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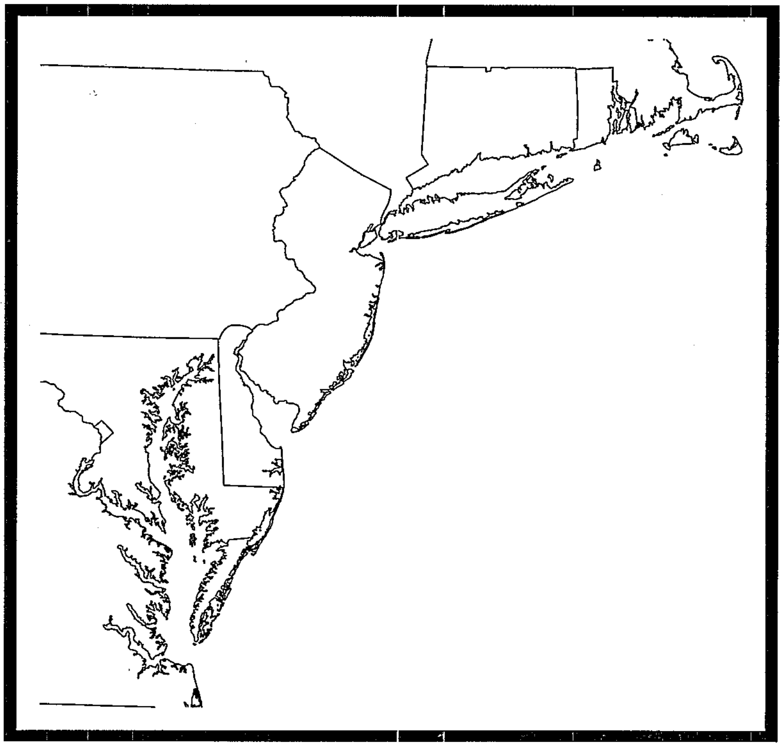
July 1994

EPA

Statistical Summary

EMAP-Estuaries Virginian Province-1992



Environmental Monitoring and Assessment Program

EMAP

EPA/620/R-94/019
July 1994

Statistical Summary
EMAP-Estuaries
Virginian Province - 1992

by

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ABSTRACT

Annual monitoring of indicators of the ecological condition of bays and estuaries within the Virginian Province (Cape Cod, MA to Cape Henry, VA) was conducted by the U.S. EPA's Environmental Monitoring and Assessment Program (EMAP) during July, August, and September, 1992. Data were collected at 126 stations within the Province. Indicators monitored included water quality (temperature, salinity, water clarity, and dissolved oxygen concentration), sediment contamination, sediment toxicity, benthic community structure, fish community structure, and fish gross external pathology. Data are used to estimate the current status of the ecological condition of Virginian Province estuarine resources, and provide a baseline for identifying future trends. Cumulative distribution functions (CDFs) and bar charts are utilized to graphically display data. Estimates, with 95% confidence intervals, are provided of the areal extent of degraded resources within the Province for those indicators where "degradation" can be defined. Data are also presented by estuarine class: Large estuaries, small estuarine systems, and large tidal rivers. Included, as an appendix, are sub-population estimates for Chesapeake Bay and Long Island Sound.

KEY WORDS: EMAP; Environmental Monitoring and Assessment Program; Environmental Monitoring; Virginian Province; Indicators (biology); Estuaries; Estuarine pollution.

DISCLAIMER

Mention of trade names, products, or services does not convey, and should not be interpreted as conveying, official EPA approval, endorsement, or recommendation.

This report represents data from a single year of field operations of the Environmental Monitoring and Assessment Program (EMAP). Because the probability-based scientific design used by the EMAP necessitates multiple years of sampling, there may be significant levels of uncertainty associated with some of these data. This uncertainty will decrease as the full power of the approach is realized by the collection of data over several years. Similarly, temporal changes and trends cannot be reported, as these require multiple years of observation. Please note that this report contains data from research studies in only one biogeographical region (Virginian Province) collected in a short index period (July to September) during a single year (1992). Appropriate precautions should be exercised when using this information for policy, regulatory or legislative purposes.

PREFACE

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ACKNOWLEDGEMENTS

The work described in this document is the culmination of the efforts and dedication of dozens of individuals. The authors would like to acknowledge the efforts of Warren Boothman, Dan Campbell, James Heltshe, Melissa Hughes, Rich Pruell, Dan Reifsteck, Steve Schimmel, John Scott, Kevin Summers, and Ray Valente for their invaluable assistance in the preparation of this document.

Researchers at EPA (Cincinnati and Narragansett), Cove Corporation, Science Applications International Corporation, and Versar, Inc. contributed significantly to this effort through the analysis of samples. Field crews were provided through an EPA Cooperative Agreement to a consortium of universities (University of Rhode Island, Rutgers, Philadelphia Academy of Science, and University of Maryland).

In addition to those listed above, reviewers of this document included Richard Latimer, Norman Rubinstein, Gerald Pesch, Brian Melzian, William Muir and Judith Pederson.

Most importantly, we would like to acknowledge the tremendous effort of all those involved in the 1992 field effort. Despite sea sickness, 16-hour days, equipment failure, uncooperative motel telephone systems, and inclement weather, the six field crews successfully completed, to the high standards set for the Program, the data collection phase. Without their dedication to the Program this Statistical Summary would not be possible. The staff of the Field Operations Center in Narragansett, RI also played a critical role in the success of the Program; managing the field effort, and tracking, checking, and managing the tremendous volume of data received over a relatively short period of time.

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ABBREVIATIONS

AVS	Acid Volatile Sulfide
BSS	Base Sampling Site
CDF	Cumulative Distribution Function
DBT	Dibutyltin
DO	Dissolved Oxygen
dry wt	Dry weight
EMAP	Environmental Monitoring and Assessment Program
EMAP-E	EMAP-Estuaries
MBT	Monobutyltin
mg/L	milligrams per liter = parts per million (ppm)
mg/kg	milligrams per kiligram = parts per million (ppm)
kg/m^3	kilograms per cubic meter
ND	Not Detected
ng/g	nanograms per gram = parts per billion (ppb)
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
QA	Quality Assurance
QC	Quality Control
SQC	Sediment Quality Criteria
TBT	Tributyltin
µg/g	micrograms per gram = parts per million (ppm)
µ	Micron
Δ	Delta
σ_t	Sigma-t
‰	parts per thousand (ppt)

EXECUTIVE SUMMARY

The Environmental Monitoring and Assessment Program (EMAP) is a nationwide program initiated by EPA's Office of Research and Development (ORD). EMAP was developed in response to the demand for information about the degree to which existing pollution control programs and policies protect the nation's ecological resources.

EMAP-Estuaries (EMAP-E) represents EMAP's efforts in near-coastal environments. These efforts are designed to provide a quantitative assessment of the regional extent of coastal environmental problems by measuring status and change in selected indicators of ecological condition. Specific environmental problems investigated include:

- hypoxia,
- sediment contamination,
- coastal eutrophication, and
- habitat loss.

In 1990, EMAP-E initiated a demonstration project in the estuaries of the Virginian Province. The 1992 field season represents the third year of sampling in the Province, which includes the coastal region of the Northeast United States from Cape Cod south to the mouth of Chesapeake Bay. It is composed of 23,574 km^2 of estuarine resources including 11,469 km^2 in Chesapeake Bay and 3,344 km^2 in Long Island Sound.

Estuarine resources in the Virginian Province were stratified into classes by physical dimension for the purposes of sampling and analysis. Large estuaries in the Virginian Province were defined as those estuaries greater than 260 km^2 in surface area and with aspect ratios (*i.e.*, length/average width) of less than 18. The areal extent of large estuaries in the Province was 16,097 km^2. Large tidal rivers were defined as that portion of the river that is tidally influenced (*i.e.*, detectable tide > 2.5 cm), greater than 260 km^2 in surface area, and with an aspect ratio of greater than 18. Approximately 2,602 km^2 were classified as tidal rivers. The third class was the small estuaries and small tidal rivers which included those systems whose surface areas fell between 2.6 km^2 and 260 km^2. This class represented 4,875 km^2 of the Virginian Province.

Three field crews sampled 126 sites in the Virginian Province during the six-week sampling period beginning on July 27, 1992. Of these, 103 were "Base Sampling Sites" (BSS) which were the probability-based sites selected according to the EMAP-E design for assessing the condition of the estuarine resources of the Province. Only data collected at these sites were used in the generation of this report.

The 1992 data reported in this document represent only one year of sampling of a four-year cycle; *i.e.*, the total number of samples needed by EMAP to characterize the Province are sampled over a four-year period (Holland, 1990). Therefore, the reader must use these data carefully, and be aware that the proportion of degraded area calculated for 1992 may differ somewhat from the regional assessment to be generated following the completion of the four-year cycle.

All EMAP-VP data used in the generation of this report were subjected to rigorous quality assurance measures as described in the 1992 Quality Assurance Project Plan (Valente *et al.*, 1992).

Biotic Condition Indicators

Biotic condition indicators are characteristics of the environment that provide quantitative evidence of the status of ecological resources and biological integrity of a sample site from which they are collected (Messer, 1990). Ecosystems with a high degree of biotic integrity (*i.e.*, healthy ecosystems) are composed of balanced populations of indigenous benthic and water column organisms with species compositions, diversity, and functional organization comparable to undisturbed habitats (Karr and Dudley, 1981; Karr *et al.*, 1986).

A benthic index which uses measures of organism health, functionality, and community condition to evaluate the condition of the benthic assemblage was utilized in the assessment of biological resources of the Virginian Province. The index under development was determined from the combined 1990/1991 data and is assumed to represent a combination of ecological measurements that best discriminates between good and poor ecological conditions. The reader should be cautioned that this index has not yet been fully validated with an independent dataset, and therefore, should be used with caution.

A benthic index critical value of zero was determined from the combined 1990/1991 Virginian Province dataset. Fourteen (± 6) percent of the bottom area of the Virginian Province sampled in 1992 had an index value of < 0, indicating likely impacts on the benthic community (Figure 1). The lowest incidence was found in the large estuaries (7 ± 8%), and the highest in large tidal rivers (37 ± 22%).

A "standard" fish trawl (trawling at a specified speed for a specified time) was performed at each station to collect information on the distribution and abundance of fish. Because many factors influence fish abundance, poor catch may not be an indication of degraded conditions, but simply the natural habitat. Catches of <10 fish/trawl (catch per unit effort) occurred at stations representing approximately 37 ± 12% of the Province, and "high" catches (>100 fish/trawl) were experienced at stations representing approximately 26 ± 11% of the area of the Province (Figure 2).

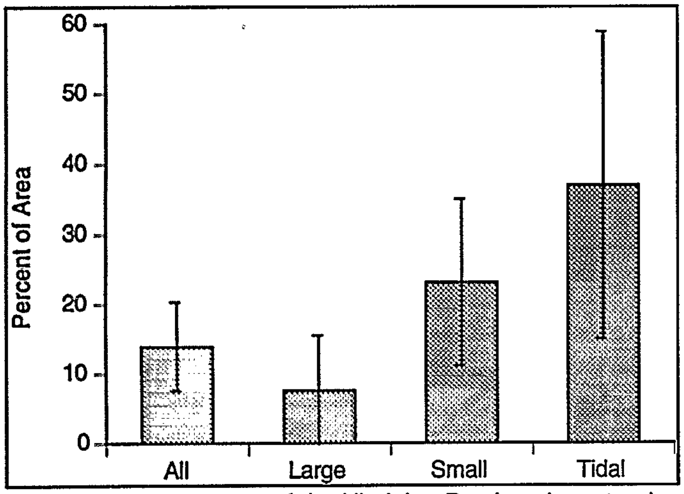


Figure 1. Percent area of the Virginian Province by estuarine class with a benthic index value below 0 in 1992. (Error bars represent 95% confidence intervals).

The incidence of the four gross external pathologies (growths, lumps, ulcers, and fin erosion) among fish collected in the Virginian Province in 1992 was 0.3%. Of the 3,290 fish examined, 10 were identified as having one or more of these pathologies. These individuals were collected at nine of the 103 base stations sampled during the index period.

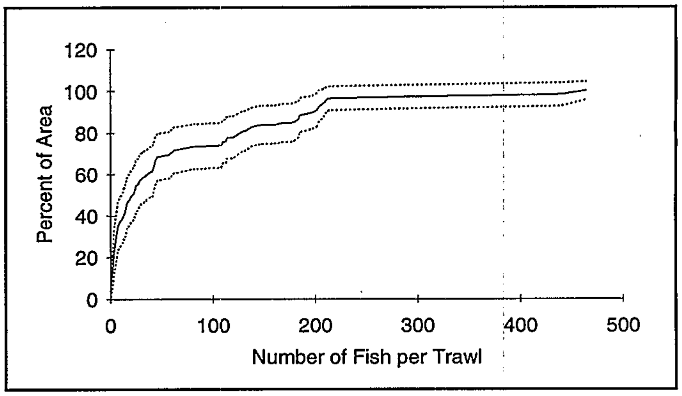


Figure 2. Cumulative distribution of fish abundance in number per standard trawl as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

Abiotic Condition Indicators

Abiotic condition indicators historically have been the mainstay of environmental monitoring programs, because these indicators quantify the levels of stresses to which organisms are exposed.

One potential stress to aquatic organisms is a low concentration of dissolved oxygen (DO). Two and five mg/L are values employed by EMAP to define severe and moderate hypoxia, respectively. Approximately 29 ± 10% of the sampled area of the Province lies in waters with bottom DO concentrations less than or equal to 5 mg/L (Figure 3). "Bottom" is defined as one meter above the sediment-water interface. Approximately 5 ± 5% of the sampled area exhibited bottom DO conditions ≤2.0 mg/L. Dissolved oxygen conditions ≤2.0 mg/l were evident in 7 ± 8% of the area of the large estuaries sampled within the Province and none of the small estuaries or large tidal rivers (Figure 3).

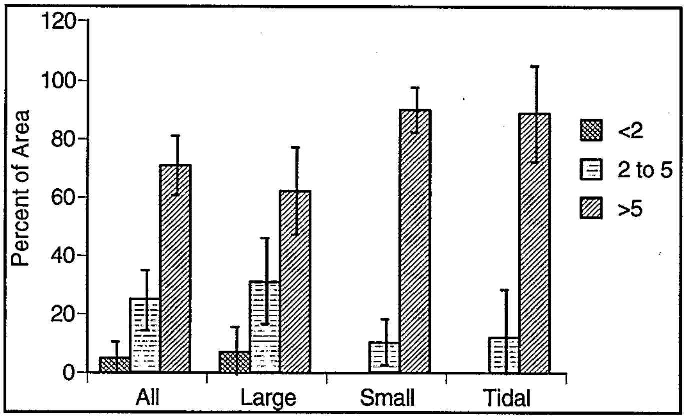


Figure 3. Percent of area by class that had low (0 to 2 mg/L), medium (2.1 to 5 mg/L), or high (>5 mg/L) oxygen concentration in the bottom waters. (Error bars represent 95% confidence intervals).

In addition to measuring individual stressors (*e.g.*, individual chemical analytes), sediment toxicity tests were performed on sediments collected at each site to determine if they were toxic to the tube-dwelling amphipod, *Ampelisca abdita*. Sediments were classified as toxic if amphipod survival in the test sediment was less than 80% of that in the control sediment and statistically different from control survival. Approximately 6 ± 5% of the sampled area of the Virginian Province contained sediments which were toxic to the amphipod during 10-day exposures (Figure 4).

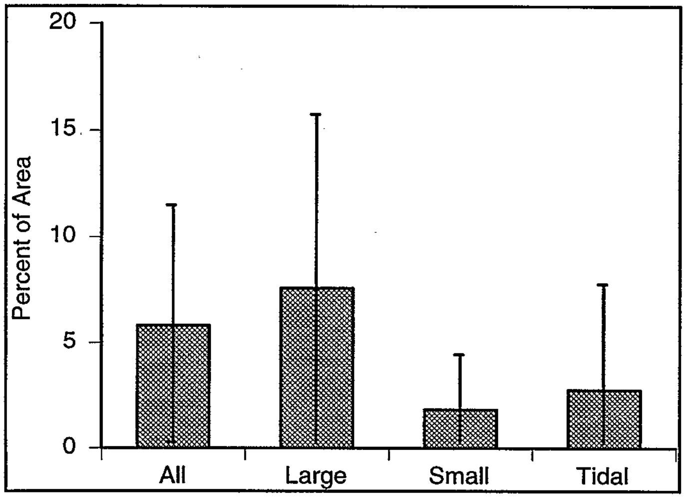


Figure 4. Percent of area in the Virginian Province in 1992, by estuarine class, with low amphipod survival (<80% of control) in sediment toxicity tests. (Error bars represent 95% confidence intervals).

Sediments collected at each station were analyzed for both organic contaminants and metals. Because of the complex nature of sediment geochemistry, the ecological impact of elevated contaminant levels is not well understood. Therefore, no attempt is made to estimate the overall aerial extent of sediment contamination in the Virginian Province.

Figure 5 shows the distribution of the sum of measured polycyclic aromatic hydrocarbons (PAHs) in the Virginian Province. The complete list of analytes included in this summation can be found in Section 3. Approximately 92 ± 7% of the Province has concentrations of PAHs below 4,000 ng/g dry weight, with a maximum measured concentration at any station of 13,219 ng/g.

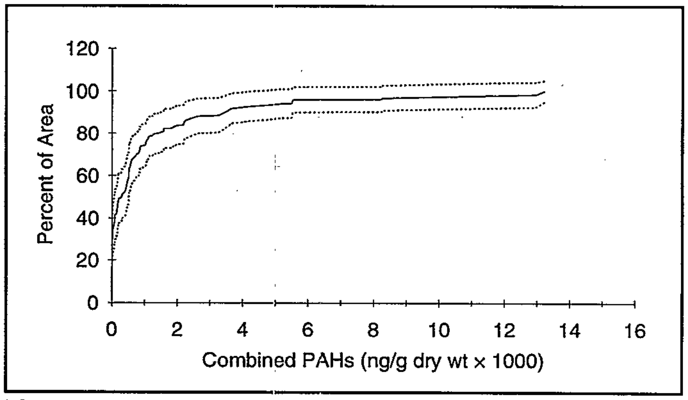


Figure 5. Cumulative distribution of combined PAHs in sediments as percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

Draft EPA Sediment Quality Criteria (SQC) are currently available for the PAHs acenaphthene, phenanthrene, and fluoranthene; and the pesticide dieldrin. Draft PAH SQC were not exceeded at any stations within the Province in 1992.

The extent to which polluting activities have affected concentrations of metals in sediments is complicated by the natural variation of metals in sediments. Crustal aluminum concentrations are generally many orders of magnitude higher than anthropogenic inputs; therefore, aluminum can be used to "normalize" for differing crustal abundances of trace metals. Figure 6 presents the results of this normalization. Approximately 31 ± 10% of the area of the Province showed enrichment of sediments with at least one metal. Twenty seven (± 13), 43 ± 13, and 34 ± 39 percent of the large estuary, small estuary,

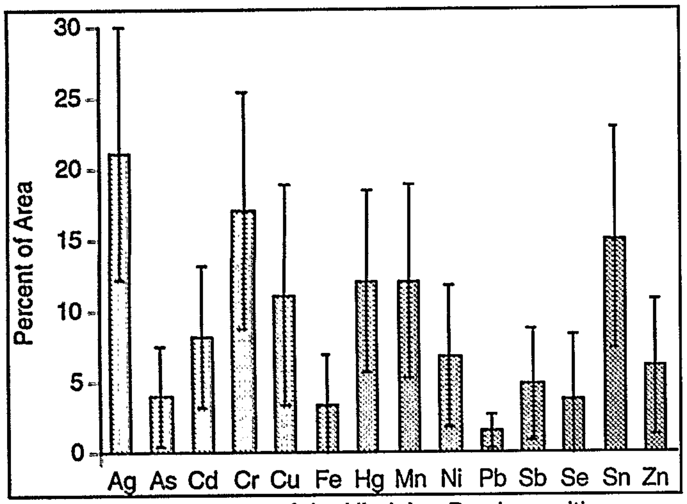


Figure 6. Percent area of the Virginian Province with enriched concentrations of individual metals in sediments in 1992. (Error bars represent 95% confidence intervals).

and large tidal river class areas sampled contained sediments with metals concentrations exceeding predicted background levels. This only shows the percent of the Province with elevated concentrations of metals, and does not indicate the magnitude of enrichment, *i.e.*, this does not imply concentrations are elevated to the point where biological effects might be expected.

Presence of marine debris in fish trawls was documented by field crews as being encountered at stations representing 25 ± 11% of the Virginian Province area (Figure 7). The small estuary class had

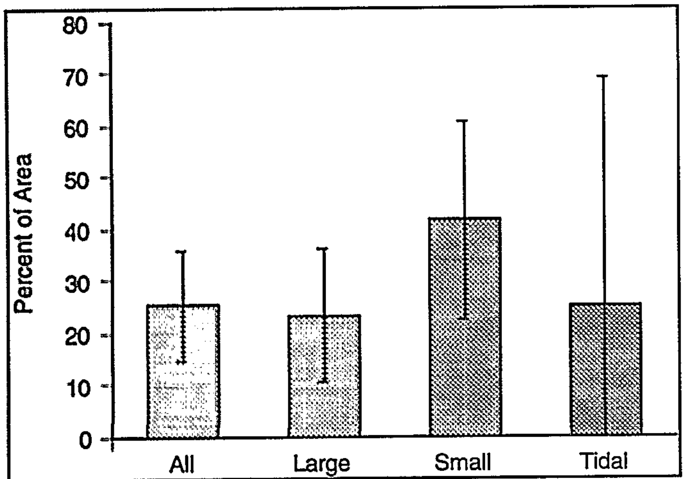


Figure 7. The percent of area of the Virginian Province by estuarine class where anthropogenic debris was collected in fish trawls, 1992. (Error bars represent 95% confidence intervals).

the largest percent area (42 ± 20%) where trash was found.

Habitat Characterization

Habitat indicators describe the natural physical and chemical conditions of the sites sampled. These parameters are important modifying factors controlling both abiotic and biotic condition indicators.

Figure 8 shows the distribution of water depth in the Virginian Province. The area shallower than 2 m is underestimated because this was the minimum depth sampled.

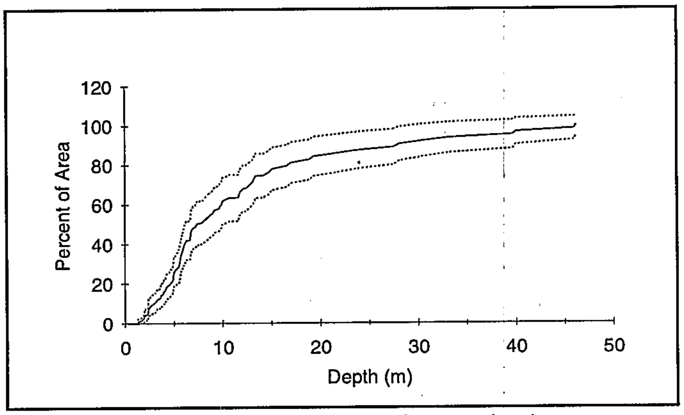


Figure 8. Cumulative distribution of water depth as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

Based on the sampling design where a single station represents a statistical area (*e.g.*, 70 km^2 for large estuary sites), 12.5% of the area of large estuaries could not be sampled due to inadequate water depth. Small systems were considered unsampleable if the water depth did not exceed 2 m anywhere in the system. Such systems account for approximately 0.5% of the area of small systems in the Virginian Province. No large tidal river stations were unsampleable due to water depth in 1992. Overall, 8.5% of the area of the Province was deemed unsampleable in 1992 due to water depth.

Bottom water temperatures in the Virginian Province ranged from 11.8°C to 27.8°C during the summer sampling season.

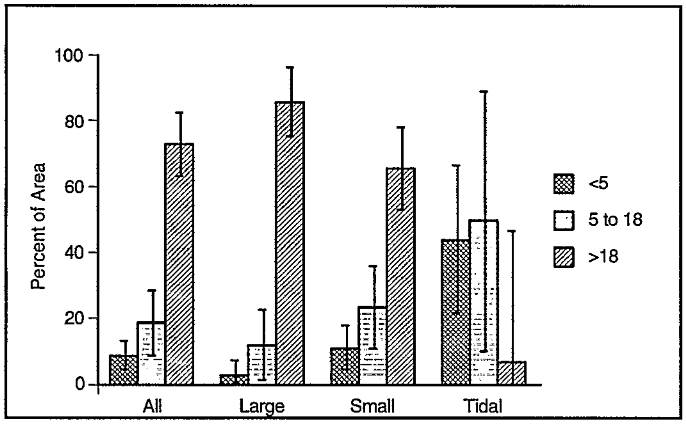


Figure 9. The percent of area by estuarine class classified as oligohaline (<5 ppt), mesohaline (5 to 18 ppt), and polyhaline (>18 ppt). (Error bars represent 95% confidence intervals).

Figure 9 illustrates the distribution of oligohaline (<5‰ salinity), mesohaline (5-18‰), and polyhaline (>18‰) water in the Virginian Province and by class.

Vertical density differences (a function of both salinity and temperature) in the waters of the Virginian Province can be large enough to result in a reduction in mixing between surface and bottom waters, potentially allowing the bottom waters to become hypoxic. Degree of stratification in the Virginian Province was measured as the delta (Δ) σ_t, which is the σ_t (sigma-t, a density measurement) difference between surface and bottom waters. Approximately 68 ± 11% of the Province area had a $\Delta\sigma_t$ of <1 unit; thus the majority of the water in the Virginian Province was well-mixed (Figure 10). Only 17 ± 10% of the Province area was strongly stratified ($\Delta\sigma_t$ >2).

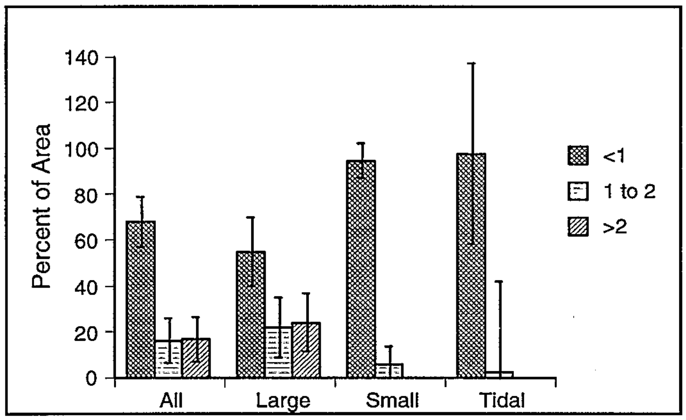


Figure 10. The percent of the area by estuarine class that had a low (<1), medium (1 to 2), or high (>2) degree of stratification (Δ σ_t). (Error bars represent 95% confidence intervals).

Water clarity was determined from light extinction coefficients, which describe the attenuation of light as it passes vertically through the water column. We are defining low water quality as water in which a diver would not be able to see his/her hand when held at arms length in front. Moderate water clarity, in terms of human vision, is defined as water in which a wader would not be able to see his/her feet in waist deep water.

Water clarity was good in 83 ± 8% of the area of the Virginian Province (Figure 11). Water of low clarity was found in 5 ± 6% of the Province and an additional 12 ± 6% had water of moderate clarity.

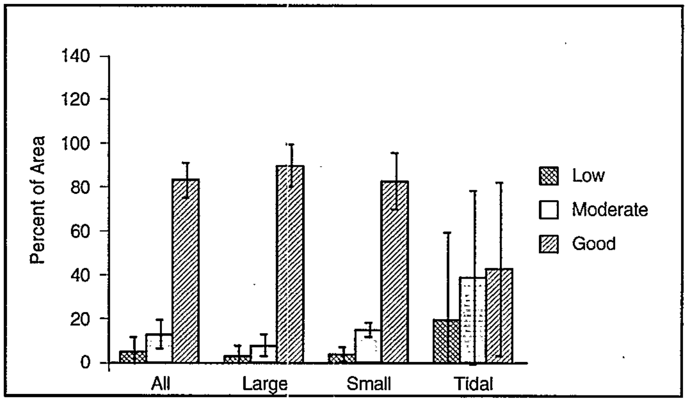


Figure 11. The percent of area by estuarine class where water clarity was poor, moderate, or good. (Error bars represent 95% confidence intervals).

The silt-clay (mud) content of sediments (the fraction <63μ particle diameter) is an important factor determining the composition of the biological community at a site, and is therefore important in the assessment of the benthic community. The distribution of mud (≥80% silt-clay) *vs* sand (≤20% silt-clay) is illustrated in Figure 12.

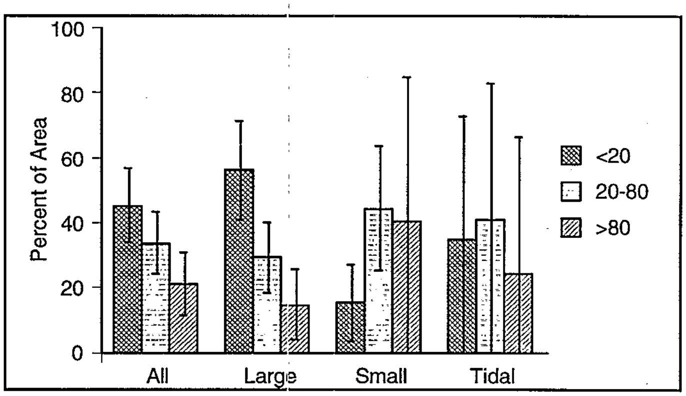


Figure 12. Percent of area by estuarine class with a low (<20), medium (20 to 80), or high (>80) percent silt-clay in the sediments. (Error bars represent 95% confidence intervals).

SECTION 1

INTRODUCTION

The Environmental Monitoring and Assessment Program (EMAP) is a nationwide program initiated by EPA's Office of Research and Development (ORD). EMAP was developed in response to the need to implement a monitoring program that contributes to comparative ecological risk assessment and decisions related to environmental protection and management. EMAP is an integrated federal program; ORD is coordinating the planning and implementation of EMAP with other federal agencies including the Agricultural Research Service (ARS), the Bureau of Land Management (BLM), the U.S. Fish and Wildlife Service (FWS), the Forest Service (FS), the U.S. Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA). These other agencies and offices participate in the collection and analysis of EMAP data and will use these data to guide their policy decisions as appropriate.

EMAP-Estuaries (EMAP-E) represents one portion of EMAP's efforts in near-coastal environments. These efforts are designed to provide a quantitative assessment of the regional extent of coastal environmental problems by measuring status and change in selected ecological condition indicators to address specific environmental problems including:

- hypoxia,
- sediment contamination,
- coastal eutrophication, and
- habitat loss.

In 1990, EMAP-E initiated a demonstration project in the estuaries of the Virginian Province (*i.e.*, estuaries, bays and sounds between Cape Cod, MA and Cape Henry, VA: Weisberg *et al.*, 1993). One of the objectives of the Demonstration Project was to test the EMAP design, logistical approach and various ecological condition indicators. Based on the experience of the 1990 Demonstration Project, EMAP-E modified minor aspects of the logistical plan for subsequent sampling years.

1.1 Objectives of 1992 Virginian Province Monitoring Activities

The specifics of the planning activities of the 1992 Virginian Province sampling effort are documented in the 1992 Virginian Province Logistics Plan (Strobel *et al.*, 1992), the 1992 Field Readiness Report (Reifsteck, 1992), and the 1992 Virginian Province Field Operations and Safety Manual (Reifsteck *et al.*, 1992). Sampling was conducted from 27 July through 31 August 1992, spanning 126 sites (stations). Approximately 30 field personnel and three extramural contracts or cooperative agreements were utilized for the sampling program.

The objectives of the 1992 Virginian Province monitoring program were to:

- continue the routine monitoring of the Province using selected indicators from the 1990 Demonstration Project;
- obtain data on Virginian Province-specific variability in ecological indicators; and
- develop and refine assessment procedures for determining the ecological status of estuaries and apply these procedures to establish baseline conditions in the Virginian Province.

As part of establishing baseline conditions in the Virginian Province, several assessment questions relating to ecological conditions were addressed. Among these questions are:

- What proportion of the bottom waters of the estuaries of the Virginian Province experience hypoxia (*e.g.*, dissolved oxygen concentrations $\leq$ 2 or 5 mg/L)?
- What proportion of the estuarine sediments of the Virginian Province have a benthic community structure indicative of polluted environments?
- What is the incidence of gross external pathologies among fish species in the Virginian Province?
- What proportion of estuarine sediments in the Virginian Province contain elevated levels of anthropogenic chemical contaminants?
- What proportion of estuarine sediments in the Virginian Province contain anthropogenic marine debris?

1.2 Program Design

Sample collection in the Virginian Province focused on ecological indicators (described in Holland, 1990 and Appendix A of the 1991 Statistical Summary; Schimmel *et al.*, 1994) during the index sampling period (July 1 - September 30); the period when many estuarine responses to anthropogenic and natural stresses are anticipated to be most severe. The proposed sampling design combines the strengths of systematic and random sampling with an understanding of estuarine ecosystems in order to provide a probability-based estimate of estuarine status in the Virginian Province.

A simple classification scheme based on the physical dimensions of an estuary was used to develop three classes of estuaries -- large estuaries, large tidal rivers, and small estuaries/small tidal rivers. Large estuaries in the Virginian Province were defined as those estuaries greater than 260 km^2 in surface area and with aspect ratios (*i.e.*, length/average width) of less than 18. Large tidal rivers were defined as that portion of the river that is tidally influenced (*i.e.*, detectable tide > 2.5 cm), greater than 260 km^2 in surface area, and with an aspect ratio of greater than 18. Small estuaries and small tidal rivers were designated as those systems whose surface areas fell between 2.6 km^2 and 260 km^2. These criteria resulted in the identification of 12 large estuaries; 5 large tidal rivers; and 144 small estuaries / small tidal rivers.

1.3 Data Limitations

The 1992 data represent only one year of sampling of a four year cycle; *i.e.*, the total number of samples needed to characterize the Province with the degree of confidence required by EMAP are sampled over a four-year period (Holland, 1990). Therefore, the reader must use these data carefully, and be aware that single-year results may differ from those reported following the completion of the four-year cycle (*i.e.*, 1990 - 1993).

EMAP is designed to provide data on a regional scale. This design creates an additional limitation for those interested in smaller scale studies. For example, each of the 144 small systems (*e.g.*, Raritan Bay or the Elizabeth River) is represented by a single station, the location of which is randomly selected. The assumption is made that this station is representative of an area of the Province equal to the area of that system. In total, these stations are expected to provide an accurate portrayal of conditions in small systems across the Province; however, the design, at its current scale, does not allow for the study of conditions in individual small systems. The reader should consult Appendix A of the 1991 Statistical Summary (Schimmel *et al.*, 1994) and the Near Coastal Program Plan (Holland, 1990) for additional information on the statistical design.

Lastly, a benthic index is currently under development to aid in the interpretation of benthic community data. This index has been developed using combined 1990/1991 data. The 1992 data appear to support the Index. However, the Index may be modified upon analysis of the complete four-year dataset; therefore, the Benthic Index that will appear in the four-year assessment report *may* differ slightly from the one included in this report.

1.4 Purpose and Organization of This Report

The Statistical Summaries that will be produced by EMAP-E are meant to provide large quantities of information without including extensive interpretation of these data. Interpretive reports are anticipated upon completion of each four-year cycle or in specialized documents such as the Virginian Province Demonstration Project Report (Weisberg *et al.*, 1993).

The purpose of this report is to provide estimates of the ecological condition of the estuarine resources of the Virginian Province for 1992 in a format similar to that used in the 1991 Virginian Province Statistical Summary (Schimmel *et al.*, 1994).

This report is organized into sections addressing the objectives and results of the 1992 Virginian Province monitoring program. Section 1 describes the objectives of the Program and limitations on the use of the data presented in this report.

Section 2 briefly summarizes logistical results of field sampling activities including station locations, percent of samples successfully collected, etc.

Section 3 is the statistical summary of the data collected during the 1992 survey.

Section 4 summarizes the findings of the 1992 monitoring program in the Virginian Province.

Section 5 lists the references cited in this report.

Appendix A provides sub-population estimates of ecological condition for Chesapeake Bay and Long Island Sound.

Appendix B presents the plots of the regressions of individual metals concentrations in sediments against aluminum concentrations used in the determination of areal extent of metals enrichment.

Appendix C summarizes the quality assurance/quality control results of the 1992 survey.

SECTION 2

OVERVIEW OF FIELD ACTIVITIES

The Virginian Province includes the coastal region of the northeast United States from Cape Cod south to the mouth of Chesapeake Bay. It is composed of 23,574 km^2 of estuarine resources including 11,469 km^2 in Chesapeake Bay and 3,344 km^2 in Long Island Sound.

The 1992 Virginian Province survey was conducted during late July through the end of August, 1992. A probability-based sampling design was used to sample major estuarine resources proportionately (Overton *et al.*, 1991; Stevens *et al.*, 1991). This design makes it possible to estimate the proportion or amount of area in the Virginian Province having defined environmental conditions.

One hundred and twenty six (126) stations in the Virginian Province, located between Nantucket Sound (MA) and Cape Henry (VA), were sampled during the six-week sampling period.

Sample collection in the Virginian Province focused on ecological indicators during the index sampling period (July 1 - September 30), when responses of estuarine resources to anthropogenic and natural stresses are anticipated to be most severe (e.g., high temperatures, low dissolved oxygen). The basic sampling design provides a probability-based estimate of estuarine status in the Virginian Province. Additional sites were also sampled to collect information for specific hypothesis testing and other specific study objectives (Strobel *et al.*, 1992).

Base Sampling Sites (BSS) are the probability-based sites which form the core of the EMAP-E monitoring design for all provinces, including the Virginian Province. Data collected from these sites are the basis of this statistical summary. There were 103 BSS to be sampled during the 1992 index period, representing approximately ¼ of the total number of base sites that will be sampled over the four-year cycle. Twenty two special study sites were also scheduled for sampling.

The 126 stations were divided among three sampling teams, each covering a specific area of responsibility (Figure 2-1). Each team was comprised of two, four-person alternating crews which sampled for six consecutive days. During the six-day period, the crew was assigned responsibility for sampling a cluster of stations. The order in which clusters were to be sampled was randomized to assure stations were not sampled across the Province in a North-South series. Each Base Sampling site was visited once during the index period. Long-term trends sites were visited twice. Figures 2-2, 2-3, and 2-4 present maps of all the base sampling sites scheduled for sampling in the 1992 Virginian Province monitoring program.

The 1992 Virginian Province monitoring program was successful in its attempt to collect large amounts of information and samples over a relatively short time period. The overall effectiveness of the 1992 sampling plan is reflected in the high percentage of stations for which usable data were obtained for the variety of parameters measured (Table 2-1). While all planned stations were sampled, not every station was sampled for every parameter, and not every sample was successfully processed. Additional stations were eliminated prior to the start of field operations due to inadequate water depth. Overall, 8.5% of the area of the Virginian Province originally scheduled to be sampled in 1992 could not be sampled due to inadequate water depth.

