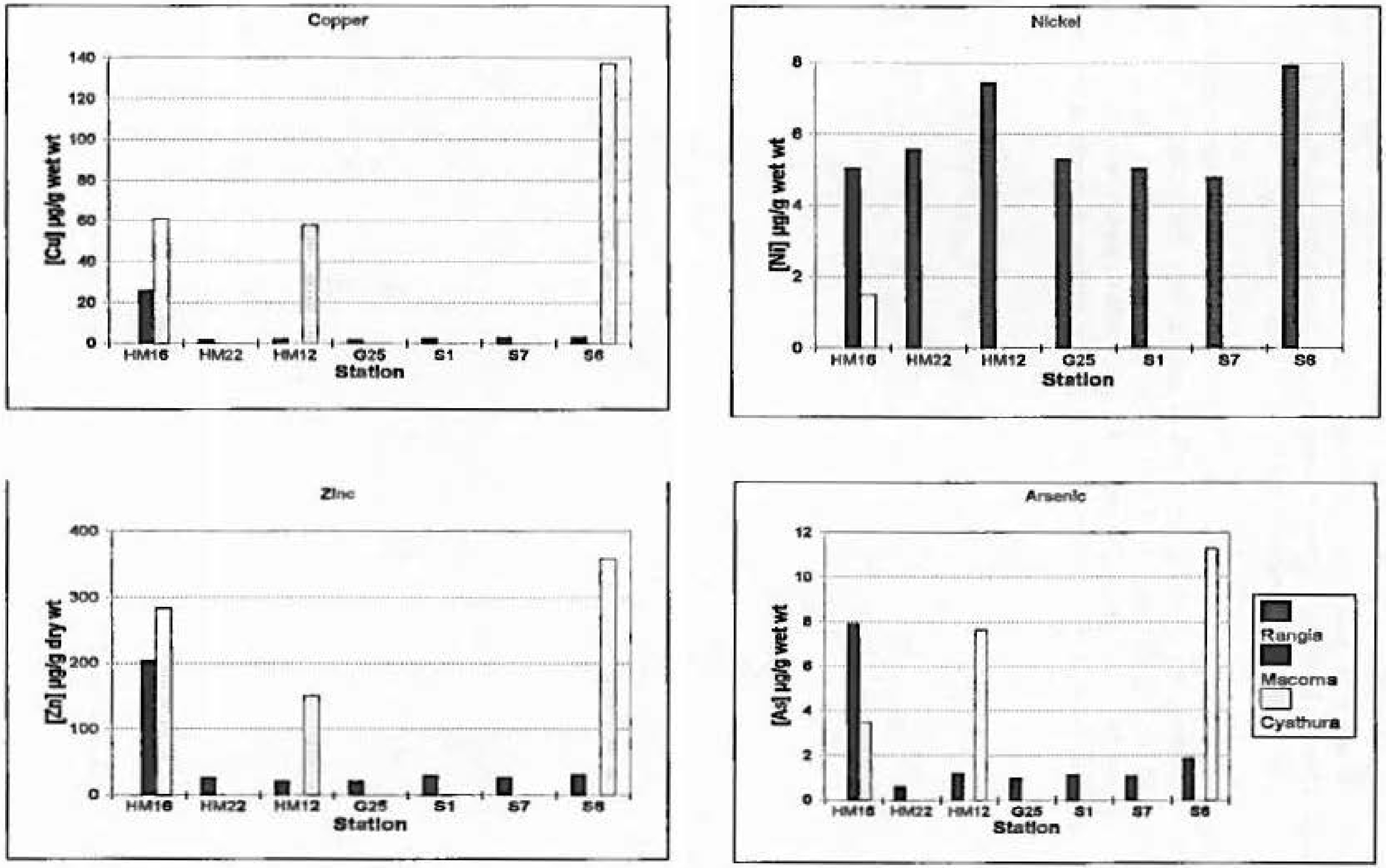

Figure 4-2. Metal tissue burdens in benthic invertebrates by station from the thirteenth year of monitoring at Hart Miller Island Dredge Contained Disposal Facility.

and zinc in *Cyathura* occur at nearfield station S6. Zinc levels tend to be lower at the zinc-enriched stations than at other station types. Few other trends in metal distribution by station type can be observed with these data.

In order to understand the distribution of metals in tissues as they relate to station type, two kinds of information are needed. One is the levels of these metals in the sediments and water from the same station. The other is whether the station types actually reflect where differences in metal loading stemming from HMI should be discernible. Information on both fronts is either lacking or underutilized.

Although the sedimentary project collects many sediment samples three times a year for metal analyses, only a few of the stations correspond to the same stations in the benthos project. Usually, data on the levels of metals in the sediments are either not available or unrequested at the time the analytical tissue data are being interpreted. Requesting sediment data again would present difficulties since benthic and.sediment stations are not mapped together and often do not correspond in time and place. This year, the percent excess zinc distributions in sediments for the Thirteenth Year were requested and available at the time this report was prepared. Examining these present and historical sediment figures for percent excess zinc in Project II reveals some information about station types that the monitoring program should consider:

Nearfield stations: Of all stations monitored, the nearfield stations, by and large, carry the lowest sediment loads of zinc, particularly those to the north and east (S1, S2, S7, S4, and S5). These areas immediately adjacent to the facility are not locations normally under the greatest influence of HMI release. However, the eastern area of zinc enrichment occasionally migrates to areas near the northeastern perimeter of the facility, where no benthic stations are located (Figure 4-1). Stations at the southern end (S6, S8) also occasionally show high levels of enrichment, as was the case in April 1990 and again in November of 1993. The high metal burdens observed in Cyathura at station S6 this year correlates with this most recent observation of sediment enrichment.

Zinc enriched stations: The area of zinc enrichment, first observed in 1989, has fluctuated in space and degree of enrichment ever since. Actually, there were two areas of zinc enrichment attributable to HMI effluent release: one east and one south of the facility. The benthos project added stations in the Ninth Year to monitor the zinc enriched area to the east. These zinc enriched benthic stations remained static, while the sedimentary area of enrichment has fluctuated, so much so, that the present benthic "zinc enriched" stations are no longer located within this area. The present zinc enriched stations designated HM12 and G25 may be on the edge of this area. The level of zinc enrichment at these two stations appear to be comparable to levels observed at reference stations HM16 and HM22 for Spring of this monitoring year, which is reflected in the benthic tissue burdens.

Reference stations: Only two reference stations have been consistently monitored for tissue metal burdens in recent years, HM16 and HM22. Examining sediment zinc distributions near the vicinity of station HM16 reveals that this station is occasionally located within the fluctuating southern area of zinc enrichment. This would explain the high tissue metal burdens seen at this location, particularly in the Twelfth and Thirteenth monitoring years. The sedimentary record near HM22 is filled with gaps in knowledge. For April of this year, it appears that some zinc enrichment is occurring in this vicinity north of the facility. The circulation gyre east of the facility, described by Wang (1993) in the Tenth Year, would provide a means of transporting effluent from the northern and eastern spillways of HMI to this reference area. Indeed, model results of pollutant dispersion surrounding the HMI facility in Wang's report indicated that the area around and beyond HM22 would come under direct influence from effluent release, under certain spillway operation and flow rates, and Susquehanna flow conditions.