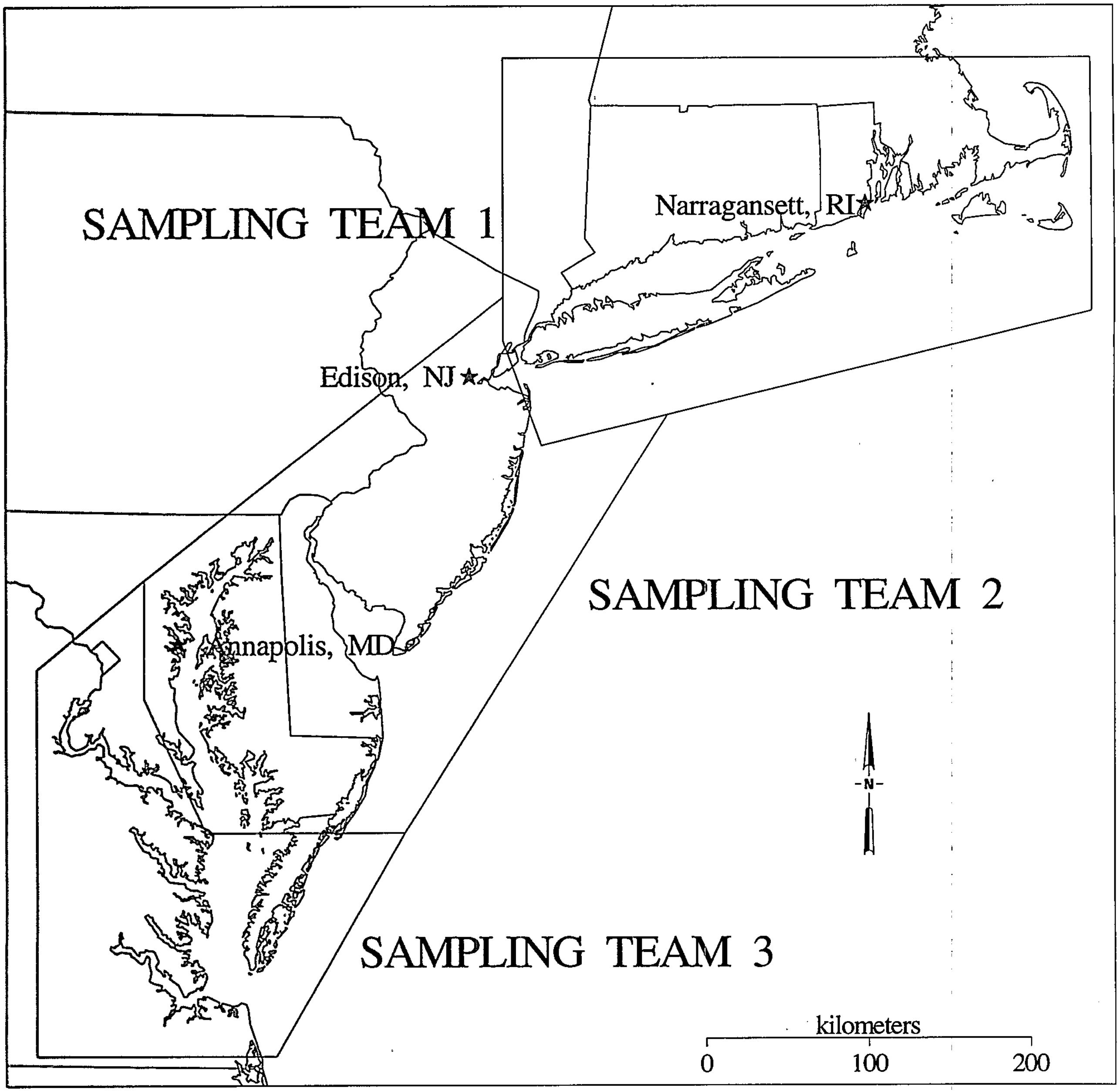


Figure 2-1. Areas of Responsibility of the EMAP-VP Sampling Teams.

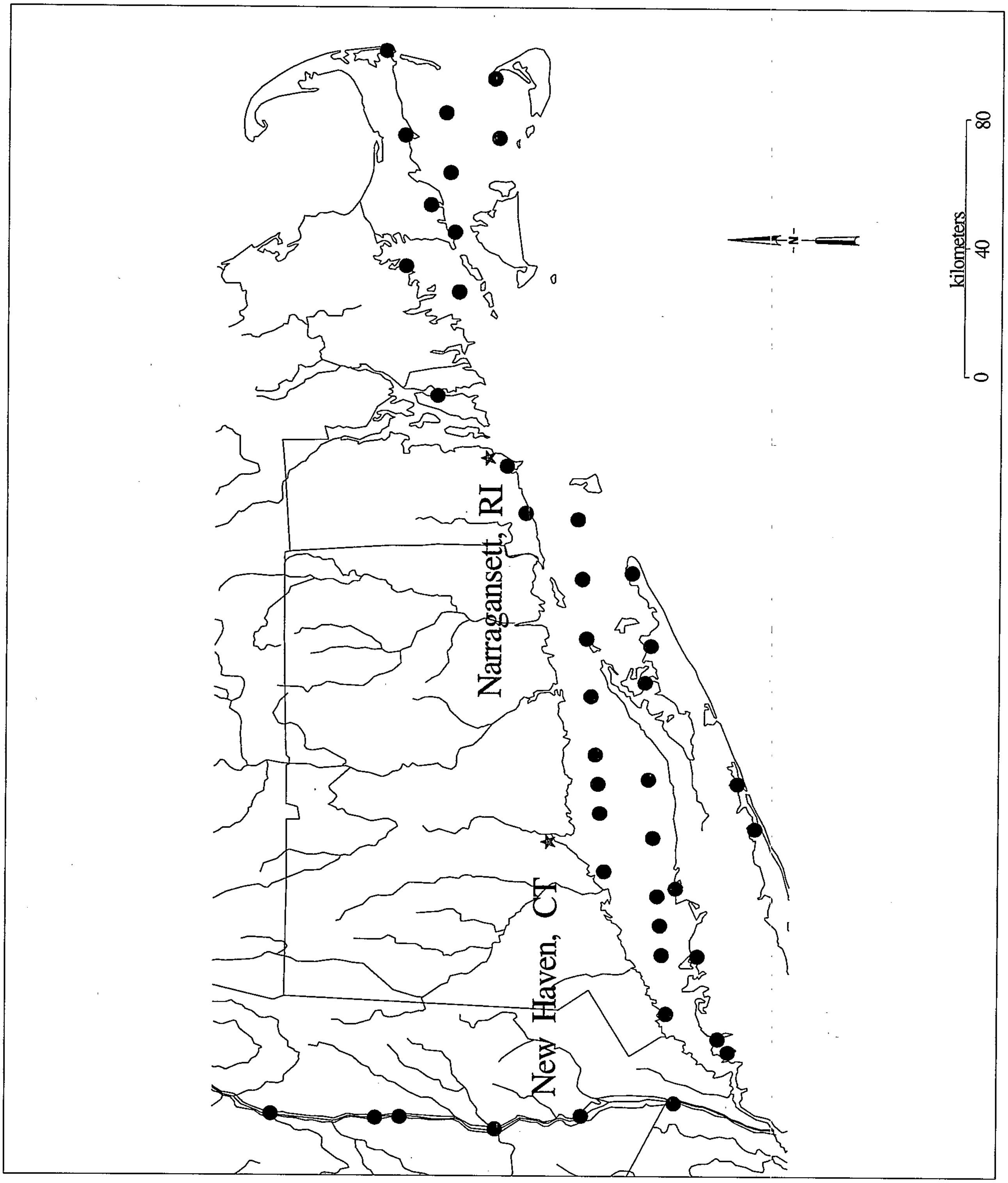


Figure 2-2. Team 1 Base Sampling Stations.

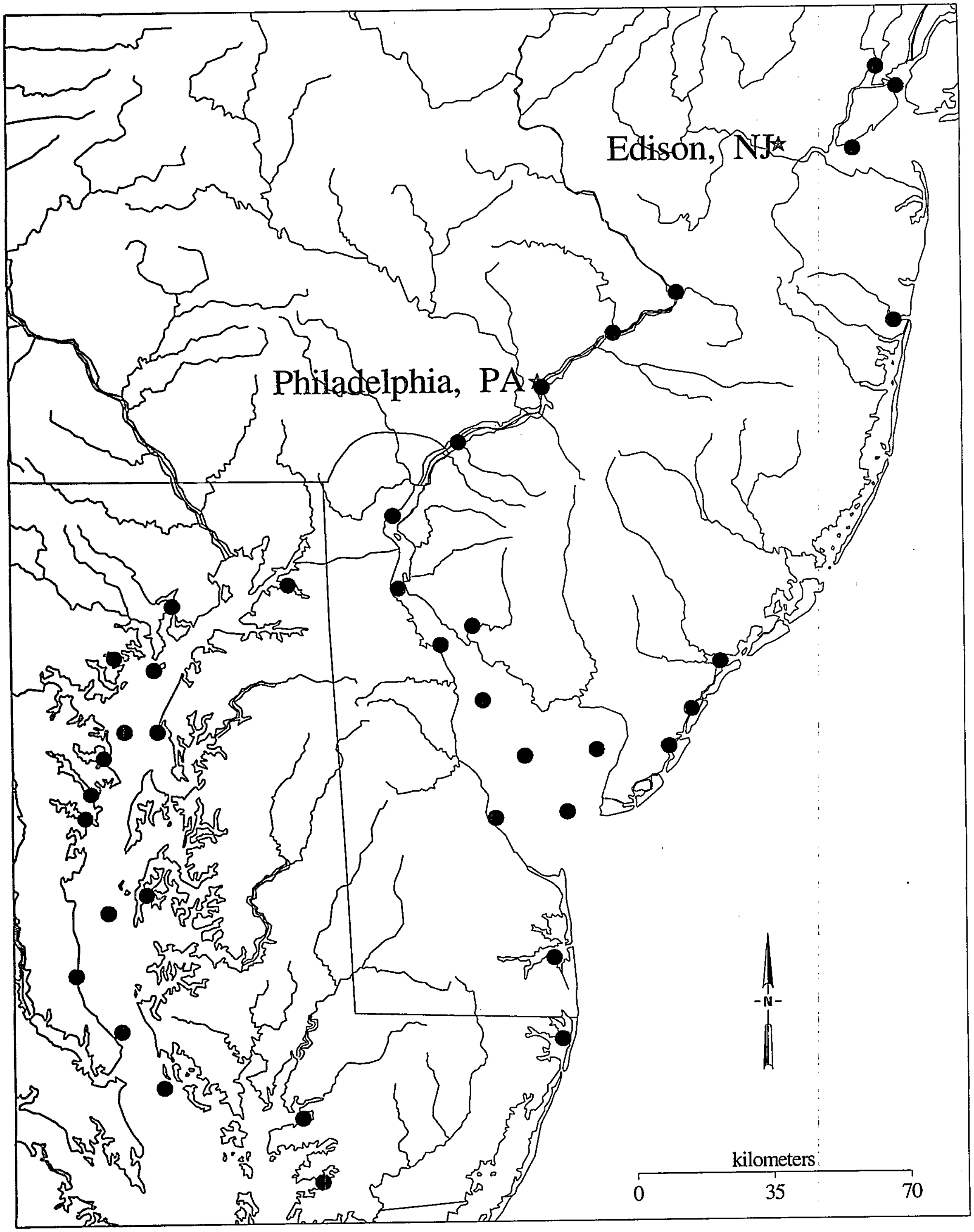


Figure 2-3. Team 2 Base Sampling Stations.

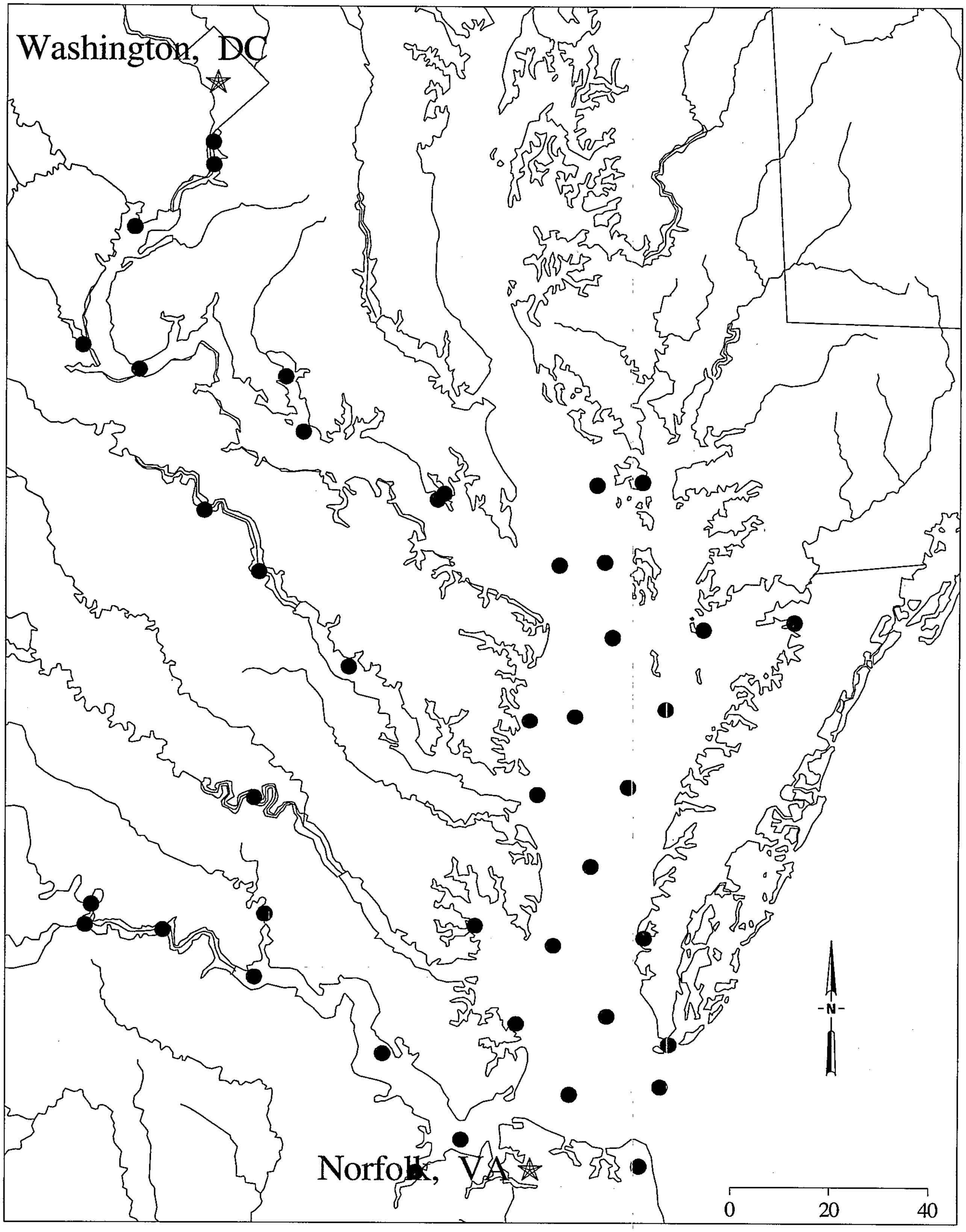


Figure 2-4. Team 3 Base Sampling Stations.

Table 2-1. Summary of collection and processing status of samples collected.

Sample Type	# Stations Expected to be Sampled[a]	# Stations Sampled (% of Expected Stations)	Percent Stations With Data Passing Final QC[b]
Water Quality (DO, Temp., Salinity)			
BSS Only	103	103 (100%)	100%
All Station Classes	126	126 (100%)	100%
Light Attenuation Coefficient (CTD cast)			
BSS Only	103	103 (100%)	98.1%
All Station Classes	126	126 (100%)	98.4%
Suspended Solids			
BSS Only	103	103 (100%)	53.8%[c]
All Station Classes	126	126 (100%)	55.6%[c]
Sediment Chemistry			
BSS Only	103	96 (93.2%)	93.2%
All Station Classes	126	117 (92.9%)	92.9%
Sediment Toxicity			
BSS Only	103	96 (93.2%)	90.2%
All Station Classes	126	117 (92.9%)	91.5%
Sediment Grain Size			
BSS Only	103	96 (93.2%)	93.2%
All Station Classes	126	117 (92.9%)	92.9%
Benthic Infauna			
BSS Only	103	99 (96.1%)	96.1%
All Station Classes	126	120 (95.2%)	95.2%
Fish Community Data (successful trawl)			
BSS Only	103	94 (90.2%)	90.2%
All Station Classes	126	116 (92.1%)	92.1%
Anthropogenic Marine Debris			
BSS Only	103	94 (90.2%)	90.2%
All Station Classes	126	116 (92.1%)	92.1%

a Number of stations expected to be sampled excludes all stations determined to be too shallow to sample prior to the start of field operations. Activities differed at different station classes resulting in the inconsistency in Expected Station Numbers for "All Station Classes" between indicators. Station classes are described in Appendix A of the 1991 Virginian Province Statistical Summary (Schimmel *et al.*, 1994).

b This value takes into account samples not collected, damaged or lost during shipping or processing, or failing to pass final Quality Control checks. The value for "BSS Only" represents the data utilized in the production of this report.

c Data are available for remaining samples; however, the representativeness of those data cannot be determined because appropriate QA samples were not run with all analytical batches.

SECTION 3

STATISTICAL SUMMARY OF INDICATOR RESULTS

The EMAP indicator strategy includes four types of ecological indicators: Biotic Condition, Abiotic Condition, Habitat, and Stressor. In this section, the statistical results of the 1992 Virginian Province Survey are described for each indicator with discussions categorized by major indicator type. Stressor data are not collected as part of the field effort; therefore, they are not discussed in this report. The following discussion is organized by indicator type. Indicators will be briefly described, and in most cases the Cumulative Distribution Function (CDF) will be shown to delineate the frequency of occurrence of observations within the Province. Bar graphs and other figures are also presented, where appropriate, to delineate the proportions of the Province or class resources that are degraded, or falling above or below values of interest.

CDFs display the full distribution of the values observed for an indicator plotted against the cumulative percentage of area in the class or Province. They provide information on both central tendency (*e.g.*, median) and the range of values in one easily interpreted graphical format (Holland, 1990). For example, Figure 3-1 shows the cumulative distribution function of instantaneous bottom dissolved oxygen (DO) concentrations for the Virginian Province.

The x-axis represents DO concentrations observed ranging from 0 to 10 mg/L. The y-axis represents the cumulative percentage of estuarine area within the Virginian Province. The dotted lines represent the 95% confidence intervals for the CDF. The CDF provides the reader with a powerful tool to evaluate the extent of conditions of any indicator within the Province or class. For example, the reader could be interested in the portion of area within the Province that was characterized by a DO concentration of 2 mg/L or less, a potential biological criterion. This concentration

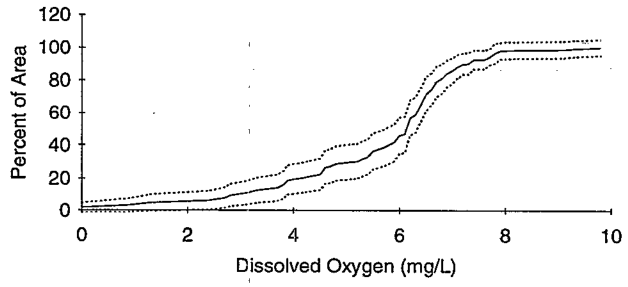


Figure 3-1. Example cumulative distribution of bottom dissolved oxygen concentrations as a percent of area in the Virginian Province. (Dashed lines are the 95% confidence intervals).

intersects with the cumulative area in the Province at 5 ± 5%. The reader might also be interested in a state regulatory criterion of 5 mg/L, and the CDF shows that, based on the 1992 data, 29 ± 11% of the estuarine bottoms waters had DO concentrations below this level. From a positive viewpoint, the reader may be interested in the amount of area above 7 mg/L (*e.g.*, as a criterion for fish farming) and the CDF shows that in 1992 approximately 16 ± 8% of the bottom waters in the Province were observed to be at or above 7 mg/L DO.

Criteria values for the assessment of degraded versus non-degraded areas are often subjective at best. Indeed, many of the criteria values used in this document, though based on reasonable scientific judgement, are debatable. The CDF allows the user to select his/her own criterion value and re-evaluate the proportion of area in the Virginian Province which is considered degraded. The reader must remain aware that the data included in this report represents only ¼ of the data that will be used to generate the four-year assessment report.

Areas reported in the text are determined from the data, not from the CDF, and may be slightly different than the reader might obtain from interpreting the CDF. Data points on the CDF are connected with a straight line, resulting in an interpolated value if there is no area associated with the "x" value of interest.

3.1 BIOTIC CONDITION INDICATORS

Biotic condition indicators are characteristics of the environment that provide quantitative evidence of the status of ecological resources and the biological integrity of the sample site from which they are collected (Messer, 1990). Ecosystems with a high degree of biotic integrity (*i.e.*, "healthy" ecosystems) are composed of balanced populations of indigenous benthic and water column organisms with species compositions, diversity, and functional organization comparable to undisturbed habitats (Karr and Dudley, 1981; Karr *et al.*, 1986). Biotic condition indicators measured include measures of both fish and benthic community structure. Because of budget constraints and the limited distribution of samples across the Province, no fish samples were analyzed for chemical contaminants in 1992.

3.1.1 Benthic Index

Benthic organisms were used as an indicator because previous studies have suggested that they are sensitive to pollution exposure (Pearson and Rosenberg, 1978; Boesch and Rosenberg, 1981). They also integrate responses to exposure over relatively long periods of time. One reason for their sensitivity to pollutant exposure is that benthic organisms live in and on the sediments, a medium that accumulates environmental contaminants over time (Schubel and Carter, 1984; Nixon *et al.*, 1986). The sedentary nature of many benthic invertebrates also may maximize their exposure to pollutants which accumulate in sediments.

A benthic index which uses measures of organism health, functionality, and community condition to evaluate the condition of the benthic assemblage was utilized in the assessment of biological resources of the Virginian Province. The index under development was determined from data collected in 1990 and 1991 and is assumed to represent a combination of ecological measurements that best discriminates between good and poor ecological conditions. The index represents EMAP-E's attempt to reduce many individual indicators into a single value that has a high level of discriminatory power between good and poor environmental conditions.

Discriminant Score =

*-0.68 * Mean abundance of opportunistic species*
*+ 0.36 * Biomass/abundance ratio for all species*
*+ 1.14 * Mean number infaunal species per grab.*

A critical value for discriminating between degraded and reference sites of -0.5 was determined (calculated as the point giving the optimal correct classification efficiency for both reference and degraded sites in the test dataset). A value of 0.5 was then added to all scores to result in a critical value of zero, *i.e.*, a negative score indicates degraded conditions. An offset was selected in place of a scaling factor (*i.e.*, scaling from 0 to 10), because a scaling factor requires recalculation every year, resulting in a new critical value each year. An offset is not affected by the range of values; therefore, the critical value will remain constant among years. A more complete description of the development of this index can be found in Appendix B of the 1991 Virginian Province Statistical Summary (Schimmel *et al.*, 1994).

The same criteria used for establishing a test dataset of reference and degraded stations in 1990 and 1991 was used to create a 1992 test dataset. Fifty-nine reference stations and four degraded stations were identified based on bottom dissolved oxygen concentrations and sediment contaminants/toxicity. The benthic index described above correctly classified all four of the degraded stations and 83% of the reference stations. Because of the limited number of stations in this dataset, this does not fully validate the Index; however, we believe it does support its use. It should be noted that this Index is still under development and will be reviewed as part of the four-year assessment effort.

Fourteen (± 6) percent of the bottom area of the Virginian Province sampled in 1992 had an index value of < 0, indicating likely impacts on the benthic community (Figure 3-2).

The percent area classified as degraded among the three classes of estuaries are 7 ± 8 %, 23 ± 12 %, and 37 ± 22 % for large estuaries, small estuarine systems, and large tidal rivers, respectively (Figure 3-3).

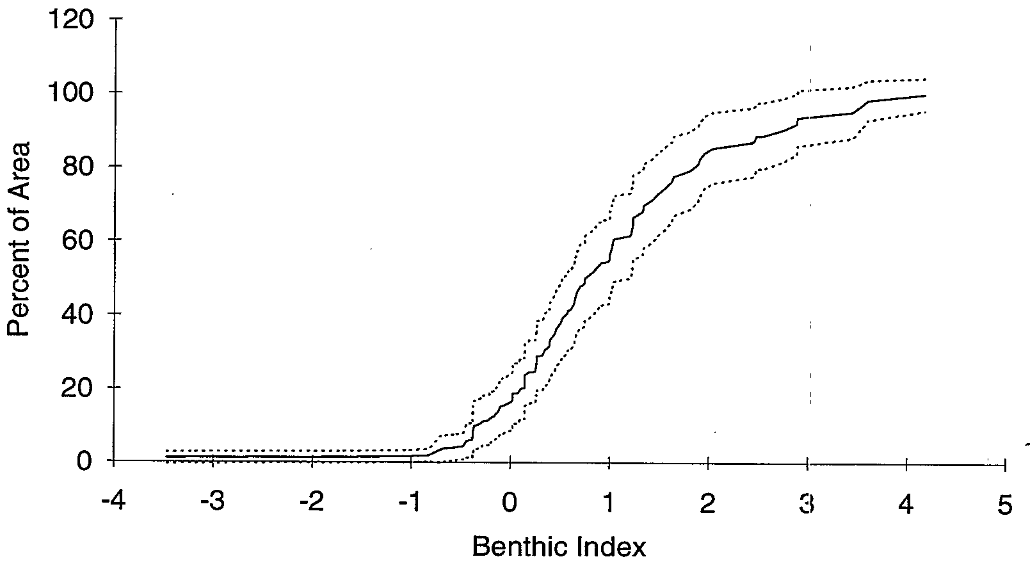


Figure 3-2. Cumulative distribution of the benthic index as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

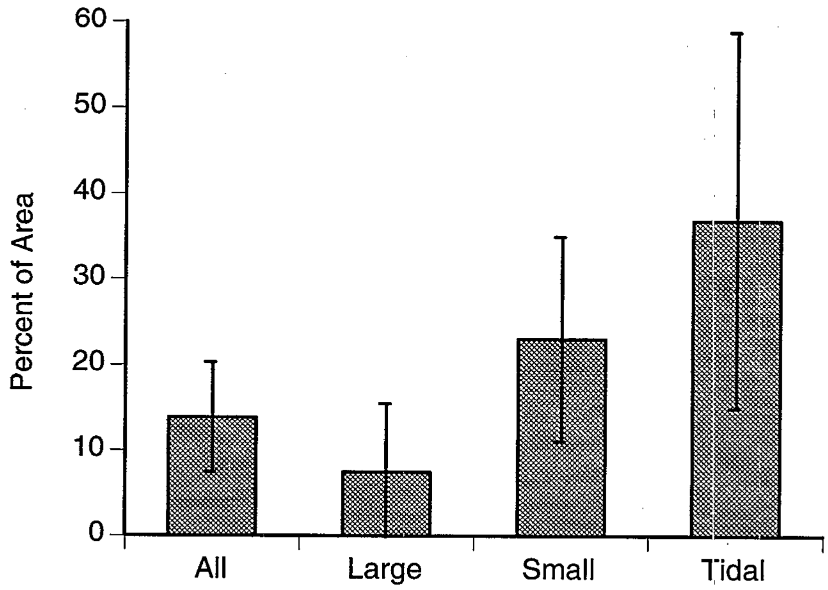


Figure 3-3. Percent area of the Virginian Province by estuarine class with a benthic index value below 0 in 1992. (Error bars represent 95% confidence intervals).

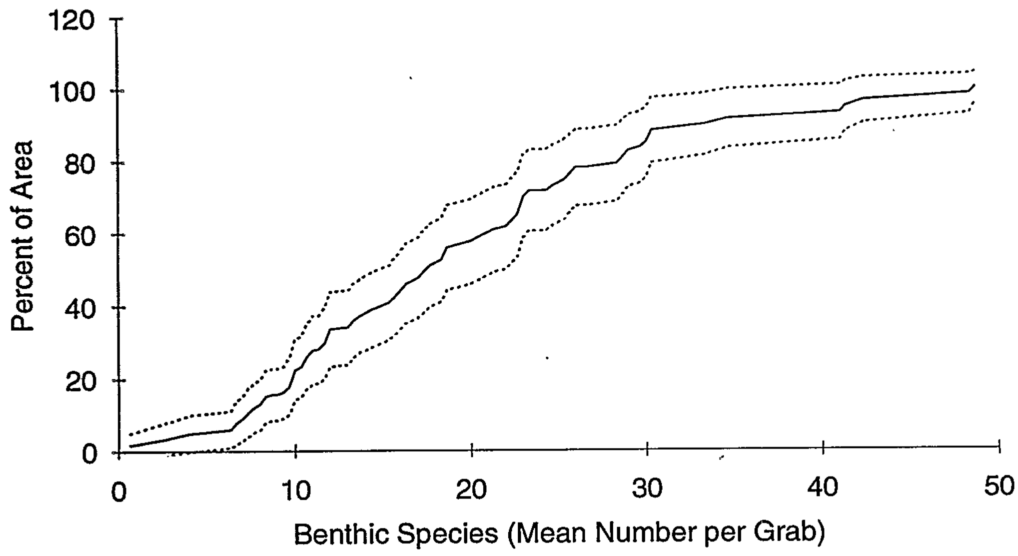


Figure 3-4. Cumulative distribution of the mean number of benthic species per grab as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

3.1.2 Number of Benthic Species

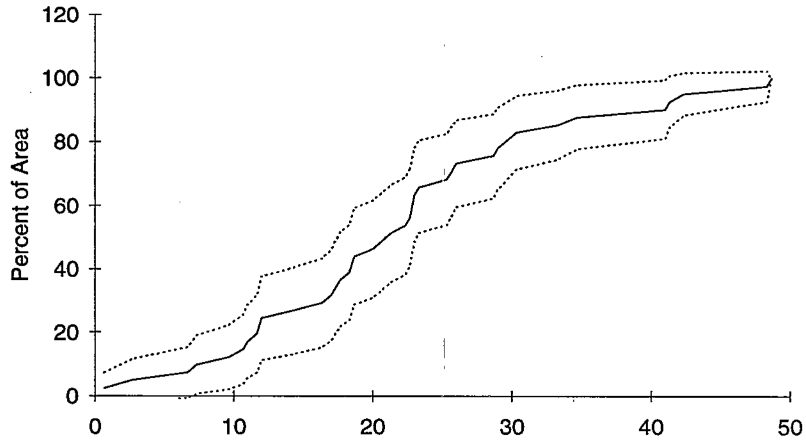
Number of infaunal benthic species has been used to characterize the environmental condition of estuarine habitats for specific salinity and grain size conditions. The mean number of species from three replicate 440 cm^2 grabs collected at each station resulted in numbers of infaunal benthic species ranging from 0 to 52 (Figure 3-4), with the maximum number of species per station being 52, 31, and 24 in the large estuaries, small estuaries, and large tidal rivers respectively (Figure 3-5). Because community composition is strongly influenced by factors other than environmental "health" (*e.g.*, salinity and grain size), we cannot infer that a low number of species necessarily represents an impacted community. However, the CDFs presented provide baseline information and can be useful tools in assessing future trends in community structure.

3.1.3 Benthic Infaunal Abundance

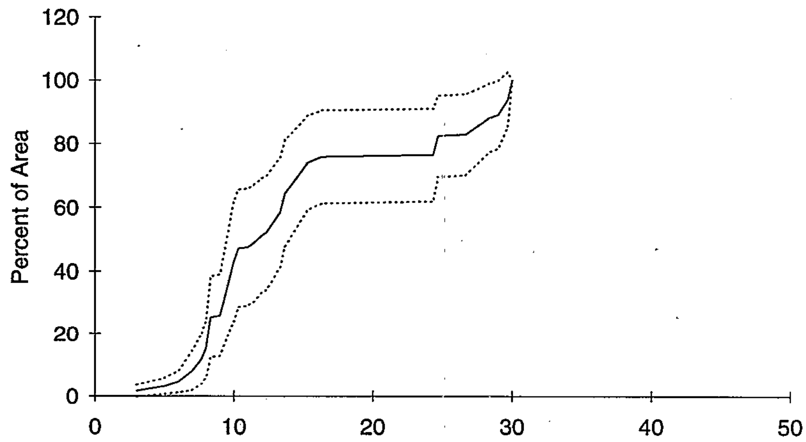
Abundant benthic organisms, particularly in communities characterized by multiple species and feeding types, suggest a productive estuarine environment. Infaunal abundances ranged from 0 to over 150,000 organisms per square meter (Figure 3-6). Using ≤200 organisms per square meter (8.8 per grab) and ≤500 organisms per square meter (22 per grab) as indicators of low and moderate abundances, respectively, 5 ± 5% of the Virginian Province had low abundances, and an additional 1 ± 6% had moderate abundances. Because of natural variation in benthic populations and modifying factors such as salinity and grain size, low abundance, as defined above, does not necessarily imply degraded communities; however, this information can be useful in detecting trends.

The percent area of low abundance was low in all three estuarine classes. Five ± 7 , 1 ± 1, and 10 ± 20 percent of the area of large estuaries, small estuaries, and large tidal rivers, respectively, exhibited benthic abundances of ≤ 200 organisms per square meter (Figure 3-7). The highest number of individuals (150,591 per m^2) was found in the large estuary class, with maximums of 54,212 and 17,508 found in the small estuary and large tidal river classes, respectively.

a) Large Estuaries



b) Small Estuaries



c) Large Tidal Rivers

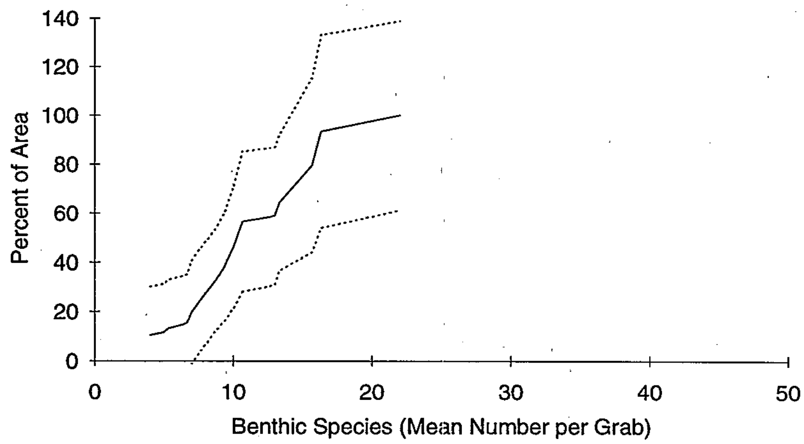


Figure 3-5. Cumulative distribution of the number of benthic species by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

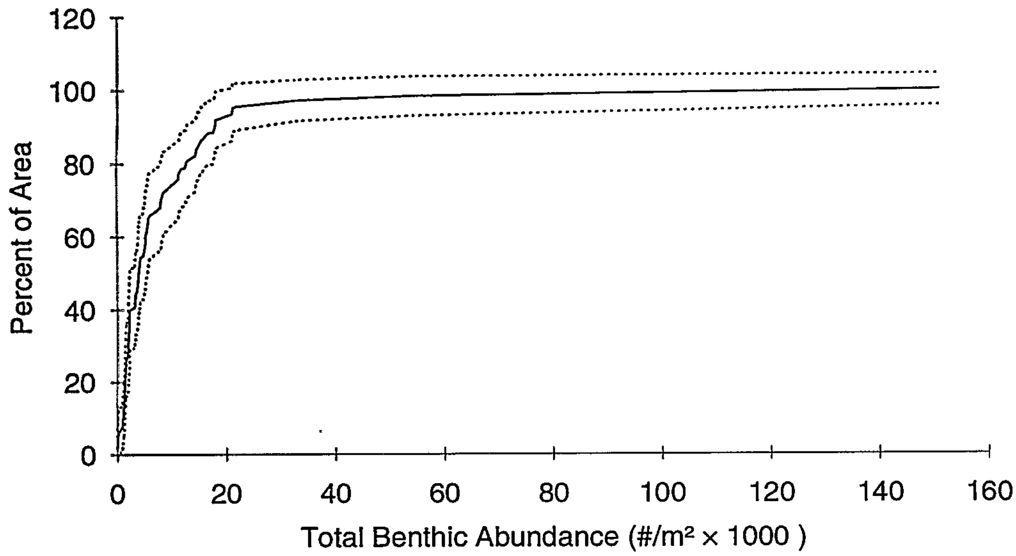


Figure 3-6. Cumulative distribution of the number of benthic organisms per m^2 as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

3.1.4 Number of Fish Species

Zero to 17 species of fish were collected from single standardized, 10 (±2)-min trawls performed at each base station in the Virginian Province (Figure 3-8). A total of 68 species were collected in standard trawls throughout the Province in 1992.

Fish catch can be affected by many variables including habitat; therefore, a critical value for the number of species that must be caught in a net for the area to be considered "healthy" is not available. We can only report the incidence of high *vs* low catches. Low catch does not imply that the area is degraded in reference to this indicator. However, as described above for benthic indicators, these data can be useful in detecting future trends in fish community structure on a provincial scale.

Two or fewer species were caught in standard trawls in approximately 37 ± 12% of the Virginian Province. Alternatively, at least five fish species were collected throughout approximately 36 ± 12% of the sampled area of the Province. No fish were collected at four stations, representing 4 ± 5% of the area of the Province. The areas producing no fish catch were located primarily in large estuaries (5 ± 7% of the area; Figure 3-9). Fish were collected in all but one small estuary station (99 ± 2% of the area) and at all stations in the large tidal river class (Figure 3-9).

3.1.5 Total Finfish Abundance

Abundant nektonic organisms, especially in communities characterized by multiple species and feeding types, suggest a stable and productive food web. Finfish abundance in standard trawls ranged from 0 to 464 fish per trawl throughout the Province (Figure 3-10). A total of 4,558 fish were collected in standard trawls conducted at base sampling sites in 1992.

Figure 3-11 illustrates fish abundance by system class. Total fish catch in the large tidal river class, although greater in number, was more variable than the other classes as evidenced by the wide confidence intervals about the curve.

No striking differences occur by class except the high percentage of area in large and small estuaries with low fish catch (36 ± 15 and 45 ± 21%, respectively, with <10 fish collected per trawl), and the high catch of over 100 fish per trawl in 47 ± 42% of the area represented

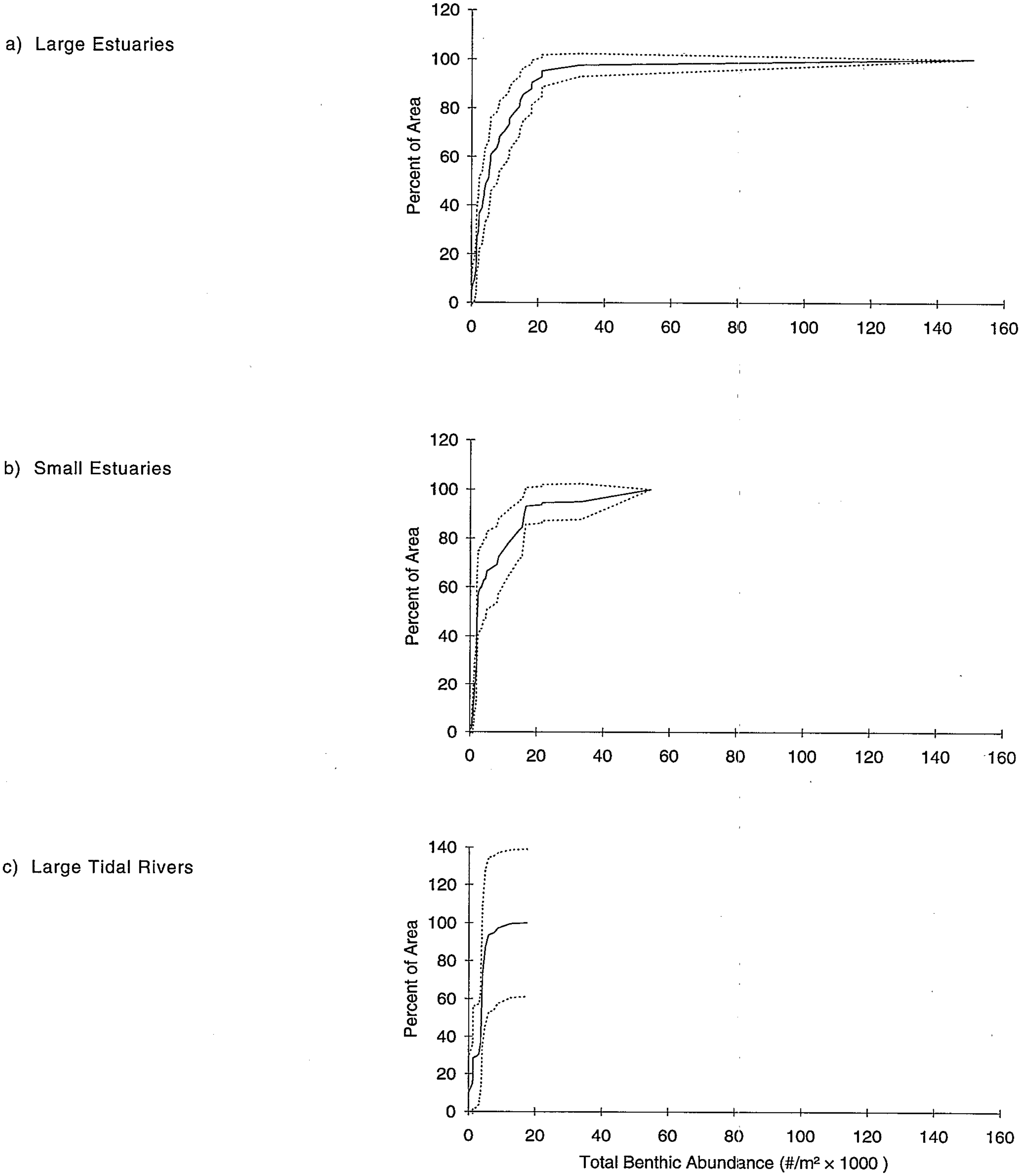


Figure 3-7. Cumulative distribution of the number of benthic organisms per m^2 by class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals)

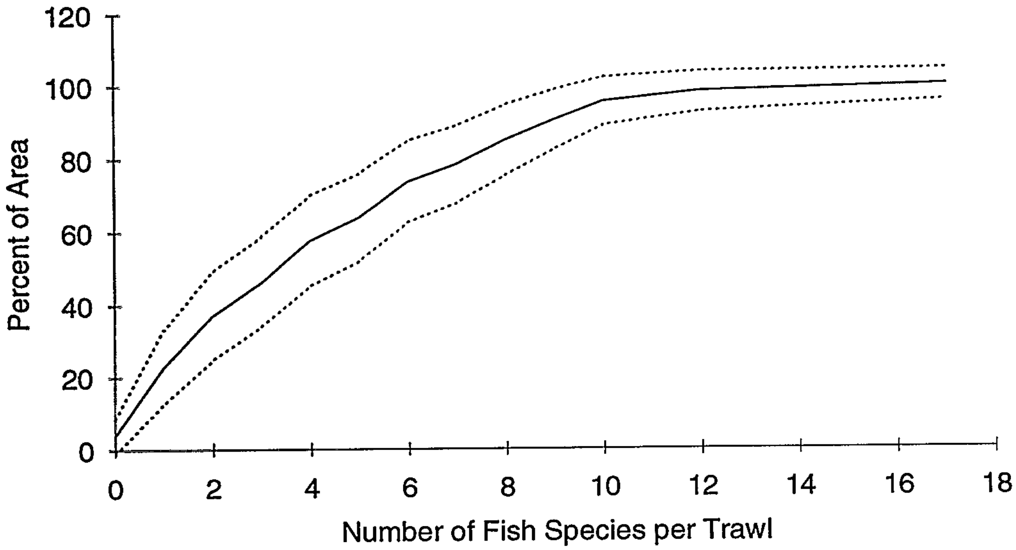


Figure 3-8. Cumulative distribution of the number of fish species per standard trawl as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

by large tidal river systems. As with the fish species indicator, only high versus low catches are reported with no inference made on the quality of the area relative to this indicator.

3.1.6 Fish Gross External Pathology

Field crews examined the first 30 individuals of each fish species for evidence of external pathology (growths, lumps, ulcers, and fin erosion). Of the 3,290 fish examined from base stations, 10 fish (0.3%) from nine of the 103 stations were identified as having one or more of these pathologies. All individuals with a pathology were of species which live or feed on the bottom.

Of the four categories, two growths, five ulcers, and three cases of fin erosion were reported.

3.2 ABIOTIC CONDITION INDICATORS

Abiotic condition indicators provide information on the potential exposure of organisms to environmental stresses, and have historically been the mainstay of environmental monitoring programs. Indicators of exposure measured during the 1992 Virginian Province Survey were dissolved oxygen concentration, sediment toxicity (*Ampelisca abdita*), sediment contaminants, and marine debris.

3.2.1 Dissolved Oxygen

Dissolved oxygen (DO) is critically important to aquatic systems because it is a fundamental requirement of fish, shellfish and other aquatic biota. Vertical profiles of dissolved oxygen and other water quality parameters were obtained using a SeaBird SeaLogger CTD. DO data included in this report are instantaneous point measurements taken one meter above the sediment/water interface.

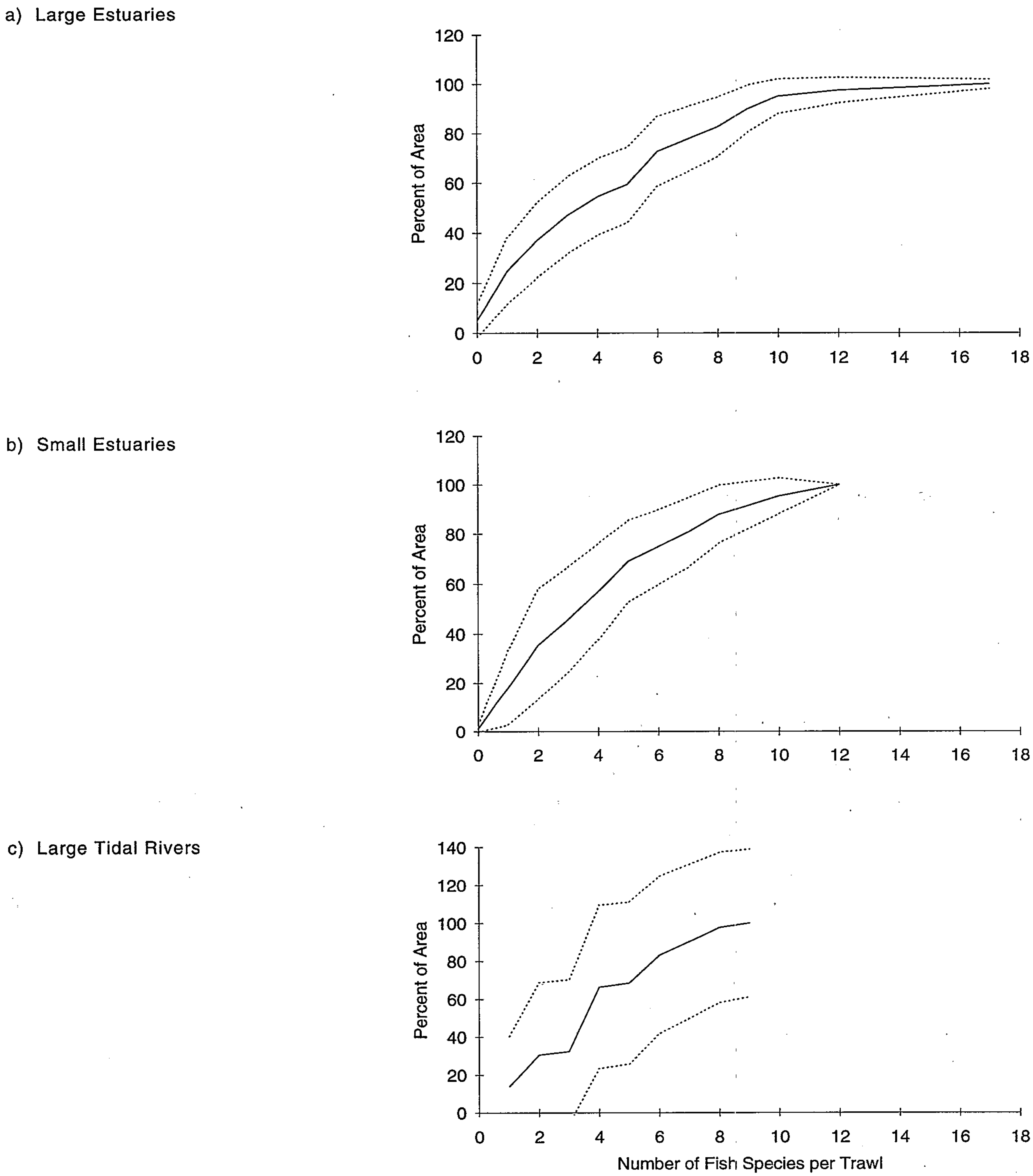


Figure 3-9. Cumulative distribution of the number of fish species per trawl by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

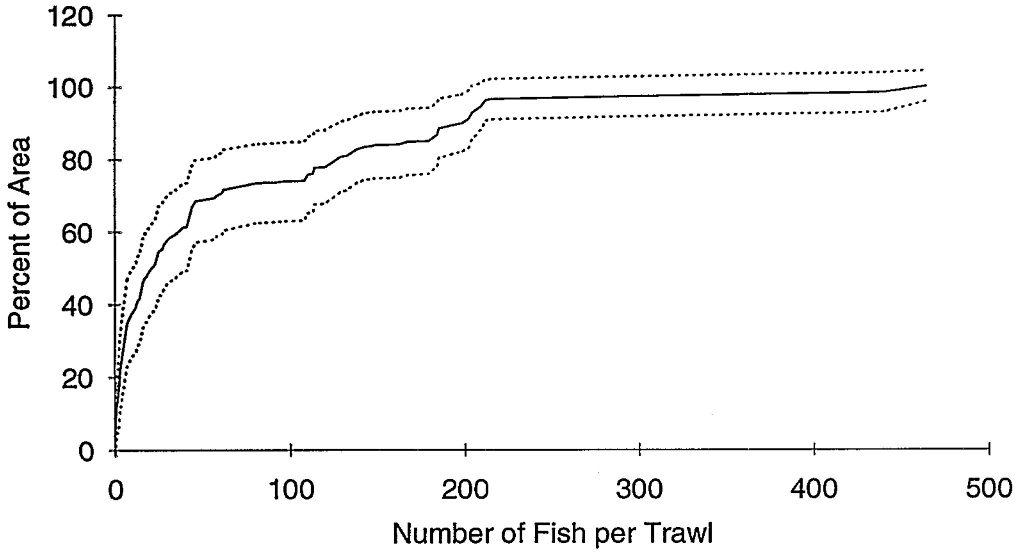


Figure 3-10. Cumulative distribution of fish abundance in numbers per standard trawl as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

3.2.1.1 Bottom Dissolved Oxygen

Data collected in 1992 indicate that approximately 29 ± 11% of the sampled area of the Province contains bottom waters with a dissolved oxygen concentration less than or equal to 5 mg/L (Figure 3-12). Approximately 5 ± 5% of the Province exhibited bottom DO conditions ≤2 mg/L, defined by EMAP-E as severely hypoxic.

Dissolved oxygen conditions ≤2 mg/L were evident only in large estuaries sampled within the Province (Figures 3-13 and 3-14). Approximately 7 ± 8% of the areas of large estuaries contained measured concentrations of bottom DO of ≤ 2 mg/L. An additional 31 ± 15%, 10 ± 8%, and 12 ± 16% of the area of large estuaries, small estuaries, and large tidal rivers, respectively, fell within the range of 2 to 5 mg/L DO.

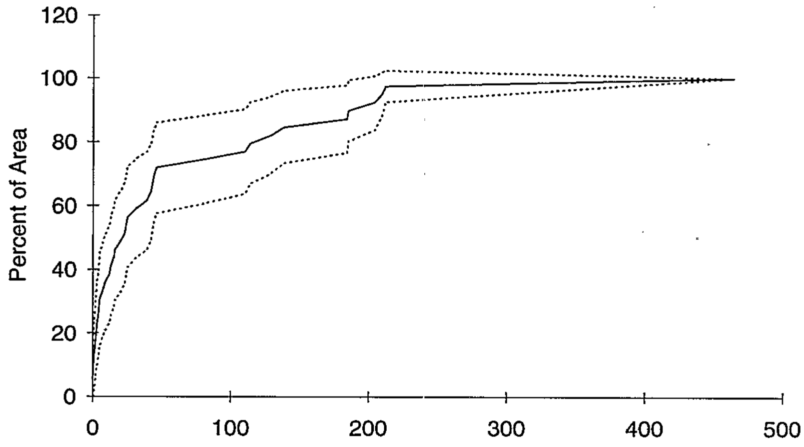
The occurrence of low dissolved oxygen in Chesapeake Bay and Long Island Sound is an area of importance to both scientists and managers; therefore, sub-population estimates for these systems are included in Appendix A.

3.2.1.2 Dissolved Oxygen Stratification

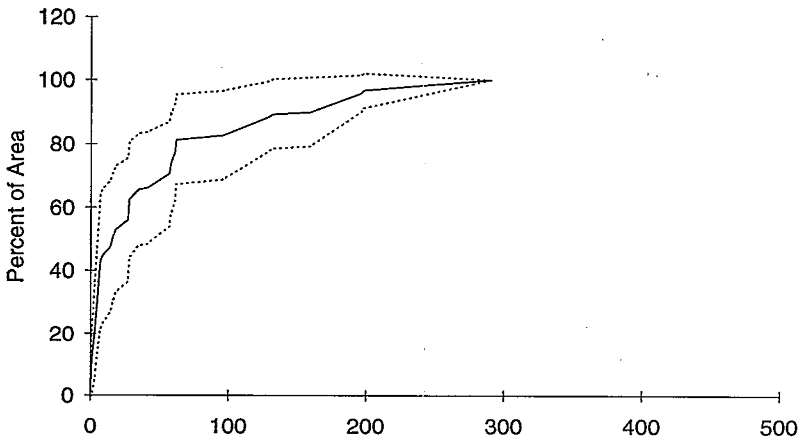
The difference between surface and bottom DO concentrations measured at base sampling stations is illustrated in Figure 3-15. Differences between bottom and surface DO were less than 1 mg/L in 59 ± 12% of the area of the Province. Approximately 10 ± 9% of the area of the Province showed differences greater than 5 mg/L. It should be noted that stratification is affected by many factors including stage of the tide and recent rainfall events. The data presented here have not been normalized or adjusted for any such factors.

Figure 3-16 illustrates DO differences by estuarine class. All of the highly stratified area was found in the large estuaries (14 ± 10% of the area with a difference exceeding 5 mg/L), with the largest Δ DO measured being 6.4 mg/L.

a) Large Estuaries



b) Small Estuaries



c) Large Tidal Rivers

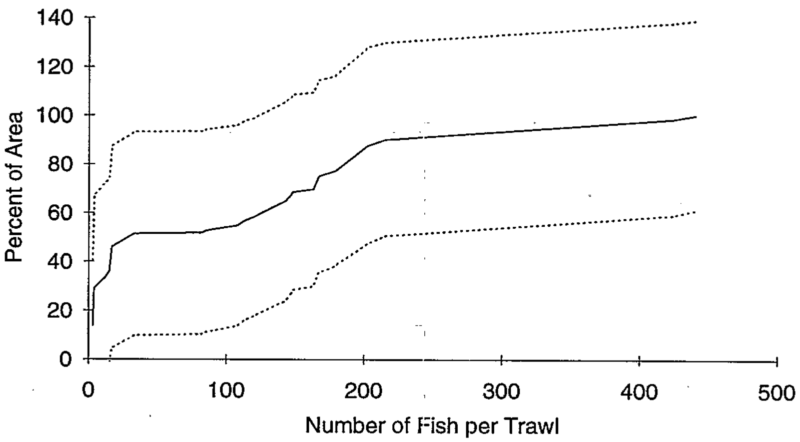


Figure 3-11. Cumulative distribution of fish abundance in numbers per standard trawl by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

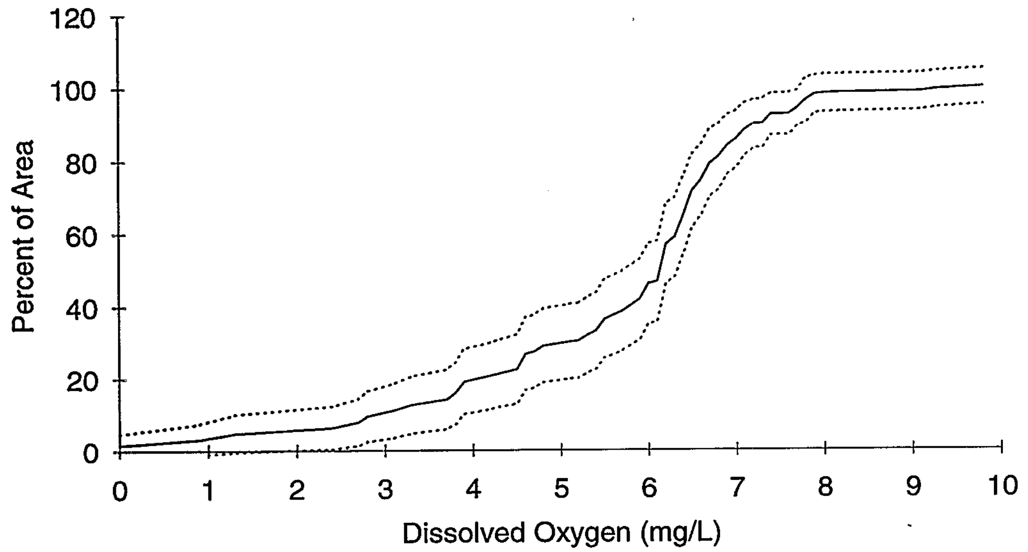


Figure 3-12. Cumulative distribution of bottom oxygen concentration in the Virginian Province, 1992 (Dashed lines are the 95% confidence intervals).

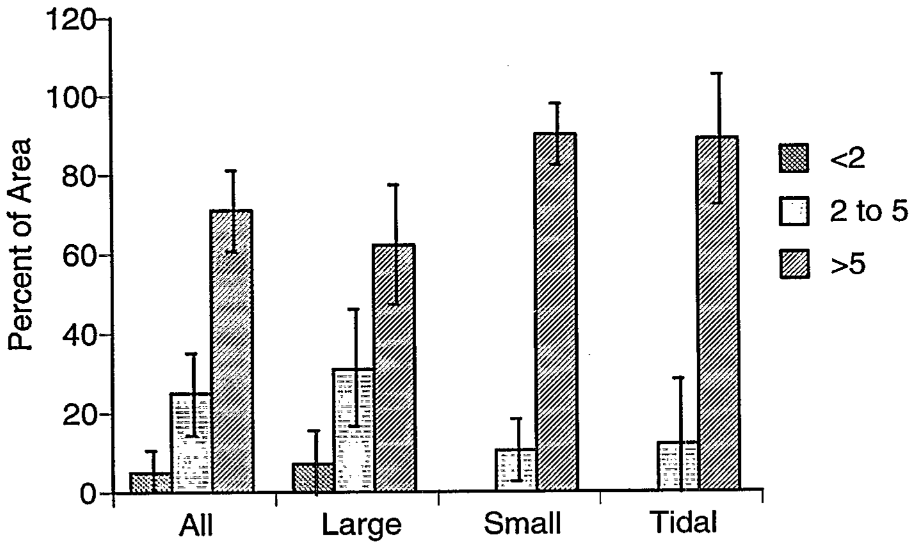
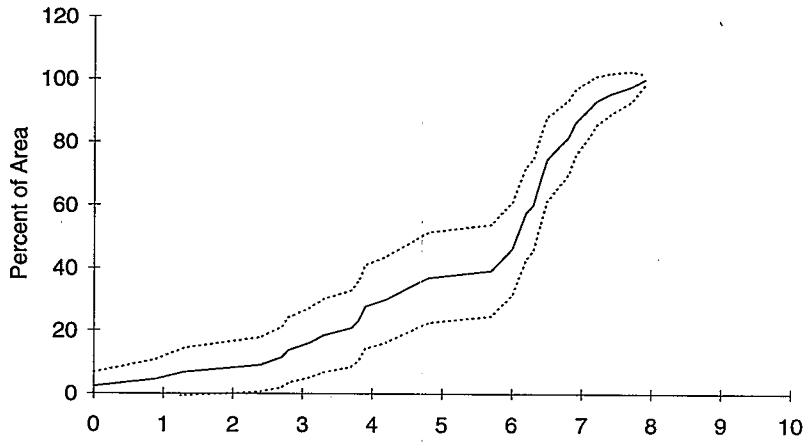
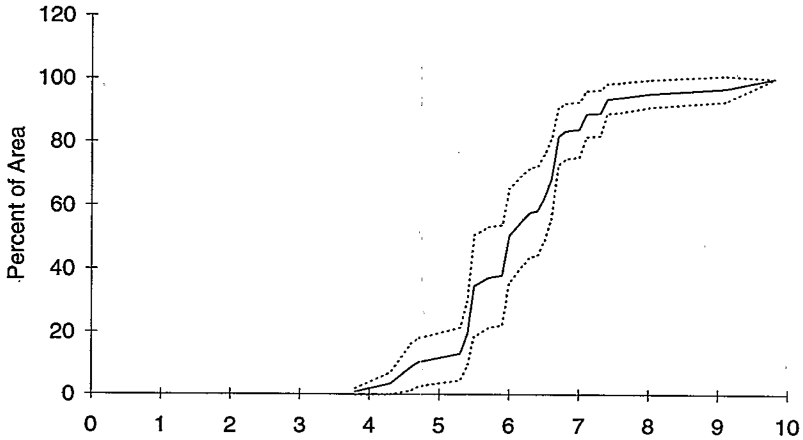


Figure 3-13. Percent area by class that had a low (< 2 mg/L), medium (2 to 5 mg/L), or high (>5 mg/L) oxygen concentration in the bottom waters. (Error bars represent 95% confidence intervals).

a) Large Estuaries



b) Small Estuaries



c) Large Tidal Rivers

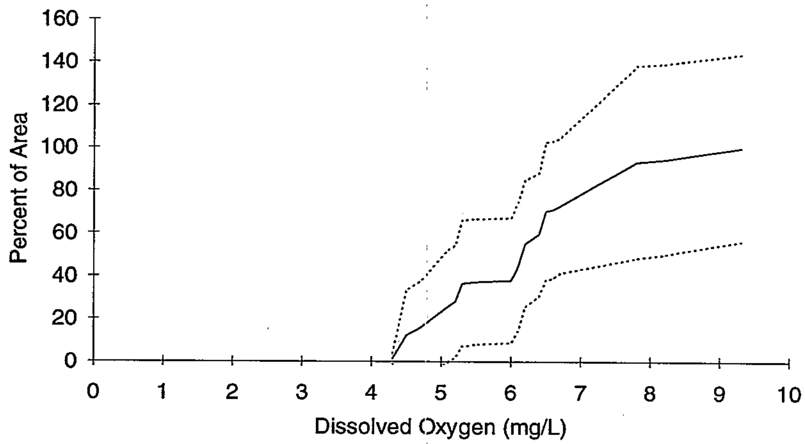


Figure 3-14. Cumulative distribution of bottom oxygen concentration by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

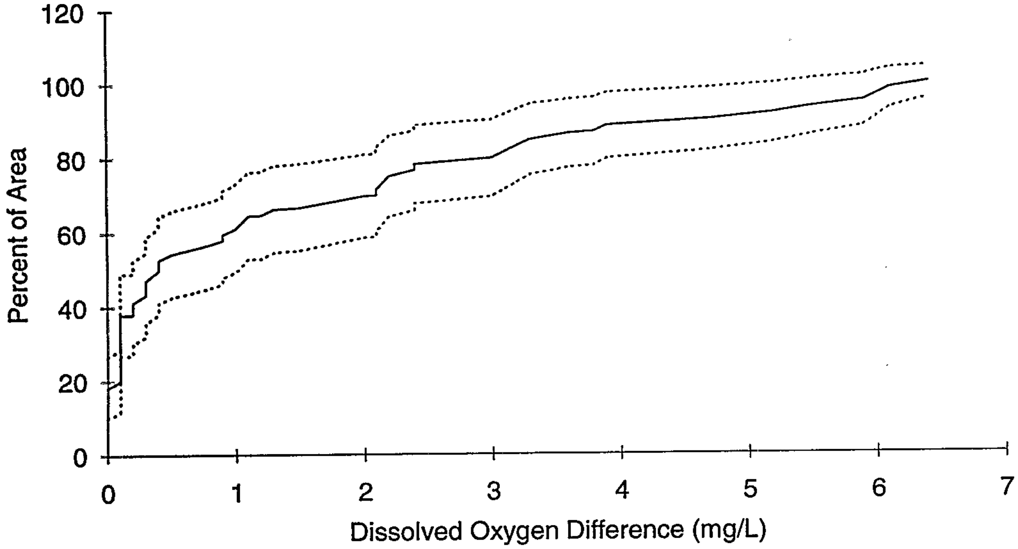


Figure 3-15. Cumulative distribution of the D.O concentration difference between surface and bottom waters as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

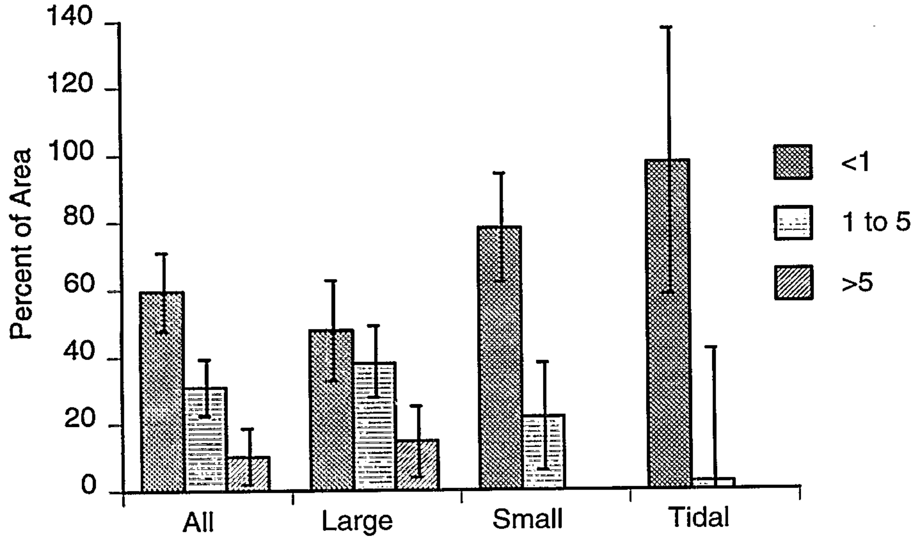


Figure 3-16. Percent area by class that had a low, medium, or high difference in dissolved oxygen concentration between the surface and bottom waters. (Error bars represent 95% confidence intervals).

3.2.2 Sediment Toxicity

Sediment toxicity tests were performed on the composite sample of surficial sediments (top two cm) collected from each sampling site. Solid-phase sediment toxicity tests (Swartz *et al.*, 1985) with the tube-dwelling amphipod, *Ampelisca abdita*, were conducted according to procedures described in U.S. EPA/ACE (1991) and ASTM (1991). Sediments were classified as toxic if amphipod survival in the test sediment was less than 80% of that in the control (a.k.a. "reference") sediment and significantly different from the control. The relative health of test organisms was determined via the use of reference toxicant tests as described in Appendix C. Approximately 6 ± 5% of the sampled area of the Virginian Province exhibited toxic sediments (Figure 3-17). However, only 0.4 ± 0.5% of the area had sediments where survival was below 60% of control survival (*i.e.*, sediments were very toxic). The estuarine class with the largest proportion of toxic sediments was the large estuarine class (8 ± 8%); with the small estuaries and large tidal river classes exhibiting a lesser extent of toxicity (2 ± 2% and 3 ± 5%, respectively: Figure 3-18). All of the highly toxic sediments were found in the small estuarine class, where 2 ± 2% of the area had sediments producing survival less than 60% of control survival.

3.2.3 Sediment Contaminants

A wide variety of contaminants have been released to marine systems due to human activities. Some of these compounds and elements have properties which cause them to associate with particulate material, and many of these chemicals are also persistent in the environment. Contaminants with this combination of properties can accumulate to high concentrations in sediments and may become available to aquatic organisms. The organic compounds measured included selected polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyl (PCB) congeners, chlorinated pesticides, butyltins and several metals. Because of the complex nature of sediment geochemistry, and additive, synergistic, and antagonistic interactions among multiple pollutants, the ecological impact of elevated contaminant levels is not well understood. Therefore, definitive estimates of percent area of the Province with overall contaminant concentrations high enough to cause ecological impacts cannot be provided. However, the data collected will form a baseline for monitoring trends in sediment contamination and are extremely valuable in that respect.

EPA is currently in the process of establishing Sediment Quality Criteria (SQC). Draft SQC are presently available for four of the analytes EMAP-VP is measuring: Acenaphthene, phenanthrene, fluoranthene,

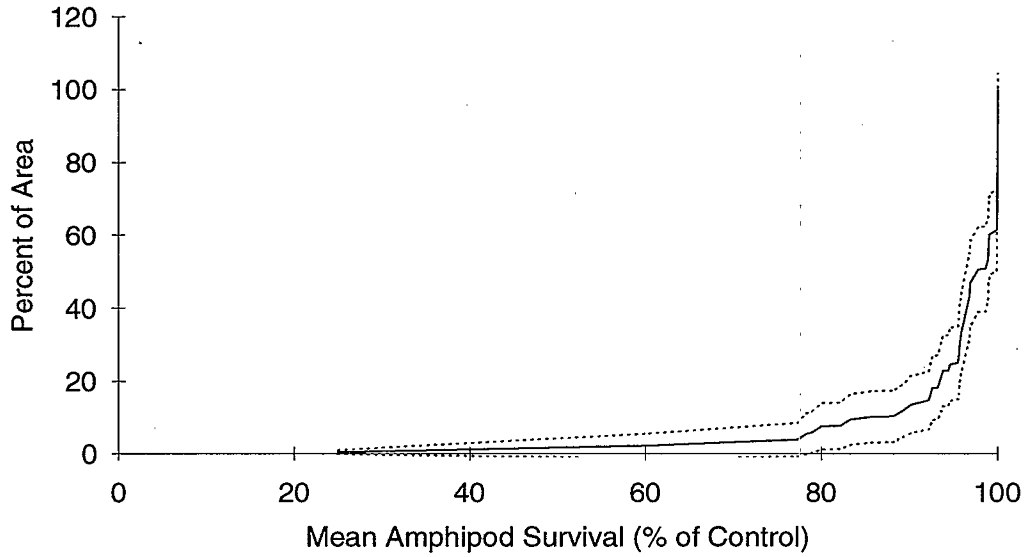


Figure 3-17. Cumulative distribution of mean survival of amphipods in 10-day laboratory toxicity tests (expressed as percent of control survival). (Dashed lines are the 95% confidence intervals).

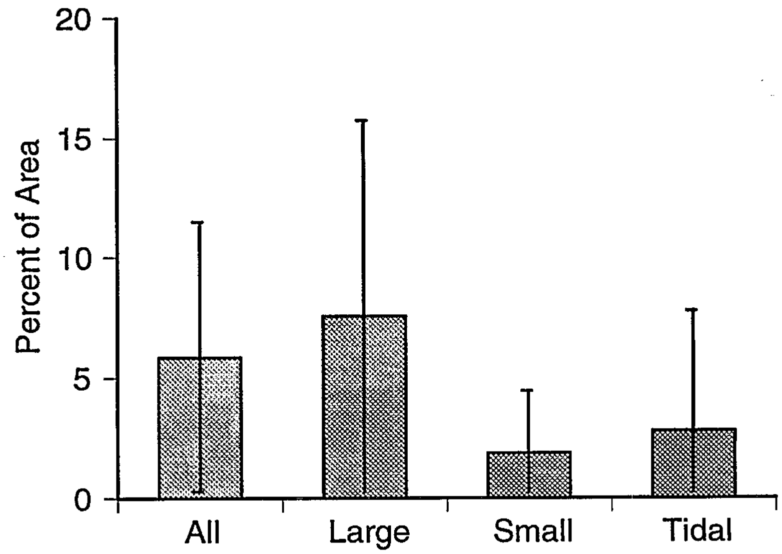


Figure 3-18. Percent area in the Virginian Province in 1992, by estuarine class, with low amphipod survival (<80% of control) in sediment toxicity tests. (Error bars represent 95% confidence intervals).

and dieldrin (U.S. EPA, 1993a-d). SQC are expressed as µg analyte / g organic carbon; therefore, concentrations must first be normalized for the organic carbon content of the sediment. Only those sediments with organic carbon concentrations ≥0.2% can be examined using this approach. Separate SQC values have been established for freshwater and saltwater sediments. Because criteria values are based on toxicity data, the definition of saltwater *vs* freshwater is based on the organisms present, not the salinity. Where both fresh and saltwater organisms are present, the more protective of the two values is applied.

SQC values for the four analytes measured are listed in Table 3-1, along with the upper and lower bounds. It is important to note that these values are still in draft form and are subject to change as the documents proceed through the peer review process.

3.2.3.1 Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous in marine sediments (Laflamme and Hites, 1978). These compounds are widespread because of the large number and variety of PAH sources including oil spills, natural oil seeps, forest fires, automobile exhaust, domestic heating, power plants and other combustion processes. With the exception of specific oil releases, the majority of PAHs found in marine sediments are believed to originate from combustion processes (Windsor and Hites, 1979). PAH concentrations tend to correlate with the degree of urbanization or industrialization and, therefore, these compounds are often considered to be indicators of anthropogenic activity.

Table 3-1. U.S. EPA draft Sediment Quality Criteria for analytes measured. Freshwater (F), Saltwater (S), and upper and lower confidence intervals are included. All values are µg/g organic carbon.

Analyte	F/S	SQC	Upper SQC	Lower SQC
Acenaphthene				
	F	130	280	62
	S	230	500	110
Phenanthrene				
	F	180	390	85
	S	240	510	110
Fluoranthene				
	F	620	1300	290
	S	300	640	140
Dieldrin				
	F	11	24	5.2
	S	20	44	9.5

Range and median concentrations for PAHs measured in 1992 are listed in Table 3-2. Combined PAH values reported in this table reflect the summation of the concentrations of all of the PAH compounds that were measured. This summation is not listed as "total" PAH because only a select list of PAHs were measured and many other PAH compounds could be found in these sediments. Combined PAH concentrations for low level samples are artificially low because analytes that were not detected (ND) were assigned a value of zero for calculation of the Combined concentration.

Combined PAH concentrations (Table 3-2) showed a large range (ND - 13,219 ng/g) with a median concentration of 661 ng/g in Virginian Province sediments.

This large range of PAH concentrations can be seen in the cumulative distribution of combined PAHs shown in Figure 3-19. This figure shows that the sediments of the vast majority of the area of the Province contain low concentrations of PAHs; for example, about 92 ± 7% of the sampled area of the Province had a combined sediment PAH concentration of less than 4,000 ng/g dry

Table 3-2. Range and median PAH concentrations in sediments of the Virginian Province, 1992.

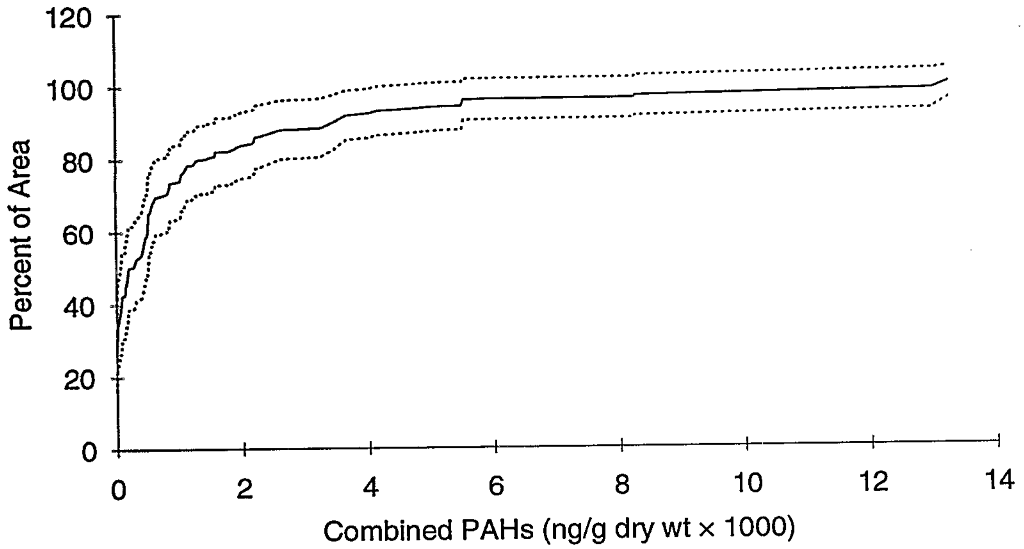
Analyte (weight[a])	Concentration (ng/g dry weight) MIN	MAX	Median	Median Detection Limit[b]
Acenaphthene (L)	ND	342	ND	10.0
Acenaphthlylene (L)	ND	209	ND	10.0
Anthracene (H)	ND	447	ND	10.0
Benz(a)anthracene (H)	ND	964	26.0	10.0
Benzo(b+k)fluoranthene (H)	ND	1,790	77.7	10.0
Benzo(g,h,i)perylene (H)	ND	876	27.9	10.0
Benz(a)pyrene (H)	ND	1,150	28.8	10.0
Benz(e)pyrene (H)	ND	925	29.7	10.0
Biphenyl (L)	ND	292	ND	10.0
Chrysene (H)	ND	1,120	37.3	10.0
Dibenz(a,h)anthracene (H)	ND	215	ND	10.0
Fluoranthene (H)	ND	2,020	57.4	10.0
Fluorene (L)	ND	501	ND	10.0
Indeno(1,2,3-c,d)pyrene (H)	ND	933	36.25	10.0
Naphthalene (L)	ND	1,500	15.6	10.0
1-methylnaphthalene (L)	ND	477	ND	10.0
2-methylnaphthalene (L)	ND	1,120	10.6	10.0
2,6-dimethylnaphthalene (L)	ND	489	ND	10.0
2,3,5-trimethylnaphthalene (L)	ND	182	ND	10.0
Perylene (H)	ND	1,670	39.5	10.0
Phenanthrene (H)	ND	1,120	50.4	10.0
1-methylphenanthrene (H)	ND	341	ND	10.0
Pyrene (H)	ND	2,670	71.35	10.0
Combined PAHs	ND	13,219	661	na

a Letter in parenthesis indicates high molecular weight compound (H) or low molecular weight compound (L).

b For each "not detected" the laboratory supplied a detection limit. This value is the median of these values for each analyte.

na = not applicable

ND = not detected



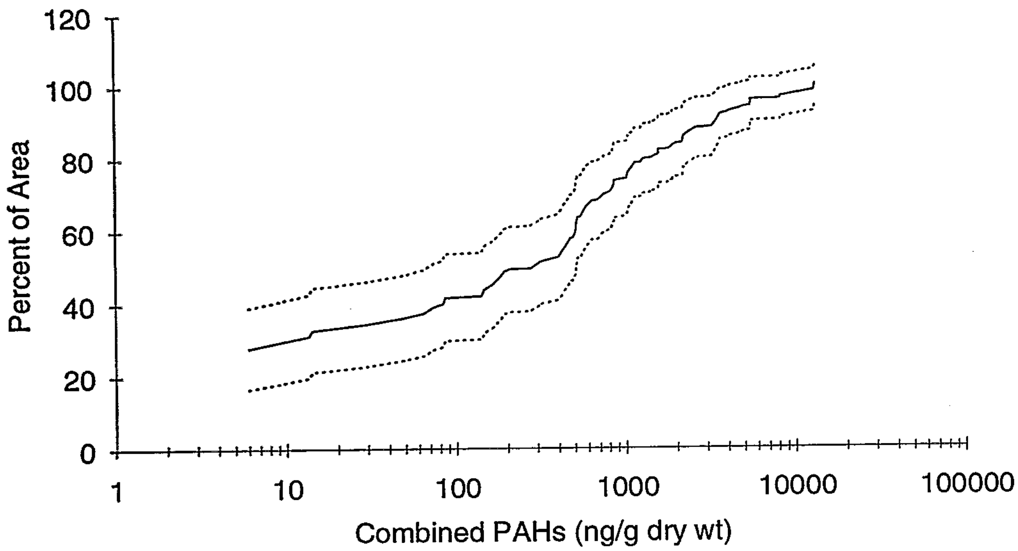


Figure 3-19a&b. Cumulative distribution of combined PAHs in sediments as percent of area in the Virginian Province, 1992 : a) Linear scale, b) Logarithmic scale. (Dashed lines are the 95% confidence intervals).

weight. This value is used not because of ecological significance but rather because it appears to be an inflection point in the CDF. Figure 3-19b is the CDF plotted on a log scale to better illustrate the distribution of concentrations at the lower end of the scale.