Since the sediment zinc record near this area is intermittent, a compilation of *Rangia* zinc tissue burdens at station HM22 is offered in place. Figure 4-3 shows zinc burdens in *Rangia* at this station beginning in the Fifth Year, apparently the first year that *Rangia* were analyzed for metal burdens in the monitoring program. Zinc levels in the Fifth and Sixth Years were converted to wet weight estimates from the original dry weight data using a conversion based on average percent moisture content of *Rangia* collected and reported in the Fifth Annual Data Report (1987). The samples from these years were not identified as to season of collection, so the average of all samples in the Fifth and Sixth Years were used. The remainder of the zinc burdens are from the Spring sampling times only, to be consistent with recent sampling regimes and to reduce the seasonal variability in metal accumulation in year-to-year comparisons. One of two samples in the Eighth Year carried anomalously high burdens and was not used.

The pattern of zinc burdens in *Rangia* at HM22 follow closely the pattern of zinc enrichment observed in sediments to the east of HMI over time. The Fifth Year was the last year of monitoring before HMI began discharging effluent and could be considered as a pre-discharge baseline condition. Initial rates of effluent discharge were high enough to preclude affecting the limited geographic scope of the monitored area. In the Eighth Year, coincident with greatly decreased effluent discharge rates, the problem of zinc enrichment in the sedimentary record was first described and corresponds to the time when *Rangia* zinc burdens at HM22 doubled from the previous three monitoring years. In the Twelfth monitoring year, zinc levels within the eastern sedimentary zinc enriched area were higher than any on record while this year, sediment levels have dropped to values more typical of other recent enrichment levels. The pattern of zinc burdens in *Rangia* at HM22 during the Twelfth and Thirteenth Years follow this sedimentary trend exactly. Given that the same upper Bay circulation pattern which compresses effluent to the east of HMI also strengthens distribution to the northeastern area surrounding HM22, it is probable that the HM22 zinc burdens in *Rangia* are a result of HMI effluent discharge. This also suggests that this area may not be the most appropriate for a reference station.

The station designations "reference," "nearfield" and "zinc enriched" presently do not differentiate which areas are or are not under the influence of HMI effluent discharge. Thus among-station contrasts based on these designations, are difficult to evaluate. The monitoring program needs to have reference areas removed from influences of the facility and monitor

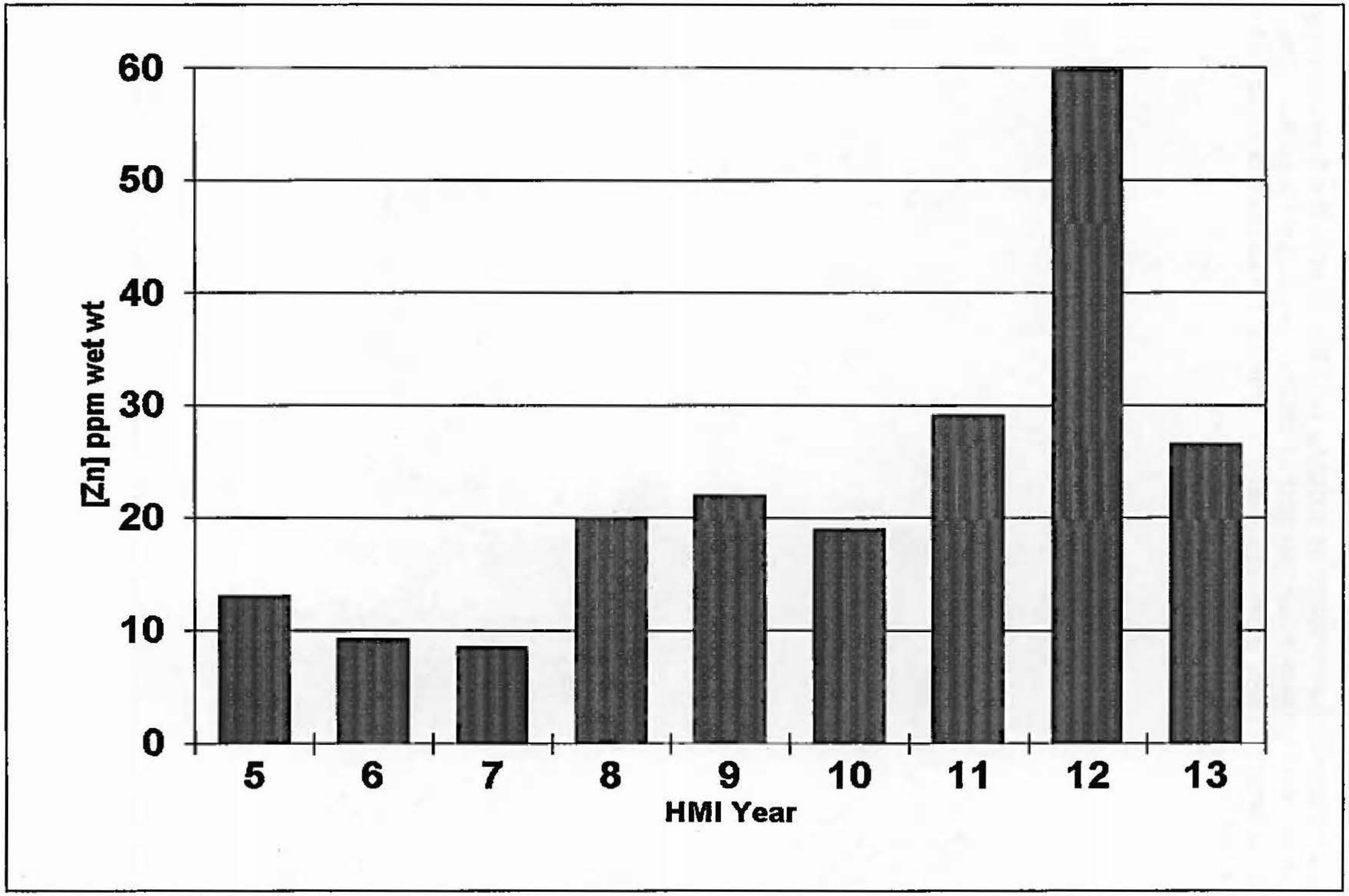

Figure 4-3. Historical Zn burdens (*Rangia cuneata*).

stations directly within the zinc enriched areas to determine if there are any effects of HMI effluent discharge and operation in any given year.

Organic Contaminants

Table 4-5 (a and b) is a listing of target organic analytes for the Thirteenth Year and the reported range of detection limits for each type of tissue. The organics are grouped into two broad categories: semivolatiles and pesticides. The pesticide grouping contains chlorinated pesticides and polychlorinated biphenyls (PCBs) while the semivolatile group contains polycyclic aromatic hydrocarbons (PAHs), hexachlorobenzene and phthalate esters. This year, semivolatile pesticides were dropped and the chlorinated pesticides, cis- and trans-chlordane, trans-nonachlor and hexachlorobenzene were added to the analyte list, in response to recommendations cited in previous interpretive reports. Detection limits were generally highest (i.e. least sensitive) in *Macoma* and *Cyathura* and lowest in *Rangia*. This year the ranges in detection limit for the pesticides in *Rangia* samples were much lower and tighter than in the previous year. Similarly, the ranges in semivolatile detection limits in this species were tighter this year than the extreme ranges observed last year. The improvements in detection limits for this species is likely a function of greater tissue masses available for this species this year (Table 4-A1). Variable and minimal sample mass contributed to the variable and often high detection limits observed for the other two invertebrates.

QC Tissue Organic Data

As mentioned previously, the extensive QC data submitted by ALI will not be extensively reviewed here. One may find all of the data and ALI's explanations for QC data results outside of the specified limits in the accompanying 13th Year Analytical Data Report (1995). In general, lab performance on semivolatiles was of higher quality than on the pesticides analytes, though the quality of the phthalate data is questionable. This is a serious caveat since the only organic analytes detected in the Thirteenth Year samples were from the phthalate ester class. Semivolatile percent recoveries from the oyster tissue standard were generally above 50% (range 34-104), though recovery on one replicate spike was much lower. Better recoveries (54-82%) were observed with the sample matrix semivolatile spikes, the exception being an over-recovery (145%) of bis(2-ethylhexly) phthalate in one matrix spike. The lowest recoveries from both matrices were observed with high molecular weight PAHs. Lab performance on the pesticide class was variable. The main problem appeared to be with the extraction and cleanup steps. Recoveries were generally low (30-86% for oyster tissue standard and 30-73% for matrix spikes) and imprecise. Several analytes (chlordane, PCB-1016,-1221,-1232, and -1248) were not tested for recovery from any tissue matrix. The median and ranges of percent recoveries for surrogate spikes for each sample are presented in Table 4-6a (semivolatile) and 6b (pesticides). The laboratory's recoveries of semivolatile surrogates were generally within specified limits, though recoveries of pesticide surrogates, both in samples and reference materials, were variable and typically very low. Surrogate spike concentrations were several orders of magnitude greater than would be expected in environmental samples. It is possible, when the laboratory could achieve better than 50% surrogate recovery, that the resultant signal swamped many analytes of interest. Where surrogate recoveries were low or absent, analytes with similar chemical characteristics (e.g. PCBs) were most likely lost during the extraction and cleanup steps.

The remaining discussion of QC data will focus only on the phthalates since this was the only class of organics detected. This year ALI consistently recovered phthalates which they spiked into tissues whereas none of the phthalate esters were recoverable from the laboratory fortified blanks and one matrix spike last year. Percent recoveries were better in the sample matrix than in the reference material, ranging from 64-82%. However, there were over-recoveries of 113 and 145% on bis(2-ethylhexyl) phthalate on two spiked tissue matrices and a detectable quantity of the same analyte in one tissue blank while in its replicate the analyte was nondetected. Laboratory reagent and fortified blank data were not provided on any organic analytes with the contractor's data reports. Only when asked did ALI provide laboratory blank data, but only then on the phthalates. It is suspected that laboratory contamination was a problem, since several phthalates were detected in laboratory blanks near levels detected in the samples (Table 4-7).

Detected Organics in Benthic Samples

Phthalates were detected in six of the 13 samples submitted: in two *Cyathura* (though one is the suspect sample S4) and four *Rangia* samples. The levels of these analytes in tissues and laboratory reagent blanks are presented in Table 4-7. Since bis(2-ethylhexyl) phthalate was detected in only one of two sample replicates (HM12a), and in view of the problem with possible laboratory contamination discussed above, these data are highly suspect, as they were in the Twelfth Year. No other organic analytes were detected this year. Although detection limits for some analytes were improved for most *Rangia* tissues this year, the detection limits were still rather high, particularly for the low tissue weight *Cyathura* and *Macoma* samples. The biggest problem, particularly for the PCBs, was likely loss of analytes during sample preparation and cleanup steps, as the surrogate recoveries demonstrate (Tables 4-6a,b). The poor quality of the HMI data for organics in tissues over the years precludes any further discussion.

Detected Organics in Sediments

Ten sediment samples from eight stations were collected April 21, 1994 by the Maryland Geological Survey and analyzed by ALI for the same suite of organic analytes as the biota according to methods listed in Table 4-1. Detection limits for the sediment samples, while improved over the previous few years, are still rather high (Tables 4-8a, b), and precluded detection of any organic analytes other than the problematic phthalates. The levels of detected phthalates, sediment carbon, hydrogen, and nitrogen, and station locations are presented in Table 4-9. Analytical problems similar to those encountered with tissues were observed with the sediment QC and sample data. Thus the phthalate levels cited in Table 4-9 may not be reliable.

SUMMARY AND RECOMMENDATIONS

Thirteen composite tissue samples of either *Macoma sp.*, *Rangia cuneata*, or *Cyathura polita* from eight stations were analyzed for eight metals and a suite of organic analytes in the Thirteenth Year. Trace metal detection levels were greatly improved this year which lead to detectable burdens of nearly all analytes in all species, save nickel and cadmium in some *Cyathura* samples. Analytical problems with organic analytes coupled with high, yet somewhat improved, detection limits lead to no detectable organics in the tissues nor in the ten sediment samples except for phthalate esters. Due to problems with laboratory contamination, these reported phthalate data are unreliable.

This was the first year in which arsenic had been monitored in tissues since the baseline studies and it was detected at appreciable levels in all samples. Burdens of arsenic, cadmium and zinc in both *Macoma* and *Cyathura* and nickel in *Macoma* have increased dramatically since the baseline monitoring year of 1983, while other trace metal levels in these species have remained similar or have decreased since the Second Year. While no *Rangia* were monitored in baseline studies with which to compare current trace metal levels, this species' burdens of arsenic, cadmium and nickel are appreciably higher than levels found in the filter feeding bivalve, *Mya arenaria*, from the upper Chesapeake Bay. Last year, the highest levels of zinc enrichment ever recorded were observed in HMI sediments, while this year levels were more typical of prior enrichment. Assuming that other metal levels correlate with zinc, in general, it appears that the deposit feeder, *Macoma* and the omnivore/carnivore, *Cyathura*, have retained a greater metal burden memory of last year's elevated metal levels, whereas in the suspension feeding *Rangia* metal burdens responded more rapidly to temporal changes in metal loadings to the environment.

The trends in patterns of zinc enrichment in the sediments around HMI and levels of metals in tissues suggest that the reference stations are often located in areas under the influence of HMI effluent discharge and that the current "zinc enriched" benthic stations are no longer in the areas where zinc is enriched in the sediments. If the same stations were monitored in both the benthic and sedimentary projects a more conclusive statement could be made. There are presently no benthic stations located in areas most affected by HMI effluent discharge. Given these observations, it is of little surprise that differences in tissue metal distributions according to station type could not be discerned this year, as in previous monitoring years.