As discussed above, draft Sediment Quality Criteria are available for three PAHs: Acenaphthene, phenanthrene, and fluoranthene. The SQCs (see Table 3-1) for freshwater and saltwater sediments were not exceeded at any station visited in 1992. Applying the more conservative Lower SQC values in Table 3-1 does not change these percentages. It is important to note that these estimates were based on only those sediments with a total organic carbon content of ≥0.2% (75 ± 10 % of the area of the Province). For the purpose of this exercise, those stations excluded were treated statistically as missing values.

Petroleum and combustion-type PAH sources contain very different PAH compound distributions. Because of this, the distributions of PAHs in a sample can provide information on the relative importance of petroleum versus combustion PAH sources (Lake *et al.*, 1979). Petroleum products contain relatively large amounts of lower molecular weight compounds relative to combustion sources which are dominated by higher molecular weight compounds (listed in Table 3-2). Examination of the distribution of PAHs in samples reveals that high molecular weight compounds dominate in almost all samples, indicating that combustion is the major source of PAHs in Virginian Province sediments.

3.2.3.2 Polychlorinated Biphenyls

Environmental measures of PCBs have been conducted using a variety of techniques including their measurement as industrial mixtures (*e.g.*, Aroclors) (Hutzinger, 1974), by level of chlorination (Gebhart *et al.*, 1985) and as individual congeners (Mullin *et al.*, 1984; Schantz *et al.*, 1990). Each of these techniques have both positive and negative aspects based on the specific application for which the PCB data are needed. For this study, PCBs were measured as a series of 18 selected congeners (Table 3-3). These congeners were selected to produce data consistent with the National Oceanographic and Atmospheric Administration's, National Status and Trends Program. The congeners included on this list are some of the more abundant chlorobiphenyls found in environmental samples as well as some (congeners 105 and 118) that are considered to have a high potential for toxicity (McFarland and Clarke, 1989).

The PCB congeners measured are identified based on the numbering convention proposed by Ballschmiter and Zell (1980). Concentration ranges and median values measured for the individual congeners are listed in Table 3-3. Also included in this table is a summation of the measured congeners referred to as combined PCBs. This term was used instead of "total" PCBs to differentiate it from measurements of all of the PCBs in a sample. Combined PCB concentrations for low level samples are artificially low because congeners that were not detected were assigned a value of zero for calculation of the combined concentration. Combined PCB concentrations ranged from the detection limit to 577 ng/g dry weight with a median concentration of 6 ng/g. The cumulative distribution of combined PCBs in the Virginian Province is shown in Figure 3-20. This plot shows that low concentrations of PCBs were found in the majority of the area of the Province. PCBs were not detected in 43 ± 12% of the area of the Province and approximately 96 ± 6% of the Province contained sediments with PCB concentrations below 50 ng/g dry weight. This value is used not because of ecological significance but rather because it appears to be an inflection point in the CDF. Figure 3-20b is the CDF plotted on a log scale to better illustrate the distribution of concentrations at the lower end of the scale.

3.2.3.3 Chlorinated Pesticides

In addition to PCBs, several other chlorinated compounds were monitored in the sediments of the Virginian Province (Table 3-4). Most of these chemicals are banned in the United States although some are still used in other countries. Several of the compounds measured (*e.g.*, DDEs, DDDs and heptachlor epoxide) are environmental metabolites of the original pesticides (Ernst, 1984) instead of the active ingredients of the original pesticide formulations.

Six DDT-series compounds were measured. These included the original insecticide, p,p'-DDT, and o,p'-DDT which is a contaminant in p,p'-DDT formulations. The four remaining compounds (p,p'-DDE, o,p'-DDE, p,p'-DDD and o,p'-DDD) are metabolites or degradation

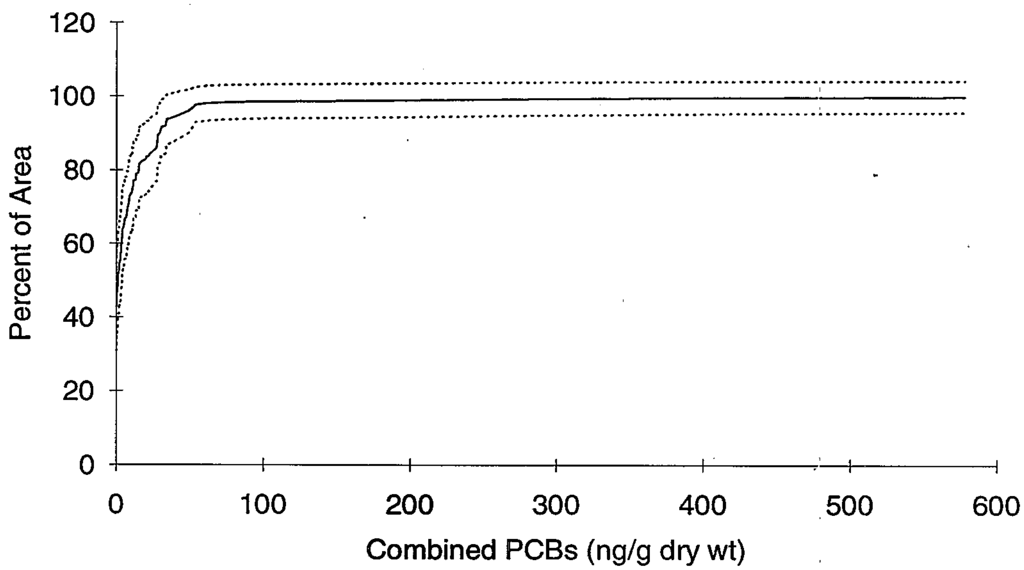
Table 3-3. Range and median PCB concentrations in sediments of the Virginian Province, 1992.

Analyte	Concentration (ng/g dry weight)			
	MIN	MAX	Median	Median Detection Limit[a]
PCB8	ND	32.6	0.291	0.250
PCB18	ND	44.7	ND	0.250
PCB28	ND	156	0.387	0.250
PCB44	ND	38.0	ND	0.250
PCB52	ND	57.1	0.260	0.250
PCB66	ND	85.9	0.597	0.250
PCB101	ND	34.4	0.474	0.250
PCB105	ND	22.8	ND	0.250
PCB118	ND	33.0	0.515	0.250
PCB128	ND	3.87	ND	0.250
PCB138	ND	31.9	0.728	0.250
PCB153	ND	25.4	0.720	0.250
PCB170	ND	5.44	ND	0.250
PCB180	ND	9.86	0.379	0.250
PCB187	ND	7.23	0.274	0.250
PCB195	ND	2.81	ND	0.250
PCB206	ND	21.6	ND	0.250
PCB209	ND	29.4	ND	0.250
Combined PCBs	ND	577	6.04	na

a For each "not detected" the laboratory supplied a detection limit. This value is the median of these values for each analyte.

na = not applicable

ND = not detected



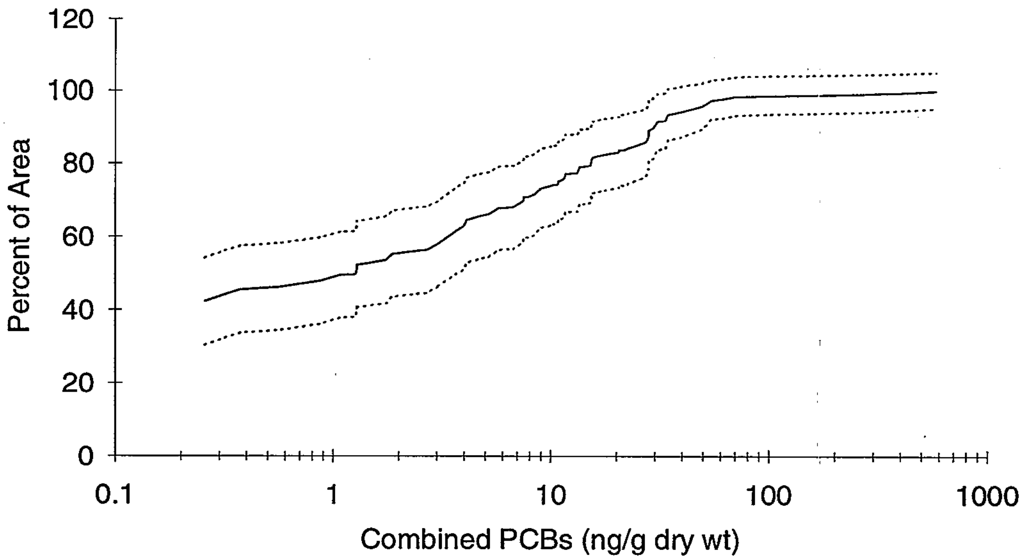


Figure 3-20a&b. Cumulative distribution of combined PCBs in sediments as percent of area in the Virginian Province, 1992: a) Linear scale b) Logarithmic scale. (Dashed lines are the 95% confidence intervals).

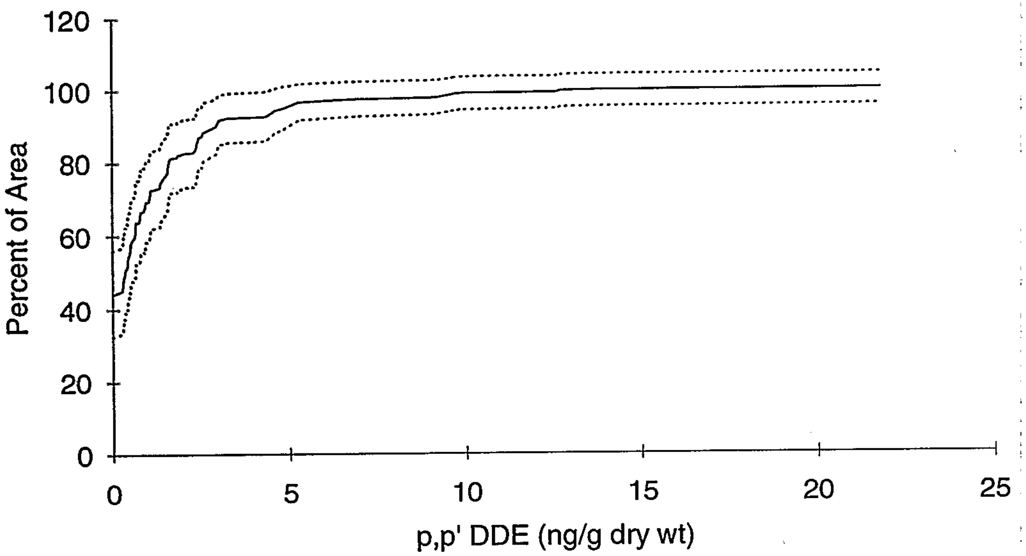


Figure 3-21. Cumulative distribution of p, p' -DDE in sediments as percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

Table 3-4. Range and median chlorinated pesticide concentrations in sediments of the Virginian Province, 1992.

Analyte	Concentration (ng/g dry weight)			
	MIN	MAX	Median	Median Detection Limit[a]
o,p'-DDD	ND	9.44	ND	0.250
p,p'-DDD	ND	21.7	0.281	0.250
o,p'-DDE	ND	11.6	ND	0.250
p,p'-DDE	ND	21.8	0.804	0.250
o,p'-DDT	ND	4.31	ND	0.250
p,p'-DDT	ND	4.80	ND	0.250
Aldrin	ND	ND	ND	0.250
Alpha-Chlordane	ND	7.03	ND	0.250
Dieldrin	ND	2.60	ND	0.250
Heptachlor	ND	0.52	ND	0.250
Heptachlor epoxide	ND	1.18	ND	0.250
Hexachlorobenzene	ND	1.47	ND	0.250
Lindane (gamma-BHC)	ND	0.63	ND	0.250
Mirex	ND	0.95	ND	0.250
Trans-Nonachlor	ND	5.44	ND	0.250
Total Chlordanes[b]	ND	13.7	ND	na

a For each "not detected" the laboratory supplied a detection limit. This value is the median of these values for each analyte.

b Total Chlordanes is the sum of alpha-chlordane, heptachlor, heptachlor epoxide, and trans-nonachlor.

ND = not detected

products of p,p'-DDT and o,p'-DDT, respectively. The use of DDT is now banned in the United States. DDT-series compounds were generally the most abundant of the chlorinated pesticides measured in the Virginian Province sediments (Table 3-4). The CDF of p,p'-DDE is presented in Figure 3-21 as an example of the distribution of DDT- series compounds measured in the Virginian Province. As was previously seen for PAHs and PCBs, the majority of the area of the Province contains low p,p'-DDE levels (93 ± 8% of the area with concentrations less than 4 ng/g). This This value is used not because of ecological significance but rather because it appears to be an inflection point in the CDF.

Chlordane is a pesticide that was widely used to control termites and other insects, but its use was severely restricted in 1987. It was sold as a technical mixture containing well over 100 chlorinated compounds (Dearth and Hites, 1991), many of which are persistent in the environment and have been found widely distributed in marine sediments. Two of these compounds (alpha-chlordane and trans-nonachlor) were measured in the sediments of the Virginian Province (Table 3-4). The maximum concentrations observed for these compounds were 7.03 and 5.44 ng/g dry weight for alpha-chlordane and trans-nonachlor, respectively. Figure 3-22 shows the cumulative distribution observed for alpha-chlordane in sediments of the Virginian Province. This plot shows that alpha-chlordane was not detected in 84 ± 7% of the area of the Province. The remaining pesticides measured generally showed concentrations near the analytical detection limits in most samples (Table 3-4).

The only chlorinated pesticide measured by EMAP-VP in sediments for which there is a draft Sediment Quality Criteria value is dieldrin. Draft EPA criteria were not exceeded at any station within the Virginian Province in 1992. It is important to note that this estimate was based on only those sediments with a total organic carbon content of ≥0.2% (75 ± 10% of the area of the Province). For the purpose of this exercise, those stations excluded were treated statistically as missing values.

3.2.3.4 Butyltins

Until its recent ban for most uses (Huggett *et al.*, 1992), tributlytin (TBT) was used in many boat anti-fouling paint formulations. As a result of this usage, TBT and its breakdown products, dibutyltin (DBT) and monobutyltin (MBT) have subsequently been detected in many harbors (Seligman *et al.*, 1989). The presence of TBT in aquatic systems has generated considerable concern because of the potent effects of this compound on some species (Rexrode, 1987; Heard *et al.*, 1989). Tributlytin can be rapidly converted to DBT and MBT in the water column but may be relatively resistant to degradation in marine sediments (Adelman *et al.*, 1990). The concentrations of butyltin compounds in this report are reported as nanograms of the respective butyltin ion per gram of dry sediment. Caution should be used when comparing TBT concentrations among studies because of the different ways that it is reported (*e.g.*, sometimes reported as ng *tin* /g sediment).

The maximum TBT concentration observed was 473 ng/g; DBT and MBT levels were generally lower than those of TBT (Table 3-5). Figure 3-23 shows the cumulative distribution of TBT in sediments as a percent of area in the Virginian Province. TBT was not detected (detection limit of approximately 12 ng/g) in 25 ± 10% of the area of the Province and 53 ± 12% of the area contained sediments with TBT concentrations of less than 25 ng/g. Concentrations exceeding 100 ng/g were detected at two stations representing only 0.6 (± 5) percent of the area of the Province.

3.2.3.5 Total Organic Carbon

Organic carbon, as measured by EMAP in the sediments, includes all forms of carbon except carbonate. Organic carbon accumulates in sediments of the marine environment as a function of the proximity and magnitude of the various sources of organic matter and the physical, and biological factors that influence erosion and deposition. The presence of organic matter is an important modifier of the physical and chemical condi-

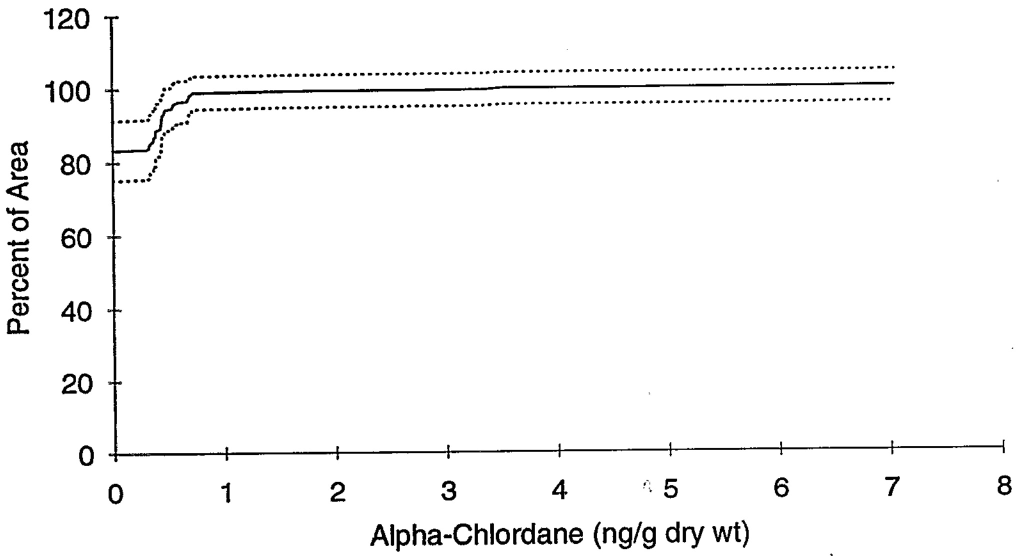


Figure 3-22. Cumulative distribution of alpha-chlordane in sediments as percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

Table 3-5. Range and median butyltin concentrations in sediments of the Virginian Province, 1992.

	Concentration (ng *ion* /g dry weight)			
Analyte	MIN	MAX	Median	Median Detection Limit[a]
Monobutyltin (MBT^{+3})	ND	54.8	ND	17.8
Dibutyltin (DBT^{+2})	ND	25.1	ND	9.8
Tributyltin (TBT^{+})	ND	473	23.0	12.2

[a] For each "not detected" the laboratory supplied a detection limit. This value is the median of these values for each analyte.

ND = not detected

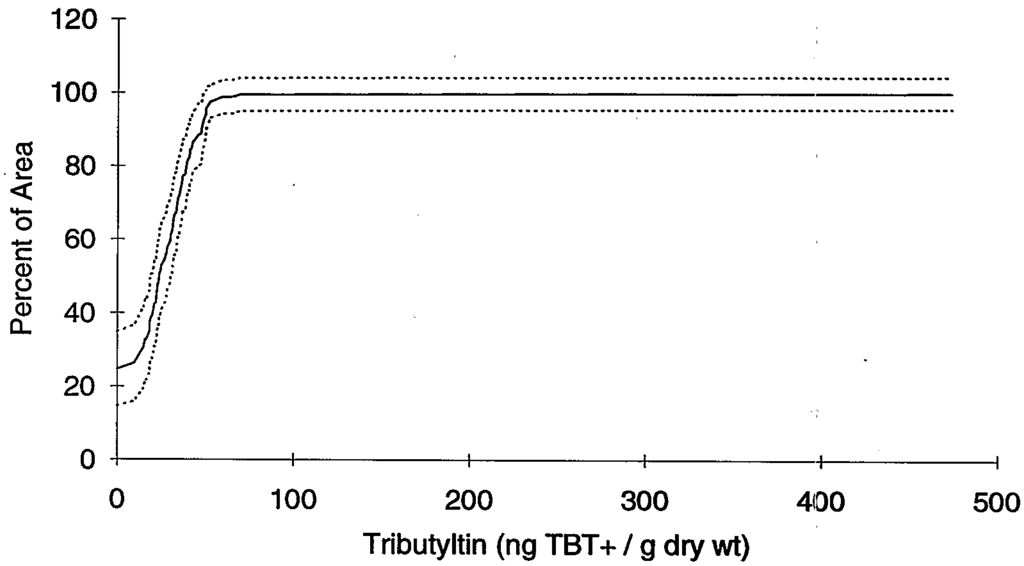


Figure 3-23. Cumulative distribution of tributyltin in sediments as percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

tions in the benthic ecosystem and serves as the primary source of food for the bottom fauna. As discussed earlier, organic carbon also plays a critical role in the geochemistry of organic contaminants in sediments.

The organic carbon content measured in sediments of the Virginian Province ranged from 0.01 to 4.65% by weight. The CDF of percent area as a function of the total organic carbon present in the sediments for all estuaries is shown in Figure 3-24. The pattern is largely determined by the large estuaries (Figure 3-25) which account for the largest part of the Province area.

3.2.3.6 Acid Volatile Sulfides

Acid volatile sulfides are defined as the fraction of sulfide in the sediments that can be extracted with cold hydrochloric acid. They exist in sediments mainly as iron monosulfide complexes, and are important in determining the biological availability of a number of cationic metals, primarily zinc, lead, copper, nickel, and cadmium. Acid volatile sulfides measured in sediments of the Virginian Province ranged from 0.86 to 3,870 mg/kg dry weight sediment. The CDFs of percent area as a function of AVS concentration is shown in Figures 3-26 and 3-27.

3.2.3.7 Metals

The median and range of metals concentrations measured in 1992 are listed in Table 3-6. Elemental concentrations in sediments are highly variable, due not only to contaminant inputs, but to natural differences in sediment types as well. Several approaches have been used to normalize sediment metals concentrations for variations due to sediment type differences. The approach taken in the 1991 Virginian Province Statistical Summary (Schimmel *et al.*, 1994) was to normalize against aluminum. Determination of metal-aluminum relationships in background sediments enables estimation of the extent of enrichment of metals in sediments.

Figure 3-28 presents an example of a metal regression plot (for Cr). The predicted metal- aluminum relationship (solid line) is obtained from the regression, along with the upper bound of the 95% confidence interval for predicted values (dashed line). Values above the upper bound are greater than expected (*i.e.*, enriched) based on the aluminum concentration measured in the sediment. This "excess" metal is derived from additional sources other than crustal background sediment, presumably, although not necessarily, from anthropogenic activity. Regressions for the remaining metals are presented in

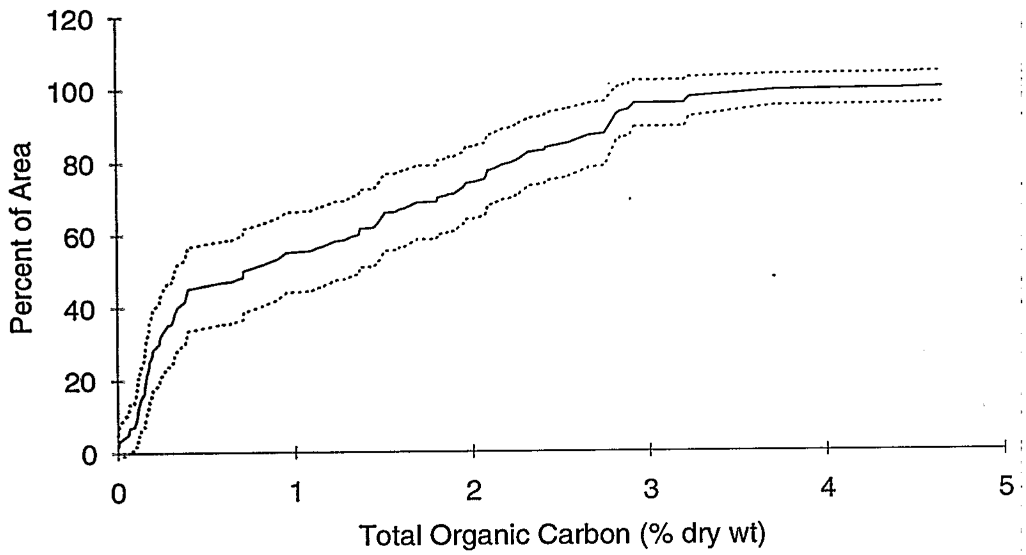


Figure 3-24. The cumulative distribution of the percent total organic carbon in sediments as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

Appendix B. Some of the metals, *e.g.*, Ni, Cr, Se, Sb and the crustally-derived elements Fe and Mn, are not highly enriched (the highest measured concentrations are generally less than 2-3 times higher than the upper bound of predicted concentrations). Two metals, Hg and Ag, are found at a number of stations in concentrations more than 10-60 times higher than predicted from the metal-aluminum relationship. The highest concentrations of other metals (Pb, Sn, Cu, As, Cd and Zn) are generally 2-10 times higher than predicted. Often a given station exhibits substantial enrichment of more than one metal. The aerial extent of enriched metals concentrations in sediments can be estimated once stations with enriched metals concentrations are identified (Figure 3-29). For several metals, the proportion of the Province in which metals concentrations are enriched is substantial, *e.g.*, Ag, Cr, and Sn. One station in Chesapeake Bay exhibited sediment concentrations of both Pb and Sb several orders of magnitude higher than any other station. This is likely due to lead shot (presumably from duck hunters) included in the sample. The co-occurrence of lead and antimony (Sb is a hardener used in lead shot) at this station supports this hypothesis.

Approximately 31 ± 10% of the area of the Province showed enrichment of sediments with at least one metal. Twenty seven (± 13), 43 ± 13, and 34 ± 39 percent of the large estuary, small estuary, and large tidal river class areas sampled contained sediments with metals concentrations exceeding predicted background levels. Although a significant proportion of the Province contains sediments with potentially enriched levels of metals, this does not imply ecological impact. The level of enrichment is generally low, and most of the metals present are likely bound by AVS or organic carbon, making them biologically unavailable.

3.2.4 Marine Debris

Anthropogenic debris is perhaps the most obvious sign of human use and environmental degradation. The presence of anthropogenic debris in the field of view or the inconvenience caused when it fouls a boat propeller or fishing line can diminish the recreational value of the estuarine environment. "Trash" is most likely to be found in large tidal rivers and small estuaries where human settlement and recreational activities are most intense.

The debris collected in bottom trawls was examined as an indicator of environmental degradation in the Virginian Province. Debris was found on the bottom of approximately 25 ± 11% of the Virginian Province area sampled in 1992 (Figure 3-30). The small estuary

a) Large Estuaries

b) Small Estuaries

c) Large Tidal Rivers

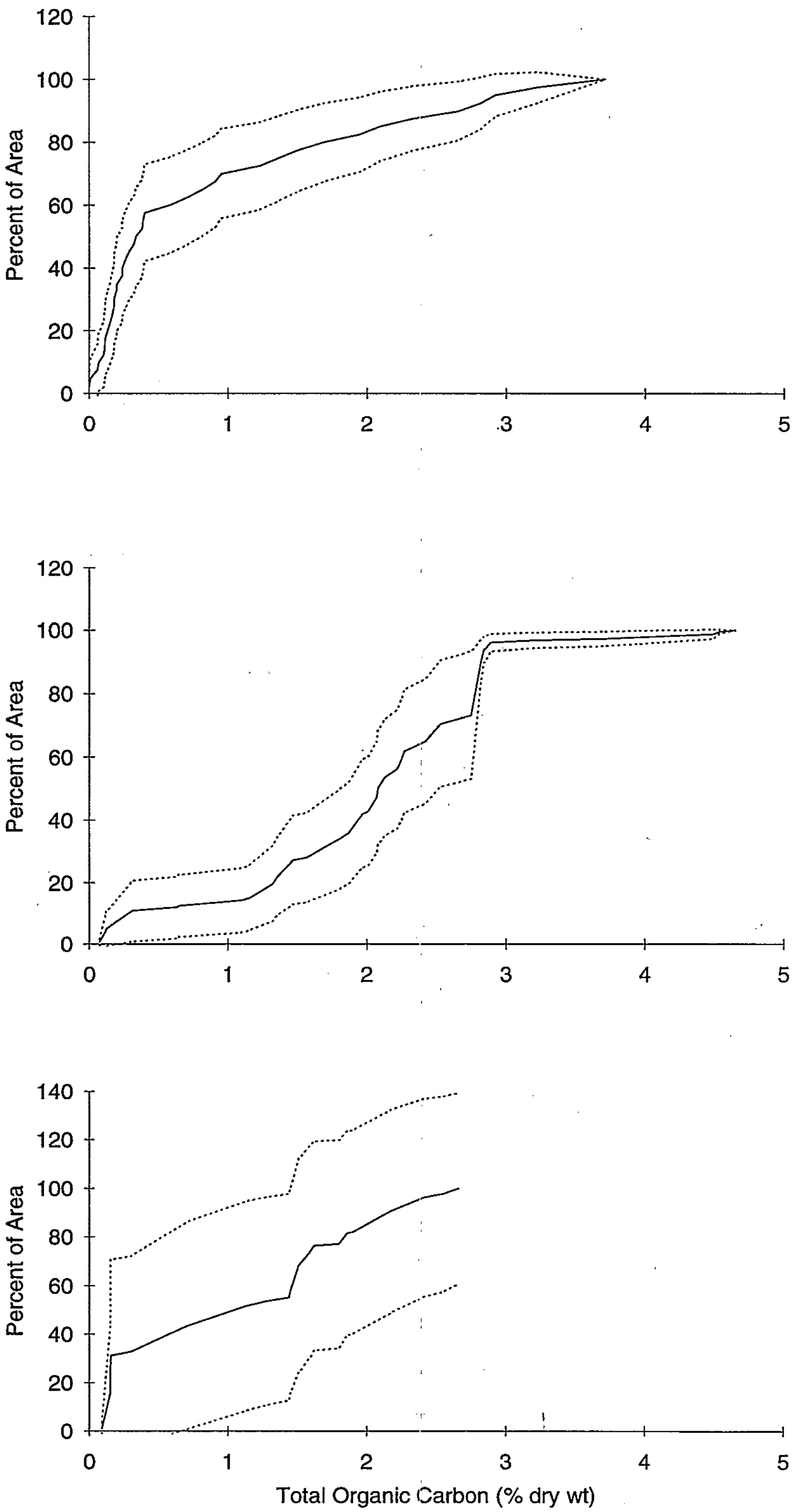


Figure 3-25. Cumulative distribution of the percent total organic carbon in sediments by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

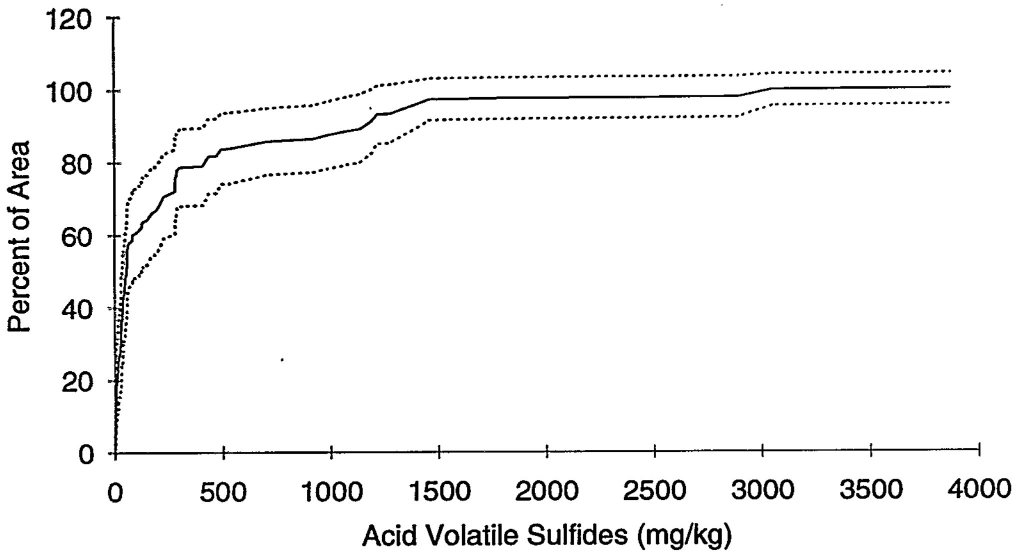


Figure 3-26. The cumulative distribution of the acid volatile sulfide concentration in sediments as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

class had the largest percent area (41 ± 19%) where trash was found. Trash was found in 21 ± 13% of the area of the large estuaries and 24 ± 45% of the area of large tidal rivers.

3.3 Habitat Indicators

Habitat indicators describe the natural physical and chemical conditions of the sites sampled in the 1992 Virginian Province study.

3.3.1 Water Depth

The depth distribution in the Virginian Province is shown in Figure 3-31. The area shallower than 2 m is underestimated because this is the minimum depth sampled. Based on the sampling design where a single station represents a given area, 12% of the area of large estuaries was unsampleable due to inadequate water depth. Small estuaries were considered unsampleable if the water depth did not exceed 2 m anywhere in the system. Such systems account for approximately 1.5% of the area of small systems in the Virginian Province. Overall, 8.5% of the area of the Province was deemed unsampleable in 1992 due to water depth.

3.3.2 Temperature

Bottom water temperature in the Virginian Province ranged from 11.8°C to 27.8°C during the summer sampling period. The cumulative distribution function of bottom temperature is shown in Figure 3-32. The lowest bottom temperatures measured in the Province occurred in a small estuary at the eastern end of Cape Cod, MA.

Bottom temperature in the small estuaries ranged from 11.8°C to 27.8°C (Figure 3-33b). Large tidal rivers had a steep CDF (Figure 3-33c) and exhibited the smallest temperature range (22.6°C to 27.5°C).

3.3.3 Salinity

Salinity is determined by freshwater discharge and seawater intrusion. Salinity in the broad sounds of the northern extent of the Province is, in general, higher than salinity in the coastal plain estuaries south of the Hudson River. The CDF for bottom salinity (Figure 3-34) reflects the different salinity characteristics of the large estuarine systems (Figure 3-35).

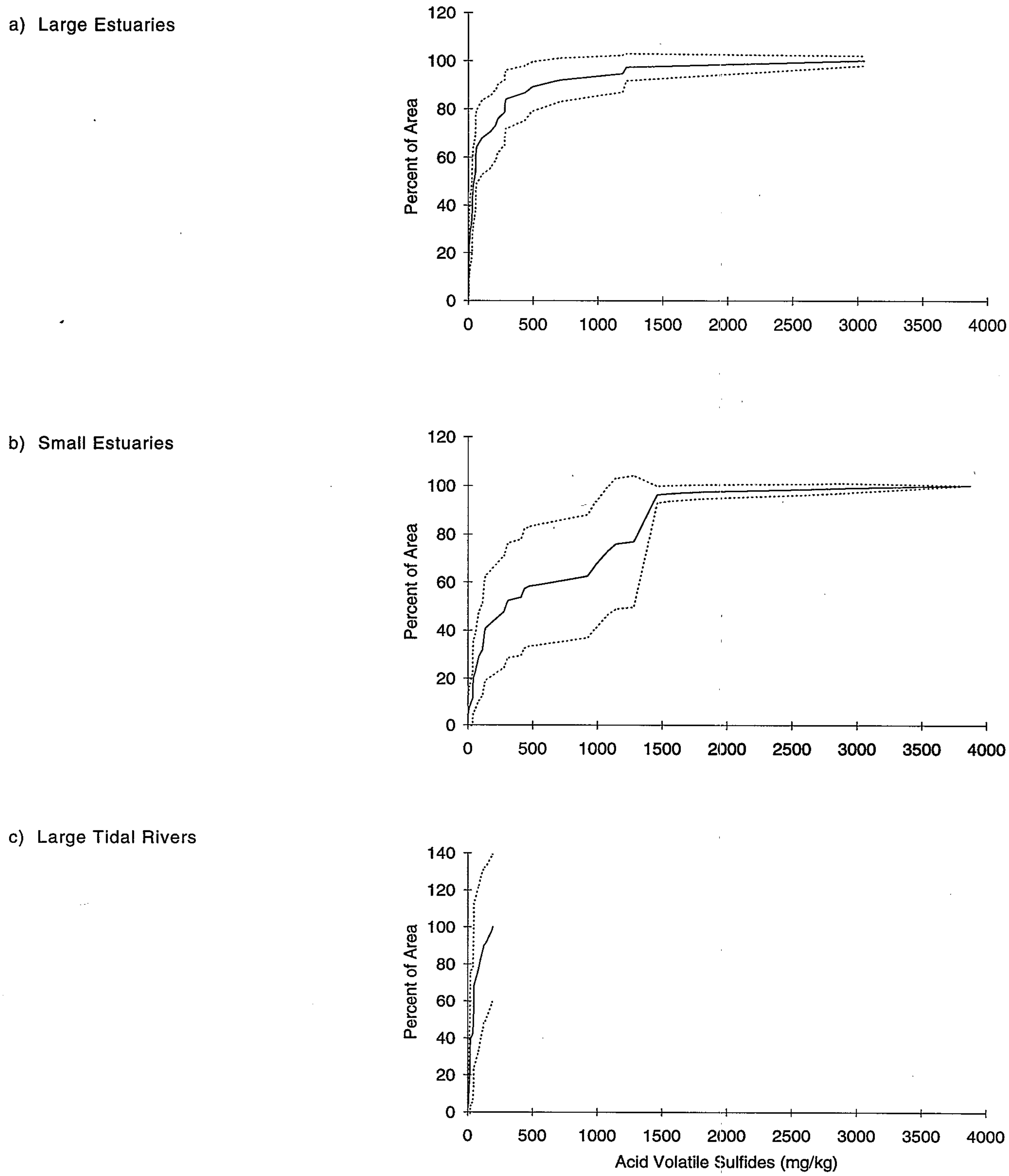


Figure 3-27. Cumulative distribution of the acid volatile sulfide concentration in sediments by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

Table 3-6. Range and median metal concentrations in sediments of the Virginian Province, 1992.

Analyte	Concentration (µg/g dry weight) MIN	MAX	Median	Median Detection Limit[a]
Major				
Aluminum	1,890	83,000	41,800	na
Iron	1,360	64,700	22,100	na
Manganese	23.9	5,850	424	na
Trace				
Antimony	ND	152	0.386	0.051
Arsenic	0.423	30.8	7.18	na
Cadmium	ND	2.39	0.207	0.031
Chromium	1.90	147	42.0	na
Copper	1.05	201	156.3	na
Lead	ND	13,600[b]	24.0	1.80
Mercury	ND	1.57	0.054	0.004
Nickel	ND	66.7	17.3	1.70
Selenium	ND	0.86	0.258	0.110
Silver	ND	8.77	0.124	0.007
Tin	ND	30.4	2.17	0.120
Zinc	3.15	402	85.0	na

[a] For each "not detected" the laboratory supplied a detection limit. This value is the median of these values for each analyte.