With respect to the metal burdens cited above, it would appear that HMI effluent discharge may have an effect, though statistical analyses would be necessary to draw firm conclusions. Since all areas currently monitored for tissue burdens are affected to some degree by HMI effluent discharge, the only appropriate analysis of HMI influence may be over time rather than space. The monitoring program may wish to consider conducting a comprehensive review of the quality of historical tissue data to determine whether such trends can be assessed and as a guidance as to which data are important to collect in the future. For example, *Rangia* has been recommended as the only monitoring species to be used. However, there were no baseline studies conducted with this species. Of the three species monitored this year, *Macoma* and *Cyathura* represent two which were monitored during the baseline studies in the Second Year and for which yearly data exist since the Seventh Year. *Rangia* has been monitored yearly for metals only since the Fifth Year and has been the most consistent monitoring species recently in terms of availability at most stations and in sufficient numbers to yield adequate tissue mass for analyses. How *Rangia* accumulates metals in comparison to other monitoring species should be better assessed. In the baseline studies, *Macoma* was suggested as a monitoring species and detailed studies assessed the appropriate number of individuals to collect to represent the population mean, seasonal and size dependent variability in metal accumulation, and comparison of metal accumulation with other species (Wright 1982, 1984). Information on the levels of metals in the water and sediments from the same stations was also available back then with which to assess these things. Given that this useful information exists for a monitoring species from the baseline years, perhaps *Macoma* should be retained and /or similar information gathered for *Rangia*.

Additional recommendations include:

- Re-evaluate the sampling locations. Relocate or add benthic stations in the more recently zinc enriched areas. Concentrate the monitoring where effects from the facility would be expected to be greatest, based on available knowledge. Design a sampling scheme able to detect contaminant gradients around the facility and to find reference sites (at least one) well-removed from the influences of HMI.

- Sample sediments and biota from the same locations and at the same times. Water samples would also be useful. Combine sediment and benthic stations on a single map so that sediment trends can clearly be seen in relation to benthic tissue and population trends.

- Monitor HMI effluent at a sensitive and comprehensive level to determine which analytes should be monitored in the surrounding environment.

- Adopt more sensitive analytical techniques for target organic analytes so that true contaminant differences can detected. With present methodology, only gross contamination, which often exceeds FDA action limits, is sporadically detected and no trends can be assessed. Since the associated costs of improved detection limits will be high, monitoring of organic analytes could be performed less frequently. It is questionable whether anything is to be gained from using less sensitive analytical techniques in intervening years.

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

●Determine and collect the minimum number of individuals needed to provide an adequate and representative composite tissue sample for analyses for each species. Continue to measure individuals and maintain consistency in size classes, when possible.

●Tissue dry and wet weights should be determined and reported, so that more accurate comparisons with historical dry weight data can be performed.

●Consider repeating the sediment toxicity tests performed in the Eleventh Year. These tests were inconclusive due to predation and/or mortality in the reference sediment. To complete the sediment quality triad concept (Chapman et al. 1987) it is important to have the same stations for sediment and tissue contaminant burdens, as for toxicity tests and benthic community assessments.

TABLES

Table 4-1. Analytical methods used to determine concentrations of metals and organic contaminants in biota.

Parameter	Media	Method Number/Reference
Arsenic (As)	Tissues	(EPA 218.2) (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 236.1) (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)
Pesticides/PCBs	Tissues/Sediments	NOAA NOS ORCA 71, 1993 (EPA 608, SW 846)
Semivolatiles (Phthalate Esters, PAHs, etc.)	Tissues/Sediments	NOAA NOS ORCA 71, 1993 (EPA 625, SW 846)

Table 4-2 (A-H). Trace metal concentrations in benthic biota, Year 13, Hart Miller Island Contained Disposal Facility.

Table 4-2A. Arsenic (ug/g wet wt.)

Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Median	Min/Max/Range
Cyathura	S 6	1	100	0.28	11.3	11.3		
Cyathura	HM 12	1	100	0.25	7.65	7.65		
Cyathura	HM 16	1	100	0.1	3.46	3.46		
Cyathura	All Stations	4	100	0.01, 0.28	11.3		7.65	3.5/ 11.3/ 7.8
Macoma	HM 16	1	100	0.19	7.89	7.89		
Rangia	S 1	2	100	0.01, 0.02	1.48	1.48, 0.81		
Rangia	S 7	2	100	0.01	1.21	1.21, 0.97		
Rangia	S 6	1	100	0.01	1.89	1.89		
Rangia	G 25**	1	100	0.01	0.97	0.97		
Rangia	HM 12**	1	100	0.01	1.22	1.22		
Rangia	HM 22	1	100	0.01	0.61	7.89		
Rangia	All Stations	8	100	0.01, 0.02	1.89		1.21	0.61/ 1.89/ 1.28

**Values given are average of duplicate analyses

Table 4-2B. Cadmium (ug/g wet wt.)

Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Median	Min/Max/Range
Cyathura	S 6	1	100	1.11	2.36	2.36		
Cyathura	HM 12	1	0	1	ND	ND		
Cyathura	HM 16	1	100	0.42	1.24	1.24		
Cyathura	All Stations	4	75	0.4, 1.1	2.36		nc	1.24/ 2.36/ 1.12
Macoma	HM 16	1	100	0.77		1.83		
Rangia	S 1	2	100	0.03, 0.06	0.42	0.42, 0.23		
Rangia	S 7	2	100	0.04, 0.05	0.37	0.25, 0.37		
Rangia	S 6	1	100	0.05	0.19	0.19		
Rangia	G 25**	1	100	0.04	0.22	0.22		
Rangia	HM 12**	1	100	0.02, 0.04	0.2	0.2		
Rangia	HM 22	1	100	0.04	0.25	0.25		
Rangia	All Stations	8	100	0.03, 0.06	0.42		0.25	0.19/ 0.42/ 0.23

* *Values given are average of duplicate analyses
nc: median not calculated due to non-detects

Table 4-2C. Chromium (ug/g wet wt.)

Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Median	Min/Max/Range
Cyathura	S 6	1	100	0.28	1.81	1.81		
Cyathura	HM 12	1	100	0.25	1.33	1.33		
Cyathura	HM 16	1	100	0.1	0.77	0.77		
Cyathura	All Stations	4	100	0.01, 0.28	1.81		1.33	0.77/ 1.81/ 1.04
Macoma	HM 16	1	100	0.19	3.64	3.64		
Rangia	S 1	2	100	0.01, 0.02	0.72	0.72, 0.26		
Rangia	S 7	2	100	0.01	7.72	3.24, 7.72		
Rangia	S 6	1	100	0.01	0.64	0.64		
Rangia	G 25**	1	100	0.01	0.32	0.32		
Rangia	HM 12**	1	100	0.01	0.3	0.3		
Rangia	HM 22	1	100	0.01	0.57	0.57		
Rangia	All Stations	8	100	0.01, 0.02	7.72		0.64	0.26/ 7.72/ 7.46

* *Values given are average of duplicate analyses

Table 4-2D. Copper (ug/g wet wt.)

Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Median	Min/Max/Range
Cyathura	S 6	1	100	0.83	137	137		
Cyathura	HM 12	1	100	0.75	57.7	57.7		
Cyathura	HM 16	1	100	0.31	69.9	69.9		
Cyathura	All Stations	4	100	0.03, 0.83	137		69.9	58/ 137/ 79
Macoma	HM 16	1	100	0.58		26		
Rangia	S 1	2	100	0.02, 0.05	2.4	1.98, 2.4		
Rangia	S 7	2	100	0.03, 0.04	2.75	2.75, 2.33		
Rangia	S 6	1	100	0.04	2.93	2.93		
Rangia	G 25**	1	100	0.03	1.82	1.82		
Rangia	HM 12**	1	100	0.02, 0.03	2.8	2.8		
Rangia	HM 22	1	100	0.03	1.83	1.83		
Rangia	All Stations	8	100	0.02, 0.05	2.93			1.8/ 2.93/ 1.13

* *Values given are average of duplicate analyses

Table 4-2E. Nickel (ug/g wet wt.)

Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Median	Min/Max/Range
Cyathura	S 6	1	0	3.1	ND	ND		
Cyathura	HM 12	1	0	2.75	ND	ND		
Cyathura	HM 16	1	100	1.14	1.5	1.5		
Cyathura	All Stations	4	50	0.1, 3.1	9.6		nc	
Macoma	HM 16	1	100	2.11	5.05	5.05		
Rangia	S 1	2	100	0.08, 0.18	6.61	6.61, 3.49		
Rangia	S 7	2	100	0.12, 0.14	4.8	4.46, 4.8		
Rangia	S 6	1	100	0.13	7.91	7.91		
Rangia	G 25**	1	100	0.11	5.31	5.31		
Rangia	HM 12**	1	100	0.07, 0.1	7.43	7.43		
Rangia	HM 22	1	100	0.12	5.57	5.57		
Rangia	All Stations	8	100	0.07, 0.18	7.91		5.57	4.8/ 7.9/ 3.1

* *Values given are average of duplicate analyses
nc: median not calculated due to non-detects
ND: not dectected

Table 4-2F. Zinc (ug/g wet wt.)

Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Median	Min/Max/Range
Cyathura	S 6	1	100	0.83	359	359		
Cyathura	HM 12	1	100	0.75	150	150		
Cyathura	HM 16	1	100	0.31	283	283	283	
Cyathura	All Stations	4	100	0.03, 0.83	359			150/ 359/ 209
Macoma	HM 16	1	100	0.58	203	203		
Rangia	S 1	2	100	0.02, 0.05	40.2	40.2, 18.8		
Rangia	S 7	2	100	0.03, 0.04	31.4	21.7, 31.4		
Rangia	S 6	1	100	0.04	30.6	30.6		
Rangia	G 25**	1	100	0.03	20.3	20.3		
Rangia	HM 12**	1	100	0.02, 0.03	20.6	20.6		
Rangia	HM 22	1	100	0.03	26.5	26.5		
Rangia	All Stations	8	100	0.02, 0.05	40.2		26.5	18.8/ 40.2/ 21.4

* *Values given are average of duplicate analyses

Table 4-2G. Iron (ug/g wet wt.)

Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Median	Min/Max/Range
Cyathura	S 6	1	100	2.8	539	539		
Cyathura	HM 12	1	100	2.5	335	335		
Cyathura	HM 16	1	100	1	404	404		
Cyathura	All Stations	4	100	0.09, 2.8	539	64-539	404	335/ 539/ 204
Macoma	HM 16	1	100	1.9	1740	1740		
Rangia	S 1	2	100	0.07, 0.16	98.4	31.1, 98.4		
Rangia	S 7	2	100	0.11, 0.12	129	105, 129		
Rangia	S 6	1	100	0.12	74.3	74.3		
Rangia	G 25**	1	100	0.1	50.4	50.4		
Rangia	HM 12**	1	100	0.06, 0.09	52.6	52.6		
Rangia	HM 22	1	100	0.11	60.2	60.2		
Rangia	All Stations	8	100	0.06, 0.16	129		74.3	31/ 129/ 98

* *Values given are average of duplicate analyses

Table 4-2H. Manganese (ug/g wet wt.)

Species	Station	N	% Detects	Min, Max Det. Limits	ug/g Maximum	ug/g Values	Median	Min/Max/Range
Cyathura	S 6	1	100	1.4	603	603		
Cyathura	HM 12	1	100	1.25	191	191		
Cyathura	HM 16	1	100	0.52	215	215		
Cyathura	All Stations	4	100	0.05, 1.25	603		215	191/ 603/ 412
Macoma	HM 16	1	100	0.96	202	202		
Rangia	S 1	2	100	0.04, 0.08	138	33, 138		
Rangia	S 7	2	100	0.05, 0.06	77.9	18.4, 77.9		
Rangia	S 6	1	100	0.06	7.91	73.8		
Rangia	G 25**	1	100	0.05	11.8	11.8		
Rangia	HM 12**	1	100	0.05, 0.07	20.5	20.5		
Rangia	HM 22	1	100	0.05	15.7	15.7		
Rangia	All Stations	8	100	0.04, 0.08	138		33	12/ 138/ 126

* *Values given are average of duplicate analyses

Table 4-3. Levels of trace metals in the soft shell clam, *Mya arenaria*, from the Upper Chesapeake Bay: 1990-1994. Original wet weight data (ug/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.

Table 4-4. Baseline trace metal levels in pooled *Macoma* and *Cyathura* samples. Data from May 1983, HMI Second Year Data Report (Wright and Striegel 1984).
Estimated ug/g wet weight concentrations from original dry weight data.*

Species		As	Cd	Cr	Cu	Ni	Zn
Macoma	Median	0.04	0.43	2.08	20.21	2.71	84.56
	Minimum	0.02	0.36	1.81	17.48	1.86	50.75
	Maximum	0.05	0.67	3.33	33.29	3.68	101
Cyathura	Median	0.01	0.36	5.49	71.38	3.85	33.63
	Minimum	0.01	0.20	3.26	39.5	0.88	25.75
	Maximum	0.02	0.69	13.50	140.25	10.24	38

* Dry weights divided by 8 for estimated wet weights.

Table 4-5 (A and B). Limits of detection: Semivolatile organics and pesticide/pcb organics, HMI Thirteenth Year Tissue Samples.

Table 4-5a. LIMITS OF DETECTION: Semivolatile organics HMI Thirteenth Year Tissue Samples

Compound	Rangia	Macoma	Cyathura*
	sample range: ug/kg wet wt.		
PAHs			
Naphthalene	320-920	11000	7800-36000
Acenaphthylene	"	"	"
Acenaphthene	"	"	"
Fluorene	"	"	"
Phenanthrene	"	"	"
Anthracene	"	"	"
Fluoranthene	"	"	"
Pyrene	"	"	"
Chrysene	"	"	"
Benzo(a)anthracene	"	"	"
Benzo(b+k)fluoranthene	"	"	"
Benzo(a)pyrene	"	"	"
Dibenz(ah)anthracene	"	"	"
Indeno(1,2,3-cd)pyrene	"	"	"
Benzo(ghi)perylene	"	"	"
Hexachlorobenzene	320-920	11000	420-36000
Phthalate esters			
Dimethyl phthalate	800-2400	26000	2000-90000
Diethylphthalate	"	"	"
Di-n-butylphthalate	"	"	"
Butylbenzylphthalate	"	"	"
Bis(2-ethylhexyl)phthalate	"	"	"
Di-n-octyl phthalate	"	"	"

* Sample S4 not included.

Table 4-5b. LIMITS OF DETECTION: Pesticide/PCB organics HMI Thirteenth Year Tissue Samples

Compound	Rangia	Macoma	Cyathura*
	sample range: ug/kg wet wt.		
a-BHC	2.2-7.1	37	37-180
g-BHC	"	"	"
Heptachlor	"	"	"
Heptachlor Epoxide	"	"	"
Dieldrin	"	"	"
4,4'-DDE	"	"	"
4,4'-DDD	"	"	"
4,4'-DDT	"	"	"
cis-Chlordane	"	"	"
trans-Chlordane	"	"	"
trans-Nonachlor	"	"	"
Chlordane	65-210	1100	1100-5300
Toxaphene	"	"	"
PCB-1016	"	"	"
PCB-1221	"	"	"
PCB-1232	"	"	"
PCB-1242	"	"	"
PCB-1248	"	"	"
PCB-1254	"	"	"
PCB-1260	"	"	"

* Sample S4 not included.

Table 4-6 (A and B). QC Semivolatile Surrogate Spikes (a) and Pesticide/PCBs Surrogate Spikes (b), HMI Tissue Samples, April 1994.

**Table 4-6a. QC Semivolitile Surrogate Spikes,
HMI Tissue Samples, April 1994**

Species	Station/ Sample	Sample #	Nitro-benzene-d5	2-Fluro-biphenyl	Terphenyl-d14
			% recovery		
Cyathura	S 6-2	94473	51	53	63
Cyathura	HM 12-2	94476	23	25	31
Cyathura	HM 16-2	94471	34	36	42
All Cyathura	minimum		23	25	31
	maximum		51	53	63
	median		34	36	42
Macoma	HM 16-1	94470	46	40	42
Rangia	S 1-1	94480	66	65	78
Rangia	S 1-2	94481	63	71	98
Rangia	S 7-1	94478	68	76	103
Rangia	S 7-2	94479	59	67	90
Rangia	S 6-1	94472	48	48	61
Rangia	G 25-1a*	94474	93	100	110
Rangia	G 25-1b		56	61	69
Rangia	HM 12-1a*	94475	38	20	18
Rangia	HM 12-1b		54	60	68
Rangia	HM 22-1	94482	30	39	55
All Rangia	minimum		30	20	18
	maximum		93	100	110
	median		57.5	63	73.5
Cyathura (Rangia ?)	S 4-1** (HM-22-2 ??)	94477	49	61	83

*duplicated sample
**Sample identity suspect. See text for explanation

Table 4-6b. QC Pesticides/ PCBs Surrogate Spikes
HMI Tissue Samples, April 1994

Species	Station/ Sample	Sample #	4,4'-Dibromoocta-fluorobiphenyl	Dibutyl-cholorendate
			% Recovery	
Cyathura	S 6-2	94473	35	291
Cyathura	HM 12-2	94476	39	43
Cyathura	HM 16-2	94471	42	50
All Cyathura	minimum		35	43
	maximum		42	291
	median		39	50
Macoma	HM 16-1	94470	0	50
Rangia	S 1-1	94480	15	190
Rangia	S 1-2	94481	37	26
Rangia	S 7-1	94478	37	37
Rangia	S 7-2	94479	3	13
Rangia	S 6-1	94472	8	116
Rangia	G 25-1a*	94474	9	27
Rangia	G 25-1b		20	30
Rangia	HM 12-1a*	94475	41	55
Rangia	HM 12-1b		26	98
Rangia	HM 22-1	94482	11	204
All Rangia	minimum		3	13
	maximum		41	204
	median		17.5	46
Cyathura (Rangia ??)	S 4-1** (HM-22-2 ??)	94477	0	7

*duplicated sample
**Sample identity suspect. See text for explanation

Table 4-7. Organic contaminant burdens in HMI Thirteenth Year biota samples.

Table 4-7. Organic contaminant burdens in HMI Thirteenth Year biota samples
Values in ug/kg wet wt.

Species	Station	Sample #	Phthalates				
			dimethyl	diethyl	bis-2-e*	di-n-butyl	di-n-octyl
Cyathura	S6-2	94473		117000	208000		
Rangia	HM-12a+	94475			11300		
Rangia	HM-12b				nd		
Rangia	S1-2	94481			1400		
Rangia	S7-1	94478		1500	800	800	1100
Rangia	S7-2	94479			7100		
Cyathura	S4-1**	94477		10000			
LRB (ppb)			700		870000	1000	

* Bis (2-ethylhexyl) phthalate (or diethylhexylphthalate, DEHP)
**Sample identity and location suspect. See text for explanation.
+duplicated sample
LRB: Laboratory reagent blank

Table 4-8 (a and b). Limits of detection: Semivolatile organics (a) and Pesticide/PCB organics (b), HMI Thirteenth Year Sediment Samples.

Table 4-8a. LIMITS OF DETECTION: Semivolatile organics
HMI Thirteenth Year Sediment Samples

Compound	detection limit range ug/kg dry wt.
PAHs	
Naphthalene	110-190
Acenaphthylene	"
Acenaphthene	"
Fluorene	"
Phenanthrene	"
Anthracene	"
Fluoranthene	"
Pyrene	"
Chrysene	"
Benzo(a)anthracene	"
Benzo(b+k)fluoranthene	"
Benzo(a)pyrene	"
Dibenz(ah)anthracene	"
Indeno(1,2,3-cd)pyrene	"
Benzo(ghi)perylene	"
Hexachlorobenzene	110-190
Phthalate esters	
Dimethyl phthalate	260-480
Diethylphthalate	"
Di-n-butylphthalate	"
Butylbenzylphthalate	"
Bis(2-ethylhexyl)phthalate	"
Di-n-octyl phthalate	"

Table 4-8b. LIMITS OF DETECTION: Pesticide/PCB organics
HMI Thirteenth Year Sediment Samples

Compound	detection limit range ug/kg dry wt.
a-BHC	10
g-BHC	"
Heptachlor	"
Heptachlor Epoxide	"
Dieldrin	"
4,4'-DDE	"
4,4'-DDD	"
4,4'-DDT	"
cis-Chlordane	"
trans-Chlordane	"
trans-Nonachlor	"
Chlordane	"
Toxaphene	250
PCB-1016	"
PCB-1221	"
PCB-1232	"
PCB-1242	"
PCB-1248	"
PCB-1254	"
PCB-1260	"

Table 4-9. HMI Sediment organics and sample descriptions. April, 1994 Samples.