[b] Lead shot is suspected as the cause of this elevated concentration. An elevated antimony level was also detected in this sample, and antimony is a hardener used in lead shot.

na = not applicable

ND = not detected

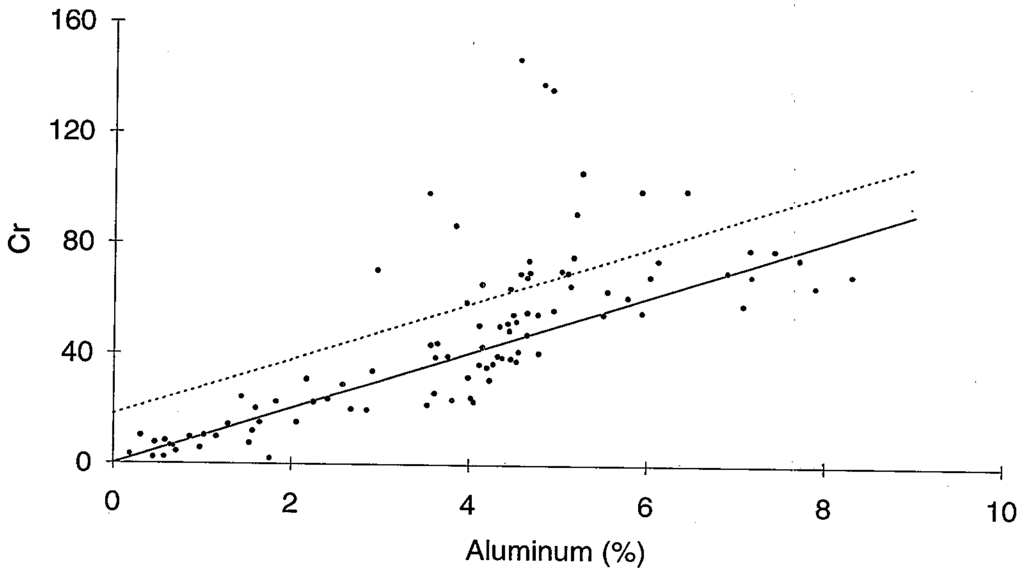


Figure 3-28. Linear regression (with upper 95% confidence intervals) of chromium against aluminum.

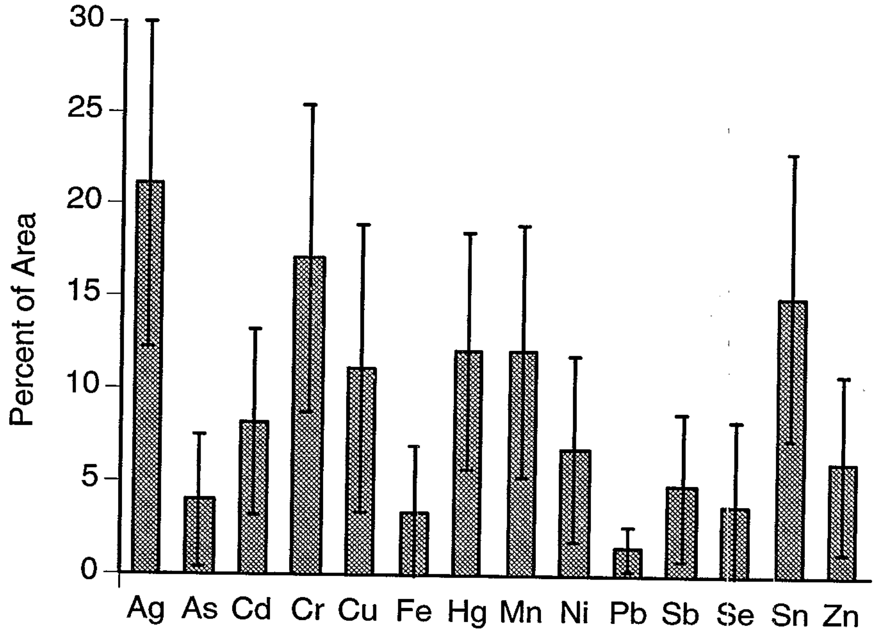


Figure 3-29. Percent area of the Virginian Province with enriched concentrations of individual metals in sediments in 1992. (Error bars represent 95% confidence intervals).

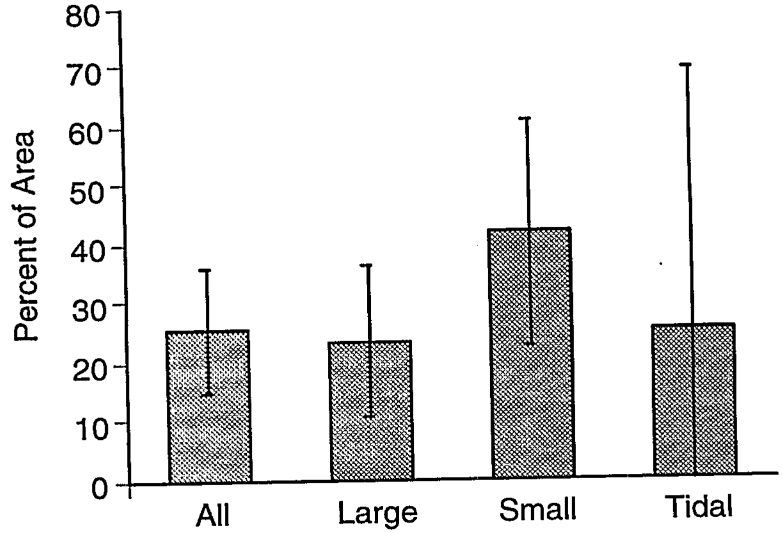


Figure 3-30. Percent area of the Virginian Province by estuarine class where anthropogenic debris was collected in fish trawls, 1992. (Error bars represent 95% confidence intervals).

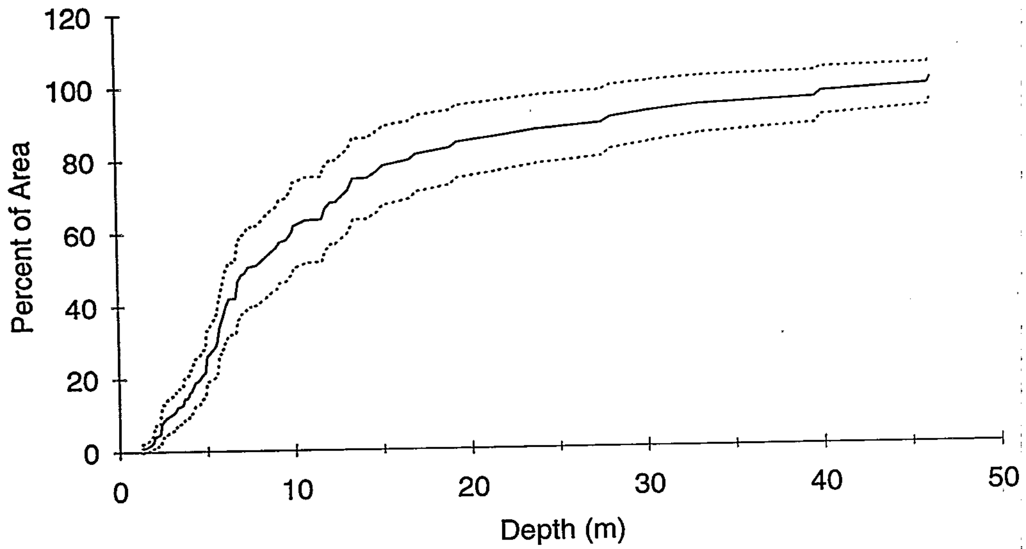


Figure 3-31. Cumulative distribution of water depth as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

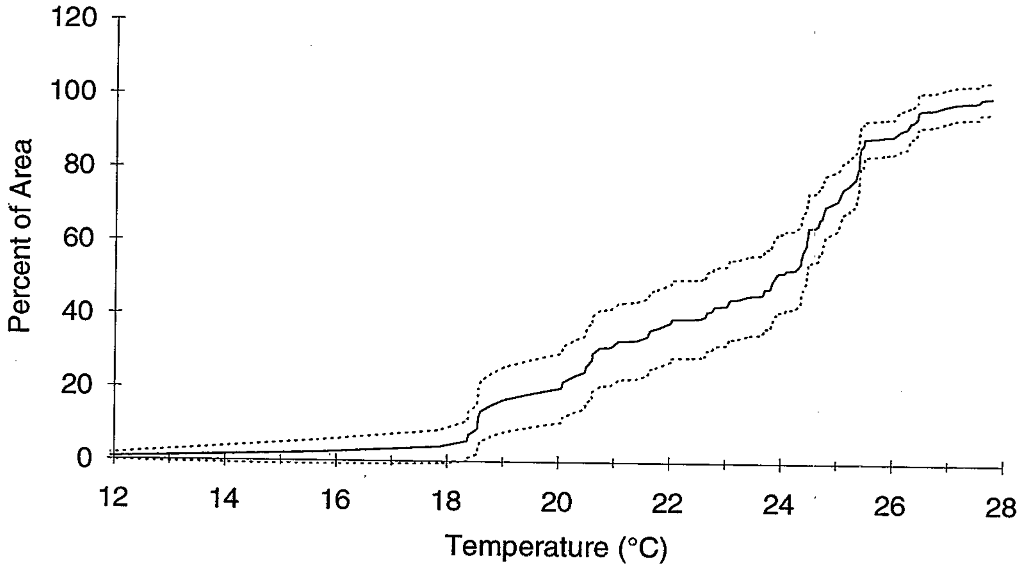


Figure 3-32. Cumulative distribution of bottom temperature as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

The CDF for small estuaries (Figure 3-35) is dominated by small systems in the Chesapeake Bay which account for most of the area between 12 and 20‰. The low salinity tail of the CDF is due to the contribution of small river systems, whereas the high salinity component is due to embayments supplied with high salinity waters from the northern sounds. The range of salinities was greatest in small estuaries (0.1 to 32 ‰), with the ranges for large estuaries and large tidal rivers being 4 to 31 and 0.1 to 22 ‰, respectively (Figure 3-36).

The 1992 data showed 26 ± 20% of the large tidal river area to be fresh water (salinity < 0.5‰). Large tidal rivers contain the largest oligohaline area (44 ± 22% < 5 ‰) compared to 11 ± 8% for small estuaries and 2 ± 5% for the large estuaries (Figure 3-36).

3.3.4 pH

The negative log of the hydrogen ion concentration, or pH, of estuarine and coastal waters, similar to salinity, depends on the mixing of sea water and fresh water from land drainage. Sea water is well-buffered, with its pH usually falling between 8.1 and 8.4. The pH of fresh water runoff depends upon the characteristics of the land drained and can be quite variable.

The measured pH of Virginian Province estuaries ranged from 6.8 to 9.2, with 64 ± 8% of the Province area between pH 7.7 and 8.2. The lowest pH values occurred in large tidal rivers, upper Chesapeake Bay, and in small estuaries associated with tidal rivers or other fresh water inflows. High pH values were generally associated with sea water inflow; however, the highest pH value was found in the upper Potomac River near Washington DC.

3.3.5 Stratification

Vertical density differences (*i.e.*, stratification), if large enough, can result in a reduction of mixing between surface and bottom waters, potentially allowing the bottom waters to become hypoxic. Stratification may also create conditions that enhance phytoplankton growth, which might ultimately result in increased biomass settling to the bottom contributing an additional biological oxygen demand in the stratified environment.

Fresh water runoff can be an important factor in this process because it both provides low density water which helps to maintain stratification and often carries high nutrient concentrations which support plant growth. Stratification may also be caused by warming of the surface waters, especially where salinity is uniform.

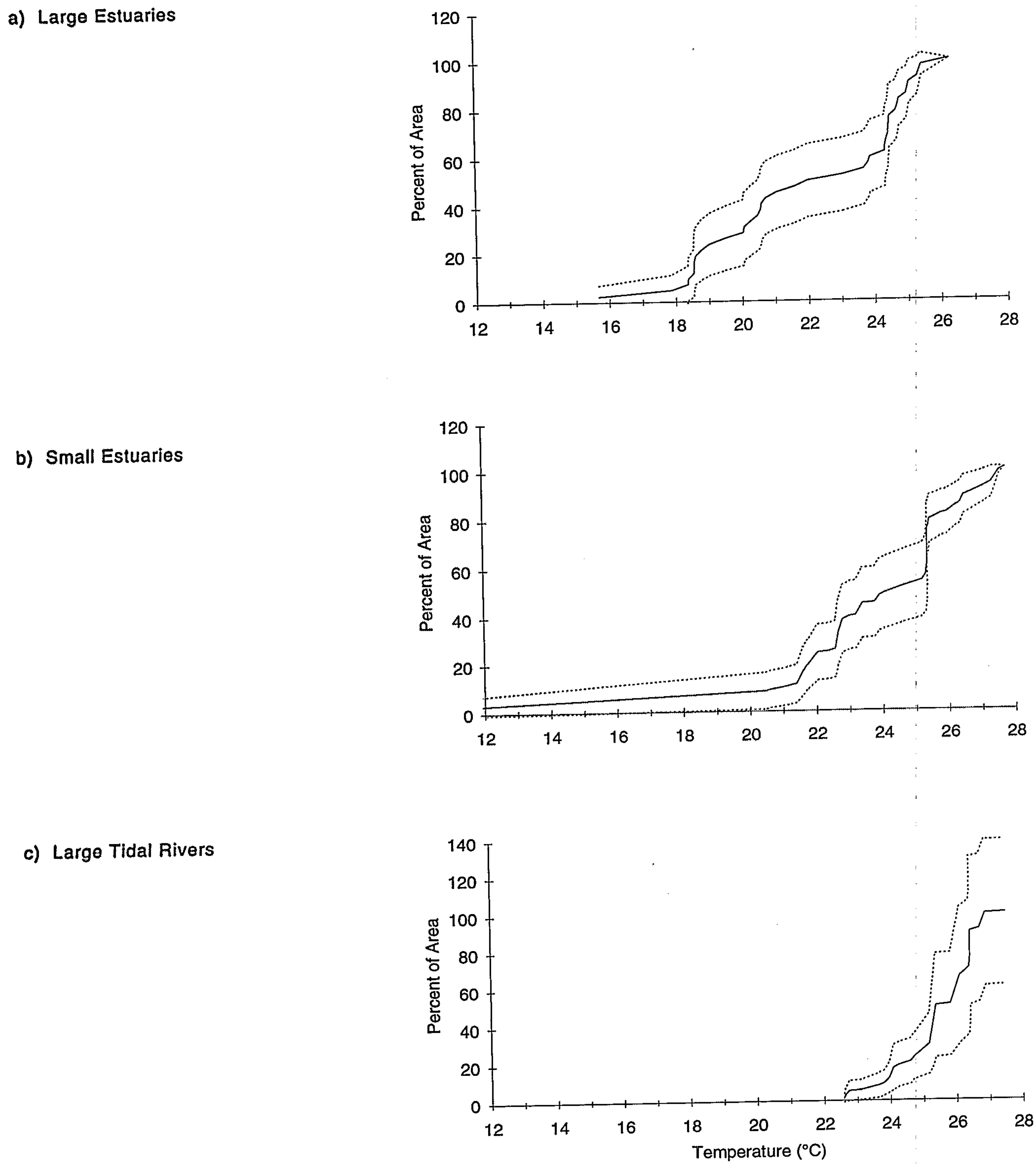


Figure 3-33. Cumulative distribution of bottom temperature by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

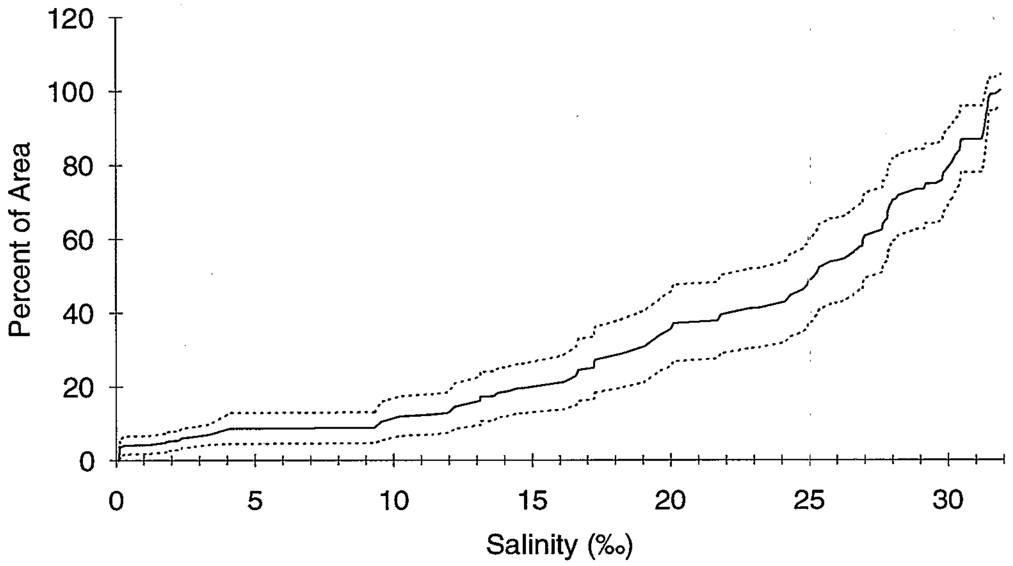


Figure 3-34. The cumulative distribution of bottom salinity as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

The development of stratification depends not only on the magnitude of the density difference between surface and bottom waters, but also on the depth of those waters and the physical energy available for mixing. Although affected by tidal stage, rainfall and other factors, no attempt was made to normalize density data.

Stratification in the Virginian Province is shown as a CDF of $\Delta\sigma_t$, which is the σ_t (sigma-t) difference between surface and bottom waters (Figure 3-37). Sigma-t is a density measurement commonly used in oceanographic studies. It is a measurement of the density a parcel of water with a given temperature and salinity would have at the surface (*i.e.*, atmospheric pressure), and is presented as:

(density - 1) x 1000

The CDF for all estuaries shows that 68 ± 11% of the Province area had a $\Delta\sigma_t$ of <1 unit, with 38 ± 11% being ≤0.2; thus the majority of the water in the Virginian Province was well-mixed. Seventeen ± 10% of the Province area was stratified ($\Delta\sigma_t \geq 2$). The bar chart for stratification by class (Figure 3-38) shows that small estuaries and large tidal rivers were least stratified (2 ± 39% with $\Delta\sigma_t \geq 2$) and best mixed (94 ± 8% and 98 ± 39%, respectively with $\Delta\sigma_t < 1.0$). Large estuaries had the greatest range of $\Delta\sigma_t$ (0 to 6).

3.3.6 Suspended Solids

The amount of suspended matter in the water is dependent on the physical and biological conditions at the site. Both the concentration and composition (*i.e.*, size distribution and organic *vs* inorganic origin) of suspended material affects light extinction and water clarity; and thus the productive and aesthetic qualities of the water.

The data presented in this section represent surface values only. Suspended solids concentrations in the waters of the Virginian Province ranged from 2.7 to 58 mg/L in 1992 (Figure 3-39). The relative condition of Virginian Province waters in large estuary, small estuary, and large tidal river classes are similar (Figure 3-40).

3.3.7 Light Extinction

The light extinction coefficient is a measure of the attenuation of sunlight in the sea. It is the natural logarithm of the ratio of the intensity of light of specified wavelength on a horizontal surface to the intensity of the same wavelength light on a horizontal surface 1 m deeper. The extinction coefficient of photosynthetically active radiation (PAR) was calculated from depth and PAR measurements made with the SeaBird CTD. The

a) Large Estuaries

b) Small Estuaries

c) Large Tidal Rivers

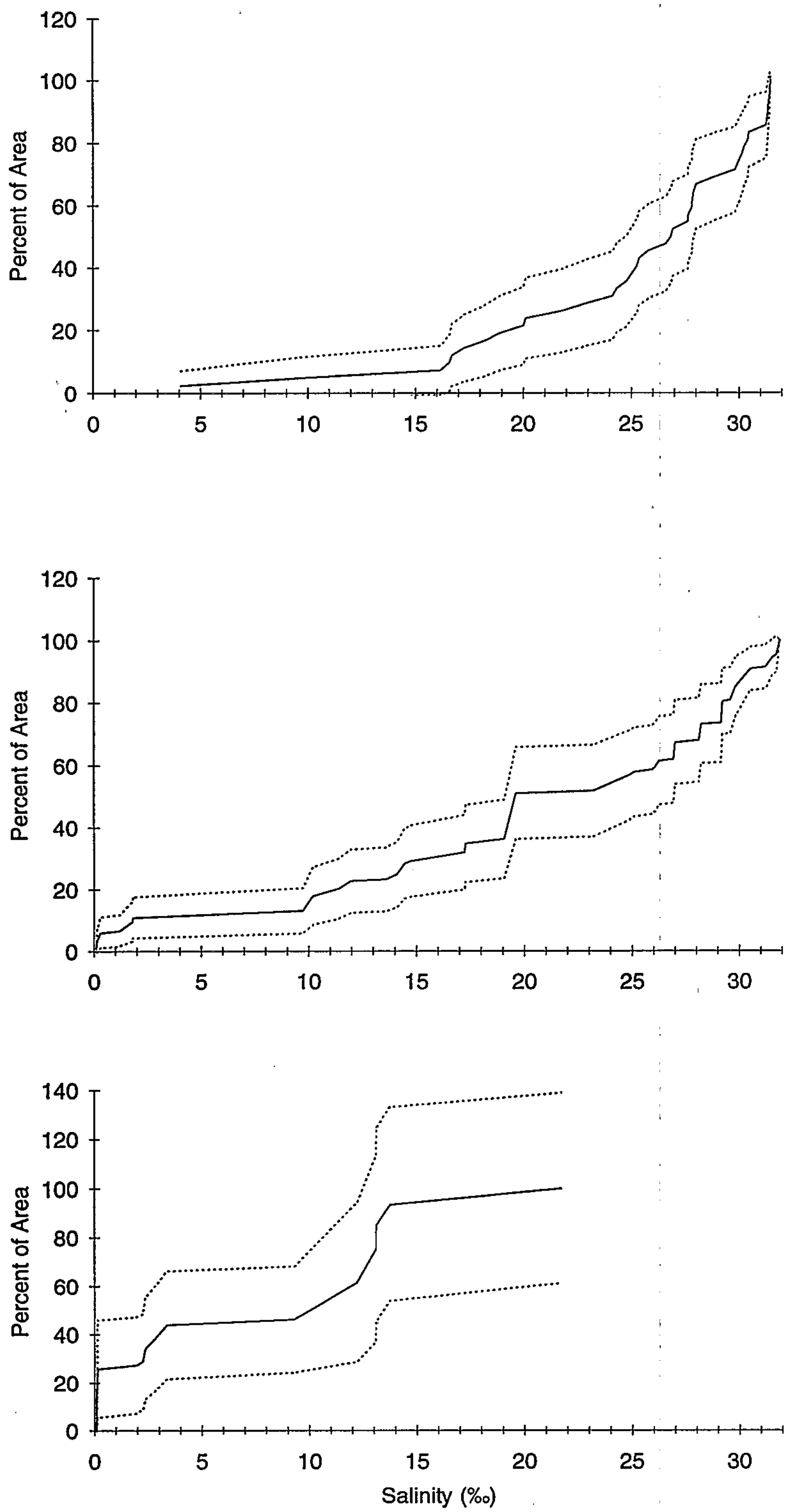


Figure 3-35. Cumulative distribution of bottom salinity by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

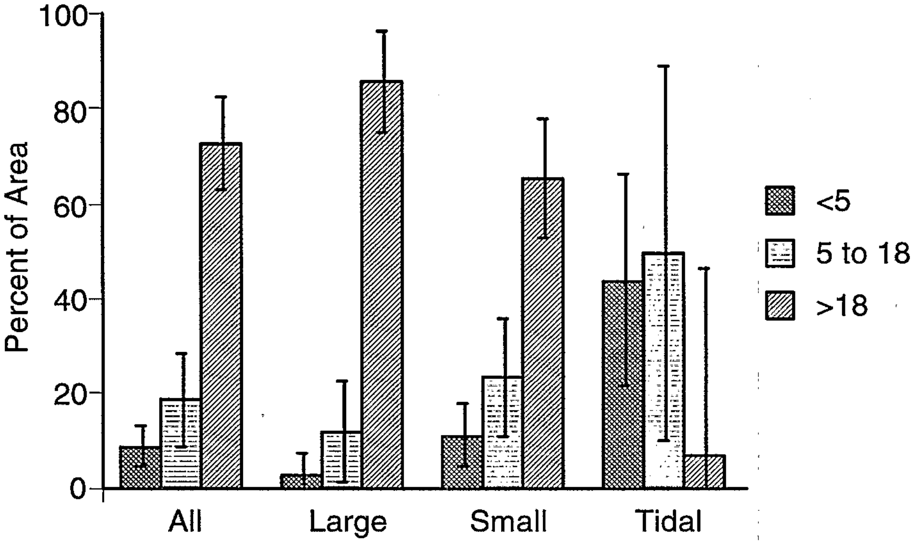


Figure 3-36. Percent area by estuarine class classified as oligohaline (<5 ppt), mesohaline (5 to 18 ppt), and polyhaline (>18 ppt). (Error bars represent 95% confidence intervals).

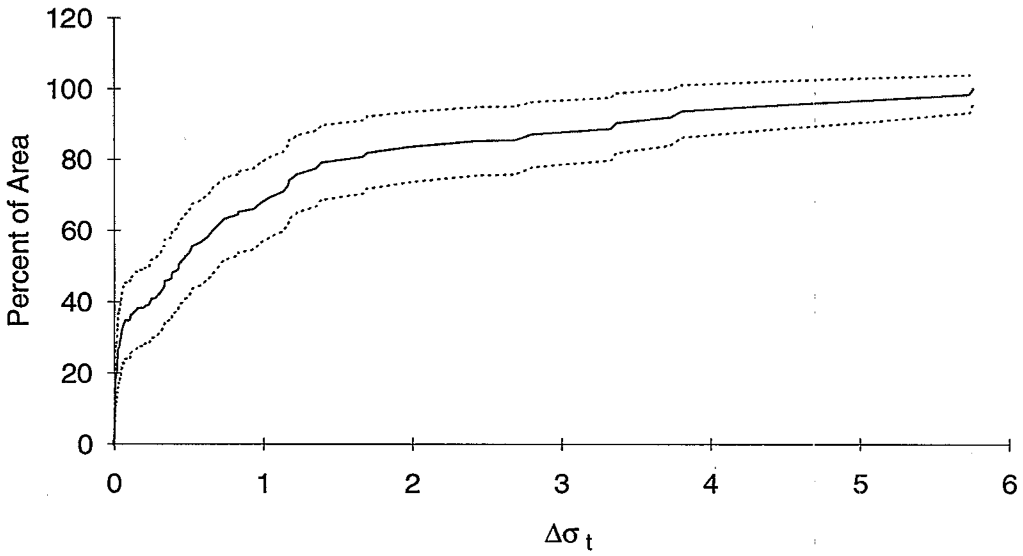


Figure 3-37. Cumulative distribution of the stratified area in the Virginian Province in 1992 based on the σ_t difference between surface and bottom waters. (Dashed lines are the 95% confidence intervals).

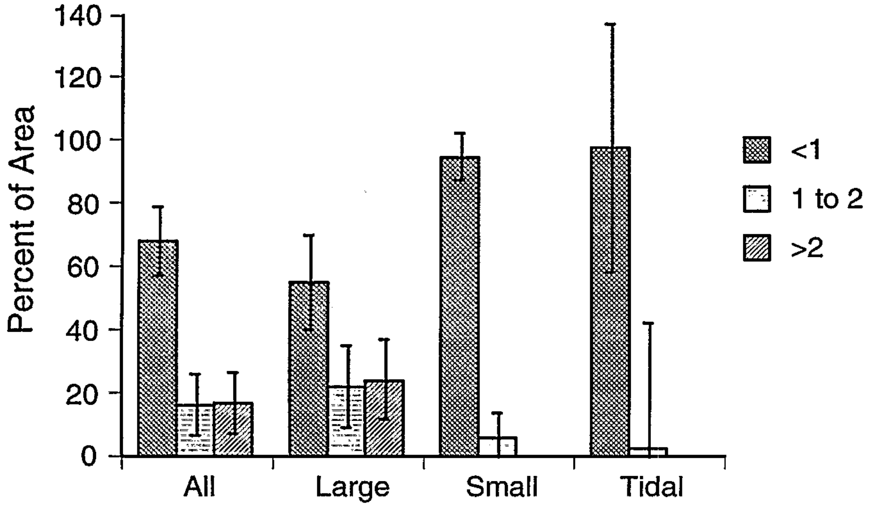


Figure 3-38. The percent of the area by estuarine class that had a low (<1), medium (1 to 2), or high (>2) degree of stratification ($\Delta \sigma_t$). (Error bars represent 95% confidence intervals).

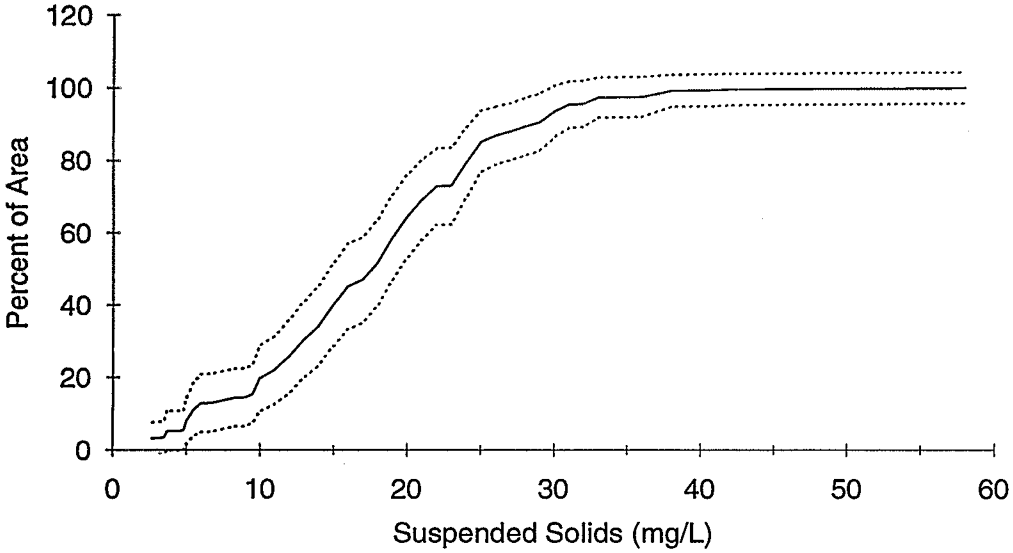


Figure 3-39. The cumulative distribution of total suspended solids concentration as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

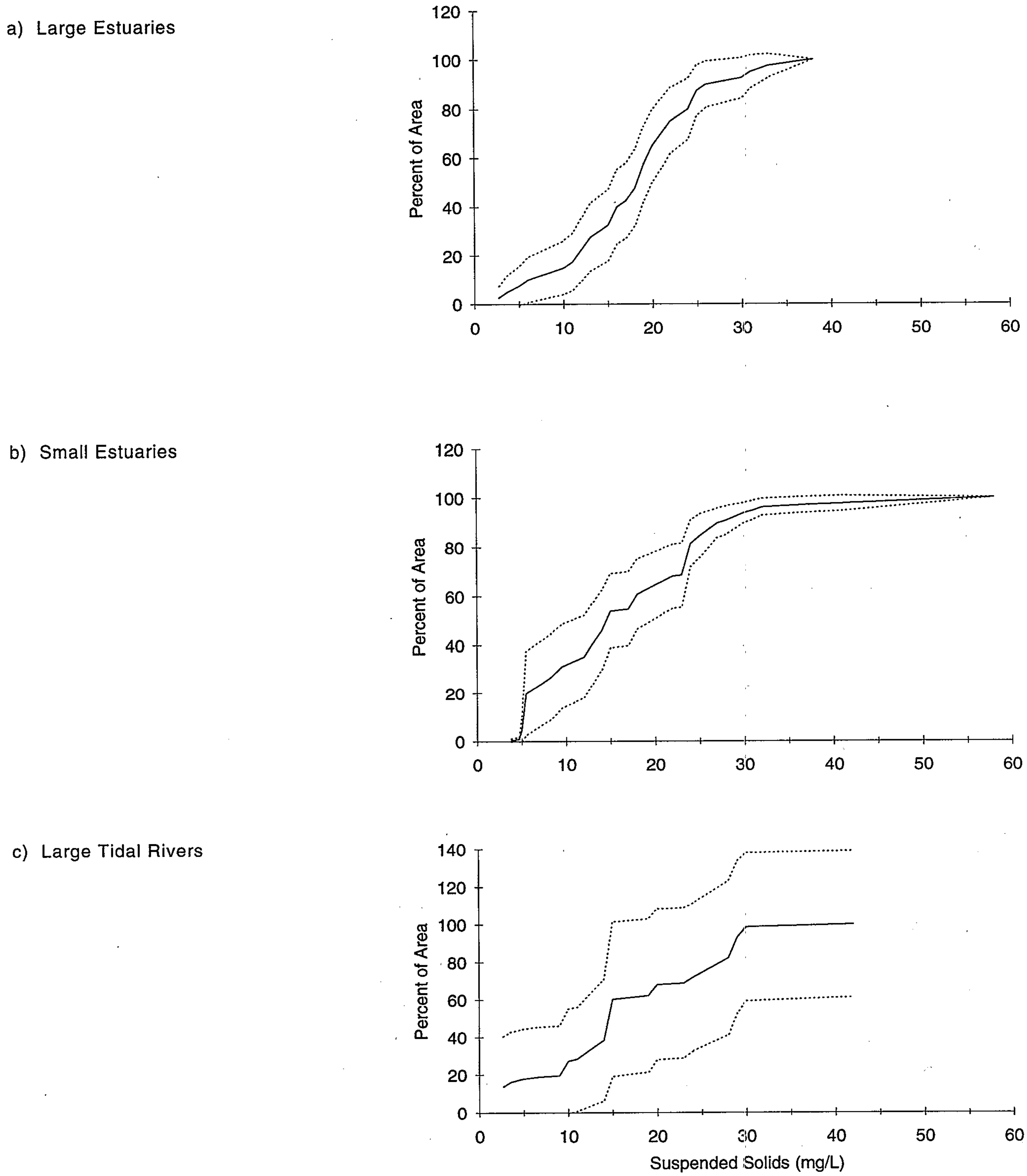


Figure 3-40. Cumulative distribution of total suspended solids concentration by estuarine class: a) Large estuaries, b) Small estuaries, c) Large tidal rivers. (Dashed lines are the 95% confidence intervals).

extinction coefficient is an important measure of the light available for photosynthesis and of the aesthetic qualities of the water for human use.

We are defining low water clarity as water in which a diver would not be able to see his/her hand when held at arms length. This corresponds to an attenuation coefficient ≥2.303 which is equivalent to the transmission of 10% of the light incident on the surface to a depth of 1 m. Moderate water clarity corresponds to an extinction coefficient of ≥1.387, which is equivalent to the transmission of 25% of the light incident on the water surface to a depth of 1 m. In terms of human vision, a wader in water of moderate clarity would not be able to see his/her feet in waist-deep water.

Water clarity was good in 83 ± 8% of the sampled area of the Virginian Province (Figure 3-41). Water of low clarity was found in 5 ± 6% of the Province and an additional 12 ± 7% of the Province had water of moderate clarity. Thus, in 17 ± 8% of the waters in the Virginian Province waders would not be able to see their toes in waist deep water. Water of low clarity was found in 3 ± 5% of the large estuarine area, 4 ± 4% of the small estuarine area, and in 20 ± 40% of the large tidal river area (Figure 3-42). These differences in water clarity may be due to fundamental differences in the dynamic properties of the classes as well as differences in the intensity of human use. Large estuaries had the greatest percent area of high water clarity (90 ± 9%).

3.3.8 Percent Silt-Clay Content

The silt-clay (mud) content of sediments (the fraction <63μ) is an important factor determining the composition of the biological community at a site, and is therefore important in the assessment of the benthic community. Percent mud is also useful when examining sediment chemistry data because the available surface area for sorption of contaminants is partially a function of grain size, with fine-grained sediments (*i.e.*, mud) generally being more susceptible to contamination than sands exposed to the same overlying water.

All silt-clay results presented in this report are for the surficial sediments (0-2 cm) collected as part of the chemistry /toxicity homogenate.

The CDF of silt-clay content for the Virginian Province is shown in Figure 3-43. Forty-five (± 12) percent of the area had sandy sediments (<20% silt-clay), and 21 ± 10% of the area had muddy sediments (>80% silt-clay). The sediment size distribution in large estuaries was dominated by sands, in small estuaries by muds, and in tidal rivers it was variable (Figure 3-44).

Sediment size distribution is primarily a result of the different physical characteristics of the separate system classes. For example, small systems are often estuaries, bays, tidal creeks and rivers with low flow rates, which result in high deposition rates of fine-grained material. The large area of sandy sediments found in the large estuaries of the Virginian Province are most likely the result of either the winnowing of sediments or the transport of marine sands. The mouth of the Chesapeake Bay is an example of the latter where sands are carried in from the ocean (Hobbs *et al.*, 1992). Long Island Sound is an example of a system where the coarser sediments at the entrance are mainly a result of strong tidal currents transporting away the fine fraction (winnowing), leaving behind the coarser sands and gravel (Akapati, 1974; Gordon, 1980).

3.4 Integration of Estuarine Conditions

The condition of estuaries of the Virginian Province to use can be estimated through the examination of multiple indicators. As an example, we have integrated data on stations that can be considered "degraded" based on aesthetic quality (poor water clarity or the presence of anthropogenic trash caught in fish trawls), low bottom dissolved oxygen concentration (< 5mg/L), and the benthic index. The summation of these indicators was used as an indicator of the maximum extent of potential degradation. Figure 3-45 shows that, in this example, 49 ± 11% of the Province is potentially degraded in terms of its benthic biology and ability to support desired human commercial or recreational uses. Aesthetic value (water clarity and presence of trash) was degraded in 25% of the Province, whereas 34% of the area may be degraded as a result of subnominal benthic communities or low levels of dissolved oxygen. In 9% of the Province area subnominal benthic communities or hypoxia existed along with evidence of aesthetic degradation, and in one percent of the area of the Province all three indicators of degradation co-existed.

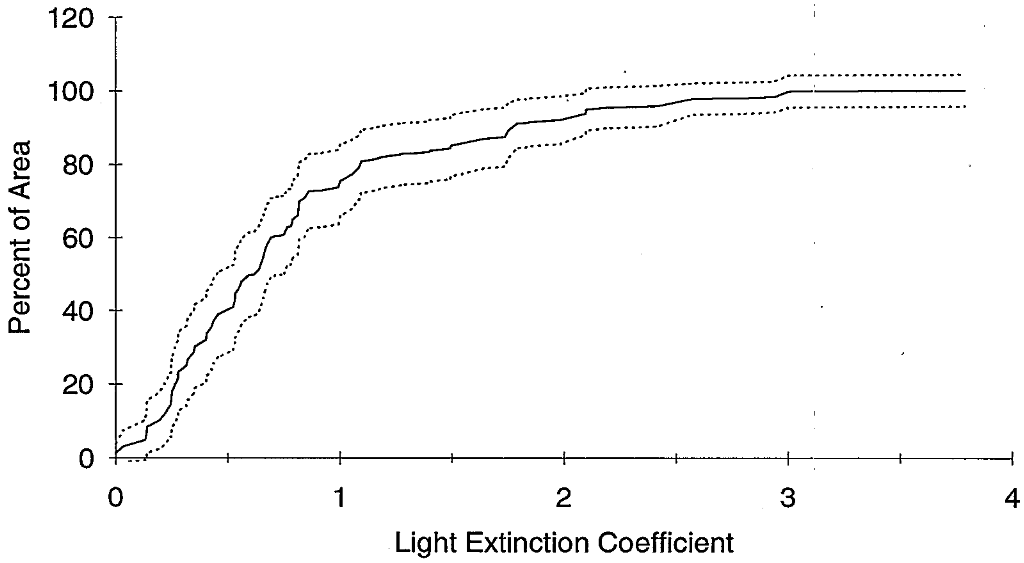


Figure 3-41. The cumulative distribution of light extinction coefficient as a percent of area in the Virginian Province in 1992. (Dashed lines are the 95% confidence intervals).