Station/ Sample	Nearest Benthic St.	%C	%H	%N	phthalates (ug/kg dry wt.)		
					diethyl	bis(2-e)*	di-n-butyl
WRA 34	HM16	3.68	1.02	0.30	1120	1250	52100
WRA 34 dup.					nd	898	30700
WRA 30	HM12	4.03	0.97	0.27	nd	nd	5680
WRA 25-1	G25	4.44	0.99	0.23	nd	505	7680
WRA 25-2	G25	4.25	0.99	0.31	nd	439	8040
WRA BC3	S3, S4	3.30	0.77	0.26	nd	526	28200
WRA 24	S7	1.04	0.30	0.08	nd	278	59800
WRA 28	HM9	2.77	0.74	0.23	nd	452	3210
WRA BC6	Hawk Cove	3.33	0.92	0.26	nd	542	35100
WRA23-1	HM26	1.94	0.52	0.21	nd	nd	1840
WRA 23-2	HM26	1.95	0.52	0.15	nd	nd	4490
LRB (ppb)					700	13000	890

LRB: Laboratory reagent blank

* Bis (2-ethylhexyl) phthalate (or diethylhexylphthalate, DEHP)

%C: % carbon; %H: % hydrogen; %N: % nitrogen

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APPENDIX A

HART AND MILLER BEACH PROFILE DATA, JUNE 1994

Analysis of Profile Changes Between:

PROFILE 21+75
Survey 121(93/06/03) and Survey 131(94/07/06)
Start Distance = 222.00 FT, Ending Distance = 412.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
1	224.98	9.20	.27	2.47	.27	.27
2	345.29	2.28	-6.74	-1.51	-6.46	7.01
END	412.00	-1.20	.90	.36	-5.57	7.91

Volume Change: Above Datum = -5.84 YD3/FT , Below Datum = .27 YD3/FT
The Shoreline changed 6.30 FT, from 368.71 FT to 375.01 FT

PROFILE 24
Survey 121(93/06/03) and Survey 131(94/07/06)
Start Distance = 214.00 FT, Ending Distance = 361.00 FT

Cut/ Fill Cell	Distance to end FT	Elevation of end pt FT	Cell Volume YD3/FT	Cell Thickness FT	Profile Cum.Vol. YD3/FT	Profile Gross Vol. YD3/FT
END	361.00	-1.11	-1.94	-.36	-1.94	1.94

Volume Change: Above Datum = -1.46 YD3/FT, Below Datum = -.49 YD3/FT
The Shoreline changed -13.65 FT, from 304.71 FT to 291.06 FT

```
PROFILE 28
Survey  121(93/06/03) and  Survey  131(94/07/06)
 Start Distance =   170.00 FT,   Ending Distance =   304.00 FT

 Cut/    Distance        Elevation        Cell        Cell            Profile          Profile
 Fill    to end          of end pt        Volume  Thickness       Cum.Vol.         Gross Vol.
 Cell    FT              FT               YD3/FT      FT           YD3/FT           YD3/FT
------------------------------------------------------------------------------------------------
   1   202.14            2.94     -2.00        -1.68           -2.00              2.00
   2   228.93             .66       .33          .34          -1.67              2.33
   3   246.00            -.51                 -.14         -.22           -1.81             2.47
 END 304.00              -1.05                 .12          .05           -1.69             2.59
 Volume Change: Above Datum = -1.72 YD3/FT, Below Datum = .03 YD3/FT
 The Shoreline changed  -4.60 FT, from 238.54 FT to 233.94 FT


PROFILE 30
Survey  121(93/06/03) and  Survey  131(94/07/06)
 Start Distance =   146.00 FT,   Ending Distance =   284.00 FT

 Cut/    Distance        Elevation        Cell        Cell            Profile          Profile
 Fill    to end          of end pt        Volume  Thickness       Cum.Vol.         Gross Vol.
 Cell    FT              FT               YD3/FT      FT           YD3/FT           YD3/FT
------------------------------------------------------------------------------------------------
   1   164.60             5.54            -.16        -.23           -.16              .16
   2   189.57             2.36            -.46        -.61           -.62              .62
   3   233.77             -.78            -.80        -.67          -1.42             1.42
 END284.00               -1.00            -.10        -.06          -1.52             1.52
 Volume Change: Above Datum = -1.02 YD3/FT, Below Datum = -.51 YD3/FT
 The Shoreline changed -13.91 FT, from 223.52 FT to 209.61 FT


PROFILE 32
Survey  121(93/06/03) and  Survey  131(94/07/06)
 Start Distance =   143.00 FT,   Ending Distance =   291.00 FT

 Cut/    Distance        Elevation        Cell        Cell            Profile          Profile
 Fill    to end          of end pt        Volume  Thickness       Cum.Vol.         Gross Vol.
 Cell    FT              FT               YD3/FT      FT           YD3/FT           YD3/FT
------------------------------------------------------------------------------------------------
   1    230.84            -.67           -1.03        -.42          -1.03             1.03
 END 291.00               -.92            -.01        -.01          -1.05             1.05
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 Volume Change: Above Datum = -.72 YD3/FT, Below Datum = -.32 YD3/FT
 The Shoreline changed  -16.59 FT, from 216.90 FT to 200.31 FT


PROFILE 36
Survey  121(93/06/03) and  Survey  131(94/07/06)
 Start Distance =   174.00 FT,   Ending Distance =   331.00 FT

 Cut/   Distance        Elevation     Cell       Cell         Profile         Profile
 Fill   to end          of end pt     Volume  Thickness    Cum.Vol.        Gross Vol.
 Cell    FT             FT            YD3/FT      FT        YD3/FT          YD3/FT
------------------------------------------------------------------------------------------
   1   193.33           4.11          -.38       -.53       -.38             .38
   2   229.61            .44           .22        .32       -.16             .60
  END 331.00           -1.36          -2.08       .55       -2.24             2.68
 Volume Change: Above Datum = -.23 YD3/FT, Below Datum = -2.01 YD3/FT
 The Shoreline changed  -7.89 FT, from 240.91 FT to 233.03 FT

PROFILE 40
Survey  121(93/06/03) and  Survey  131(94/07/06)
 Start Distance =   176.00 FT,   Ending Distance =   238.16 FT
 Data extrapolated to Datum.  Extrapolated cells
 and values affected by extrapolation marked with *

 Cut/   Distance        Elevation     Cell       Cell         Profile         Profile
 Fill   to end          of end pt     Volume  Thickness    Cum.Vol.        Gross Vol.
 Cell    FT             FT            YD3/FT      FT        YD3/FT          YD3/FT
------------------------------------------------------------------------------------------
  END* 238.16          .18            1.78        .77        1.78             1.78
 Volume Change: Above Datum =  1.79 YD3/FT*
 The Shoreline changed  2.37 FT*, from  238.16 FT  to  240.53 FT*


PROFILE 44
Survey  121(93/06/03) and  Survey  131(94/07/06)
 Start Distance =   140.00 FT,   Ending Distance =   290.00 FT

 Cut/   Distance        Elevation     Cell       Cell         Profile         Profile
 Fill   to end          of end pt     Volume  Thickness    Cum.Vol.        Gross Vol.
 Cell    FT             FT            YD3/FT      FT        YD3/FT          YD3/FT
------------------------------------------------------------------------------------------
   1    152.78          7.06          -.15       -.32       -.15             .15
   2    209.47          -.23          2.76       1.32       2.61             2.91
```

```
 END  290.00        -1.19         .32        .13        2.94          3.23
Volume Change: Above Datum =  2.59 YD3/FT, Below Datum =  .34 YD3/FT
The Shoreline changed 4.70 FT,  from 202.76 FT to  207.46 FT


PROFILE 48
Survey  121(93/06/03) and  Survey  131(94/07/06)
 Start Distance =  104.00 FT,   Ending Distance =   266.00 FT

Cut/   Distance       Elevation      Cell       Cell         Profile        Profile
Fill   to end         of end pt      Volume   Thickness    Cum.Vol.       Gross Vol.
Cell    FT            FT             YD3/FT      FT          YD3/FT         YD3/FT
------------------------------------------------------------------------------------------
   1   126.07          8.65          -.40       -.49          -.40           .40
   2   240.06         -1.08         -2.97       -.73         -3.37          3.37
 END  266.00          -1.16          .03        .03         -3.34          3.39
Volume Change: Above Datum = -2.40 YD3/FT , Below Datum = -.95 YD3/FT
The Shoreline changed -15.16 FT,  from 178.88 FT to 163.71 FT


PROFILE 49
Survey  121(93/06/03) and  Survey  131(94/07/06)
 Start Distance =  128.00 FT,   Ending Distance =   270.00 FT

Cut/   Distance       Elevation      Cell       Cell         Profile        Profile
Fill   to end         of end pt      Volume   Thickness    Cum.Vol.       Gross Vol.
Cell    FT            FT             YD3/FT      FT          YD3/FT         YD3/FT
------------------------------------------------------------------------------------------
 END   270.00         -1.02         -1.47       -.31         -1.47          1.47
Volume Change: Above Datum = -1.05 YD3/FT , Below Datum = -.42 YD3/FT
The Shoreline changed   -8.40 FT,  from 187.47 FT to 179.07 FT
```

APPENDIX B (Project IV): Benthic Sample Descriptions and Summary of HMI Metal Analyses, April 1994.

Appendix B-1. Benthic Sample Descriptions, April 1994 Samples

Species	Station/ Sample	Sample #	ALI sample #	# organisms in sample	size range mm	% lipid	tissue wt (g)		
							total	metals	organics
Cyathura	S 6-2	94473	4	12	16-22	N/A	0.28	0.09	0.16
Cyathura	HM 12-2	94476	7	18	12-22	N/A	0.37	0.1	0.22
Cyathura	HM 16-2	94471	2	21	15-21	N/A	0.95	0.24	0.61
Macoma	HM 16-1	94470	1	6	16-17	N/A	0.82	0.13	0.59
Rangia	S 1-1	94480	11	7	31-36	24	8.04	1.54	5.26
Rangia	S 1-2	94481	12	5	41-43	11	13.49	3.43	9.15
Rangia	S 7-1	94478	9	6	40-41	4.3	15.41	2.31	11.15
Rangia	S 7-2	94479	10	8	31-33	7.7	7.68	2.03	4.92
Rangia	S 6-1	94472	3	3	42-45	17	7.95	2.14	5
Rangia	G 25-1a* G 25-1b	94474	5	19	32-38	7.3	36.95	2.45 2.2	8.77 8.62
Rangia	HM 12-1a* HM 12-1b	94475	6	10	38-43	4.3	38.22	2.65 4.03	8.94 7.95
Rangia	HM 22-1	94482	13	14	31-33	7.8	17.3	2.31	6.75
?Cyathura Rangia??	S 4-1 ?? HM-22 ??	94477	8	6	12-22	9.4	13.92+	2.77	8.28

* Duplicated sample

+Sample tissue weight suspect. ALI confirmed accuracy of weight determination, but could not verify species identification as provided on chain of custody form.

N/A: not applicable. Insufficient sample to obtain reliable result for lipid analysis

Appendix B-2. Summary of HMI Metal Analyses, April 1994 Samples

Species	Station	Size range	As	Cd	Cr	Cu	Ni	Zn	Fe	Mn
		mm	ug/g wet wt.							
Cyathura	S 6-2	16-22	11.3	2.36	1.81	137	<3.1	359	539	603
Cyathura	HM 12-2	12-22	7.65	<1	1.33	57.7	<2.75	150	335	191
Cyathura	HM 16-2	15-21	3.46	1.24	0.77	69.9	1.5	283	404	215
Cyathura	All Stations	12-22	1.1-11.3	0.2-2.4	0.4-1.8	2.1-137	1.5-9.6	27-359	64-539	22-603
Macoma	HM 16-1	16-17	7.89	1.83	3.64	26	5.05	203	1740	202
Rangia	S 1-1	31-36	1.48	0.42	0.72	1.98	6.61	40.2	98.4	138
Rangia	S 1-2	41-43	0.81	0.23	0.26	2.4	3.49	18.8	31.1	33
Rangia	S 7-1	40-41	1.21	0.25	3.24	2.75	4.46	21.7	129	18.4
Rangia	S 7-2	31-33	0.97	0.37	7.72	2.33	4.8	31.4	105	77.9
Rangia	S 6-1	42-45	1.89	0.19	0.64	2.93	7.91	30.6	74.3	73.8
Rangia	G 25-1a	32-38	0.84	0.28	0.3	1.99	5.29	20.4	47.5	11.6
Rangia	G 25-1b		1.1	0.16	0.34	1.66	5.33	20.2	53.3	11.9
Rangia	HM 12-1a	38-43	1.39	0.21	0.34	2.3	6.89	20	61.5	19.8
Rangia	HM 12-1b		1.06	0.19	0.26	1.87	7.97	21.1	43.7	21.2
Rangia	HM 22-1	31-33	0.61	0.25	0.57	1.83	5.57	26.5	60.2	15.7
Rangia	All Stations	31-45	0.6-1.9	0.16-0.4	0.26-7.7	1.7-2.9	3.5-8	19-40	31-129	12-138
?Cyathura (Rangia ??	S 4-1* ?? (HM 22-2)	12-22	1.13	0.25	0.36	2.06	9.6	27	64.5	22.4

*Sample identity suspect. See text for explanation- Not used in either Rangia or Cyathura summary and discussion.

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