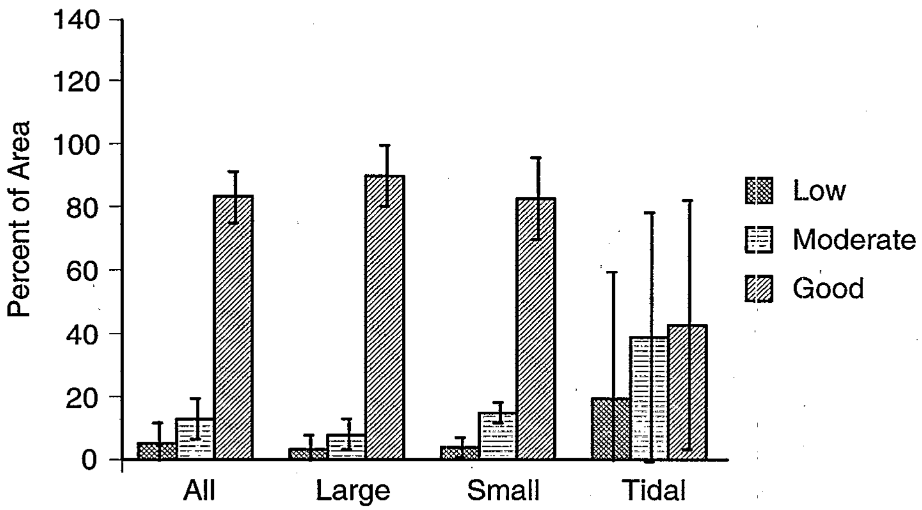


Figure 3-42. Percent area by estuarine class where water clarity was low, moderate, or good. (Error bars represent 95% confidence intervals).

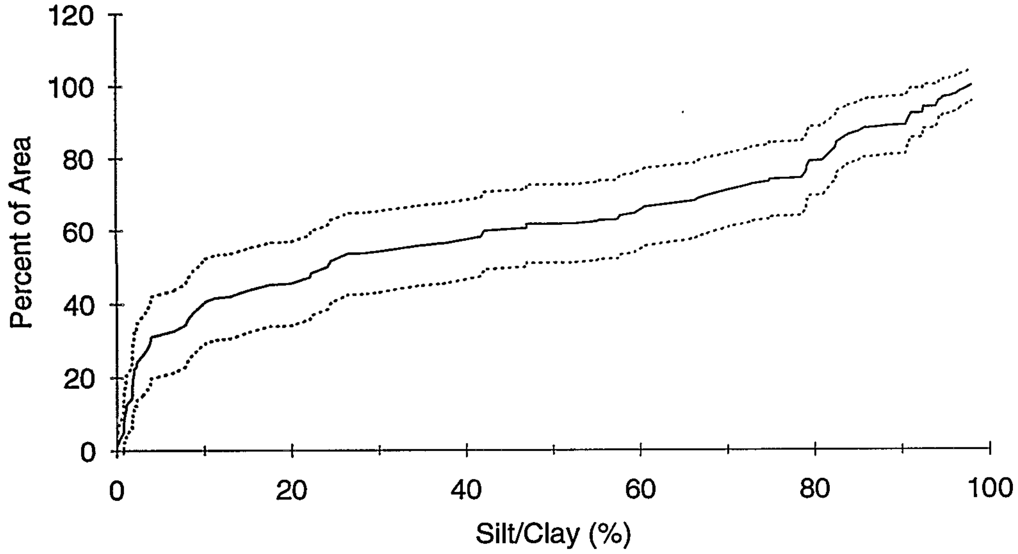


Figure 3-43. The cumulative distribution of the percentage of silt-clay in the sediments as a percent of area in the Virginian Province, 1992. (Dashed lines are the 95% confidence intervals).

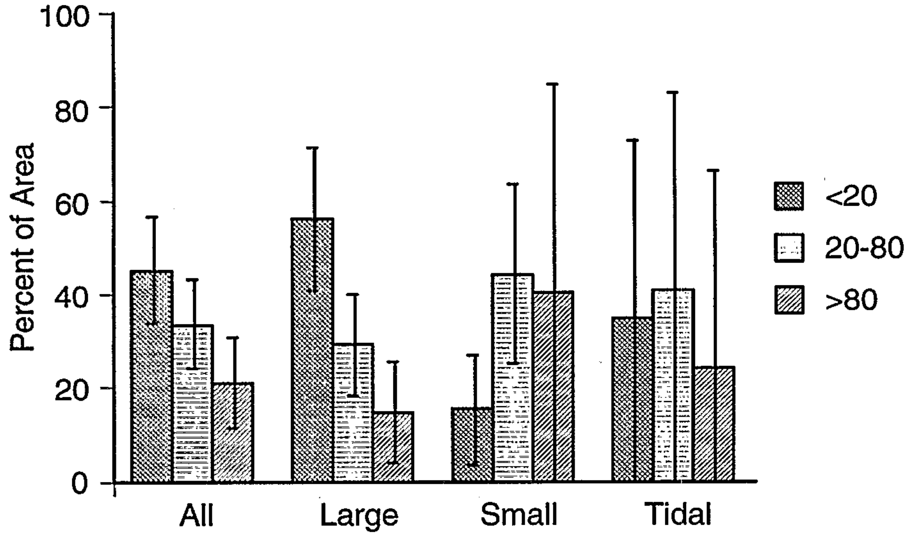


Figure 3-44. Percent of area by estuarine class with a low (<20), medium (20 to 80), or high (>80) percent silt-clay in the sediments. (Error bars represent 95% confidence intervals).

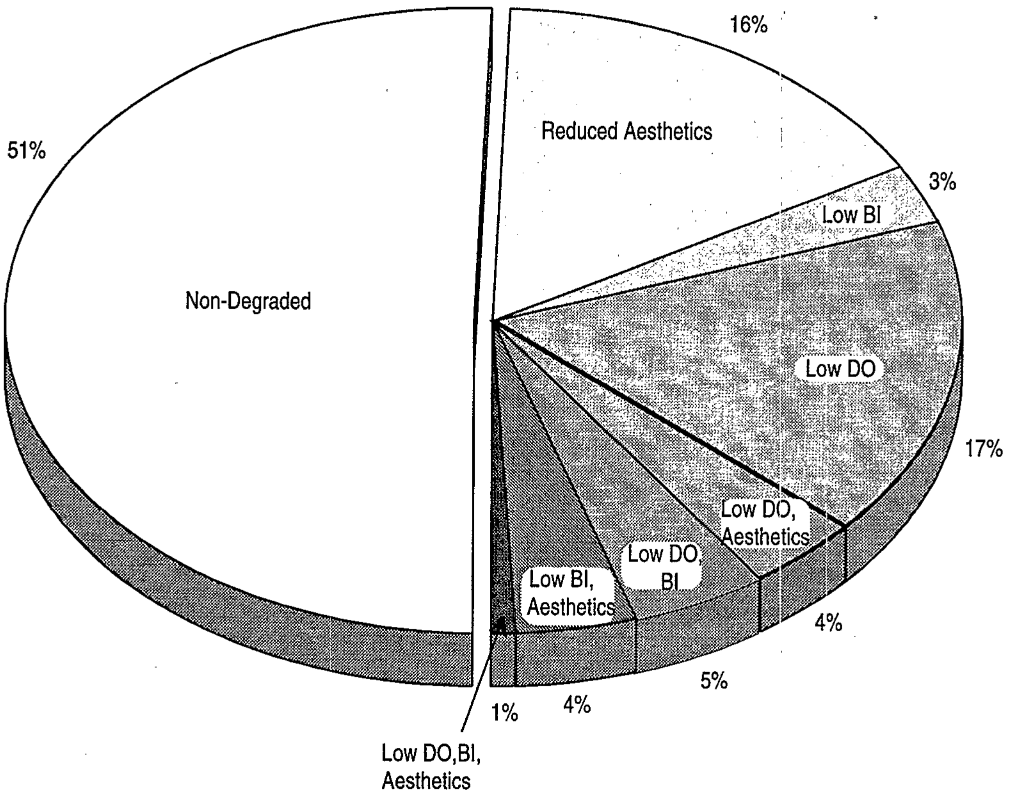


Figure 3-45. Integration of estuarine conditions based on aesthetic quality (presence of bottom trash and water clarity), bottom dissolved oxygen (< 5mg/L), and the benthic index.

Poor water clarity and the presence of anthropogenic debris may dictate impairment of some human uses, but are probably not good indicators of ecological degradation; therefore, the area of the Virginian Province that is, in fact, degraded is probably much less than indicated in this example.

This evaluation is intended solely as an example of how these data may be used. To truly estimate the percent area degraded, all indicators should be included. Due to the current state of understanding of sediment geochemistry and its relationship with the biota, such an exercise could not be undertaken at this time.

SECTION 4

SUMMARY OF FINDINGS

Thousands of pieces of information on the condition of estuarine resources in the Virginian Province in 1992 were collected and analyzed. The major findings of the 1992 study year are highlighted in this section.

4.1 Virginian Province Fact Summary

- The Virginian Province includes the coastal region of the Northeast United States from Cape Cod south to the mouth of Chesapeake Bay. It is composed of 23,574 km^2 of estuarine resources including 11,469 km^2 in Chesapeake Bay and 3,344 km^2 in Long Island Sound.
- Estuarine resources in the Virginian Province were stratified into classes for purposes of sampling and analysis. The classes and their areal extent are as follows: Large estuaries, 16,097 km^2; small estuaries, 4,875 km^2; and large tidal rivers, 2,602 km^2.
- The large estuary class includes Chesapeake Bay (main stem plus lower Potomac River), Delaware Bay, Long Island Sound, Block Island Sound, Buzzard's Bay, Narragansett Bay, and Nantucket Sound.
- The large tidal river class includes the James, Rappahannock, Potomac, Delaware, and Hudson Rivers.
- The small estuary class includes 144 estuarine systems of various types between 2.6 and 260 km^2 in area of which 39 were sampled in 1992.

4.2 Findings of the 1992 Sample Year

- All of the 126 scheduled stations were successfully sampled. The majority of the data collected at these stations met the quality control standards set by the Program.
- A benthic index was developed to discriminate between good and poor environmental conditions. Based on this index, approximately 14 ± 6% of the Province area could be classified as potentially degraded relative to the benthic community.
- Bottom dissolved oxygen concentrations ≤2 mg/L were measured at stations representing 5 ± 5% of the Province area. Concentrations ≤5 mg/L were measured in 29 ±11% of the area of the Province.
- Draft EPA Sediment Quality Criteria (SQC) are currently available for four of the analytes EMAP measures in sediments: acenaphthene, phenanthrene, fluoranthene, and dieldrin. SQC were not exceeded at any Virginian Province station sampled in 1992.
- Sediments collected from stations representing approximately 31 ± 10% of the Province area were determined to contain elevated levels of metals.
- Table 4-1 summarizes the data presented in Section 3 for selected Biotic Condition, Abiotic Condition, and Habitat indicators.

- Overall, approximately 49 ± 11% of the area of the Province is potentially degraded in terms of its benthic biology, bottom dissolved oxygen, or aesthetic appeal.

Table 4-1. Percent area of the Virginian Province (with 95% confidence intervals) above or below values of interest for selected indicators in 1992.

	Percent area			
Estuarine Condition	Province	Large Estuary	Large Tidal River	Small Estuary
Benthic Index				
<0	14 ± 6	10 ± 10	37 ± 22	23 ± 12
Total Benthic Abundance				
≤200 / m^2	5 ± 5	5 ± 7	10 ± 20	1 ± 1
Bottom DO				
<2 mg/l	5 ± 5	7 ± 8	0 ± 0	0 ± 0
<5 mg/l	29 ± 10	38 ± 15	12 ± 16	10 ± 8
Sediment Toxicity (% control survival)				
<80%	6 ± 5	8 ± 8	3 ± 5	2 ± 2
Enriched metals				
any metal above background	31 ± 10	27 ± 13	34 ± 39	43 ± 13
Marine Debris				
presence	25 ± 11	21 ± 13	24 ± 45	41 ± 19
Salinity				
Polyhaline (>18‰)	73 ± 9	86 ± 11	7 ± 40	65 ± 12
Mesohaline (5 to 18‰)	18 ± 9	12 ± 11	49 ± 48	24 ± 12
Oligohaline (< 5‰)	9 ± 4	2 ± 5	44 ± 22	11 ± 8

SECTION 5

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APPENDIX A

SUB-POPULATION ESTIMATES FOR CHESAPEAKE BAY AND LONG ISLAND SOUND

The two largest systems within the Virginian Province are Chesapeake Bay (11,469 km^2) and Long Island Sound (3,344 km^2). Combined, these two systems represent 63% of the surface area of the entire Province. Because of their size, and therefore the number of sampling locations in each, estimates of ecological condition of these systems are possible using the EMAP design. However, the level of uncertainty will remain higher than for estimates for the Province as a whole or individual classes.

This appendix provides the tools for generating these estimates, *i.e.*, data for these two systems are summarized using CDFs and bar charts. Each system is defined as including all adjacent tributaries and small systems. For example, the data set for Chesapeake Bay includes the Potomac, James, and Rappahannock Rivers, and all the small systems connecting to the mainstem of the Bay. Since the Long Island Sound data set contains no large tidal rivers and fewer small systems than Chesapeake Bay, this may account for some of the differences observed between these two systems. Fifty three stations are included in the Chesapeake Bay data set and 14 in the Long Island Sound data set.

A.1 Biotic Condition Indicators

A.1.1 Benthic Index

A benthic index value below zero is indicative of a degraded benthic community. Approximately 20 ± 13% of the sampled area of Chesapeake Bay produced a benthic index value below zero, and the corresponding area of Long Island Sound was 3 ± 4% (Figure A-1).

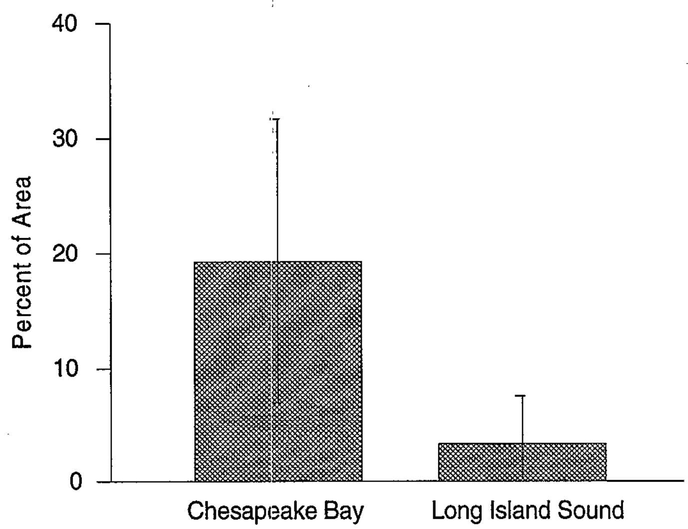


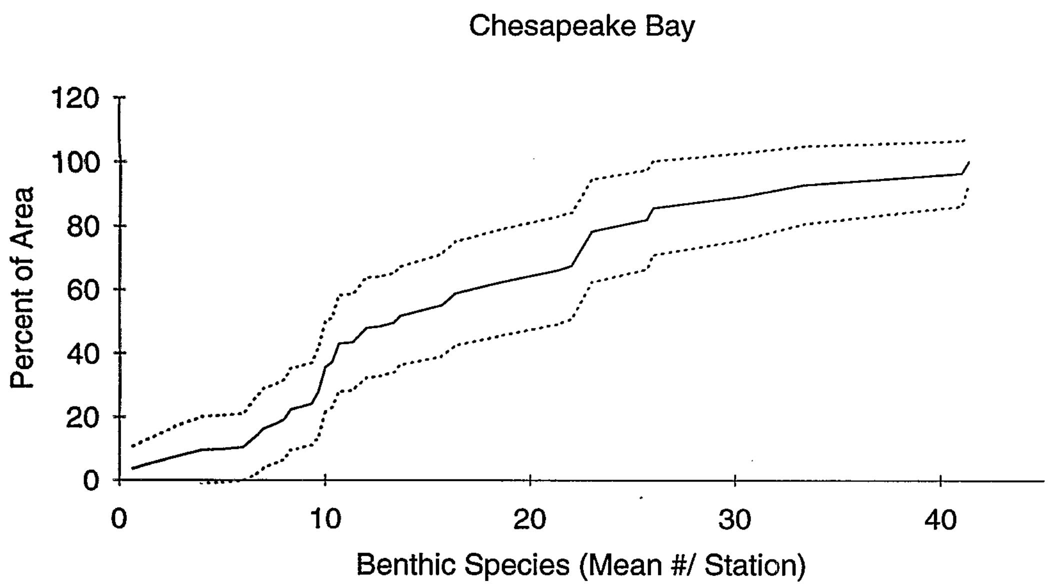
Figure A-1. Percent area of Chesapeake Bay and Long Island Sound in 1992 with a benthic index below 0. (Error bars are the 95% confidence intervals).

A.1.2 Number of Benthic Species

The total number of species collected at each station, as percent area in these systems, is illustrated in Figure A-2. The distribution and maximum (41 and 36 species) values are similar for Chesapeake Bay and Long Island Sound, respectively.

A.1.3 Total Benthic Infauna Abundance

Figure A-3 shows the distribution of total number of benthic individuals per m^2 measured in Chesapeake Bay and Long Island Sound. The maximum number of individuals collected at a station was higher in the Sound than in the Bay (21,265 and 16,712, respectively).



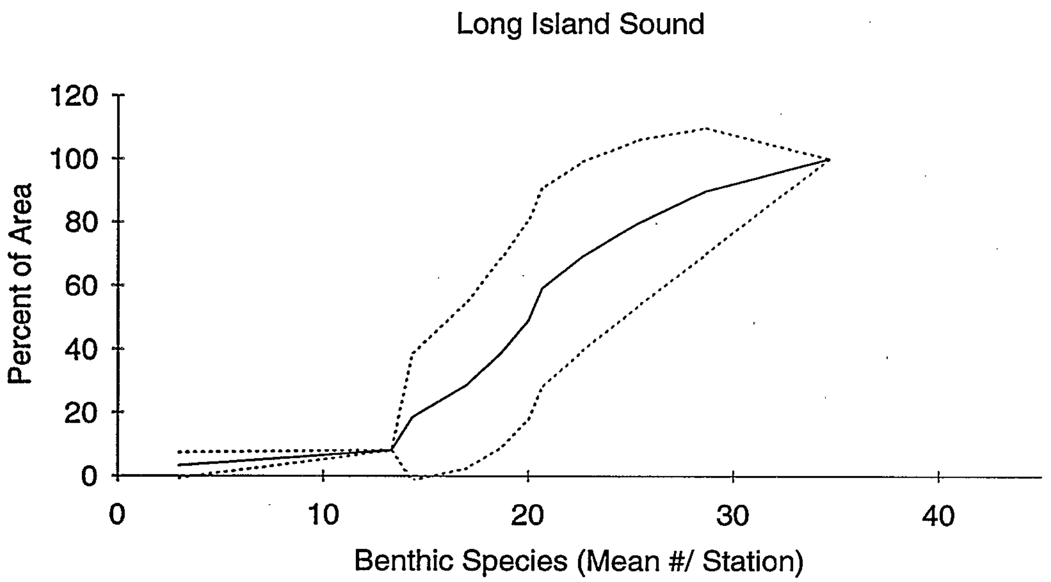
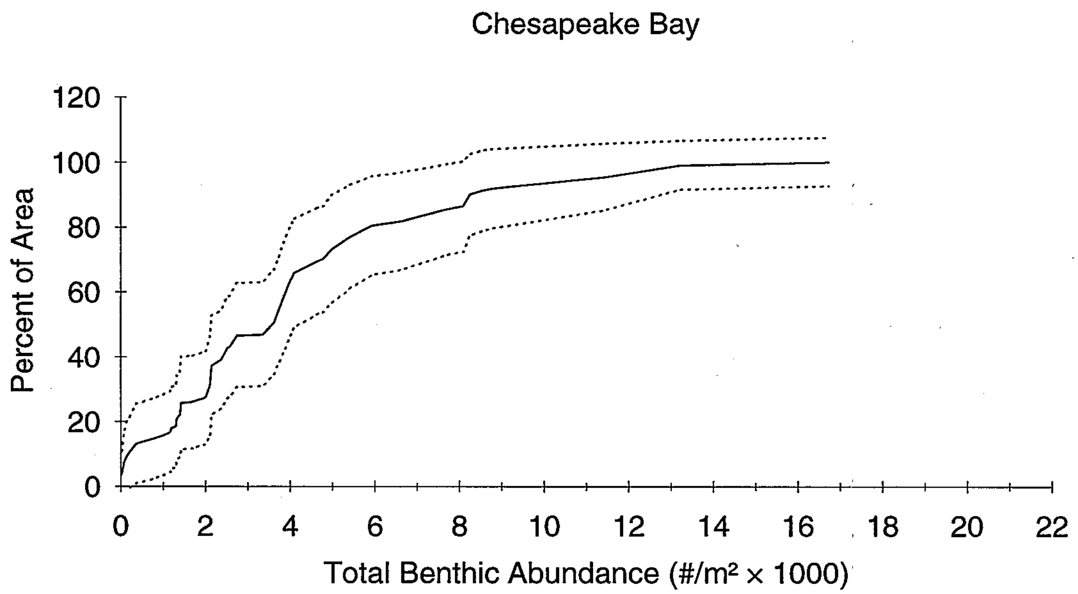


Figure A-2. Cumulative distributions of the mean number of benthic invertebrate species per station as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence intervals).



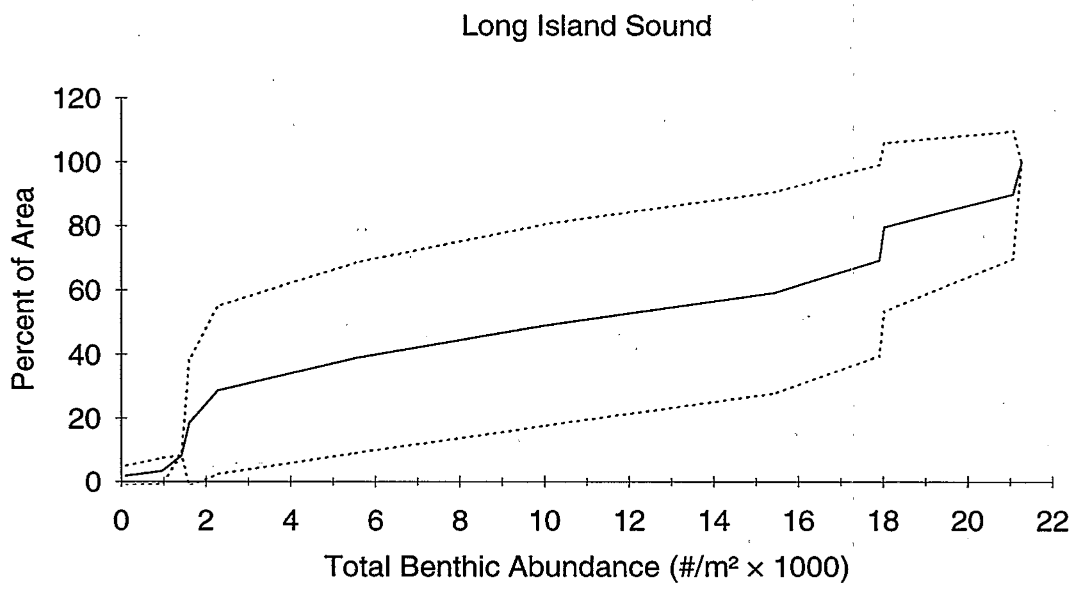


Figure A-3. Cumulative distributions of the number of benthic invertebrates collected per m^2 as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence intervals).

A.1.4 Number of Fish Species

The number of fish species collected per standard trawl is shown in Figure A-4. Between 0 and 7 species the distributions are similar; however the maximum number of individuals caught at a station in Chesapeake Bay was approximately double that in Long Island Sound (17 and 9, respectively).

A.1.5 Total Finfish Abundance

The total number of fish captured per standard trawl (catch per unit effort) was greater at Chesapeake Bay stations than Long Island Sound stations (Figure A-5). The maximum catch in the Bay was 424 individuals; whereas, no more than 212 were collected at any station in Long Island Sound. This is presumably due to habitat and cannot be related to man's impact.

A.1.6 Fish Gross External Pathology

All fish species were examined for evidence of gross external pathologies. Only two pathologies were observed in Chesapeake Bay and none in Long Island Sound; however, only 314 fish were collected and examined in Long Island Sound compared to 1,756 in Chesapeake Bay (Table A-1).

A.2 Abiotic Condition Indicators

A.2.1 Dissolved Oxygen Concentration

CDFs for bottom dissolved oxygen concentration in Chesapeake Bay and Long Island Sound are shown in Figure A-6. Approximately 11 ± 11% of sampled area of Chesapeake Bay contained severely hypoxic water (DO ≤2 mg/l). A DO of less than 2 mg/L was not measured at any station in Long Island Sound in 1992. Approximately 55 ± 29% of the Sound was marginal, with DO values less than 5 mg/L (compared to 40 ± 15% for the Bay).

A.2.2 Dissolved Oxygen Stratification

The difference in measured DO concentrations at the bottom compared with surface measurements taken at those same stations are illustrated in Figure A-7. The stations with the greatest Δ DO were found in Chesapeake Bay.

A.2.3 Sediment Toxicity

Sediments were classified as toxic if amphipod survival in the test sediment was less than 80% of that in the control sediment, and significantly different from the control. Sediments sampled from Chesapeake Bay in 1992 representing 0.6 ± 1% of the Bay's area exhibited toxicity. Approximately 10 ± 20% of the area sampled in Long Island Sound contained toxic sediments (Figure A-8).

A.2.4 Sediment Contaminants - Organics

Draft EPA Sediment Quality Criteria (SQC) exist for four compounds for which EMAP is monitoring: acenaphthene, phenanthrene, fluoranthene, and dieldrin. No station in Chesapeake Bay or Long Island Sound exceeded any of the SQCs.

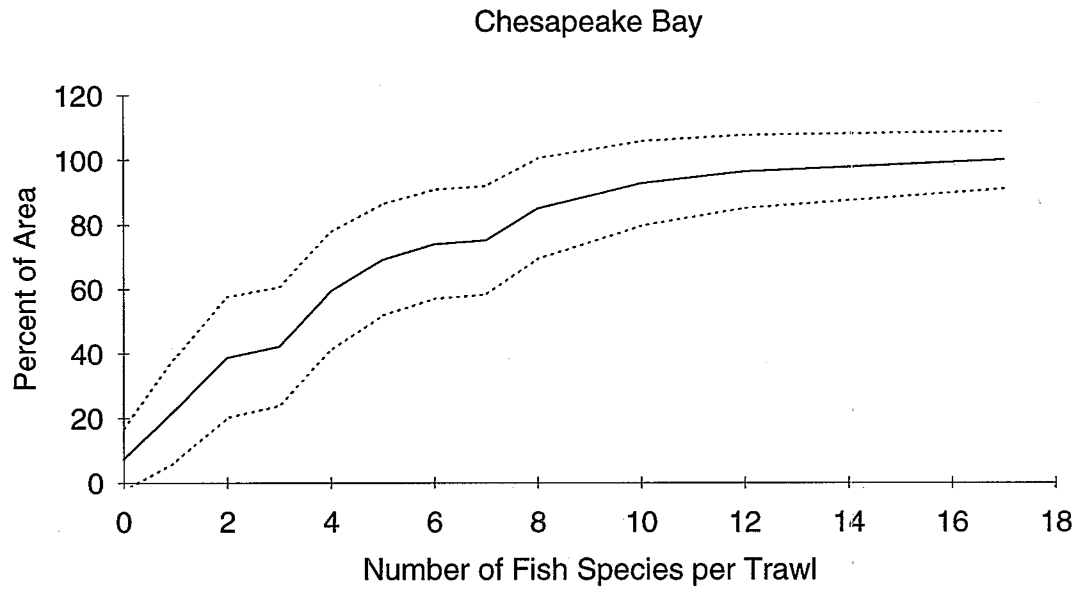
CDFs for combined PAHs are presented in Figure A-9. Although the maximum concentration measured was higher in Chesapeake Bay than Long Island Sound (13,219 and 8,235 ng/g dry weight, respectively), the distributions are similar with 97 ± 3% of the sampled area of Long Island Sound containing concentrations less than 4,000 ng/g compared to 87 ± 12% for Chesapeake Bay.

A.2.5 Sediment Contaminants - Metals

Table A-2 lists minimum, maximum, and median bulk sediment concentrations of metals measured in Chesapeake Bay and Long Island Sound in 1992. Median values for most metals were higher in Long Island Sound than in Chesapeake Bay.

A.2.6 Marine Debris

The incidence of trash collected in trawls is illustrated in Figure A-10. Trash was found in 27 ± 17% of the area of Chesapeake Bay and 18 ± 22% of the area of Long Island Sound.



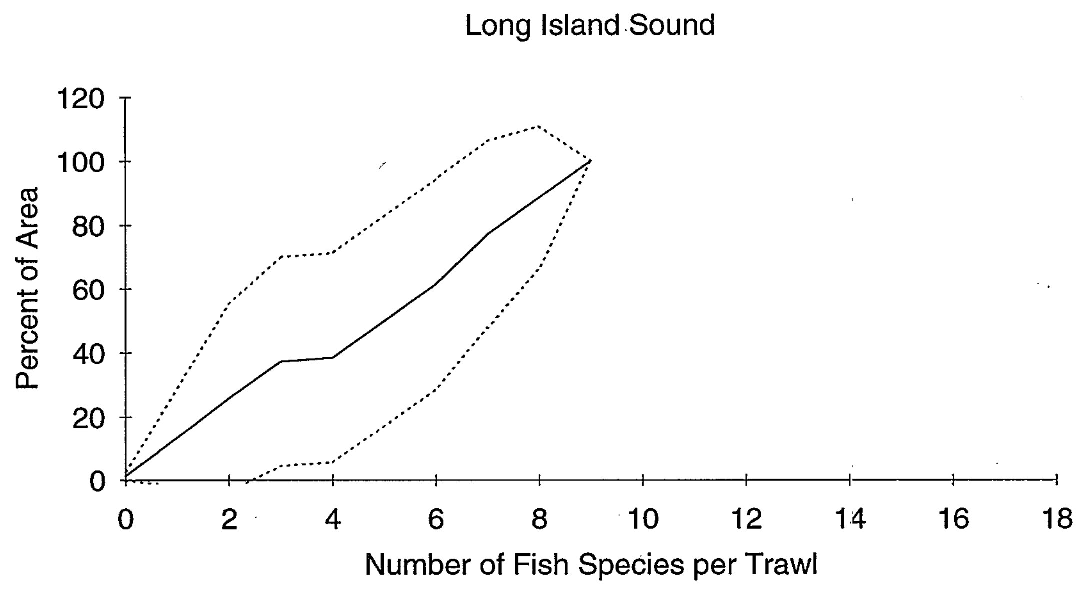


Figure A-4. Cumulative distributions of the number of fish species collected in standard trawls as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence intervals).

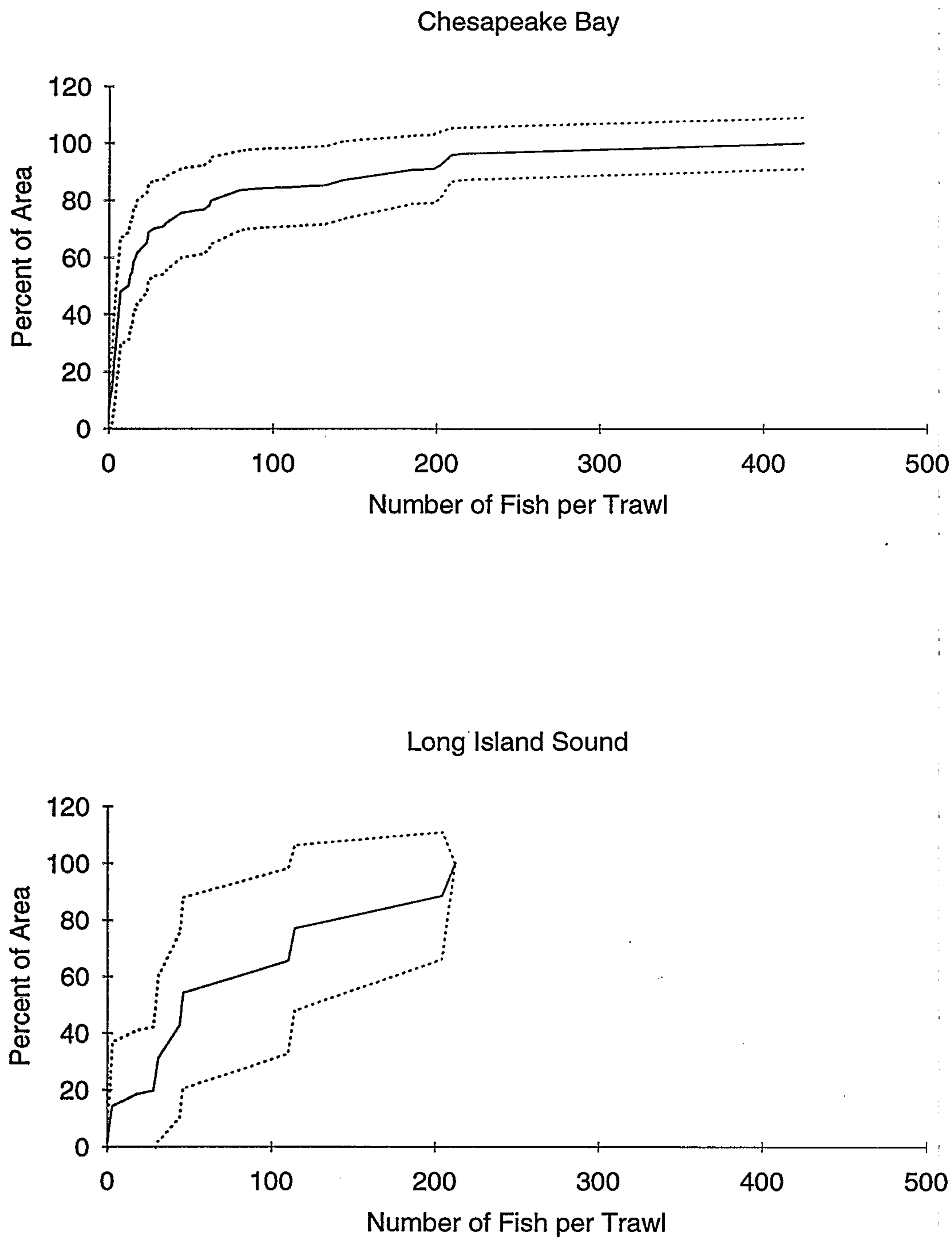
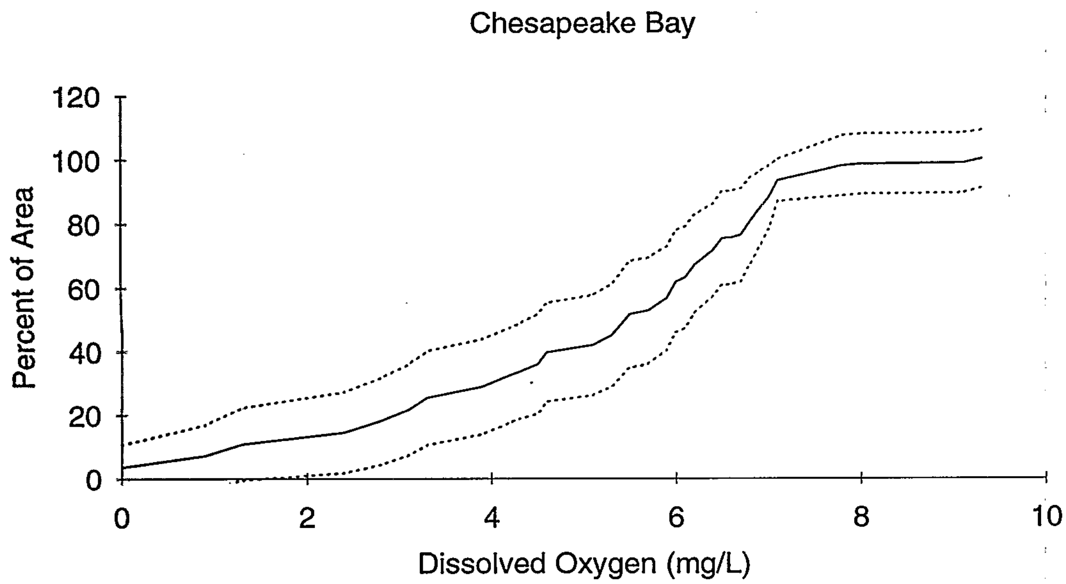


Figure A-5. Cumulative distributions of the number of fish collected in standard trawls as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence intervals).

Table A-1. Incidence of gross external pathology for Chesapeake Bay and Long Island Sound observed by field crews in 1992.

	Lumps	Growths	Ulcers	Fin Rot	Total
<u>Chesapeake Bay</u>					
Frequency	0	0	2	0	2
Total # Fish Examined	1,756	1,756	1,756	1,756	1,756
Percent Incidence	0%	0%	0.11%	0%	0.11%
Number Stations Represented					2
<u>Long Island Sound</u>					
Frequency	0	0	0	0	0
Total # Fish Examined	314	314	314	314	314
Percent Incidence	0%	0%	0%	0%	0%
Number Stations Represented					0



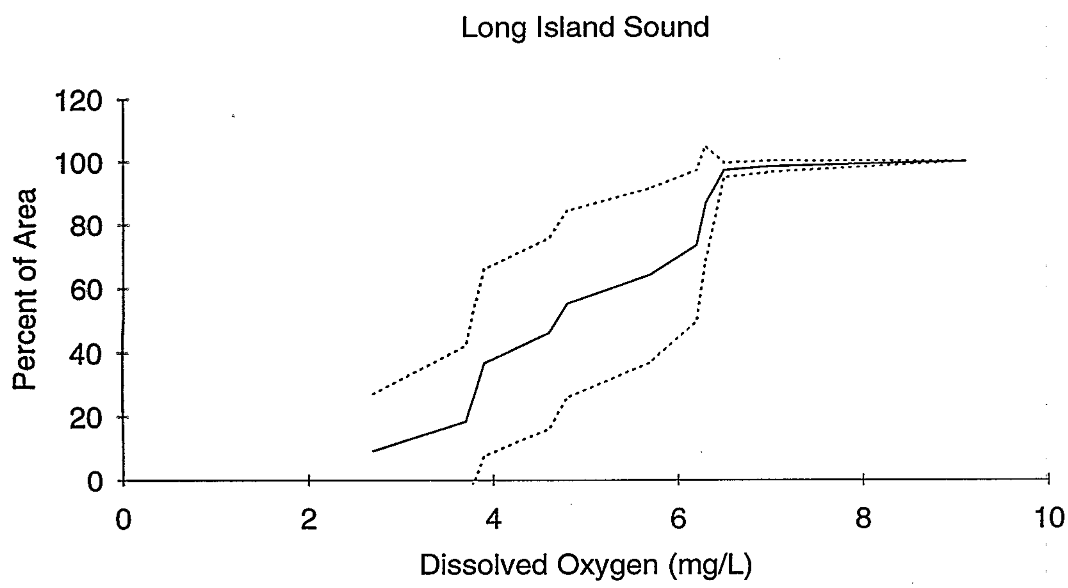
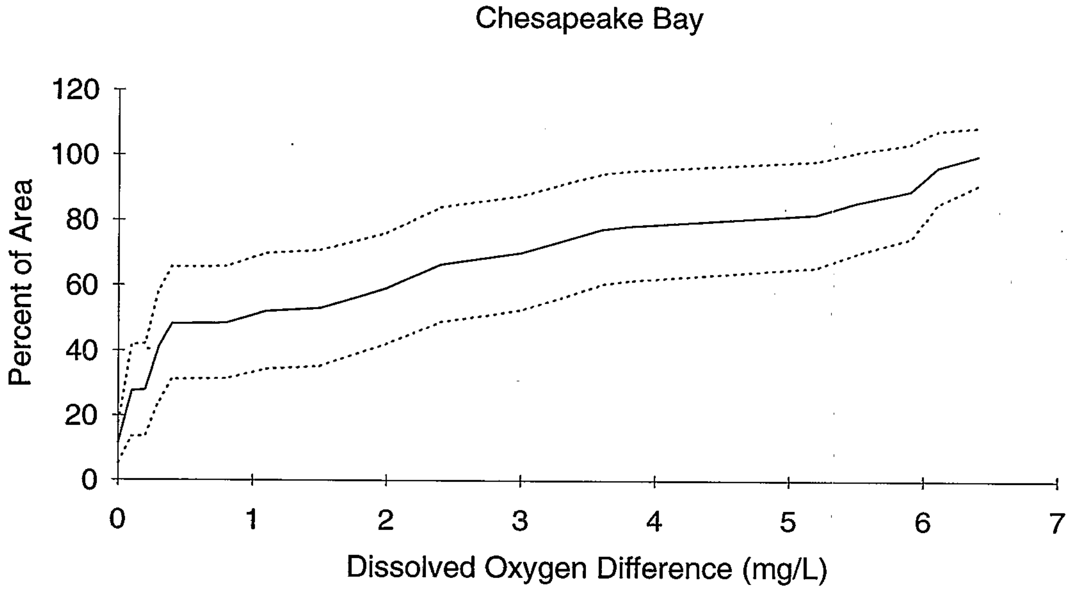


Figure A-6. Cumulative distributions of dissolved oxygen in the bottom waters as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence intervals).



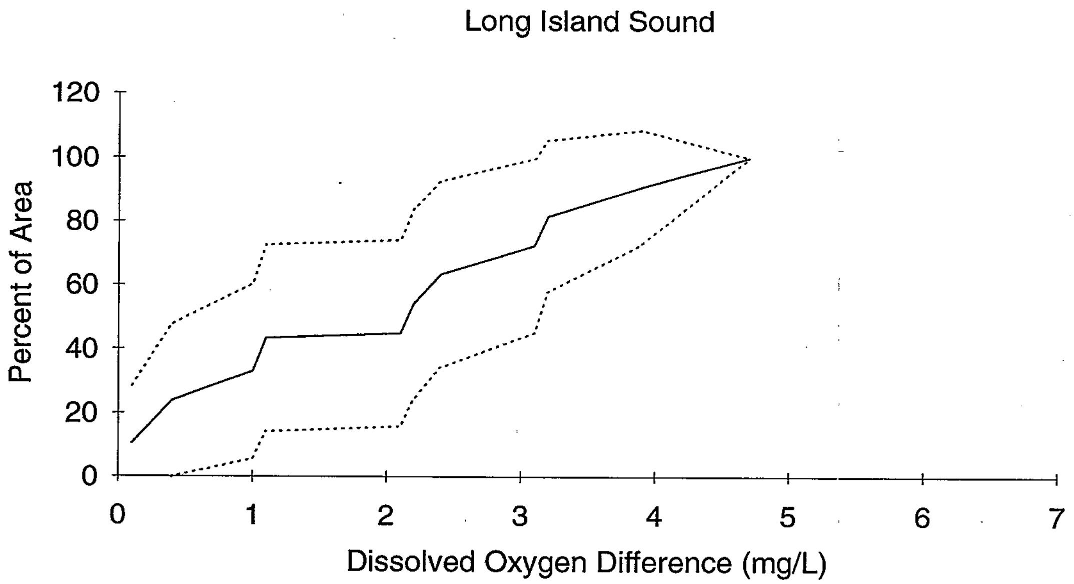
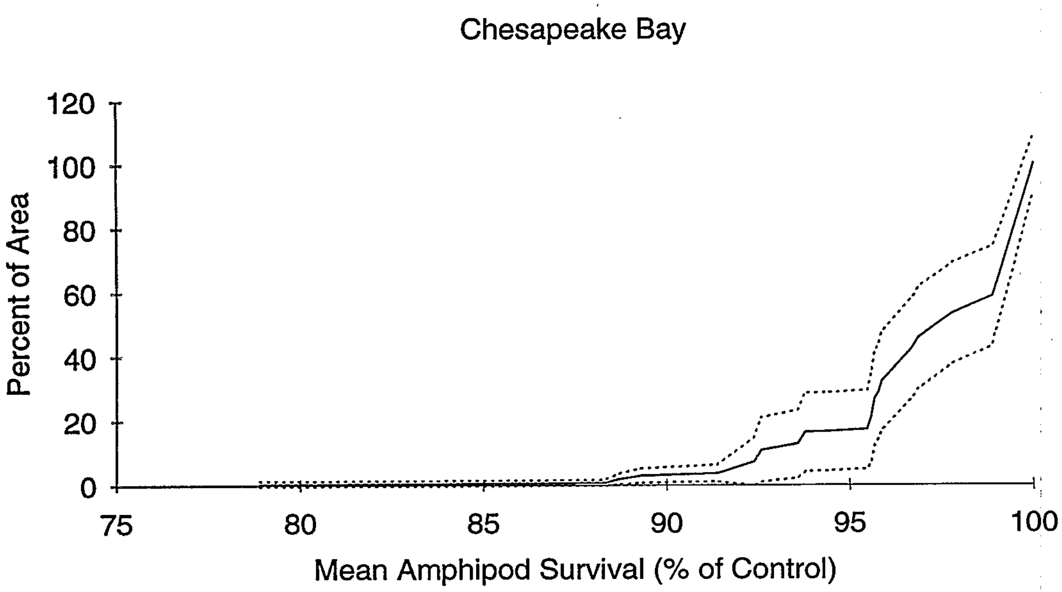


Figure A-7. Cumulative distributions of the DO difference between surface and bottom waters as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence intervals).

Chesapeake Bay



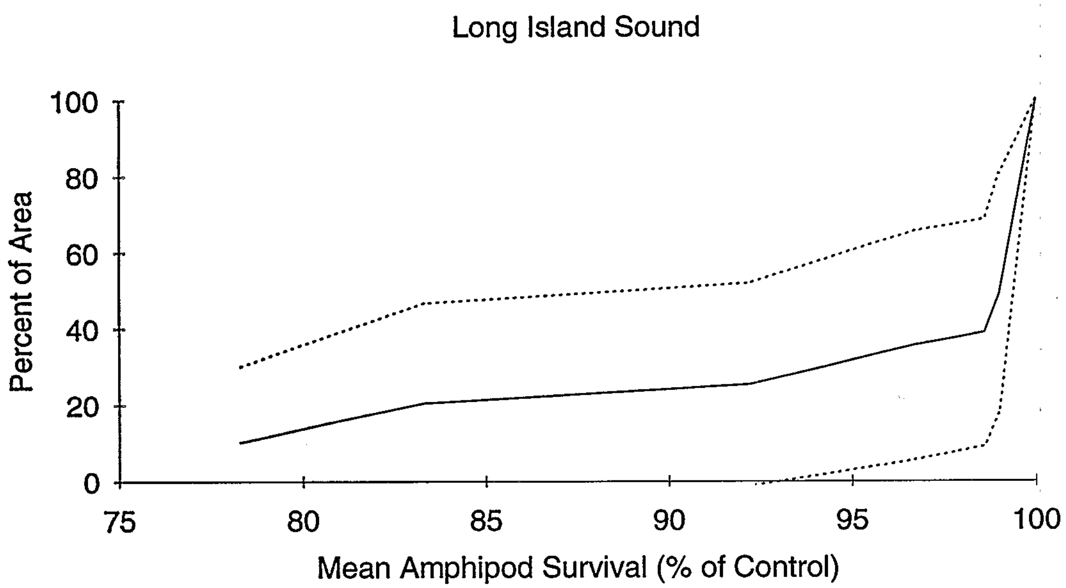
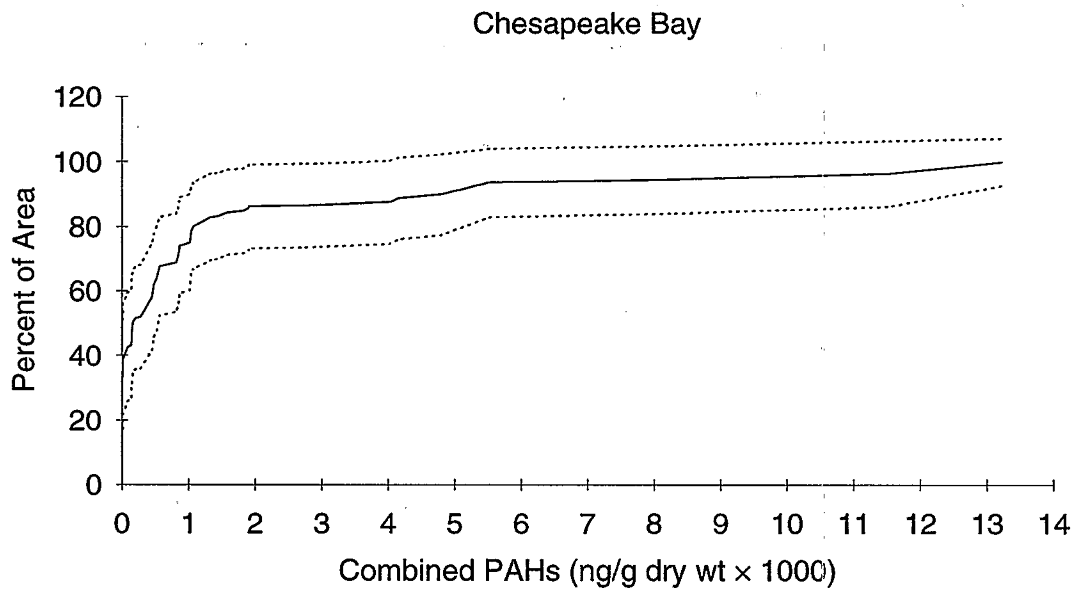


Figure A-8. Cumulative distributions of amphipod survival (% of control) in 10-day toxicity tests as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence intervals).



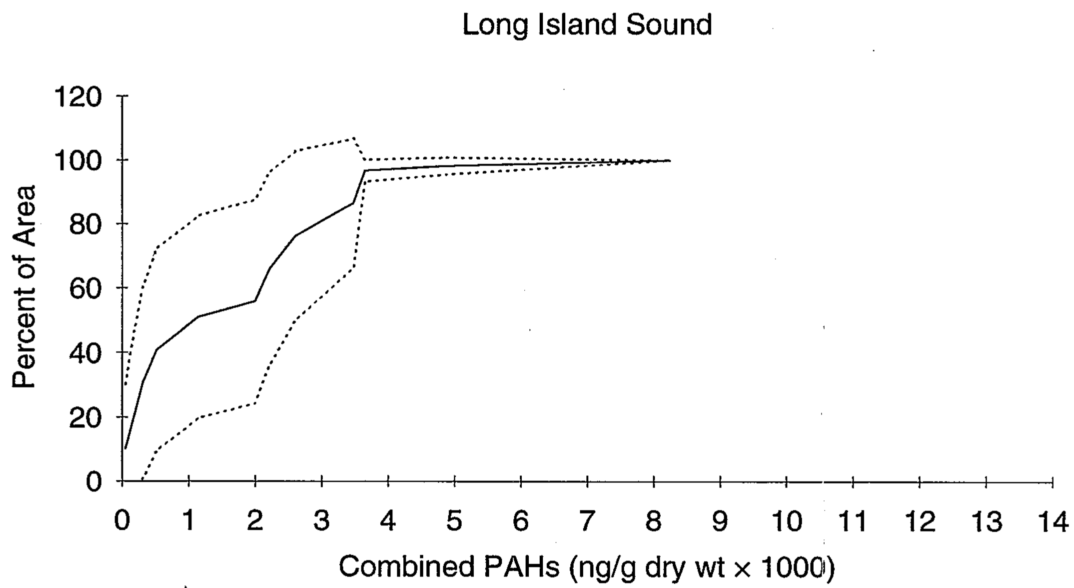


Figure A-9. Cumulative distributions of combined PAH concentrations as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence intervals).

Table A-2. Range and median metal concentrations in Chesapeake Bay and Long Island Sound sediments, 1992. Concentrations are as µg/g dry weight.

Analyte	MIN	MAX	Median
		Chesapeake Bay	
Major			
Aluminum	3,100	83,000	44,500
Iron	2,700	64,700	27,700
Manganese	52.1	5,850	447
Trace			
Antimony	ND	152[a]	0.451
Arsenic	0.423	30.8	7.93
Cadmium	ND	2.39	0.206
Chromium	6.19	147	50.3
Copper	1.91	118	22.5
Lead	ND	13,600[a]	24.3
Mercury	ND	0.21	0.054
Nickel	ND	66.7	19.8
Selenium	ND	0.86	0.314
Silver	ND	8.77	0.112
Tin	ND	11.6	2.15
Zinc	9.05	402	91.5
		Long Island Sound	
Major			
Aluminum	25,800	59,300	43,950
Iron	15,000	34,600	26,700
Manganese	464	1,230	605
Trace			
Antimony	0.228	0.820	0.445
Arsenic	3.48	17.7	6.83
Cadmium	0.063	2.23	0.168
Chromium	22.9	136	66.8
Copper	4.85	201	43.3
Lead	5.34	147	44.2
Mercury	ND	1.26	0.088
Nickel	9.7	37.1	22.9
Selenium	ND	0.760	0.336
Silver	0.017	6.44	0.541
Tin	1.05	16.3	4.47
Zinc	32.0	309	125

ND = Not Detected

[a] Lead and antimony were elevated by several orders of magnitude in sediments from one station in Chesapeake Bay. Lead shot is suspected as the cause.

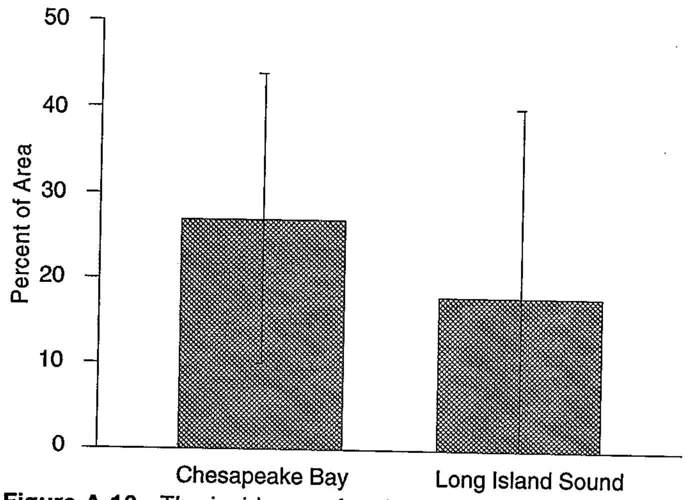


Figure A-10. The incidence of anthropogenic debris in fish trawls as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Error bars represent the 95% confidence intervals).

A.3 Habitat Indicators

A.3.1 Water Depth

Cumulative distribution functions for water depth in Chesapeake Bay and Long Island Sound are presented in Figure A-11. The Bay is generally much shallower than Long Island Sound. The maximum depths measured in the two systems in 1992 were 22 and 46 m, respectively.

The area shallower than 2 m is underestimated because this is the minimum depth sampled, and, because of the statistical design, unsampleable areas were distributed across the CDF as missing values.

A.3.2 Temperature

The CDFs for bottom water temperature in Chesapeake Bay and Long Island Sound show the Sound to generally contain lower temperature bottom waters than Chesapeake Bay (Figure A-12). This is most likely a function of both water depth and latitude.

A.3.3 Salinity

The CDFs for Chesapeake Bay and Long Island Sound (Figure A-13) illustrate their different salinity patterns, with Long Island Sound generally containing higher salinity water than the Bay.

Long Island Sound contains only polyhaline waters with a minimum bottom salinity measured in 1992 of 25‰. Chesapeake Bay, because of the inclusion of three major tidal rivers as well as the Susquehanna River, contains a significant area of oligohaline and mesohaline water (49 ± 16% of the area sampled).

A.3.4 Stratification

Stratification is shown as CDFs of $\Delta\sigma_t$, which is the σ_t (sigma-t) difference between surface and bottom waters (Figure A-14).

The greatest stratification in the Province occurred in the lower portion of the Chesapeake Bay. Chesapeake Bay and Long Island Sound were similar in the percent area with well-mixed water (64 ± 16% and 54 ± 30% respectivly, with a $\Delta\sigma_t < 1$). Chesapeake Bay had the highest percent area with significantly stratified water ($\Delta\sigma_t > 2$). All of Long Island Sound fell between $\Delta\sigma_t$'s of 0 and 1.5.

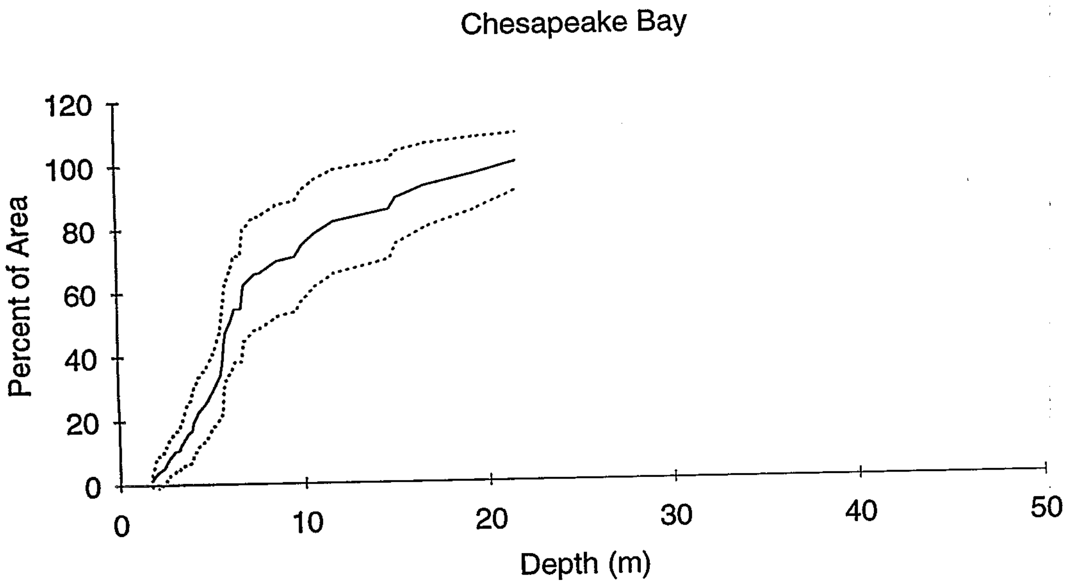
A.3.6 Percent Silt-Clay Content

The CDFs of silt-clay content for Chesapeake Bay and Long Island Sound are similar, with approximately the same percent area of mud and sand in each system (Figure A-15).

The large area of sandy sediments found in the mouth of Chesapeake Bay is likely due to sands being carried in from the ocean (Hobbs *et al.*, 1992). In Long Island Sound coarser sediments at the mouth are mainly a result of strong tidal currents transporting away the fine fraction (winnowing), leaving behind the coarser sands and gravel (Akapati, 1974; Gordon, 1980).

A.3.5 Light Extinction (water clarity)

Water clarity showed definite differences between Chesapeake Bay and Long Island Sound. Approximately 19 ± 13% of the water of Chesapeake Bay was classified as poor or marginal (light extinction coefficient ≥1.387), meaning that a wader could not see his/her toes in waste deep water, compared to 2 ± 2% of the area of Long Island Sound (Figure A-16).



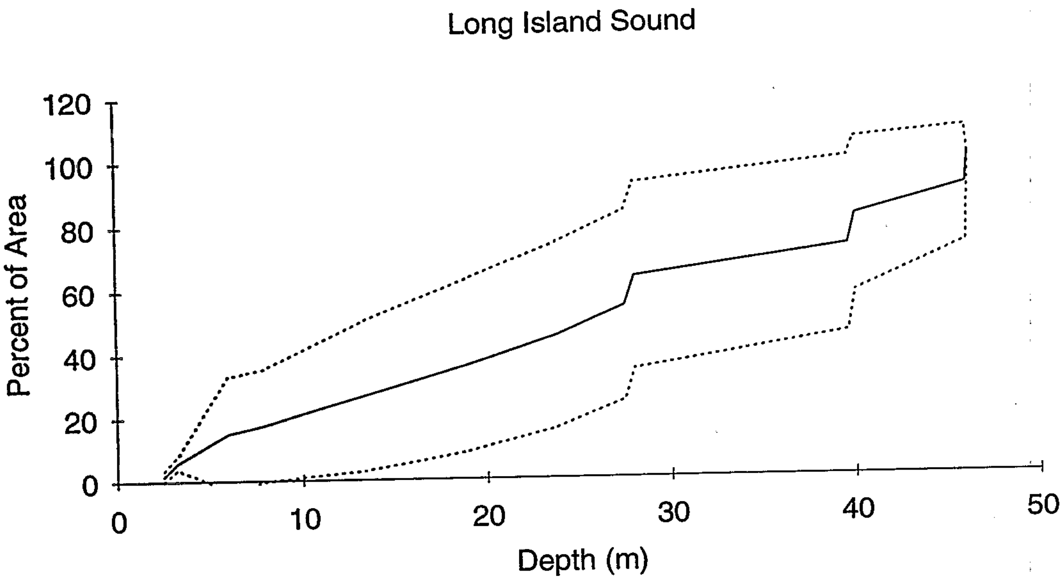
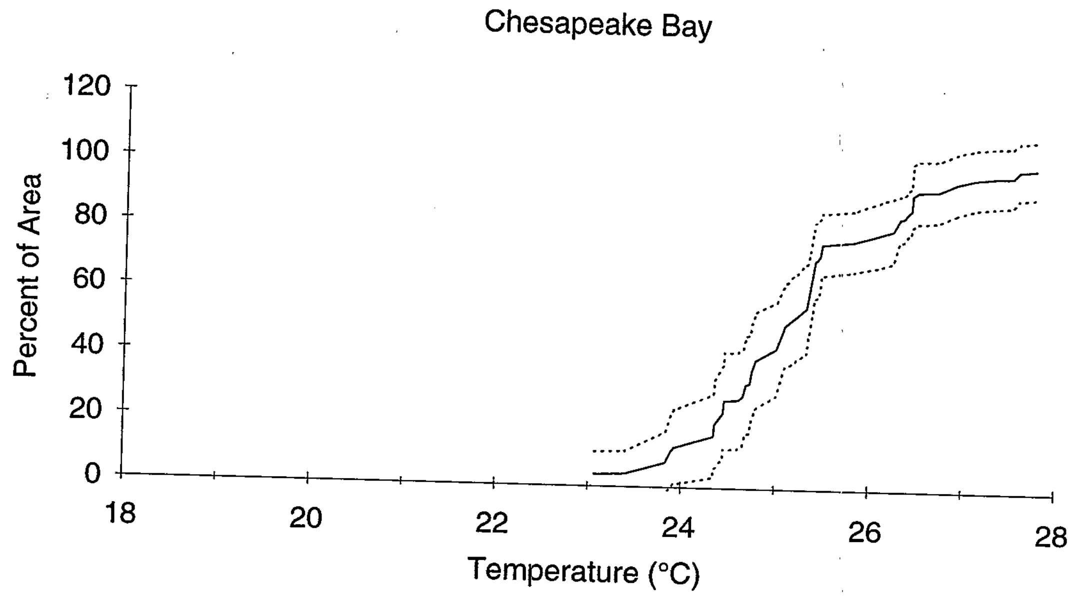


Figure A-11. Cumulative distributions of water depth as a percent of area aof Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence intervals).



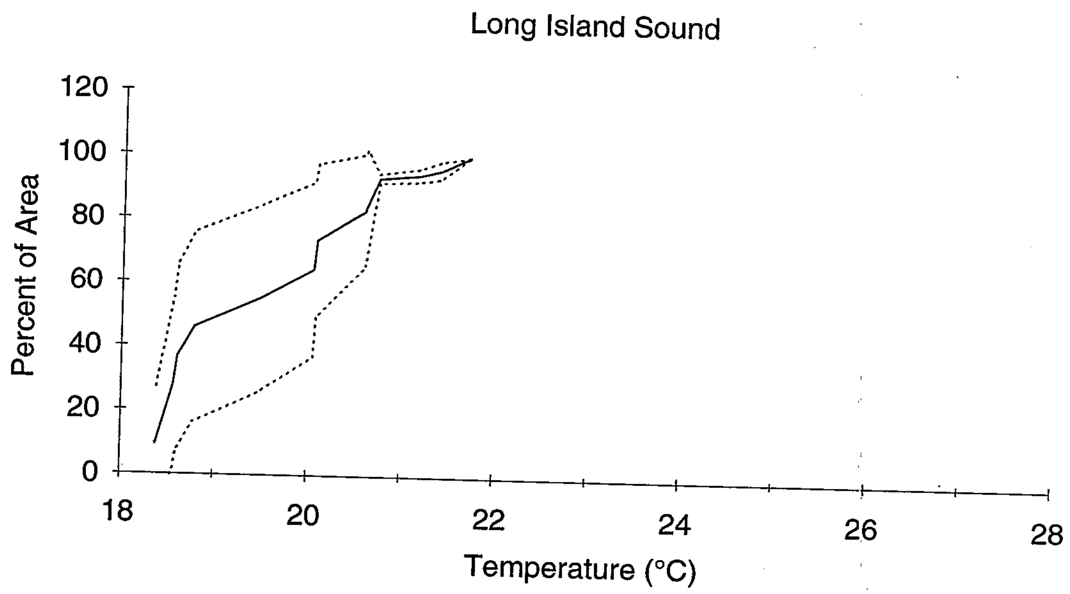
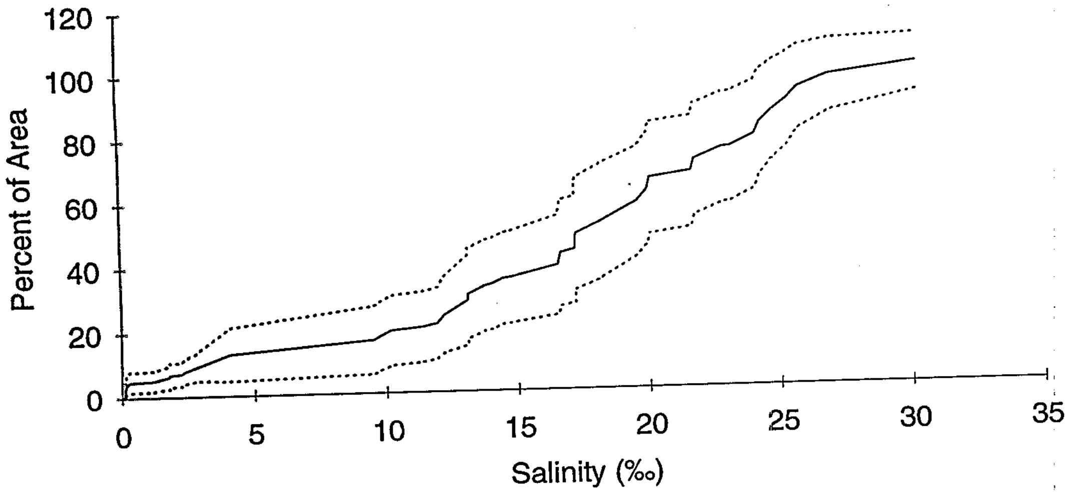


Figure A-12. Cumulative distributions of bottom water temperature as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence intervals).

Chesapeake Bay



Long Island Sound

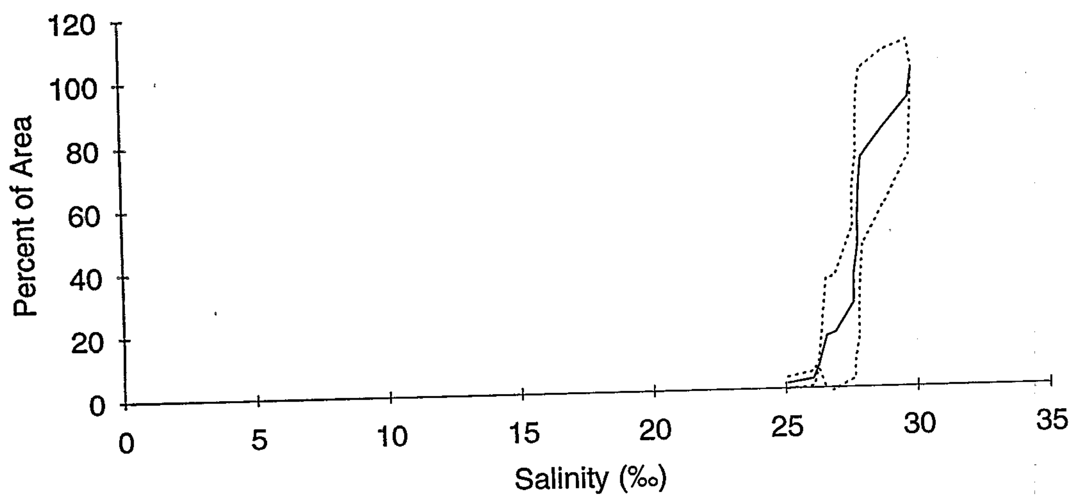
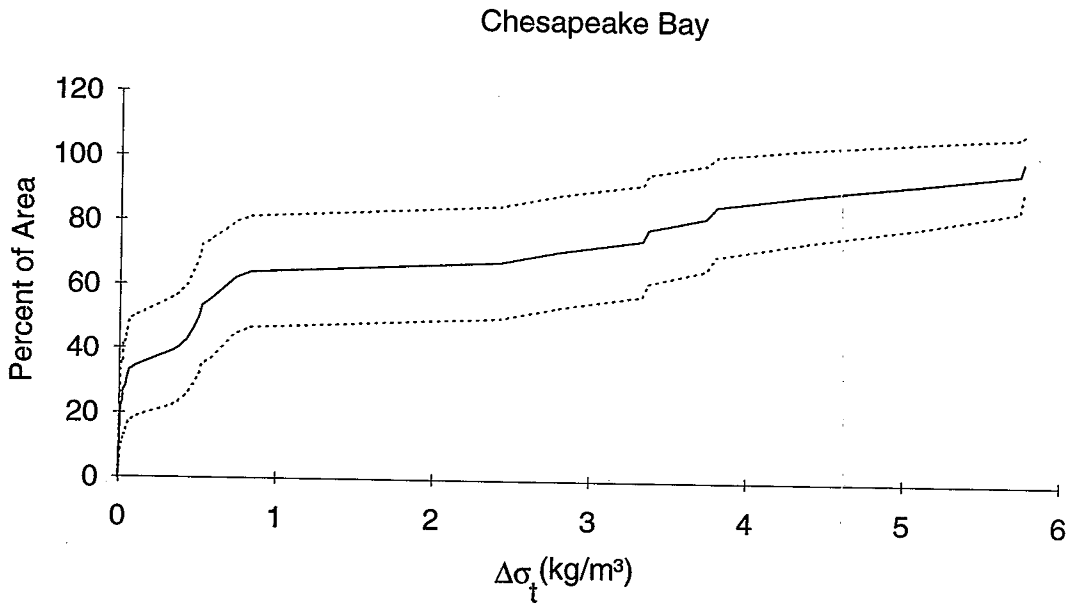


Figure A-13. Cumulative distributions of bottom water salinity as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence intervals).



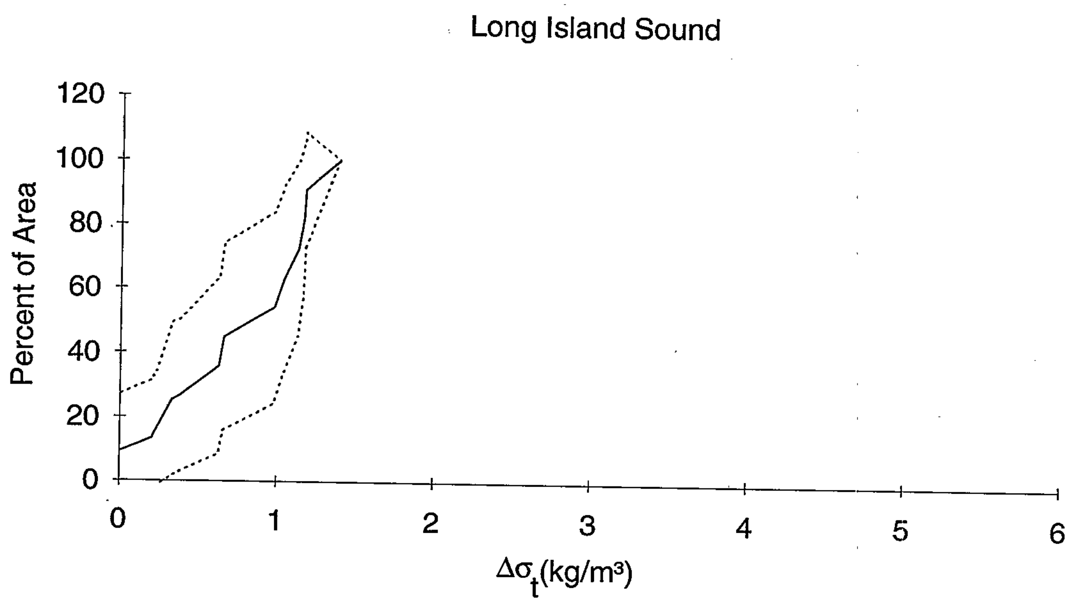
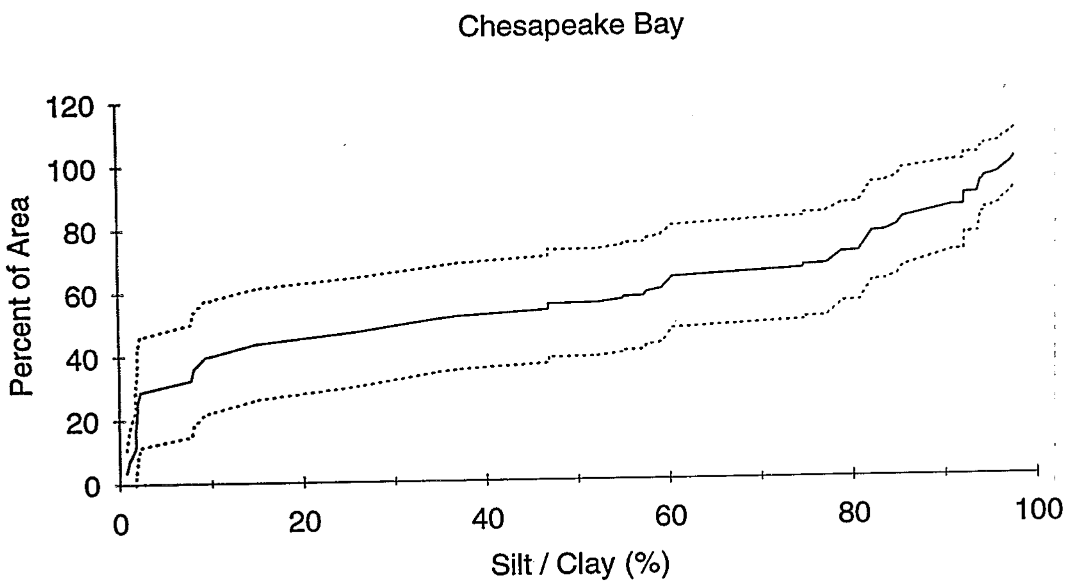


Figure A-14. Cumulative distributions of surface to bottom sigma-t difference as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence intervals).



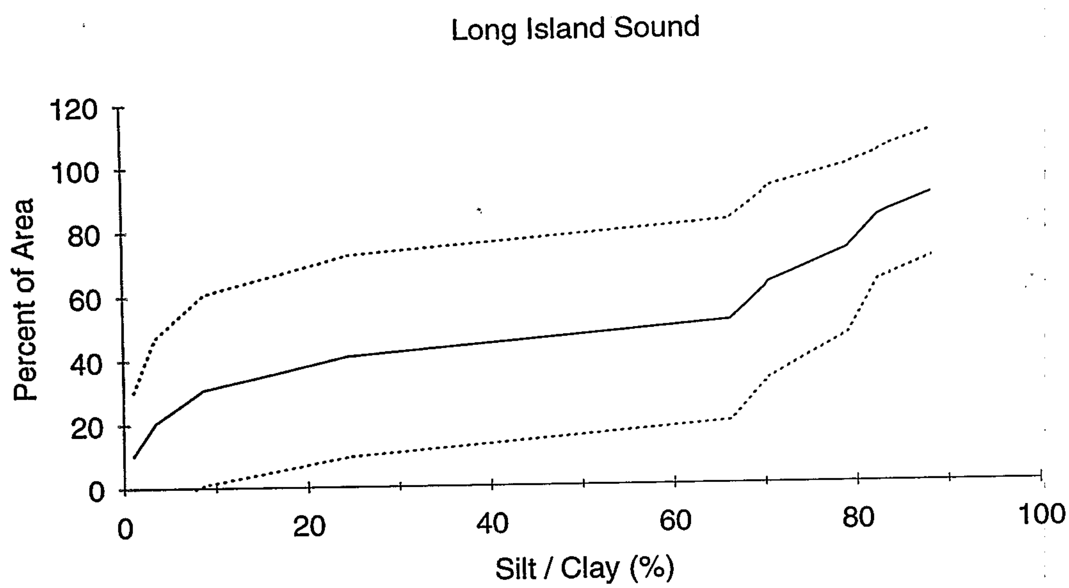


Figure A-15. Cumulative distributions of sediment silt/clay content as a percent of area of Chesapeake Bay and Long Island Sound, 1992. (Dashed lines are the 95% confidence interval).

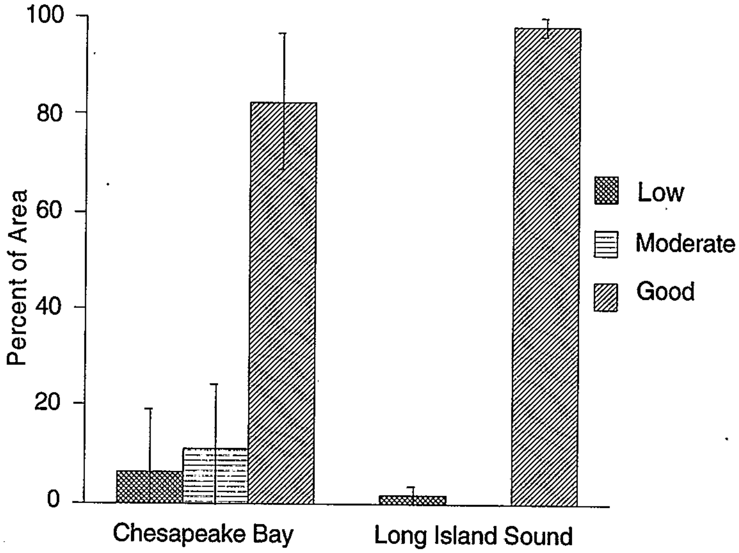


Figure A-16. Percent area of Chesapeake Bay and Long Island Sound with water clarity classified as low, moderate, or good based on light extinction coefficients. (Error bars represent 95% confidence intervals).

APPENDIX B

LINEAR REGRESSIONS OF INDIVIDUAL METALS AGAINST ALUMINUM USED IN THE DETERMINATION OF METALS ENRICHMENT OF SEDIMENTS OF THE VIRGINIAN PROVINCE

As discussed in Section 3.2.3.7, concentrations of individual metals were normalized against the crustal element aluminum in an attempt to provide a basis for estimating the areal extent of enrichment of these metals in Virginian Province sediments. The method utilized is described in Appendix A (Section A.8.2.3) of the 1991 Virginian Province Statistical Summary (Schimmel *et al.*, 1994). For each metal, a regression and an upper 95% confidence interval was determined and plotted (Figures B-1 to B-14). Stations with concentrations falling above the upper 95% confidence interval were classified as enriched for that metal. Regression parameters (slope, intercept, and correlation coefficient) are listed in Table B-1.

As described in Appendix D of the 1991 Virginian Province Statistical Summary (Schimmel *et al.*, 1994), results of this method compare well with those obtained by other researchers.

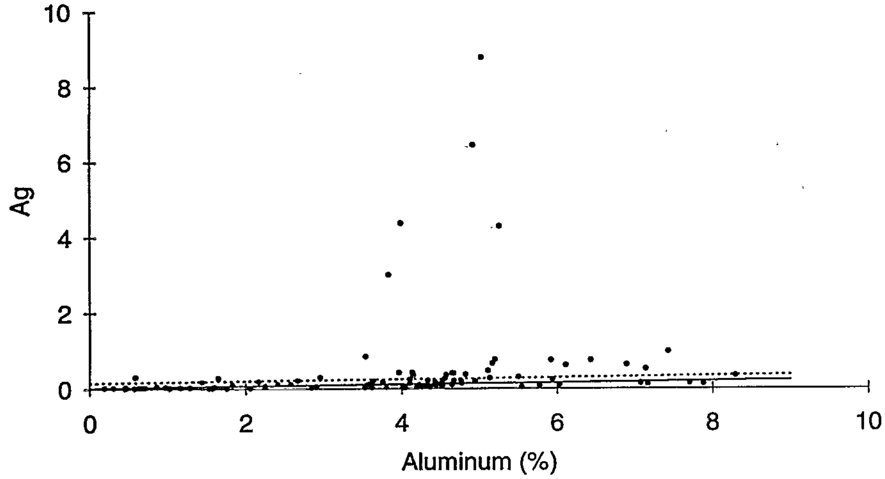


Figure B-1. Linear regression of silver against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as µg/g dry weight.

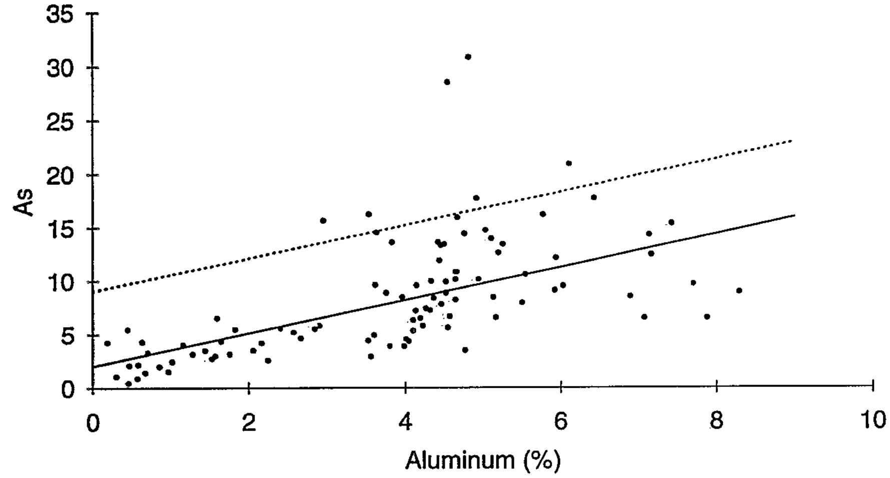


Figure B-2. Linear regression of arsenic against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as µg/g dry weight.

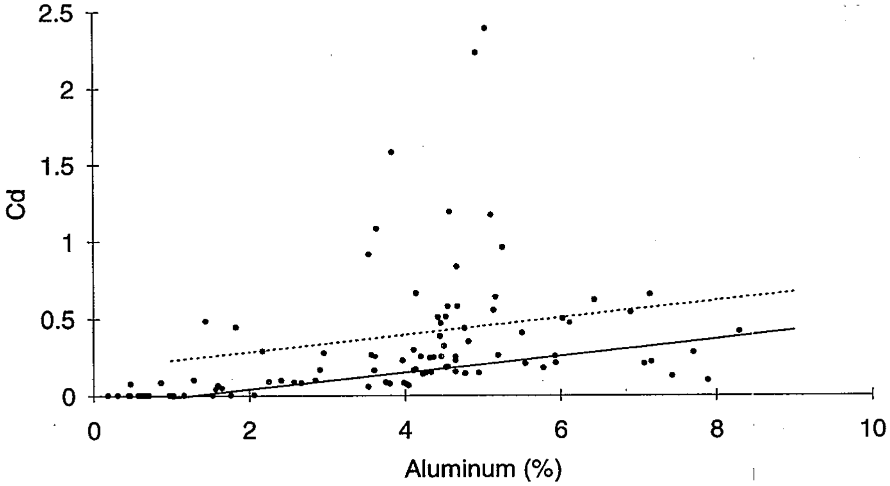


Figure B-3. Linear regression of cadmium against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as µg/g dry weight.

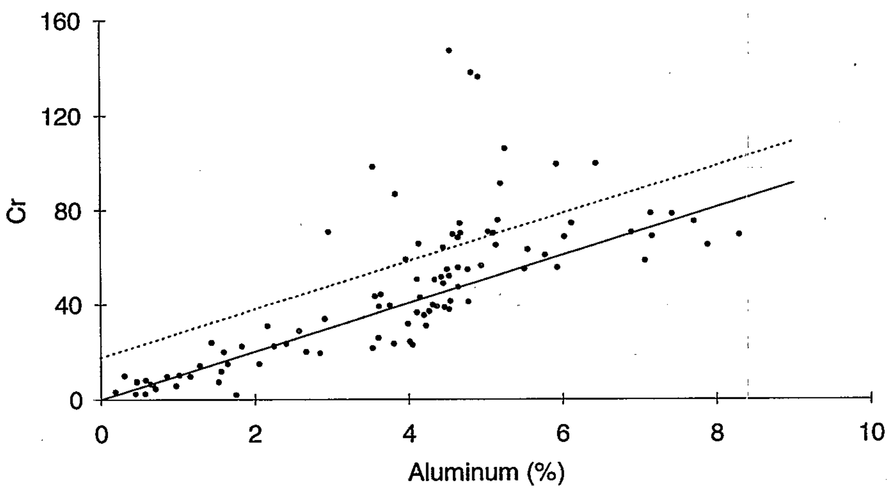


Figure B-4. Linear regression of chromium against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as µg/g dry weight.

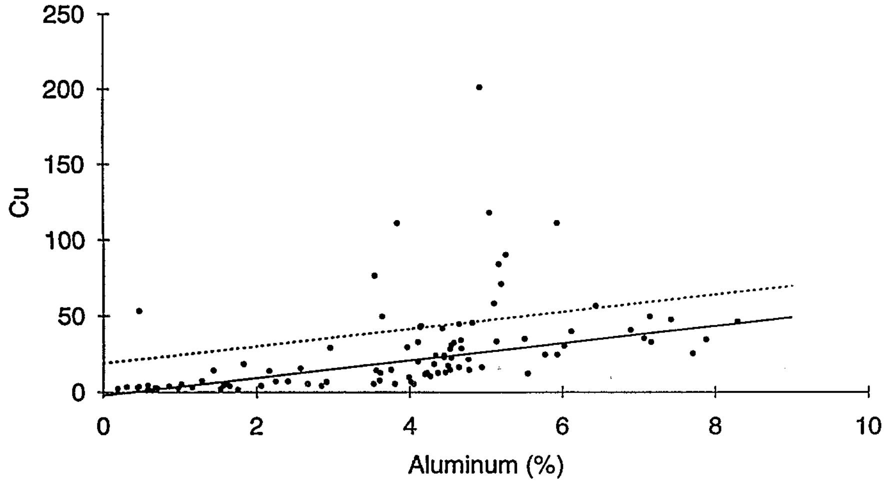


Figure B-5. Linear regression of copper against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as µg/g dry weight.

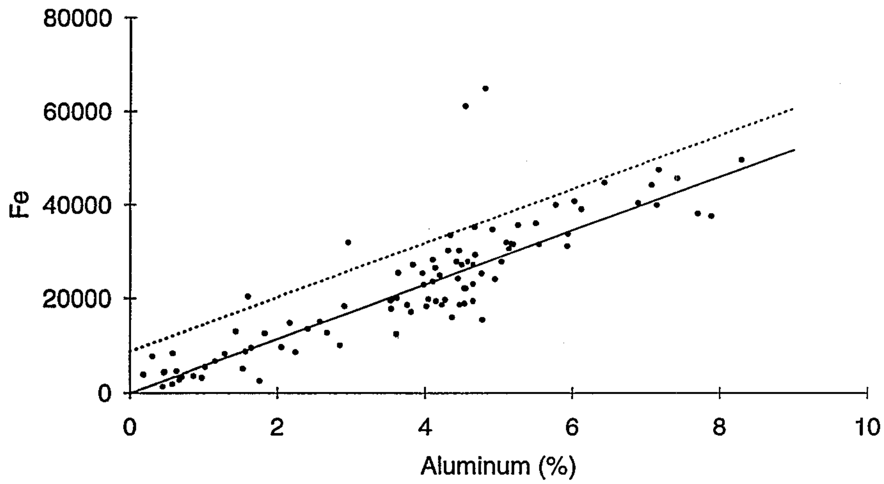


Figure B-6. Linear regression of iron against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as µg/g dry weight.

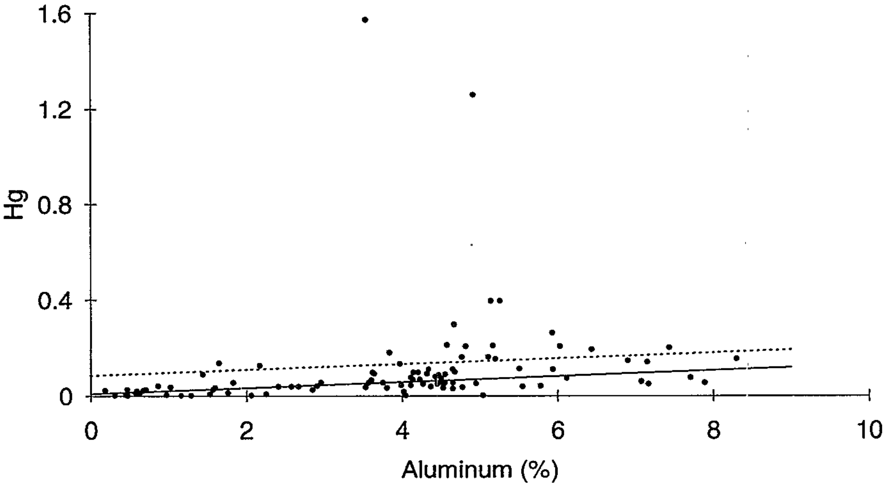


Figure B-7. Linear regression of mercury against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as μg/g dry weight.

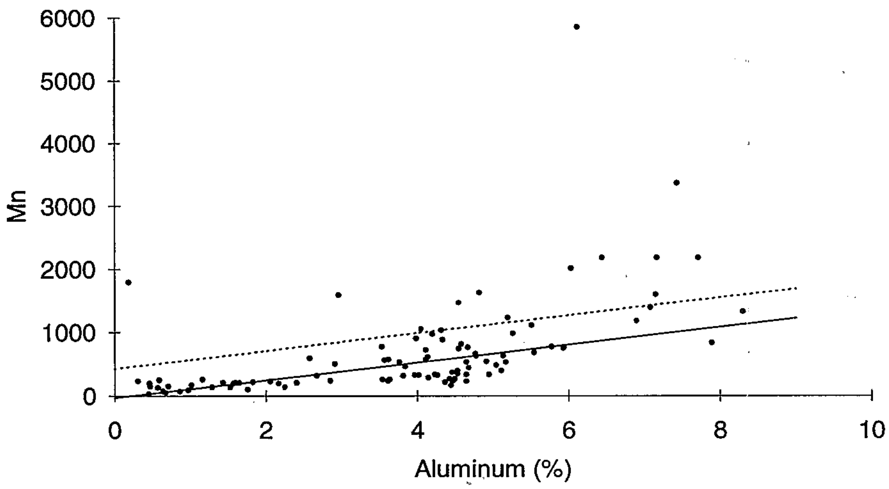


Figure B-8. Linear regression of manganese against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as μg/g dry weight.

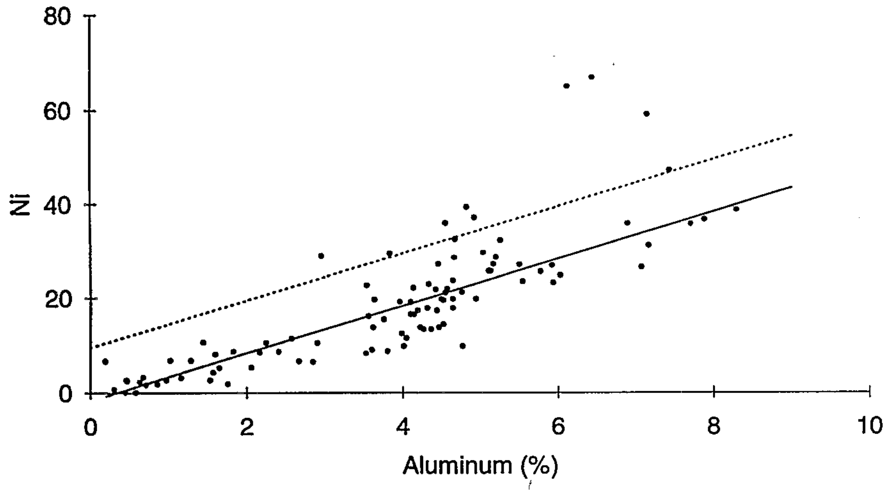


Figure B-9. Linear regression of nickel against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as µg/g dry weight.

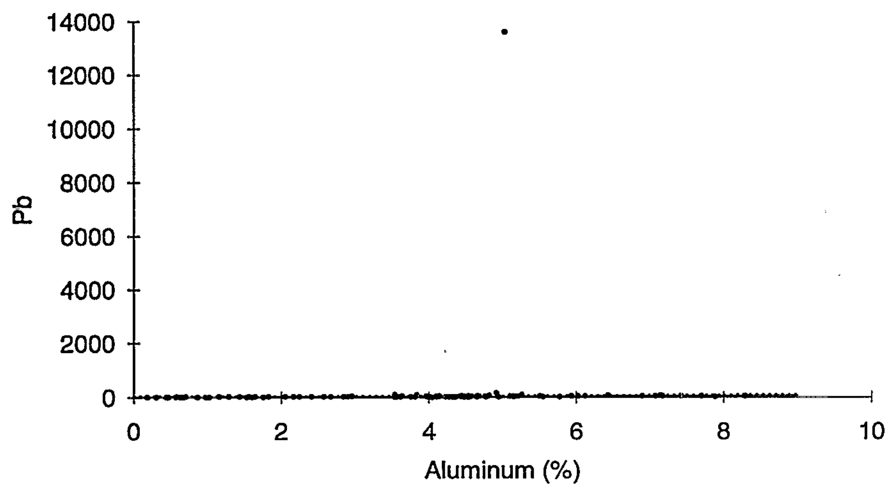


Figure B-10. Linear regression of lead against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as µg/g dry weight.

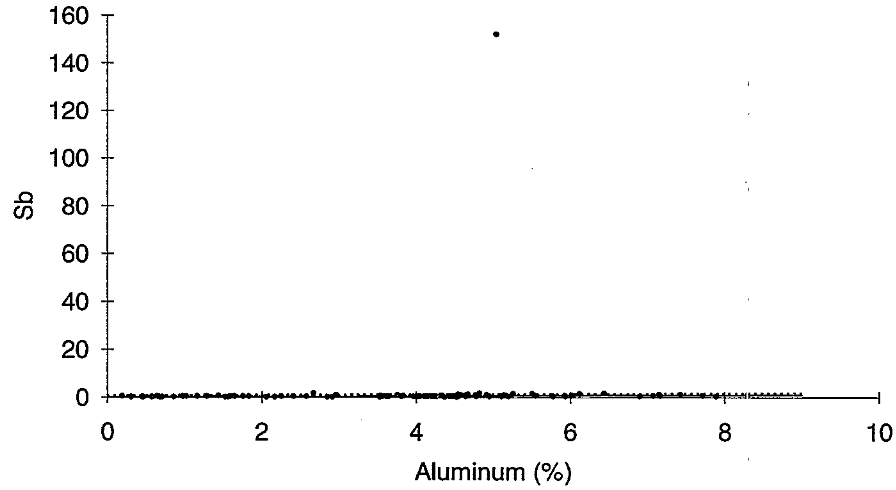


Figure B-11. Linear regression of antimony against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as µg/g dry weight.

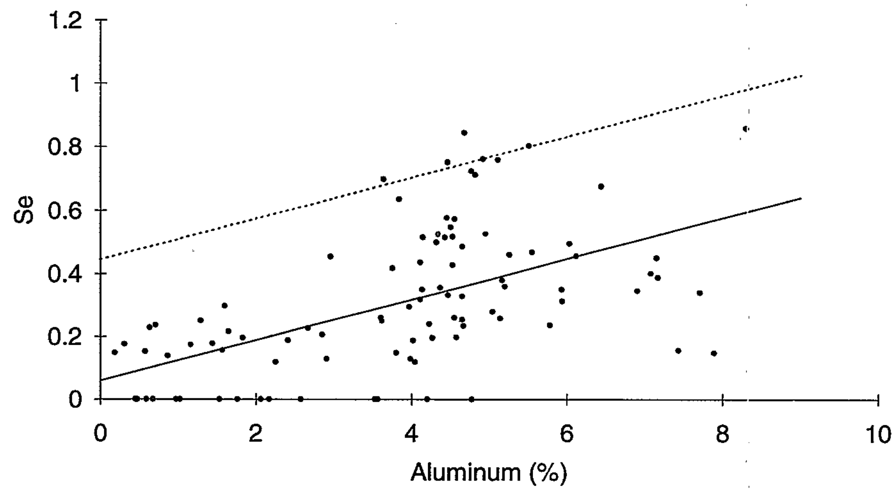


Figure B-12. Linear regression of selenium against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as µg/g dry weight.

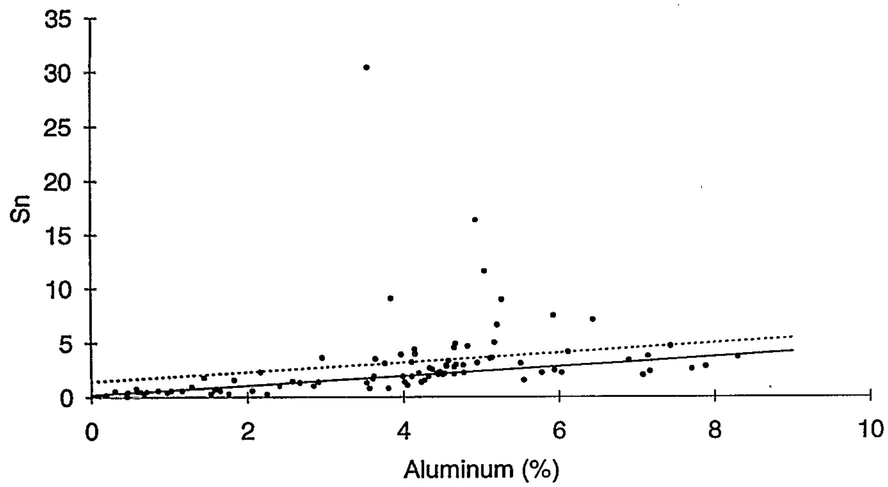


Figure B-13. Linear regression of tin against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as µg/g dry weight.

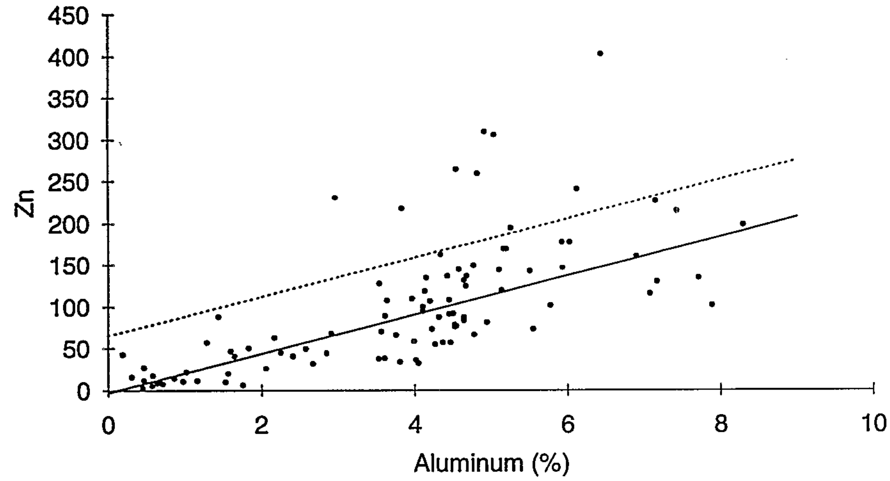


Figure B-14. Linear regression of zinc against aluminum (dashed line is the upper 95% confidence interval). Metal concentrations are as µg/g dry weight.

Table B-1. Metal-aluminum regression parameters obtained from 1992 Virginian Province sediment data (m = slope, b = intercept, r^2 = correlation coefficient).

Element	Regression parameters		
	m	b	r^2
Ag	0.0243	0.0128	0.35
As	1.5462	2.0021	0.44
Cd	0.0549	-0.0149	0.47
Cr	10.1341	0.0220	0.85
Cu	5.6758	-2.2951	0.55
Fe	5,763	-133.14	0.87
Hg	0.0122	0.0087	0.39
Mn	139.67	-32.1638	0.56
Ni	5.0110	-1.7338	0.75
Pb	6.6833	2.5058	0.32
Sb	0.1067	0.0895	0.28
Se	0.0646	0.0597	0.31
Sn	0.4453	0.1523	0.69
Zn	23.3211	-3.1249	0.66

APPENDIX C

QUALITY ASSURANCE

The 1992 Virginian Province monitoring effort was implemented using a quality assurance program to ensure comparability of data with those collected in other EMAP-E provinces, and to assure data quality consistent with the goals of the Program. As described in the Quality Assurance Project Plan (Valente *et al.*, 1992), Measurement Quality Objectives (MQOs) were established for data quality. Quality control steps taken to assure that MQOs were met included intensive training of field and laboratory personnel, field performance reviews of sampling crews, laboratory certification and audits. This document provides only a brief summary of QA results for 1992. A more comprehensive QA document is currently being prepared.

C.1 CREW TRAINING

One of the most critical components of the EMAP-VP QA Program was the thorough training of field personnel. Training was divided into two distinct courses: crew chief training and crew training.

Crew chiefs, who were all returnees from previous years, underwent a refresher training course during the last week of May, 1992. This training was conducted at the U.S. EPA Environmental Research Laboratory-Narragansett, RI (ERL-N) and focused mainly on the sampling methods, with emphasis placed on the electronic measurements and the computer system. Crew chief training was conducted by SAIC and CSC (Computer Sciences Corporation) personnel with oversight by EPA ERL-N staff.

Crew training was held from 15 June to 17 July 1992. Both safety and sampling methods were important components of training. Crew training was broken into two phases: formal training which lasted for approximately 3 weeks, and one week (per crew) of dry runs.

Dry runs consisted of five days in the field during which crews operated as they would during the sampling season, monitoring practice stations for all parameters. Crew members stayed in motels, prepared samples for shipment, entered data into the field computer, and electronically transmitted all data to the Field Operations Center (FOC) just as they would during actual field operations. In addition, the Field Coordinator or the QA Coordinator visited each crew during dry runs, completing a performance review sheet to determine the crew's readiness. All crews were deemed properly prepared to begin sampling activities on 27 July, 1992.

Certification examinations for crew chiefs and field crew members were administered at the end of each course and proved to be very useful. Unlike previous years, no crew chiefs were found to need additional training, and all subjects covered during training appeared to have been adequately covered.

C.2 FIELD DATA AND SAMPLE COLLECTION - QUALITY CONTROL CHECKS

Several measures were taken during the 1992 field season to assure the quality of the data collected. These consisted of QC checks, the collection of QC samples, and performance reviews by senior Program personnel (QA Coordinator or Field Coordinator).

C.2.1 Water Quality Measurements

Generally the first activity performed at each station was to obtain a vertical profile of the water column for key parameters. The instrument chosen for this operation was the SeaBird SBE 25 SeaLogger CTD. This instrument is generally regarded as a very sensitive, accurate and reliable device. All CTDs were calibrated according to manufacturers instructions at the EMAP-VP calibration facility just before the field season began. The procedures for calibration and checks are described in the 1992 Quality Assurance Project Plan (Valente *et al.*, 1992).

Field QC checks on the performance of the CTD fell into two categories: daily and weekly. The daily check consisted of taking duplicate surface and bottom measurements with a YSI Model 58 dissolved oxygen meter (instrument air calibrated at each station), a refractometer (salinity), and a thermometer (temperature) at every station. Acceptable differences are listed in the QA Plan. It is worth noting that the salinity values produced by the CTD are expected to be much more accurate than those from the refractometer, and are more accurate than is required by EMAP. The refractometer only provided a "gross" check to determine if there was an electrical problem with the CTD's conductivity sensor; it provided no information about gradual drift. If the instrument failed QC, the cast was repeated. If it failed on the second attempt, the cast was saved but flagged. Of the 143 casts for which separate dissolved oxygen measurements were successfully obtained with the YSI meter, 91.6% passed QC, showing differences of $\leq$ 0.5 mg/L. Values obtained using the YSI meter were used in this assessment for those stations where the CTD failed QC. All temperatures and salinities passed QC.

In addition to the daily checks, a more thorough weekly (once per 6-day shift) check was also performed. First, a bucket of water was bubbled with air for at least two hours to reach saturation for dissolved oxygen. The YSI meter was air-calibrated according to manufacturer's instructions, and the dissolved oxygen concentration of the water determined. At the same time multiple water samples were drawn off for Winkler titration using a Hach digital titrator. The YSI value was compared to the concentration determined by titration. Since the YSI meter was calibrated prior to each use, this served as a check on the validity of the air calibration method.

Following this check of the YSI meter, the CTD was immersed in water and the DO, temperature, and salinity compared with values obtained from the YSI, thermometer, and refractometer respectively. The unit was brought back on the deck and the pH probe immersed in a pH 10 standard for comparison (pH 10 was used instead of pH 7 because the instrument defaults to a reading of 7 when malfunctioning). If the unit failed for any variable it was returned to the Field Operations Center for recalibration. A total of 17 checks were performed during the field season, with all meeting the criteria for acceptance.

C.2.2 Benthic Indicators

As described in Section 3, several different benthic samples were obtained at each station. Three of the samples were processed for benthic community structure and biomass determination.

Crews were observed closely during field performance reviews to ensure that standard protocols were being followed for all benthic sampling. Laboratory QA measures are described below in Section C.3.

In addition to the infaunal samples, sediment was collected for chemical analysis, toxicity testing, and grain size determination. Additional QC samples were collected for chemistry at one station per crew. A second duplicate sample was removed from the homogenate, and a "blank" bottle was left open whenever the sample was exposed to the atmosphere. The purpose of the blank was to determine if atmospheric contamination was a significant problem. Additional analytical measures are described in Section C.4. Grain size and toxicity QA results are discussed in Section C.3.

C.2.3 Fish Indicators

The two fish indicators for which field data, as opposed to samples, were collected were fish community structure and gross external pathology. The QA Project Plan (Valente *et al.*, 1992) called for QA samples to be collected for both of these indicators.

To verify each crew's ability to correctly identify fish species for the community structure indicator, the first individual of each species collected by each crew was shipped to ERL-N or Versar for verification by an expert taxonomist.

Three types of errors were detected: misspelled or incomplete species names (in the database), misidentifications, and fish that could not be identified in the field. Errors falling into the first category were easily detected, corrected in the database, and documented.

The second type of error was mis-identifications. Of the 397 fish sent in for taxonomic verification, 36 were misidentified. In all cases the crew identified a closely-related species, such as longspine porgy instead of scup, or brown bullhead catfish instead of the yellow bullhead. An additional eight individuals were sent in as unknowns or partial unknowns (*e.g.*, herring uncl.). Most mis-identified or partially identified individuals were juveniles.

The total of 44 incomplete identifications or misidentifications represent 116 fish records in the database (including other fish of the same species caught in the same trawl). A total of 14,704 fish were collected in all trawls (both standard and non-standard) from all station types during the 1992 field season representing 78 species. The percentage of errors detected was therefore less than one percent.

C.2.4 Field Performance Reviews

In addition to the crew certification visits performed during dry runs, each crew was visited by a senior EMAP staff member during field operations. All aspects of sampling, from boat operations to shipping, were observed by the reviewer. Some of the activities included confirming the presence/absence of external pathologies, re-measuring fish, assuring that all precautions were taken to avoid contamination of the chemistry samples, assuring proper processing of benthic infauna samples, observing data entry, and assuring that all necessary safety precautions were observed. The reviewer used a "field review check-off sheet" to provide guidance during the review, and to document the crew's performance. Both reviewers concluded that the crews were sufficiently concerned with all QA issues, and that the data generated were representative of ambient conditions.

C.3 LABORATORY TESTING AND ANALYSIS

Quality control requirements for laboratory testing and sample analysis are covered in detail in the 1992 EMAP-VP QA Project Plan (Valente *et al.*, 1992) and the EMAP-E Laboratory Methods Manual (U.S. EPA, 1991) and will not be reiterated here. All laboratories were required to perform QA activities, and the results of those activities will be discussed in this report. Because of the complexity of chemical analyses, QA results for those analyses are listed separately in Section C.4.

C.3.1 Sediment Toxicity Testing

All sediment toxicity testing was performed at the SAIC Environmental Testing Center (ETC) in Narragansett, RI. Certification of the ETC occurred in 1990 and those results will not be discussed here, with the exception of stating that the laboratory successfully met EMAP requirements.

As per the QA Project Plan, the laboratory was required to maintain a control chart for toxicity testing using a reference toxicant. The ETC used SDS (sodium dodecyl sulfate) as their reference material, running a standard 48-hour water-only toxicity test with SDS whenever EMAP samples were run. The control chart shows that the LC50 for SDS ranged from < 2.57 to 11.2 mg/L, with all but the lowest value falling within two standard deviations of the mean as required in the QA Plan. Results of the one reference toxicity test falling outside two standard deviations of the mean were examined, as were all testing performed during the same time period. No anomalies in the tests were apparent and no re-testing was performed.

C.3.2 Grain Size Analysis

All "sediment grain size" and "benthic grain size" samples were analyzed for the determination of percent silt/clay. Approximately 10% of these analyses were performed in duplicate and the Relative Percent Difference (RPD) determined as per the EMAP-E Laboratory Methods Manual (U.S. EPA, 1991). The maximum allowable percent difference for the predominant fraction (silt/clay or sand) is 10%. The mean difference for the samples analyzed was less than 1%, with none exceeding 10% so no remedial action or retesting was required.

C.3.3 Benthic Infauna Analysis

Two QA steps were required by the EMAP-VP 1992 QA Project Plan: 10% recounts and independent verification of species identification. The recounts (multiple types - see Table C-1) and preliminary species verification were performed by the laboratory performing the analyses. All of these met the requirements established in the QA Plan. Definitive verification of species identification was performed by an independent laboratory and the results are described below.

C.3.4 Total Suspended Solids Analysis

The QA Plan requires that at least 10% of all samples analyzed for Total Suspended Solids (TSS) concentration be analyzed in duplicate. The RPD between the duplicates is then calculated. To pass QA, this value must be less than 10%. If it exceeds 10%, all samples analyzed since the last successful QC check must be repeated.

Due to an apparent mis-communication at the analytical laboratory, the first group of samples did not have the appropriate QA samples run. Therefore, the quality of the resultant data cannot be evaluated and are "flagged" in the EMAP database. A sufficient number of duplicate analyses were performed with the remainder of the samples; however, several failed QA, with the RPD exceeding 10%. Unfortunately this was not discovered until several months after the analyses were completed, and the original samples (degradable) had been discarded. As a result, approximately 44.4% of the data have been flagged as being of questionable quality.

C.4 LABORATORY CERTIFICATION AND CHEMICAL ANALYSIS

EMAP-E requires that analytical laboratories participate in an extensive certification process prior to the analysis of any EMAP-E chemistry samples. This certification is in addition to normal quality control measures that are required during analysis to ensure quality data (*e.g.*, blanks, spikes, controls, duplicates, etc.). Standard Reference Materials (SRMs) with known or certified values for metals and organic compounds were used by the Virginian Province laboratories conducting analyses to confirm the accuracy and precision of their analyses. Many of the SRMs used extensively in the EMAP-E program are naturally-occurring materials (*e.g.*, marine sediments or oyster tissue) in which the analytes of interest are present at levels that are environmentally realistic, and for which analyte concentrations are known with reasonable certainty. The certification results for the laboratory conducting the sediment analyses can be found in Table C-2.

The 1992 Virginian Province QA Project Plan (Valente *et al.*, 1992) lists warning and control limit criteria for the analysis of Certified (or Standard) Reference Materials. The more conservative warning limit for all organics is stated to be "Lab's value should be within ± 25% of true value on average for all analytes; not to exceed ± 30% of true value for more than 30% of individual analytes for each batch". The laboratory's performance during certification resulted in permission being granted for the analysis of samples to begin.

Table C-1. Results of recounts performed by the laboratory processing benthic infauna samples. Approximately 10% of all samples were processed in duplicate.

Measurement	Mean Error	Range of Error
Benthic sorting	1.7%	0 - 18%
Species identification and enumeration	1.8%	0 - 12%
Biomass	1.2%	0 - 1.4%
Weighing blanks for biomass	7×10^{-5} g	0 - 7×10^{-4} g

Table C-2. Results of certification analysis for sediment contaminants performed by EMSL-Cinn. The Reference Material for the organics certification was NIST SRM 1941. The SRM for inorganics was the National Research Council of Canada BCSS-1 CRM. For organic analyses, only those analytes with certified values at least 10x the detection limit are included.

Analyte	Certified Concentration	Measured Concentration
Inorganics (µg/g dry weight)		
Al	62700 ± 2173	58,600
As	11.1 ± 1.4	11.0
Cd	0.25 ± 0.04	0.20
Cr	123 ± 14	81.3
Cu	18.5 ± 2.7	18.4
Fe	32900 ± 980	29,800
Mn	229 ± 15	199
Ni	55.3 ± 3.6	47.0
Pb	22.7 ± 3.4	27.8
Sb	0.59 ± 0.06	0.56
Se	0.43 ± 0.06	0.42
Sn	1.85 ± 0.20	2.24
Zn	119 ± 12	96.4
Organics (PCBs/pesticides - ng/g dry weight)		
PCB 18	9.90 ± 0.25[1]	2.82
PCB 28	16.1 ± 0.4[1]	12.8
PCB 52	10.4 ± 0.4[1]	11.6
PCB 66	22.4 ± 0.7[1]	20.4
PCB 101	22.0 ± 0.7[1]	15.1
PCB 118	15.2 ± 0.7[1]	16.2
PCB 153	22.0 ± 1.4[1]	14.5
PCB 187	12.5 ± 0.6[1]	7.50
PCB 180	14.3 ± 0.3[1]	13.2
PCB 170	7.29 ± 0.26[1]	4.95
PCB 206	4.81 ± 0.15[1]	3.11
PCB 209	8.35 ± 0.21[1]	6.49
4,4' DDE	9.71 ± 0.17[1]	8.43
4,4' DDD	10.3 ± 0.1[1]	8.24
4,4' DDT	1.11 ± 0.05[1]	1.47

(continued)

Table C-2 continued.

Analyte	Certified Concentration	Measured Concentration
Organics (PAHs - ng/g dry weight)		
Phenanthrene	577 ± 59	535
Anthracene	202 ± 42	170
Fluoranthene	1220 ± 240	1100
Pyrene	1080 ± 200	1020
Benz(a)anthracene	550 ± 79	572
Benzo (b & k) fluoranthene	1224 ± 239	983
Benzo(a)pyrene	670 ± 130	494
Perylene	422 ± 33	252
Ideno(1,2,3-cd)pyrene	569 ± 40	609
Benzo(g,h,i)perylene	516 ± 83	526
Naphthalene	1322 ±14[1]	722
2-Methylnaphthalene	406 ± 36[1]	355
1-Methylnaphthalene	229 ± 19[1]	191
Biphenyl	115 ± 15[1]	94
2,6-Dimethylnaphthalene	198 ± 23[1]	203
Fluorene	104 ± 5[1]	101
Benzo(e)pyrene	573[1]	579
Chrysene	449[1]	709

[1] Value provided by NIST but not considered a "certified" value, meaning the values were determined via a single method. Despite not being certified, these values are still considered accurate.

During sample analysis, the laboratory was required to analyze a Laboratory Control Material (LCM) with each batch of samples being analyzed. An LCM is identical to an SRM with the exception that the true values need not be certified by an external agency (however, in these cases the same SRMs used during certification were used as the LCM). In addition to the LCM, duplicate "matrix-spiked" samples were required for each batch.

In addition to the analysis of the required QA data, summary data have been reviewed by an environmental chemist to verify that they are "reasonable" based on past studies and known distributions of contaminants in East Coast estuaries. This included examining the ratios of individual congeners (*e.g.*, PCBs); and PAH and DDT analytes. Any data that were deemed "questionable" were flagged for further study.

As stated earlier, at each sediment chemistry QA station crews opened a blank bottle whenever the sample was exposed to the atmosphere. The analytical laboratory solvent rinsed this bottle and then analyzed the solvent for contamination. Results showed no evidence of contamination, which if present, could have come from either the field or the laboratory.

C.5 DATA MANAGEMENT

To expedite the process of data reporting, all field data were entered into field computers and transmitted electronically to the Information Management Center. Upon receipt of the "hard copy" data sheets, a 100% check was performed by the EMAP data librarian (*i.e.*, every record in the computer was manually compared to the data sheet). Following corrections, a different individual then performed a second 100% check. A third check (20%) was then performed by a third person. By the completion of this exercise we were confident that the computer data base accurately reflected what the crew reported.

The number of data errors detected can be classified as "record" errors or "value" errors. A value refers to a single observation recorded as part of a record. A record refers to an entire set composed of "n" values, such as a data sheet. Record errors generally refer to duplicate or missing data sheets. Duplicate electronic data sheets can result from the crew accidentally saving the same page twice, but with different page numbers. Value errors refer to missing or incorrect values recorded on a data sheet.

Results of the checks described above showed a value error rate of 0.3%. The rate of record errors was approximately 1.35%.

The next step in data QA was data verification and validation. Verification was another step in assuring that the data were correct (*e.g.*, assuring that each CTD cast was associated with the correct station). Validation was the process of checking to make sure all data were reasonable (*e.g.*, making sure that fish lengths were all entered in mm, not cm). These processes were extensive; therefore, only a few examples will be provided here.

Part of the process of verifying CTD dissolved oxygen profiles was to compare cast depth to water depth. If they were significantly different, the cast was flagged for additional investigation. Validation then consisted of an expert examining every cast to assure the DO values were realistic and that the profile appeared reasonable.

One of the steps in validation of the fish community data set was to compare each fish length to the reported size range for that species. Geographic distributions were also examined to determine if the species had previously been reported where EMAP crews found them.

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